

THE SCIENCE OF COMPOSTING

PART 1



Edited by
Marco de Bertoldi
Paolo Sequi
Bert Lemmes
Tiziano Papi



Springer-Science+Business Media, B.V.

The Science of Composting

**European Commission
International Symposium**

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OF COMPOSTING**

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Bert Lemmes
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Introduction

The European Union initially demonstrated its interest in waste in the late 70s with the programme on Waste Recycling Research and Development. At that time composting was only present as a coordination activity and it was only later that specific research programmes in the area were within Europe which was largely instrumental in setting up a series of European conferences, seminars and workshops. Some of these have resulted in publications which have made significant contributions to developments in the understanding of composting and the use of composts. In particular the outputs from meetings in Oxford (1984), Udine (1986), Neresheim (1988) and Angers (1991) are worthy of note.

Composting has seen significant changes since the 70s when the major thrust in Europe was using mixed municipal solid waste as a feed material. Many composting plants which were built to use this material were closed due to the poor quality of the compost which made it very difficult to market. As a result the main areas of interest, as far as the municipalities are concerned, are now with biowaste and source-separated organics. This interest is apparent from the many new plants which are being constructed across Europe, and the ready market which exists for the products. In parallel with the renewed interest of the municipalities other areas, such as agriculture and the wastewater treatment industries, are also developing their own schemes.

The EU produces in excess of 2500×10^6 tonnes of waste each year a high proportion of which is organic. The disposal options for this waste are fewer every year as we become aware of the potentially adverse environmental impacts of using them. A clear alternative for the organic fraction of this waste is composting which not only enables us to treat the waste but also to maximise its beneficial properties through re-use. This is particularly important in southern Europe where the soils are very poor in relation to their organic content, but it is not only these regions which need this attention to their soils. Many areas in our northern regions also need this type of input following many years of exploitation of inorganic fertilizers without attention to the long term implications for soil structure.

The many new composting plants opening in Europe confirm the interest in the utilisation of our organic wastes but we need to move forward with research and development to ensure that this resurgence does not die in a similar way to that of the 70s. Conferences, like the one in Bologna, are vital to this process bringing together researcher and practitioners in a forum where their ideas can be presented, discussed and moved forwards.

The interest in this area is confirmed by the attendance of in excess of 500 delegates from 36 different countries. This is a recognition of the vision of the sponsors who have actively supported this initiative.

Marco de Bertoldi
Professor of Industrial Microbiology
University of Udine

September 1995

Publisher's note

Due to the short preparation time required to produce this book, some papers were not received in time to be included in the first setting. To ensure completeness of coverage, these papers have been included at the end of the appropriate volume.

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Round Table on Legislation
W.A. Van Belle, ORCA

Legislation in the European Union on Compost Production and Use
A. Piavaux, European Commission

Volume 2
Biological Treatment, the Perfect Eco-efficient Tool in a Sustainable Integrated Waste Management
B. Lemmes, Managing Director, ORCA

ORCA Compostability Criteria: A Framework for the Evaluation of Feedstock for Source-Separated Composting and Biogasification
K. Mesuere, ORCA

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Preface

The scale of the problem of waste management and disposal continues to grow as landfilling and incineration face both environmental and economic concerns. The European Union alone has 2000 million tonnes of refuse a year to deal with and, in addition to the rest of the developed world, developing countries are having to confront the issue. With this background, increasing attention is now being given to integrated or alternative solutions involving composting and recycling. This book provides a state-of-the-art description of available and potential composting technologies, and all the associated scientific, economic and legislative issues. It indicates the best practical solutions for composting as an integrated method of waste management and discusses the adaptation of composing technologies to suit social, economic and geographic conditions in different countries.

Among its aims are the identification of the most profitable directions of future research in the field, and the examination of legislation and guidelines suitable for the practical implementation of composting policies.

Written for professionals and academics concerned with waste technology, science and management, this book is also an essential reference source for those with an interest in environmental technology including microbiologists, biochemists, chemists, biotechnologists and opinion and policy makers in government institutions.

Plenary Section

Historical Review of Composting and its Role in Municipal Waste Management

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Abstract

Simply stated, the role of composting in waste management is to be a productive option for the treatment and disposal of biodegradable waste. This paper focuses on two major categories of biodegradable wastes – they are: 1) the solid waste generated by households, businesses, and light industry (municipal solid waste (MSW)); and 2) settleable waste water solids, i.e., dewatered sewage sludge. Sewage sludge ('biosolids') is included because it is a major municipal waste which, if not managed properly, can very adversely affect environmental quality and public health. Because it is an option in solid waste management, the vicissitudes of composting mirror those of MSW management. This paper explores and attempts to explain and illustrate the role of composting as a waste management option. It does this by tracing the chronological status and development of waste management and composting and analyzes their interrelation. For purposes of this presentation, the chronology of this combination is somewhat arbitrarily divided into three broad, loosely defined periods; namely, 1930–1940, 1950–1960, and 1970–current.

Introduction

Much of the material presented in this paper is based upon sixty years of firsthand experience and direct observation of municipal solid waste management practice and 40 years with composting. Major reasons for the reliance on experience are assurance of greater realism and filling of gaps in the literature. Until the 1960s, publications devoted to solid waste management, and particularly to composting, were few in number and were to be found mostly in the form of project reports and articles in obscure periodicals which were rather difficult to obtain. A large share of the scarcity ultimately can be attributed to professional disinterest and perhaps some snobbery. The disinterest and snobbery persisted until ecology, resource conservation, and environmental quality became major concerns of the public in the

early 1970s. Prior to the 1970s, organic gardening and farming accounted for most of the interest and activity in composting [Duthie 1937; Maynard 1994]. Inasmuch as this paper is not intended to be a 'literature review,' the list of references cited in it is by no means exhaustive nor necessarily representative. Furthermore, since spatial and temporal constraints preclude the full coverage warranted by an historical review, the account that follows is of necessity somewhat abbreviated. Finally, it should be mentioned that although this paper mainly deals with the situation of solid waste compost in the United States, it does have relevance to the European situation, because the course of developments in both locales has been fairly parallel.

First Period (1930–1940)

Solid Waste Management

A major and decisive constraint on the status of composting during this period, especially during the 1930s, was the very low priority accorded MSW management and disposal. In small communities, formal management was almost nonexistent, and it was not much greater in large communities. Several factors were responsible for this unfortunate situation. Among the principal contributing factors was the popular misconception that aside from being aesthetically repulsive and constituting a more or less serious nuisance, MSW *per se* had little public health and environmental significance. Awareness of unfavorable impacts was highly localized, i.e., perceived only by those in the immediate vicinity of the dumped wastes. Furthermore, the level of the public's fastidiousness with regard to aesthetics was much lower than it is now. Of equal, if not greater, importance was a prevailing disinterest in resource conservation. Natural and renewable resources were abundant, moderately accessible, and except by a small minority of the populace, were regarded as being almost inexhaustible.

Storage, collection, transport, and disposal technologies were primitive. Transport technology was far from its present state of advance. Internal combustion power had only recently replaced equine power. Despite its many objectionable features and characteristics, the open dump was a commonly practiced method of disposal [Institute for Solid Wastes of American Public Works Association 1970].

Perhaps the major consequence of the primitive technology was its lowering of the cost of conventional management and disposal to a level far below that of composting. This disparity posed an economic obstacle to the choice of composting as an option in solid waste management, i.e., disposal. In effect, decision-makers regarded composting as a luxury reserved for the dedicated few who were truly concerned with the quality of the environment, and conservation and protection of our resources.

A feature of MSW management that should have been beneficial to composting was the separate collection of 'wet garbage' (food waste) and dry garbage (rubbish) – a practice that was quite common at the time [Institute for Solid Wastes of

American Public Works Association 1970]. The primary motivation of this separation was economic. The wet garbage was sold to swine growers for use as a feedstuff for swine. Not surprisingly, separation soon disappeared when regulations forbade the use of raw garbage as a feedstuff for swine in the early 1950s [Hyde 1932B].

Composting

During the 1930s and to a less extent in the 1940s, MSW composting was in many respects in its infancy both in science and in practice. Its microbiological fundamentals were recognized and efforts were made to translate them into operational and design factors and parameters [Adams 1941; Carlyle 1941; Howard 1935; Waksman 1939]. Key basic principles and their related factors were identified. Among the principal areas of controversy in compost research were anaerobic vs. aerobic [Hyde 1932A], and mesophilic vs. thermophilic composting [Golueke 1977]. It would be several decades later that anaerobiosis would be divorced from composting by virtue of definition. In the 1930s and 1940s, advocates of anaerobic composting offered many arguments in favor of their stand [Carlyle 1941; Hyde 1932A; Hyde 1932B]. Unfortunately for them, the Becari System, purported to be an anaerobic process, fell short of its claims [Beccari 1922; Hyde 1932A]. Moreover, their argument was weakened by the fact that the final stage of anaerobic systems current at that time was aerobic. The relative advantages of mesophilic over thermophilic composting, and vice versa, were quite vigorous at the time. However, the question became moot when the implications of the temperature curve characteristic of composting were finally appreciated.

Second Period (1950–1960)

Solid Waste Management

The first of three extremely significant developments during this period was the rapid shift in the food industry and public consumption from canned food to frozen food; in other words, from heat to freezing as means of preservation and distribution. The second was the onset of the plastics era. In the food industry, it marked the beginning of the decline of the traditional ‘tin can.’ The introduction of the ‘TV dinner’ brought an influx of aluminum trays into the MSW stream [Golueke 1953]. The increase in the consumption of frozen food sharply reduced the output of so-called ‘wet garbage.’ The output was further reduced by the almost explosive expansion in the number of kitchen (‘under the sink’) garbage grinders. As a result, separate collections, and with it source separation, all but disappeared. Significant advances were made in MSW management technology during this time period [Pearson 1952]. Among them was the introduction of the enclosed packer collection vehicle. It soon replaced the open-body truck in all but a few applica-

tions. Storage began to be regulated. Limitations were placed on the size of the receptacles and tightly-fitting covers were prescribed. Hitherto, all sorts of receptacles had been used – ranging from discarded cardboard boxes to 55-gallon steel drums.

The open dump continued to be the usual method of disposal despite the growing awareness of its damaging impact upon public health, quality of the environment, and conservation of resources [Black 1964]. Not surprisingly, the principal reason for its persistence was economic; namely, the required monetary outlay was modest. On the other hand, there was a growing recognition that this monetary advantage was only illusory. This realization was accompanied by attempts to postpone the day of reckoning through the introduction of palliative measures. Among such measures were the banning of open burning at the dump and the imposition of some restrictions on siting.

Composting

During this period, the substantial advances made in the understanding and application of the fundamentals of the compost process materially improved the utility of composting as a MSW management option.

Despite the very modest sophistication and capabilities of analytical expertise and instrumentation, considerable advances were made in the understanding and application of the fundamentals of composting and in translating them into practice. For example, in the 1950s, it was recognized that temperature of the composting mass should not be allowed to exceed 60° to 65°C [Carpenter 1977; Golueke 1953; Schulze 1964; Wiley 1957]. This upper limit was attributed to the lethal effect on all but the most thermophilic members of the microbial population. Microbes not killed usually lapse into dormancy or into the spore stage, and as a result active decomposition all but ceases. The relation between permissible moisture content and its bearing upon the effect of integrity of porosity and aeration capability was established [Golueke 1953]. The effectiveness of certain bulking materials in supplying the needed porosity to ‘amorphous’ materials was determined. Permissible moisture contents were established for common feedstocks (e.g., MSW, 55% to 60%) [Golueke 1953].

Important advances were made in the microbiology of composting [Forsyth 1946]. Due recognition was given to the dynamic succession of microbial populations. The importance of actinomycetes in the decomposition of paper and lignaceous materials was emphasized [Golueke 1953]; two genera of actinomycetes were identified, namely *Streptomyces* and *Micromonospora* [Golueke 1953; Wiley 1957; Duthie 1937]. Interestingly, the temperature range of the thermophilic species *Actinomyces thermophilus* was established as being 40° to 60°C [Wiley 1957; Gilbert 1947]. Among the fungi identified were *Penicillium dupontii*, *Aspergillus fumigatus*, and *thermoyces spp.* [Gilbert 1947].

Research during the second period was further characterized by serious efforts to replace folklore with ‘science’ in composting, or at least to arrive at parameters and protocols that are based on sound engineering and scientific principles. A con-

siderable amount of basic and applied research was carried out at the Sanitary Engineering Research Laboratory of the University of California at Berkeley [Diaz 1989; Goldstein 1989; Golueke 1972; Logsdon 1989]. Oxygen demand and supply, i.e., aeration, became the center of attention. Attempts were made to quantify the demand through experimentation and hypothesis and modelling [Chrometzka 1968; Popel 1961; Schulze 1960].

As frequently occurs when new fields are explored, a tendency toward oversimplification regarding the significance of oxygen in compost practice began to develop. The feeling was that upper limits of speed and extent of decomposition, as well as all operational problems, ultimately were traceable to adequacy of aeration. In short, the rule of the 'limiting factor' was ignored. It should be noted that this aberration was short-lived. Genuine progress was made in defining key parameters such as moisture content, pH, temperature, C/N, and nutrient availability. The relation between upper permissible moisture content and aeration, porosity, and resistance of substrate particles to compaction was thoroughly explored. Progress in analytical and monitoring technology greatly facilitated the exploration and refinement of compost principles. During that time period, academic involvement in research took hold, but only slightly. Governmental agencies and laboratories continued to be the principal centers of compost research and development. The U.S. Public Health Service (PHS) was a leading entity in this respect. (The PHS later became the U.S. Environmental Protection Agency (U.S. EPA).) A governmental research undertaking particularly worthy of mention was the Tennessee Valley Authority (TVA) project. The project was a joint venture of the U.S. PHS/EPA and the TVA [Stone 1975]. The scope of the project embraced almost every aspect of composting (e.g., technology, crop production, marketability of the product, economics).

Although excellent reports were to be found in publications by the U.S. government laboratories and agencies, the dearth of papers and other coverage in the scientific and technical literature persisted. Fortunately, the dearth was greatly lightened in 1960 by the introduction of *Compost Science*, a periodical that was and is entirely devoted to composting and associated land utilization. Eventually, its name was changed to *BioCycle*. Since its debut in 1960, the periodical has remained an important element in the entire field of composting.

Technology

Although windrow composting was the most common practice, projects involving in-vessel composting received greater publicity [Golueke 1960; McGauhey 1960]. Unfortunately, the in-vessel projects also were characterized by almost universally poor records and abrupt terminations due to disastrous economics and inferior performance. The inability to market the compost product resulted in the failure to recover the high capital and production costs. The balance between capital and production costs and monetary income from sale of the product was crucial to continued survival of the projects. Poor performance aggravated the disastrous situation with the result that the majority of the closures were imposed because of

public pressure. It should be kept in mind that the inferior performances primarily were consequences of inept planning, design, and operational shortcomings, rather than of technology.

The absence of the required market often could be blamed on poor product quality and to a lesser degree on other factors such as sporadic availability and physical characteristics of the product that were not amenable to large-scale agricultural practice. However, the real problem was a misconception that prevailed at that time. The misconception was that the contribution of organic matter to soil quality and fertility and to erosion prevention was negligible.

An occurrence of major significance was the beginning of the development of mechanical sorting to remove noncompostable materials from the incoming waste stream. However, the mechanical sorting had to be augmented by manual sorting to recover a certain amount of primarily paper products. The abandonment of source separation, i.e., separate collection of wet garbage and dry garbage (rubbish), necessitated some type of separation. Not surprisingly, the technology was quite rudimentary in that magnetic removal of ferrous metal and size reduction were the principal components.

Third Period (1970–Current)

Solid Waste Management

Major strides were made in municipal management and compost practice with respect to stature, policy, and technology. The full extent of the impact of the municipal solid waste stream upon the quality of the environment, public welfare, and the protection of air, water, land, and natural resources finally was appreciated. Symbolic of this shift in attitude was the public and academic transfiguration of the designation ‘Sanitary Engineering’ into ‘Environmental Engineering.’ Many factors made this shift inevitable; the number is too great to permit cataloguing, much less discussion, within the confines of this presentation. Suffice it to call attention to some of the more significant developments.

Among the symptoms of the shift were the higher standards upon which quality of life, i.e., of the environment, was judged; the explosive expansion of urban sprawl; and an increasing realization of the long-term effects and true costs of pollution on our air, water, and land resources. To have a true understanding of these symptoms, it is necessary to know their sources, i.e., the developments of which they were symptomatic. In this case, the three most significant developments were the failing fortunes and final demise of the open dump, replacement of the open dump by the sanitary landfill [Anonymous 1961B; Anonymous 1961A], and a dramatic amplification of biosolids production. A manifestation of the impact of the biosolids situation was a decided expansion of compost practice.

Ranking high among the problems attributable to sanitary landfilling is the fact that the practice makes serious inroads upon the rapidly shrinking area dimensions of land available not only for other uses, but also for disposal of wastes.

Unless appropriate precautionary measures are taken, sanitary landfilling generally is accompanied by the pollution of water resources, particularly of groundwater. Such measures usually are expensive in terms of materials, application, maintenance, and monitoring. This collection of problems triggered a steady barrage of regulatory restrictions and requirements regarding landfilling that persist to this day, and undoubtedly will be continued beyond the foreseeable future. The outcome of all of these factors is that in terms of total monetary outlay, sanitary landfill rivals the compost and incineration options.

An additional factor worthy of note was that during this time period, the world experienced an energy ‘crisis.’ Solid waste was viewed by many as a potential source of energy to a number of communities around the United States. This situation led to a considerable amount of research in the production of energy from refuse. Candidate systems included incineration, pyrolysis, and the production of refuse-derived fuel (RDF) [Diaz 1982]. The production of various forms of RDF and the recovery of potentially usable materials from the waste also were the subject of a number of research programs, most of which were funded by the U.S. EPA and the U.S. Department of Energy (DOE) [Diaz 1982].

Composting Research

The pace and magnitude of research and development reflected the improvement in the prospects of composting in waste management. Of equal importance were the dramatic advances made in analytical technology, particularly in instrumentation and in the microbiological disciplines. For example, oxygen demand and consumption were thoroughly investigated [Golueke 1977; Haug 1980; Stone 1975]. These advances led to the refinement of existing parameters and process protocols. An eminently beneficial result was a trend toward realism with respect to claims and expectations.

A potentially disadvantageous development was a tendency in research to over-emphasize engineering at the expense of biology in modelling and design and operation. The problem is that composting is not an ‘exact science,’ inasmuch as each and every variable cannot be predicted. As a consequence, serious miscalculations lead to shortcomings in siting, design, and operation. With regard to parameters, an unfortunate manifestation of the trend is an over-promotion of drying to the extent that inadequate moisture content becomes a seriously limiting factor. If treated as a goal, deliberately imposed drying should be reserved for the very last stages of curing. Deliberate drying is appropriate only in the final stages to meet product specifications (e.g., handling, application, etc.). There is an important exception to this rule; namely, correction of excessive moisture. Deliberate drying should be introduced whenever moisture interferes with aeration – but only to the extent needed to stop the interference. In research regarding design and operation, attention continues to be focused on the control of emissions, particularly of malodors. The search for a simple, reliable, and yet inexpensive test to determine the degree of maturity continues.

Status of Composting Practice

During the early 1970s, interest in composting as an option was at a very low ebb, primarily because of the very unattractive economics discussed in a preceding section. However, this dismal situation was destined to be replaced in the late 1970s by a period of improvement that continues to persist. This improved future was presaged by the three developments described in preceding paragraphs; namely, demise of the open dump, replacement of the open dump by sanitary landfilling, and the explosive surge in sewage sludge production.

The replacement of the open dump by the sanitary landfill diminished economic disparities between it and composting, and intensified the aforementioned awareness of the importance of environmental and resource conservation. In short, the many serious problems generated by the switch to sanitary landfilling made the difficulties rightly or wrongly associated with composting seem much less formidable [Diaz 1993].

The seemingly roseate prospects of MSW compost practice were threatened in the late 1980s and early 1990s by the failure of three large-scale projects. Major causes of the failures were disastrous siting and poor design of the facilities. Some of the technical problems were associated with odor generation and control. Fortunately, potentially negative repercussions of the failures on the progress of MSW composting did not fully materialize.

Between the early 1980s and the early 1990s, a series of events resulted in banning the disposal of yard trimmings in landfills in many states in the United States. This situation lead to the explosive growth of composting operations aimed at processing yard trimmings. Unfortunately, in several cases, the regulatory and institutional structure was not sufficiently developed to deal with the growth. In addition, the tendency to oversimplify and underestimate the composting process resulted in several problems, some of which involved fires and severe odor problems. Nevertheless, composting of yard trimmings became a common and popular means of processing and stabilizing the material and at the same time conserving valuable landfill space.

Biosolids Composting

Composting gained widespread acceptance as a method of treatment and disposal of sewage sludge because of its superior suitability for the task. Thus, compost practice benefited from the expanded production of dewatered biosolids and attendant difficulties in biosolids management and disposal. This acceptance continues despite constraints resulting from potential heavy metals and toxic chemical content and to a lesser extent pathogens. However, the trend toward regulating discharge of hazardous substances by industry into its effluents will diminish the constraints. In the composting process, biosolids were mixed with bulking agents to reach a desired level of porosity. Initially, the most common bulking agents for composting biosolids were wood chips. Competition for the woodchips with other uses, such as energy production, increases the price of the material in some areas

of the United States. Consequently, some facilities began the search for alternative sources of bulking agents. One common and obvious source is yard trimmings. Several biosolids composting facilities are either using or are considering using yard trimmings as bulking agent.

The acceptance and wide application of composting as a means to stabilize biosolids magnified the importance of careful design and proper management of the overall process. In particular, both the operators and the designers became painfully aware of the importance of odor control.

Co-composting MSW and biosolids is attracting increasing attention. The advantages accruing from co-composting are readily apparent. MSW serves as a bulking agent. The contribution by the biosolids is a readily available source of nitrogen and moisture. Co-composting is by no means a novel approach. It was thoroughly and systematically researched and tried in the 1950s [Black 1964; Diaz 1982]. At that time, the limiting factor was the high moisture content (e.g., 96%) of the digested biosolids. Dewatered biosolids were not common.

Observations and Conclusions

The factors responsible for lessening of the economic disparity between composting and its competitive options continue to be effective. Indeed, the magnitude of the burden resulting from the collection of restrictions and requirements imposed upon sanitary landfilling and incineration matches that of the onus often associated with composting. In effect, whereas the cost/benefit ratios associated with sanitary landfilling and incineration are substantial, those redounding from composting can be minimal. In other words, costs far outweigh benefits from landfilling and incineration; whereas the reverse is true with composting. The fortunes of composting are being further improved by the continuing strengthening of recycling. Composting benefits from recycling because successful recycling demands source separation. Recycling prompted advances in collection programming and vehicle technology.

The stimulative and supportive impact on compost practice brought by the spread of biosolids composting in the 1970s and subsequent years are being duplicated by the currently increasing emphasis on yard and food waste composting. The effect will be exerted on it in this and subsequent decades simply because other options are not as well suited. Nevertheless, as has happened in the past, this favorable situation is endangered by oversimplification, complacency, and underestimation of potential pitfalls such as inadequate processing capacity, mis-handling of the raw wastes, and shortcomings in facility siting and operation. An operational failing that can have serious repercussions on a yard waste compost undertaking is procrastination manifested by sizeable backlogs of incoming waste. These shortcomings are particularly disastrous when food waste is concerned.

Summary and Conclusions

The past, present, and future status of composting in its role as an option in solid waste management can be summarized in the following four statements:

1. Prior to 1970, composting played a very minor role because of the greatly unfavorable balance between its economics and those of the principal competing option; namely, the open dump. A secondary factor was the popular disinterest in resource conservation.
2. Starting in the 1970s, the fortunes of composting began to rapidly rise because of: a) the demise of the open dump; b) the problems generated by the spread of sanitary landfilling; and c) the recognition of the advantages associated with composting as an option in sewage sludge disposal.
3. Although somewhat improved, the status of composting in municipal solid waste management, nevertheless, continues to be relatively minor.
4. As happened with the rapid growth of biosolids composting, the present and future fortunes of MSW composting are primarily in food and yard waste management.

Significantly favorable developments and trends that have and will favourably affect the fortunes of MSW composting are: 1) drastic diminution of the economic imbalance between composting and its competitive options, 2) compulsory source separation, and 3) the growing importance of yard and food wastes management and disposal – functions for which composting is well suited.

The future of large-scale composting depends upon a number of factors. Some of the most important ones deal with site selection, sufficient capital to design and build the facility according to specifications, adherence to basic principles of engineering and biology, and management of liquid and gaseous discharges. Finally, professionals must be involved in all aspects of the planning, design, and construction of the facilities.

MSW composting has had a long and checkered past, in the course of which its fortunes have waxed and waned. It has finally found its niche in MSW management and all indications are that its role will be an integral element of MSW management in the foreseeable future.

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The Thermie Programme and Composting Projects in the Energy from Biomass and Waste Sector

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Abstract

The paper briefly presents the Community Energy Demonstration Programme (1978–1989), the THERMIE Programme (1990–1994) and the JOULE THERMIE Programme (1995–1998) of the Directorate General for Energy of the European Commission.

More specific informations are given on the Energy from Biomass and Waste Sector, and on the ongoing and terminated project in the Composting sub-sector. The future perspectives of composting projects in the THERMIE and FAIR Programmes are briefly outlined.

The THERMIE Programme

THERMIE is the follow-up of the previous Community Energy Demonstration Programme which was initiated in 1978 and has proceeded via a number of Council Regulations in three phases covering the years 1978–82, 1983–85, 1986–89.

1989 was the last year for application under the EEC Regulation No.3640/85, on which the Programme was based. However, many projects selected during the previous years are still ongoing and, furthermore, a new Programme entitled 'THERMIE' started in 1990.

Although the detailed content of the Demonstration Programme has changed somewhat over the years, the main subjects that have been covered throughout are:

- Exploitation of Alternative Energy Sources
- Energy Saving
- Substitution of Hydrocarbons
- Combustion, Liquefaction and Gasification of Solid Fuels.

The aim of the Demonstration Programme was to provide a means of promoting new technologies.

The new economic and industrial context provided for Europe by the Internal Market objective requires a strong energy base. The Community's energy situation still suffers from insecurity, regional disparities and unresolved environmental concerns. The key to these problems is to develop and exploit new energy technologies.

This is the reason why the Council of the European Communities adopted a new Regulation (EEC No. 2008/90) in 1990 allowing the Community to grant financial support to projects for promotion of energy technologies in Europe called the 'THERMIE' programme.

The 'THERMIE' programme differs from the previous Demonstration Programme, notably in the following respects:

- much more importance is given to the active dissemination of projects and results. In particular, financial support is given not only as before to innovative energy projects, but also to dissemination projects to encourage the wider use within the Community of innovative new technology after the first successful project, but under different economic or geographical conditions or with technical modifications and which still entailed some risks.
- financial support could also be granted to targeted projects fostered by the Commission to bridge observed gaps in the development of technology in some specific sub-sectors.
- in parallel to the support for projects, the associated measures were strengthened. These included: evaluation of market potential and characteristics, dissemination of information on energy technology and project results, audits of approved projects and sectorial energy audits, technological cooperation forums such as seminars and workshops, promotion of industrial cooperation with third countries.

The 'THERMIE' programme with a total budget of 700 MECU was designed to run for 5 years from 1990 to 1994 having an important role to play in the achievement of Community policies:

- helping to ensure that Community industry has access to secure and competitive supplies of energy;
- encouraging joint ventures between enterprises from more than one Member State, giving particular support to small and medium sized Enterprises;
- reinforcing the Community's efforts to maintain Europe in the forefront of World technological development;
- improving the quality of the European Environment – a matter of increasing concern to our citizens – by improving energy efficiency and diversifying energy supplies;
- strengthening of the technological base of European industry by encouraging industrial cooperation;
- bringing important benefits to the less-favoured regions of the Community through its particular emphasis on transferring technology to them, thus

- strengthening economic and social cohesion;
- creating new employment opportunities through the implementation of new energy technologies.

The 'THERMIE' programme covered four sectors:

- rational use of energy in the industry, buildings, transport and energy industry;
- renewable energy sources: solar, biomass and waste, geothermal, wind and hydro-electricity;
- solid fuels: combustion, conversion and gasification integrated with a combined gas/steam cycle;
- hydrocarbons: exploration, production, transport and storage.

For the realisation of its dissemination strategy objectives, the European Commission has implemented a network of 58 OPET's (Organisation for the Promotion of Energy Technologies). The OPET's are private or public institutions, working at national or regional level in Member states, which collaborate in dissemination activities with the Commission and among themselves.

In order to promote cooperation with Third countries through technology transfer, the activities of the OPET network have been extended to countries outside the Community through the implementation of local Energy Centers and Energy Information Services (Central and Eastern Europe, C.I.S., Scandinavia, Austria and possibly in the near future in non-Community Mediterranean countries, U.S.A. and Japan).

Between 10% and 15% of the total THERMIE budget was devoted to the dissemination activities.

The Joule-Thermie Programme

On 23 November 1994 the Council decided a new programme of Research and Technological Development (RTD), including Demonstration in the field of Non-Nuclear Energies. The Programme's R&D component is called JOULE, and the Demonstration component is called THERMIE.

Building upon the results of a European scientific seminar on energy research organised in 1993, the prime objective of the JOULE-THERMIE programme in the field of non-nuclear energy are to improve energy security in the broadest sense – i.e. ensuring durable and reliable energy services at affordable cost and conditions and, recognising that a major concern today is the protection of the environment, to reduce the impact of the production and use of energy, in particular the emissions of CO₂.

Within this frame, JOULE-THERMIE also aims to contribute to the achievement of other important EU objectives such as strengthening the technological basis of the energy industry, with benefits for the economy, employment and export potential, improving social and economic cohesion and contributing to co-operation with Third Countries (in particular Central & Eastern European and developing countries).

JOULE-THERMIE merges within one programme both R&D and Demonstration actions which had previously been carried out separately within the JOULE and THERMIE programmes, and introduces a new activity in support of an overall energy RTD strategy in the inter-disciplinary area of energy-environment-economy. This strategy is of course not restricted to non-nuclear energy activities; it also embraces the safety of nuclear energy and, as a long term option, the pursuit of thermonuclear fusion. JOULE-THERMIE addresses non-nuclear activities and supports the development of the energy research and technological development (RTD) strategy. The other two objectives on nuclear fission safety and on nuclear fusion are covered by separate specific programmes.

The JOULE-THERMIE programme has a total budget of 967 MECU for the period 1995-98, of which 532 MECU are allocated for the THERMIE component. THERMIE covers all demonstration activities as well as other activities such as strategy, dissemination, preparatory, accompanying and support measures, concerted actions and technology stimulation for SME's. It will provide a continuity to the previous (1990-94) programme, also called THERMIE.

Demonstration activities, Type A Actions, cover:

- Rational use of energy in:
 - industry
 - the building sector
 - energy industry and fuel cells
 - the transport sector
- Renewable energy sources:
 - solar photovoltaics
 - renewable energies in buildings
 - wind energy
 - energy from biomass and waste
 - small scale hydroelectric plants
 - geothermal energy.
- Fossil fuels:
 - solid fuels (combustion, gasification and waste)
 - hydrocarbons (safety and environmental protection, exploration, production, transport and natural gas).

Type B Action covers other activities such as:

- Energy demonstration strategy
- Dissemination of energy technologies
- Preparatory, accompanying and support measures
- Technology stimulation for SME's.

With reference to the previous THERMIE programme the main differences are the following:

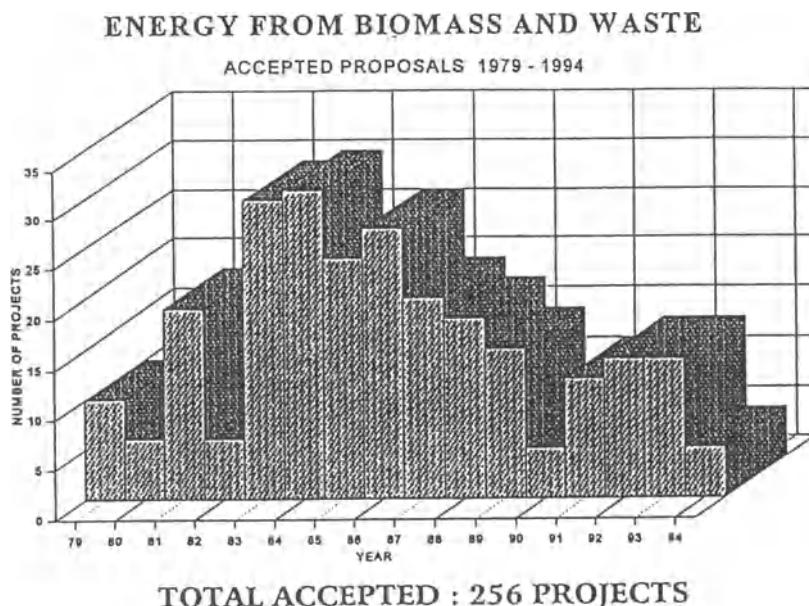
- to obtain financial support the project must use innovative techniques, processes or products;

- as a general rule projects should involve at least two entities from different Member States, or from at least one Member State and one Associated State;
- dissemination projects are not eligible.

Energy Projects Supported under the demonstration and Thermie Programmes in the Field of Composting

Full size projects supported by the Directorate-General for Energy of the European Commission in this field are essentially included in the sector 'ENERGY FROM BIOMASS AND WASTE' originally in the Demonstration programme and subsequently in the THERMIE programme.

The sector 'ENERGY FROM BIOMASS AND WASTE' comprises 11 sub-sectors that can roughly be put into two principal groups. On one side there are biological treatment processes of biomass and waste, leading notably to the production of biogas (including landfill gas) and compost; the other group contains processes aimed at the thermal valorisation of biomass and waste, primarily by combustion but also by gasification, pyrolysis, carbonisation and production of Refuse Derived Fuel (RDF).



Since 1978, 256 projects have been selected in the above sector for a total financial support of 160.5 MECU. This is illustrated by figures 1 and 2 which also show that since 1983 and for approximately the same annual financial support (with the exception of 1990 where the call for tender was restricted to combustion only), the annual number of selected projects has diminished while their size has increased.

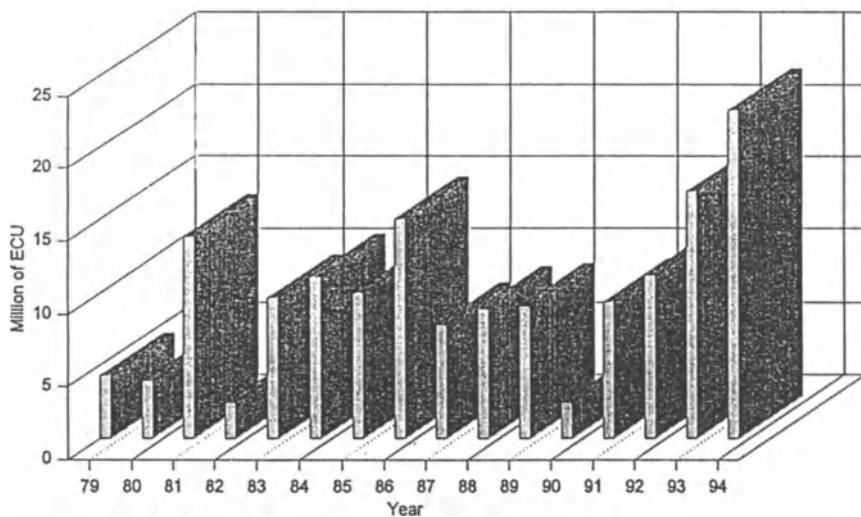
In 1994, 5 new projects have been selected in the sector 'ENERGY FROM BIOMASS AND WASTE' for a support of 22,6 MECU, namely 2 projects dealing with sewage sludge treatment and 3 large targeted projects on the gasification of SRF biomass in combined cycle for CHP production.

Up to now 6 projects are ongoing or terminated in the specific sub-sector 'Production of compost and fertilizers'. It is to note that most of the projects listed in the sub-sector 'Production and utilisation of biogas' are also producing compost.

Table 1 lists the 6 projects on compost, not including 2 projects abandoned before implementation.

ANNUAL ALLOCATION OF FUNDS 1979 - 1994

TOTAL SUPPORT : 160,5 MECU



Perspectives for the Future

In the ALTENER Programme of Directorate General for Energy Biomass is considered to play an important rôle between RES in the future. By the year 2005 it is expected that biomass will contribute for about 5,1% to the total energy

Table 1 Composting projects supported under the community 'Energy Demonstration' and 'Thermie' Programmes

Project No.	Title	Contractors	Objective	Comments
BM/193/85.HE	Waste separation and composting plant in the municipality of Kalamata	Municipality of Kalamata	Construction of a sorting and composting plant for municipality wastewater with depuration plant sludges	Ongoing project. The civil construction of the plant has been completed and the mechanical is about 40% completed. This project was merged with
BM/446/86.DK	Composting heat plant as an element of an integrated manure treatment system Composting of agricultural waste together with biogas plant residue.. Use of heat pump to recover composting waste heat	Mullerup	See project BM/300/87 project BM/300/87 in April 89	Completed project. The results achieved were not as good as expected. In order to improve the economic viability of the process a larger amount of waste should be treated.
BM/047/87.LU		Municipality of Petingen	To demonstrate the reliability and profitability of an innovative composting device in a closed-well insulated reactor.	Completed project. The project proved to be technically successful but not economically in all aspects.
BM/300/87.DK	Composting heat plant in an integrated production of compost, earth worms, pisciculture, greenhouse and out door culture	VJ-Kompostierungs- system	To demonstrate improved perspective concerning energy, resources, environment and economy by utilisation of composting heat plants and anaerobic fixed film reactors in integrated systems.	Ongoing project. Innovative aspects are up to 40% energy savings compared to conventional plant, best quality of final product and maintenance of the plant.
BM/236/88.IT	Compost curing integrated plant with computerized process	Ecologia SpA	Reduction of energy consumption of the plant and maximum income from recycled product.	Ongoing project. The construction has been completed and the project is in the commissioning phase.
BM/238/92.IT	Plant for the production of compost from food and agricultural wastes, amended with tree barks	CAVIRO	Production of high quality compost reducing the quantity of wastes of agro-food industry.	

consumption of the E.U. (Table 2). In the new THERMIE programme we will continue to support innovative technologies for the production of energy from biomass and waste.

In respect to composting technologies we consider at the moment, the major disposal options as following: waste reduction, re-use, recycling, composting and landspreading, energy from waste, landfilling, incineration, permanent storage.

Composting is therefore a very important option, which has been strongly supported in the past.

The results achieved so far in the completed projects and the expected results for the ongoing projects are very encouraging. Evaluating the perspectives of composting plants in the E.U. it is important to point out that the conversion of refuse and/or green waste to compost is an essential part of an integrated waste management system. Possible energy savings in reduced production of fertilizer which otherwise would have to be used instead of compost, or in the recuperation and utilisation of the heat produced during the composting process, or energy savings in relation to other waste treatment processes, are all interesting options from an energy point of view.

It is premature at the moment to foresee if it will be possible in the future to support other innovative and economically viable composting processes in the framework of the THERMIE programme, which is presently oriented mainly to the production of electricity and heat at large scale in combustion or gasification plants. We consider that composting is a mature technology which needs to be applied in many plants in order to produce a good quality compost starting from accurately selected materials.

If limited and technology specific R&D or Demonstration activities should be carried out, it is possible to integrate them in the Agriculture and Fisheries Programme, managed jointly by Directorate-General XII (Science, Research and Development), Directorate-General VI (Agriculture and Rural Development) and Directorate-General XIV (Fisheries), of the European Commission.

Table 2 Energy production from Biomass and Waste (12 EU Countries)

	1991 – MTEP	2005 – MTEP
<i>Thermic Energy Production</i>		
– Wood Biomass	20.0	50.0
– Other Biomass (Biogas, Wastes, etc)	2.7	8.0
TOTAL	22.7	58.0
<i>Biofuels</i>	0.0	11.0
<i>Electric Energy Production</i>		
– Biomass and Waste	2.7	8.6
Total Energy Production from Biomass	25.4	77.6
TOTAL RES	42.6	108.7
BIOMASS SHARE	59.6%	71.4%
TOTAL ENERGY CONSUMPTION	1160.0	1400.0
BIOMASS SHARE	2.2%	5.1%

The Role of Composting in Sustainable Agriculture

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Abstract

Incineration, landfill and recycling are the three main strategies to face the problem of waste disposal, and they may co-exist. However, it is essential to encourage recycling, the only sustainable practice among the three above cited which avoids the existence itself of wastes by transforming possible waste materials in a series of products. Composting, as sustainable transformation of potential wastes in organic fertilizers, tunes up with sustainable agriculture, and must be optimized and encouraged. The importance of the use of compost in agriculture is a commonplace, and does not correspond to reality, particularly if rules and technical parameters for its application are not given by the proper professional and institutional competence, as is often happening. The use of compost in agriculture has much more than the importance of the application of an amendment to the soil. The three requisites needed in order that agriculture can be considered sustainable are discussed, and the use of compost is shown to enhance sustainability, not only of the agricultural activity, but in a more general context. Sustainable agriculture, and the use of compost in agriculture can be considered as essential activities for a sustainable society.

Introduction

Although it is common today to talk about sustainable agriculture, as well as of sustainability of any human activity, the meaning of ‘sustainable’ is seldom defined.

Sustainable is a fashionable word. So, it is possible to mistake sustainable agriculture for organic farming, or for some biological or biodinamic version of agriculture, or for the reduction of agrochemical inputs, or for the application of some recent EC directive or U.S. EPA recommendation, and so on. As a matter of fact it is possible to realize the existence of some confusion of ideas with reference to the precise meaning of sustainability.

At a first approximation, any activity or any economic system able to maintain

itself for an indefinite period of time can be defined as sustainable.

However, we must endorse the above concept in the broadest sense. An activity or a system cannot be considered separately and isolated from other activities and systems. Let us consider a breeding of trouts in mountain. There will be many problems of balanced feed supply and of veterinary precautions which must be adopted in order to prevent fish diseases. In addition, a main technical item will concern the decision of how regulate the turnover of trouts, i.e. how many fishes could be sold per week in function of the reproductive potentiality in the breeding. Once all technical problems are optimized, the breeding will be considered sustainable *per se*, but not economically speaking and from the environmental point of view. For instance, the resources used for the nutrition of trouts or the same trouts sold at local markets will reveal to be insufficient or excessive, or, simply, trout excrements will heavily contaminate the effluent stream.

In other words, sustainability of any activity could not be assessed without considering all the related activities. Sustainability of a human activity is a comprehensive concept, which cannot be examined apart from the whole context of other human activities influenced or interconnected with that we are considering.

Wastes and residues: disposal and utilization

As is well known, three possible strategies are available to dispose or re-utilize any waste or residue produced by human activities: incineration, sanitary landfill, and recycling. The three practices are not absolutely alternative, because they may co-exist in large part or totally, but a strong political will is necessary in order to orientate the choices that technical operators are called to make. A good policy may seem sometimes a challenge: it may reveal to be fruitful only in the medium term.

Incineration seems to be a clean technology, at least at a first glance. Disposal of wastes by incineration allows energy recovery, so that theoretically after the initial supply of fuel, a self-sufficient energy supply internal to the cycle will occur. As a matter of fact, however, disposal is more apparent than actual, because incineration reduces the volume of wastes substantially, but not their mass. From municipal solid wastes, for instance, about one third, and sometimes much more of the initial weight, is transformed in inorganic slags, which contain some of the less important or noxious materials, and of course still need to be disposed. The energy recovery sometimes will remain a dream. Finally, the risk of pollution from the emissions to the atmosphere cannot be neglected: organic (e.g. dioxins) and inorganic substances (e.g. cadmium and mercury compounds) are among the most common and harmful compounds emitted. It is possible to abate the content of dioxins in the emissions by raising the combustion temperature at 1200–1300 °C, but the process becomes more and more expensive. It is also possible to abate the content of heavy metals in the emissions, e.g. by washing the chimney smokes, but waters used to wash the steams will need of course further treatments. If such waters will be con-

veyed to a sewage treatment plant they could heavily contaminate sewage sludges, making them unsuitable for application in agriculture.

Landfill is another technology which can appear even more fascinating: wastes are disposed without apparent difficulties in appropriately selected areas and at the end their volume may be utilized to re-model the areas themselves, e.g. to fill up opencast mines and to mould them pleasantly in order to give them new destinations, e.g. for recreational purpose. The first obstacle arises from the relative low availability of suitable land surface. Due to their scarcity, landfill disposal becomes expensive. Another great difficulty is caused by the slow evolution of the landfill caused by the transformation of the disposed materials: landfills undergo a slow and continuous bedding along the years, with variations of volume, emission of gases to the atmosphere in the short term, and leakage of potentially harmful percolates in the medium and long term. This requires the adoption of a number of cautions for many years, and such cautions mean additional expenses.

Recycling is in general the most difficult practice to face the problem. For this reason is not popular as one could expect. On the other hand, recycling is also the only totally sustainable strategy dealing with the problems of wastes. For this reason it must be encouraged enthusiastically. As stated above, recycling is not easy and requires the highest degree of professional competences. A wise policy in matter of wastes should promote and subsidize the formation of such competences.

Recycling is the technology which prevents the existence itself of wastes. Recycling transforms any material, or complex of materials which actually could become wastes if their owner should get rid of them, in useful materials or even commercial products. Recycling of organic residues may give foods, feeds, fertilizers, and many other useful materials. Composting is the process of recycling fermentable organic residues.

Composting, like other recycling technologies of residues, avoids the existence itself of many categories of wastes. Among the different recycling technologies, however, composting avoids the existence of wastes which are probably the more important from a quantitative point of view. So the process of composting is of great benefit for the human society.

Composting

Many animal and plant by-products that are rich in organic carbon and nitrogen, such as leather meal, ground feathers, horn and hooves, waste wool, oilseed cakes, and so on, are fertilizers as they are. They do not need any composting process. They do not contain humic substances and normally do not need any fermentation process. The evolution of the organic matter of these organic fertilizers will occur directly in soil (Sequi et al. 1991).

Another group of organic residues is composed of materials sometimes also rich in organic carbon, but comparatively poor in organic nitrogen, such animal dung, agricultural residues and urban refuse. They can be applied to the soil only

after a period of fermentation of organic matter, often called 'maturation', which is the process of composting. Such organic residues, after composting, are generally denominated organic amendments.

The process of composting is essential because the use of raw organic residues of this second group may be inappropriate for a series of reasons. The main results of a composting process properly carried out on organic residues to obtain organic amendments are the elimination of phytotoxic substances, the abatement of pathogenic organisms, the elimination of undesired seeds, the reduction of fermentability with the connected stabilization of organic matter, the reduction of bad odours, and the increased easiness of handling.

Since the process of composting plays an essential role in providing so many valuable properties from the agronomic point of view, it is imperative to follow its evolution both quantitatively and qualitatively. This is possible because whereas the process proceeds, the total organic carbon content generally decreases, while the proportion of humified against non-humified carbon increases; on the other hand, the organic matter components undergo strong transformations due to the stabilization processes, which show some similarities to those occurring in soil for any organic substrate, including the organic residues or fertilizers of the first group previously cited. The use of parameters such as the degree of humification may be of help in order to follow the increase of actual amounts of humic fractions in the compost piles, while from a qualitative point of view the evolution of the organic matter can be monitored using electrofocusing techniques (Ciavatta et al., 1993). The last techniques can be adopted also to differentiate the different organic matrices.

The use of compost in modern agriculture

We must debunk a myth. Compost often does not fit the needs of modern agriculture. Of course soils need organic matter. In recent years the organic matter content in soils has generally decreased, sometimes to worrying levels, particularly due to the effect of increased soil tillage. However, farmers are generally reducing the intensity of tillage, at present, and may reasonably prefer to manage the organic matter balance of their soils simply by proper crop rotations and selecting different organic fertilizers.

The application of compost to the soil in modern agriculture is somewhat troublesome. Undoubtedly the use of chemical fertilizers in general is more convenient for a farmer, due to the easier handling, storage, and other characteristics of feasibility. In addition, the use of compost *per se* does not solve the problems of crop nutrition. The application of organic amendments to the soil is not sufficient to fit the nutrient requirements of modern crop varieties: their use must be always accompanied by that of a mineral fertilization.

In addition, before the addition of organic matter to the soil it is necessary to take into account the balance of soil organic matter. In a given pedoclimatic con-

dition, turnover of organic matter in soil is controlled by the kinetics of mineralization rate of organic matter. Mineralization kinetics are correlated to the quality of organic matter and its humification degree. But variations in ecologically contrasted conditions can be dramatic, difficult to foresee and impossible to generalize, so that application rates and methodologies are not always simple: they take for granted an additional effort of farmers and their advisors (Sequi and Benedetti, 1995).

In a certain sense, agriculture must adapt itself to the use of composted materials.

Needless to say, we must resolutely promote a widespread use of compost in agriculture. But the use of compost in agriculture is first of all an indispensable need of the human society. The primary requirement originates more in the human society than in the agricultural practice. A current reality in modern societies is that nutrient cycles are broken. Breaking of nutrient cycles occurs by neglecting the problems of organic waste recovery. In order to attain the equilibrium of nutrient cycles it is enough to follow a very simple recife: what comes from soil must be returned to the soil (Sequi, 1990).

Of course, compost may play an important role in soil and improve many soil properties, including the behaviour of chemical fertilizers. According to FAO (1995), an integrated plant nutrition system is an approach which ensures that plant nutrition be environmentally, socially and economically viable. In this context, a judicious combination of mineral fertilizers with locally available organic sources of plant nutrients should be promoted. In fact, mixed applications are not only complementary, but synergistic, since organic inputs have beneficial effects beyond their nutritional components. The use of composts, however, may also imply negative effects if their content of heavy metals and undesired elements is higher than the allowed amounts or, if maximum allowable levels have not been fixed, overcomes reasonable proportions. Sometimes the coolness of farmers, if not the full failure of the attempt to introduce the use of compost in agriculture, has been due to an ill-defined consideration of its properties. The definition of the agronomic value of composts must be committed to the agronomists, on an experimental basis! Although it could seem paradoxical, however, some lists of technical parameters have been compiled in the Ministries of the Environment or even of the Public Works. The lack of professional competence, and of a proper institutional origin is the first step towards bad results.

Sustainable agriculture and composts

Agriculture, like any other human activity, can be defined as sustainable by completing the definition given at the beginning of this report. In practice, agriculture is a sustainable activity if fulfils simultaneously three different requisites:

- it must guarantee the conservation of environmental equilibria so as to allow

- that productivity lasts on a permanently durable basis, i.e. should not lead in particular to dissipation of unrenewable materials or energy (sustainability of resources);
- it must guarantee full safety to the farmer and any other operator, in addition to hygienic and sanitary safe conditions to the consumer (sustainability of human health);
 - it must guarantee economically convenient productions, i.e. a profit to farmers (economical sustainability). This last requisite is that more frequently forgiven. Sometimes it is also concealed, either with financial subsidies to farmers or, worse, by frauds against consumers.

When applying the above principles to the transformation of organic residues in useful fertilizers, the use of compost in agriculture reveals to be a fully sustainable practice and also something more. In fact:

- for what concerns sustainability of resources, the use of compost avoids both utilization of unrenewable resources and excess of energy expenses (for waste treatment, production of chemical fertilizers, and so on);
- with respect to sustainability of human health, the use of compost may avoid to the organic residues an improper fate, with indirect benefit for the human society;
- concerning the economic sustainability, the low cost of composts is useful to the farmers, but even more to the entire human society, who does not afford different expensive solution for the disposal of wasted materials.

First of all, in any case, compost satisfies our simple recife cited above, i.e. everything comes from the soil must be returned to the soil.

Conclusions

The use of compost is important in modern sustainable agriculture. However, the use of compost is an essential hinge not only in sustainable agriculture, but also for the equilibria of the entire human society.

In this sense, composting transcends the meaning it has as an useful practice to be recommended in sustainable agriculture. Also sustainable agriculture cannot be considered only as a form of agriculture to be recommended to farmers and encouraged with all the possible incentives. Sustainable agriculture is something more: is a keystone for a sustainable society.

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I.S.W.A. Policy in the Regard of Composting as an Integrated System of Waste Management

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Introduction: Solid Waste Management, The Environmental Issue of the '90's

Solid waste management has moved to the forefront of the environmental agenda. The level of activity and concern by citizens and governments worldwide have reached unprecedented levels. Nations are considering restrictions on packaging and controls on products in order to reduce solid waste generation rates. Local and regional governments are requiring wastes to be separated for recycling, and some have even established mandatory recycling targets. There is considerable interest in composting and other forms of biological waste treatment in order to reduce disposal requirements and produce useful products. Concerns about emissions from incinerators and waste-to-energy plants have resulted in imposition of state-of-the-art air pollution controls. Landfills are being equipped with liners, impervious caps and liquid collection systems, and gas and groundwater is being routinely monitored. There is wide scale public opposition to the establishment of new solid waste treatment and disposal facilities. As a result, the costs of solid waste management are increasing rapidly.

Previously considered a local issue, it is now clear that solid waste management has international and global implications. Concerns about transboundary shipment of hazardous waste has led to the adoption of the Basel Convention by the United Nations. Recognizing the interrelationship between solid waste standards and economic development, the European Community is moving forward to harmonize waste disposal requirements in member countries. Around the globe countries are discovering thousands of sites where hazardous wastes have been spilled, dumped or otherwise discarded resulting in contamination of soils, surface waters and ground water. The economic costs of clean-up these sites will stress national economies and at the same time offer enormous international business opportunities.

Solid waste management in countries with developing economies poses a special set of problems. In these countries quite often financing is not available for the construction of waste treatment facilities, and there is a lack of trained personnel to

operate waste management systems. Also, there are generally no regulations or control systems, no administrative body responsible for solid waste control and no obligation for industry to dispose of wastes properly. The United Nations Environment Programme has focused on solid waste management in developing economies as a priority concern.

More than ever before, solid waste management policy makers world wide need sound and reliable information on the technical performance, environmental impact and costs of solid waste collection, recycling, treatment and disposal systems.

The Mission of ISWA.

The mission of ISWA is to promote and develop professional solid waste management world wide. Our goals include protection of human health, natural resources and the environment through effective and economically sound solid waste management practices. ISWA is a professional association open to members from all countries in the world. Its activity is solely in the public interest through professional development of its members; it does not pursue any commercial or political aims.

ISWA is truly an international organization in that its governing body, the General Assembly, is made up of National Members from 20 countries around the world. Most countries with an established solid waste management infrastructure hold National Membership in ISWA. National Members must be national organizations representing all professional activities related to solid waste management in the member country. Pending the establishment of a fully functioning National Member organization, countries may join as Development Members. ISWA also has over 700 Individual and Organizational members in over 70 countries. It is this international network of national, organizational and individual members that provides ISWA the ability to reach thousands of solid waste professionals throughout the world.

Integrated Solid Waste Management.

Most solid waste management professionals recognize that there is no single, simple solution to solid waste problems. Instead an integrated approach is necessary combining the elements of several techniques. Integrated solid waste management is a comprehensive strategy involving four key elements applied in a hierachial manner:

1. Reducing the volume and toxicity of the solid waste that is generated,
2. Recycling or reusing as much as possible of what is generated,
3. Recovering energy from the remaining waste through combustion systems equipped with the best available pollution control technology, and

4. Utilizing landfills with adequate environmental controls.

Composting and other forms of biological treatment of solid waste fits into this hierarchy in two places. Composting offers the potential for producing a usable product from the organic fraction of solid waste and as such is a form of recycling. Biological treatment of solid waste can also produce a combustible fuel for energy recovery purposes.

In the following sections each of the elements of this strategy will be discussed in turn.

Waste Reduction.

Waste reduction activities are important to halt or slow down the increasing rate of waste generation per-capita. For example, the most recent data from the U.S. indicates that from 1988 to 1990, the per capita generation rate increased from 1.82 to 1.95 kg. per person per day. In 1990, ISWA published data on municipal solid waste generation rates in 15 countries which showed rates ranging from a low of 0.6 kg. per person per day to a high of 2.6 kg. per person per day.²

Waste reduction has several aspects, all of which should be addressed. One is toxicity reduction, in which the nature of waste is changed by reducing manufacturer's use of toxic materials in consumer products. Another is volume reduction – cutting the amount of waste generated by using less material in the first place. A prime example of this is a reduction in packaging. Waste reduction also includes encouraging the production of products that can be recycled more easily, such as shifting from multi-material to one-material packaging. Other options to reduce wastes include the redesign of products, material use changes, and restrictions on specific product types.

The approach to reducing waste must be broadly based incorporating actions that can be taken by industries, individuals, commercial enterprises and governmental agencies. Industry can reduce waste through raw material substitution and redesign of products and processes. Individuals, commercial enterprises and agencies can use their purchasing power to create a demand for low waste products or items produced from recycled materials. Governments should investigate the use of economic and other incentives to encourage waste reduction. Waste reduction efforts also need to focus on consumer behavior. Education and information dissemination programs can be effective means of causing desired behavioral and attitudinal changes.

There are many cases of successful reduction of wastes produced by industrial processes. Experience has shown that modifications to industrial processes that reduce waste also result in lower raw material, energy and waste disposal costs. Productivity is often enhanced and liabilities related to release of hazardous substances are reduced. The fact that waste reduction quite often pays has been demonstrated repeatedly.

Recycling , Including Composting.

There are two basic approaches to recycling solid wastes. The first involves separating recyclable materials by the waste generator and separately collecting and transporting these materials to recycling markets. The second involves collecting mixed wastes or commingled recyclable materials and separating them at a central processing facility. The highest recycling rates, reported in 15 countries in 1990, were in the range of 10 to 18 percent. There are many good examples of successful recycling programs in countries throughout the world.

Composting or biological treatment of solid waste offers the potential of producing a recyclable product in the form of a soil conditioner or cover material. Biological treatment can also produce a combustible gas which can be collected for energy recovery.

Prior separation of recyclable materials has the advantage that the materials are not contaminated by other wastes. However, this requires the waste generator (e.g. householder) to separate the wastes correctly and store them in separated form. Also, the generator needs to transport the separated material to recycling centers or separate or compartmentalized collection vehicles need to be used. Key factors in success of pre-separation efforts are the cooperation and willingness of the generator to participate in the program over the long term, and the additional collection and transport costs that may be required.

Many communities in Europe are currently separating organic food wastes from other wastes at the household level and separately transporting these organic materials to biological treatment facilities. Separate collection of lawn and garden waste is frequently practiced in the US. these wastes are then composted, sometimes in conjunction with sewage sludge, at centralized municipal facilities.

Mixed solid waste can be separated for recycling at local processing centers or materials recovery facilities. Some plants process segregated recyclable materials; others separate mixtures of glass bottles, aluminum cans and steel cans; still others process mixed residential or commercial wastes, separating the recyclable materials. The success of these plants depends on the processing costs and the quality of the recyclable material produced. Many attempts at producing usable products from composting or biologically treating mixed municipal wastes have not been successful because of contaminants resulting from the metallic and other non-organic fractions of the mixed waste.

A major impediment to recycling is the question of continued viability and availability of markets for the recovered products. For composting and biological treatment to be commercially successful, markets for the recovered solid product and bio-gas are necessary. It is important to understand that separation of materials from the solid waste stream in itself does not constitute recycling. Recycling only occurs when these materials are incorporated into products that enter commerce. Therefore requirements to separate certain fractions of materials from waste may produce a supply of materials, but these requirements in themselves will not ensure recycling. In fact, if markets for these materials are not found, and

the materials are subsequently disposed of, all of the costs of recycling are experienced with none of the benefits. Similarly, requirements to incorporate separated waste materials in products will not result in recycling unless these products are of a quality and price that they successfully compete in the marketplace.

A major factor affecting recycling economics is the difference in cost between disposal and recycling. In many locales this cost difference is narrowing. To analyze the economic feasibility of recycling one must consider the price received for the recycled material, the solid waste collection and disposal costs avoided and the costs of separation, collection and processing the separated materials. In making these cost comparisons it is important that all environmental costs and benefits are internalized. Also, the benefits to future generations in terms of natural resources conserved or landfill space conserved must be considered. Any virgin raw material subsidy that artificially drives down the price must be accounted for so that virgin materials and recycled materials compete in an equitable manner. Similarly, procurement specifications that arbitrarily discriminate against recycled materials should be eliminated.

Combustion with Energy Recovery.

Waste-to-energy facilities employ the controlled combustion of solid waste for the purposes of reducing its volume. Municipal waste-to-energy facilities produce a number of benefits to a waste management system. Combustion can destroy bacteria and viruses in wastes as well as harmful organic compounds. Combustion can reduce the volume of solid waste by up to 90 percent thereby conserving landfill space. It also offers the possibility of recovery of energy in the form of steam or electricity. Modern solid waste-to-energy facilities burn wastes at high temperatures with residence times necessary for efficient combustion. There are several decades of experience with this technology and research and technological developments have significantly advanced the state-of-the-art and practice. There are hundreds of examples of well designed and operated municipal waste combustion systems around the world.

In some countries, waste combustion is used to treat a very high percentage of the solid waste stream. In Denmark, Switzerland and Luxembourg over 75 percent of the municipal solid waste stream is treated by combustion with energy recovery. In Sweden the percentage is 60 percent, in France 43 percent, in the USA 17 percent and in Germany 38 percent. Japan uses waste combustion to treat over 70 percent of the waste remaining after recycling. This attests to the compatibility of waste-to-energy and recycling.

Environmental management of municipal waste combustion facilities include the control of air emissions and the management of ash residues. Standards for control of air emissions incorporate good combustion practices, emissions monitoring and highly efficient air pollution control systems to control organic emissions (dioxin and furans), metals, acid gases and other pollutants. In many countries there has been a substantial financial investment to control air emissions

from municipal waste combustion systems. In the USA it is estimated that in 1994 the national costs of such air emission controls will be over \$470 million a year.

With respect to management of ash from municipal waste combustion facilities, technologies are available to safely dispose of these residues. These include specially designed landfills for ash disposal and technologies to chemically extract metals or to solidify and stabilize the ash. The added costs of these techniques can be offset if the ash is treated to the extent that it can be used safely as an aggregate or building material.

Sanitary Landfills.

The disposal of waste on the land continues to be a predominant method used world wide. The 1990 ISWA report indicates that the percentage of waste disposed of by landfill ranged from 20 to over 90 percent for the 15 countries reported. It is important here to distinguish here between sanitary landfill and uncontrolled open dumping. The open dumping of waste on the land without adequate controls can result in serious public health, and safety problems and severe adverse environmental impacts. However a sanitary landfill is an engineered structure that is designed and operated to protect public health and the environment.

Sanitary landfill technology has advanced very rapidly over the past decade. Today's state-of-the-art landfills are equipped with leachate collection systems, liner systems, systems for control of landfill gas, groundwater monitoring, closure and post-closure care and much more. The objective is to ensure that landfilling is performed in a manner that greatly reduces the chance of release of contaminants to the environment – and also, to assure that any release that does occur is quickly detected and corrected. Since land disposal of solid waste is practiced on such a wide scale basis it is important that the best available technologies be used.

A Strategy for Continuous Improvement in the Future.

Any discussion of solid waste management policies for the future must refer to Agenda 21, adopted at the United Nations Conference on Environment and Development in Rio de Janeiro in 1992. Agenda 21 addresses the pressing environmental problems of today and aims at preparing the world for the environmental challenges of the 21st Century.

Agenda 21 deals explicitly with solid waste management in two chapters: Chapter 20 on the environmentally sound management of hazardous waste, and Chapter 21 on the environmentally sound management of solid wastes. Agenda 21 tells us that humanity stands at a defining moment in history. We are confronted with a perpetuation of disparities between and within nations, a worsening of poverty, hunger, illness and illiteracy and the continuing deterioration of ecosystems on which we depend for our well being. However, it holds out the hope that sustainable development, that integrates environmental protection and economic development, will lead to the fulfillment of basic needs, improved living standards

for all, better protected and managed ecosystems and a safer, more prosperous future. It sounds a clarion call for active contributions to this effort by international, national, regional and sub-regional organizations with the broadest participation and involvement of the public and non-governmental organizations.

In order to be consistent with sustainable development, solid waste management systems must meet the needs of the present without compromising the ability of future generations to meet their needs. This involves efficient management of today's wastes while conserving resources and protecting the environment for current and future generations.

Using Agenda 21 as a starting point, I would like to suggest ten principles or strategies for future solid waste management policies and programs. I offer these as a vision of solid waste management consistent with sustainable development.

1. Waste Prevention and Toxic Reduction as Strategies of Choice.

Traditional waste management strategies have relied primarily on collection of wastes followed by treatment and disposal. A waste prevention strategy emphasizes not creating the waste in the first place, and reducing the use of toxic materials so that the wastes that are generated are less toxic or less hazardous. Waste prevention not only enhances environmental protection, it often involves economic benefits. Waste prevention is a very powerful concept that has significant potential for reconciling both environmental and economic goals. Waste prevention should be the cornerstone of sustainable waste management policies.

2. Economically Sound Recycling and Recovery.

Recycling and recovery of materials and energy from solid waste not only reduces the volume of waste for disposal but also conserves natural resources. However, in order for recycling to be consistent with sustainable development it must be economically feasible. Otherwise, resources are wasted not conserved. These same remarks apply to composting and biological treatment.

In order to effectively carry out successful recycling, composting and biological treatment programs, solid waste managers must operate in a business-like manner as raw material and fuel suppliers. They must treat the users of their materials as customers. This means they must produce products that meet the customer's material quality requirements at a price competitive with other material supplies. They must operate their separation, collection and processing systems to produce competitively priced, quality materials at the lowest possible costs. The elements of success of a recycling or composting operation are the same as for any successful business; staying close to the customer, understanding and meeting their quality needs and operating in a cost effective manner to produce a competitively priced product.

3. Product Stewardship.

It is important to understand that wastes are simply discarded products and the design and use of a product can have a very significant impact on the nature of the waste that is produced. For example, waste prevention and toxic reduction can be accomplished by substituting raw materials, changing product designs, increasing process efficiencies, and extending product lifetimes. Recycling and reuse can be enhanced by designing products so that components and materials can be easily separated, by eliminating contaminating materials that inhibit recycling, and by using more recycled materials in the original product. Eliminating certain materials from products can also reduce the release of toxic materials to the environment during waste treatment and disposal.

Product stewardship involves taking responsibility for a product throughout its entire life cycle including responsibility of management of wastes after the product is discarded. While persons responsible for waste management can identify desirable changes in products from a solid waste management perspective, the responsibility for making such changes lies with product manufacturers.

We are beginning to see the implementation of this concept in laws that are being passed in various European countries requiring manufacturers to take-back discarded products and packaging for reuse or recycling. It is important that these programs produce strong economic incentives for manufacturers to reduce and recycle wastes and not just establish separate waste collection systems financed by a small hidden tax paid by consumers. Product stewardship will be encouraged when the full costs of managing the product as a waste, including all environmental costs, are reflected in the economic decisions of product manufacturers and consumers.

4. Establishment of Environmentally Sound Treatment and Disposal Facilities.

Even with maximum feasible rates of waste reduction and recycling, there will still be a need for waste treatment and disposal facilities. The state-of-the-art of waste treatment and disposal has advanced rapidly in recent years, primarily due to requirements of environmental regulatory programs. Today, technologies are available to effectively treat and dispose of wastes in an environmentally sound manner.

It is important that new facilities employing these new technologies capable of meeting stringent regulatory standards are established and issued operating permits. Otherwise older, less environmentally sound facilities will continue to be used resulting in adverse environmental impacts and higher long term costs.

5. Rigorous Enforcement of Environmental Laws and Standards.

The establishment of national regulatory control program with appropriate legislation, regulations, ordinances and licenses is an extremely important step in pro-

tecting human health and the environment from the mismanagement of solid wastes. Furthermore, in the absence of regulatory controls, adequate treatment and disposal facilities are not developed.

Environmental standards must be rigorously enforced in order to assure the public that our solid waste systems are operated in ways that protect human health and the environment. Enforcement must create an incentive for compliance with environmental standards. It must level the playing field so that violators are not at a competitive economic advantage to the good citizens that comply.

6. Control of Transboundary Waste Shipments and Elimination of Illegal International Traffic.

Agenda 21 points out that illegal traffic of hazardous wastes may cause serious threats to human health and the environment and impose a special burden on the countries that receive such shipments. The prevention of illegal traffic in hazardous waste will benefit the environment and public health in all countries, especially developing countries. The Basil Convention on the Control of Transboundary Movements of Hazardous Waste and their Disposal controls transboundary movements of hazardous wastes through a system of prior notification and written consent.

Recognizing that simple elimination of transport of wastes is not sufficient for environmental protection, the Basil Convention also encourages efforts to reduce waste generation, develop national self sufficiency in hazardous waste disposal, and ensure environmentally sound treatment and disposal systems. Wide scale ratification and implementation of the Basil Convention is essential to control international shipments of hazardous waste and assure their proper treatment and disposal.

7. Building Institutions and Capacity Development.

Many countries lack the national capacity to handle and manage solid wastes, primarily due to inadequate infrastructure. This includes inadequate facilities, lack of trained personnel, lack of information and monitoring systems, inadequate regulatory programs and insufficient financing. Therefore establishment of an effective waste management system involves building institutions, training, development of human resources and in general, building the capacity to control and manage wastes.

Developing the capacity to carry out research and development programs is important to improve understanding of the environmental impacts of solid waste management systems and develop solutions. Research into the social and economic aspects of solid waste management is necessary to understand and better design economic incentives and information and education programs. The results of research programs must be transferred into the field as new and improved solid waste management systems are developed. Therefore, outreach efforts to apply

the results of research are essential. Technology transfer to countries with developing economies is especially important.

8. Full Cost Accounting Consistent with the Polluter Pays Principle.

Often the true economic costs of solid waste management are hidden and far removed from producer and consumer decisions. For example, some solid waste management costs are paid out of general tax revenues and are not apparent to the tax payer. Obviously this does not produce any incentive to reduce wastes. Improper disposal of wastes often requires future clean-up actions that are borne by other parties. Uncontrolled releases from solid waste management units can result in environmental damages with economic implications. All of these costs must be fully accounted for and paid for by the responsible parties. Economic and environmental efficiency depends upon the polluter paying for the costs of pollution and not subsidizing these costs in an indirect way through other parties.

While discussion of such issues tend to date on economic theory, there are a number of practical approaches which begin to account for these costs and incorporate them into production, consumption and waste management decisions. Pay-as-you-throw programs, which charge waste generators for the amounts of waste discarded is one example which produces an economic incentive to reduce and recycle wastes. Liability standards for waste generators produce a very strong economic incentive for waste reduction and on-site waste treatment. Product labelling programs attempt to influence consumer purchases by identifying recyclable products or products made from recycled materials.

Market based economic incentives can be used as an alternate to regulation or as a means of making regulations more effective. Other economic incentives such as pollution charges and deposit systems should also be evaluated for future solid waste management policies.

9. Public Participation and Education.

Providing data and information to those who make or influence decisions can lead to voluntary actions with significant environmental benefits. A good example is when various production facilities are required to inform the public of the release of certain toxic wastes to the environment. This can result in public demand for a reduction of such releases and encourage voluntary industry programs to reduce these wastes. Public information is a powerful tool which can stimulate real results and an informed public can be an effective force in environmental protection.

However, it is important to provide the public with accurate and scientifically sound information. Environmental education is very important and there is a need for (1) support for curriculum development on solid waste management and environmental issues, (2) assistance for teacher training, (3) scholarships and fellowships for educational programs, and (4) incorporating environmental and solid waste management issues into curriculum for students of engineering, law, sci-

ence, business, economics and other disciplines. It is very important to increase environmental literacy to build public support for programs to train future generations of solid waste management and environmental professionals.

10. Integration of Waste Policies with Other International and National Policies.

Many national and international policies can have a strong influence on solid waste management practices. Consider the effect of: (1) energy policy on the incentives for waste-to-energy facilities, (2) transportation policy on freight charges for recycled materials, (3) agricultural policy on the uses of sludge as fertilizers or soil conditioners. Other examples include the effect of financial policy on investment into environmental technologies and military policy's effect on clean-up of defense installations. Solid waste management professionals must play a role assuring the solid waste management implications of these policies are assessed in national and international forum.

In summary, there remains a tremendous opportunity to improve waste management practices. This International Conference on the Science of Composting gives us an excellent opportunity to study the advances that have been made in this field and consider how composting and biological treatment fit into the scheme of integrated solid waste management. Any vision for improvement of solid waste management practices, must include the development of a professional and scientific work force, in both the public and private sector, capable of dealing with issues such as waste and toxic reduction, product design, market development, public information and education, enforcement strategies, research and development, technology transfer, and economic incentives. It is my hope that ISWA can play an important role in defining solid waste management practices that are consistent with sustainable development, and in helping solid waste management professionals bring about continuous improvement in solid waste management world wide.

¹Presented at the International Conference The Science of Composting, Bologna, Italy May-June 1995.

²International Perspectives on Municipal Solid Wastes and Sanitary Landfilling, Joseph S. Carra and Raffaele Cossu, Academic Press 1990, included data for Austria, Canada, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, Poland, South Africa, Sweden, Switzerland, UK and USA.

Waste Management and Legislation

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History of Waste Management in Europe

The situation in Europe, in the aftermath of the second world war, was very poor. In most European countries the industrial infrastructure was either destroyed or looted. It is estimated that ca 15 Mio people in Western Europe were without a home, many more people were jobless. Food supplies were limited, both in quantity and variety. Common articles for consumption were in short supply and subject to rationing. People were undernourished, many people died prematurely due to combined effects of malnutrition and lack of proper medication.

All Governments in Western Europe were faced with the daunting task of restoring normal living conditions for their citizens. Priorities were clear. They had to provide as soon as possible food, housing, medical care and jobs for millions of people as a first priority, less they face severe social unrest that could result in massive popular uprising threatening the West-European democracies.

In Western Europe, Government called for – and organised a concerted action involving all societal partners (authorities, industry, trade unions, politicians) for the development of national restoration plans.

The national restoration plans did not concern themselves with the short-long-term impact of the increased industrial and social activities on the environment. Handling of waste arisings was left to the lower authorities (municipalities). Guidelines for collection and disposal dealt with short-term effects only, namely the protection of public health, by imposing collection frequencies and dumping practices that reduced health risks by controlling flies and vermin infestation. Household waste and industrial waste (sometimes hazardous waste) was dumped in every evacuation found in the proximity of the municipality. The only refinement that took place was the introduction of the so-called sanitary landfill, where waste dumped had to be covered by soil at the end of each working day, to reduce the risk of odours, flies and rat infestation.

It has been estimated that today in the EU countries, there are between 60.000–120.000 of these waste dumping sites.

In the last decennia, a large number of dump sites have been closed and replaced by centralised technical landfills (e.g with double barrier system, methane collection and leachate treatment system). However, the practice of waste dumping

is still occurring in France, Italy, Greece and Portugal.

It is estimated that the leachate from old waste dumps will increase the pollution of Europe's aquifers at a rate of 120km² per year, for many years to come. Corrective action will be a significant burden on Member States budgets for environmental protection, for many years to come.

During the 60s–70s, many municipalities invested in waste treatment technologies, as a solution for the diminishing availability of landfill space, and a growing recognition of the adverse effects on the environment of the waste dumping practices.

Incineration

Waste incinerators (with or without energy recuperation) were build. Today, there are approximately 500 such installations in the EU, treating approximately 20–25% of the 150 MMT of municipal solid waste generated in the EU each year.

In the early 80's, new incinerator construction stagnated, mainly due to the detection of dioxins in the incinerator flue gas emissions, and the public reaction to the discovery of the incinerator as being a major source for the so called Seveso poison. A reduction of incinerator capacity will occur in 1995–96, when the Directive on incinerator emissions will have to be implemented, which will force the closure of the older type incinerators that can not be economically upgraded to the new standards. In the EU, overall capacity decline will be minimal since new incinerators being build do have larger capacities than the old ones that are shut-down.

The new, state of the art, energy from waste installations, that are currently operating or being build, rather than being a source of pollutants, actually act as an important clean-up tool for a large number of micro pollutants that are ubiquitous in the environment and therefore present in all waste materials. Persistent toxic and bio-accumulative chemicals, such as PCB's, Dioxins, Chlorobenzenes, Chlorophenols and heavy metals which are present to a certain extend in all fractions of municipal solid waste, will either be destroyed or concentrated in a manageable rest fraction.

Composting

Composting of municipal solid waste gained acceptance in the 60s – 70s, however it became apparent that due to quality reasons, e.g. visual impurities, like glass-plastic, the market for compost was slow to emerge. A further problem emerged in the late 70s when the risks for plant life and soil quality by the input of compost containing heavy metals were identified by numerous scientists in Europe (Jager, Kloke, Sauerbeck, et.). In the 80s, the renaissance of composting occurred when feedstock to the composting plants was changed from municipal solid waste

to so-called biowaste. This is a source separated organic (putrescible) fraction of the household waste, together with the garden waste.

Composting of biowaste, today, is mandated in Austria, Netherlands, several German Lander and optional in Belgium-Flanders region. (Some 30 Mio citizens.) Composting is also considered for stabilisation of organic materials prior to landfilling (the so-called cold combustion). Anaerobic digestion of organic waste has moved from pilot plant stage to full size operating plants.

Since this technology, which treats the fraction of household waste that is non-combustible (not fit for incineration), and that causes major environmental problems when landfilled (leachate and methane generation), it is to be expected that other EU Member States will show an interest, especially those that are still composting municipal solid waste (France, Italy, Spain, and Portugal).

Material Recycling

Recycling of materials from household waste stream has a long history in the EU. Supported and encouraged by an industry, in search for cheap secondary raw materials, the glass and waste paper collection has reached high recovery rates in several Member States. Consumers glass collection achieves 60–70% recovery rates by using bottle banks at a ratio of one bank per 600–800 inhabitants.

Waste paper (newspapers – magazines – junk mail – cartons) is usually collected door-to-door by youth – and sport organizations, which are sponsored by the municipalities. Its performance is rather cycling, since municipalities tend to stop the exercise when world market prices for this commodity drop too low (or became negative).

Waste Management Practices

Current waste management practices in the EU Member States are by no means uniform. It is possible to classify the EU Member States' performance on waste management by using a set of parameters, such as:

- % of GNP spent on environmental control.
- Ratio waste dumping versus controlled landfilling.
- Closure programs for out of limits incinerators.
- Material recycling program and % recovery.
- Regulation in place for specific waste streams e.g batteries, waste oil, used tires, car wrecks.

Infrastructure in place for bulky waste e.g. container parks.

Grouping of municipalities in regional waste authorities. etc. etc.

Such an assessment yields following result:

1. Leading countries: Germany, Netherlands, Sweden.
2. Following countries: Austria, Belgium-Flanders, Denmark, France, Luxemburg.

3. Lagging countries: Belgium-Wallonia, Finland, Italy, Spain, UK.
4. Not in the race (yet): Greece, Ireland, Portugal.

Waste Management Plans in the EU

'Waste' is not an indication of an inherent property of any material or product. It merely describes a situation, namely the transition of a material/product from being 'useful' to being 'no longer needed' by the owner. Materials/products can be inherently harmful or benign, this is a matter of toxicity. 'Waste' material/products may be harmful or benign due to their handling during the 'useful' life and/or during the 'waste' life.

Waste problems do occur when there is negligence in the handling of materials/products either during their useful life and/or waste life. This can happen either because of ignorance or irresponsible behaviour. The average citizen in Europe, although only confronted with household waste, has become increasingly conscious of the ecological consequences of mishandling of waste, and in general, is willing to participate at the household level in corrective action. This explains the success of a plethora of initiatives at the local level, that require the participation of the citizen to succeed (e.g bottle banks, waste paper collection, container parks, green waste composting).

Local pressure groups, active at grass roots level, have evolved into so-called 'Green political parties' which in turn have resulted in the 'greening' of the traditional political parties. Today, the perceived issues of the environment have become an intrinsic part of the government declarations in Europe.

The Treaty of Rome, as amended by the New Treaty on European Union, signed at Maastricht in 1992 lists Environmental Policy amongst the principal official policies of the European Union. The listed objectives are:

1. To preserve, protect and improve the quality of the environment.
2. To contribute towards protecting human health.
3. To ensure a prudent and rational usage of natural resources.

Already in 1975 the European Union in its Directive 75/442/EEC requested that the Member States establish Waste Management Plans by 1977. In 1991, the Directive 75/442/EEC was modified by the Directive 91/156/EEC. While the 75 Directive was essentially a request for planning, the 91 Directive was much more precise and demanding on content of such plans. Priorities were established for prevention of waste and valorisation of waste. Disposal and/or valorisation of waste should occur without creating risks for people and the environment.

The principles of proximity and self-sufficiency were introduced which oblige the Member States to install integrated waste management systems and adequate infrastructure for treatment and disposal of waste. The limit date for implementation of Directive 91/156/EEC was set for April 1993. In January 1994, DG XI organised an Expert Meeting on Waste Management Planning to review the status

of the plans in the Member States. During the review, it became apparent that the waste management plans, resulting from the implementation of the Directives by the Member States were far from uniform and could be broadly subdivided into three categories:

1. Plans with a legal status.
2. Plans limited to declaration of intent.
3. Plans limited to administrative guidelines for waste management.

In some Member States, the role of the Waste Management Plan is entirely passive, and limited to a more or less precise accounting system for the various waste management activities of the local authorities. Other Member States do have active Waste Management Plans, in that they provide a dynamic support for waste management activities.

On the basis of a waste analysis (quantity and quality) the treatment and disposal capacities needed to reach prescribed targets in time, are identified and the instruments (fiscal-legal) are put in place to follow the implementation of the Plan by the local authorities. Objectives of such active plans are oriented towards waste management that includes the priority for prevention and valorisation of waste.

The future role of the landfill is illustrative of the diverging policies of waste management in the EU. Some Member States envision a major role for the landfill in the waste management plan, apparently for pure economic reasons. Other Member States foresee the complete elimination of landfilling for untreated waste by a combination of prevention of waste arisings and the treatment of the remaining waste by a combination of material recycling – composting and energy recuperation. The objective is to arrive at a landfill, requiring no further management since its content will be fully inert material.

The waste management plans, as such, are therefore revealing the political will (or opportunism) of the leaders of the EU Member States when dealing with the issues of waste management. Also, geographies, demographies, economics, institutional structures and infrastructure do have a direct influence on the plans. A recent development is the introduction of the Directive on Packaging Waste. This Directive was needed in order to harmonize the abundance of various Member States activities that have emerged as a result of the introduction of the German DSD system. This short cut in an overall integrated waste management plan, while politically opportune, is an unfortunate decision for following reasons:

1. It addresses only a minor fraction of the waste, and its problems (e.g. 20–25% of household waste).
2. Its impact on the landfill is small, both in quantity (e.g. 12–15% landfill diversion) and quality (50% of packaging waste is inert: glass, plastics, metals)
3. It detracts funds, manpower and public attention away from the main problems, such as the need for clean-up of existing waste dumps and the necessity for a fully integrated waste management system for the future, that encompasses all waste.

4. Finally, and importantly, it violates the principle of concerted action by all societal partners needed to establish an integrated waste management policy and system, by shifting the full responsibility towards the industry partner solely.

Final Remarks

The EU Members States are facing high investment costs in the future, for installation of the so-called integrated waste management systems. Part of the funds will have to go towards cleaning up old waste dumps that are now contaminating the aquifers. Funds will also be spent on upgrading of existing incinerators to more strict emission standards, or replacement of capacities that can not be upgraded.

The need for new capacity for incinerators will have to be evaluated against the installation of composting facilities. It is a fact that the country wide introduction of biowaste composting in the Netherlands, saved incineration capacity of 1.7 Mio t/year. It is also true that obtaining permits for composting plants is rather more easy than obtaining permits for incinerators, which almost everywhere in Europe meet a strong opposition from citizens. New installations, whether they are landfills, composting plants or incinerators, inevitably meet local opposition (NIMBY). This is understandable since modern waste treatment/disposal plants do have an economy of scale that is far beyond the needed capacity of the majority of municipalities in Europe.

A modern biowaste composting plant (e.g 40.000 t/year) requires the input of biowaste of 400.000 inhabitants (100kg/cap/year). A state of the art incinerator (e.g. 200.000 t/year) requires the total waste input of 600.000–800.000 inhabitants.

Such installations can only be planned and permitted at the regional-provincial level. It seems also fair that the single community that is blessed (burdened) with the waste treatment installation, should be compensated for the service provided (and hardship suffered?) to the region-province.

A1 Composting Process

Composting Control: Principles and Practice

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Introduction

A composting system consists of three parts:

- materials reception and pretreatment;
- the composting process; and
- compost post-treatment.

The first of these is where the materials are received, shredded and blended to give the optimum nutrient balance, mass structure and moisture content for successful composting. The post treatment is either for removing unwanted components (such as large particles by screening) or preparing the compost for a particular market. Both of these process areas have a profound influence on the overall composting installation, but for the purpose of this paper it is the composting process itself which will be the focus.

There are three principal factors to control during the composting process:

- aeration;
- temperature; and
- moisture content

The control of each of these will be considered together with their interaction.

Aeration

The control of aeration is very much dependent on the type of composting system being employed since this determines whether air is supplied by:

- agitation (eg. in windrows);
- forced aeration (eg. aerated static pile); or
- a combination of (i) and (ii) (eg. aerated/agitated bay systems).

The air requirements of the microorganisms are dependent on:

- the type of waste (eg nutrients, particle size, etc)
- the process temperature;

- the stage of the process (higher requirements in the early stages); and
- the process conditions (eg moisture content, structures, etc)

This requirement can be measured in the laboratory using some form of respirometry. However, these measurements themselves are method dependent particularly regarding the operating temperature of the respirometer. Table 1 gives some laboratory based respirometry results for composting systems using sewage sludge and MSW.

In practice with most composting systems utilising temperature feedback control of some form based on forced aeration the respirometric requirements are a small part of the total air budget. At the early stages in some systems, such as the aerated static pile, the air required for cooling can represent up to 90% of the total need (Finstein and Miller 1985).

Table 1 Respirometric values for a range of composted wastes

Starting Material	Compost Age(d)	SOUR	Conditions	Source
Sludge + woodchips 1:1 by volume ^c	0 5 30	4 mgO ₂ gVS/h <1 30	liquid suspension 30°C ~ 0.5	Robinson (1991)
Sludge + composted sludge 1:1 by volume ^c	0 10 20	8 1.5 <1		
Sludge + woodchips 1:1 by volume ^c	0 5 30	21 10 ~ 1.5		
Sludge + sawdust	0–11 11–25 25–50	1.5 (ave) 0.5 (ave) 0.33 (ave)	Liquid suspension Room temp (20–25°C)	Haug & Ellsworth (1991)
MSW	0 10 14 20 8 months 10 months	1.33 0.79 mg/gDS/h ^b 1.06 0.67 0.13 0.05	Dry at 34°C ^a	Pressel & Bidlingmaier (1981)
MSW			mg/gVS/h Dry at 37°C	Frost <i>et al</i> (1992)

^a Dry refers to work done with a sample of compost as against values taken in a liquid suspension

^b The use of volatile solids (VS) rather than dry solids (DS) would increase these values

^c Sludges of different origins (domestic and industrial)

Windrowing

The majority of windrow turning cycles operate to suit the working plan of a particular installation. In most modern systems there is a recognition that the different phases of the process require different aeration rates. The results of this are turning programmes which for example recommend ‘turning every 3–4 days’ for the first 2–3 weeks and on a weekly basis thereafter. In process terms provided a particular

turning sequence does not cause local problems (eg odour) and the final product is 'acceptable' there is no reason to modify it.

On a more rational basis systems using temperature as a turning indicator have been developed. Briefly these work on the basis that as soon as a certain temperature (typically 55 or 60°C) is achieved in the pile core the material is turned. However, with many wastes, such as the organic fraction of MSW, this would lead to very frequent turning in the early stages which would not be economically viable. In one rationally based system, being implemented widely in Brazil and other South American countries, a modified turning sequence frequency is used starting at 3 days and eventually extending to 6–7 days (Pereira-Neto and Stentiford 1992).

Forced Aeration

Forced aeration systems are intended to supply air to the composting mass using pressurised air systems (typically using low head, < 150 mm, high volume fan units) rather than turning the mass. These work in one of three modes:

- (i) blowing into the mass ('positive' pressure);
- (ii) sucking through the mass ('negative' pressure); and
- (iii) hybrid (a combination of (i) and (ii)) (Pereira Neto et al, 1991)

There is an ongoing debate about which system is 'best' and it is likely that in the long term some form of hybrid will become the 'norm'. Many companies are now moving in this direction to give them greater flexibility in operation.

Regardless of the aeration combination systems in the future will suit the air supply to the requirements of the composting mass. This will either be done using:

- (i) temperature feedback control;
- (ii) oxygen feedback control; or
- (iii) a combination of (i) and (ii).

In most cases by satisfying the needs of the temperature feedback criteria the oxygen requirements are met. However, attention must be paid to the 'heating' and 'cooling' phases of the process to ensure that adequate oxygen remains in the mass (Stentiford et al, 1985).

Agitation and Aeration

The disadvantage of windrow systems (agitation only) is that the temperature of the mass is never properly under control. Figure 1(a) shows the typical 'saw tooth' pattern related to windrowing systems, with the core temperature rising steadily and dropping abruptly when the pile is turned. This does not allow optimum temperature conditions for biodegradation to be maintained in the composting mass

and the frequent remixing of the ambient outer layers extends the period needed for sanitisation (Pereira Neto and Stentiford, 1986).

The disadvantage with the static pile systems relates to the inability to readily change the physical conditions within the pile mass. For example if excessive drying occurs, which is typical of these systems, rewetting is difficult leading to process inhibition due to desiccation, although research in this area has led to improvements (Robinson and Stentiford, 1993).

The combination of agitation and aeration overcomes the major disadvantages of both systems but it does require an increase in the capital investment. Provided the scale of the operation merits this type of investment then the improved process control will not only shorten processing time but also improve the quality assurance of the product.

Enclosed Systems with Air Recycle

Completely enclosed systems have been operated for many years in the mushroom industry where very specific goals are set for the process in terms of compost quality. This technology has over the past 10 years been adapted for use in the waste industry. This adaptation has been necessary to allow for the variability of the feedstock which does not occur to any great degree in the mushroom industry.

In these systems exhaust air is recirculated into the mass and when necessary, either to control temperature or prevent gaseous inhibition, fresh air is drawn into the supply fan. Using this system very close control of the composting process is possible, with temperature variations between inlet and outlet often recorded as a maximum of 5–7°C (Harper et al 1992 – give 6.5°C as a maximum). The difficulty that can occur with biowaste based composts is the deterioration of the structural properties of the mass. Improvements are often achieved in ‘closed box’ type systems by removing the mass from the box, agitating it in some way, and then refilling the box.

The selection of this type of relatively high cost box system using a recycled air loop depends very much on the prevailing local economic situation and the type of control of product quality required.

Temperature

The temperature within a composting mass determines the rate at which many of the biological processes take place. Within a composting mass the thermal properties and the breakdown rates are such that a wide variation of temperature can exist. In aerated static pile systems for example core temperatures can be as high as 70°C whilst the outer surface zones remain at or near ambient (Finstein and Miller, 1985, Stentiford *et al* 1985).

The operating temperature(s) within the composting mass are selected in most cases to maximise both:

- sanitisation (high temperatures are most effective); and
- stabilisation (high temperatures inhibit the process)

In most cases what we end up with is a compromise position which is not optimum for either objective. In process terms the operating temperature bands can be seen as follows:

- >55°C – to maximise sanitisation;
45–55°C – to maximise the biodegradation rate; and
35–40°C – to maximise microbial diversity.

Control

In windrow systems the control of temperature is left largely in the hands of the operator who determines the turning frequency. Figure 1(a) shows the typical saw tooth temperature time relationship we would expect in this type of operation. In relation to the various 'standards' used across Europe, which are shown in Table 2 (ORCA, 1992) it is interesting to consider where the windrow fits into these requirements.

In aerated static pile (ASP) systems it is relatively straightforward to control the temperature at one particular place in the pile using a feedback loop. This system of control linked with a parallel system for supplying air in the heating and cooling phases produces the classical curve shown in Figure 1(b) (Leton and Stentiford, 1990). The heat carrying capacity of the air used in a forced aeration system is not itself responsible for removing the excess heat from the system, this it does indirectly by evaporating moisture from the composting mass. This system of temperature control is very effective for maintaining a set point temperature in the mass, but it cannot prevent the wide variation in temperature across the mass which was mentioned earlier.

The agitated/aerated systems bring an improvement over both the windrow and ASP in terms of more even temperature distribution. This assumes that some form of temperature feedback control is used for the aeration. Some systems of this type have developed a method for measuring temperature in a regularly mixed mass without destroying the monitoring probes. For example in bay type systems, such as that of International Process Systems, the probes are set in the containing walls. These are linked with the fan supplying air to the section of plenum chamber immediately below the probe. This ensures that the supply rate is appropriate to the requirements of the local mass unlike other systems where the same rate is applied to the whole of the mass regardless of the degradation stage (Byers, 1994).

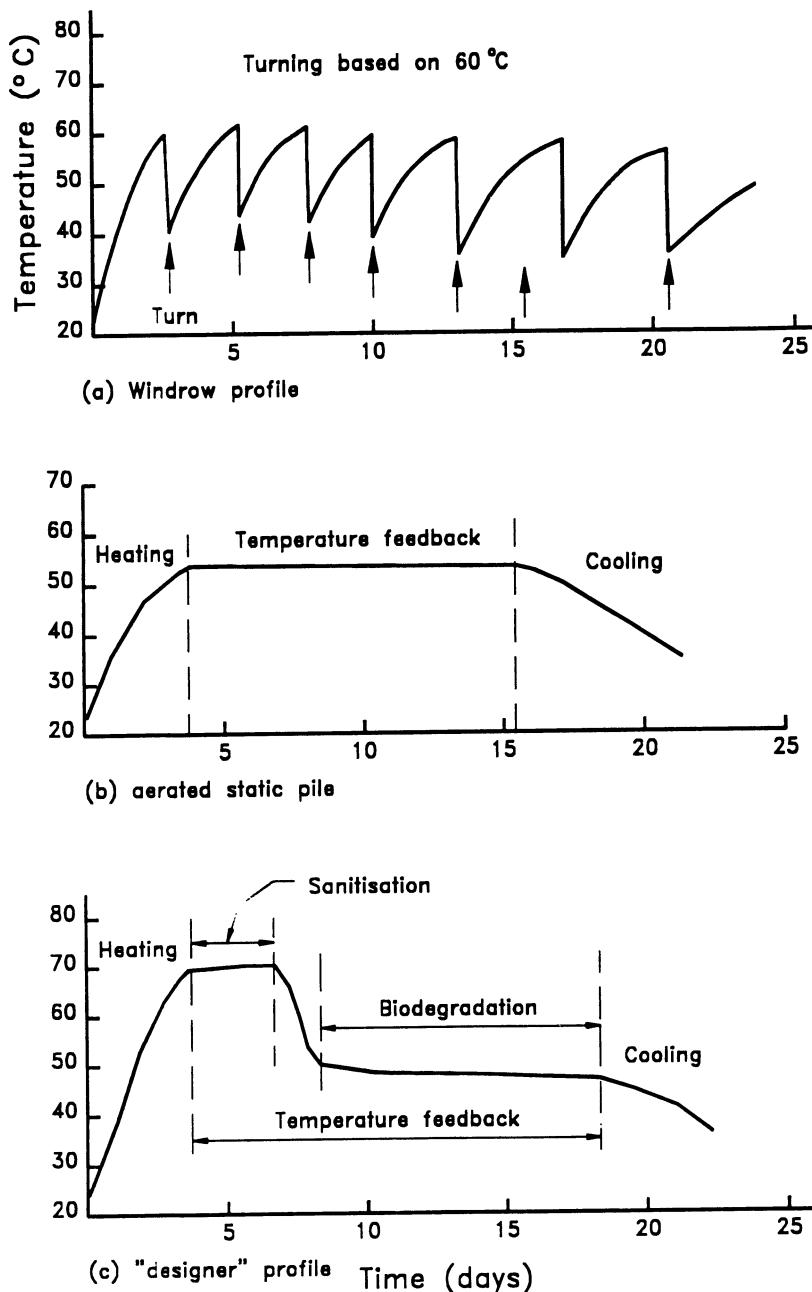


Figure 1 Typical temperature/time profiles for different compost systems.

In the enclosed, 'box', systems much of the control of temperature is based on monitoring the exhaust air from the units. Since these work on the basis of recycling much of the air into the mass this type of system can give very close control of temperature across the mass.

Operating Cycles

The typical operating cycles for the windrow and ASP have been mentioned briefly. In both systems it is possible to change regimes such that we modify either the core temperature or the period of time for which that temperature is maintained.

Improved understanding of the composting process and more sophisticated control systems, as with ‘box’ units, allows for greater flexibility in adjusting temperature time profiles. Figure 1(c) shows a ‘tailored’ control profile which seeks to both ensure maximum sanitisation, by having a relatively short high temperature phase, and high rate stabilisation, by having an extended thermophilic phase.

The ‘tailored’ profile of Figure 1(c) has its high temperature phase in the early part of the process when a large amount of readily degradable substrate is available to fuel the process. However, this high temperature stage can be included at any point in the composting process provided enough residual substrate exists to produce the energy needed.

Table 2 Sanitisation requirements for composting in certain European countries

Country	Temperature (°C)	Exposure (days)
Austria	65	6 (or 2 × 3)
Belgium	60	4
Denmark	55	14
France	60	4
Italy	55	3
Netherlands	55	2

Moisture

The maximum rate of transfer of nutrients and waste products takes place in a liquid environment (100% moisture). However, it is not possible to operate a composting system on this basis where solid substrate is being used. The initial moisture content used in a composting process will typically lie in the range 55–65% depending on the materials being used. The maximum amount of moisture which can be tolerated varies between starting materials being limited by the inhibition of aerobic activity (Golueke and Diaz, 1990).

A major part of the composting process is the loss of water, as a result of evaporation as the process progresses. There is generally no target value for the final moisture content as it depends on the post composting treatment needs (eg screening 40% – approx) and the product market. However, it is widely accepted that marked inhibition of microbiological activity occurs when values drop below 30–35%. Rapid drying to moisture levels less than these can produce an apparent end to the initial phase of composting when in fact the process was stopped prematurely due to desiccation. This can cause difficulties further down the line when

the material is rewet and uncontrolled biodegradation takes place, often under anaerobic conditions, with the associated odour problems.

On the basis of a wide range of research results it would seem that the majority of composting processes should operate with moisture contents in the 40% to 60% band. Initial values typically being high and decreasing throughout the process related to moisture content. In most systems the control of moisture is relatively straightforward, however, it is often the case that the operators are unaware of inhibitory levels.

The moisture content of the compost affects:

- the structural properties of the materials;
- the thermal properties of the materials; as well as
- the rate of biodegradation (Stentiford and Zane 1995).

Measurement

It is relatively straightforward to measure the moisture content of a compost sample using either a conventional oven (4 hrs at 105°C), air drying ('overnight' at 40–60°C) or a microwave oven (5–20 min depending on the compost). The accuracy of each of these methods is variable and their selection depends on the use to which the data will be put.

In compost systems which employ regular agitation or turning of the material it is simple to obtain a representative sample for measuring moisture content. However, in static systems (such as the ASP) there is often a wide variation in moisture content over the cross section of the pile mass, and these systems are difficult to sample routinely and representatively because of the lack of regular mixing and this variation throughout the pile mass.

Soil would appear in many respects to be similar to compost and therefore there seems to be some logic in using measurement systems intended for this medium. However, tests with gypsum blocks, glass fibre moisture cells and electrode probes have met with varying degrees of success.

Gypsum blocks give reasonably good values at steady-state for moisture content above 30%, however, whilst they responded reasonably well, under experimental conditions, with increasing moisture contents their response with falling moisture contents was slow. Blocks which were initially saturated were left in compost at 33% moisture content and no significant change was found in the output signal after one month.

The glass fibre cells did not respond to increasing moisture until the sample containing 61% moisture was used. The response from a saturated condition to a decreasing moisture content was more rapid, but even so with the 33% moisture content sample it took 3 weeks before a stable reading was obtained.

In laboratory based trials the electrode probes developed in the project gave an excellent response in the 30–60% moisture range. The response in field trials was

more variable but the type of probes, once calibrated with the particular compost gave a reasonable response curve. Part of the difficulty with these systems is the local variation in particle size which can produce spurious results.

Non-contact systems using a variety of methodologies have been tried in composting with varying degrees of success. It is necessary with these methods to expose a representative sample of the compost mass on a routine basis. They are therefore only suitable for agitated systems. One method based on an infra-red device is currently being employed successfully with an automated windrow system.

Control

In agitated or turned systems the control of moisture is relatively straightforward. A trained operator, by observing the composting mass during the agitation phase, is able to decide whether the material is too wet or too dry and make appropriate adjustments. Alternatively, on-line non-contact automatic monitoring systems can be used to replace/enhance the operator's role. In most cases the adjustment is one of adding water to a system which is drying too rapidly. In non-agitated systems, such as the ASP, the possibility does not exist for adding moisture during the agitation phase. It is with the latter type systems that in-situ moisture measurement is needed.

The objective in developing in-situ moisture measuring systems for static compost piles is to enable a moisture feedback facility to be added to the control system. This close control of moisture would prevent the premature cessation of composting due to desiccation, with the associated product quality problems this produces.

Having identified a moisture deficiency the problem then is how do we add moisture to the composting mass. Table 3 summarises some off the options which are available and comments on their applicability (Stentiford 1992). Injecting moisture into the airstream has produced promising results, but does necessitate positive pressure aeration (blowing) (Robinson and Stentiford 1993).

Table 3 Methods of adding moisture to an aerated static pile

Method	Comments
Remixing with water addition	Defeats part of the object of ASP and moves towards windrowing
Changing the operating temperature	High set temperature reduces air requirements but also reduces biodegradation rates
Remixing mature compost	Reduces the heat output per unit mass but increases the composting area for a given throughput
Adding moisture without remixing – injecting water into the pile – injecting water into the air stream – spraying on the pile top	Various strategies attempted with varying degrees of success
Changing aeration regimes	Still at the experimental stage, initial results are encouraging

Overview

The control of a composting process demands an understanding of the interaction between aeration, temperature and moisture. Improvements in our understanding over recent years had led to the development of sophisticated control and operational systems. Waste managers now have available to them composting technology which can guarantee a product which is both stable and sanitised, however, the costs of some of these systems is very high.

It is the costs of these systems when compared to alternative disposal routes which will, affect their selection. Plants which are appropriate in parts of Germany where MSW landfill prices are in excess of £100/tonne will probably not be economically feasible in parts of the UK with landfill less than £10/tonne.

An additional dimension is the need for the product. In parts of Europe where soil organic contents are high then the pressure composting is primarily to divert the organic wastes from landfill. However, in many parts of the world, such as the arid regions of South America, there is a desperate need for organic material in the soil. In these latter circumstances the control of the process and the product quality will have lower priority than the production of a compost.

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Composting Plant Design and Process Management

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Abstract

The modern composting plant is a biological processing facility designed to convert raw feedstocks to a usable, high quality end product. The desired end product is a stable, mature, and high quality compost which can be used for soil conditioning and fertilization. Many feedstocks can serve as starting substrates for the composting process. However, the characteristics of these feedstocks are most important to both design and operation of the composting plant and to the quality of the final product. The thermodynamic window of operation and the kinetic rates of reaction are determined largely by feedstock characteristics. This paper discusses the effect of feedstock characteristics on plant design and process management, describes the use of simulation models as design and operating tools, and presents several case studies where computer modeling helped resolve process problems.

Introduction

Composting is *the biological decomposition and stabilization of organic substrates, under conditions that allow development of thermophilic temperatures as a result of biologically produced heat, to produce a final product that is stable, free of pathogens and plant seeds, and can be beneficially applied to land*. A key element of this definition is the production of a usable, stable, mature end product that can be called *compost*. The composting plant itself is a materials handling and biological fermentation facility, designed to take starting feedstocks and biologically process them to the desired compost product. Obviously, the plant's success depends in large measure on the quality and characteristics of the starting feedstocks. Further, the design and operation of the plant must recognize the starting feedstocks and the quality of the desired end product.

Industrial facilities are normally designed to produce high quality end products which can be marketed successfully against other competing products. Most such

facilities take great efforts to assure the highest quality feedstocks for their process. It is generally recognized that higher quality feedstocks equate to a higher quality product and that changing the feedstocks will effect product quality. With industrial plants the normal design approach is to define the final product, including its quality and characteristics, and then secure the feedstocks needed to produce the desired product.

Unfortunately, the design approach used with industrial plants is not always possible with composting plants. Feedstocks for a composting plant are often the waste products of other industries. Because compost competes in a market characterized by marginal pricing, it is generally not feasible to pay high prices for better feedstocks. Therefore, the composting plant will always be constrained in its selection of feedstocks and generally limited to waste products. Despite these constraints, a compost plant must recognize the effect of feedstock characteristics on final product quality. What is true for industrial processes is also true for composting; *it's very difficult to make a high quality product with low quality feedstocks.* Indeed, many process problems owe their origin to either failure to consider feedstock characteristics or failure to understand product quality and the marketplace in which the product must compete.

The purpose of this paper is to discuss those feedstock characteristics important to establishing the mass and energy balance for the composting plant, the required solids residence times, and the final product maturity and stability. Computer simulation models, which integrate feedstock characteristics with kinetic and thermodynamic principles to produce a dynamic model of the process, will also be described. Several case studies will be presented, each of which involved changing feed characteristics which required redesign and/or operational changes to the composting process. In each case, the simulation models proved to be a useful tool in diagnosing the problem and predicting the course of corrective actions.

Feedstock Characteristics Important to Process Control

All materials added to the composting process should be considered as feedstocks or substrates. Amendments and bulking agents are substrates because they add new materials to the process. Recycle is *not* a substrate because it does not add new materials to the process, but merely recycles material within the system boundary. The use of terms, such as amendment and bulking agent, is convenient but it is important to recognize that they are also feedstocks or substrates.

Input Weights

The input mass of feedstocks to the process is determined by the following characteristics:

$X(J)$ = daily wet weight of substrate J, kg/day

$S(J)$ = fractional solids content of substrate J

$V(J)$ = fractional volatile solids (VS) content of substrate J

These characteristics are relatively easy to determine and most designers and operators understand their importance to the plant's mass balance.

Thermodynamic and Kinetic Characteristics

The composting process is driven by energy release which accompanies organic decomposition. Therefore, the energy or thermodynamic balance is largely determined by the extent of decomposition and its associated heat release. While thermodynamics describes the *quantity* of energy release, kinetics deals with the *rate* of reaction. Composting is equally dependent on kinetics. The question 'how long do you have to compost to reach a mature product' is a kinetic question. Reaction rates during composting are relatively low compared to waste treatment processes which operate on more soluble substrates. Composting is slowed considerably because of the solid nature of its feedstocks which require hydrolysis and solubilizing to make the substrates available for biological metabolism. Both thermodynamics and kinetics are important to composting plant design and operation and are determined by the following:

$K(J)$ = degradability coefficient for substrate J, fraction of volatile solids.

$H(J)$ = higher heat of combustion of substrate J, kcal/kg of organics oxidized.

$T(J)$ = temperature of substrate J, deg C.

$RATE(J)$ = first-order rate constant for substrate J, per day.

The degradability coefficient is defined as the fraction of organics which are likely to degrade under composting conditions. With the above definitions the major components for each feed substrate can be described as follows:

$BVS(J)$ = biodegradable volatile solids (VS) for substrate J, kg/day

= $K(J)V(J)S(J)X(J)$

$NBVS(J)$ = nonbiodegradable VS for substrate J, kg/day

= $[1 - K(J)] V(J)S(J)X(J)$

$ASH(J)$ = ash or inert solids for substrate J, kg/day

= $[1 - V(J)] S(J)X(J)$

$WAT(J)$ = water present in substrate J, kg/day

= $X(J) - S(J)X(J)$

The *rates* at which BVS are consumed during composting depends on the reaction rate constants and can be modeled using a first-order rate equation.

$$\frac{d[BVS(J)]}{dt} = -K(J)[BVS(J)]$$

Rate constants and degradabilities are the most difficult data to determine for composting substrates. All other characteristics are relatively easy to determine using

standard laboratory procedures. Haug (1993) has compiled summaries of literature values for reaction rates and degradabilities determined for composting substrates. Much of the literature data is based on measurement of the oxygen uptake rate during composting, which is an indirect measure of the reaction rate constant.

A number of procedures have been developed for measuring rates and degradabilities. A constant pressure respirometer was described by Haug and Ellsworth (1991) and used to measure the oxygen consumption rate and degradability of various substrates. The oxygen uptake data presented in Figure 1 was developed using this approach. Oxygen uptake of hardwood sawdust was followed for 850 days in an enclosed respirometer; during which time about 85% of the hardwood sawdust was decomposed to carbon dioxide and water. The rate of reaction was well modeled by assuming a first-order reaction and dividing the substrate into two fractions: one fraction with a higher rate constant and a second fraction with a lower rate constant. This approach has proven useful in the modeling of many other substrates.

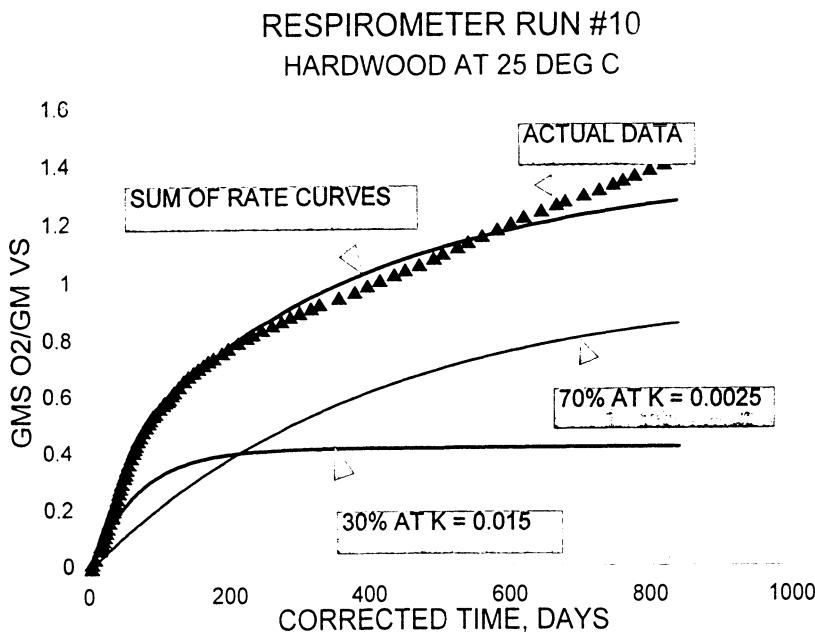


Figure 1 Oxygen consumption, measured as gms O₂/gm volatile solids (VS), as a function of time. The data are modeled by assuming that biodegradeable volatile solids (BVS) are composed of two fractions: 30% of the BVS with a first-order rate constAnt, K, of 0.015, and 70% of BVS with a slower rate constant of 0.0025.

Several observations can be made from data such as that in Figure 1. First, the first-order kinetic model appears to adequately describe the decomposition of many composting substrates, even in long term studies spanning over 800 days.

Second, the accuracy of fit can sometimes be improved by dividing the substrate into fractions with different rate constants. Third, rate constants for composting substrates are less than for more soluble substrates. For example, the BOD rate constant for municipal sewage is typically about 0.23 day^{-1} (base e) at 20°C . By comparison, the rate constant for many composting substrates is on the order of 0.01 day^{-1} at 20°C . This large difference in reaction rates is due to two factors; the need to hydrolyze solid substrates and the refractory nature of some components such as lignin. As a result, residence times for composting are considerably longer than for most other biological treatment processes. A solids residence time of 100 days is typical for many composting plants where efforts are made to control process operations and minimize kinetic rate limitations.

If both faster and slower rate constants are considered, the following substrate characteristics can be defined.

FASTFRAC(J)= fraction of BVS with faster rate constant for substrate J

SLOWFRAC(J) = fraction of BVS with slower rate constant for substrate J

RATEKM20F(J) = rate constant for the faster fraction of substrate J at 20°C ,
 day^{-1}

RATEKM20S(J) = rate constant for the slower fraction of substrate J at 20°C ,
 day^{-1}

Chemical Characteristics

To properly determine parameters such as oxygen consumption, carbon dioxide production, and ammonia production, it is necessary to know the average chemical formulation of the BVS fraction of each substrate. It is usually sufficient to use a formulation such as $C_AH_BO_CN_D$ where:

A(J) = molar carbon content of substrate J

B(J) = molar hydrogen content of substrate J

C(J) = molar oxygen content of substrate J

D(J) = molar nitrogen content of substrate J

Many other chemical characteristics, such as heavy metals and trace organics, are important to defining compost quality. However, these characteristics seldom effect process operation which is the focus of this paper.

Aesthetic Properties

Nuisance contaminants, such as plastic, glass, aluminum film, can seriously impact the marketability of an otherwise good compost. Such contaminants seldom effect process operation and, again, are not the focus of this paper. However, it's worth repeating that *it's very difficult to make a high quality product with low quality feedstocks.*

Simulation Models

If all of the above characteristics are known for each substrate, the problem becomes one of using them constructively to model process performance. With multiple substrates and so many characteristics for each, the task of keeping track of everything is indeed formidable. Fortunately, computer models are available to ease this task and to apply the principles of mass and energy conservation and reaction kinetics. A more complete description of such models is beyond the scope of this paper, but is available from Haug (1993). Simulation models have undergone considerable refinement in recent years and a model for personal computer use is commercially available from the author.

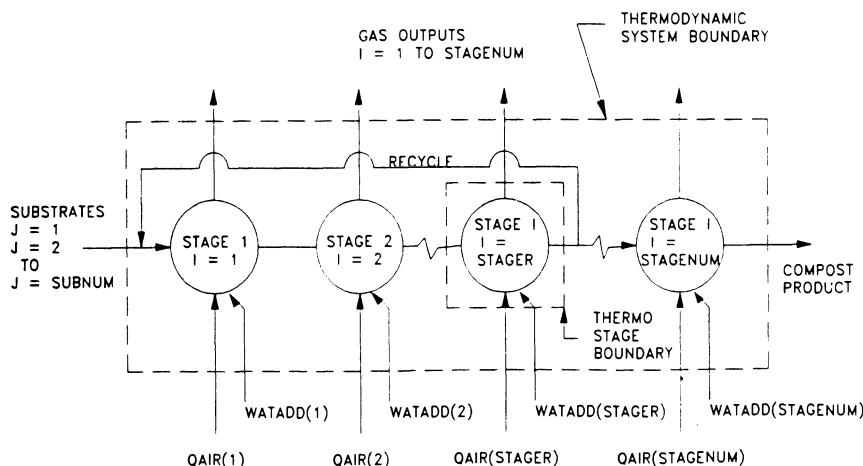


Figure 2 Schematic diagram of a system composting homogenous substrates. A portion of the mixture can be recycled downstream of stage STAGERb and returned for conditioning of the feed to stage 1.

A schematic of a generalized composting system is presented in Figure 2. The process is broken into a number of stages arranged in series. All feed substrates are introduced into stage 1. Output from stage 1 becomes the input to stage 2, and so on. Output from the final stage is the end product of the process. The entire system is surrounded by a thermodynamic system boundary. All mass and heat flows across the boundary must be balanced. Each stage of the process is also surrounded by a thermodynamic stage boundary. Again, all mass and heat flows across the individual stage boundaries must balance. Recycle can occur from any one stage of the process, identified as STAGER in Figure 2. Bulking agent screening can also be defined at the user's discretion. Each stage is assumed to be completely mixed and the hydraulic residence time (HRT) for each stage I is input as HRT(I). Air flowrate to each stage is input as QAIR(I). Options are available which allow the model to predict the QAIR(I) required to maintain a setpoint temperature TSET(I) in stage I and the amount of water addition WATADD(I) to maintain a setpoint solids content SMSET(I).

An example of a typical model run is presented in Figure 3. The substrates include food waste, yard waste, and sawdust, typical of 'mix compostables.' A reactor (in-vessel) system is assumed and is modeled as six consecutive stages, each with a 3 day HRT. Curing is modeled as six additional stages, each with a 10 day HRT, giving a total solids residence time of 78 days. Setpoint moisture contents are set at 50% in the reactor stages; setpoint temperatures are 55 °C. The weight of final product is about 41% of the wet weight of feed substrates. Supplemental water addition to maintain the specified moisture is 75% of the total weight of all substrates; while air addition outweighs the feed substrates by about a factor of 10x. Air supply and exhaust gases are always the dominant terms in a composting mass balance.

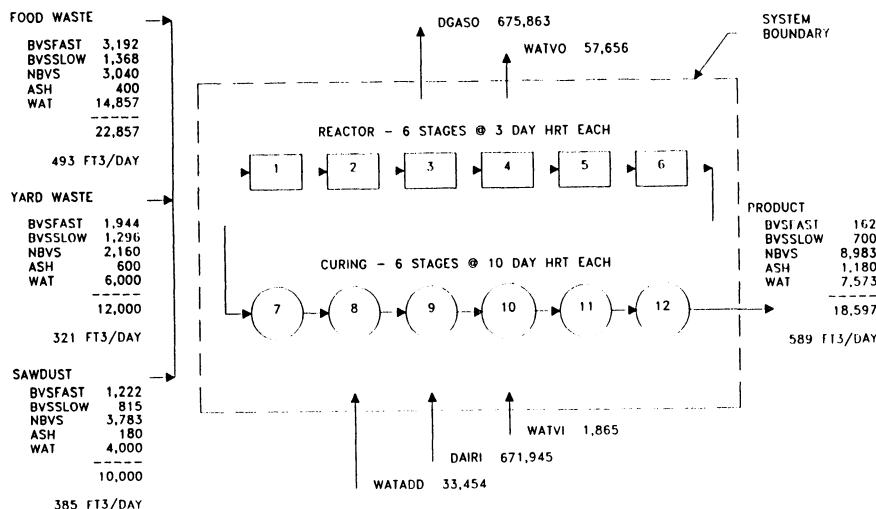


Figure 3 Example mass balance for mixed compostables processed in an 18 day reactor system followed by 60 days curing.

Compost product from this process is predicted to be both stable and mature based on achieving four criteria: (1) a specific oxygen uptake rate of 50 mg O₂/kg VS-hr or less, (2) a minimum 90% BVS reduction across the system, (3) a decrease in composting temperatures at the end of the process, and (4) a final solids content above 55% TS to avoid marketing a wet product, but below 65% TS to avoid dusty material. These criteria are an indirect measure of compost maturity and the absence of phytotoxicity as discussed by Zucconi and de Bertoldi (1981).

Case Studies

The following case studies are presented to highlight the importance of substrate characteristics and the insight that can be provided when laboratory testing is coupled with simulation modeling.

Plattsburgh, New York

The City of Plattsburgh composts dewatered, wastewater biosolids (sludge), sawdust and papermill sludge in two circular, agitated bin reactors. The reactors are each 41 meters diameter with about 2 to 3 meter depth of material. The facility was commissioned in 1986. A number of operational problems surfaced almost immediately, particularly in cold winter weather when thermophilic temperatures were difficult to maintain, drying was limited, and the process failed repeatedly. These symptoms were indicative of a 'stressed' energy balance. A number of factors appeared to contribute to the process failures. Cake solids tended to decrease in winter months, oftentimes less than 18% solids, placing an increased water load on the plant. In addition, degradability of the sludge and sawdust then used as an amendment began to be questioned. The facility failed or had difficulty achieving proper temperatures during three successive winters.

Studies were begun in 1989 to determine substrate degradability and reaction rate constants and to use simulation models to guide the necessary process improvements. Constant pressure respirometers were used for the laboratory testing. Degradability of the raw biosolids, which then contained a high industrial load was determined to be less than 50% of the total volatile solids. More importantly, the softwood sawdust (white pine species) then used as an amendment was only about 11% degradable. Simulation modeling clearly pointed to the problem; the energy balance was marginal because of the low cake solids and modest energy contribution from the sawdust. As a result the system tended to fail when stressed, such as during extremely cold conditions.

Having identified the problem, the next step was to find a solution. Improved dewatering and a more degradable energy amendment seemed the obvious solutions. The City did improve its dewatering process and eventually achieved cake solids above 25%. The respirometers were then used to screen for potential 'high energy' amendments. The results presented in Figure 1 clearly showed that hardwood sawdust was far more degradable, approaching 85% in 850 days. Simulation modeling predicted that the combination of higher cake solids and hardwood sawdust would produce an energy 'rich' starting mixture and that the repeated wintertime failures should be resolved. Acting on this prediction, the City replaced its original softwood with a hardwood sawdust. Process improvements were noticed almost immediately and wintertime failures became a matter of history.

An ironic twist to this story occurred shortly after the conversion to an energy rich mixture. Potential energy release from the substrates was now considerably greater than that needed by the process, including the rather significant evaporative burden from the biosolids cake. With high temperatures and high air flowrates, the process drove itself to dryness and the associated low moisture rate limitations. Alarmed by the fire hazard posed by large quantities of hot and dry organics, the City was urged to begin water addition. The plant operators were somewhat reluctant to accept the concept of water addition after so many years of battling too much water. Eventually, they came to realize that this was the only way to opti-

mize process conditions with an energy rich mixture. Ellsworth (1995) reports that the plant now takes daily readings of moisture content across the reactor and uses this information to determine that day's water addition. Simulation modeling also helped in this regard by predicting the amount of water that was needed. This experience demonstrated the importance of adding water *before* over drying the compost because it tends to become hydrophobic.

Montgomery County Composting Facility (MCCF), Maryland

The Washington Suburban Sanitary Commission has operated the MCCF since 1984. The facility composts raw biosolids received from the Blue Plains Treatment Plant serving Washington, DC. Wood chips are blended with the biosolids and the mixture composted using the aerated, static pile process. The facility has a long history of innovative odor control and process improvements, described by Murray, et al (1991) and Thompson, et al (1994). In 1994, a new generation of high-solids centrifuges were placed into service at Blue Plains. Dewatered cake solids increased from the range of 16 to 20% to 30 to 35%. The drier substrate had an immediate effect on the composting process. The product became overly dry and dust was a serious nuisance problem. The plant implemented a 'quick fix' by adding back water to the biosolids ahead of the pug mills used to blend biosolids and wood chips. The effect was to produce a starting mixture at about 40% TS, about that experienced prior to the new centrifuges.

Simulation modeling verified the field observations and showed that the new feed characteristics, with existing process parameters, could produce a dusty 75% TS product. Also, product stability was predicted to be compromised because of the low moisture, rate limitations during the process. Modeling also showed that water addition to the initial mixture and to the uncured compost after screening would largely resolve the dust problem. More frequent water addition throughout the process was better from a process standpoint, but the static pile system does not lend itself well to such practice. A second point of water addition was subsequently added immediately downstream of the vibratory screens used to separate wood chips prior to aerated curing.

Grimes (1995) reported that the two points of water addition worked well to mitigate the problem of over drying. However, odor emissions were judged to be higher with the centrifuged cake, even with the water addition and even though it was treated by post-liming after dewatering. Because the centrifuge material is too dry and post-liming does not seem to be as effective for odor control, the facility temporarily has returned to processing vacuum filter cake. However, the vacuum filters at Blue Plains are scheduled for demolition and belt presses are being installed on an emergency basis to supply dewatered cake to the composting plant. The belt presses will produce a cake solids between that of the original vacuum filters and the high-solids centrifuges. WSSC is studying the possibility of pre-liming prior to the belt presses in the hope that this will improve odor potential compared to post-liming.

Hawk Ridge Composting Facility, Waterville, Maine

The Hawk Ridge Composting Facility (HRCF) is a regional, privatized composting facility, owned by Browning-Ferris Industries, which accepts a number of waste substrates including: biosolids from as many as 22 nearby wastewater plants, short paper fiber (pulpmill sludge), sawdust, pulpmill waste mixed with bioash, and mouse bedding material. The facility started operation in January, 1990, using a covered windrow process but experienced repeated odor problems. In October, 1993, HRCF completed the installation of a Dutch air recirculation, tunnel system to improve process control and odor management. Six tunnels are provided, each 34 m long, 5.5 m wide, and 4.6 m high. The tunnels are batch loaded with mixed substrates and then sealed. A recycle fan pulls air from the top of the tunnel and recirculates it via a floor distribution plenum to the composting mass. Oxygen, temperature, and moisture content are measured in the recirculated gases. Fresh, makeup air can be added based on oxygen and/or temperature signals. The addition of outside fresh air causes an equivalent amount of compost gases to exhaust from the system. Exhaust gases are directed to a biofilter for odor reduction.

Segall (1995) and Ecker (1994) reported that the tunnel system would not adequately control temperatures to the setpoint condition. Fresh air makeup would increase to the maximum possible and yet the process would exceed setpoint temperatures and often exceed 70 to 75 °C. Process temperatures could not be controlled as originally planned. The high temperatures had two major process effects: (1) increased ammonia volatilization, which caused very high ammonia levels to pervade the biofilter area and aggravated the facility odor problems, and (2) reduced reaction rates which increased the stabilization load on the curing system and in turn reduced the total plant throughput.

To understand the problem at Hawk Ridge, one must remember that recirculation of air does not remove heat from the process, unless there is heat exchange on the recirculated gas, which was not the case at Hawk Ridge. The only significant heat removal is in the net exhaust gases which leave the process. Simulation modeling, assuming reasonable degradabilities and rate constants for the substrates, demonstrated that the starting mixture consumed oxygen and generated heat at a rate faster than the control system could remove. In other words, removal of heat in the exhaust gas was insufficient to balance the rate of heat production at set-point temperatures. As a result, process temperatures increased to the point where excessively high temperatures eventually limited the reaction rate. The temperature control concept was sound, but these particular substrates exceeded the system's range of control.

There were several possible solutions to the Hawk Ridge problem. First, less active substrates could be added to the mixture, but the facility's economics are based on receiving locally available waste products. Second, the amount of mixture loaded into the reactor could be reduced, but with a serious loss in throughput capacity. Third, the control system could be redesigned to provide greater rates of

fresh air supply, but this turned out to be expensive. Fourth, some form of heat removal could be applied to the recirculated gases, again at high cost. According to Ecker (1995) HRCF is installing an acid scrubbing system to deal with the high ammonia levels. During winter, higher process temperatures are accepted until the control system can return the process to setpoint conditions. In summer, less material is loaded to reduce the rate of heat generation.

Summary

Substrates used as feedstocks for composting can effect both the design and operation of the process. Feedstock characteristics, coupled with design and operational parameters for the plant, determine the mass and energy balances, the kinetic rates of reaction, and the eventual stability of the final product. Computer simulation models have been developed to study the dynamics of the composting process by integrating feedstock characteristics with plant operating parameters and with basic principles of mass and energy conservation and reaction kinetics. These models have been used in a number of case studies to improve understanding of the process, guide engineering design and process operation, and predict responses to changing conditions.

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Odour Emissions from Composting Plants

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Introduction

We look into the past we see the history of composting as a history of problems. So, we have discussed:

- 1965 glass in compost
- 1970 plastic in compost
- 1975 heavy metals in compost
- 1978 PCBs in compost
- 1984 odour emissions from composting plants
- 1989 dioxin in compost
- 1990 micro-organisms in the exhaust air

Every single problem mentioned above is enough to prevent composting. Especially odour is becoming an increasingly sensitive issue as people move closer to existing treatment plants. When sites for new facilities are proposed, the potential for odour is invariably one of the first concerns raised by local residents. Therefore, odours have been rated as the primary concern of the public relative to implementation of composting facilities. Designers must be conscious of this fact and be familiar with odour generation and odour control.

Some odours have an extreme influence on the well-being of human beings. Given this premise, it is understandable that limits for odour emissions must be fixed for composting plants that operate at high temperatures during the rotting process, especially when there are residential areas nearby.

Both inorganic and organic compounds can be malodorous. When we consider odour from composting plants, we usually talk about emissions from odorous organic compounds. Organic sources generally come from low molecular weight, more volatile compounds such as methyl mercaptans, methyl sulphides and amines. Many such compounds are produced during the rotting process as an intermediate product and can be set free into the atmosphere.

The locations and/or the place of generation of the odours are determined by the processes shown in a flow sheet of a composting plant:

- receiving area
- pretreatment

- rotting area
- post-treatment or final treatment
- biofilter

The following sections will discuss the results of an investigation of the effects on the environment of odour emissions from a composting plant.

Sources of odour

The determination of odour emissions is done by olfactometry. Two main groups, which must be judged differently, can be identified.

Firstly, there are the values that can be assigned directly to an airstream, such as the rotting gas from a rotting drum. With this information, volume and concentration data, it is possible to calculate the odour load and to forecast the spreading of odour emissions. In any case, these exhaust gases can easily be collected and rendered odourless in a biofilter. Therefore, these emissions do not affect the environment.

Table 1 Odour concentration in the receiving area (Number of plants: 9)

Waste	Type of bunker	Source e ^a	Z ₅₀ ^b [OU/m ³]	FID ^b [mgC/m ³]	Load [OU/s]	Remarks
MIXED	DEEP	1	46 (–)	13 (–)	–	–
MIXED	DEEP	1	117 (90–165)	11 (6–20)	–	Air exchange five times
MIXED	DEEP	1	91 (82–99)	11 (11–10)	–	
MIXED	DEEP	1	350 (247–512)	16 (14–17)	–	
MIXED	DEEP	1	190 (160–220)	13 (7–18)	790	15.000 m ³ /h
MIXED	DEEP	1	140 (128–152)	–	500	12.900 m ³ /h
BIO	DEEP	1	30 (7–73)	–	95	4.700 m ³ /h (7 GE/m ³) 72.000 m ³ /h (73 GE/m ³)
BIO	FLAT	2	4.010 (150–8.450)	–	3.31 ^c (0.12–6.97)	fresh delivered
Leaf	FLAT	2	30	–	–	–
Gardenwaste	FLAT	2	355	–	–	–
DEEP:= Bunker more than 2m deep		MIXED:= mixed collected waste				
FLAT:= Bunker less than 2m deep		BIO:= source separated organic waste				

^a 1:= Airconcentration 2:= Concentration at the sourface of the pile

^b In brackets min/max

^c [OU/s,m²]

The other group of measured values consists of data for the surface of the windrows and for the receiving area. They cannot be assigned to a specific airstream and thus a load cannot be calculated. This means that it is almost impossible to compute the spreading of this odour load; therefore the effects can only be roughly calculated.

In the following, the data for a plant with 20 000 Mg/a are discussed.

Receiving Area b head

In terms of odour control, the receiving area is almost a critical point. Fresh refuse emits odours continuously. Anaerobic processes can take place at this stage because there is normally no aeration. Therefore the retention time for the waste has to be as short as possible. We calculate on the basis of 24 hours in the receiving area. Odour emissions and airstreams from this area are as shown in Table 2.

Table 2 Air management and odour concentrations in the receiving area

	Volume (m ³)	Air exchange rate per h	Air exhaust (m ³ /h)	OU/m ³
Hall	10466	4	41820	300
Bunker 1 (biowaste)	250	5	1250	2500
Bunker 2 (biowaste)	250	5	1250	2500
Bunker 3 (sludge)	200	5	1000	2500

So at least the exhaust air from the receiving area is 45320 m³/h with an odour concentration of 470 OU/m³. The load is calculated to 2130 OU/h × 104 =

Pretreatment

Pretreatment includes shredding, screening, magnetic separation, homogenisation and some transport facilities. All these aggregates are situated in an aerated hall. Screen, separator and mixer are separately sucked. Thus the exhaust air situation is as shown in Table 3.

Table 3 Air management and odour concentrations in the pretreatment area

	Volume (m ³)	Air exchange rate per h	Air exhaust (m ³ /h)	OU/m ³
Hall	9150	1.5	13725	100
Screen	100	3	300	300
Classifier	100	3	300	300
Mixing drum				
(with sludge)	100	5	500	1000
(without sludge)	100	5	500	300

In the pretreatment the amount of air is 14825 m³/h with 142 OU/m³. The odour load is then 211 OU/h × 104.

Final Treatment

In the final treatment the finished composted material is screened to a usable diameter and cleaned of unwanted materials such as glass, stones and plastics. Here again we normally find screens and classifiers in a closed building. The air of the hall and from the separately covered aggregates is sucked. The odour emissions by the final treatment are then as shown in Table 4.

Table 4 Air management and odour concentration in the final treatment area

	Volume (m ³)	Air exchange rate per h	Air exhaust (m ³ /h)	OU/m ³
Hall	1500	2	3000	100
Aggregates	150	2	300	300

Final treatment exhausts 3300 m³/h with 118 OU/m³. The emitted odour load is 39 OU/h × 104.

Storage Area

Following the composting process, it is normally necessary to store the compost. This can be done with or without aeration. If there is no aeration, the odour emissions are negligible. Table 5 gives the emissions in case of aeration.

Table 5 Air management and odour concentration in the storage area

	Exhaust air	OU/m ³
During turning		1000
Aeration	3400	100

The odour emission from the storage area is calculated to a load of 34 OU/h × 104.

Rotting Area

The rotting process itself is the main source of odours. The amount and strength of odours depends on:

- the amount of material handled on the composting site;
- support with oxygen;
- kind of aeration (blowing or sucking);

Table 6 Odor concentration on different pile systems (Number of plants: 4)

waste	location	age of compost [d]	Z ₅₀ ^a	V _{air} [OU/m ³]	V _{compost} [m ³ /h]	load ^b [m ³]	remarks [OU/s,m ³]	
WET	Surface of table piles h = 1,80 m	ca. 7	9.700	1.100	260	11.4	—	
		ca. 21	4.100	1.800	260	7.9	—	
		ca. 28	480	1.500	260	0.8	—	
		ca. 42	1.400	1.300	260	1.9	—	
		ca. 56	860	1.200	260	1.1	—	
		ca. 70	1.500	850	260	1.5	—	
		ca. 77	680	1.400	260	1.0	—	
		—	—	—	—	—	—	
BIO	Surface of table piles	max. 7	14.600	—	—	—	h = 2,30 m	
		max. 35	7.300	—	—	—	h = 1,90 m	
		max. 70	1.370	—	—	—	h = 1,50 m	
		—	—	—	—	—	—	
BIO	Surface of table piles h = 2,30 m	max. 7	2.420	ca.	860	1.6	air on top of the pile	
		max. 10	18.300	2.100	820	12.4	after turning	
		max. 31	25.900	ca.	690	18.2	after turning	
		max. 70	1.240	2.000	470	0.9	air on top of the pile	
		max. 77	395	ca.	430	0.3	—	
		—	1.750	ca.	—	—	—	
		—	—	1.190	ca.	—	—	
		—	—	1.200	ca.	—	—	

WET:= rest of household waste after separt collection of recyclable materials

BIO:= source separated organic waste

Werke in Klammern ():= Streubereich

^a air concentration^b Specific load per m³ compost

Table 7 Odour concentration from piles aerated by pressure (Number of plants: 4)

Waste	Place of measurement	age of compost [d]	Z_{50}^a [OU/m ³]	V_{air} [m ³ /h]	$V_{compost}$ [m ³]	load ^b [OU/s.m ³]	remarks
BIO	Surface of the pile $h = 2,50\text{ m}$	1	51,900 (47,730– 56,070)	0	91 (78– 104)	–	directly after turning
		5	340	340	78	5,8	
		8	4,830	700	78	12,4	
		14	4,960	805	78	6,6	
			3,070	104			
		14	27,840 (19,560– 43,910) 3,340	375 (305– 470) 560	84 (78–91) 78	32,6 (25,0– 44,8) 6,7	1 day after turning
		19					
		20	76,930	370	83	95,3	1 day after turning
		22	15,440	920	104	37,9	
		26	5,730	625	78	12,8	
		26–28	14,090 (12,720– 16,720)	610 (540– 675)	84 (78–91)	28,9 (24,3– 37,8)	1 day after turning
		32	5,030	450	104	6,9	
		33	3,450	620	78	5,7	
		35	2,110	540		4,1	
		35	10,650	680	83	24,2	1 day after turning
		36	220	590	104	0,3	end of the process
		42	100	510	78	0,2	end of the process

BIO:= source separated organic waste

Brackets:= min/max

^a airconcentration^b specific load per m³ compost

- process temperature
- geometric design of the piles
- age of the piles
- the rotting system.

Considering these facts, the values in Table 6 and 7 give some data from various rotting systems.

Table 8 Odour Emissions from Various Aggregates in the Biowaste Composting Process (Müsken 1991)

		Range of values (OU/m ³)	Mean values (OU/m ³)
1	Receiving areas for biowastes	256 – 8450	4800
2	Raw gas – rotting drum	14600 – 27600	20400
3	Discharge – rotting drum	4100 – 11590	8340
4	Raw gas – rotting reactor	15940 – 17400	16670
5	Discharge – rotting reactor	11300	–
6 a	Piles 1 before turning	30 – 790	210
6 b	Piles 1 after turning	260 – 3770	1640
7 a	Piles 2 before turning	85 – 4100	810
7 b	Piles 2 after turning	360 – 3770	810
8 a	Piles 3 before turning	30 – 1150	355
8 b	Piles 3 after turning	90 – 15940	4455

Piles 1 = Pre-rotting in a rotting drum

Piles 2 = Pre-rotting in a rotting reactor

Piles 3 = Sole composting in piles

Data for a specific plant are given in Table 9. It is calculated that 6800 m³ of raw material are in piles for composting. The aeration rate is 1 m³ air per 1 m³ of material. The highest concentration of odours is during the turning process. Values of 5000 OU/m³ can be measured in the surrounding air during turning of a four week old pile. Immediately prior to the turning process the concentration is only about 1000 OU/m³.

Table 9 Rotting Area (6800 m³ material). Piles aerated by pressure/sucking with 3 m³ air/m³ material and hour

	Volume (m ³)	Air exchange rate/h	Air exhaust(m ³ /h)	OU/m ³
Hall (closed)	39800	1	33000	5000
– with turning			33000	1000
– without turning			20400	20000
– sucking and turning			33000	500
– blowing and turning			33000	4000
sucking			53400	7950
blowing			33000	4000

Table 10 Odour Emissions from Different Composting Processes

	OU/m ³
- Raw gas (rotting drum after 1 day)	14600
- Raw gas (rotting drum after 6 days)	27600
- Raw gas (rotting reactor after 7 days)	15940 – 17400
- Raw gas (pile aerated by sucking)	14800 – 22000
Discharge (compost)	
- Rotting drum (after 1 day)	2810 – 9480
- Rotting drum (after 7 days)	11590
- Rotting reactor (after 7 days dry)	360 – 1220
- Rotting reactor (after 7 days wet)	11300 – 15900
- Windrow (after 14 days wet)	5300 – 19600

Piles which are aerated by blowing do not have a lower level of odour emission than those aerated by sucking. The reason is that the surface of the pile works like a biofilter. After ventilation by blowing, the air passes through the pile from bottom to top and is rendered partly odourless in the top layer. The odour concentration is only about 1200. In the exhaust air from sucking, the same pile gives a concentration of about 20 000 OU/m³ in the discharge from the fan.

Conclusion and Recommendations

With increasing age of the piles, the odour intensities decrease. After 4 weeks only 1/10 of the initial concentration was found.

Periodic turning of the piles, an optimal structure of the rotting material (e.g. mixing with wood chips), or a layer of wood chips as drainage support under the piles, can help to avoid odour emissions.

The first turning process should not be implemented until two weeks of rotting time have passed. After this time only 40% of the odour intensity that can be expected with an initial turning after one week will be generated (Fricke et al. 1988).

Diffuse sources of odour such as compost lying on the ground outside the plant premises, stagnant leachate on the site, etc., must be avoided by regular cleaning of the plant area.

Odour emissions which are generated during delivery, treatment and the rotting processes, can be avoided by using closed facilities and exhaust air collection systems, as well as by purifications of this exhaust air, for example with biofilters. At the moment it is difficult to calculate the odour emissions from the open piles because the methods for doing so have yet to be developed. By using a qualified rotting system, the emissions can be reduced to an acceptable level.

So the minimum odour emissions from a composting plant, as discussed, are likely to be as shown in table 10.

The total odour emission from a composting plant can be assumed für a plant

without aeration		
with turning	5660	OU/h $\times 10^4$
without turning	18860	OU/h $\times 10^4$
with aeration (sucking)	44960	OU/h $\times 10^4$
with aeration (pressure)	15560	OU/h $\times 10^4$

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Table 11 Estimated odouremissions from a plant with a throuput of 6500 Mg/a and one with 25000 Mg/a.

location/aggregat	'6500 Mg/a' ^a	Kompost-mengeKonzentration [m ³]	[dB OD]	Fracht [OU/s]	amount compostconcentration [OU/s.m ³] ^b [m ³]	[OU/m ³] ^c	[dB OD]	[OU/s]	load [OU/s,m ³] ^c
bunker (daily input)	46	350 (710)	25 (29)	390 (790)	8.5 (17)	174 (17)	180 (510)	23 (27)	600 (1.700)
Input (daily	46	5.000 (5.500)	37 (40)	470 (880)	10 (19)	174 (19)	5.000 (9.500)	37 (40)	660 (1.250)
- fresh, pretreared, not aerated	46	1.250 (2.500)	31 (34)	120 (230)	2.6 (5.0)	174 (2.500)	1.250 (2.500)	31 (34)	3.8 (7.2)
- dto., with cover									0.95 (1.9)
Rottingdrum (air 5 m ³ /m ³ ,h)	115	15.000 (t=2.5d)	42	2.400	21	261	30.000 (t=1.5d)	45	10.875 (42)
Rottingcontainer									
- air 5 m ³ /m ³ ,h (input per week)	230	30.000	45	9.500	41	-	-	-	-
- air 20 m ³ /m ³ ,h (input per week)	230	10.000/200 ^c	40/23 ^c	6.8 ^d	30 ^d	-	-	-	-
- output (wet, t = 7 d, dailyintake)	41	13.300	41	1.120	27				
not treated triangle piles (dailyintake)									
- without aeration max. 2 weeks old	42 ^d	1.000	30	85	2.0				
- without aeration over 2 weeks old	32 ^d	200	23	13	0.41				
not treated triangle piles (dailyintake)									
- turning after 1 week	41	13.300	41	1.120	27				
- without aeration max. 2 weeks old	37	3.100	35	240	6.5				
- without aeration over 2 weeks old	30 ^d	580	28	36	1.2				
table pile aerated by sugging (h = 2,30 m, age 0-70 d)									
- surface	-	-	-	-	-	6.600	350	25	970 (36) (11.900) (41) (63.250) (43) (110.000)
- exhaustair (19.800 m ³ /h)						6.600	11.500 (20.000)	25	970 (36) (11.900) (41) (63.250) (43) (110.000)
table pile aerated by pressure (h = 2,30 m, age 0-70 d)									
- without turning (air 19.800 m ³ /h)						6.600	8.000 (20.000)	39	44.000 (45) (33.000)
- 20% turned (air 3.960 m ³ /h)						1.320	30.000	45	6.7 (25)
piles in the store									
- (amount per week)	115	80 (200)	19 (23)	19 (48)	0.17 (0.42)	435 (200)	80 (200)	19 (23)	31 (78)
- digested (amount per week)	23	250 (1.100)	24 (30)	12 (53)	0.52 (2.3)	87 (1.100)	250 (1.100)	24 (30)	20 (86)
^a In brackets max- values	^b Spezif.load related to the compostvolum	^c start/end of the week	^d average						

Environmental Impact of Composting Plants

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Abstract

Planning to build a composting plant in Germany will almost surely provoke the emergence of an action group to prevent its erection. It is especially the odours emitted by a number of compost plants that effect the relations with the residents. Beside the odours we found some other possible emission like dust, noise, leakage water and micro-organisms.

Environmental impacts of new and carefully planned plants are reduced to odours and germ-emissions, whereas the other emissions can be disregarded according to the closed buildings.

Nevertheless the first main point of the paper will be the leakage water. If we believe in compost industry, new composting plants do not produce any waste water. This contention seems to be wrong. Actually the volume of leakage water often is higher than the low quantities we found in literature.

Next main point of the paper will be new measuring dates of odour concentrations and odour flow rates. We will look to the problems of the authorities with this dates.

The third main point is the description and valuation of investigations on germ-emissions. The loading of microorganisms - special fungi – on composting–workman seems to be dangerous. Opposite to this there are no risks for the neighbours of a composting plant.

Introduction

The erection of a composting plant in Germany almost surely provoke problems with the residents. We know a lot of composting plants where the neighbourhood complained of for many years. Therefore in Germany now only closed plants are erected but anyway they need an expensive air cleaning too.

Besides the odours the apprehension is growing that a composting plant will be a dangerous source of germ-emissions.

Another, more financial problem, is the quantity of leakage water. With this high concentrated water I would like to begin. At this point I emphasize that all dates of my paper based on the treat of source separated compostable material (SSCM).

Leakage water

The leakage water set free during the composting process is composed of

- press-water from the input material
- endogenous water, which results from the disintegration of the cells during the decomposition of organic substances
- exogenous water: rain-water from maturation pile

We asked some compost plants upon the quantities of leakage water and found very different numbers. The range was from 0 to 400 l/mg input material. The analysis of the waters also differs in a wide range (table 1).

With concentrations as shown, it is not allowed to seep away leakage water, it must be cleaned in a special waste water treatment. Only water with low concentrations may be used for moistening at periodic mechanical turning of the rows. There also could be a problem with increasing salt-concentrations in compost. By no means leakage water can be used for moistening the biofilter. High amounts of odorous substances are in this water. If they come into the biofilters, all these substances would evaporate and produce bad smelling clouds.

Table 1 Concentrations in leakage water of source separated compostable material (SSCM)

BOD	10000 – 50000 mg/l
COD	15000 – 70000 mg/l
pH	5,0 – 10,0
Potassium	5000 – 15000 mg/l
Phosphorus	50 – 300 mg/l
Ammonia	300 – 1200 mg/l
Nitrate	1 – 25 mg/l
Chloride	1000 – 5000 mg/l
Zinc	0,001 – 10 mg/l
Lead	0,01 – 0,2 mg/l
Chrome	0,01 – 0,2 mg/l
Cadmium	0,01 – 0,1 mg/l

The treatment of leakage water could be very expensive. For normal waste water of a household in Germany we pay about 5,- to 6,- DM/m³. The costs for leakage water raise up to from 50,- to 400,- DM/m³. Therefore a compost plant with 20.000 Mg input in worst case should pay up to 400.000,- DM per year (= 200.000 ECU).

Odour Emissions

As already mentioned in Germany the most problems with the neighbourhood arose from the odour emissions from the compost plants.

Odours from compost plants consisted of a conglomerate of single substances. The following compounds are found until now:

- alcohols
- ketones
- esters
- organic acids
- aliphatics (methane)
- aromatic hydrocarbons
- organic sulfur compounds
- amines
- ammonia.

The concentrations of this compounds are mostly in the reach of some mg/m³. Few of them reach a maximum of some mg/m³. The total concentration mostly is in a reach of 100 mg/m³ organic carbon or below that (measurements with the flame ionization detector). Because of that the odour respectively odour concentration will be not detected by the analytic of the single substances. Instead of that the human nose is used as a detector.

Within the region of compost plants very different odourant concentrations are measured (table 2).

Table 2 Typical odourant concentrations and odour levels in the region of compost plants.

	odourant concentration (OU/m ³)		Odour level in dBod
delivery low shelter	100	– 300	20 – 25
pretreatment	50	– 500	17 – 27
mixing drum	20000	– 80000	43 – 49
compostdamp/box	200	– 5000	23 – 37
damp suction			
vacuum operation	5000	– 50000	37 – 47
compoststore	20	– 200	13 – 23
traffic area	20	– 200	13 – 23
biofilter (cleargas)	50	– 300	17 – 25

To explain this measuring result I would like to present how we take odour samples.

Sampling and examination are regulated in the VDI guidelines (VDI 3881, 3882). The first important point is the correct sampling. With the help of vacuum sampler the gas sample is filled in a bag. Because of the moisture and warmth of compost gas, the sample must be diluted in the bag (pre-delution) otherwise watervapour conclosed at the inside bag side and also a part of the odourants.

Without this predilution there would be measured lower values. As the human sense of smell is very different from man to man (is perceived subjectivly) 4 appropriate panelists have to smell for 3 times to find out the odour concentration. Then out of these 12 results the average is taken. Panelists can just be persons who pointed out with the help of test substances that they have a ‘normal’ nose.

The odour measuring has to be carried out at a place that should be as neutral as possible. The procedure is like this. The sample bags are transported to a measuring carriage or laboratory with an olfactometer and the panelists. The olfactometry works this way. First the panelist receive neutral, non-smelling air. The sample gas is mixed as long with the neutral air, till the panelists are able to smell something. This concentration is called odour threshold. The exact definition of the VDI guideline is:

Odour threshold

The concentration of odorous substances at threshold level leads to an odour impression with 50 % of the defined population. The odorant concentration at the threshold is 1 OU/m³ by definition.

From the predilution of the sample gas with the neutral air results simultaneously the concentration unit of odour: OU/m³ (Odour Units per m³).

Odour unit (OU)

Based on the definition of the odour threshold, 1 OU is the very quantity (muber of molecules) of odorants which just induces an odour sensation when dispersed in 1 m³ of neutral air. 1 OU/m³ is also the bench mark of the odorant concentration scale (C_{od})

Is there identified a concentration of 100 OU/m³ of a waste air source, this means, that the air can be diluted for a 100 times, so that we can recognize it even yet. If the air will be diluted even more, the odour threshold is remained, it means for the human nose this smell is vanished.

Like hearing the stimulance of the odour sense is not linear. Practically this means that with the araise of odour concentration from 100 OU/m³ up to 1000 OU/m³ the odour impression is not 10 times higher but only 2 times. Air of 1000 OU/m³ will be recognized twotimes as strong as air of 100 OU/m³. This is the reason why odour concentration is declared in OU/m³ as well as in dB_{od}.

The olfactometric measurement is subjected to a higher struggling than chemical or physical measurements. The variation (95 % probability) by the time is about fresher 4 from the lower up to the upper limit of the 95 %-region.

This means for a measured value of 100 OU/m³ measured values of 50 OU/m³ or 200 OU/m³ could both be right. Many administrative bodies in Germany have problems with this wide spread.

Compost plants have to observe special limiting values. The conditions of administrative bodies can be for example:

- the concentration of waste gas is maximum 100 OU/m³
- the emitting mass flow is maximum 3000 OU/s.

Sometimes there are many difficulties to explain to the administrative bodies why a measurement value of 190 OU/m³ performed the condition of 100 OU/m³ completely.

The limit values for emissions of composting plants based on a calculation of air-diffusion. In maximum 3 or 5 percent of the hours of a year odours may be recognized. Based on this decree, the highest concentration of the emissions can be calculated. In figure 1 is shown an example for such a calculation. Outside of the iso-lines there are no odours, inside you will have 2, 10 or 15 percent of hours with odours.

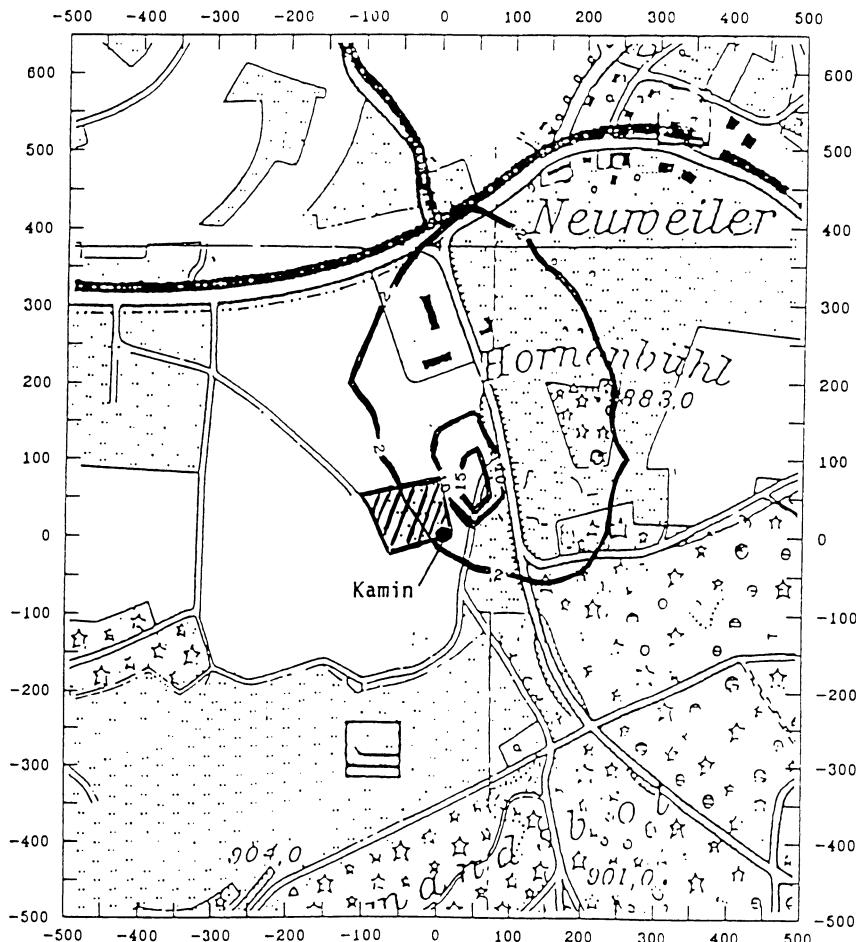


Figure 1 Calculation of emissions from a compost plant. Outside of the outer line, no odours are perceptible.

Germ emissions

Degradation and transformation of organic matter to compost is based on numerous micro-organisms. Main groups are bacteria, fungi and actinomycetes. Some of these microorganisms are pathogenous germs. Other excitants of disease could come into compost with the input raw material.

In this paper we take only into consideration the airborne emissions of germs. When refuse or compost are transported, microorganisms are conveyed into the environmental air, where they can hover for quite a long time, due to their reduced mass. Numerous germs can be carried by one hovering dust particle. Thus one may assume that at places with high dust-concentration there is also a big number of micro-organisms in the air. This is mostly the case at places where the material is quite dry, i.e. in the final phase of composting, but also during the processes of crushing and separation (table 2).

In Germany at present exist no law or rules about maximum germ-emissions in compost-plants. The country Niedersachsen (in North Germany) enacted an edict last year (02.08.94) about 'demands for protection of the working classes in sorting installations'. Probably these rules also come into the new VDI-guideline 3475. According to that in respiration air maximum concentrations from 10000 germs/m³ are allowed. Bacteria and fungi must be detected separately. Moreover measurements of endotoxines are necessary.

Table 3 Germ-Concentrations in Composting Plants

	actinomycetes	bacteria	fungi
delivery low shelter	5–30	40–100	
sorting	40	600	5
closed composting	20	20–50	10000
sieving	80	20–300	
traffic area	1–2	1–4	
limit value		10	

The above mentioned results are very high. Therefore an endangerment of the health of the personnel working in composting plants cannot be ruled out. This is the reason why we must strongly recommend the use of dust-masks in the composting area. The cabines of repiling machines must have necessarily installed efficient filter-systems.

These high concentrations of microorganisms only were found in the composting plants. An endangerment for the inhabitants outside of the plant is not to be expected.

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Production of functional compost which can suppress phytopathogenic fungi of lawn grass by inoculating *Bacillus subtilis* into grass clippings

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Abstract

Bacteria which can suppress the growth of the phytopathogen, *Rhizoctonia solani* K1 causing large patch disease of lawn grass, were isolated from compost products made of various organic wastes. Then, the bacterium which shows the largest suppressive effect on the pathogen was identified as *Bacillus subtilis* N4.

A spontaneous streptomycin-resistant mutant, *B. subtilis* N4-1 was selected from *B. subtilis* N4 and was used for inoculum into lawn grass clippings as a composting raw material. This makes it possible to estimate the change in cell number of the strain N4-1 in the composting material.

Optimum temperature for growth of the strain N4-1 in the composting material was found to be 40 C. And at 40 C composting, the lower the concentration of the other bacteria existed in the raw material, the higher the concentration of N4-1 became in the compost product. Then the feasibility of repeated use of compost product as a seed for the next composting was also examined. The concentration of N4-1 in the compost product decreased gradually with increasing in the number of repeated times. However, it can be ascertained by in vitro test on the agar plate that the compost product remained the suppressive effect to the phytopathogen until repeated times was 4 at which the concentration ratio of N4-1 to the total bacteria in the compost product was still higher than $1/10^5$.

Key Words- Compost, Biological control, *Bacillus subtilis*, Plant disease, Lawn grass, Phytopathogen, *Rhizoctonia solani*

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Introduction

Application of useful microorganisms into soil to repress plant diseases have been investigated by many researchers(Kuter et al.XCourier6een used to control various plant diseases biologically in expectation of the antibiosis which is one of the most important aspect of the antagonistic activity. Most of biological control using compost were applied to agricultural plants.

Large patch disease of mascarene grass (Korai lawn grass which is popularly used in Japan) is the most common yet difficult lawn grass disease to control. It can now be controlled by chemical pesticide application to soil. This control technic, however, is increasingly viewed as ecological undesirable(Kono 1990). Therefore, methods based on biological control which enable to repress the disease by action of competitive microorganisms (effective microorganisms) against the pathogen without the use of chemical pesticides, have been lately interested (Goodman & Burpee 1991; Nakasaki & Kubota 1994).

Compost can be used for biological control of large patch disease, if it contains the microorganism suppressible for the phytopathogen at high concentration level. Therefore, we first tried to isolate a microorganism which can suppress pathogenic fungi for lawn grass from compost, then to use the effective microorganism as an inoculum for composting to make reproductively the functional compost which can suppress the phytopathogen.

Materials and Methods

Screening of an effective microorganism

Rhizoctonia solani K1 isolated from lawn grass suffering from Rhizoctonia patch disease in a golf course was used as a phytopathogen. Seven commercial compost products from Compost A to G prepared from various raw materials were examined for screening suppressive compost. The compost suspension were put on the center of the Potato-dextrose agar plate where the pathogenic fungus suspension was spread beforehand. After incubation at 25 C for 5 days, the compost which made a clear inhibitory zone on the agar plate was judged as a suppressive compost.

The center part of the Potato-dextrose agar plate including clear inhibitory zone was then homogenized in sterile water and the suspension was spread on the Trypticase-soy agar plate (trypticase peptone 17 g, phytone peptone 3 g, NaCl 5 g, K₂HPO₄ 2.5 g, glucose 2.5 g, agar 20 g per one liter of distilled water).

The cells of the purified bacteria were spotted with a platinum string in the center of Potato-dextrose agar plates where the fungus suspension was spread beforehand. The bacteria which made clear inhibitory zone on the agar plate were picked up as suppressive bacteria.

Preparation of inoculant of spontaneous streptomycin-resistant mutant from B. subtilis N4

A spontaneous streptomycin-resistant mutant, *B. subtilis* N4-1 was selected from *B. subtilis* N4 on Trypticase-soy agar medium supplemented with streptomycin 1 g/l. It was confirmed that the strain N4-1 kept suppressive effect on the pathogen and growth rate in Trypticase-soy medium of the strain was almost the same as that of the wild strain. To estimate the cell number of the strain N4-1 in the samples withdrawn during composting, Trypticase-soy agar medium containing streptomycin 1 g/l was prepared, and the colonies appearing on this medium plate were judged as the strain N4-1.

Inoculant of the strain N4-1 was prepared by cultivating in a 500 ml shaking flask in the Trypticase-soy medium containing streptomycin 1 g/l at 30 C for 24 h. After cultivation, the culture was centrifuged at 7500 rpm for 10 min and washed with phosphate buffer solution for three times.

Composting materials and operation

Lawn grass clippings from golf course were used as a composting material. They consisted of Korai lawn grass, clipped about 10 mm in length using a lawn mower in early summer, containing 68.8 % of moisture. The grass clippings, saw dust as a bulking agent, and compost product made in our laboratory as a seeding material were mixed at the ratio of 10:10:1 on dry weight basis to prepare composting raw material. At the start of experiment, the inoculant as mentioned above was added to the composting raw material.

The composting reactor was cylindrical(45 mm in diameter, 80 mm in depth) and made of thermoresistant glass with silicone rubber stopper at the both ends. The rubber stoppers equipped with glass pipes through which air can be introduced. In addition, the rubber stopper at the bottom of reactor was installed with screen made of stainless steel(3 mesh) to distribute the air supplied from a air pump. Twelve gram of raw material was put into the reactor and was introduced into an incubator where both temperature rising rate from room temperature to the set point and maintaining the set point were controlled with the aid of micro-computer.

Changes in cell concentration of N4-1 and the other mesophilic bacteria were measured on the agar plate with and without streptomycin in the Trypticase-soy medium, respectively. Microflora of mesophiles doesn't change after 48 h from the start of experiment, and the cell concentrations of the strain N4-1 and the other mesophilic bacteria become constant were observed in our preliminary experiment. Therefore, composting operation was stopped at 48 h have passed from the start of experiment for the sake of conducting the experiment more effectively. Compost products for each runs were subjected to analysis of suppressive effect to the phytopathogen as the same manner described above.

Composting temperature as an operational condition

Effect of temperature was examined by varying the temperature in the incubator at three set points, 60 C(Run A), 50 C(Run B), and 40 C(Run C) ,respectively. Composting raw material mentioned above was used for all the experimental runs, and the initial cell concentration of *B. subtilis* N4-1 was adjusted at 1.5×10^8 cfu/g-ds.

Changes in cell concentration inhabiting in the raw material

Initial cell concentration inhabiting in the raw material was varied by autoclaving it under different conditions; 2.5×10^8 cfu/g-ds (without treatment), 3.5×10^5 cfu/g-ds(100 C for 5min), and non-detectable level less than 102 cfu/ g-ds (121 C for 5min). Experimental runs of each initial cell concentration were denoted as Run D, E, and F, respectively. Cell concentration of *B. subtilis* N4-1 inoculated into the raw material was adjusted at 3.2×10^5 cfu/g-ds and composting temperature was set at 40 C.

Repeated use of compost product as a seed for next composting

Feasibility of repeated use of compost product as a seed for the next composting was tested by using the same raw material of Run F. Compost product of Run F was added to the raw material at the ratio of 1:20 on dry weight basis, then the mixture was composted as Run F-1. The product of Run F-1 was next used for Run F-2, and so on. Four times of repeated use of compost product from Run F-1 through Run F-4 were conducted at 40 C.

Results and Discussion

Suppressive bacteria against phytopathogen

Three compost products showed a distinct inhibition on growth of *Rhizoctonia solani* K1(see Table 1). Since filtrates of these compost suspension did not show suppressive effect, it can be deduced that the suppressive effect depended on the growth of microorganisms inhabiting in the compost products on the agar plate used for testing. Three suppressive bacterial strains could be isolated from these compost products and one of them, *Bacillus subtilis* N4 which showed the largest inhibitory zone was selected for further investigation (see Fig. 1).

Effect of temperature on growth of the strain N4-1

Figure 2 shows the changes of cell concentration of N4-1 and the other mesophilic bacteria during compostings of different set temperatures. In Run A and B, the strain N4-1 couldn't grow, especially, it decreased drastically to non-detectable

level during early stage of composting in Run A. These results correspond to the fact that the vegetative cells of N4-1 inoculated into the raw material don't have heat-resistant property. In fact, the strain N4-1 could survive in the composting material at 60°C for longer than 200h if it was inoculated as a spore form (data are not shown).

Table1 Suppressive effect of compost to *R. solani* K1

	Effect
Compost A	negative
Compost B	negative
Compost C	moderate
Compost	strong
Compost E	negative
Compost F	negative
Compost G	slight

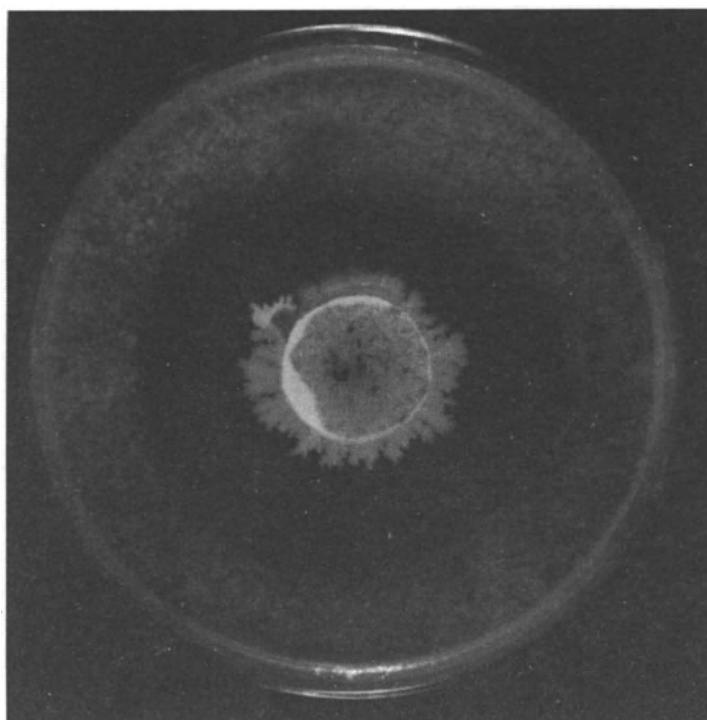


Figure 1 Photograph of clear inhibitory zone made by the strain, *Bactillus subtilis* N4.

By contrast to Runs A and B, cell concentration of N4-1 once decreased then levelled off around 10^6 cfu/g-ds in Run C. Since the strain N4-1 can grow vigorously at 40 °C in the Trypticase-soy liquid medium, the reason why the strain N4-1 couldn't grow at the same temperature in the composting may be the composting

raw material contains the other mesophilic bacteria than the strain N4-1 at high concentration level. The other mesophilic bacteria than the strain N4-1 grew up to 10^{10} cfu-g-ds for Run C.

Only the product of 40 °C composting (Run C) represented the suppressive effect to the pathogen.

Effect of cell concentration inhabiting in the raw material on growth of the strain N4-1

Time courses of cell concentration of N4-1 and the other mesophilic bacteria for Runs D, E, and F are shown in Fig. 3. The strain N4-1 could grow rapidly and attain high concentration level in Run F, whereas it decreased to very low level at the early stage of composting in Run D. Final cell concentration of N4-1 in the compost was largest at the composting of lowest concentration level of the other bacteria in the raw material. Growth of the other bacteria delayed, but finally reached to the high concentration level of 10^9 cfu/g-ds in Run F. Concentrations of the other bacteria for both Runs D and E became 10^{10} cfu/g-ds, and were larger than that for Run F. Products of Runs E and F showed the suppressive effect on the pathogen.

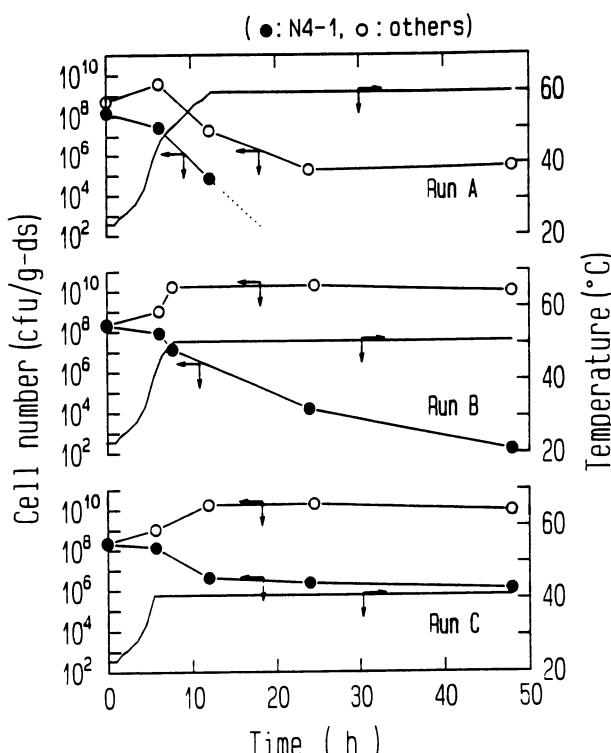


Figure 2 Effect of temperature on growth of *B. subtilis* N4-1 in the composting material. Open and close symbols refer to *B. N4-1*, and the other mesophilic bacteria, respectively.

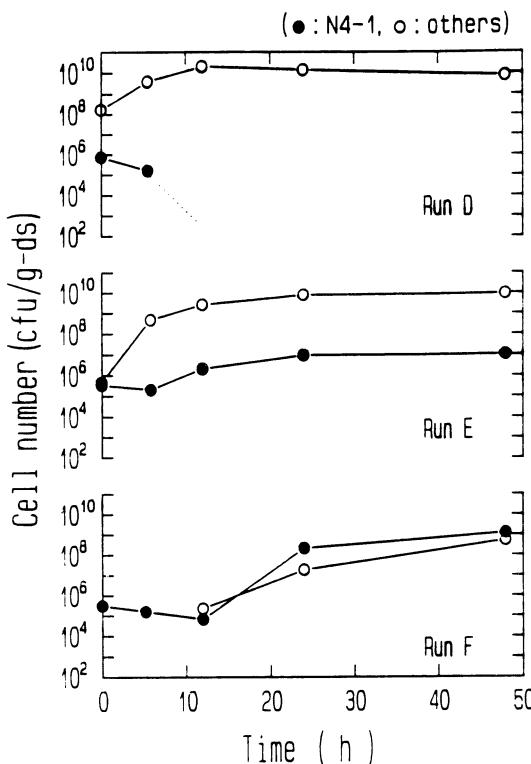


Figure 3 Effect of cell concentration inhabiting in the raw material on growth of *B. subtilis* N4-1. Open and close symbols refer to *B. subtilis* N4-1, and the other mesophilic bacteria, respectively.

Feasibility of repeated use of compost product as a seed

Changes in cell concentration of N4-1 and the other mesophilic bacteria during composting from Run F through Run F-4 are shown in Fig. 4. The final cell concentration of the strain N4-1 in each composting decreased gradually with the increasing in the repeated times, whereas that of the other mesophilic bacteria increased. These results, which reveal a banishment of the strain N4-1, seem to be due to the slower growth rate of the N4-1 than that of the other bacteria in this composting material.

The results shown in Fig. 4 are replotted in Fig. 5. This figure contains the final cell concentrations of N4-1 and the other mesophilic bacteria from Run F through F-4. In addition, the concentration ratios of the N4-1 to the total bacteria estimated by summing up the strain N4-1 and the other mesophilic bacteria for all the experimental runs were also shown in the same figure. The ratio dropped approximately by one order of magnitude with increasing the repeated times, and finally reached around $1/10^5$ at Run F-4. It can be ascertained by *in vitro* test that the compost products showed the suppressive effect to the phytopathogen until repeated times

became 4 at which the concentration ratio of N4-1 to the total bacteria in the compost product was larger than $1/10^5$. As was not shown here, the ratio in the product of the next composting (repeated times was 5) was smaller than $1/10^5$ and the product lost the suppressive effect to the pathogen. These results indicating that the ratio of N4-1 is important in order to repress the pathogen correspond well to that obtained from our former research in which mixtures of cell suspension of the pure cultured N4-1 and a mesophilic bacterial strain E2 were used (Hiraoka 1994).

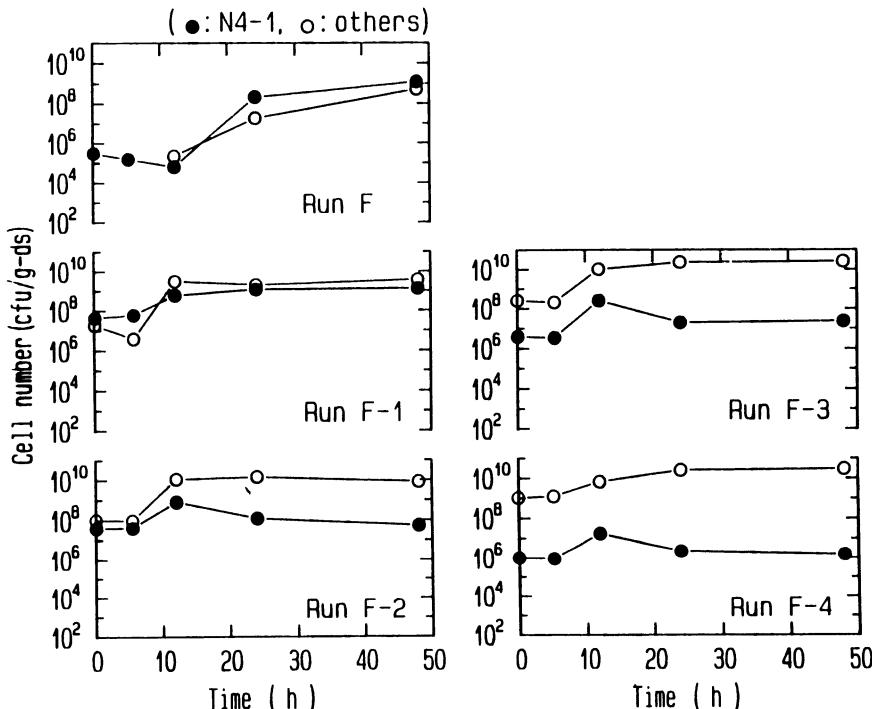


Figure 4 Time courses of cell concentration of N4-1 and the other mesophilic bacteria during compostings from Run F to F-4.

Conclusions

Bacillus subtilis N4 which can suppress the growth of the phytopathogen, *Rhizoctonia solani* K1 causing large patch disease of lawn grass, could be isolated. Dynamic change of *B. subtilis* N4-1 (streptomycin-resistant mutant) inoculated into lawn grass clippings of composting raw material indicated that the optimum temperature for growth of the strain N4-1 was 40 °C. Furthermore, the lower the concentration of the other bacteria inhabiting in the raw material, the higher the concentration of N4-1 became in the compost product at 40 °C composting. Feasibility of repeated use of compost product as a seed for the next composting was restricted for few times. It is because the strain N4-1 was banished from the composting material with increasing in number of repeated times.

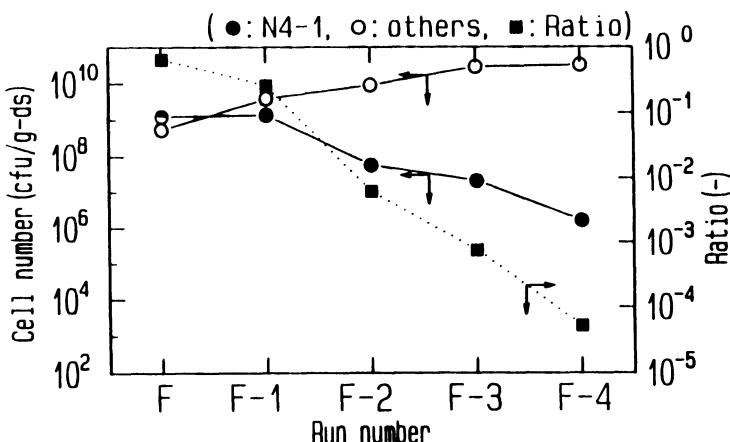


Figure 5 Cell concentration of the strain N4-1 and the other mesophilic bacteria, and the concentration ratio of N4-4 to the total mesophilic bacteria in the compost product where inoculum was repeatedly used. The total mesophilic bacteria was estimated by summing up the strain N4-1 and the other mesophilic bacteria. The number on the abscissa refer to the repeated times.

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Nutrient transformation of pig manure under pig-on-litter system

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Abstract

A ten-month study was carried out in an experimental farm in Hong Kong to investigate the changes in the forms and content of carbon, nitrogen, phosphorus and potassium of the pig manure under a pig-on-litter (POL) system. This system, known as in-situ composting, utilizes a mixture of sawdust and a commercial bacterial product as the bedding material on which pigs are kept and the pig excreta are decomposed within the bedding. The effects of the commercial bacterial product recommended by the POL system (the treated group) on nutrient transformation of the pig manure were evaluated and compared with the control group (without any bacterial product).

It was found that there was no significant difference between the treated and the control groups in terms of the concentrations of organic carbon, total and extractable N, P and K of the sawdust pig manure litter samples. The patterns of how these nutrient changed with the experimental time were similar between the treated and the control groups. The concentrations of total N, NH₄⁺-N, total and extractable P and K increased rapidly at the beginning of the experiment and the rate of these accumulations became slower towards the end of the study. On the other hand, total organic carbon content of the litter samples declined dramatically in the first few weeks, with C values dropped from an initial 40% to 31% at week 10. Further decrease in total carbon concentration was observed as the experiment proceeded. A very drastic drop of the C:N ratio was found within the first few days, from an initial 175:1 decreased to 40:1 within one day then further dropped to 14:1 at the end of week 1 in both treated and control groups. At the end of the experiment, the C:N ratio reached a very low value (10:1). These results suggest that (1) the commercial bacterial product did not have any significant effect on nutrient transformation of pig manure under the POL system; (2) the nutrients released from pig excreta were rapidly assimilated and immobilized by microorganisms colonized within the bedding material, with an accumulation of total nutrients (N, P and K) but a decline in C throughout the experiment; and (3)

the bedding material of the POL system appeared to become more stable and mature as the study continued, the samples collected at later stage of the experiment had a more constant nutrient level and a very narrow C:N ratio.

Introduction

Intensive growth in livestock industry has resulted in the production of large quantities of livestock waste. Due to its high moisture and nutrient content, pasty consistency and unpleasant odour, livestock waste is difficult to dispose of and causes eutrophication problem in surrounding aquatic ecosystems. Surveys on Hong Kong freshwater habitats have shown that streams and rivers in the farming area have been contaminated by nutrients and organic matter released from pig waste (EPD, 1988). Research and development have been carried out by the Hong Kong Government since 1987 to treat livestock waste before disposal (EPD, 1989, 1990). A pig-on-litter (POL) system, also known as in-situ composting, has been developed as one of the recommended methods for pig waste disposal (EPD, 1989). The POL is a pig production method where pigs are reared on a litter bedding and pig waste (both faeces and urine) is decomposed in-situ. The method was first introduced to Hong Kong from Japan in 1987. It involves the mixing of sawdust with a bacterial product to make up the litter bedding. The pig excreta, once deposited, were quickly mixed with the bedding material. The nitrogenous compounds decomposed rapidly leading to the eradication of the offensive odour of ammonia. There was no unpleasant sight of the faeces and discharge of effluent was unnecessary (Tam and Vrijmoed, 1990). Initial addition of the bacterial product was expected to assist in the establishment of the initial microbial population in the litter bedding and subsequent additions would facilitate the sustenance of the large and active microbial activities for in-situ composting of pig waste. This enhancement effect on microbial activities is claimed by all the suppliers of the more than ten different bacterial products available on the market. On the other hand, pig manure itself contains a high density of bacteria with different functional groups and is biologically active (O'Neill and Phillips, 1991). The nutrient and organic matter of pig manure can also provide the necessary environmental conditions for continual proliferation of the bacterial population. This view is reinforced by Tam (1995) who showed that the addition of commercial bacterial product had no significant effect on the microbial population sizes and activities. Thus the significance of the commercial bacterial product is still uncertain. The present study therefore aims (1) to evaluate the effect of a commercial bacterial product on nutrient transformation of pig excreta under POL system and assess the necessity of the bacterial inoculum; and (2) to investigate the changes of organic matter and various forms of nutrients during three batches of pig rearing and the long-term performance of the in-situ composting process under the POL system.

Materials and Methods

Experimental Design

A 10-month study was carried out in the experimental farm in Ta Kwu Ling Pig Breeding Centre, New Territories, Hong Kong. Eight ordinary pig pens of equal size (3.7 m² each, excluding the feed troughs) employing the POL system were set up. Fresh sawdust obtained from sawmills was placed on the floor at a depth of 35 cm and was used as the bedding material in each pig pen. In four pig pens labelled as 'Treated Group' (four replicates), a Japan-imported bacterial product, known commercially as 'Elimexal' (which the supplier claims to contain *Bacterium luwiti* at 50 million cells per g product) was added to and mixed thoroughly with the sawdust bedding at an initial inoculum size of 600 g m⁻². This was followed by a biweekly inoculation of 120 g m⁻² throughout the experimental period as recommended by the supplier. Another four pig pens were used as the control, i.e. without any addition of the commercial bacterial product. After the pig pens were prepared, they were left idle for 4 days. Four piglets of similar initial weight (about 20 Kg each) were kept in each of these pig pens for 10 weeks (Batch 1). The pigs were removed and the pig pens were then left idle for 3 weeks (first idle period) before the second batch (Batch 2) of piglets were raised over another 13 weeks. The pigs were again removed and the pig pens left empty for 5 weeks (second idle period). The third batch (Batch 3) of piglets were then introduced and kept for 13 weeks. The mixing and turning of the bedding material, adjustment of moisture content, temperature changes of the air and the bedding material, and the growth and behaviour of the pigs were described by Tam (1995).

Sampling and Measurements

At each sampling, litter material (a mixture of partially degraded pig excreta and sawdust bedding) was collected at five locations (the centre and the four corners) within each pig pen and pooled together to form a composite sample for nutrient analyses. The first sample was collected immediately after the pig pens were prepared (labelled as 'pre-exp' sample). The second sample was collected four days later when piglets were introduced (designated as 'Day 0' sample), and on Day 1, Day 5, then weekly. The pH, moisture, conductivity, total carbon, total and inorganic nitrogen (include NH₄⁺, NO₂⁻ and NO₃⁻-N), total and extractable P, total and extractable K were analyzed as described by Tam and Vrijmoed (1990). All nutrient data were presented on 105 °C oven dry weight basis. The mean and standard deviation of the four replicates in the treated and control group were calculated.

Results

Total N, Inorganic N, Total Carbon and C:N Ratio

There was no significant difference between the control and the treated groups in all forms of nitrogen, total carbon and C:N ratios (Fig. 1). The total N content of both groups elevated significantly during the first 10 weeks (Batch 1), declined during the first idle period. The total N continuously increased to a higher level during Batch 2, dropped at idle and rose again during the third batch (Fig. 1A). The rate of increases in total N appeared to be more rapid during the first than the second batches of pig rearing, and the rate of N accumulation was slowed down at the third batch. A rapid rise of $\text{NH}_4^+ \text{--N}$ was found within the first few days, reached a peak of 6 mg g⁻¹ at Week 2, and maintained at a high value till Week 10 (end of Batch 1). Similar to total N, the $\text{NH}_4^+ \text{--N}$ content also dropped during the idle periods. The rate of $\text{NH}_4^+ \text{--N}$ accumulation was also the highest during Batch 1. $\text{NO}_2^- \text{--N}$ was not detected throughout the study and the $\text{NO}_3^- \text{--N}$ was much lower than $\text{NH}_4^+ \text{--N}$ especially during the first batch (< 1 mg g⁻¹ in most samples). Some accumulation of $\text{NO}_3^- \text{--N}$ was observed during the third batch and the values fluctuated between 1–3 mg g⁻¹ (Fig. 1D). The pattern of changes in inorganic N throughout the study was the same as that found in $\text{NH}_4^+ \text{--N}$. The inorganic N accounted for less than 2 % of total N (Table 1) as the nitrogenous compounds from pig waste were assimilated into microbial and organic N.

In both control and treated pig pens, there was a slight increase in total carbon from “pre-exp” to Day 0 samples due to the deposition of pig excreta. The C content then dropped rapidly from 42% to around 30% at the end of Batch 1. During the first idle period, the total C concentrations increased to 37%, probably due to the addition of fresh sawdust material for the maintenance of a constant bedding depth (Fig. 1E). Thereafter, the C level continuously declined and reached a value of around 30% at the end of the study. In both the control and treated groups, the C:N ratios dropped dramatically within the first few days, from an initial 210:1 decreased to about 40:1 within first day and further declined to 14:1 at the end of Week 1 (Fig. 1F). After the initial drop, C:N ratio continuously dropped but at a very slow rate, reached a value of 10:1 towards the end of the study except idle periods.

pH and Conductivity

The changes in pH and conductivity value of litter material throughout the study were similar between the control and the treated pig pens (Fig. 2). There was a sharp rise in pH values within the first 1–2 days, from initial 5.2 to a peak value of 8.8, pH then decreased gradually to below 7 at the end of Batch 1. A similar pattern, an initial rapid increase followed by a gradual decline, was found in both Batches 2 and 3 (Fig. 2A). In both groups, the litter material had extremely low initial conductivity but the conductivity levels elevated sharply in the first few

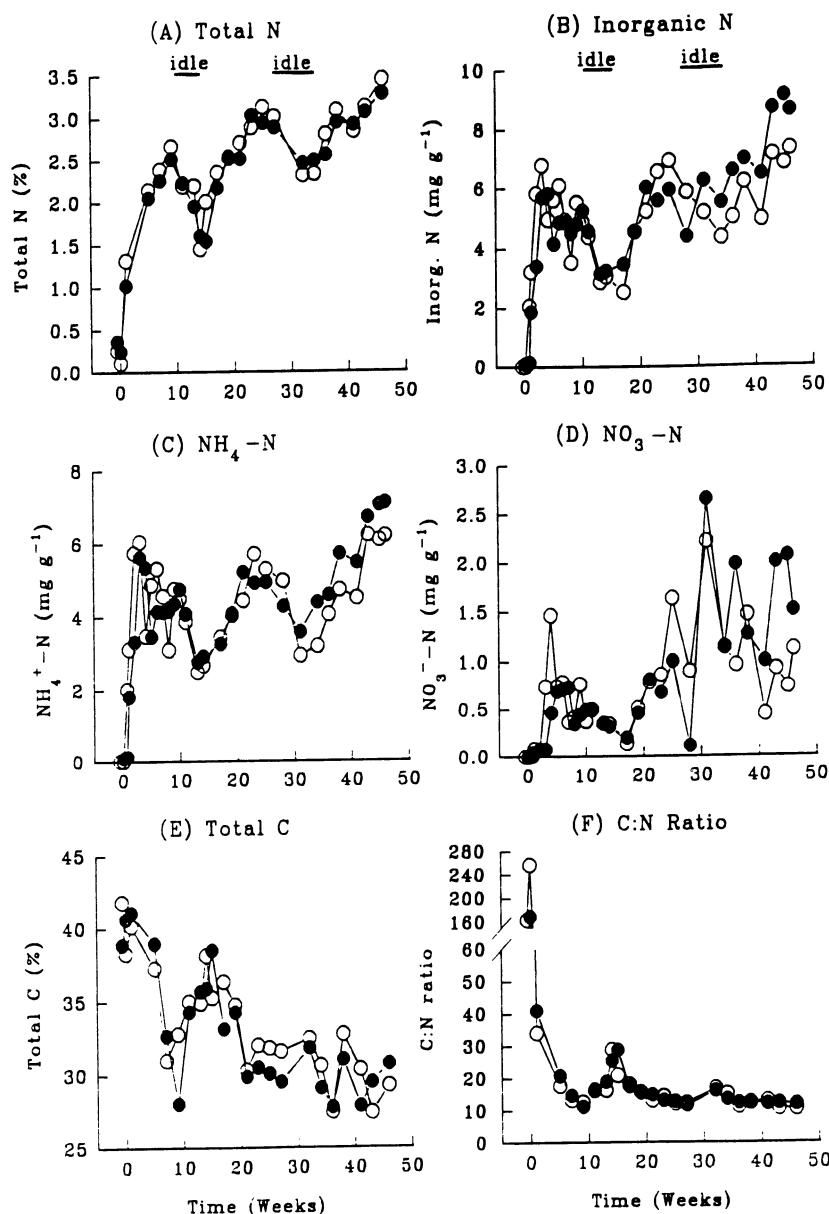


Figure 1 Changes in total N, inorganic N, $\text{NH}_4^+ - \text{N}$, $\text{NO}_3^- - \text{N}$, total C and C:N ratio of litter samples during the study. (O: control; O: treated; the two idle periods were shown)

days. The values then increased gradually and reached a very high value towards the end of the study, above 5 mmhos cm⁻¹. A slight drop in conductivity was observed during the two idle periods as no excreta was deposited (Fig. 2B).

Total and Extractable K and P

Both the total and extractable K values increased with experimental time and there was no significant difference between the control and the treated groups (Fig. 2C & D). The accumulation of total K appeared to be more rapid during the first 10 weeks (Batch 1) than Batches 2 and 3. A slightly lower total K content was found during the idle periods. Most K was not bio-available and only less than 10% of total K was water-extractable (Table 1). The extractable K increased more rapidly during Batch 3 of pig rearing. The changes of total P during the study were similar to that of total K, again, no difference was found between the control and the treated groups. The total P concentrations increased continuously throughout the study period, with more rapid accumulation during the first than the other two batches of pig rearing. More fluctuation in extractable P content was found especially during the first batch of pig rearing. The extractable P values appeared to remain at a relatively stable level from Week 20 onwards in both control and treated groups, a pattern differed from other parameters including total P, total and extractable K.

Discussion

In both the control and the treated groups, the conductivity value, content of total N, inorganic N, NH₄⁺-N, total and extractable K, and total P increased continuously with experimental time except the two idle periods (Table 1). On the contrary, total carbon and C:N ratio dropped throughout the study except idle periods. These drops were very rapid during the first few weeks, indicating that active microbial respiration took place in the bedding material which oxidizes organic substrate (from both sawdust and pig waste) to carbon dioxide. The rapid microbial decomposition was also reflected by the fast accumulation of total nutrients especially total N at the beginning of the study. The speedy mineralization of organic material to atmospheric CO₂ and N-immobilization resulted a dramatic decline in C:N ratio as shown in Fig. 1 and Table 1. The continual decline of the C:N ratios and the very narrow C:N ratio (10:1) achieved at the end of the study suggest that the litter samples might have reached maturity. Many previous studies concluded that a C:N ratio of 20:1 or 25:1 in compost could be regarded as an indication of maturity of the final product (Levi-Minzi et al., 1986). The slight rise in C:N ratio during the idle periods was due to (1) addition of fresh sawdust (during first idle period) and (2) exhaustion of pig manure and the supply of nitrogenous compounds.

During idle periods, total and extractable nutrients declined while total C

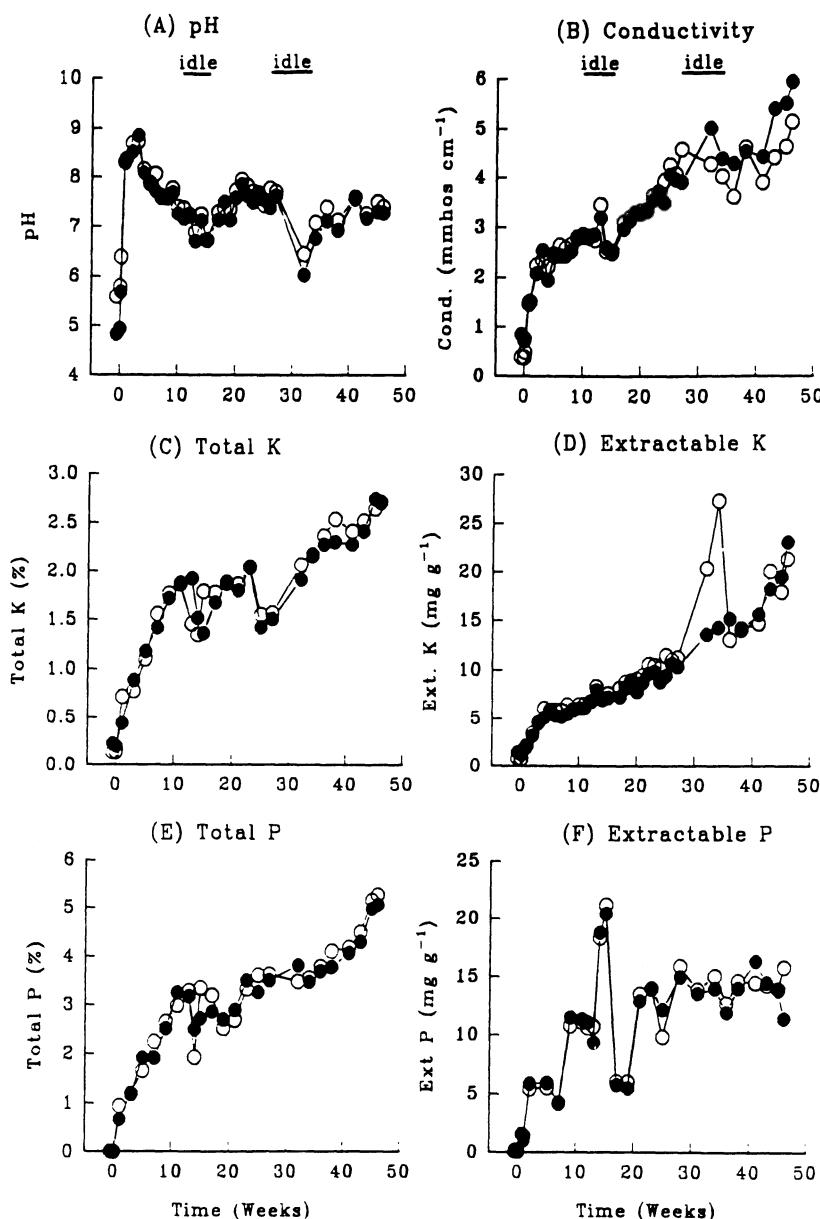


Figure 2 Changes in pH, conductivity, total K and P, inorganic K and P of litter samples during the study. (O: control; ●: treated; the two idle periods were shown)

content and C:N ratio increased. These results suggest that no further decomposition occurred when there was no pigs kept in the pig pens, which further implies that the microbial degradation was strongly controlled by the availability of pig excreta (urine and faeces) and the process might be very rapid. Therefore degradation stopped when there was no pigs and no waste deposited onto the bedding material. Tam (1995) reported that when no pigs were kept in the pig pens during idle periods, microbiological parameters including bacterial count and biomass declined significantly.

Table 1 Effect of commercial bacterial product on nutrient content of litter material during *in-situ* composting.

Parameter	In-situ Composting					
	Batch 1		Batch 2		Batch 3	
	Begin Wk 0	End Wk 10	Begin Wk 14	End Wk 28	Begin Wk 33	End Wk 46
pH	5.37 (0.44)	7.33 (0.13)	7.18 (0.37)	7.66 (0.37)	6.92 (0.20)	7.33 (0.22)
Conductivity (mmhos cm ⁻¹)	0.55 (0.18)	2.84 (0.37)	2.56 (0.36)	4.25 (0.95)	4.22 (0.89)	5.54 (0.93)
Total C (%)	39.5 (2.7)	30.4 (5.9)	37.1 (1.9)	30.6 (1.9)	32.2 (4.1)	30.0 (2.2)
Total N (%)	0.18 (0.08)	2.19 (0.28)	1.53 (0.24)	2.96 (0.20)	2.41 (0.30)	3.36 (0.25)
C:N ratio	213 (48)	11.9 (2.8)	27.1 (4.1)	11.9 (1.3)	14.3 (1.9)	11.2 (1.6)
NH ₄ ⁺ -N (mg g ⁻¹)	0.07 (0.07)	4.63 (1.92)	3.37 (1.08)	4.64 (1.92)	3.81 (1.81)	6.66 (1.45)
NO ₃ -N (mg g ⁻¹)	0.002 (0.003)	0.44 (0.26)	0.17 (0.11)	0.51 (0.81)	1.14 (0.61)	1.31 (0.79)
Inorg. N (% of total N)	0.41 (0.09)	2.32 (0.27)	2.32 (0.24)	1.74 (0.20)	2.05 (0.32)	2.37 (0.24)
Total P (%)	0.004 (0.001)	2.59 (0.38)	2.21 (0.43)	3.56 (0.29)	3.51 (0.29)	5.17 (0.32)
Ext. P (mg g ⁻¹)	0.17 (0.07)	11.14 (1.58)	18.57 (1.97)	15.42 (2.51)	14.49 (1.67)	13.57 (2.98)
Ext. P (% of total P)	42.5 (0.71)	4.30 (0.32)	8.40 (0.41)	4.33 (0.25)	4.13 (0.28)	2.62 (0.32)
Total K (%)	0.17 (0.03)	1.74 (0.20)	1.43 (0.18)	1.97 (0.27)	2.17 (0.18)	2.71 (0.16)
Ext. K (mg g ⁻¹)	0.97 (0.29)	6.34 (0.67)	7.11 (0.77)	10.81 (1.83)	20.84 (9.49)	22.24 (9.15)
Ext. K (% of total K)	5.71 (0.29)	3.64 (0.47)	4.97 (0.44)	5.49 (0.95)	9.60 (0.55)	8.21 (0.95)

Ammonium nitrogen levels increased rapidly in the first few weeks due to the increased microbial degradation of nitrogen-containing compounds. The release of ammonium nitrogen from N-mineralization was also reflected by the rapid increase in pH value (a peak of around 9). These results are similar to those reported by Mahimairaja et al. (1994). The rising temperature (around 50 oC) and pH in at the beginning of the study led to increased volatilization of ammonia and a decrease in nitrogen content (Fig. 1). This is consistent with the findings of Schwab et al. (1994). The decline in NH₄₊-N concentration was also due to the temporary immobilization of NH₄₊-N by microorganisms as the litter samples were rich in carbon and having a wide initial C:N ratio. Nitrates were in relatively low levels during Batch 1 and the values were more fluctuated than other nutrients. This might be related to the fact that the concentrations of nitrates were influenced by the rate of nitrification and denitrification. Denitrification is possible in aerobic composting as anaerobic pockets could be existed within the bedding material due to its high moisture contents and high biological oxygen demand (Tam and Vrijmoed, 1990). When the concentrations of total nutrients were compared with their respective extractable forms, very small proportions of total nutrients were extractable. For instance, the inorganic N in litter samples comprises less than 3% of total N (Table 1), a value similar to that reported by previous researchers (Castellanos and Pratt, 1981). Golueke (1972) also suggested that the composting of agricultural waste reduces the soluble nitrogen content due to its assimilation into microbial biomass. These findings indicate that the organic compounds from pig excreta were rapidly mineralized and immobilized into microbial cells during in-situ composting, probably due to the large population sizes and active microorganisms present within the bedding material (Tam, 1995).

The changes in pH, carbon, nutrient and C:N ratios at the beginning of the study were more dramatic than those recorded towards the end. The slower rates of nutrient and salt accumulation during the third than the first batch of pig rearing suggest that the aged bedding of the POL system might be more stable and had larger capacity in assimilating pig waste material. Tam and Vrijmoed (1993) have reported that the bedding material of the aged pig pens was more stable and mature.

Conclusion

This study clearly reveals that addition of commercial bacterial product "Elimexal" did not have any significant effect on the in-situ decomposition of pig wastes under Pig-on-Litter system. The litter samples collected from the treated pig pens had very similar pH, nutrient and organic carbon values to those recorded in the control groups throughout the study. The changes of nutrients and organic matter were more rapid at the beginning but slowed down towards the end of the study, indicating that the litter samples became more stable and mature. These results show that the Pig-on-Litter system could be operated on a more economi-

cal basis as (1) no addition of commercial bacterial products would be required and (2) the bedding material could be utilized for a fairly long period (at least six months or three batches of pig rearing) without replacement. However, careful control and monitoring of the environmental conditions such as ambient temperature, humidity, wind speed and degree of mixing are essential to ensure the optimal bedding condition for the microorganisms to carry out efficient and effective in-situ composting.

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Heat Evolution During Composting of Sewage Sludge

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Abstract

A physical model system was developed to permit measurement of heat evolved during the composting of sewage sludge, and to remove heat through ventilation and conduction in a manner realistically comparable to field scale systems. Heat evolutions of approximately 15,000 to 22,000 Joules per gram decomposed were observed, with peak outputs of almost 700 J/g initial sludge volatile per 12 hour period. Composting activity appeared to be enhanced by ventilation, independent of temperature or high interstitial oxygen concentration, but possibly related to particle surface turbulence factors improving oxygen transfer.

Introduction

Composting systems are characterised by an elevation of composting mass temperature as heat is released by microbial metabolism. The effect of temperature on composting activity is now well understood (reviewed by Miller 1992) and ventilative heat removal is now widely practiced for temperature control.

While the effect of temperature is well understood, the kinetics and thermodynamics of heat evolution are less well investigated. Heat evolution during composting is worthy of investigation for both scientific and engineering reasons. Heat evolution, occurring simultaneously and in proportion with metabolic activity, is a fundamental means of observing the rate of composting microbial activity *in situ*. The effect of various parameters on microbial activity can be quantified through metabolic heat evolution. In the engineering design and management of composting systems, heat management is the basis of temperature control. A prediction of heat evolution rates, related to the substrate to be composted and processing conditions, can serve as a rational basis for system design.

Heat evolution during composting can be calculated based on rates of heat transfer per unit time. Calculating heat evolution from heat loss does not account for hysteresis caused by heat storage. System hysteresis makes the use of short calculation periods, less than an hour or two, likely to produce misleading results, even

though on average the results are correct.

Small scale composting units can be useful for basic investigation and for deriving engineering data. A difficulty with small scale systems is the control of conductive heat flow related to the increase in surface area to volume ratio. Permitting conduction to account for a large portion of heat flow in small systems leads to results that are unrealistic compared to full scale systems. This is especially true for moisture management. Ventilative heat removal is mainly through evaporative cooling, while conduction removes no water but promotes the formation of a wet condensation layer. In large composting masses over 90% of the total heat removed is by ventilation related evaporation of water (Finstein et al. 1986). Further, each gram of matter metabolised by composting produces about 0.50-0.60 grams of water (Miller 1991), so that when temperature is controlled by conduction the total water content of a composting mass can actually increase. This change in moisture content can alter porosity, gas exchange rates, and oxygen availability to a significant extent (Miller 1989), thereby altering decomposition rate and extent.

This paper describes the results of investigations of heat evolution occurring during the composting of sewage sludge in a scaled heat model system. Rates and total heat evolution under various control conditions were investigated.

Materials and Methods

The physical model system used in this study is similar to the system described by Hogan et al. (1989), and identical to the system described by Miller (1984, 1989). Fundamental to the system was a semi-independent control over, and measurement of, conductive and ventilative heat loss.

Experimental reactors

Composting was carried out in 14 litre cylindrical glass reactors. Ventilation was introduced through a glass nipple near the base of the reactor upward through a perforated stainless steel false floor (63% open area) within the reactor. The inside diameter of the reactor was 21 cm, with a working height of 42 cm. The top of the reactor was closed with a removal bulkhead. Ports for ventilation exhaust, pressure measurement, a ventilation control thermistor, and insertion of thermocouple probes, were in the bulkhead. All fittings were checked for gas tightness for each trial.

Reactor weights were tared, and a known mass of material at a known moisture content was placed in the reactors for composting. At the end of a trial period, the entire reactor plus contents could be weighed, and the mass in the reactor known by subtracting the tared chamber weight.

Temperature measurement

Temperature measurement and monitoring were performed with a Doric Digitrend 220 data logger (Doric Scientific, San Diego, Calif.) using copper- constantan type T thermocouples. Temperatures were logged hourly. Thermocouples were electrically insulated with Scotchkote electrical coating (3M Co.). Thermocouples inserted into the composting mass were fixed with electrical coating within stainless steel sheaths. Three thermocouples at different depths were used per reactor.

Ventilation

A dried compressed air stream at 600–700 kPa was stepped down in pressure and regulated with a Harris Model No. 92-45 two stage gas regulator (Harris Calorific Co., Cleveland, Ohio). Flow of air into the reactors was controlled by a solenoid valve. Volume of flow during ventilation events was regulated by an adjustable variable area flow meter (Lab Crest, Warminster, Pa., precision bore meter tube FP1/4-10-6-10/ 443U396U10). Ventilation increased reactor air pressure by less than 150–200 Pa (pascals) above ambient at the highest flow rate used of 10 litres per minute (LPM).

Ventilation could be actuated by either a timer or a thermistor controlled temperature control unit (Fenwal Series 551, Fenwal, Inc., Ashland, Mass.) driving the inlet control solenoid valves. That is, a timer provided adequate baseline ventilation to provide oxygen to promote composting activity. A temperature ceiling for the composting mass could be set using the temperature controller, so that on achieving a desired composting temperature, a temperature feedback controlled ventilation pattern was established. Duration of ventilation events was monitored using a Rustrak Model 292-4 Event Recorder (Gulton Industries, Inc. East Greenwich, Rhode Island).

Inlet air temperature was measured and recorded hourly. Inlet air dew point was maintained in the 0–10°C range by a Prentech (Kenosha, Wisc.) compressed air drier. Compressed air dew point varied little day to day, but was measured twice a day using a EG & G Model 880 (Waltham, Mass.) chilled mirror dew point hygrometer. Measurement of the inlet air temperature and dew point, and the individual volume flow rate and duration of ventilation for each reactor, permitted the calculation of a mass inlet air flow rate per hour. These measurements also permitted the calculation of the inlet air enthalpy.

For calculation of exhaust air enthalpy, the air mass value calculated for the inlet mass was used, and for calculation it was assumed that the exhaust air was fully saturated. Saturation of the exhaust air was supported by water mass balance calculations and has been confirmed in other studies (Hogan *et al.*, 1989, Harper *et al.* 1992). Exhaust air flowed upward through a chilled water condenser system, which removed most of the water vapour in the exhaust. Efficiency of the water condenser system was confirmed using the above mentioned dew point hygrometer. The mass of the water removed by the condenser system was measured every

12 hours, and correction was made for the small amount of water that escaped the condenser system. Exhaust water totals and the air mass value were used to derive the exhaust air temperature and enthalpy from a psychometric chart.

Calculation of the mass air flow per hour through the reactors, along with the inlet and exhaust enthalpy, permitted calculation of the heat removed by ventilation per hour.

Conduction

Conductive heat loss was controlled by surrounding the reactors with layers of polyurethane foam of known thermal resistance and placing the reactors inside an air temperature controlled incubator. Incubator air temperatures were manually adjusted periodically so as to maintain a small temperature gradient across the layer of insulation regardless of the actual composting mass temperature.

Conductive heat flux was calculated as the sum of heat loss from the base and bulkhead of the reactor vessel, and the heat loss from the cylindrical reactor wall. The equation for the flat base and bulkhead was $q = KA(T_0 - T_1)/X$, where q = conductive heat flow, A = area of conductive surface, K = thermal conductivity, X = thickness of insulation, T_0 = outer temperature, and T_1 = inner temperature.

Being cylindrical, the equation for the heat loss from the chamber wall was $q = 2\pi HK(T_0 - T_1)/In(r_o/r_i)$, where H = cylinder height, r_o = outer radius of insulation, r_i = inner radius of insulation, and π = the value of pi.

For the polyurethane insulation used, the value of $K = 3.89 \times 10^{-4}$ J/s/cm/ $^{\circ}$ C. Inner and outer temperature values were based on single pairs of thermocouples for the reactor bulkhead and base, and the average of three vertically arranged pairs for the walls of the reactor. Temperatures were recorded hourly.

Exhaust gas analysis

Exhaust gases from the reactors were vented using a low pressure duct and hood, but an automatic pneumatic multiplexing system directed exhaust gas samples every 4 hours to O_2 and CO_2 analyzers (Beckman models 775 (paramagnetic O_2) and 865 (infrared CO_2), Fullerton Calif.) Gas analysis was recorded on a strip chart recorder (Beckman model 8720A). Lines and analyzers were purged with clean air between samples. Calibration of analyzers was performed daily.

Substrate for composting

All trials used a sewage sludge mixed with a wood chip bulking agent as provided by the Camden County Municipal Utilities Authority (CCMUA) in Camden, N.J. Sludge was 90% fresh primary settling tank sludge and 10% partially digested Imhoff Tank sludge. The CCMUA sludge was a mixed industrial – residential type, with a significant and variable input from a very large food processing plant. Sludge was dewatered to about 25% solids by the addition of 1 kg of polymer

(Allied Colloid Percal 728) per dry ton and treatment in a belt filter press. Wood chips were mixed hard and soft woods, with nominal dimensions of 2.5cm × 2.5cm × 0.6cm.

Moisture contents were determined by oven drying to constant weight at 104°C. Volatile solids were determined by ignition to constant weight at 600°C in a muffle furnace.

In the first two trial series, sludge and wood chips were mixed using the CCMUA's pug mill. In later trials sludge and wood chips were mixed by hand, as this gave better control of proportioning. Sludge moisture contents varied, requiring variation of wood chip addition to achieve an appropriate initial moisture content. Suitable proportioning of sludge and wood chips was determined by eye, with actual mix proportions and moisture contents determined on samples of the final mixture. For all trials, initial moisture contents varied from 61.6 to 64.0% with a mean value of 62.9%. Ratios of sludge to wood chip on a dry weight basis varied from 1.35 to 0.59%

Detailed analysis of the CCMUA sludge and wood chips, including extensive information on field composting characteristics of this material, is available (Toth and Nocitra 1982, MacGregor et al. 1981, Finstein et al. 1985).

Details of specific trials

Five series of trials, referred to as Series A, B, C, D, and E, are reported herein. Each series consisted of three reactor experiments. Individual reactor experiments are numbered sequentially as 1 through 15, with a series letter prefix to group trials by series. Each trial series used a single batch of sludge and wood chip mixture.

Experiments D11 and E14 used wood chips with inorganic nutrients only to determine the loss rate of the wood chips under composting conditions. In Series A, and in B5, the wet weight loading of the sludge and wood chip mixture was 7000 g. For all other experiments reactor loadings were 8000 g.

In Series A, B, and C, timer controlled baseline ventilation was set at 1.5 minutes of ventilation every 15 minutes. In Series D and E timers were set to provide 1.0 minutes of ventilation every 15 minutes. In Series A, flow rates during ventilation were set at 3.35 LPM except for A3 which was set to 6.5 LPM. Series B used a rate of 6.87 LPM, while Series D used 6.0 LPM. In Series C and E an initial rate of 10.0 LPM was used, which was reduced to 8.0 LPM after 74 hours.

Temperature feedback control set points were used in many trials (see Results) to try to maintain composting mass temperatures in the optimal range of 50 to 60°C. Set points were 50, 55, 60, and 58°C for series A, B, C, and E respectively. Series D used timer control only in an attempt to achieve inhibitively high temperatures.

Results

Oxygen monitoring showed that for all experiments oxygen concentrations were maintained in the reactors usually in the 14 to 19% range. Occasional single readings of as low as 10 and 12% were observed in some experiments just before the onset of a temperature feedback ventilation period. The oxygen concentrations observed would not be considered low enough to inhibit activity (De Bertoldi *et al.* 1988, Miller 1993). Generally, oxygen concentrations were somewhat lower than the 18 to 19.5% range observable in full scale temperature feedback controlled systems (Miller *et al.* 1990), or in model systems with better conductive heat loss control (Hogan *et al.* 1989). Excessive conductive heat loss reduced the need for ventilative heat removal, thereby also reducing oxygen concentrations.

Table 1 provides a summary of results of the composting experiments. In general, the heat evolved per gram volatile matter decomposed is fairly consistent within each experimental series. As this number is a product of both the calculated heat production and the mass balance evaluation, consistency in the heat evolution value within a series indicates that differences in the extent of decomposition within each experiment within a series are real. Some variability in results between similarly set up reactors was expected, in that true uniformity in a sludge and wood chip mixture is difficult to achieve.

Table 1 A summary of experimental results. Explanation of the special notes follow the table.

Experiment	% loss sludge volatile	% of total heat loss exhaust	J/ gram matter loss	special notes
A1	29.1	63.1	2,190	3.35 LPM
A2	27.5	61.3	1,190	3.35 LPM
A3	38.1	67.4	0.840	6.5 LPM
B4	40.7	51.4	5,310	
B5	28.4	47.3	5,610	7kg start
B6	30.0	44.4	4,980	timer 60°C
C7	42.7	78.1	15,070	
C8	38.6	—	—	no insul.
C9	32.5	54.8	14,820	timer 64°C
D10	9.8	79.2	30,840	72°C peak
D12	15.7	91.8	28,396	70°C peak
E13	19.5	62.1	22,230	
E15	22.7	64.2	21,640	

Explanation of special notes

The LPM values given for Series A refer to the litres per minute flow rate during a ventilation event. Experiment B5 had a total reactor fill of 7000 grams, while B4 and B5 had 8000 grams. Experiment B6 was left on timer control only, and reached a peak temperature of 60°C instead of the mid 50°C's for B4 and B5. Experiment C8 was not insulated and achieved composting temperatures in the low 50°C's. Experiment C9 was left on timer control only and reached a peak tem-

perature of 64°C. Experiments D10 and D12 were controlled by timer only to maximise temperature achievement, and reached 72 and 70°C as peak values. Loss of sludge volatile solids was corrected for composting loss of wood chips which was measured as 4% in 300 hours in trial E14.

Heat evolution per gram decomposed fell into two groupings (not including series D, considered later). Series A and E together averaged 21,600 J/g decomposed, while Series B and C together averaged 15,200 J/g. This difference can be interpreted as a real difference in the composition of the waste stream. Heats of combustion in J/g are 39,700 for animal fat, 24,500 for casein (mixed protein from milk), 17,500 for starch, and 14,600 for glucose (Weast 1972). Metabolism is not combustion, but combustion values can be used to approximate metabolic energy yields for different substrates. Yield of heat per gram decomposed during composting is determined by the kind of specific nutrients available, the heat value of the nutrients metabolised, and the difference in chemical energy between the substrate and the biomass produced by growth.

A very large vegetable cannery periodically discharged large amounts of vegetable processing waste into the CCMUA system which became part of the sewage sludge. Vegetable waste contains a large amount of sugars and simple carbohydrates, which would tend to have a low heat yield per weight decomposed. Series B and C had a difference in heat yield from Series A and E, which can be explained as a real difference in available sludge nutrition related to the cannery input.

Heat evolution over the time for selected experiments is given in Fig. 1. Experiments A1 and A3 were selected as an example of a consistent phenomenon where the rate or extent of ventilation appeared to promote composting activity. The only control difference between A1 and A3 is that the rate of ventilation was 3.35 LPM for A1 and 6.5 LPM for A3. While the percent concentration of interstitial oxygen was similar for A1 and A3, A3 would have experienced higher ventilation velocity and turbulence and slightly more air pressure during a ventilation event. This presumably improved oxygen exchange at the microsite level, and enhanced composting activity. Both peak composting rates and total decomposition were significantly greater in A3, as supported by both the heat output and mass balance data.

An outcome similar to that observed for A1 and A3 occurred between B4 and B6. Ventilation rates were 6.87 LPM for both reactors, but B4 was permitted to go into temperature feedback control while B6 was kept on timer control. B6 lost sufficient heat by conduction to not exceed 60°C, and so can not be considered temperature inhibited. Between hours 60 to 180 interstitial oxygen concentrations averaged approximately 18% for B4 and 16% for B6. Final moisture contents were 40.3% for B4 and 39.3% for B6, indicating that moisture related oxygen exchange at the microsite level might not have been a factor. The major difference between B4 and B6 was the volume of air flow, and B4 experienced higher peak and total activity.

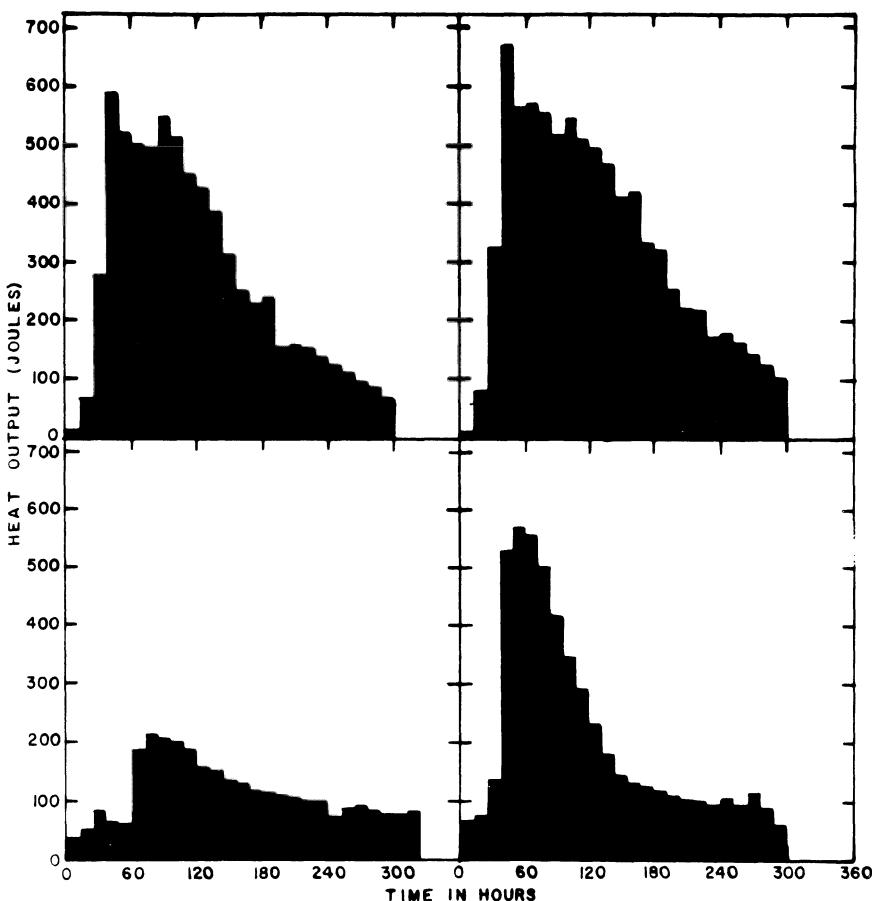


Figure 1 Heat output expressed as the total output per 12 hour period per gram initial sludge volatile. Experiment A1 is shown in the upper left, while proceeding clockwise are A3, D10, and E13.

Experiment D10 illustrates the effect of genuine temperature inhibition of activity. Peak heat evolution rates were low. Instead of high rates of activity followed by a great decrease in activity by hour 300, as observed in other trials, in D10 activity at hour 300 was still almost half of the peak rate. Interstitial oxygen levels were generally in the 16% range until hour 60, and then increased into the 18% range. Mass balance data supports the slow rate of decomposition in this experiment. The high heat per gram decomposed in Series D could be related to selective substrate utilisation by the very restricted number of species that can be found at the temperatures reached. Over 70°C, activity is restricted to a few *Bacillus* sp. (Strom 1985).

Experiment E13 is an example of a batch of sludge with low nutritional availability. Conditions were favorable for activity, but available substrate was depleted rapidly. This substrate variability of the CCMUA sludge had been observed earlier in field composting trials (Miller and Finstein 1985).

Discussion

The physical composting heat model did not duplicate the proportion of ventilative and conductive heat losses expected in full scale systems, but activity was still fairly realistic. The time course of activity rates presented herein compare fairly closely to the relative rates of activity reported for field trials using the CCMUA sludge composted with wood chips (McGregor *et al.* 1981, Finstein *et al.* 1985). Loss of sludge volatile solids in these trials was lower than that reported for CCMUA sludge composting in large field experiments by Miller and Finstein (1985). The results reported herein were corrected for wood chip decomposition, which the field studies were not, and the model studies here permitted a direct mass balance.

The rates, total heat evolution, and heat per gram decomposed presented herein can not be compared to similar data for sewage sludge, as the literature lacks other reports. Other heat model studies, such as the bench trials of Hogan *et al.* (1989) and the 7 tonne pilot scale trials of Harper *et al.* (1992) corroborate the approach described herein. Large composting systems, like that described by Harper *et al.*, can be heat modelled with a high degree of certainty, and questions of scale affecting results can be dismissed at a 7 tonne working level. Miller *et al.* (1989b) composted a straw and poultry manure mix in the system described by Hogan *et al.* (1989) and observed equivalent heat data to that observed by Harper *et al.* (1992) using the same substrate mixture.

The effect of ventilation on composting activity, as evident in trial series A and B, appeared to be a real and significant effect independent of interstitial oxygen concentration. Oxygen diffusion limitations at the particle level in composting are significant (Miller 1989, Hamlers 1993). It can be proposed that the turbulence of air movement during ventilation can decrease the dimensions of oxygen gradients at particle surfaces and in small pores, thereby increasing oxygen diffusion into particles. Another factor that might be significant is that increasing the proportion of heat removed by ventilation increases substrate drying, and decreasing water film thickness would increase oxygen transfer into particles (Miller 1989). Separating the effect of interstitial oxygen gradients and gas turbulence versus rates of oxygen diffusion across water boundary layers on oxygenation within particles is difficult.

The superior performance of temperature feedback controlled composting systems might be not only an effect of temperature, but also due to turbulence induced improved oxygen transfer, and improved oxygen diffusion related to water removal. Operationally, high velocity ventilation might improve composting process performance. Decomposition efficiency might be significantly improved in tunnel composting systems where air turbulence and uniform drying is promoted by a high rate of recirculation of ventilation air.

Variations observed herein indicate that the engineering approach of designing composting systems based on combustion heat data and estimations of expected decomposition could lead to errors in design. As actual composting activity, in

terms of heat management, can be realistically physically modelled, real composting data for specific substrates can be used as a basis for facility design instead of less direct models based on engineering handbook values.

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Process Control based on Dynamic Properties in Composting: Moisture and Compaction considerations

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Abstract

Effect of moisture levels and compactability (i.e. change in volume with load) were studied to determine their influence on aeration. Replicated experiments were conducted to measure pressure drop versus airflow using biosolids and cow manure composts at four moisture levels and loadings in the range of 0–43.2 kPa. Biosolids compost showed significant increase in compactability and pressure drops with increasing moisture levels. Cow manure compost behavior did not significantly change with increasing moisture. A generalized airflow model was developed based on the Kozeny Carman equation of permeability in porous media. The model successfully described the air permeability of the materials at all moisture and compaction levels. Data of moisture and temperature profiles during 21 days of composting are presented from a full scale invessel ($6.1 \times 3.0 \times 220 \text{ m}^3$) biosolids composting system. Based on this data and the air flow model it is quantitatively shown that management strategies using variable depth of compost can improve product uniformity and reduce operating costs. Maximum critical bed depth at different moisture levels and the potential for the formation of anaerobic conditions at different depths of the compost bed and at different moisture levels are described.

Introduction

Deep bed composting of compressible materials has to be treated with care regarding compaction and channeling of air flow. Compaction in reactor systems result in high pressure drops and high power requirements for aeration. High aeration results in the formation of channels, thereby causing uneven aeration and development of temperature and moisture profiles. Such systems require frequent mix-

ing and longer detention time to compost materials to stable levels. In order to keep the composting process economical and efficient, the biological and physical conditions for rapid degradation have to be uniformly maintained in reactors for long periods of time.

The optimal moisture content for composting varies for the type of material being composted and values reported in the literature range from 45–70 %, wb (Jeris and Regan, 1973; Suler and Finstein, 1977). The free airspace in the compost matrix is influenced by the moisture content and becomes limiting when the moisture is raised above 60 % (Schulze, 1961). Based on oxygen consumption rate as an indicator Jeris and Regan (1973) showed that for maximal degradation, free air space in compost should be in the range of 30–36 %. The re-aeration capability of compost is reduced when the free air space reduces to 28 % and below. They however did not consider the effect of compaction in changing free air space levels.

As the moisture is increased most materials become more plastic and susceptible to compaction. In beds of higher moisture, the increased wet bulk density causes higher compressive stresses and compaction of the bed due to its own weight cause significant vertical variation of free air space and permeability. A quantitative understanding of this effect can help engineers incorporate flexibility into the design of composting systems. Plant operators can vary the height of the bed of compost at each remix thereby increasing reactor usage efficiency without causing excessive compaction and its negative side effects such as anaerobic regions, channeling, etc.

A knowledge of resistance to airflow in packed beds of composting materials is important in the design of aeration systems in composting. Keener *et al.*(1993a) have discussed the implications of pressure drop in aeration systems on the design process and economics of composting. Parameters of airflow resistance in biosolids-wood chips compost have been determined in the velocity range 0.25 to 1.02 m/sec (Higgins *et al.*, 1982). That study however did not consider the influence of moisture on compactability and pressure drop in the material.

The objective of this study is to quantify the influence of moisture on the compaction and pressure drop in two types of compost and to determine process control modifications based on this knowledge. Specific materials are chosen and testing is done to determine general trends and effects. The two compostable materials studied are biosolids+bark+sawdust compost and cow manure compost. Biosolids compost is a non-homogeneous mixture of fibrous (bark) and clayey (biosolids) materials with moderate moisture retaining capacity, whereas cow manure compost is a homogeneous flaky material with very high moisture retaining capacity.

Compactability of Compost Porous Media

Numerous models of soil compaction are found in the literature (e.g. Dexter, 1988; Morland *et al.*, 1993). Since compost media is a porous media similar to soil, its

behavior can be characterized using approaches similar to soil compaction studies. Compaction in porous media can be assumed to be due to reduction in inter-aggregate voids only (Dexter, 1988). Hence at large compactive loads the sample of compost will asymptotically approach a maximum compressed height (H_i). The nondimensionalized height of the sample at any intermediate compressive stress is given by the compression curve as :

$$h_i = h_\infty + \Delta h_o * \exp(-\beta P_i) \quad \text{Equation (1)}$$

Where, h_i , D_h , and b are compressibility parameters of the material at a specified moisture level. If h_0 is the height of an uncompressed sample, then $h_i = H_i/H_0$, $h_i = H_i/H_0$ and P_i is the load on the sample at h_i . In physical terms, h_i represents the uncompressed fraction at infinite load, D_h represents the total compressible fraction and beta is a rate term (Dexter, 1988).

The changes in physical properties of the sample are computed based on the parameters of the compression curve and preliminary measurements of weight of sample, moisture content and particle density using the following equations (Hillel, 1982)

$$\rho_{bd} = \frac{\text{Weight of Sample}}{h_i A} \quad \text{Equation (2)}$$

$$\epsilon = 1 - \frac{\rho_{bd}}{\rho_p} \quad \text{Equation (3)}$$

$$\theta = \frac{MC}{\rho_w} \rho_{bd} \quad \text{Equation (4)}$$

where h_i is defined by equation (1), A is the cross-sectional area of flow, MC is the moisture content dry basis, ρ_p is the particle density of the material, and ρ_w is the density of water. The free air space of the sample material is calculated as

$$FAS = 1 - \frac{\rho_{bd}}{\rho_p} - \frac{MC * \rho_{bd}}{\rho_w} \quad \text{Equation (5)}$$

Permeability of Compost Porous Media

For fine homogeneous particle beds the permeability is a function of porosity, shape and orientation of particles, surface area exposed to flowing fluid and the pore size distribution. The Kozeny-Carman “mean hydraulic diameter” model describes the relationship between permeability (K) and porosity (ϵ) in a packed bed as follows (Dullien, 1992),

$$K = \frac{\epsilon^3}{K_0 \gamma S_0^2 (1 - \epsilon)^2} \quad \text{Equation (6)}$$

In the denominator gamma is the Tortuosity factor, k_0 is a particle shape factor, and S_0 is the specific surface area of the particles. These factors are difficult to measure and hence a lumped parameter evaluation is made, and the product $(1/k_0 g S_0)$ commonly called the Kozeny constant (C) is evaluated by measuring permeability and porosity directly in the material. The permeability (K) is related to the velocity of flow (V) by Darcys law, as follows,

$$V = \frac{Q}{A} = \frac{K}{\mu} \frac{\Delta P}{\Delta h} \quad \text{Equation (7)}$$

Experimental Materials and Methods

A sample cylinder, 0.31 m (12 in.) in diameter was used to fill compost to a depth of 0.41 m (16 in.). Air was forced in through a 2" sch 40 pipe, id 0.053 m (2.07 in.). The volumetric airflow into the sample cylinder was measured using an orifice plate. The pressure drop across the orifice plate was measured using a 0–0.025 m–H₂O (0–1 inch H₂O) incline tube manometer and the Spink equation (Spink, 1967) was used to calculate the airflow through the pipe. Control valves were used to control airflow into the sample cylinder. A perforated retainer plate and a perforated force distribution plate were placed on top of the sample to hold the sample and distribute the mechanical load evenly over the sample cylinder cross-section. The whole setup was placed in a model 37F hydraulic press (Mfg. K.R. Wilson, Buffalo, NY).

Biosolids compost samples were obtained from the in-vessel reactors at the City of Akron Compost Facility. A four day composted mixture of biosolids: recycle: bark: sawdust = 0.34:0.45:0.18:0.03 (v/v) was used in this study. The moisture content of the material at sampling was 57.4 % (wb). The separated cow manure (separated from liquid by pressing) samples were collected from the Dairy Science Research Center of the OARDC, Wooster. The materials were brought to the laboratory and divided into four fractions. The first fraction was used for the first run. The remaining three fractions were sun dried with periodic stirring on a clean concrete floor for durations ranging from 2 to 6 hours. At two hour time intervals each fraction was taken into the laboratory for study. Each test fraction was first mixed well and subsamples were taken for moisture content evaluation. All measurements were performed on three independently selected random samples of the material. Data reported in this paper are averages of the three replications. The particle densities of the compost mixes were measured on the wettest fraction following the Pycnometer method described by Blake and Hartge (1986).

For each run material was weighed and filled into the sample cylinder to a depth of 0.41m. Care was taken to ensure that the material was well mixed prior to filling and no compaction of the sample occurred during filling. The perforated retainer plate and the force distribution plate were placed on the sample. The initial depth of the sample was recorded and the pressure drop was measured at five

superficial velocities in the range of 0.05–0.20 m/sec. The pressure drop was measured from the bottom of the plenum to atmospheric pressure using a 0–0.102 m-H₂O (0–4 inch H₂O) inclined tube manometer.

After one scan the material was compressed using the ram of the hydraulic cylinder to an effective compressive stress of 6.97 kPa. While this stress was maintained on the sample, the height of the sample was measured and the pressure drop was measured at the five superficial velocities as before. The compressive stress was raised to levels of 13.9 and 20.8 kPa and the process was repeated. Finally the compressive stress was raised to 43.2 kPa and the compression of the sample was recorded. At this compressive stress, pressure drops over 100 cm-H₂O/m-Compost (12 inches/ft) were reached. This description entailed one replication of one run. Each run (one moisture level) was replicated three times. Four runs were performed at different moisture levels. In the case of cow manure samples the maximum compressive stress was 20.8 kPa.

Results and Discussions

The compression curves for the samples are shown in Figures 1 and 2. The volume reduction clearly fits an exponential decay as seen in studies of soil compaction by Dexter (1988). The coefficients of equation 1 for biosolids and cow manure composts are presented in Table 1. Due to the more plastic nature of the material at high moistures, greater sensitivity to compressive stress is exhibited.

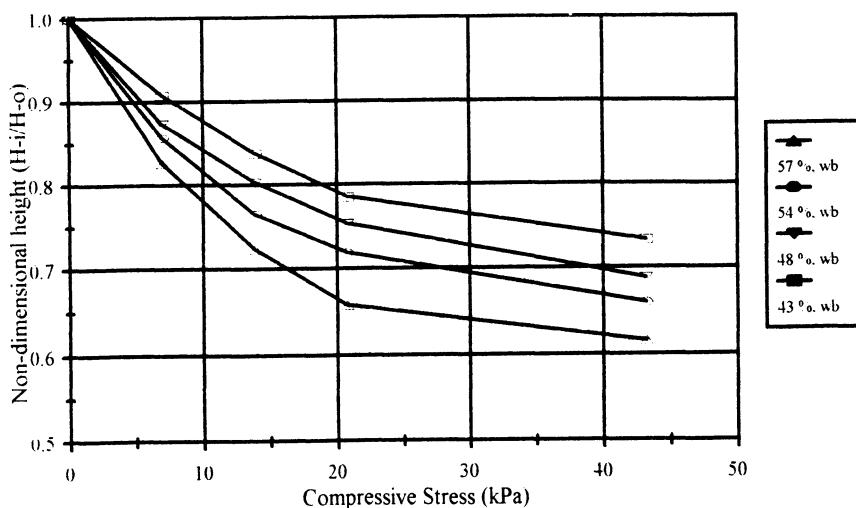


Figure 1 Compression curve for biosolids compost.

Air permeability decreased exponentially with increasing compressive stress (Figure 3). At low compression, the dry materials show lower permeability. This is due to the shrinkage of aggregate resulting in an increase in the fraction of fines and packing density in drier materials. As the material is compressed the velocity

term (in Equation 1) affects the rate at which porosity changes and the difference in permeability is reversed. The free air space is calculated using equation 5. A regression using equation 6 is performed to relate free air space and porosity and estimate the lumped parameter 'C'. The results for different moisture levels are presented in table 1. In contrast with biosolids compost, cow manure showed no consistent influence of increasing moisture levels. The effect of compaction on permeability was similar to biosolids compost showing an exponential decay, but without any noticeable influence of moisture. It can be concluded that cow manure compost is a material with high moisture absorbing character and the presence of water does not increase its compactability in the range studied.

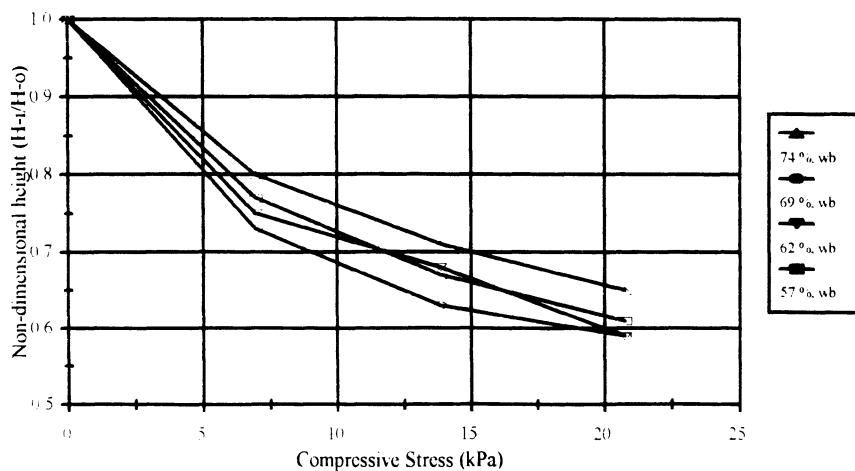


Figure 2 Compression curves for cow manure compost.

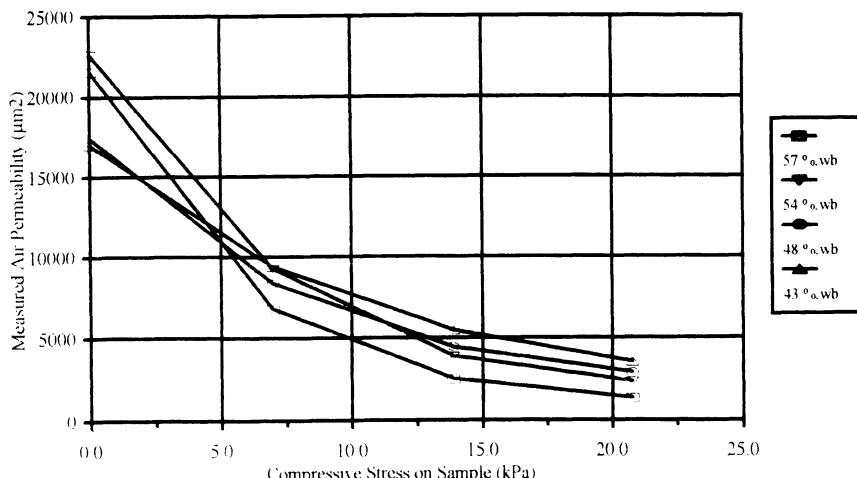


Figure 3 Permeability changes of biosolids compost at different locations in the bed and different bed depths. Symbols are used only for clarity and do not represent experimental data points.

Table 1 Compactability Characteristics, Particle Density and Permeability characteristics of compost materials.

Material: Biosolids Compost						
Mean Particle density (Std Dev.): 1365.7 (67.8) kg/m ³						
Initial Moisture (%, wb)	Compactability Equation Coefficients				Kozeny–Carman Constant	
	a0	a1	a2	R ²	C	R ²
57.4	0.601902	0.400256	0.086758	1.00	28244	0.99
53.7	0.646668	0.354161	0.077089	1.00	19988	0.97
47.6	0.670009	0.328925	0.066329	1.00	11679	0.95
42.8	0.707997	0.294688	0.059926	1.00	9410	0.93

Material: Cow Manure Compost						
Mean Particle density (Std Dev.): 1380.5 (80.4) kg/m ³						
Initial Moisture (%, wb)	Compactability Equation Coefficients				Kozeny–Carman Constant	
	a0	a1	a2	R ²	C	R ²
73.7	0.598066	0.401186	0.095886	1.00	3579	0.99
68.4	0.566557	0.43373	0.139518	1.00	1643	0.98
61.6	0.554230	0.44225	0.106588	0.99	730	0.96
57.3	0.563237	0.436171	0.104976	1.00	443	0.94

Process Control Considerations: FAS Limitations

Based on the compactability parameters (table 1), the expected profiles of free air space are shown in figure 4. The free air space is the volume available for free oxygen at any location in the bed. As the material gets compacted at lower levels in the bed the free air space reduces. The reduction is more dramatic in high moisture materials due to their higher compactability.

To prevent free air space limitations during composting we should ensure that FAS >0.28 as discussed in the introduction. In figure 4 we see that at moisture levels below 55 % there is no limitation even to bed depths of 4 m. At 57 % we can expect the bottom layers in beds of 3.5 m depth to have sub-optimal conditions. In beds of moisture 63%, in order to maintain an environment for maximum degradation based on free air space considerations, the critical depth of the material would be 2.25 m.

Data was collected at a full scale deep bed composting reactor (6.1m width, 220 m long) at the city of Akron composting facility. Figure 5 shows the moisture profile from 20 locations across the cross section of the reactor. The material was loaded in the reactor at a moisture content of 58% and to a depth of 3 meters. It was seen that the moisture reduced to an average value of 43 % in 6 days. Most of the drying takes place in the first few days when high rate composting occurs.

The analytical model of composting kinetics presented by Keener *et al.* (1993b) can be used to estimate the rate and amount of moisture loss. If the bed is at 60 °C undergoing high rate composting the required air flow rate is based on the amount of heat generated and would be about 12 kg(DA)/kg(DM)-day. Assuming the rate of degradation, k = 0.2/day, heat of combustion of compost, hc = 22.1 × 10⁶ J/day,

and non-compostable fraction, beta = 0.75. For a bed of depth 2 meters, wet bulk density 535 kg(WM)/m³, moisture content 63 %(wb), the rate of aeration would be 712 kg(DA)/day. If the air entering the bed is at 25 °C, its water removing capability will be 379 kg(water)/kg(DA). The moisture content of the bed will reduce to a level of 56 % (wb) if the above stated conditions are maintained in about 3 days. A turn of the bed can be scheduled at the 4th day, effecting sufficient mixing of materials and increasing the bed depth up to 3.5 m.

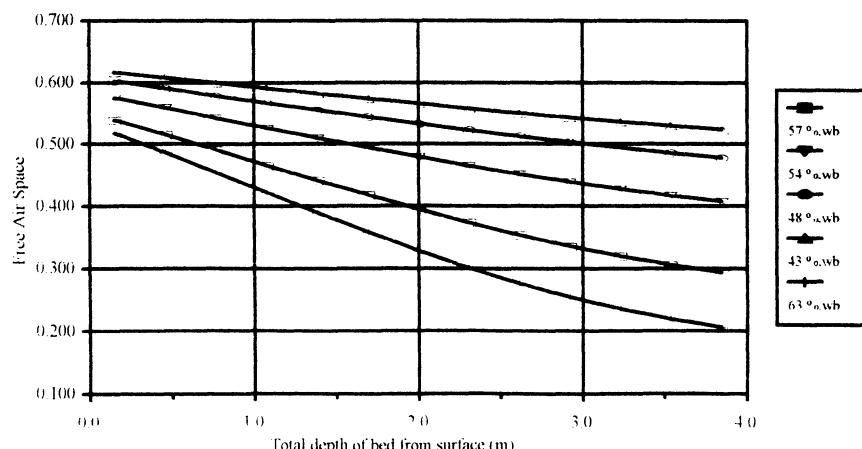


Figure 4 Free air space changes of biosolids compost at different locations in the bed and different bed depths. Symbols are used only for clarity and do not represent experimental data points

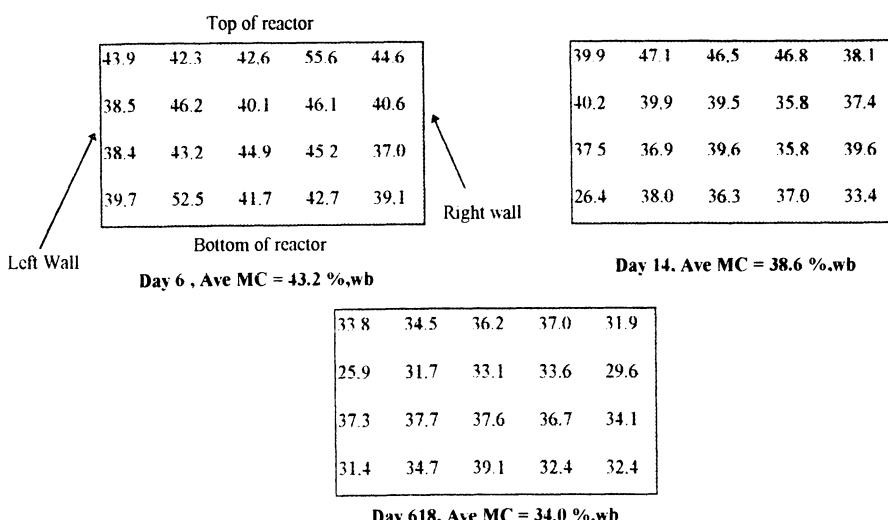


Figure 5 Cross sectional moisture profile changes with time. Samples were taken from the cross-sectional face of a deep bed reactor 6.1 meter from left wall to right wall, and 3.1 meter deep from top to bottom of reactor. Moisture at start of composting was 58 %, wb.

Power Requirements for Aeration:

Figure 6 shows the total fan power requirements in a bed as a function of depth of the bed. The equations used to calculate power consumption are described in Keener *et al.* (1993b). In general the power requirement, P (W/kg(DM)) = $Q^* P/\text{eff}^* \text{DM}$, where Q is the volumetric flow through the bed, P is the pressure drop at that flow, eff is the efficiency of the fan and DM is the amount of dry matter in the bed. Pressure drop is based on Darcy's law equation 7. The calculations are performed on a bed of unit cross sectional area at a superficial velocity of $Q/A = 0.05$ m/sec. Dramatic increases in total power requirements are found when moisture levels approach 60 %. As suggested earlier, if the material at an initial moisture of 63 % is packed to a bed depth of 2.0 m instead of 3.0 m, the power required per unit mass dry matter is reduced by one half, along with avoiding compaction.

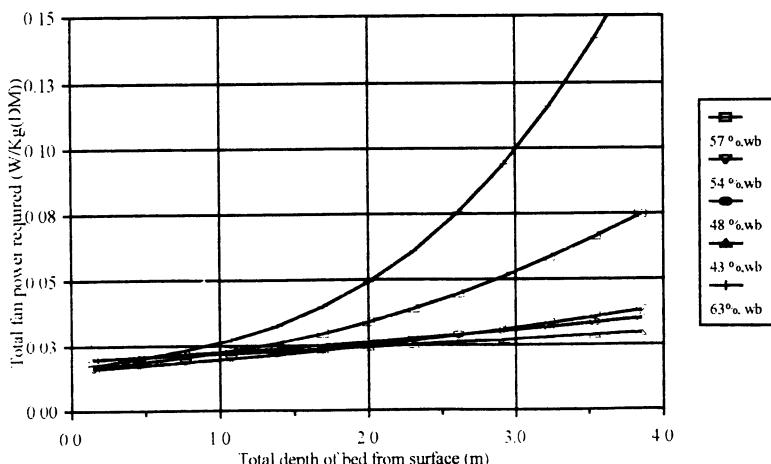


Figure 6 Estimated power consumption per unit mass of dry matter in a bed. Air flow was assumed to be a superficial velocity of 0.05 m/sec.

Summary and Conclusion:

This paper has extended the theory on compaction in soil to describe the process in deep bed composting of compressible materials. Through laboratory experiments on two compost mixes, the effect and interaction between compost moisture and compaction on changing FAS has been evaluated. Results are compost specific but clearly showed that critical moisture levels exist in compost above which loss of FAS can occur, even at relatively shallow depths.

Acknowledgments

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Compost Facility Operating Guide

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Abstract

Compost must satisfy customers to secure reliable and sustainable markets. Proper management of feedstock and all phases of composting are essential for the production of marketable compost. The continuity of compost production and market supply also requires proper facility and environmental management. The basis to develop site- and technology-specific composting facility management strategies and control is provided by the *Compost Facility Operating Guide*, a guidance developed by the Standards and Practices Committee of The Composting Council (USA).

The *Operating Guide* focus is on producing market quality compost from discarded compostable organics recovered from the Municipal Solid Waste stream. MSW contains a variety of biodegradable organics of which 30 to 60% can be returned to beneficial use by composting. This secondary resource from residential, institutional and commercial sources includes food waste, yard waste, and paper waste, especially soiled paper products and packaging. Compostable material can be source separated and recovered at curbside, or under exceptional conditions left mixed and recovered at central-sort facilities, transformed into compost, and marketed.

Composting plant design and operation relies on a variety of processing and material handling technologies, but each must provide capability to prepare for and manage the biology of composting. Certain elements are common to all composting that are key to producing consistently marketable compost. These key elements are presented in the *Compost Facility Operating Guide*. The *Operating Guide* divides the composting process into seven basic unit operations. For each unit operation, the *Operating Guide* identifies operating parameters, and explains the principle, objectives, operating boundaries, control procedures, control monitoring, and control sample analytical test methods.

Introduction

Municipal-scale composting is a managed and controlled production of compost that uses natural aerobic processes to transform discarded organic materials into commercially valuable product. Long term success for operation of a composting facility is dependent on predictable results in the management of feedstocks, production of compost, compliance with environmental regulation and satisfying facility neighbors, along with a sound economic basis for the project.

The Composting Council (USA) has developed a reference guidance for composting facility managers and operators, called the *Compost Facility Operating Guide*. The *Operating Guide* presents principles for managing municipal-scale aerobic composting and for managing facility operations. The *Operating Guide* provides the basis to deal successfully with a variety of composting feedstock materials, with a variety of composting technologies and with odors and other environmental issues of concern. This paper is an introduction to the *Operating Guide*.

Development of the Operating Guide

The 389-page *Operating Guide* was developed by the Standards and Practices Committee of The Composting Council, with the help of scientists, engineers, technology vendors, operators, laboratory analysts, consultants and state and federal regulators.

CONTRIBUTORS

- Scientists
- Engineers
- Technology Vendors
- Operators
- Laboratory Analysts
- Consultants
- State and Federal Regulators

Development required nearly four years to complete. The original draft was based on published scientific research, and was taken to a number of operating facilities for assistance to develop a format and content easily usable by plant managers and technicians. Charts and graphs were added to aid in its usefulness. Two rounds of collaborative peer review were conducted in different parts of the nation before the document won consensus acceptance by more than 100 of the leading composting experts in the industry, and was approved for publication.

Composting Unit Operations Model

A simple model was developed on which to base guidance for managing municipal-scale aerobic composting, as shown by Figure 1 on the next page.

At the box in the upper left corner of the schematic diagram, this first-level model shows **Materials Delivered to a Composting Facility**. At the box in the lower right corner, **Finished Product** is shown produced by the facility. In between, the composting process is shown by seven Steps, moving from left-to-right and top-to-bottom.

Compost quality control measures normally begin outside the composting facility to help insure compliance with finished product standards concerning chemical and organic contaminants for public health, safety and environmental protection and enhancement objectives. Measures include collection and delivery of clean compostable feedstock, that contain a minimum of chemical and organic contaminants. Compost quality control requires the instruction and training of waste generators and waste haulers; their cooperation determines to a large extent the level of these contaminants in finished product. Success in the feedstock delivery infrastructure, however, must be supplemented by central facility sorting to remove unavoidable mistakes that creep in to the materials delivery stream.

Step 1 Feedstock Recovery is the final inspection and separation of chemical contaminants and residue (physical contaminants) from the composting feedstock at the facility. In addition to recovery of compostable organics, other recyclable materials may also be recovered by Step 1. These are shown in the box off to the right. **Step 2 Feedstock Preparation** involves establishing initial porosity and degradability.

Step 3 Composting involves pathogen treatment, biodegradation and stabilization of the compost. **Step 4 Odor Treatment** is offset to the right in the diagram. It involves collection of air from the process and other odor sources, and treating it in a biofilter or other positive odor treatment system.

Step 5 Compost Screening and Refining is a finishing step that removes physical contaminants (residue) down to 4 millimeters, including glass, metal fragments, plastic bits, film plastic and sharps. Oversized materials, like stones and bulking agents, are also removed. **Step 6 Compost Curing** is another finishing step to develop the level of compost stability required for particular end markets.

Step 7 Compost Storing and Packaging, the final step, stores product until it is needed and readies it for market. The **Finished Product** that is produced for distribution must be tested for compliance with standards and market requirements.

The Standards and Practices Committee has noted that all aerobic composting systems, for all feedstocks, can be described by this model.

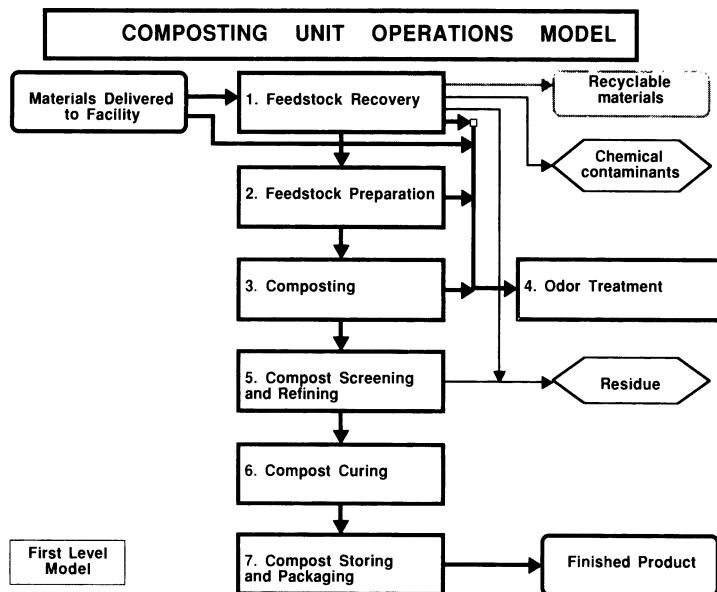


Figure 1

The first level model has been expanded to the second level with added detail as shown by Figure 2, to include process inputs and outputs for each unit operation. Inputs include additives, air, inoculum, mixing and turning, water and sometimes bulking material, and amendments. In addition to outputs already shown by the first level model, the second level version shows clean air exhaust from **Step 4 Odor Treatment**.

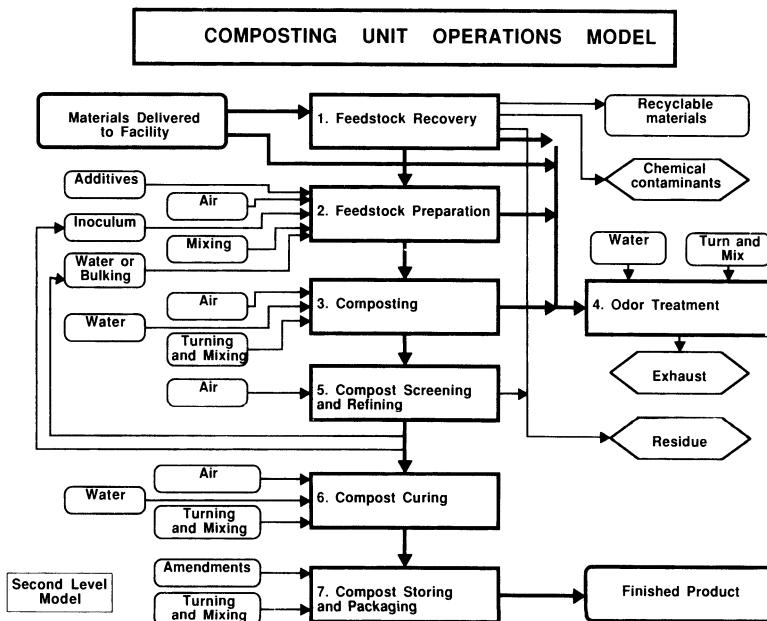


Figure 2

Operating parameters

Within each composting unit operation, operating parameters are identified as shown in Table 1. Each parameter for each Step is separately discussed in the *Operating Guide*.

Table 1

OPERATING PARAMETERS
Set Particle Size
Mix Additives and Amendments
Set/Control Carbon to Nitrogen Ratio
Set/Control Moisture
Biological Activation
Porosity
Turn and Mix
Control pH
Aerate
Control Temperature
Control Pathogens
Test Feedstocks and Compost

Parameters discussed include particle size, carbon to nitrogen ratio, moisture, porosity, pH and temperature. The process management discussions include additives and amendments, biological activation and microbial diversity, turning and mixing, aeration, and pathogen reduction. Odor management is discussed in two parts, odor control and odor treatment.

Figure 3 is an enlarged segment of the third level model, which shows still more detail. This example shows operating parameters for **Step 3 Composting** and **Step 4 Odor Treatment**.

Step 3 Composting receives input, indicated by the arrow pointing from above, from the previous **Step 2 Feedstock Preparation** (not shown), and from the left including air, water, and turning and mixing. Key process control parameters for **Step 3 Composting** are listed in the box and include the process to further reduce pathogens, temperature, moisture, porosity, aeration, pH, homogenization and odor control.

Step 3 Composting has two outputs. One output is toward the right. This is odor-laden process air that is collected and routed to **Step 4 Odor Treatment**. The other output is the arrow down to the next step, which is **Step 5 Compost Screening and Refining** (not shown).

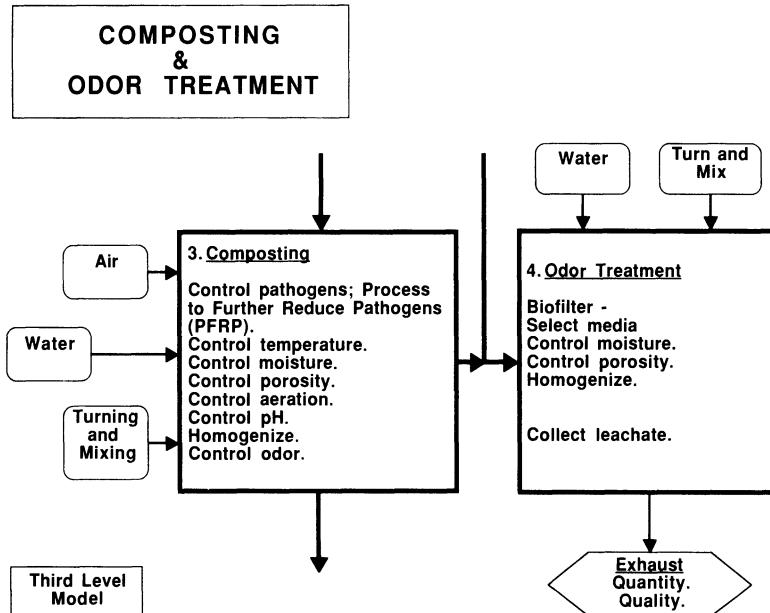


Figure 3

Step 4 Odor Treatment has input of odor-laden air collected from the **Materials Delivery** area, from **Step 1 Feedstock Recovery**, from **Step 2 Feedstock Preparation** (not shown), and from **Step 3 Composting**. It also receives input from the top; namely, water, and turning and mixing. Operating parameters for odor treatment depend on the technology used. For example, if a biofilter media is used, then moisture, porosity and homogenization are key parameters that must be controlled. Outputs from **Step 4 Odor Treatment** are the air exhausted to atmosphere, and, depending on the technology, may include leachate that must be collected.

Each parameter for each step is presented separately in the *Operating Guide*. As a result, the *Guide* contains about 50 chapters (Sections).

Operating Guide Application to Composting Technologies

A variety of technologies have been developed that approach the model in a variety of ways. Technology vendors assisted the Standards and Practices Committee in characterizing the various technologies and in placing them in five Groups as shown by Table 2.

Table 2

GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5
<i>Open Piles</i>	<i>Open Windrows and Piles</i>	<i>Covered Piles and Tunnels</i>	<i>Covered Windrows, Bays/Trenches and Beds</i>	<i>Covered Tunnel and Vessel Systems</i>
Undisturbed and Unmanaged	Turned and with Water Make-up	Static Aerated and with Temperature Control	Turned and Aerated, with Temperature Control and Water Make-up	Turned and Aerated, with Temperature Control and Water Make-up

Group 1 is open piles, undisturbed and unmanaged. Although some municipalities use this approach to manage leaves and brush, the Standards and Practices Committee does not consider this to be composting. This approach does not reduce pathogens, and is basically anaerobic.

Group 2 is open windrows and piles that are turned, with water make-up. Group 3 is piles and tunnels under roof, that are static, with forced aeration and temperature control. Group 4 is windrows, bays/trenches/horizontal silos and beds, under roof, that are turned and have forced aeration, and have temperature control and water make-up. Group 5 is covered tunnel and vessel systems, that are turned and have forced aeration, and that have temperature control and water make-up. Principles discussed in the Operating Guide apply to all managed technologies Group 2 through 5.

Operating Guide Format

A common format is utilized throughout the Guide to present each of the operating parameters. The Section Title Page is an illustration of the format, as shown by Figure 4 on the next page.

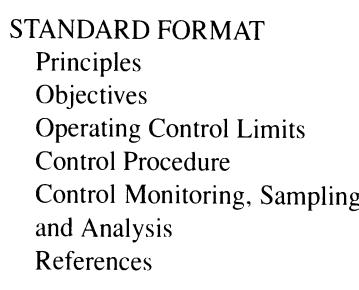
Each Section starts with a Title Block. The Section and Part number are in the upper right corner. This example Title Block is for Section 4, Part 6.

Also in the upper right is the name of the Process Step and Operating Parameter. This example is the Composting high rate step and Temperature Control parameter. To the left in the Title Block is a list of Key Objectives for management of the operating parameter during this step. Below that is a list of operating Control Points with targets, and upper and lower control limits required to achieve the stated objectives. The Title Block serves to preview material presented in the sections. Checks along the bottom indicate what Technology Groups this Section applies to.

Text in the Guide is presented in a Standard Format. The Format discusses the Principles and Objectives for process control to manage the biology of composting. Guidance for managing the biology of composting is the real strength of the Guide.

<p>KEY OBJECTIVES</p> <ul style="list-style-type: none"> • Reduce pathogens • Control temperature by removing heat via aeration • Maintain aerobic conditions • Maximize microbial efficiency • Reduce odor generation 	<p>4.6</p> <p>COMPOSTING HIGH RATE</p> <p>Temperature Control</p>			
<p>CONTROL POINTS</p> <ul style="list-style-type: none"> • Pathogen Control: <ul style="list-style-type: none"> Upper control limit: 60°C (140°F) Lower control limit: 55°C (131°F) • Decomposition: <ul style="list-style-type: none"> Target: 45°C (113°F) Upper control limit: 50°C (122°F) Lower control limit: 40°C (104°F) 				
TECHNOLOGY APPLICATION				
GROUP 1 <u>Open</u> <u>Piles</u> Undisturbed and Unmanaged	GROUP 2 <u>Open</u> <u>Windrows</u> <u>and Piles</u> Turned and with Water Make-up	GROUP 3 <u>Covered</u> <u>Piles and</u> <u>Tunnels</u> Static Aerated and with Temperature Control	GROUP 4 <u>Covered Windrows,</u> <u>Bays/Trenches</u> <u>and Beds</u> Turned and Aerated, with Temperature Control and Water Make-up	GROUP 5 <u>Covered</u> <u>Tunnel and Vessel</u> <u>Systems</u> Turned and Aerated, with Temperature Control and Water Make-up
:	x	x	√	x

Figure 4



The Objectives also describe managing compliance with minimum product safety standards and marketing standards, managing industrial hygiene and the facility environment, and others, like materials handling.

Operating control limits are based on statistical process control, with measurements and adjustments to keep the process within predetermined boundaries. Control procedures discusses interventions, control monitoring, sampling and analysis. The Guide includes references used, and references available for further study.

Operating Parameter Illustration

The content of the Guide includes many charts, graphs and tables for illustration and reference use in planning process management.

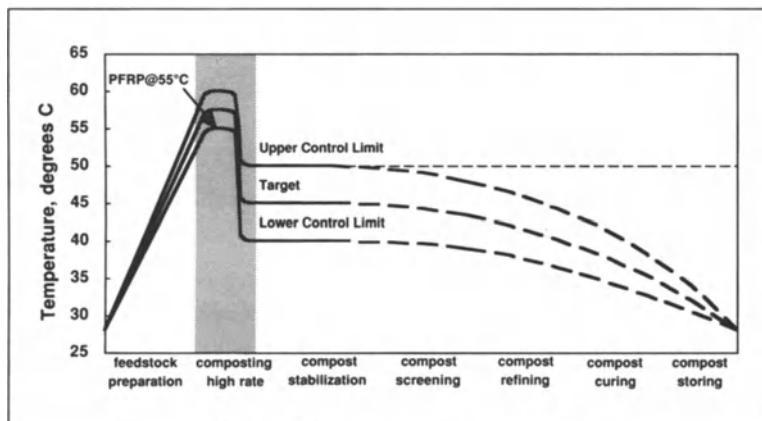


Figure 5 Temperature Profile Graph

Figure 5 is an example process Temperature Profile Graph as found in Section 4.6. The vertical axis shows temperatures. The horizontal axis shows steps, and has no scale.

The temperature profile shows the Process to Further Reduce Pathogens (PFRP), and shows the temperature target and limits for maximizing the rate of decomposition. The profile shows temperature tapering off corresponding to decreasing energy availability in the pile.

The shading in this example is located at the Composting High Rate Step on the process continuum associated with Section 4.6. The profile lines show where the process temperature should have been prior to this Step. It shows where the process temperature should be going, in order to maximize the rate of decomposition as it moves on to the next Steps in the continuum.

Operating for Success

As already mentioned, municipal-scale composting is a managed and controlled production of compost. It uses natural aerobic processes to transform organic waste material into commercially valuable product. Long term success is dependent on predictable results.

**SUCCESS CRITERIA –
*PREDICTABLE RESULTS***

- Management of feedstocks
- Compliance with environmental regulation
- Good community relations
- Satisfied compost customers
- Sound project economics

Predictable results are essential in the management of feedstocks, compliance with environmental regulation, satisfying facility neighbors and supplying reliable compost markets. These, along with a sound economic basis for the project, lead to success.

Predictable results are not a happy accident. They are the result of careful planning and execution. They are the result of knowledgeable, competent and committed personnel, making the right decisions.

The *Operating Guide* provides the basis to develop sound, site specific, process management plans, and standard operating procedures. It provides the basis for odor management, and for dealing with other regulatory and neighborhood concerns. It provides the basis for operator training and qualification. It presents process control variables that determine product attributes, and can assist facility operators in the consistent production of marketable product.

PURPOSE

- Sound process management
- Standard operating procedures
- Environmental issues management
- Operator education and training
- Consistent production of market compost

The *Guide* presents principles for managing the biology of composting. The Guide does not discuss materials handling, or equipment operation and maintenance.

Users of the Operating Guide

The Operating Guide was published last fall by The Composting Council (USA), in partnership with the United States Conference of Mayors, the National Association of Counties, and the United States Environmental Protection Agency, in cooperation with The Louisiana State University Agricultural Center.

CURRENT USERS

State of Louisiana

- Certified Operator Training

State of Washington

- Operator Roundtables

Solid Waste Association of North America

- Certified Operator Training

United States Department of Commerce

- Best Practices Workshops

Professional Consultants

- Regulatory design compliance documentation

The *Operating Guide* is being used by the State of Louisiana for Certified Operator Training, and in the State of Washington for Operator Roundtables. Planning is underway to use the Operating Guide for a national program of operator training and qualification.

The *Operating Guide* was selected by the United States Department of Commerce for use in its Recycling Technology Assistance Partnership Program of Best Practices Workshops. Workshops will be conducted at selected sites in the United States during 1995 for service providers to the composting industry.

The *Operating Guide* is being used by local project planners, consultants and regulators.

In conclusion, the *Operating Guide* is intended to focus process management based on sound scientific principles, proven in practice among a variety of technologies. It helps move composting facility operations management from an art to a science. It is a tool that can help the composting industry become a reliable supplier of compost, and a long term user of organic resources recovered from the solid waste stream.

Widespread use of the *Operating Guide* within the composting industry and its clients can promote a common understanding of composting, and lend consistency and credibility to projects. The Operating Guide is a foundation for the industry to help insure its long-term success.

The *Operating Guide* comes in a three-ring file. It is available from The Composting Council, 114 South Pitt Street, Alexandria, Virginia 22314, USA.

For information, call: + 703-739-2401 or fax: + 703-739-2407.

Glucose Influence on the Asymbiotic Nitrogen Fixation During Lignocellulic Waste Composting

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Abstract

Asymbiotic nitrogen fixation by a free N₂-fixing strain has been followed in biofermentor during straw-sawdust mixtures composting added up or not in glucose. The physico-chemical and microbiological analyses have placed in prominent position different phases of microbiological activity during aerobic decomposition of these wastes, but especially proved the primordial part of a soluble carbon compound such as glucose, on the asymbiotic nitrogen fixation. In fact, with glucose, three nitrogen fixation phases have been observed. The first one, occurred since the first days of composting, seems to be due to microorganisms both N₂-fixers and cellulolytic. The nitrogen enrichment of the medium has reached value of 7.86g Kg⁻¹ initial dry matter(D.Mi). The two other phases have appeared on day 42 and day 97 with nitrogen gains of the medium of 2.37 and 1.29g Kg⁻¹ DMi, and would be due as to Azotobacter. Without glucose, the nitrogen fixation which has only intervened on day 99 of fermentation with a N₂ enrichment of the medium of 2.96g Kg⁻¹D.Mi seems to be due to Azotobacter. During this experimentation, no phosphorus, an element necessary to free N₂-fixers was added. However, a relatively important nitrogen fixation has been registered and no effect of deficiency of phosphorus has been observed in the free living N₂-fixers.

Introduction

Agricultural productivity increase due to mineral fertilizing intensification has led to neglect the important part of organic matter and telluric microflora activity on soil fertility. However, the use of organic wastes (urban, industrial or agricultural

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wastes) appears to be the most logical solution not only to restore the organic matter to the soil, closing like this the ecological cycle, but also to eliminate some polluting substances.

Among the technics elaborated to valorize these so abounding raw materials, the most interesting in environmental term and in recovery of residual energy in form of organic fertilizers is *composting*, and particularly reactor accelerated composting, a practical and performant biotechnological method. This composting could be used and exploited for getting from lignocellulosic residues, a nitrogen enriched organic amendment, which would then allow a judicious nitrogenous fertilizing. In fact, the plant would have at its disposal the necessary nitrogen amounts at the right time, and loss risks (ammonia volatilization, denitrifying.) would be then decreased, which would preserved soils and waters.

Biological dinitrogen fixation can allow this nitrogen enrichment, and this, to a low energy cost. If the most important fixing activity for the soil nitrogenous economy is the one proceeding from symbiosis, that of asymbiotic fixers, due to microorganism 'free living' in soils is far from being negligible. These microorganisms convert N₂ into an organic form available to telluric microflora and hereafter assimilable by plants, like the nitrogen from fertilizers (ITO & WATANABE, 1981).

According to Piquemal (1981), the wintry burying of cultural residues (maize or sorghum) with a not very high C/N ratio can supply the next culture with a supplemental contribution running to 50 nitrogen units. This excess suggests the existence of an asymbiotic N₂-fixing activity during the decomposition of vegetable tissues by the microflora, which takes place in spring.

The N₂--- 2NH₃ reduction brings in a HYDROGENASE-NITROGENASE enzymatic complex whose mechanism depends on different parameters such as O₂ pressure, some mineral element content, pH, temperature (Carnaghan & Castle, 1963; Fottrell, 1968; Hardy and Burns, 1968). However, one of the main limiting factors is the availability of soluble carbon compounds in the medium. These compounds can be non-polymerized glucides or organic acids (Jensen, 1965), aliphatic and aromatic compounds (Winogradsky, 1932), simple (methanol-ethanol) and complex (mannitol-sorbitol) alcohols or can result from cellulolytic microorganism activity (Vartiovaara, 1938; Jensen, 1940; Lynch, 1985).

Some of these carbon compounds seem to promote the proliferation of a N₂-fixer determined bacterial genus. Thus, according to Winogradsky (1949) and Tompson and Skerman (1979), glucose and mannitol would be energy-giving substrates determining for *Azotobacter*, microorganism the most frequently encountered in the soils of temperate regions but equally the most studied (Rubenchick, 1960).

The objective of here reported works is to study the glucose influence on the asymbiotic N₂ fixation by free diazotroph microorganisms: *Azotobacter*, during lignocellulosic waste (straw-sawdust) composting. To achieve that, the evolution of the physico-chemical and microbiological characteristics of the substrate placed in controlled conditions have been followed during the composting process.

Methods

Bench-scale reactors

The aerobic decomposition of lignocellulosic wastes was followed by using horizontal bioreactors, made of PVC cylinders, 10cm in diameter, 35cm long, with a total volume of 2.4 litres. Aerobic conditions were provided by a constant air flow-rate ($10\text{ml} \cdot \text{mn}^{-1}$). In order to ensure a homogenous distribution of air, a wet sponge was placed inside the reactor, just in the entry. Two absorbor systems, where the air dives into an acidic solution was set at both the entry and the exit of the reactor. The incoming air bubbled through a diluted solution of H_2SO_4 , which enabled to saturate with water the air supplying the system, but above all to avoid unwanted nitrogen gains. At the reactor exit, the effluent gas bubbled in a titrated solution of H_2SO_4 (measured at the end of the experimentation) preventing nitrogen losses in form of ammonia; then, it was dehydrated over calcium chloride and CO_2 was absorbed on soda lime. The color of the soda lime changed from yellow to purple as it was saturated with CO_2 . So, mere length measurements could provide an approximate estimation of the microbial activity and by mere weighings we could have a strict measure of this activity.

Experimentation

1. Lignocellulosic used wastes were: 5mm-crushed wheat straw and air dried and sieved poplar sawdust. These residues were used in mixture in 1:3 proportion and their physico-chemical characteristics are given in table 1. 400g dry matter of this mixture were inserted into the reactors and, a nutrient solution (table 2) was added to this substrate. The mixture moisture was then adjusted to 50%.
2. Inoculum: it was constituted by the mixture of *Azotobacter* ($14 \cdot 10^5$ bacteria for the whole reactor) obtained on *Azotobacter* liquid medium (Pochon and De Barjac, 1958) and of lignocellulolytic microorganisms of two origins, one from gross lignocellulose residues and the other from decomposing residues.
3. The reactor filling: the load was divided into parts and inserted into the reactor. Regular compressions were made to achieve an optimal use of the active volume and to ensure a homogenous compaction. Then, the reactors were put in a room kept at 28°C for four months.

Table 1 Characteristics of the Straw-Sawdust initial mixture (1:3 w/w)

Organic Matter	95.89%
Cellulose	46.04%
Hemicellulose	20.00%
Lignin	19.50%
C/N Ratio	119
Carbone	46.10%
Nitrogen	0.38%
ASH	3.27%
P	0.03%
K	0.25%
Ca	0.03%
Mg	0.10%
Na	0.10%
Cu	30 ppm
Mn	10 ppm
Zn	30 ppm
Physical characteristics	
Moisture	8.88%
pH	7.2
Colour	yellow

Table 2 Composting of the Nutrient Solution Supplied

Element	Molecular Species	Nutrient Supply (g for 400g Substrate)
Mg	Mg SO ₄ , 7H ₂ O	1.12
Zn	Zn SO ₄ , 7 H ₂ O	0.40
Mn	Mn SO ₄ , H ₂ O	0.30
Cu	Cu SO ₄ , 5 H ₂ O	0.30
Co	Co (NO ₃) ₂ , 6 H ₂ O	0.02
Mo	Mo Na ₂ OH, 2 H ₂ O	0.04
B	Na B ₄ O ₇ , 10 H ₂ O	0.16

Analyses

Physico-chemical analyses

Moisture was determined by drying the wastes to a constant weight at 105°C. The pH value was obtained on 1-g wet sample suspended in 20 ml water and stirred for 30mn. Organic matter was estimated from the weight loss after calcination at 800°C for 4h and organic carbon by the U44-161 AFNOR method (oxydation by a sulfochromic solution in excess). Cellulose, hemicellulose and lignin were determined by using sodium lauryl sulphate, cetyltrimethylammonium bromide and potassium permanganate (Van Soest, 1963; Van Soest and Wine, 1967, 1968). Total nitrogen was titrated by Kjeldhal method. The elemental analyses were carried out after calcination at 800°C and ash solubilization. The total phosphorus was determined by a colorimetric method measuring the coeruleomolybdic complex at 820nm. Sodium, potassium, calcium, magnesium were analyzed by atomic absorption spectrophotometry.

Microbiological analyses

Numeration of total microflora

The numeration was made by a classical method: suspension-dilution of the sample from 10^{-1} to 10^{-10} and inoculation of 0.1 ml on agar medium in petri plates.

Cultural medium composition: Winogradsky (1949) saline solution: 50ml; KH_2PO_4 : 2g; $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$: 1g; soil extract (Nuntagij, 1989): 50ml; yeast water: 100ml; trace element solution: 2ml; glucose: 1g; KNO_3 : 1g; $(\text{NH}_4)_2\text{SO}_4$: 1g; CaCO_3 : 10g; peptone: 2g; agar-agar: 15g; H_2O : 1000ml; adjust to pH=7.0.

Numeration of N_2 -fixers microorganisms:

The same method as previously was used (suspension-dilution) but in this case, 1ml of suspension served to inoculate the *Azotobacter* liquid medium (Pochon and De Barjac, 1958) distributed in 3 different tubes. They were placed inside a 30°C incubator and observed every 3 days for two weeks. The presence of N_2 -fixers was revealed by a light trouble of the medium and the appearance of a quite thick grey dull veil at the surface of it. When the result kept constant, generally about the 15th day, the use of the Mac Grady statistical tables allowed to know the probable number of N_2 -fixers.

Azotobacter medium: Glucose: 10g; CaCO_3 : 0.5g; soil extract (Nuntagij, 1989): 150ml; Winogradsky (1949) saline solution: 50ml; trace element solution: 1ml; H_2O : 1000ml; the pH was adjusted to 7.0.

Results

Microbial activity

CO_2 production which revealed the microbiological activity within the straw-sawdust mixtures is shown by figures 1 and 2. Five phases characterized by different levels of microbiological activity could be distinguished.

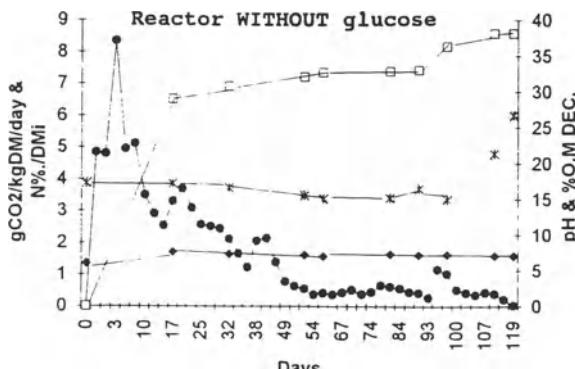


Figure 1 Evolution of some parameters during composting of straw-sawdust mixture without glucose.

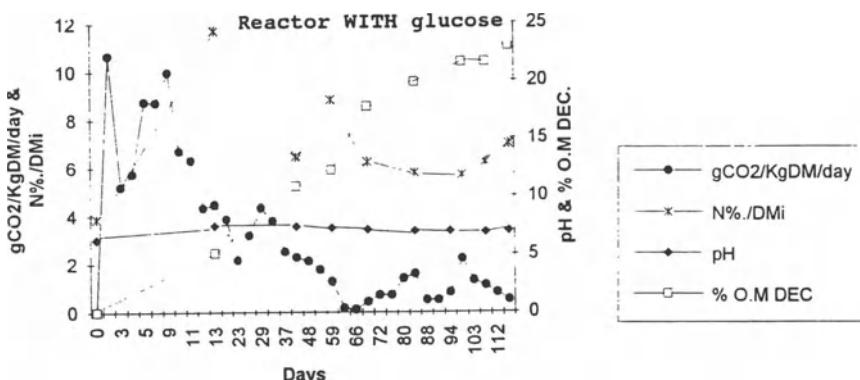


Figure 2 Evolution of some parameters during composting of straw-sawdust mixture without glucose.

With glucose: Since the first days of fermentation, CO₂ production was 10.66g kg⁻¹D.M day⁻¹. Then, the microbiological activity decreased quickly and was 5.5g kg⁻¹D.M. day⁻¹ on day 3. The renewal of this activity appeared since the day 4 and CO₂ production reached a maximum value of 9.96g kg⁻¹D.M. day⁻¹ on day 9. The 3rd, 4th and 5th microbial activity phases were characterized by quick CO₂ production increases which however remained relatively low with maximum values of 4.60(on day 29), 1.60(on day 84) and 2.20g emitted CO₂ kg⁻¹D.M. day⁻¹ (on day 97) respectively. Following these CO₂ production peaks, microbial activity gradual decreases were observed reaching low levels below 0.50 emitted CO₂ kg⁻¹D.M. day⁻¹ on an average.

Without glucose:

CO₂ emission was 4.84g kg⁻¹D.M. day⁻¹ on the 1st day of composting and the maximum value was only reached on day 4 with 8.35g CO₂ kg⁻¹D.M day⁻¹. Then, a quick microbial activity decrease followed and this, until the 16th day. During the 2nd and 3rd phases of microbial activity which occurred on day 20 and day 39 of fermentation, a CO₂ production increase was observed with a maximum values of respectively 3.70 and 2.15g kg⁻¹ D.M.day⁻¹. Then, in both cases, a quick microbial activity decrease was noted with minimum levels of 1.20 and 0.35g CO₂ kg⁻¹. D.M.day⁻¹ for respectively the 2nd and 3rd phases. From the 54th day to the 93rd day (phase 4) there was a stabilization of the microbial activity with an average CO₂ production of 0.40g kg⁻¹D.M day⁻¹. The last phase was characterized by a new increase of CO₂ production with maximum value of 1.20g kg⁻¹D.M day⁻¹ (on day 99), which gradually decreased until the end of the experimentation.

The pH, after an increase from 6 to 7.5 on an average for both reactors, the 15 first days, probably in relation to NH₃ release in the medium, remained included between 7.5 and 7 until the end of the composting.

Analysis of straw-sawdust mixture microbial populations

Table 3 shows that the total microflora decreased throughout the composting for both reactors.

With glucose, the diazotroph component (*Azotobacter*) which was very low during the 15 first composting days increased appreciably on day 42 and represented 83% of the total microflora; it was 60% on day 97.

Without glucose, the diazotrophs which appeared on day 99 represented then only 12% of the total microflora and at the end of the experimentation, they were 14%.

Table 3 Enumeration of the various microflora. (Number of germs/g D.M*)

Days	WITH glucose		WITHOUT glucose	
	Total Microflora	Diazotroph Microflora	Total Microflora	Diazotroph Microflora
14	1,97E+08	4,00E+04	3,40E+08	5,00E+04
42	9,00E+07	7,50E+07	—	—
97	5,00E+07	3,00E+07	2,08E+08	2,50E+07
117	1,10E+07	9,00E+04	1,44E+08	2,00E+07

*dry matter

Organic matter decomposition (figures 1 and 2)

The organic matter degradation percentage was calculated taking into account the apparent increase in ash content resulting from the dry matter weight loss.

With glucose, the organic matter decomposition percentage doubled from 5.10% (on day 14) to 10.80% (on day 42). Then, there was a slackening of the degradation process and on day 60 this percentage was only 12%. From day 60 to day 94, an increase of organic matter decomposition percentage was noted, up to 20%. Then, until the end of the composting, a low organic matter decomposition was observed, up to a final 23%.

Without glucose, the initial decomposition period (days 1–17) with 29% decomposition was followed by a slackening phase until day 89 and organic matter decomposition then reached 33% at the end of this stage. Then, from day 89 to day 109, there was a high degradation increase of the straw-sawdust mixture with 38% decomposition, which value was observed until the end of composting.

Tables 4A & 4B Decomposition of the Organic Matter of Straw-Sawdust Mixture

	Reactor with Glucose					Reactor without Glucose					
	Ash	Organic Matter	Cellulose		Lignin	Ash	Organic Matter	Cellulose		Lignin	
			Hemi-cellulose	Lignin				Hemi-cellulose	Lignin		
Initial (DM)	2.28	95.89	46.04	20.00	19.50	Initial (DM)	2.31	95.89	46.04	20.00	19.50
Final (DMI)	2.94	70.49	30.90	13.61	20.88	Final (DMI)	3.68	56.94	21.63	10.17	20.01
Decomp. %	—	22.97	32.87	31.95	7.10	Decomp. %	—	38.11	53.02	49.15	2.61

The data listed in tables 4A and 4B representing the various organic matter fractions showed that the saprophytic microorganisms of the fermentor with glucose used 30% of the theoretically available carbon, and these of the fermentor without glucose about 50%. Cellulose and hemicellulose were decomposed in a more important way without glucose, about respectively 53 and 49% whereas 33% with glucose. Lignin decomposition was very low within both reactors: 7.10% with glucose and 2.60% without glucose.

Nitrogen fixation (figures 1 and 2)

The nitrogen values are brought back to initial dry matter (D.Mi) as, during the composting, there is an increase of the nitrogen amount no matter there is fixation or not ($N_f = N_d(\%) \cdot D.M_i \cdot (C_i/C_f)$, Ci and Cf are respectively the initial and final ashes). This phenomenon is due to organic matter decomposition by microorganisms during the composting, therefore provoking a decrease of the dry matter content and an apparent increase of nitrogen percentage.

With glucose, N_2 fixation occurred since the first days of composting and on the 14th day a $11.71 - 3.87(No) = 7.84\% \cdot (D.Mi)$ nitrogen enrichment of the medium was noted (No is the initial nitrogen content, % · D.M). Two other phases of N_2 fixation, always taking place after a nitrogen loss within the medium, were observed on the 42nd and 97th days of the fermentation. For these reasons, for the N_2 fixed percentage calculation during those two other fixation phases, we made the difference between the nitrogen amount remaining in the medium after each loss and the maximum amount obtained during the fixation phase. Thus, for the second fixation phase (from day 42 to day 60), the nitrogen enrichment of the medium was $8.82 - 6.45 = 2.37\% \cdot (D.Mi)$ and for the third phase (from day 97 to day 117), the amount of fixed nitrogen was $6.96 - 5.67 = 1.29\% \cdot (D.Mi)$. Thus, in spite of the nitrogen losses of the medium, a $6.96 - 3.87(No) = 3.09\% \cdot (D.Mi)$ nitrogen enrichment was obtained.

Without glucose, on the other hand, there was a N_2 fixation only from the 99th day of composting with a $6.03 - 3.87(No) = 2.96\% \cdot (D.Mi)$ nitrogen enrichment of the medium.

Discussion

During the four months' experimentation, five microbiological activity phases were noted within both reactors, but in general, microbial activity within the reactor with glucose was much more intense and precocious.

During the first phase, since the first day of composting, CO_2 production within the reactor with glucose was maximum owing to the glucose use, an easily degradable compound, by the heterotroph microbial populations here present; organic

matter being then only very lightly decomposed (0.5% decomposition). This low decomposition can be due to an inhibition of the cellulolytic heterotroph group. In fact, our works were made with 0.5% of glucose and, according to Stewart and Leatherwood, 1976), reducing sugars such as glucose for high percentages (between 0.5 and 1%), are potentially cellulolysis inhibiting factors.

On the other hand, without glucose, CO_2 production was maximum only on the 4th day of composting. This light delay probably corresponded to the time necessary for heterotroph microorganisms to decompose the organic matter, mainly cellulose and hemicellulose, in order to provide for their own needs; the organic matter decomposition percentage was then 7%.

In presence of glucose, the first microbiological activity phase and the first N_2 fixation were developed in a parallel way, but without glucose, no N_2 fixation phase was observed. Therefore, glucose seems to promote the fixing activity of diazotroph microorganisms. This result is confirmed by Dommergues and Mangenot (1970) which showed that glucose was easily used by N_2 -fixers as a source of carbon and energy. Moreover, Mwaura (1986) proved that glucose stimulated the Nitrogenase activity in soils and found a N_2 fixation from 10 to 20mgN glucose g^{-1} . In our works, we obtained 14.4mgN glucose g^{-1} . However, obtaining a nitrogen fixation by *Azotobacter* since the first days of composting seems to be a very surprising phenomenon according to previous works. In fact, *Azotobacter* are very active if they have an assimilable carbon source, together with a low nitrogen content of the medium, and at last, with a 0.4% phosphorus minimum amount (Simon, 1970). De Lassus (1986) had obtained a nitrogen fixation after 75 days of composting and with 0.2% phosphorus. Nntagij (1989), in her works, succeeded in reducing the latency phase observed before the appearance of the diazotroph activity to 25 days and no few, but with 0.4% phosphorus. Now, in our case, the two first parameters were represented, but there was no phosphorus in our nutrient solution; only 0.03% was naturally present in the straw-sawdust mixture, a lowly amount in relation to fixer needs. In fact, phosphorus deficiency inhibits the free N_2 -fixing bacteria activity and particularly the respiratory chain functionning, which, by consuming the available O_2 , ensured the protection of Nitrogenase (Dalton and Postgate, 1969; Dommergues and Mangenot, 1970; Abd-El-Malek, 1971). Therefore, to explain the N_2 fixation since the first composting days, the hypothesis of the existence of both N_2 -fixers and cellulolytic microorganisms was put forward. In previous writings, few works were devoted to the study of nitrogen fixation and cellulolysis in the same microorganism, and to the research of both N_2 -fixing and cellulolytic species. Sharp (1975) and Deschamps and Lebeault (1980), the first turned to the searching of N_2 -fixers and the two others to that of cellulolytic bacteria, isolated from wood a *Bacillus circulans* and a *Pseudomonas sp.*; so, both cellulolytic and N_2 -fixing strains. The various microbiological analyses carried out on the straw-sawdust mixture supported this hypothesis, proving that *Azotobacter* only represented 0.02% of the total microflora after 15 days' composting. Now, that stage was the most important concerning N_2 fixation.

During the second phase, a high renewal of the microbial activity was observed within the reactor with glucose, since the 4th day and without any latency phase. It can be explained by the absence of toxic compounds that were either metabolized or copolymerized into no toxic 'prehumic' molecules (Bailly, 1985). Thus, heterotrophs were quickly developed using the most easily degradable compounds and they metabolized nitrogen which has been fixed in large amount. Then, the noted decrease of CO₂ production can be assigned to the immobilization of the nitrogen into organic form in microbial cells or to the presence of toxic compounds.

On the other hand, within the reactor without glucose, the microbial activity only resumed on the 16th day and was relatively low. This low activity phase can be due to gradual running out of soluble carbon compounds.

The third phase was characterized for both reactors by a quick rise of CO₂ production.

For the reactor *with* glucose, this phase can be explained probably by the intensification of lignocellulolytic microflora activity in relation to the slow releasing of the immobilized nitrogen by the previous microbial population. There was an acceleration of the organic matter attack which doubled, from 5.12% on day 14 to 10.83% on day 42. Then, a fixation phase was observed on the 42nd day of composting, allowed by the ecotrophic conditions (abundant available carbon sources and lack of assimilable nitrogen) propitious to the N₂-fixer implication. In fact, a nitrogen loss was noted from day 15 to day 42. The NO₃⁻ formation can be envisaged but cannot be proved since it was not investigated. However, the nitrogen loss cannot be due to a volatilization into an ammonia form because our apparatus prevents this phenomenon. Moreover, very low NH₄⁺ amounts were found in the titrated solution of H₂SO₄ placed at the reactor exit.

In this case, *Azotobacter* representing then 84% of the total microflora would have taken over, by getting in the medium itself the phosphorus essential to their metabolic activity. In fact, according to Hafidi (1990), the phosphorus plays a determining part in the constitution of some structural components essential to cell life (15 to 20% in microorganism membranes in form of phospholipids; 30 to 50% in the D.N.A. and 2 to 10% in the R.N.A.). Microbiological analysis revealed a light decrease of the total microflora; the lysis of those microorganisms could then released into the medium phosphorus constituting so, a real reserve for *Azotobacter*.

For the reactor *without* glucose, this quick rise of CO₂ production can be due to cellulolytic microflora activity which metabolized the nitrogen resulting from organic matter decomposition whose percentage was 31%.

The fourth phase of microbial activity within the reactor with glucose was characterized by a renewal of CO₂ production, which yet remained quite low. The heterotrophs then, used the soluble carbon compounds coming from the 20% organic matter decomposition.

On the other hand, the microbiological activity within the reactor without glucose was stabilized from day 54 to day 93, probably because of a lack of soluble

components or assimilable nitrogen, or a partial inhibition by toxic substances such as fatty and phenolic acids released during the 3rd microbial activity phase (Nuntagij, 1989).

In presence of glucose, the fifth phase was characterized by a renewal of the microbial activity and by a N_2 fixation occurred on the 97th day of fermentation. In this case, as previously, the ecotrophic conditions (presence of soluble carbon compounds and nitrogen loss) were favourable to the implication of *Azotobacter* which here represented 60% of the total microflora.

In absence of glucose, the low rise of CO_2 production noted on the 93rd day of fermentation was parallel to the appearance of N_2 fixation unique phase on the 99th composting day. This N_2 fixation seems to be due to *Azotobacter* which then represented 12%. These microorganisms took the necessary phosphorus from the medium reserve made of the degradation products from microbial bodies. Moreover, the medium conditions were propitious to the development of those free N_2 -fixers because organic matter had been decomposed to 36% (presence in the medium of a sufficient amount of soluble carbohydrates), in addition, there probably was no more assimilable nitrogen in the medium after 93 composting days.

After 4 months' composting, the gradual decrease of CO_2 production observed for both reactors cannot be attributed to the medium nitrogen content which almost doubled, from 3.87 to 6.96‰ N(D.Mi) with glucose and from 3.87 to 6.03‰ N(D.Mi) without glucose. In fact, the decrease must result rather from the remaining lignocellulose resistance to the microbial attack, owing to structural association and chemical interactions between cellulose and lignin (Lundqvist *et al.*, 1980; Kirk and *al.*, 1981).

The main limiting factor was then the absence of carbon sources adapted to the requirements of the various microbial populations whose actions are both complementary and competitive.

The data presented here show that an easily degradable compound such as glucose promotes the activity of the N_2 -fixers, that include also cellulolytic microorganisms. However, more studies are needed to characterize these microorganisms with both activities. So, lignocellulosic wastes might be valorized through microbial N_2 fixation in temperate as well as tropical regions, through composting.

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Taxonomic and Metabolic Microbial Diversity During Composting

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Summary

A great variety and high numbers of aerobic thermophilic heterotrophic and/or autotrophic bacteria growing at temperatures between 60–80°C have been isolated from thermogenic (temperature 60–80°C) composts in several composting facilities in Switzerland. They include strains related to the genus *Thermus* (*T. thermophilus*, *T. aquaticus*, and several other new strains), *Bacillus schlegelii*, *Hydrogenobacter spp.*, and of course heterotrophic sporeforming *Bacilli*. This contrasts with the generally held belief that thermogenic composts (> 60°C) support only a very low diversity of heterotrophic thermophiles. This biodiversity suggests efficient decomposition of organic matter at temperatures above 60°C. and a good thermo-hygienization.

During the terminal cooling or maturation phase of composts high numbers and a great metabolic diversity of mesophilic bacteria was observed, including nitrogen-fixers, sulfur-oxidizers, hydrogen-oxidizers, nitrifyiers, and producers of extracellular polysaccharides or bacterial humin. This microbial diversity plays an essential role for compost stabilization. It is suggested that mature compost application improves soil chemistry and microbiology, and can thus be regarded beneficial for agriculture.

Introduction

Among the various processes used to manage organic wastes (landfill, incineration), only the biological process of composting can bring about a stabilization of

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the waste, making its return to the environment as soil fertilizer and conditioner possible. Composting is a self-heating, aerobic solid phase biodegradative process of organic waste materials. The composting process at the microbial level involves several interrelated factors, i.e. metabolic heat generation, temperature, ventilation (oxygen input), moisture content, and available nutrients (12,14,18). The temperature both reflects prior microbial activity and the current rate of activity. The initial rapid increase of temperature involves a rapid transition from a mesophilic to a thermophilic microflora. The compost ecosystem then tends to limit itself due to inhibitory high temperatures, resulting from excessive heat accumulation. If a good management is continuously provided (i.e. regular aeration or frequent turning), the thermogenic stage continues until the heat production becomes lower than heat dissipation, due to the exhaustion of easily metabolizable substrates. During the terminal cooling or maturing phase, the amount of readily available nutrient becomes a limiting factor, causing a decline in microbial activity and heat output. During these temperature changes various microbial groups succeed each other, each of which being adapted to a particular environment.

We present here the results of the research in our laboratory on different microbiological aspects of the composting process. The purpose of this report is to provide a better understanding of the taxonomic and functional diversity of microorganisms, particularly aerobic bacteria, during the composting process.

Microbial diversity during the composting process

A large variety of mesophilic, thermotolerant and thermophilic aerobic microorganisms (including bacteria, actinomycetes, yeasts, molds and various other fungi) have been extensively reported in composting and other self-heating organic materials at temperatures between 20–60°C (2,14,17,18,20,27,28,31,32,34). Many factors determine the microbial community during composting. Under aerobic conditions, temperature is a major factor determining the type of microorganism, species diversity, and the rate of metabolic activities. At an early phase of the composting process (temperatures between 20–40°C) mesophilic/thermotolerant fungi, principally yeasts and molds, and acid producing bacteria are the dominant active degraders of fresh organic waste. Actinomycetes develop far more slowly than most bacteria and fungi and are rather ineffective competitors when nutrient levels are high. Mesophilic microorganisms are partially killed or are poorly active during the initial thermogenic stage (temperatures between 40–60°C), where the number and species diversity of thermophilic/thermotolerant bacteria, actinomycetes and fungi increase (14,18,34). The optimal temperature for thermophilic fungi is 40–55°C, with a maximum at 60–62°C. Fungi are killed or are present transiently as spores at temperatures above 60°C (4, 18). Thermophilic actinomycetes are generally more tolerant than fungi to high temperatures and their number and species increases markedly at their optimum growth temperatures of 50–55°C (2,17,18,34). At temperatures above 60°C their number and the species diversity

decreases, and their importance in the degradation process becomes negligible. Thermophilic bacteria are very active at 50–60°C, and at temperatures above 60°C the degradation process is performed essentially by these microorganisms (18,20,27,30,31). All research focused on enumeration and isolation of aerobic thermophilic bacteria from composts has been performed essentially on rich organic complex media.

Aerobic thermophilic bacteria isolated from thermogenic composts

A high diversity of obligately heterotrophic *Bacilli* was isolated from thermogenic composts at temperatures between 50–60°C (20,31,32). However, bacterial species diversity dropped markedly at temperatures above 60°C, and at the highest temperatures studied (65–69°C) only strains related to *Bacillus stearothermophilus* were identified (31,32). The present state of knowledge on microbial diversity at higher temperatures remains surprisingly poor. We report here for the first time the presence of taxonomic and metabolic bacterial diversity in hot composts (60–80°C). We examined compost samples (mainly garden and kitchen waste, and sewage sludge) from 10 different compost facilities throughout Switzerland, representing different industrial composting systems (classical open air windrow, semi-closed aerated and/or turned boxes, and closed automatically aerated bioreactors of 24 m³ and 200 m³). The compost facilities were located at 30–250 km distance from the authors laboratory. None of the compost facilities studied used seeding with a commercial compost-starter containing thermophilic bacteria. Our results showed the presence of different taxonomic and metabolic aerobic thermophilic bacteria, related to the following genera or species:

Hydrogenobacter spp.: 10⁴–10⁶ cells / g CDW, growth at 60–80°C, optimum 70–75°C
Bacillus schlegelii: 10⁵–10⁷ cells / g CDW, growth at 55–75°C, optimum 65–70°C
Thermus spp.: 10³–10¹⁰ cells / g CDW, growth at 40–80°C, optimum 65–75°C
Heterotrophic Bacilli: 10⁷–10¹¹ cells / g CDW, growth at 35–70°C, optimum 50 or 60°C
(g CDW = g compost dry weight)

These strains can be splitted into four groups:

Obligately autotrophic sulfur-and hydrogen-oxidizers (*Hydrogenobacter spp.*)

All strains isolated (14 strains) were rods 0.5 × 1.5–6 µm in size, no spore-formers, gram stain negative, variable in motility, and penicillin G sensitive proving to belong to the Bacteria domain. These bacteria were able to grow under microaerophilic conditions with either hydrogen, crystalline elemental sulfur or thiosulfate as sole energy and electron donor, and with CO₂ as carbon source. They were not able to grow on the simple and complex organic substrates tested. Thus, we regard them as obligate autotrophic strains. These strains had DNA % mol guanine + cytosine contents (35–39.4) similar to those published for the reference

strains related to *Hydrogenobacter spp.*, isolated at this time only from geothermal areas (3). Almost all strains shared a high DNA:DNA homology (71–92%) among each other, and a similar homology with *Hydrogenobacter* reference strain T3, belonging to a DNA:DNA homology group found in geothermal springs in Italy and in the USA. One strain showed no significant homology with strain T3, but a high homology (86%) with *Hydrogenobacter* reference strain MF-3, belonging to another DNA:DNA homology group (3).

*Facultatively autotrophic sulfur- and hydrogen-oxidizers (*Bacillus schlegelii*)*

Nine of the strains isolated (total 10 strains) were rods $0.6 \times 2.5\text{--}5 \mu\text{m}$ in size, formed spherical ($0.8\text{--}1 \mu\text{m}$ in diameter) and terminal endospores, were gram stain variable, variable in motility, and penicillin G sensitive, proving to belong to the Bacteria domain. One strain formed no spores. Metabolism was strictly aerobic. These bacteria were able to grow autotrophically under microaerophilic conditions with hydrogen, but they were not able to grow autotrophically on reduced inorganic sulfur compounds (9). However, all strains possessed constitutive rhodanese, thiosulfate- and sulfite-oxidizing activities. Under mixotrophic growth conditions (e.g. pyruvate or acetate or hydrogen + thiosulfate) these sulfur-oxidizing activities were strongly increased (Beffa et al unpublished). They were able to grow on amino and organic acids, but not on sugars. All strains isolated had similar DNA % mol guanine+cytosine content (60–64) and shared high DNA:DNA homology (74–84 %) with the reference strain of *B. schlegelii*. This is the first report of the isolation of *B. schlegelii* from hot composts. Previous studies reported the presence of *B. chlegelii* in several geothermal and nongeothermal (fresh-water lake sediments, glacier ice, air) environments, and all strains isolated were related to the same genospecies (3).

*Obligately heterotrophic non spore-formers related to the genus *Thermus**

High numbers ($10^7\text{--}10^{10}$ cells/g CDW) of obligately aerobic, thermophilic bacteria related to the genus *Thermus* (12 strains) were isolated in our laboratory from hot composts ($> 65^\circ\text{C}$). Their number was lower at the beginning and at the end of the composting process. Isolation was done by incubation at 75°C in unshaken cultures in basal mineral medium containing 0.8 % nutrient broth (NB) + 0.2 % yeast extract (YE). Enrichment at 60°C and 65°C on the same media yielded mostly spore-forming bacteria. Preliminary results showed positive growth at high concentrations of organic compounds. All strains isolated were non-motile, non spore-forming rods and filaments ($5\text{--}30 \mu\text{m}$ in length and $0.5\text{--}0.8 \mu\text{m}$ diameter), but during repeated transfer the filaments become shorter. The morphology of the organism is influenced by temperature of growth. These bacteria usually lacked pigments, but two strains presented yellow-orange pigments with absorption spectra typical for *Thermus*.

All strains isolated from the dominant heterotrophic population in hot composts showed similar DNA base composition (58–64 % mol G+C). Studies of DNA:DNA homology by the reassociation rate method with the *Thermus* reference strains showed strains related to *Thermus thermophilus*, *Thermus aquaticus*, and several other new strains. The physiological and taxonomical features of the strains isolated clearly correspond to the characteristics reported for the genus *Thermus* (13,35).

Two non spore-forming strains of thermophilic bacteria have previously been isolated at 60°C from sewage sludge compost (20). Their optimum temperature ranged from 60–65°C, and they were tentatively identified as *Thermus spp.* No taxonomical studies and numbers of these bacteria in compost have been reported.

Obligately heterotrophic oval endospore-formers Bacilli

Thermophilic heterotrophic *Bacilli* are dominant at temperatures between 50–65°C. More than 30 strains were isolated in our laboratory, showing a wide variation in colony morphology. Several strains were motile, spreading on agar plates. High heterogeneity and several different taxonomically distinct groups has been previously reported (30, 32). On the basis of their growth temperature optimum, 2 groups could be distinguished, with optima at 50°C and 60°C, respectively. Several strains growing fast at 50°C were unable to grow at 65°C. The upper limit of growth temperature for all strains isolated from hot compost was 70°C. Growth characteristics and genomic studies of the strains growing at 65–70°C gave strong evidence for these strains belonging to the *B. stearothermophilus* complex (30), as previously reports (31).

We have also isolated 3 strains of facultatively aerobic heterotrophic *Bacilli* growing anaerobically at 65°C on an organic medium with nitrate as terminal respiratory electron acceptor.

Microbial diversity during the cooling or maturing phase

The degree of maturity of the compost critically affects its successful utilization in agriculture. Immature composts induce high microbial activity in the soil for some time after their incorporation, causing oxygen deficiency and a variety of indirect toxicity problems to plant roots (22,36). Compost maturation varies considerably in function of the system and the composting management. Chemical and biological stability of the end-product seems to be very difficult to define with only a single analytical methods, whether chemical (22) or biological (36). Benefits of compost application in agriculture and its role in biological control of plant diseases have been previously reported (1,16,21).

A decisive factor for the maturation of composts is the microbial populations involved in the nutrient cycles (i.e. C, N, S, P). Knowledge of the microbial composition of mature composts is important to predict its potential impact on soil

fertility and other biological parameters.

The present-state of knowledge on microbial diversity, particularly bacteria, during the maturing phase of composting is surprisingly poor. During this phase the diversity and the number of mesophilic/thermotolerant actinomycetes and fungi, attacking and/or degrading natural complex polymers (i.e. lignin, hemi-cellulose, cellulose) increases strongly (14,18,34). During the cooling phase, the bacterial population decreases of 1 or 2 logarithmic order in comparison with the numbers present during the thermogenic phase (10^8 – 10^{11} cells/g CDW), but its taxonomic and metabolic diversity increases markedly.

The microbiological characterization of four samples of composted urban refuse (15) showed 10^8 – 10^9 viable microorganisms per g CDW. The bacteria represented 80% of the total counts, and a small proportion was spore-forming. Actinomycetes and fungi were present in numbers between 10^7 – 10^8 cells/g CDW and 10^5 – 10^8 cells/g CDW, respectively. Algae were absent. Most of the population (10^4 – 10^8 cells/g CDW) involved in the carbon cycle had proteolytic, ammonificant, amylolytic, and aerobic cellulolytic capacities, followed by free-living nitrogen fixers (*Azotobacter*, 10^3 – 10^5 cells/g CDW), denitrifiers (10^4 – 10^6 cells/g CDW), sulfate reducers (10^4 cells/g CDW), and sulfur oxidizers (10^4 cells/g CDW). An important feature was the scarcity or absence of ammonium- and nitrite-oxidizers.

Microbial diversity in maturing composts in a classical green waste windrow system

We report here the preliminary results of microbial diversity, particularly bacteria, in maturing composts from a classical windrow open air industrial composting system using an intensive management. The starting material consisted of 70 % green waste, 10% kitchen waste, and 20% shredded wood, with a good structure and porosity. The initial carbon/nitrogen ratio was 25–28. The compost was considered to be satisfactory mature after about 10–12 weeks. Sampling was performed on the surface and in the center. Prior to sampling the following parameters were measured in the heaps: Temperature, oxygen-, ammonia-, sulfide-, methane-, and carbon dioxide-concentration. The temperature of all samples were comprised between 22–43°C.

Enrichment and quantification were performed at 25°C on a rich organic complex medium (nutrient broth supplemented with yeast extract) and in a basal mineral medium supplemented with the appropriate energetic or assimilative compounds (8–11).

To ascertain the metabolic functions of mixed populations (directly from enrichments) and of isolated strains some electrode-respirometry measurements for hydrogen-, thiosulfate-, sulfur-, ammonium-, nitrite-, and organic-oxidizing activities were carried out (8–11). Respiratory chain inhibitors were used to detect respiratory chain linked reactions. Nitrogen-fixing activity (nitrogenase) was confirmed by gas chromatography measurements (Carlo Erba, Porapack N col-

umn, FID detector) of the reduction of acetylene to ethylene. Controls were made without acetylene and with NH₄Cl (1 g/l) to exclude any non-nitrogenase-dependent ethylene production. Extracellular polysaccharide production was confirmed by sugar analysis after acid hydrolysis of the bacterial polymers produced. Colorimetric analyses of nitrite and nitrate were performed to measure non respiratory chain linked reactions.

Our results confirm an increase of bacterial metabolic diversity during the terminal maturing phase of the composting process. Several bacterial functions important for compost maturation that are absent or not detected in the thermogenic phase appear during the cooling phase, such as autotrophic and heterotrophic nitrogen fixation, nitrification, production of large amount of exopolysaccharides or bacterial humic compounds.

Heterotrophs High numbers of heterotrophic bacteria were isolated by enrichment on organic media. Surprisingly, metabolic studies revealed that several heterotrophic strains isolated were not simple organic oxidizers, but possessed other metabolic properties, such as nitrogen-fixation, autotrophic or heterotrophic sulfur-oxidation, exopolysaccharide production, nitrite production from ammonium under heterotrophic conditions, hydrogen-oxidation, and growth on methanol and ethanol. Spore-forming heterotrophic bacteria were not dominant and represented < 1 % of the total viable heterotrophic bacteria isolated from composts.

Hydrogen-oxidizers All strains isolated under autotrophic conditions on hydrogen were also heterotrophic strains, and the majority were able to fix nitrogen under autotrophic (hydrogen) and heterotrophic (pyruvate) conditions. Several strains had yellow pigments, and were related to the genera *Hydrogenophaga* (old name *Pseudomonas*) and *Xanthobacter*.

Sulfur-oxidizers The majority of the strains isolated were facultatively autotrophic, growing on different organic substrates and on thiosulfate and elemental sulfur as unique electron donors. Two species have been characterized: *Thiobacillus versutus* (10) and *Paracoccus denitrificans*.

Nitrifyers Autotrophic nitrifying bacteria growing on ammonium or nitrite were not isolated. The nitrification capacity, principally related to the production of nitrite from ammonium, was related to heterotrophic strains.

Nitrogen-fixers High numbers of autotrophic and heterotrophic nitrogen-fixing bacteria were isolated. Several strains formed exopolysaccharides, and oxidized inorganic sulfur compounds under heterotrophic growth conditions .

Arthrobacter-like bacteria These strains were isolated on the selective medium according to (23). High numbers of *Arthrobacters* were principally isolated from maturing composts at low temperatures (< 30°C). All strains isolated presented the typical *Arthrobacter* morphology changes during the growth cycle. Nitrification seemed positive in 2 strains.

Table 1 Metabolic diversity of microorganisms isolated under aerobic conditions from maturing composts after 12 weeks of composting. The minimal and maximal cells numbers are reported. The two last positive dilutions of the enrichments were used for isolation and preliminary biochemical characterizations. nd = not determined.

Type of metabolism or microorganism	Number of different strains or species	Cells numbers (g compost dry weight)
Bacteria:		
Heterotrophic (no spore-forming)	18	$10^7 - 10^9$
Heterotrophic (spore-forming)	3	$10^5 - 10^6$
Hydrogen-oxidizing (facultatively autotrophic)	6	$10^5 - 5 \times 10^6$
Hydrogen-oxidizing (obligately autotrophic)	0	< 10
Sulfur-oxidizing (obligately autotrophic)	2	$10^3 - 10^4$
Sulfur-oxidizing (facultatively autotrophic)	7	$10^4 - 10^7$
Sulfur-oxidizing (obligately heterotrophic)	3	$10^5 - 10^7$
Nitrifying (obligately autotrophic)	0	< 10
Nitrifying (obligately heterotrophic)	4	$5 \times 10^4 - 10^6$
N ₂ -fixing (autotrophic on hydrogen)	5	$5 \times 10^4 - 5 \times 10^6$
N ₂ -fixing (heterotrophic on pyruvate)	7	$10^5 - 10^7$
Exopolysaccharide producers (on glucose)	10	$10^6 - 10^8$
Arthrobacter-like	4	$10^5 - 10^7$
Thermophilic sporeforming bacteria (growth at > 40°C)	nd (> 3)	$10^6 - 10^8$
Fungi:		
Total molds	14	$10^4 - 10^5$
<i>Aspergillus fumigatus</i>	nd	$10^2 - < 10^4$

Other microorganisms A low number but a high diversity of molds (isolated on malt extract agar with the antibiotics novobiocin and streptomycin) were present in maturing compost, and *Aspergillus fumigatus* represented < 5 % of the total counts. High numbers of thermophilic sporeforming bacteria, most probably as inactive spores, were present. Actinomycete numbers and diversity will be considered in the future.

Further characterization and confirmation of the taxonomic and metabolic properties of these different strains are being presently performed in our laboratory.

Microbial diversity and management

Composting is defined as an aerobic process, and several factors influence the concentration of oxygen in compost, and therefore the microbial population diversity and their type of metabolism (aerobic or anaerobic). The nature and structure of the initial substrates, the particle size, the compost volume, the moisture content, the consumption by the microbial biomass and in particular the compost technology used and the management influence considerably the oxygen concentration in composts (12,14,18,19). Industrial composting is a controlled process. This implies an active or intensive management, i.e. a judicious mixture of the initial substrate, a frequent mixing of the compost, and sufficient aeration and hydration. These conditions are met by composting in closed industrial bioreactors with automatic aeration and/or turning, in classical open air windrows with frequent or daily

turnings of the heaps, or in automatic aerated and turned semi-closed boxes. Under these conditions an intense aerobic microbial degradation can be insured for a long period of time in almost the whole composting mass. The microbial diversity and degradation rate are homogenous.

In contrast, in extensive management composting systems, such as classical open air windrows which are poorly structured and turned, in too dense or hydrated, poorly mixed and aerated composts in boxes or bioreactors, the temperature stratification is heterogeneous, and only a small thermogenic zone is observed (4,6). This is followed generally by the formation of large and less thermogenic anaerobic zones with production of large amounts of methane, carbon monoxide, sulfides, ammonia, and volatile organic acids. Under these conditions the degradation of the organic matter is slow, discontinuous and heterogeneous. Destruction of pathogens is not assured, and nauseating odors can be created.

Influence of temperature on the composting process and the hygienization

The composting process can, if not properly managed, induce the proliferation and dispersion of potentially pathogenic and/or allergenic thermotolerant/thermophilic molds and bacteria (4,5,7,24,26). Among the fungi, the mold *Aspergillus fumigatus* is predominant. Because of its cellulolytic and thermotolerant properties (best growth between 30°C and 45°C, and transient resistant to temperature up to 60°C) it finds ideal growth conditions in compost, particularly in the outer layers of compost heaps (4). Numbers were high in fresh compost (10^5 to 10^7 CFU/g CDW), remained high in extensive managed composts systems, and diminished towards at the end of the composting process (4,5). An intensive management, with temperatures exceeding 60°C for several weeks was necessary for decreasing significantly *A. fumigatus* numbers, and preventing significative recolonisation of cooling composts by this mold. Organic matter degradation, with regard to the carbon dioxide production and the constant high temperatures observed during several weeks in intensive compost systems, seemed not be significantly affected (Figure 1).

Conclusions

A great variety and high numbers of aerobic thermophilic heterotrophic and/or autotrophic bacteria growing optimally at temperatures of 65–75°C have been isolated from thermogenic (> 60°C) composts of several industrial facilities in Switzerland. Bacteria related to *Bacillus schlegelii*, *Hydrogenobacter spp.* and particularly to the genus *Thermus* (*T. thermophilus*, *T. aquaticus*, and other new strains) appear to be the main active microorganisms in these hot composts (>65°C–80°C). This is also the first report of composts as habitats for thermophilic bacteria known to date only from geothermal manifestations, or other natural hot environments.

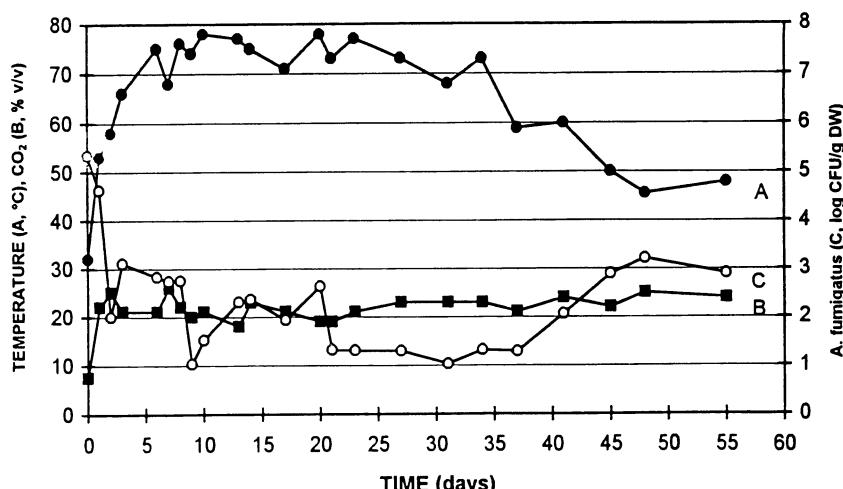


Figure 1 Temperature (closed circle), carbon dioxide (square), and *Aspergillus fumigatus* (open circle) evolution during intensive compost management in a classical open air windrow system. All parameters were measured lateral at 60 cm of depth.

Microbial diversity is of course a prerequisite for a satisfactory composting process. High temperatures ($> 60^{\circ}\text{C}$) are often considered to reduce dramatically the functional biodiversity. It is generally assumed that to obtain efficient and rapid decomposition temperatures should not be allowed to exceed 55–60°C (25,33). However, at these temperatures the thermohygienization towards potentially pathogenic and / or allergenic microorganisms is not guaranteed.

Few studies reported high decomposition rates at 60–75°C (28,29). The metabolic diversity of highly thermophilic bacteria reported in this study suggests that the thermogenic phase of the composting could be performed for a long period of time at temperatures higher than 50–60°C, but not exceeding 75°C. More microbiological and physico-chemical research on industrial and laboratory composting systems are necessary to further elucidate the advantages or inconveniences of high temperatures during the thermogenic phase.

However, we think that an intensive management of the composting process, permitting to reach transiently high temperatures during the thermogenic phase, is necessary to obtain a homogenous and satisfactory aerobic decomposition rate, the reduction or elimination of human, animal and plant pathogens, and the destruction of seeds and phytotoxic compounds. Furthermore it prevents the formation of large anaerobic zones that are sources of nauseating odors.

Our preliminary results demonstrated that a high bacterial diversity of mesophilic bacteria appeared during the cooling or maturing phase of the composting process, e.g. nitrogen fixers, nitrifiers, and producers of large amounts of extracellular polysaccharides. These microbial properties play an essential role for compost maturation and mineralisation. Incorporation of compost to soil could therefore improve soil chemistry and fertility (by nitrogen fixers, nitrifyers, sulfur-oxidizers), structure (by exopolysaccharides producers) and microbiology.

The breakdown rate of lignocellulose by actinomycetes and fungi, and lignin

by fungi with production of complex polymers is usually low during the short processing time of industrial composts. The presence of high numbers of heterotrophic bacteria able to produce (under laboratory conditions) large amounts of exopolysaccharides suggests that complex polymers are abundantly synthetized during the maturing phase. These bacterial polymers (bacterial humin) and/or bacteria synthesizing them could improve soil structure and water and mineral retention.

Strains described taxonomically could be related to soil-living bacteria (i. e. genera *Arthrobacter*, *Hydrogenophaga* or *Pseudomonas*, *Xanthobacter*, *Thiobacillus*). Bacteria related to the genus *Arthrobacter* form a numerically important fraction of the natural bacterial flora of soils, and their presence and numbers in mature composts could be used as one additional microbiological parameter for compost maturity evaluation.

Multidisciplinary, fundamental and applied laboratory, and particularly field research, involving engineers, agronomists, microbiologists, and pedologists, would be helpful for a better understanding and promotion of the composting process, and for a beneficial use of compost in agricultural and other soils.

Acknowledgments

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A new composting plant realized within the THERMIE program of the European Commission

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My contribution aims at introducing you to a composting project developed after years of small scale trials and various researches on the best utilization of important organic matrices.

This project obtained an EEC reward within the THERMIE program of DG XVII and this originated my idea of this Symposium.

Starting from previous experiences, I decided to go into this matter at the CAVIRO plant in Faenza, which also houses the head office of the Company.

Faenza is situated in a region where agricultural and food production is important and environmental awareness is well developed.

My Company represents agricultural producers and it is well aware of these problems. It was within this frame that the program started and it includes a broader system, that I would like to define as the ‘ENVIRONMENT-CAVIRO ENERGY’ system.

In fact, Caviro has been working in various agricultural fields:

- wine
- fruit
- sugar
- cereals
- biomasses as a whole

and since many years it has been offering useful services to its members, in particular by developing techniques for the recovery and reutilization of residual products, obtaining important products such as:

- alcohol
- brandy
- ‘grappa’
- sugar from grapes
- tartaric acid
- absolute alcohol for unleaded petrol
- electric energy
- heat

and now also a COMPOSTED ORGANIC FERTILIZER.

Our plant in Faenza can work 400.000 tons/year of raw material, with an integrated system for energy production from further pruduction wastes:

- biogas from purification of liquid wastes
- thermic energy from burning of solid wastes
- steam and electric energy that we let into the national net
- COMPOSTED ORGANIC FERTILIZER from the most humid solid wastes and from concentrated matter resulting from the fermentation of raw material.

In this way, we close the cycle and we let finished product out, not wastes:

- purified water and air
- electric energy
- COMPOSTED ORGANIC FERTILIZER.

This scheme allows us to outline the main structure of our composting process.

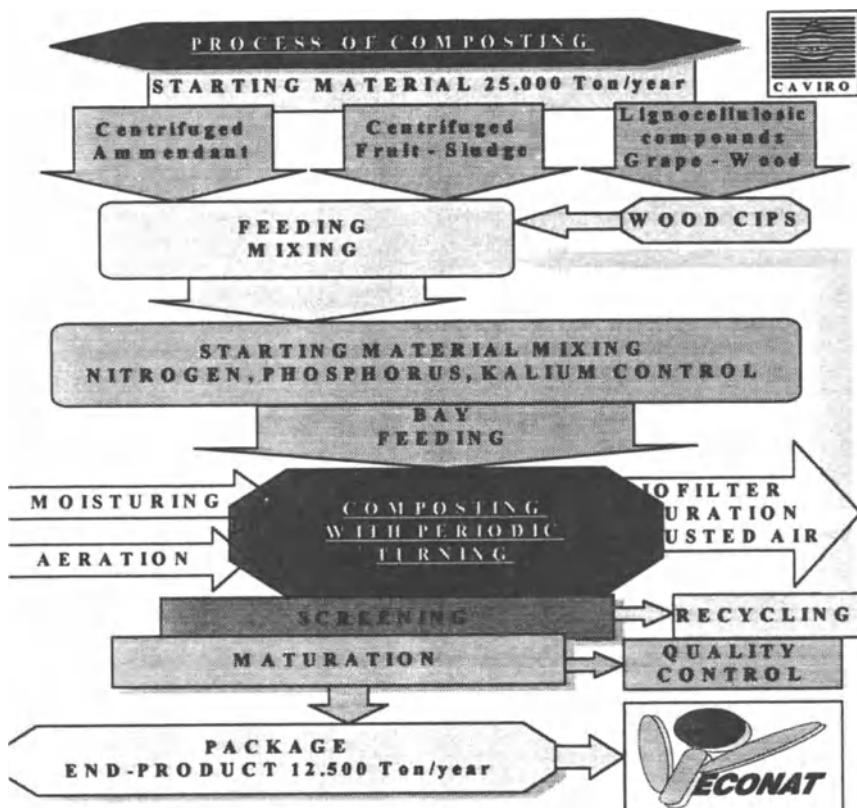


Figure 1

Examining the working phases, process compost we can find out the different activities defining the process up to the finished product: a high-quality organic fertilizer called ECONAT.

Now, I would like you, where you can follow how the process starts and develops.

First of all, we produce concentrated matter in our plants and we obtain energy from the purifier, which then is also turned into electric energy, further employed in our plants.

Wastes from the working process are brought to special tanks where solid wastes are separated by centrifugation from liquid matter, solid raw materials are stored in special areas and wooden matter is reduced into CHIPS.

At the beginning, we have a thickening area where wastes are stored with conditioning matter, while liquid substances are sent to anaerobic digesters to product biogas.

The thickened matter is conveyed to the loading area of the plant where charging hoppers are connected to conveyors, which, on their turn, bring raw material to the mixing plant.

There are three hoppers, whose activity covers the plant in an eight-hour period.

First of all, the process foresees a premixing phase of the different raw materials.



Figure 2

The four-screw feeder leans on four loading cells connected to the computer.

This allows us to check and file weights and to define a different combination of the mixing matter for every conversion line, so that already from the loading phase we are able to define the finished product required.

All phases of the process are completely computerized, so that we are able to record every phase.

The analytic characteristics of the various raw materials being available, we can find out in advance some useful parameters for the following aerobic conversion.

After the premixing phase, the product reaches its destination through various conveying belts, the latter of them being able to spot the unloading point.

The 9 conversion trenches forming the microbiologic conversion area cover 1,566 square metres, while the walls are 2 metres high.



Figure 3

Along the trenches, a machine turns up the mixing compounds.

This machine was assembled taking into consideration our previous experience and the needs of the conversion matter.

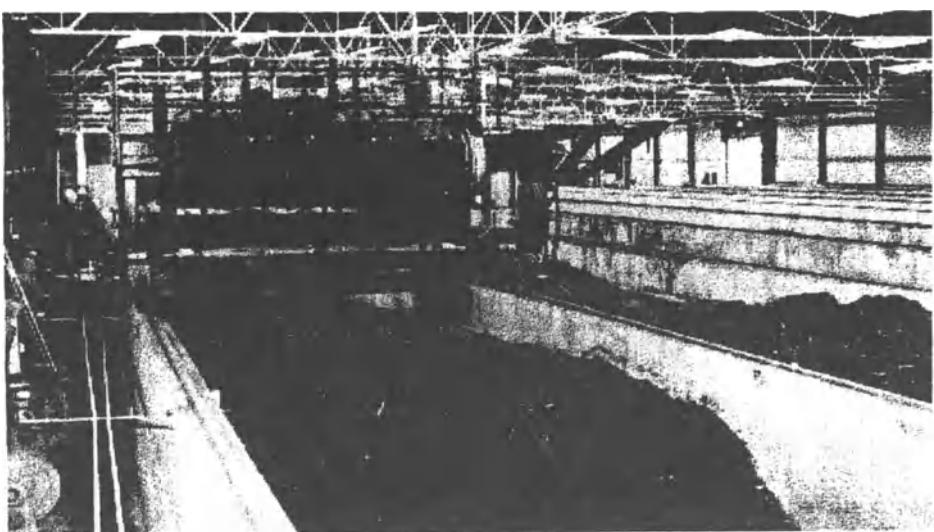


Figure 4

In fact, as we will see later on, the machine first mills and mixes the matter, then it turns the mixing matter over and it displaces it towards the ripening area.

Therefore, it covers various functions: homogenization of mixing matter, aeration of fermenting matter, their displacement to the following ripening area and, of course, cooling of the matter.

As far as the automation systems governing the ventilation is concerned, the requirement of air is 0.1 m^3 per minute per ton of dry organic matter, so that the set point will be determined according to the following data: 15% oxygen into the mixture – 5% oxygen is the lower point acceptable.

The plant is fully automatized.

In fact, the CAVIRO computer system includes automation and control of parameters of every production process, which are connected through an 'ETERNET' data transmission recorder.

The data of the process are controlled through high-quality systems of the plants and production parameters are surveyed.

These are connected through fibre-optic cables allowing to assemble the production data and the company management data giving rise to a management token-ring.

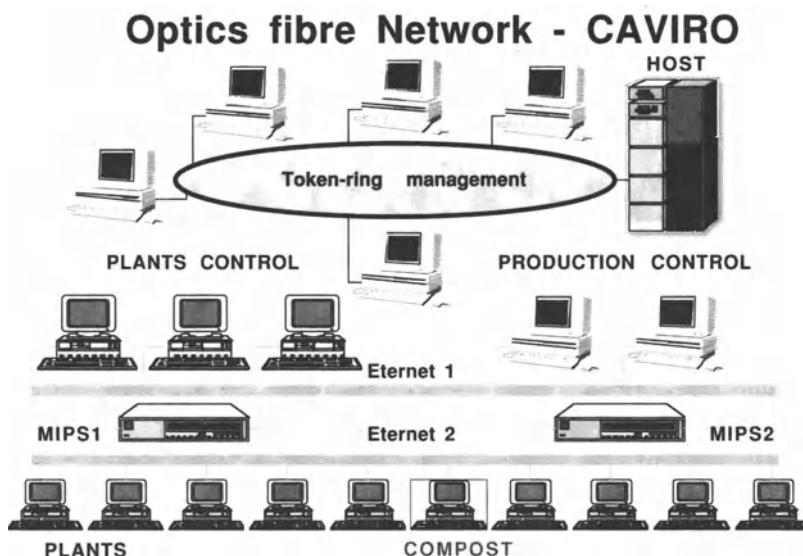


Figure 5

From our screen we can check the whole feeding phase.

We visualize every engine or sensor and our software also allows to monitor any irregularity thanks to signals and/or automatic stop of the plant.

Next page's graphic allows us to manage the milling phase as follows:

- activation of the trenches

- continuous monitoring of the machine position
- trolley position
- instant temperatures to movable probes
- activation of every engine and locating unit
- Amperage of revolving belt, operating some automatic movements protecting the engine.

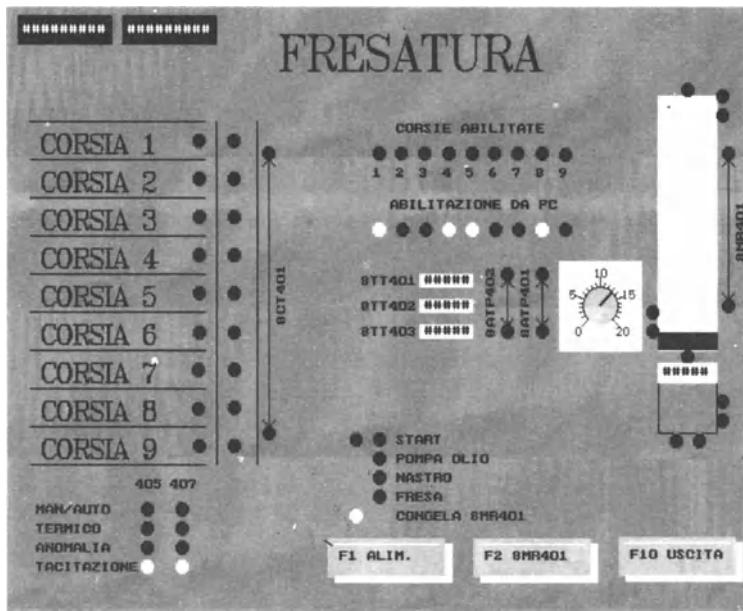


Figure 6

Following are the average data emerging from two years crops for the matrices being available.

CAVIRO: Composting Plant * Analysis of starting raw materials										
Raw Materials	Dmg of processed grapes Dried 1	Dmg of processed grapes Dried 2	Dmg of processed grapes Washed 3	Chestnut Peel	Olive Husk	Centrifuged Fruit	Centrifuged Sludge	Mosses Waste 60 brix	Centrifuged Ammonium	
Umidity %	45.50	14.50	71.97	62.34	65.70	70.52	79.05	43.30	79.12	
C org. % s.s. (TOC)	45.76	50.28	53.05	47.82	57.85	25.99	38.89	31.47	31.86	
S. O. % s.s.	78.71	86.48	91.25	82.25	99.50	44.70	66.89	54.25	54.80	
N tot. % s.s.	2.57	2.18	2.34	1.23	1.94	1.46	3.08	5.10	3.80	
C/N s.s.	17.81	23.06	22.67	38.88	29.82	17.80	12.63	6.17	8.38	
pH (1:2.5)	7.95	4.16	7.35	4.50	5.15	3.96	3.75	5.16	8.04	
K2O s.s. %	2.30	1.63	0.89	0.60	1.46	0.53	1.12	12.58	1.62	
P2O5 s.s. %	0.78	0.60	0.62	0.25	0.34	0.27	1.53	0.64	1.69	
Pb s.s. ppm	85	105	47	35	12	11	245	34	22	
Cu s.s. ppm	185	297	105	25	13	63	55	350	454	
Cd s.s. ppm	0.3	0.5	0.3	0.8	2.0	0.8	0.3	1.0	1.5	
Cr s.s. ppm	8	19	13	15	10	7	73	9	-	
Zn s.s. ppm	635	1197	820	755	450	31	220	220	124	
Ni s.s. ppm	10	31	13	9	8	9	7	12	13	

Figure 7

WE REPORTED THE DEVELOPMENT OF THE MAIN PARAMETERS OF THE PRODUCT DURING THE MICROBIOLOGIC TRANSFORMATION

	Start	10 Day	20 Day	30 Day
Umidity %	58,5	46,1	36,2	30,1
C % s.s.(TOC)	48,0	42,2	40,5	38,5
Org. Mat. %s.s.	82,5	70,3	64,5	60,3
N tot. %s.s.	2,6	2,7	2,7	2,8
C/N s.s.	20,4	18,6	16,1	13,9
DH% s.s.	49	64	75	79
HR% s.s.	16	23	25	29
pH (1:2,5)	6,95	5,55	7,43	7,90

Figure 8

The temperature set point for reaction area is 55°.
APRIL – Average values of the month

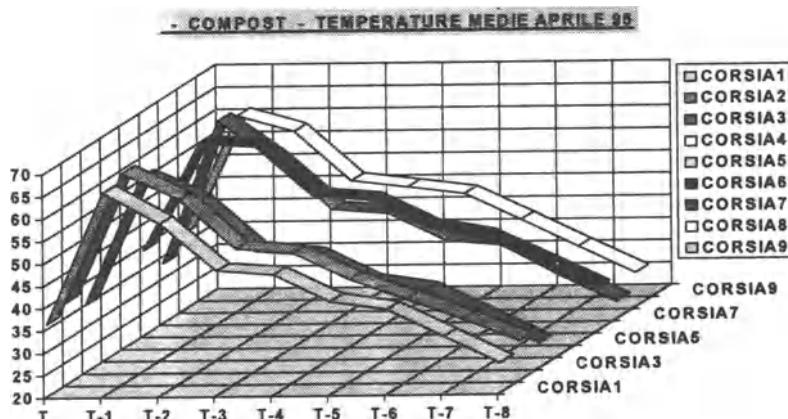


Figure 9

The minimum quantity of blown air is 0.1 m³ per minute per ton of dry organic matter.

The adjustment set point is 15% of O₂ in the air sucked up from the matter.
minimum value 5%.

APRIL – Average values of the month

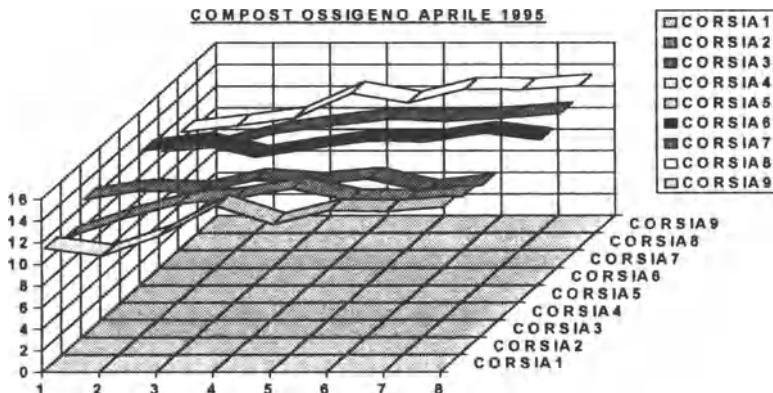


Figure 10

MINIMUM VALUE OF COMPOST

HUMIDITY %	20.75
ORG. MAT. % S.S.	52.29
HR % = [(HA+FA)/TOC]*100	12.93
DH % = [(HA+FA)/TEC]*100	77
N Tot. % S.S.	2.64
P ₂ O ₅ S.S. %	0.70
K ₂ O S.S. %	2.85

I am also glad to inform you that we have filed the request for the certification of the product and of the process according to the ISO 9001 norm.

Management of Caviro Composting Plant in compliance with the ISO 9001 Quality Control System

Introduction

Market requirements and expectations together with law regulations concerning product quality and environmental safety cause a cultural and managing change of company behaviour towards the ever demanding international market.

Even companies producing fertilizers should take into account this fact to grant their future.

Therefore, today's requirements are:

- to offer products complying with regulations and satisfying users who are more and more aware and can choose among a large variety of products, due to the market competition where boundaries have been eliminated.

Only the companies able to foresee the market needs will get a leading position and win future challenges.

In order to reach such aim, it is important to modify one's production strategies, more and more considering the customer's needs, combining a good quality control and a production system able to prevent risks and to cope with immediate response to emerging problems.

Which fertilizer today?

After a period of strong chemical fertilization and of forced soil exploitation, new problems and new requirements are developing, following studies and researches from various parts.

Production results, climatic analysis and soil preservation show a loss in fertility and increase in erosion and impoverishment, together with sometimes irreversible changes in the environmental balance.

In addition, health and security needs about food-stuffs require the agricultural use more and more restricted substances and production techniques.

Nowadays, environmental defence and preservation are a problem involving everyone and agriculture should rearrange its position face to public opinion, that's more and more demanding but at the same time confused and alarmist. It should become once again the first and last ring of the production chain, offering new services to the community, also by using waste products to maintain the environmental balance.

Caviro aims

After having considered the needs of users, of legislation and of farmers, CAVIRO tries to give an answer to these new requirements with this Composting plant, giving rise to a product whose quality standards comply with all market demands. With the help of BUREAU VERITAS, a company operating in the quality system of this field, CAVIRO is developing

A QUALITY ASSURANCE SYSTEM

within its composting plant.

This company management through quality, adopting a prevention method, which is consistent, optimized, documented, well known and based on the ISO 9001 regulation (model for quality assurance in design, development, production, installation and servicing) is designed to integrate all business functions, from marketing to production and supplies.

How the quality assurance system CAVIRO COMPOST works (annexe 1)

The Management will is clearly stated through a POLICY OF QUALITY declaration, indicating measurable objectives, and is expressed through a set of

documents including the quality manual, the procedures, the definition of products, working conditions and files for the activities and the controls carried out. These papers give an answer to the following questions: who does what, how, when, with what, and why. The people involved follow the rules fixed by the system, they carry on their activities, checks, tests and controls in compliance with formalities, criteria, timetables and they record the results on files.

Those registrations are kept on files and are the demonstration of standard obtained, but they are also useful to improve company performances, according to the statistical analysis of data.

A product identification system, from raw material to finished products, allows to trace their history and find out their compliance with fixed criteria along the process. This allows the best possible management of the non-complying elements, which are then sent back to the beginning of the cycle, to be worked again or to be eliminated. Evidence derives from the checks on raw material, during the process and on finished product. A steady monitoring of the working process allows to preserve the ideal conditions at any time and it also gives constant information useful for its improvement. Monitoring implies qualified and serviced plants, precise sizing and testing devices and skilled personnel.

Suppliers are checked in advance and their materials are tested at arrival. At the same time, special attention is given to customers' needs and complaints, by sale and servicing activities, but also by monitoring the market changes.

The quality system works well thanks to surveys and reaction techniques such as:

Planned internal audits, in order to check the implementation of inner rules.

Problem solving techniques such as brain storming and risks analysis to find out improving or revising actions allow us to cope in a positive way with the whole organization.

At regular intervals, the Management will check the quality system trend and will compare the results with the foreseen goals. Therefore, they will be able to find out the improvements required, setting new goals and priorities, granting new resources and, if necessary, varying standards.

Only such a dynamic and reactive system can offer CAVIRO the right tools to face the market, which is more and more demanding as far as the quality and the environment are concerned.

We are now developing and implementing the system, which is going to start autonomously within 8 months.

An Acknowledgment: SAQ certificate

As a consequence, CAVIRO intends to have its system examined by an internationally recognized third party, able to certify its compliance with existing rules, in order to offer further warranties to its customers.

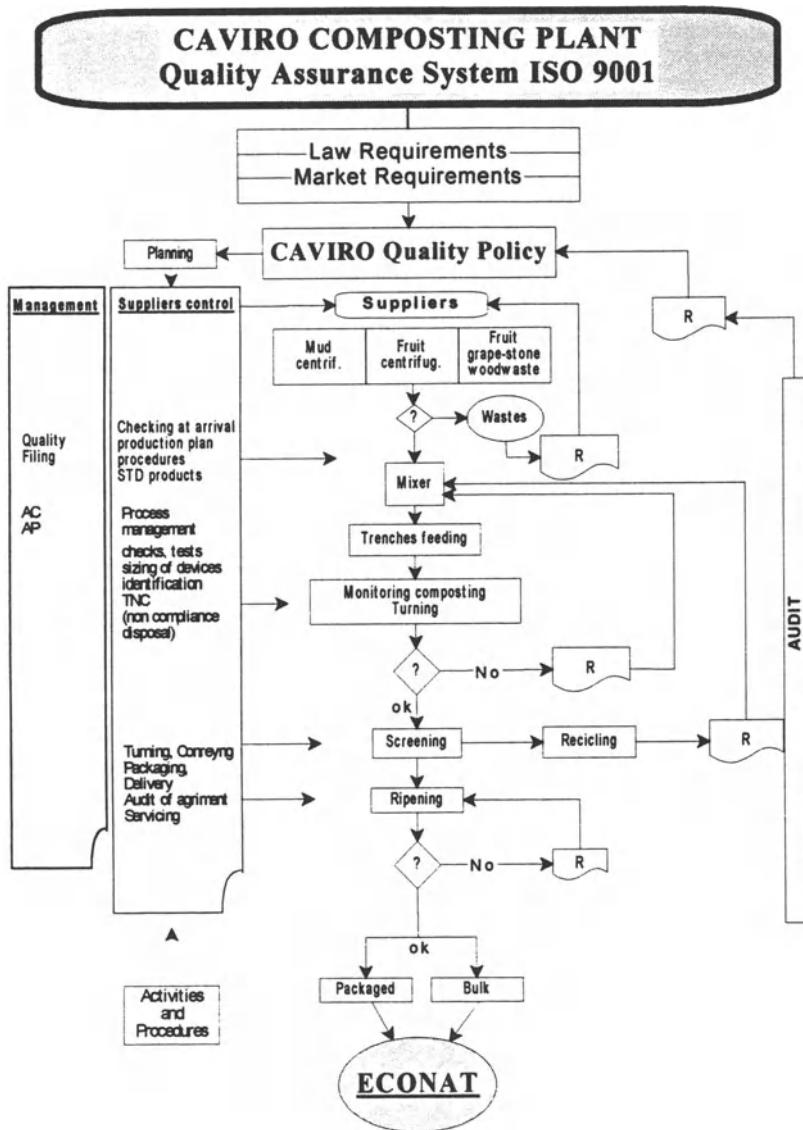


Figure 11

A2 The Quality of Compost

Evaluation of Compost Stability

RENZO BARBERIS and PINA NAPPI – Istituto per le Piante da Legno e l’Ambiente I.P.L.A. Torino

Introduction

Production and application of compost from organic wastes can be the correct solution to the increasing lack of organic matter in soils and to the problem of organic waste disposal.

Certainly composting of separated wastes, i.e. from source separate collections, is a highly competitive system from the economic and environmental points of view as compared with other forms of waste disposal (dumping, incineration).

The composting system though is a valid choice if the final product can be successfully put on the market which ultimately depends on compost quality. By this we mean low pollutant content, high concentration, maturity and stability of compost organic matter.

Field application of insufficiently stabilized organic materials can negatively influence crop development. Take for example fertilizing using fresh manure or green manuring.

In the same way the application of immature compost can interfere with plant growth for the following reasons: nitrogen immobilization when a high C/N ratio causes the competition between root and soil microorganisms for the available nitrogen; toxicity due to nitrogen compounds when the C/N ratio is low.

Other factors too can inhibit plant growth: oxygen deficiency for the root system, when excessive quantities of oxygen are utilised by microorganisms metabolizing the organic matter, lack of phytotoxin degradation – phytotoxins are normally produced in the first stages of organic matter degradation and then metabolized during the composting process.

Furthermore stocking and bagging of a wet, immature product can induce compost anaerobic decomposition, with the result of toxic substances such as alcohol, methane and acetic acid storing up. In addition the concentration of soluble carbon of non-stabilized composts can support pathogen growth.

Analytical methods to evaluate compost stability.

Chemical methods.

Determination of humic substances

Quantity and quality of compost humic substances have often been studied in the last ten twenty years; let's remember some studies (Roletto et al., 1985; Sequi et al., 1986; Saviozzi et al., 1988; Genevini et Adani, 1994) whose merit is to suggest possible parameters and evaluation indexes for compost maturity.

I.P.L.A. (Barberis et al., 1984; Roletto et al., 1985) devised the following method: humic substances are extracted using a solution of sodium pyrophosphate at pH 9,0 and 0,5 M ionic strength, using a product/extractant ratio of 1:100. The extraction takes place over 24 h shaking.

The total humic carbon (Cext) is then separated into humic acid carbon (CHA) and fulvic acid carbon (CFA) on the basis of their different solubility in an acid environment.

During maturation humic substances evolve from a qualitative point of view but not only, there is in fact a progressively increasing predominance of humic acids over fulvic acids: the ratio between the two being an important index of compost maturity. It is thought that it should be more than 1 in a mature compost.

Through the determination of Cext and of CHA it is possible to express two further parameters that are directly related to the humification process:

the humification ratio (HR) = (Cext/Corg.) 100; the humification index (HI) = (CHA/Corg.) 100.

Sequi et al. (1986) proposed a purification system relying on polyvinylpyrrolidone (PVP) capacity of absorbing humic and fulvic acids.

The humification index (HI) is given by the ratio between the non-humified fraction carbon (HN), which is not retained into the column, and the carbon of humified fractions (HA+FA); the ratio is going to decrease in time as the non-humified fractions decrease.

In order to quantify compost humic substances Ciavatta et al. (1988) proposed two different indexes: the humification degree (DH), that's to say the percentage of humic substances with respect to the extracted carbon, and the humification rate (HR) that is the percentage of humic substances with respect to the total carbon present in the sample.

The humification degree (DH) is directly related to the quantity of extracted humic substances and in theory it can range from 0 to 100, low values corresponding to immature composts, and values approaching 100 to mature composts. HR values instead correlate the quantity of humic substances to the total carbon content of the sample. As it happens with DH, HR values can range in theory from 0 to 100 and are directly related to humic and fulvic acid content.

Genevini and Adani (1994) suggest a more complex series of purifying treatments for humic substances. They identify a stability index (SI) which is the ratio between purified humic acid carbon and carbon of non purified humic acids; SI can vary from 0 to 1 and it increases as compost maturity increases.

To get further information on the quality of compost humic substances De Nobili et al. (1989) suggested an electro-focusing. This technique allows to follow the structural evolution of humic substances during the humification process by observing the changes in the profile obtained through densitometric scanning of bands formed by humic substances focusing.

During humification low molecular weight substances, with a high density of carboxylic groups, are produced first, while more complex substances having a higher molecular weight are produced later on; the corresponding bands appear in the electro-focusing profile approximately four weeks after the composting process has started.

As one can easily imagine there is a long list of other possible ways of determining humic substances extracted from composts (elemental analysis, IR and NMR spectra, studies on functional groups and on complexing capacities....), all of them tending to better define chemical and chemico-fisical characteristics of humus extracted from composts as compared with those of humus extracted from soils.

The complexity of the above-said techniques, the possible interferences due to some organic fractions such as lipids, proteins and carbohydrates, and, at times, difficulties in interpreting the results prevent a widespread and continuative utilisation of these methods to determine compost maturity parameters.

Other methods to evaluate compost maturity

C/N is one of the most widely utilized parameters to follow the evolution of substances undergoing a composting process, it varies remarkably depending on starting materials and in itself can hardly give reliable indications on compost maturity.

Organic matter evolution during composting implies considerably strong variations in the correlation between different nitrogen forms (N-org., N-NO₃, N-NO₂, N-NH₃).

Due to microbial transformations realised by microorganisms, nitrogen is progressively included into humic substance aromatic structures, at the same time N-NH₃ after an initial increase, begins to decline as a consequence of its volatilization and oxydation into N-NO₂, N-NH₃ and N-NO₃ concentrations should be comparable, according to Trombetta et al. (1988) N-NO₃ content of a dried sample should be more than 0,04%.

Others (Chanyasak et al. 1982) suggest to rely on maturity indexes connected to the different nitrogen forms in the water extracts of the examined materials.

Another parameter evolving in a typical way is the content of readily fermenting polysaccharides. Their concentration decreases during composting. Some authors (Lossin, 1971; Morel et al., 1979; Inoko, 1982) think that through carbohydrate determination one can indirectly determine compost biodegradability in the soil; Morel et al. (1979) have come to establish a biodegradability index related to organic carbon, warm water soluble sugars, maturation days.

Among the existing chemico-fisical methods to determine maturity in composts from different starting materials let's mention circular paper chromatography of

extracted humic substances (Hertelendy, 1974).

Colorimetric measures of compost substances extracted using different reagents are also often utilized (Ladd, 1969; Morel, 1982; Roletto et al., 1982); this instrumental method is based on the property of humic substances of changing to darker colors as composting progresses.

Depending on the different optical intensities read at wave lengths varying from 280 to 665 nm, it is possible to get indications of the humification rate and therefore of compost maturity. In some cases (Roletto et al., 1982) the relation between absorbance measured at 465 nm and at 665 nm (ratio E_4/E_6) is referred to; in other cases (Salfeld, 1975; Roletto et al., 1985) differential spectra between 220 nm and 340 nm are used.

Temperature is another valuable indicator of maturity, as it should approach room temperature in a mature compost. The typical smell of earth emitted by compost at the end of its transformation is important too as a symptom of maturity (Brodie et al., 1994).

All chemical methods generally give fairly good results in following the evolution of specific materials; it is less easy to compare composts from complex and differing starting materials as you have to establish a maturity index based on one parameter only.

Biological methods

While chemical parameters can give a punctual determination of each substance, biological parameters can be very helpful as they evaluate compost stability as a whole.

Three biological methods formulated by I.P.L.A. are here described: phytotoxicity assay, respiration assay and nitrogen mineralization assay (Nappi et al., 1990. Piedmont Region, 1992).

a) Phytotoxicity assay

This method is based on two connected assays, *in vitro* and *in pot*, using *Lepidium sativum* as test plant. The method aims at detecting phytotoxic substances in composts when the composting process has not evolved correctly (anaerobiosis, lack of mass homogenizing, insufficient composting time). Among them, both mineral substances ($N-NO_3$, acetic acid, etc.) and organic ones (volatile fatty acids, phenols, etc.) are specific growth inhibitors and important indexes of the process evolution: in other words their presence reveals that the compost is not sufficiently stable.

The *in vitro* assay evaluates germination and root growth for *Lepidium sativum* seeds in compost water extract. The Germination Index (Ig) calculates the average of germinated seeds and multiplies it by root length (percentage) with respect to a control. Ig of a non toxic compost is > 40%.

The *in pot* assay consists in evaluating *Lepidium sativum* growth on a substrate made of sand, peat and increasing percentages of compost. The assay lasts 21

days. The Growth Index (Gm) is the percentage ratio between the sample dry weight and the control dry weight, the control consisting of *Lepidium sativum* grown on sand and peat alone. A compost is not phytotoxic if Gm >100%. For Ig values > 70% it is not necessary to proceed to the pot assay.

Other methods have been devised: Zucconi (1983), for instance, evaluates phytotoxicity as a function of *Lepidium sativum* seed germination, Wong (1985) uses *Brassica parachinensis* seeds and Kuboi et al. (1984) test 20 plant species in liquid shaking culture.

Phytotoxicity trend

As Fig. 1 and 2 point out, toxicity during the composting process varies as for intensity and duration.

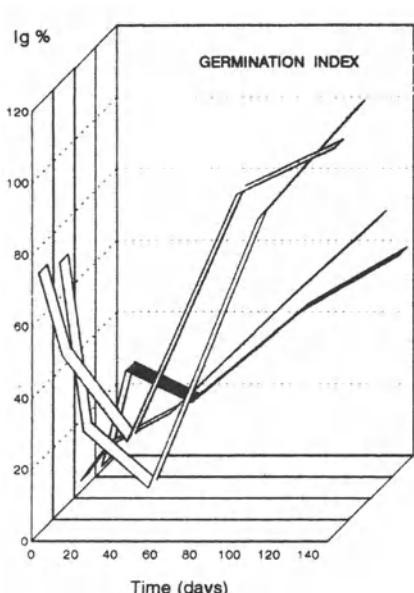


Figure 1

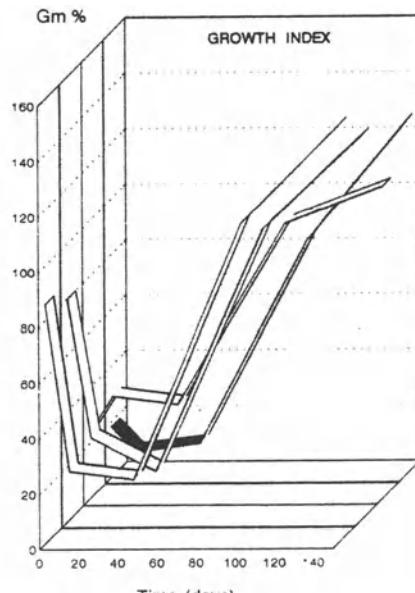


Figure 2

It generally tends to increase in the early phases of composting, corresponding to a peak of microbial multiplication and to an intense biodegradation of the most readily fermenting organic materials releasing toxic metabolites. In later phases when toxic substances metabolism has already taken place, phytotoxicity decreases and it disappears completely at the end of the composting process. This indicates that the produced compost is stable and mature.

b) Nitrogen mineralization index

Organic nitrogen mineralization is a useful parameter to determine readily biodegradable nitrogen compounds and therefore it can be inversely correlated to compost stability.

The nitrogen mineralization assay evaluates organic matter stability as a func-

tion of the existing equilibrium between organic and mineral nitrogen during a 10 days incubation period. If the materials are sufficiently stable there is balance between the different nitrogen forms and no remarkable variations can be found. A compost is stable when the Nitrogen Mineralization Index (IMA) is < 3,5%.

There are other methods to evaluate nitrogen mineralization and precisely those of Bitzen et al. (1988) and of Pronold (1986).

Nitrogen mineralization trend.

Fig. 3 shows in a graph the evolution of the Nitrogen Mineralization Index during the composting process of some organic materials. By examining this graph it is possible to notice that the index increases in the early phases of composting when nitrogen forms are highly unstable. Later on IMA values decrease considerably and remain low till the end of the process thus denoting a stable balance between nitrogen forms in the last composting phases and in the final products.

IR mg O₂/kg VS/h

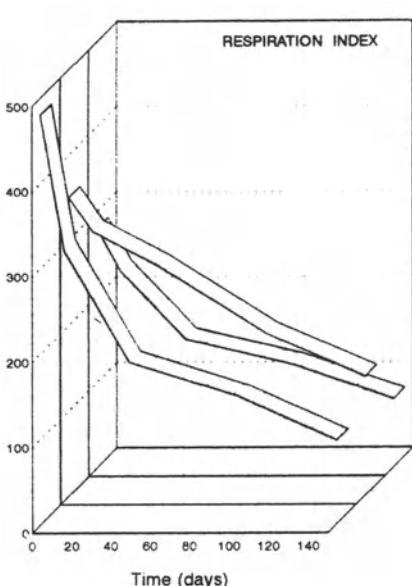


Figure 3

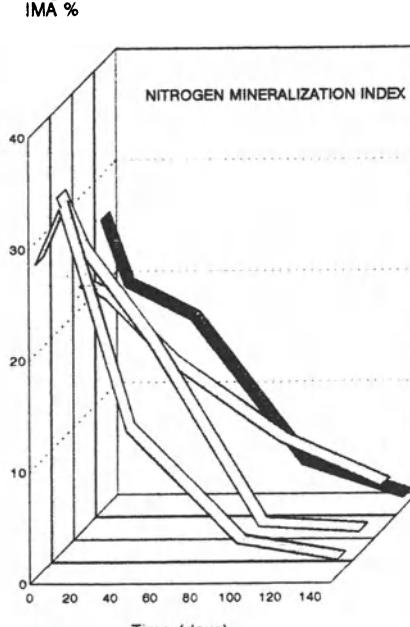


Figure 4

c) Respiration assay

Respiration intensity is directly related to the speed of microbial metabolism and therefore it is inversely related to compost maturity. Consequently in the early composting phases, corresponding to a fast microbial multiplication due to the most readily fermentable organic fraction, respiration intensity is very high. Later on, after a decrease in biologic activity, respiration intensity too decreases strongly until it reaches low values that remain constant in a stable product. The method determines oxygen consumption by measuring the depression taking place in a closed system when produced CO₂ is absorbed by NaOH.

As it is possible to calculate O₂ consumption speed, the assay can last 1 to 2 days, for highly biodegradable products, and up to 5–6 days for very stable materials. If the Respiration Index (IR) is < 150 mgO₂/kgVS/h the compost is said to be stable. Other methods evaluating stability as a function of respiration are those devised by Ciccotti et al. (1989) e by Wilson et al. (1986).

Respiration trend

Fig. 4 reports respiration trends during the composting of some organic materials. It is clear that the Respiration Index evolves as a function of the composting phase. For instance material n° 1 at time 0 has a very intense microbial activity due to high contents of readily biodegradable organic materials, the microbial activity then decreases progressively as these substances decrease until O₂ reaches a value of 23 mg/kgVS/h in the stable and mature final product. In the case of material n° 2 respiration intensity decreases with difficulty as the composting process does not evolve correctly.

Finally sample n° 3, from the very first measures, shows low values further diminishing during the composting process. This means that the starting materials of sample n° 3 are transforming correctly.

Correlations between biological parameters and humification indexes.

Some simple correlations were made between the values of different biological parameters, surveyed during the composting process and on the final product, but also between biological parameters and some humification indexes such as humic-acid carbon/fulvic-acid carbon ratio (CHA/CFA) and the Humification Index (HI) (Roletto et al., 1985).

In the first case results point to some very interesting considerations:

- The Germination Index (Ig) is positively related to the Growth Index (Gm) and inversely related to both the Respiration Index (IR) and to the Nitrogen Mineralization Index (IMA).
- The Growth Index is inversely related to IR and IMA.
- The Respiration Index is positively related to IMA.

Instead by correlating biological parameters and humification indexes it turns out that the CHA/CFA ratio is positively related to Ig, while the Humification Index is positively related to Ig, Gm and IMA for p ≤ 0,05 (table 1).

These correlation coefficients permitted to verify whether it is possible to predict the stabilization level to be reached by one aspect of biological activity as related to another. The results were encouraging: in fact the regression line between Ig and IR values ($y = 316,2 - 2,1x$) shows an Oxygen consumption of 169 mgO₂/kgVS/h when Ig is 70%, above this value in fact a compost is certainly not phytotoxic. Likewise the regression line between IMA and IR values ($y = 177,2 + 6,0x$) points to an Oxygen consumption of 156 mgO₂/kgVS/h when the

Nitrogen Mineralization Index is 3,5; this value is the upper limit for a stable compost as far as nitrogen forms are considered.

If we wish to predict the entity of the humification process as a function of biological activity it appears that the regression line between Germination and Humification Index ($y = 0,61 + 0,004x$) for Ig = 70% points to a HI value of 0,89 near the optimal HI = 1.

These results confirm what other authors found (Zorzi et al., 1993).

Table 1 Simple correlation coefficient between biological parameters and humification indexes.

	Ig	Gm	IR	IMA
Ig		0,67 (77) **	-0,53 (77) **	-0,48 (77) **
Gm	0,67 (77) **		-0,48 (77) **	-0,62 (77) **
IR	0,53 (77) **	-0,48 (77) **		0,47 (78) **
IMA	-0,48 (77) **	-0,62 (77) **	0,47 (78) **	
CHA/CFA	0,34 (35) *	0,27 (35) n.s.	0,21 (35) n.s.	0,21 (35) n.s.
HI	0,35 (35) *	0,36 (35) *	0,29 (35) n.s.	0,36 (35) *

* meaningful for $p \leq 0,05$

** highly meaningful for $p \leq 0,01$ values in brackets indicate the number of samples.

Conclusions

There is not one single method which alone can give a certain indication of compost maturity and stability. There are in fact many useful and reliable chemical parameters helping to follow the evolution of the different materials during the composting process, they are useless though if we mean to characterize and to discriminate among composts of different origin and often from unknown starting materials.

Stability determination of a compost of unknown origin is better carried out by integrating different stability indexes.

The biological assays here reported were tested on different kinds of composts: composts prepared from sludges, from the organic fraction of MSW, from grass clippings and pruning residues, etc. The assays were repeated during the com-

posting process and on the final product. The results prove the validity and reliability of biological indexes because they evaluate compost stability as a whole by considering different aspects of compost organic matter such as phytotoxins, fermentable substances, nitrogen form stability. Not only are the results strictly interrelated, but they are also meaningfully related to the parameters indicating organic matter and especially humic substances quality.

Furthermore the adopted methods responded to the desired requirements, they follow in fact a well defined protocol, they are simple and easy to carry out, the obtained data can be reproduced; everything considered, biological assays make a valid complement to compost chemical characterization.

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Quality of Composts: Organic Matter Stabilization and Trace Metal Contamination

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Summary

Recycling organic wastes in agriculture after appropriate biological treatment can produce organic matter resources and be of great interest in countries where soils are depleted. However the quality of end-products must be assessed. This paper deals with two main problems:

- the development of reliable, rapid and normalized procedures for the monitoring of organic matter,
- the evaluation of risks arising from the presence of micropollutants such as trace metals.

Information provided by various analytical procedures is presented. Special attention is given to spectroscopic measurements for the monitoring of organic matter and, for trace metal speciation, to chemical sequential extraction and to gel exclusion chromatography coupled with a double detection (U.V. and atomic absorption spectrophotometry).

Introduction

Production of municipal solid waste, including organic waste, is increasing while soils are progressively losing organic matter due to intensive cultivation and climatic conditions. This makes the recycling of organic waste as soil amendment a useful alternative to incineration. However, owing mainly to the difficulty of making the process profitable, the development of composting plants has been limited. Poor control of the process and, in the case of combined collection of domestic wastes, imperfect industrial sorting have often led to composts of unreliable quality. Moreover, compost spreading is time-consuming and the quality is rarely suitable for specific agricultural needs. All these factors contribute to mak-

ing compost an unattractive product for farmers. It is necessary to establish the conditions of its sustainable use.

Four major points may be identified:

- the development of reliable, rapid and normalized procedures for the monitoring of organic matter,
- the evaluation of the availability of nutrients,
- the adaptation of the quality of the compost to the nature of soils and agricultural needs,
- the evaluation of risks arising from the presence of micropollutants such as trace metals.

Only the first and last points will be considered.

Assessment of the degree of stabilization of urban composts

Bio-oxidative processes involve an initial stage during which a destabilization of the substrate prevails and at the end of which only the compounds which are more resistant to biological degradation remain. It is followed by a stabilization stage characterized by the acquisition of a humic structure. A monitoring of organic matter throughout the process is required.

During the first stage, a thermal rise occurs caused by the oxidation of easily fermentable compounds. Temperature must be controlled on the one hand, to prevent excessive temperature, and, on the other hand, in order to insure that it remains at a minimum of 65°C for at least two or three days, as this is one of the conditions for compost sanitization. As organic matter is broken down, intermediates of degradation such as volatile fatty acids are formed. They are often the cause of odours and, if they accumulate, they can make the end-product phytotoxic. All the parameters governing the composting process must be optimized in order to insure their ultimate oxidation.

The major reasons for maximizing the rate of decomposition of easily degradable compounds may be summarized as follow:

- to reduce the duration of the process
- to control the temperature
- to limit the problem of odours
- to avoid the presence of phytotoxic compounds in the end-product.

Whereas many tests and criteria have been developed for the long term monitoring of organic matter, the only parameters which are usually used for the management of the first stage of the process are moisture, oxygen, temperature and pH. A critical analysis of the different types of parameters that could be used was made by Finstein et al. (1986). The latter concluded that, among the tests involving organic matter (volatile solids, total organic carbon, carbon-to-nitrogen ratio, starch, cellulose...), amino acids and lower volatile fatty acids (VFA) have the most potential

for the evaluation of process performances. However, volatile fatty acid concentration is rarely used as a control parameter (Saviozzi et al., 1992; Liao et al., 1993). The results we have obtained (Domeizel et al., 1995) show that, as in anaerobic digestion, accumulation of these compounds, whether transient or not, is a response to environmental stress such as moisture depletion or inversely pore-clogging. Although it is a less convenient parameter for field management than temperature, oxygen or ventilation demand, it may be applied for discrete controls and for the optimization of the process in a pilot-plant. Blower demand, moisture level and bulking agent addition must be adapted to the composition and structure of the waste.

Supplying an end-product of satisfactory stability also implies the monitoring of organic matter during the next steps of its evolution. It is essential to avoid a high increase in microorganism activity after incorporation in soils and subsequent indirect toxicity such as oxygen or nitrogen depletion. It is also necessary, as shown by De Bertoldi et al. (1988), to prevent pathogen regrowth. At the end of the first stage, the evolution of VFA concentrations is no longer representative of the main process, which is now the acquisition of a humic structure, and other parameters must therefore be found. The methods most often used for assessing compost maturity, can be grouped into five types: physical analyses, chemical analyses, microbiological assays, plant bioassays and studies of humified organic matter (Jiménez et al., 1989). Curiously, experimental protocols based on spectroscopic measurements have been little developed and are generally more specifically devoted to the characterization of humic substances (Deiana et al., 1990; Niemeyer et al., 1992; García et al., 1992). Inbar et al. (1990) proposed to analyze the evolution of bulk organic matter by solid state cross-polarization magic angle spinning ^{13}C -nuclear magnetic resonance and by infrared spectroscopy. These procedures make it possible to describe the decomposition of biodegradable substances and trends in transformations of organic matter during composting. Indices of compost maturity can be provided. However, these technologies, which are of a great interest for understanding maturation processes, seem too sophisticated and too expensive to be a real monitoring tool in small or medium-sized plants. Although it has been studied to a lesser degree, the less costly U.V. or U.V.-visible spectroscopy might provide useful results. The efficiency of an index of maturity, based on absorbency measurements at one or two wavelengths of the visible spectra has been tested (Chen et al., 1977; Sugahara et al., 1981; Morel, 1982). However, the observation of U.V. spectra tends to indicate that more information might be obtained by the utilisation of the whole spectrum.

The U.V. spectra of fulvic fraction, humic acids and total humic substances, realized in a wavelength range of 200 nm to 350 nm are shown in Figures 1 to 3. Total humic substances of composts, at various level of maturity, were extracted by $\text{K}_4\text{P}_2\text{O}_7$ under nitrogen and then separated into humic acids and fulvic fraction by acidifying to pH 2 with H_2SO_4 . In fact, the information that can be derived from U.V. spectra can be compared to that obtained by chemical analyses of humic-like substances. The well-known fact that extractable organic matter generally

increases with time of composting is illustrated by the increase of the absorbencies.

A shoulder-like absorption around 250 – 280 nm, also noticed by Sugahara et al. (1981) and Giusquiani et al. (1992), is observed on all the spectra. An expansion of this shoulder with composting time is probably due to an enlargement of the variety of organic compounds containing some chromophoric groups related to the development of aromatic or unsaturated structures. The increase of the absorbency around 210 nm, principally observed on the spectra of the fulvic fraction (Fig. 1), is certainly related to the presence of mineralization compounds. Simple degradation products such as nitrite, nitrate or carboxylic acids are known to absorb this radiation. This evolution in the shape of the spectra corresponds to significant changes in the humic substances of fresh to mature composts, changes which have also been demonstrated by authors using other analytical procedures. The difference, with time, in the quantitative evolution of the fulvic fraction and the humic acids influences the evolution of the shape of the spectra of the humic substances. Utilisation of the whole of a U.V. spectrum of total humic substances, which includes all the information, can provide quantitative data. It is performed by applying the rank method (Gallot et al., 1993). In this method, any spectrum can be restored by a linear combination of reference spectra. The spectrum base is previously selected from a spectrum data bank. The ratio of coefficients of the linear combination is proposed as an Index of maturity (Prudent et al., 1995). An example of the evolution of this index with composting time is presented in Table 1. Similar results were obtained with other composts. The proposed index belongs to the class of indices based on humification of organic matter that were developed by several authors (De Nobili et al., 1988; Saviozzi et al., 1988; Riffaldi et al., 1992, Govi et al., 1993).

Table 1 Evolution with time of the Maturity Index (M.I.) obtained by U.V. spectrum analysis.

	M.I. fresh	M.I. 1 month	M.I. 3 months	M.I. 6 months	M.I. 12 months
Compost 1	0.9	1.50	1.60	2.1	2.0
Compost 2	1.1	1.45	1.55	1.9	2.0

This rapid and low-cost procedure could also be adapted to the monitoring of organic matter in soil. In Figure 4, it can be seen that the evolution of the U.V. spectra of humic substances extracted from a compost-amended soil (loamy-sandy soil), sampled at various depths, visualises the slow transfer of humic substances into soil. However, a passage to quantitative results would require the enrichment of the data bank and an adaptation the reference spectrum base.

Trace metal contamination

In the case of global waste collection the quality of the separated organic matter depends on the quality of mechanical sorting. It is now well recognized that grind-

ing domestic waste at the start of the process must be avoided since impurities are ground simultaneously and cling to paper and organic matter making a further separation inefficient. Satisfactory results are obtained by taking advantage of the decrease in granulometry of organic matter during the bio-oxidative process which facilitates later sorting (Morvan, 1992).

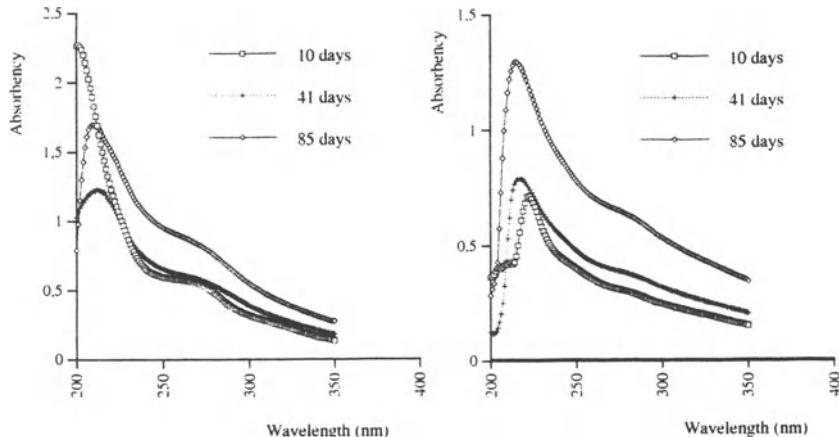


Figure 1 U.V. spectra of fulvic fractions extracted from 10, 41 or 85 day-old urban composts.

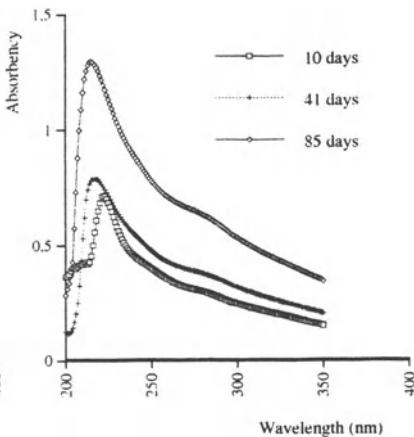


Figure 2 U.V. spectra of humic acids extracted from 10, 41 or 85 day-old composts.

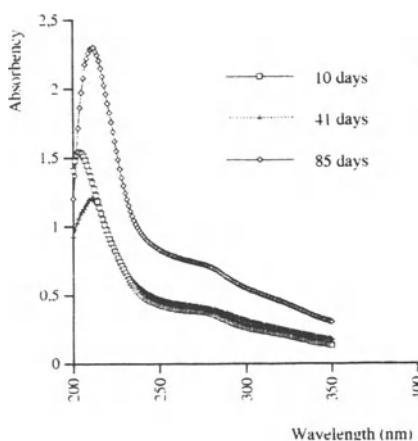


Figure 3 U.V. spectra of total humic substances extracted from 10, 41 or 85 day-old compost.

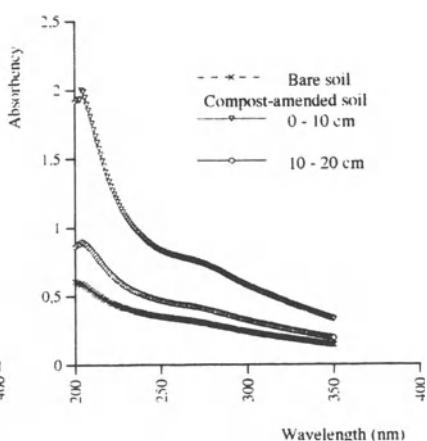


Figure 4 U.V. spectra of total humic substances extracted from soil and compost-amended soil, 3 months after compost spreading.

At the present time, legislation in different countries limiting the use of compost in agriculture refers to total trace metal concentrations. However, it is not a sufficient criterion since mobility, environmental diffusion and bioavailability will largely depend on their chemical forms. For the assessment of these different forms, the

experimental approach and more particularly sequential extraction procedures have been developed. A review of the various extracting solutions and procedures has been recently reported by Kersten M. et al. (1995). They are widely applied to sediments, soils, sludge or sludge-amended soils and to a lesser extent to waste or refuse composts. Although this approach for the evaluation of short-term and long-term risks presents real difficulties in simulating the complex chemical situation of soil, it provides operational information. The major parameters influencing metal solubility which are taken into account are pH, Eh and concentrations of organic and inorganic ligands.

In composts, the partition of metal forms is influenced by biological activity. It has been shown that the percentages of trace metal solubilized in water, in alkaline or alkaline-earth salt solution, or in EDTA or DTPA solution, vary during the composting process and that the quantities of metal extracted with EDTA or DTPA solutions are greater than those extracted with water or salt solutions (García et al., 1990; Canarutto et al., 1991). Analyses carried out on a six-month-old compost show that quantities of metal extracted by salts depend on the nature of the trace metal, on the cation involved in ion-exchange reactions, on pH and on the compost/extracting solution ratio. However their quantities, expressed as percentage of total metal content, are small, generally less than 10 %.

A whole sequential extraction procedure may also be applied to compost. For example, results for copper and lead are presented in Figure 5. The speciation scheme was previously reported (Prudent et al., 1993).

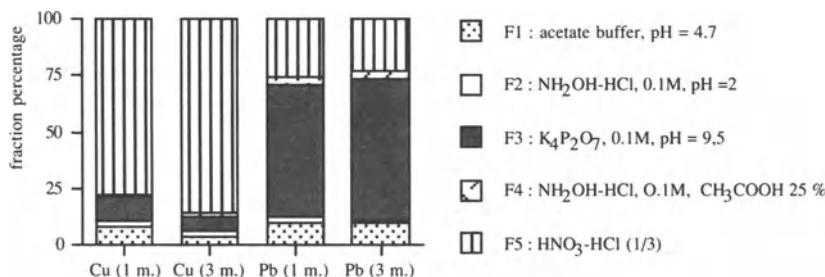


Figure 5 Sequential chemical extraction of copper and lead contained in 1 or 3 month-old compost.

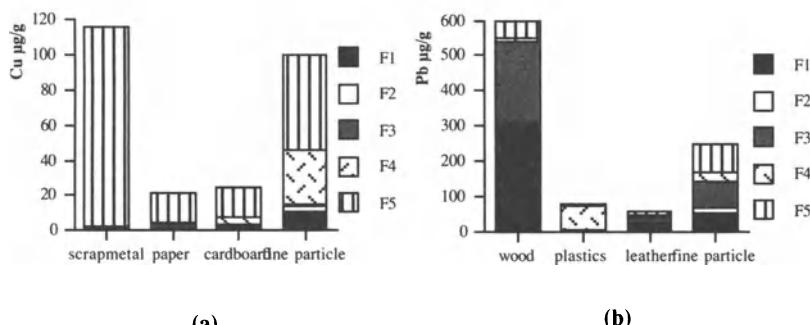


Figure 6 Sequential chemical extraction of metal, (a:b: lead) in constituents of waste in which most of the load originates.

copper; Though proportions of the different forms can vary according to the origin of the compost, the trends observed in the present example are representative of the general tendency for the two trace metals considered:

- metal extracted in reducing conditions (F_2 , F_4) is insignificant,
- metal extracted in acetate buffer (F_1) generally represents less than 20 % of the total metal,
- more than the half of the copper is extracted with the residual fraction (F_5),
- although copper is also bound to $K_4P_2O_7$ extractable organic matter (F_3), this fraction is predominant for lead.

Results differ according to the trace metal but they also differ from those obtained with sludge. The quasi-absence of copper or lead extractable in reducing conditions is noticeable. Differences have to be sought in the origins of the metal in waste. If the constituents of the raw material in which most of the load originates are considered, it can be seen that copper (Fig. 6-a) is principally extracted with the residual fraction, even in fine particles. This is explained by the fact that copper is mainly associated with scrap metal. The case of lead is different as it is scattered principally among three fractions (F_1 , F_3 , F_5) even in fines which are an important source of lead contamination (Fig. 6-b). For lead, the fraction which is soluble at pH 4.7 or extractable in $K_4P_2O_7$ solution is significantly greater than for copper. It must also be noted that the pH 4.7 soluble fraction can originate, for a part, in the slow solubilization of metallic lead at this pH. A close relation between trace metal origin in the waste and trace metal forms in composts, is observed. This origin of trace metals implies that small-sized particles containing metal in its elementary form could be found in composts. This demonstrates that results obtained with sludge or sludge-amended soils cannot be directly transposed to urban composts and that further reflection is necessary.

A partition of the element among various chemical forms exists but a physical partition may also be observed. Petruzzelli et al (1989) show that trace metal concentration increases with the decrease in size of the physical fractions obtained by sieving and that more than 50 % of lead was found in the < 1 mm fraction. Our results are in agreement with these observations: the highest copper and lead concentrations are found in the < 50 μm fraction (50 μm < d < 2 mm: [Cu] = 50 $\mu g/g$, [Pb] = 180 $\mu g/g$; d < 50 μm : [Cu] = 302 $\mu g/g$, [Pb] = 826 $\mu g/g$) which may be present in trace metal scattering in soils. Particulate migration in soil has to be taken into account.

The binding of metal to humic complexes also seems to be an important factor that potentially can control the mobility of metal in soils. Throughout composting, structural modifications occur that may, for example, modify the bonding strength. Classical chemical sequential extraction procedures are not sufficient to study the influence of maturation processes on metal binding with humic substances. Procedures coupling humic substances fractionation and metal analyses in the fractions have been developed. The fractionation of organic matter may be performed on the bases of chemical properties (Canarutto et al., 1991) or on the bases

of molecular weight (Baham et al., 1978). In the work presented the second way was chosen. Humic substances were extracted by K4P2O7 (0.1M) under nitrogen atmosphere and were then separated by gel exclusion chromatography (Sephadex G.75 and Sephadex G25). A double detection was used: U.V. and atomic absorption spectrophotometry (Prudent et al., 1993). Maturation is characterized by the emergence of new compounds with high molecular weight probably resulting from polycondensation reactions (Fig 7). Compounds with molecular weight > 70,000 Da are formed (fraction 15). In fresh compost copper and lead are mainly bound (Fig. 8) to the 8,000 Da compounds (eluted around fraction 42). Lead is also eluted with fraction > 50. This may correspond to lead associated with small organic compounds or to lead that before extraction was weakly bound to humic substances and is displaced by the presence of the extracting agent. It is noticeable that the maturation process induces modification of binding sites, which mainly influences copper binding to humic substances. The availability of metal bound to humified organic matter is generally considered very low. However, the interactions of humic substances with metal ions are complex because of the fact that humic substances are polyfunctional and polyelectrolytic. Different types of bonding exist with various bonding strengths for a given metal. The equilibrium may be displaced by a modification of pH (Gamble, 1986; Wang et al., 1987) or of the concentration of competitive soluble ligands. Such conditions may be found in soil locally, inducing a slow release of the metal. The metal binding to humic substances cannot be considered as irreversible.

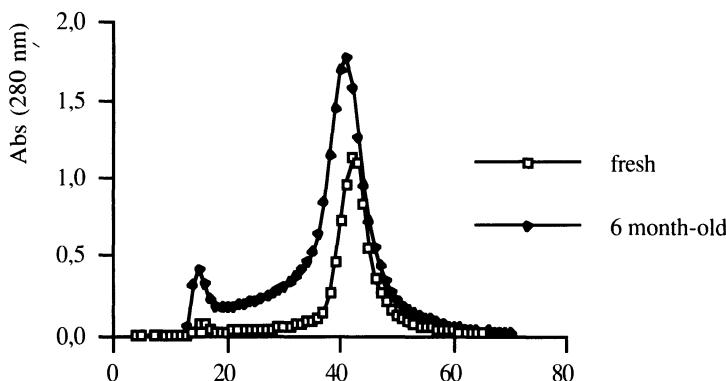


Figure 7 Sephadex G75 absorbancy chromatograms of humic substances extracted from fresh or 6 month-old composts.

Conclusion

Many works deal with the evaluation of the quality of composts with reliable criteria. The characterization of the evolution of organic matter during composting as well as the evaluation of risks induced by the presence of trace metal are concerned. However, the procedures are multiple and make comparisons difficult.

There is a lack of reference analytical methods. It seems that rapid spectroscopic methods should be developed for the monitoring of organic matter. Chemical extraction procedures, if unified, should give operational information on trace metal speciation which, only in conjunction with information on the characteristics of the soil, can help to draw up a hierarchy of dangers. Particular attention must be paid to metal migration in soil with fine particulate material and further investigations seem to be necessary on the influence of the evolution of compost humic substances on metal mobility and availability in soil.

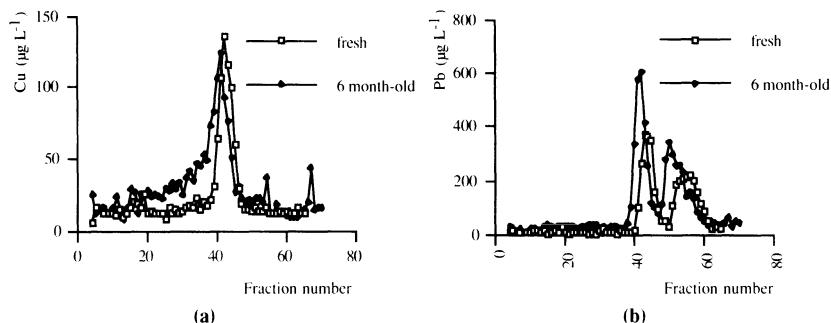


Figure 8 Sephadex G75 Copper (a) or lead (b) chromatograms of humic substances extracted from fresh or six month-old compost.

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Chemical and Physico-Chemical Parameters for Quality Evaluation of Humic Substances Produced during Composting.

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Abstract

The principal scope of the composting process is to transform organic wastes of various origins and nature into a stable, mature, humus-like material suitable for use as soil amendment. The knowledge of the quality of humic acid-like and fulvic acid-like fractions formed during the composting process is of primary importance for the evaluation of the economic value, agronomic efficacy and environmental safety of the final product, the compost, which will be applied to soil. In this review paper, the chemical and physico-chemical analytical properties and data available for the evaluation on a molecular scale of the humic acid-like and fulvic acid-like constituents in composts are summarized and discussed in comparison with indigenous soil humic acids and fulvic acids. Discussed data include elemental and functional group composition, E_4/E_6 ratio, molecular weight distribution, isoelectrofocusing patterns, pyrolysis-gas chromatography-mass spectra, and infrared and Fourier transform infrared, nuclear magnetic resonance, electron spin resonance and fluorescence spectra. With respect to native soil humic and fulvic acids, humic and fulvic acid-like fractions in composted sewage sludges, municipal solid wastes, animal manures and plant wastes are generally characterized by (i) higher molecular heterogeneity; (ii) lower degree of aromaticity and structural polycondensation; (iii) higher aliphatic character; (iv) marked presence of incorporated proteinaceous materials, partially modified lignin moieties and polysaccharide-like structures; and (v) lower amounts of oxygen containing and acidic, especially carboxylic, functional groups. With composting, however, a loss of N-containing groups, alkyl chains and carbohydrates, and an increase in oxygenation, carboxyl groups and aromaticity generally occur in fulvic acids and, especially, humic acids. This is an important result which supports the validity of the composting process for organic wastes in approaching the quality of humus-like components to native soil humic substances.

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Introduction

Humic substances (KS) are considered to be the most important constituents of non-living organic matter in soil. They contribute substantially in improving the global soil fertility status by exerting a number of functions that are specific and typical of 'humified' organic matter. These include, among others, the improvement of soil physical properties such as soil structure, porosity and water retention capacity, enhancement of cation exchange capacity and pH buffer capacity, slow release of nutrients such as N, S and P, and extended interactions with micronutritive and/or microtoxic metal ions and xenobiotic organic molecules such as pesticides (Stevenson, 1982).

Soil KS are constituted by a physically and chemically heterogeneous mixture of macromolecular organic compounds of mixed aromatic and aliphatic nature, rich in chemically reactive functional groups (Schnitzer, 1978). They are formed by complicated biochemical and chemical resynthesis and polymerization processes, known as 'humification', from a variety of contributing molecular moieties which originate during the microbial and chemical degradation of plant, animal and microbial debris indigenous in the soil, and continuously produced during the natural turnover of soil organic matter (SOM). Crop residues and animal manures have also been traditionally applied to soil, as a means for maintaining and increasing SOM content and related fertility functions.

In recent years a great generalized interest has grown in the possible recycling as soil amendments of the large amounts of organic residues and wastes such as sewage sludges, municipal solid wastes, urban yard refuses, food industry by-products and refuses, wood processing wastes and agricultural crop residues, which are extensively produced by a wide variety of human activities. Several reasons have contributed to the rapid growth of interest in agricultural recycling of organic waste materials. These include: the rising demands for resource-recovery through proper waste recycling in primary production activities, such as agriculture; the necessity of restoring SOM content and related fertility functions in soils intensively-cropped and/or organic-depleted; the raising public objections concerning the protection of the atmosphere from waste-incinerator emissions, and surface and ground waters from pollution; the decline in landfill facilities and capacity, with consequent increasing costs for disposal; and the lower operational costs in comparison to the beneficial use of the end products.

Soil application of organic wastes and residues of any nature requires, however, that these materials be previously subjected to appropriate treatment. These treatments tend, on one hand, to minimize or possibly eliminate a number of causes that may produce more adverse than beneficial effects on soil properties and, on the other hand, to optimize their efficiency, i.e., their fertility functions, once in the soil.

The 'composting' process is generally considered the most efficient treatment in producing an environmentally safe and agronomically advantageous soil organic amendment at acceptable operational costs. Basically, composting is an accelerated version of the processes occurring in the natural decomposition of organic debris

in soil, and is achieved through the provision of the most favourable conditions for microbial activity. The principal scope of the composting process is to transform the organic material into a mature, stabilized organic matter, in which the humification process typically occurring under natural soil conditions has started and proceeded to a marked degree, producing a humic-like end-product. Composting principles and several processing technologies have been successfully developed and described in several publications (e.g., Hoitink and Kecner, 1993).

The principal requirement for an organic material to be safely, conveniently and efficiently used as a soil amendment is the stability, or maturity, achieved after the treatment process. Currently, a number of criteria based upon various physical and chemical indexes, enzymatic and microbiological tests, plant bioassays, and physico-chemical parameters, have been proposed and are used as guidelines for testing the evolution and modifications occurring in the organic material during composting and for evaluating the degree of maturity achieved in the end-product, i.e., the compost (e.g., reviews by: Zucconi and De Bertoldi, 1986; Senesi, 1989; Boyd and Sommers, 1990; Inbar et al., 1990a; Ke et al., 1992).

The requisite of maturity implies an extended conversion of the initial, 'fresh' or 'raw', organic matter into stabilized, refractory organic forms, that are humus-like components. The formation of these components, and their presence in the final product are explicitly required for an acceptable economical value and agronomic efficacy of the organic amendment. The amount and quality of humuslike substances in the end-product are, therefore, considered important indicators of the organic matter maturity and stability for a successful application in agriculture and safe environmental impact of the amendment. As a consequence, the most appropriate and reliable criteria to evaluate compost maturity should be based on the chemical and physico-chemical analyses of the molecular, structural and functional 'identity' and properties of the humus-like components, i.e., the humic acid (HA)-like and fulvic acid (FA)-like fractions in the compost.

The main objective of this review is to summarize and briefly discuss the chemical and physico-chemical analytical data available for the evaluation on a molecular scale of the HA-like and FA-like components in composts of various origin and nature, in comparison with the corresponding properties of native soil HAs and FAs. Humus-like materials in soil organic amendments produced by waste treatments other than composting, e.g., aerobic and anaerobic digestion, various fermentation processes, and other chemical and biological technologies, will not be considered in this review.

Elemental and Functional Group Composition and E_4/E_6 ratio

The elemental composition, atomic ratios, functional group content and E_4/E_6 ratio of HA-like fractions isolated from a variety of composted and vermicomposted sewage sludges (SS), municipal solid wastes (MSW), animal manures and plant

wastes (Almendros et al, 1983a, b; Riffaldi et al, 1983; Businelli et al, 1984; Gerasimowicz and Byler, 1985; Gonzales Vila and Martin, 1985; Gomez and Jeune, 1987; Hainmouda and Adams, 1987; Roletto and Luda, 1987; Garcia et al, 1989; Giusquiani et al, 1989; Hervas et al, 1989; Inbar et al, 1990b; Diaz-Burgos and Polo, 1991; Hanninen and Lilja, 1994) are shown in Tables 1, 2 and 3, in comparison with corresponding average data for native soil HA (Schnitzer, 1978).

The C content in HAs from composted wastes of any origin and nature fluctuates around the mean C value in soil HA, whereas the O content, with the exception of HAs from composted poplar bark, is generally lower than the mean value of soil HA (Tables 1 and 2). Compared with soil HA, the N and H contents of HAs from composted SS and MSW, and from wheat straw composted with various N sources are much higher, and those in HAs from composted animal manures and wastes are slightly higher, whereas N and K contents in HA-like fractions from composted plant materials are lower. As a consequence, the C/N and C/H ratios of composted SS and MSW HAs are generally much lower, those of composted animal manure and wastes are lower, and those of composted plant materials are higher than mean values measured for soil HA. The O/C ratio of HAs from composted wastes fluctuates around the mean value of soil HA. The S content, available for a limited number of samples, is generally higher than the mean value of soil HA.

Table 1 Elemental composition and atomic ratios of humic acid-like fractions isolated from composted sewage sludges and municipal solid wastes of various origins and nature, compared with mean values of soil humic acids.

Sample origin and type	C %	K	N	S	O(+S) Atomic ratios	C/N	C/K	O/C
<i>Sewage Sludges</i>								
Mixed with grape debris (3:1), 3m-composted ^a	46.7	6.2	5.8	—	41.3	8.1	0.6	0.7
Mixed with grape debris (3: 1), 7m-compost ^a	53.6	5.2	4.1	—	37.8	13.0	0.9	0.5
Mixed with tree prunings, 1 week-composted	62.4	8.1	4.2	—	25.3	17.3	0.6	0.3
Mixed with tree prunings, 14 weeks-composted	62.0	6.4	5.4	—	26.2	13.4	0.8	0.3
Mixed with wine shoots, 1 week-composted	55.3	7.7	6.1	—	30.9	10.6	0.6	0.4
Mixed with wine shoots, 14 weeks-composted	55.1	7.0	5.7	—	32.2	11.3	0.7	0.4
Mixed with wood chips 3m-composted ^c	46.5	5.8	4.8	—	28.2	11.3	0.7	0.5
Vermicomposted ^d	57.8	5.7	4.5	1.4	30.6	15.0	0.8	0.4
<i>Municipal Solid Wastes</i>								
3m-composted ^a	55.4	6.7	7.2	—	30.7	7.7	0.7	0.4
7m-composted ^a	47.9	6.1	6.4	—	39.6	7.5	0.7	0.6
4m-composted ^e	48.2	—	5.4	1.1	—	8.9		
Composted ^f	59.3	5.8	7.7	—	29.7	9.0	0.8	0.4
Composted, means of 3 samples ^g	52.6	6.6	6.6	—	34.4	9.3	0.7	0.5
Vermicomposted ^d	54.6	6.0	4.6	1.2	33.6	13.9	0.8	0.5
Soil, mean values ^h	56.2	4.8	3.2	0.8	35.5	20.5	1.0	0.5

^a Garcia et al (1989); ^b Diaz-Burgos and Polo (1991); ^c Gerasimowicz and Byler (1985); ^d Hervas et al (1989); ^e Gomez and le Jeune (1987); ^f Riffaldi et al (1983); ^g Gonzales Vila and Martin (1985); ^h Schnitzer (1978).

Table 2 Elemental composition and atomic ratios of humic acid-like fractions isolated from composted animal manures and plant wastes of various origins and nature, compared with mean values of soil humic acids.

Sample origin and type	C %	K	N	S	O(+S)	C/N Atomic ratios	C/K	O/C
<i>Animal manures and Wastes</i>								
Cattle manure, raw solids	58.5	5.7	3.6	1.0	30.4	19.0	0.8	0.4
Cattle manure, 147d-composted ^a	57.8	5.3	3.8	1.1	31.3	17.8	0.9	0.4
Cow, vermicomposted ^b	54.2	5.5	4.3	1.3	34.6	14.7	0.8	0.5
Slaughter waste + peat, 4m-composted ^c	61.3	5.6	3.4	—	29.7	21.1	0.9	0.4
Slaughter waste + bark, 4m-composted ^c	56.2	5.2	3.9	—	34.7	16.9	0.9	0.5
<i>Plant wastes</i>								
Wheat straw 2mcomposted ^d	60.5	5.4	2.7	—	31.6	26.2	0.9	0.4
Wheat straw + N additives, 2 to 4m-composted ^{d,e}	60.6	7.7	4.8	—	30.0	14.8	0.7	0.4
Poplar bark, 12m~composted ^f	51.0	4.4	2.0	—	42.6	29.7	1.0	0.6
Poplar bark, 30mcomposted ^f	51.5	4.4	2.4	—	41.6	25.0	1.0	0.6
Soil, mean values ^g	56.2	4.8	3.2	0.8	35.5	20.5	1.0	0.5

^a Inbar et al (1990b); ^b Kervas et al (1989); ^c Kanninen and Lilja (1994); ^d Almendros et al (1983b); ^e Almendros et al (1983a), means of 13 samples; ^f Roletto and Luda (1987); ^g Schnitzer (1978).

With few exceptions, the carboxylic and phenolic hydroxyl group contents, and, as a consequence, the total acidity of HA-like fractions of composted wastes of various origin and nature are much lower, or lower, than the corresponding mean values for native soil HA (Table 3). Values slightly higher than in soil HA are reported for COOK group content in HAs from composted cattle and horse manure (Businelli et al, 1984) and composted poplar bark (Roletto and Luda, 1987), and for phenolic OH group content in some composted SS and MSW HAs (Gonzales Vi/a and Martin, 1985; Garcia et al, 1989). Further, the E4/E6 ratio for HA-like fractions in composted wastes of any type is generally much higher than that typical for soil HA (Table 3).

These results suggest that HA-like fractions in composted organic wastes of various origin and nature are rich in proteinaceous materials possibly incorporated during composting, and feature a relatively high aliphatic character and low level of functional acidity. These properties are typical of uncompletely humified materials characterized by a low degree of condensation and humification, with respect to soil HA.

Table 3 Functional group contents and E₄/E₆ ratios of humic acid-like fractions isolated from composted organic wastes of various origins and nature, compared with mean values of soil humic acids.

Sample origin and type	COOH meq g ⁻¹	Phenolic OH	Total acidity	E ₄ /E ₆
<i>Sewage Sludges</i>				
Mixed with grape debris, 3m-composted ^d	1.8	5.2	7.0	—
Mixed with debris,		2.6	3.6	6.3
<i>Municipal Solid Wastes</i>				
3m-composted ^a		1.8	4.8	6.6
7m-composted ^a		2.3	2.7	5.0
Composted, means of 3 samples ^b	1.8	4.7	6.2	5.8
Vermicomposted ^c	2.0	1.1	3.1	8.2
Composted ^d	2.7	3.4	6.1	4.9
25 days-composted ^e	2.2	2.3	4.5	8.4
<i>Animal manures and Wastes</i>				
Cattlemanure, raw solid ^f	1.9	1.3	3.2	7.3
Cattle manure, 147d-composted ^f	2.2	1.3	3.5	7.8
Cow and rabbit manure ^c	1.4	1.0	2.4	7.5
Cattle and horse manure ^c	4.4	3.9	8.3	7.2
Horsemanure ^c	3.4	1.8	5.3	8.3
Cow and sheep manure ^c	2.5	1.8	4.4	8.6
<i>Plant Wastes</i>				
Poplar bark, 12m-composted ^g	4.3	2.2	6.5	—
Poplar bark, 30m-composted ^g	4.5	2.3	6.8	—
Herbaceous materials, 6m-composted ^h	2.1	2.2	4.3	6.0
Soil mean values ⁱ	3.6	3.9	6.7	5.0

^a Garcia et al (1989); ^b Gonzales Vila and Martin (1985); ^c Businelli et al (1984); ^d Riffaldi et al (1983); ^e Giusquiani et al (1989); ^f Inbar et al (1990b); ^g Roletto and Luda (1987); ^h Kammouda and Adams (1987), means of 3 samples; ⁱ Schnitzer (1978).

With increasing time of composting, however, H, N and phenolic OH contents of SS and MSW HAs decrease, O and COOK group contents increase, and C/N and C/H ratios become closer to the value typical of soil HA (Gerasimowicz and Byler, 1985; Garcia et al, 1989; Diaz-Burgos and Polo, 1991). These results indicate a partial loss of N-containing groups and aliphatic groups, and formation of more polycondensed and oxidized HAs with increasing maturation (curing) of the compost.

Data available in the literature on the elemental composition and functionalities of FA-like fractions in composted organic wastes of various origins and nature (Tables 4 and 5) are much more limited than those available for the corresponding HA fractions.

With few exceptions, the C and O contents and O/C ratio of FAs from composted organic wastes are quite similar to mean values of native soil FA, whereas the contents of K and N and values of atomic ratios fluctuate widely among various samples (Table 4) (Schnitzer, 1978; Almendros et al, 1983a; Riffaldi et al, 1983; Roletto and Luda, 1987; Hanninen and Lilja, 1994). In particular, the K content of FAs from composted MSW and slaughter wastes composted with peat or bark is higher, and C/H ratio is lower, than the corresponding mean values of native soil FA. The opposite occurs for the K content and C/K ratio of composted poplar bark and wheat straw composted with various N sources. The N content of composted MSW is three times higher and C/N ratio three times lower than soil FA, whereas N content of composted poplar bark is much lower and C/N ratio much higher than the corresponding values of soil FA. The acidic functional group content of the FA-like fraction of MSW is much lower than that of soil FA (Table 5) (Schnitzer, 1978; Riffaldi et al, 1983; Roletto and Luda, 1987). With increasing time of composting, the phenolic OH and, especially, the COOK group contents of poplar bark FA become close to the corresponding values of native soil FA.

Table 4 Elemental composition and atomic ratios of fulvic acid-like fractions isolated from composted organic wastes of various origins and nature, compared with mean values of soil fulvic acids.

Sample origin and type	C %	K	N	O(+S)	C/N Atomic ratios	C/H	O/C
Municipal solid waste ^a	45.7	6.6	6.5	37.7	8.2	0.6	0.6
Slaughter waste + peat, 4m-composted ^b	42.6	6.4	1.7	49.3	29.3	0.6	0.9
Slaughter waste + bark, 4m-composted ^b	45.7	7.3	2.9	44.1	18.4	0.5	0.7
Poplar bark, 12m-composted ^c	49.9	3.3	0.8	46.0	72.8	1.3	0.7
Poplar bark, 30m-composted ^c	42.3	3.3	1.4	53.0	35.3	1.1	0.9
Wheat straw + N additives, 2 to 4m-composted ^d	43.5	4.4	2.4	49.7	21.2	0.8	0.9
Soil, mean values ^e	45.7	5.4	2.1	44.8	25.4	0.7	0.7

^a Riffaldi et al (1983); ^b Kanninen and Lilja (1994); ^c Roletto and Luda (1987); ^d Almendros et al (1983a), means of 11 composts; ^e Schnitzer (1978).

Table 5 Functional group contents and E₄/E₆ ratios of fulvic acid-like fractions isolated from composted organic wastes of various origins and nature, compared with mean values of soil fulvic acids.

Sample origin and type	COOK meq g ⁻¹	Phenolic OH	Total acidity	C=O	E4/E6
Municipal solid waste ^a	1.5	0.8	2.3	—	3.3
Poplar bark, 12m-composted ^b	7.4	0.5	7.9	5.8	—
Poplar bark, 30m-composted ^b	8.2	1.1	9.3	3.5	—
Soil, mean values ^c	8.2	2.1	10.3	2.7	9.6

^a Riffaldi et al (1983); ^b Roletto and Luda (1987); ^c Schnitzer (1978).

The high N and K contents and the low C/N ratio and acidic functional group content of MSW FA indicate that, similar to MSW HA, proteinaceous and aliphatic materials low in functional acidity are possibly incorporated in the FA-like fractions during MSW composting. In contrast, the low H content and high C/H ratio and functionally acidity of FA in composted poplar bark would suggest a marked aromaticity and oxidation degree achieved in this FA, similar to soil FA.

Molecular Weight (MW) Distribution by Gel-Chromatography

Gel-chromatographic analysis by Sephadex G-100 of HAs isolated from composted SS mixed with either chips from city tree pruning or wine shoots shows an increase in molecular size of HAs with increasing composting time from 1 to 14 weeks (Diaz-Burgos and Polo, 1991). Similar results were obtained in a comparative, Sephadex G-50 permeation study of unfractionated (HA + FA) extracts of SS composted with grape debris for 3 to 7 months (Garcia et al, 1992a). These results are attributed to partial mineralization and resynthesis processes of complex organic molecules during composting.

The evolution pattern on Sephadex G-100 of a MSW compost HA shows only two bands corresponding to mean apparent MW of 100,000 and 1,300 Daltons, differently from a soil HA, which shows, in addition to these bands, a third band at intermediate MW (26,000 Daltons) (Giusquiani et al, 1989). Furthermore, the ratio of the 100,000 to 1,300 peak is higher for the MSW compost HA than for the soil HA.

Sephadex G-100 and G-25 gel filtration chromatograms of, respectively, HAs and FAs isolated from wheat straw composted with various N-sources for 2 to 4 months feature the predominance of high MW fractions, different from those of HA and FA isolated from wheat straw composted alone, and soil HA and FA (Almendros et al, 1983a, b). The high MW fraction in these HAs and FAs was ascribed to the presence of lignin-like structures bearing peripheral aliphatic chains.

The nominal MW distributions, estimated by gel fractionation on Sephadex G-25, G-50, G-75, and G-100, of unfractionated KS extracts of a spruce bark composted up to 24 months and a poplar bark composted up to 84 months shows almost no variation with composting time in the peak of the small size particle fraction (<5,000 Daltons), a decrease of the intermediate size particles (5,000 to 10,000 Daltons), and a corresponding increase of larger particles (10,000 to 50,000 Daltons) (Roletto et al., 1985a, b). Similar results were previously found for unfractionated KS extracts of bark residues composted up to 12 months (Maggioni and Ferrari, 1980). These results indicate the polymerization of KS precursors with increasing composting time of bark.

Isoelectrofocusing (IEF)

Unfractionated KS from composted SS (De Nobili et al, 1986; Garcia et al, 1992a) and composted MSW HAs (De Nobili et al, 1984, 1989; Ciavatta et al, 1993) display a well structured and resolved IEF pattern with intense peaks in the pH gradient region between 6.5 and 5.0, similar to soil KS, and different from uncomposted SS KS, which show a simpler IFF pattern with bands focused only at pH 5.0. The electroforetic mobility index calculated from the electrophoregrams by means of a densitometer is higher for composted MSW HA than soil HA (Gomez and Le Jeune, 1987).

With respect to KS from uncomposted manures, unfractionated KS from earthworm-composted cattle, sheep and swine manures produce IEF profiles with decreased band intensity at isoelectric points below pH 4.0, and increased intensity of components focused between pH 4.0 and 5.0 (Petrussi et al, 1988).

In general, the trends observed suggest that the stabilization and humification degree of organic matter increases with composting, and approaches the characteristics of soil KS.

Pyrolysis-Gas Chromatography-Mass Spectrometry (Pyr-GC-MS)

Data from GC-MS analysis of methylated products obtained by persulfate and alkaline-permanganate oxidation of HAs from mixtures of SS and grape debris composted for either 3 months or 7 months do not show any appreciable difference (Garcia et al, 1989, 1992b). The chromatograms feature, besides the presence of phthalates possibly derived from plastics in the SS, the predominance of aliphatic structures over aromatic ones. The persistence in composted SS HA of fatty acids apparently resistant to biodegradation suggests that they are not coextracted isolated materials, but rather true constituents of the HA macromolecules stably associated in a form not accessible to the enzymes responsible for degradation (Garcia et al, 1992b).

The pyrolysis-mass spectrum of a HA isolated from a 2-month vermicomposted SS exhibits characteristic peaks of lignins, polysaccharides and proteins, which are considered important structural constituents of this HA (Kervas et al, 1989).

Pyrolysis-GC analysis of a HA isolated from a SS composted with wood chips for 14 weeks shows a decrease in phenol and carbohydrate content and an increase of aromatic fragments, compared with the HA from the uncomposted SS (Diaz-Burgos et al, 1994). These results indicate an increase in the humification degree with composting.

The major pyrolysis products identified by GC-MS analysis in HA-like fractions isolated from vermicomposted cow and mixed animal manures consisted of lignin residues, similar to those observed in the chromatograms of grass lignin (Fig. 1) (Hervas et al, 1989; Saiz-Jimenez et al, 1989). These results suggest an incomplete degradation, or selective preservation, of grass lignin during earth-

worm composting, in addition to lignin pyrolysis products, minor amounts of N-containing compounds typical of protein pyrolysates, a few furan derivatives typically derived from carbohydrate pyrolysis, tocopherols, and some microbially synthesized phenols are identified in vermicomposted manure HA pyrolysates (Hervas et al, 1989; Saiz Jimenez et al, 1989).

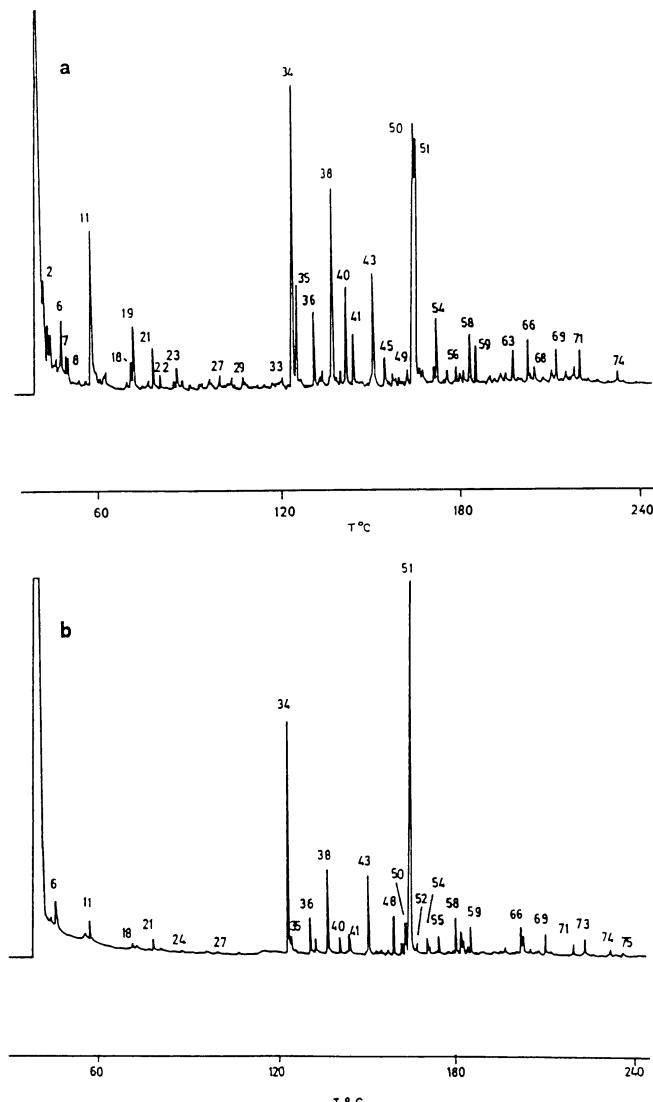


Figure 1 Pyrolysis-gas chromatograms of humic acids extracted from vermicomposted cow manure (a) and grass lignin (*Bambusa* sp.) (b) (from Saiz Jimenez et al., 1989).

Infrared (IR) and Fourier Transform Infrared (FT IR) Spectroscopy

The IR analysis of HAs from composted SS and composted mixtures of SS and grape debris indicates a loss of N-containing groups, alkyl chains and carbohydrates, and a relative increase in the aromatic character during composting (Gerasimowicz and Byler, 1985; Garcia et al, 1989, 1992b), thus approaching IR spectra typical of soil HAs (Stevenson and Goh, 1971).

Composted-MSW HAs exhibit IR spectra that partially differ from those typical of soil HAs in featuring more intense bands of amide-carbonyl groups (proteinaceous chains) and aliphatic structures, and less intense carboxyl group absorptions (Businelli et al, 1984; Gonzales-Vila and Martin, 1985; Gomez and Jeune, 1987; Sugahara and Inoko, 1987; Garcia et al, 1989; Hervas et al, 1989; Giusquiani et al, 1989, 1992, 1994).

Cattle manure HAs isolated at different stages of composting show similar FT IR spectra, regardless of the composting time (Inbar et al, 1990b). Pronounced IR bands are present of both aromatic and aliphatic structures, whereas absorptions typical of carbohydrates and carboxyl groups are relatively weak. Similar IR spectra are obtained for HAs isolated from animal manures of various origin and nature composted for different times (Businelli et al, 1984; Hervas et al, 1989).

The IR spectra of HAs isolated from wheat straw composted with various Nsources exhibit a number of bands typical of partially-degraded graminaceous lignin structures associated with N-containing moieties, known as lignoproteins or lignopeptides, and are markedly different from JR spectra of soil HAs (Almendros et al, 1983a, b). In contrast to the HA fractions, the FA fractions of these N-enriched wheat straw composts show JR spectra similar to soil FA, with a typical carboxylgroup band and limited or no evidence of absorption bands of N-groups and lignin structures (Almendros et al, 1983a).

The HA and FA fractions isolated from a 30-month composted poplar bark (Roletto and Luda, 1987) show FT JR spectra which feature strong bands of carboxyl and carbonyl groups and aromatic structures and weak aliphatic and polysaccharide absorptions, thus closely resembling Type I and Type II JR spectra of soil HA and FA (Stevenson and Goh, 1971).

The FT JR spectra of the bulk, unfractionated organic matter measured during composting of the grape marc, i.e., seed and skin by-products from wine grape processing, show an increasing peak intensity of aromatic structures and carboxylate groups, as compared with the intensity of bands of aliphatic, polysaccharide and carboxyl groups, which decreases with composting time (Inbar et al, 1991).

Nuclear Magnetic Resonance (NMR) Spectroscopy

Solid state CPMAS ^{13}C -NMR spectra of HAs from composted mixtures of SS and grape debris or wood chips show, with respect to HAs from uncomposted materials, a decrease in the aliphatic-C and an increase in aromatic-C and per-

centage of aromaticity, with no evident variations in the peaks of aminoacids and carbohydrates, and carboxylic-C, amides and esters, (Gerasimowicz and Byler, 1985; Garcia et al, 1992b). These results confirm that some aliphatic components are lost during the composting process and, as a consequence, an enrichment in aromatic structures occurs. However, the aliphatic character of composted-SS HAs appears still more pronounced than that of soil HAs.

Interrupted ^{13}C - ^1K decoupling CPMAS ^{13}C -NMR measurements of HAs from composted SS are able to enhance the resolution and reveal the complexity of the underlying organic constituents, allowing a qualitative assessment of the relative aromaticity degree of these complex heteropolymers (Gerasimowicz and Byler, 1985). In particular, a prominent peak attributed to methoxyl groups of lignin origin is found to increase with composting.

Solid state CPMAS ^{13}C -NMR spectroscopy has also been successfully applied for profiling organic matter quality in intact samples of composted and uncomposted SS (Piotrowski et al, 1984). With respect to uncomposted SS spectra, composted SS show a markedly reduced intensity of the resonances of aliphatic C adjacent to -OK and -N and carboxylic C, relative to the intensity of the aromatic C signals. Also in this case, interrupted decoupling experiments can simplify the complex spectra of intact SS, thus allowing the differentiation between lignin and humic components contained in these materials (Piotrowski et al, 1984).

The FA and HA fractions of composted MSW show ^1H -NMR spectra (Fig. 2, left, top) characterized by a lower content of protons attached to C or to O and aromatic protons, and a higher content of protons of methylene chains and alicyclic structures, compared with soil HA and FA (Giusquiani et al, 1994). Similarly, the ^{13}C -NMR spectra of composted-MSW HA and FA (Fig. 2, right) show more abundant aliphatic C in methylene chains and lower amounts of aromatic C, aliphatic C bound to OH groups and anomeric C in polysaccharides (Giusquiani et al, 1994). Furthermore, the DEPT spectrum of the composted-MSW FA shows sharp resonances of methyl and methoxyl groups, and methylene groups bound to O and/or N atoms (Fig. 2e) (Giusquiani et al, 1994). The ^{31}P -NMR spectra of HAs and FAs from composted-MSW and soil (Fig. 2 left, bottom) are, respectively, qualitatively similar, but the P signals are less intense for the former as compared with the latter (Giusquiani et al, 1994).

Surprisingly, solid state CPMAS ^{13}C -NMR spectra obtained for HAs extracted from a cattle manure composted up to 147 days show almost no differences with composting time (Inbar et al, 1990b). However, methoxy and alkyl group peaks are slightly reduced, and the peaks resulting from aromatic C, carboxyl and ester groups slightly increase in intensity during the composting process. As a whole, the NMR spectra of composted cattle manure HAs resemble those of lignins in the spectral region of aromatic ring C of lignin and in the signal of methoxyl C (Inbar et al, 1990b). With respect to lignin, the composted cattle manure HA contains, however, less aromatic C and is higher in carboxyl groups and O-alkyl C, possibly indicating carbohydrates incorporated into tannins or lignin. In general, the major structural components identified in composted cattle manure HA are

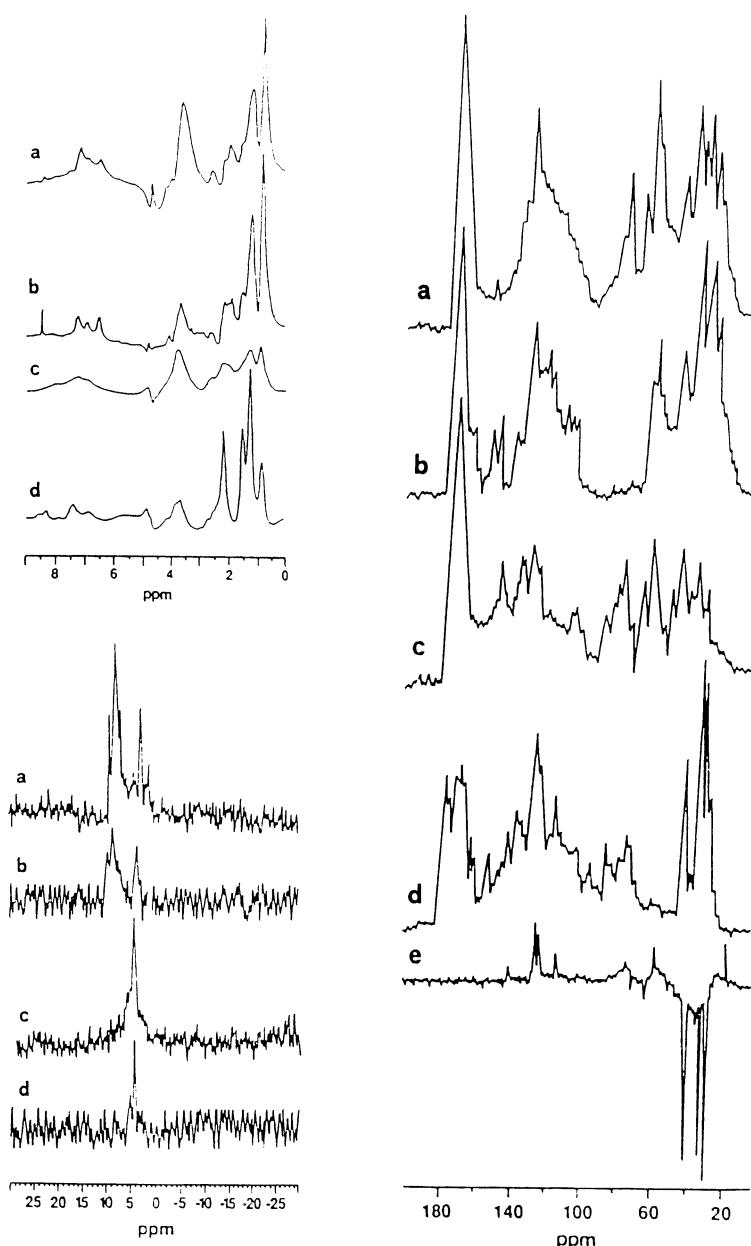


Figure 2 ¹H-NMR spectra (left, top), ¹³C-NMR spectra (right), and ³¹P-NMR spectra (left, bottom) of humic acids and fulvic acids extracted from soil (respectively, a and c), and composted municipal solid wastes (respectively, b and d), and DEPT spectrum of fulvic acid from composted municipal solid waste (e) (from Giusquiani et al., 1994).

partially degraded constituents of plant tissues, such as lignin, carbohydrates and long-chain aliphatic groups, which still retain to some extent their original structure. Thus, HA from composted cattle manure more resembles peat HA and young, incompletely humified forms of soil HA than well-humified soil HAs.

The CPMAS ^{13}C -NMR analysis of composted grape marc shows that the relative intensity of the main peaks in the aliphatic region, which are attributed to carbohydrates and /or aliphatic alcohols, slightly decreases during the composting process (Inbar et al, 1991). On the contrary, the intensity of the methoxy peak, representing lignin, the two peaks in the phenolic region, and the peak resulting from carboxylic and ester groups increases during composting.

Fluorescence Spectroscopy

Fluorescence emission of HAs from vermicomposted SS, MSW and cow and mixed animal manures and from various composted plant residues is much less intense than that of soil HA (Senesi 1989, 1992; Senesi et al, 1991). The fluorescence emission spectra of these HAs feature a broad emission maximum centered at a much lower wavelength (450–470 nm) than that typical of soil HAs, and close to that of soil FAs (Fig. 3 left).

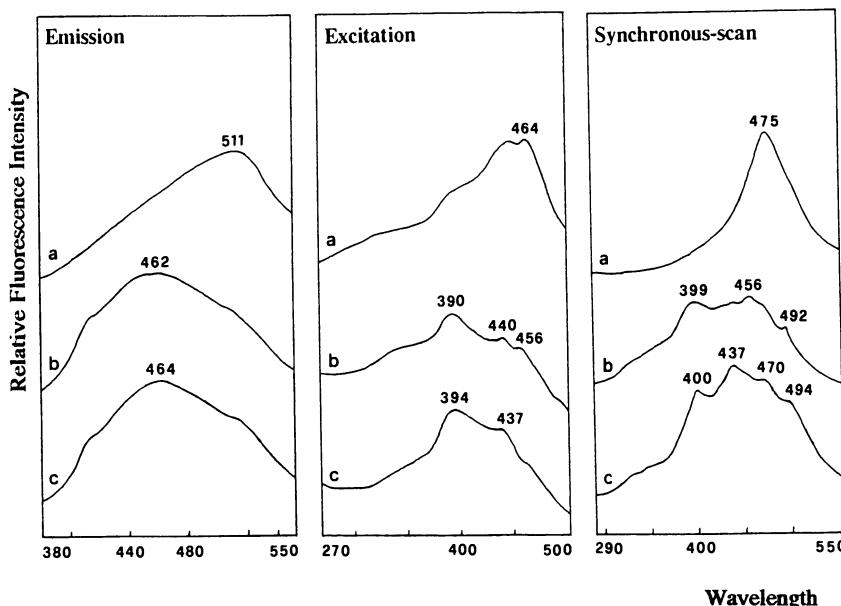


Figure 3 Fluorescence emission (left), excitation (center), and synchronous-scan (right) spectra typical of soil HA (a), vermicompost HA (b), and compost HA (c) (from Senesi et al., 1991; Senesi, 1992).

Excitation fluorescence spectra of the same vermicompost and compost HA samples show a major peak at intermediate wavelength (at about 390 nm) and less intense peaks or shoulders at long wavelengths (about 440 and 450 nm) (Fig. 3 center). These spectra are similar to those of soil FAs and different from those of soil HAs (Senesi, 1989, 1992; Senesi et al, 1991).

Synchronous-scan fluorescence spectra of vermicompost and compost HAs show several peaks and shoulders (at about 400, 440, 460, 470, and 490 nm) (Fig. 3 right), and are markedly different from those of soil HAs which feature only an intense broad peak at about 470 nm with small shoulders on both sides (Senesi et al, 1991a; Senesi, 1992).

These results likely suggest a high heterogeneity of fluorescing groups associated with simple structural units of low degree of aromatic polycondensation and conjugated chromophores in sludge HAs, compared with the high structural homogeneity and great degree of aromatic conjugation and condensation of soil HAs.

Electron Spin Resonance (ESR) Spectroscopy

The ESR spectrum of organic free radicals indigenous in HAs from composted and vermicomposted SS, MSW, and animal manures consists of a single, symmetrical resonance line characterized by ESR parameters similar to those of soil HAs, and consistent with semiquinone moieties in conjugation with an aromatic network (Senesi, 1990). The organic free radical concentration in compost HAs is, however, one to two orders of magnitude lower than that in soil HA (Kervas et al, 1989). This result reflects the lower degree of aromaticity and structural polycondensation and conjugation in compost HAs, as compared with soil HAs.

The ESR spectroscopy has been also used to characterize both indigenous and laboratory-prepared paramagnetic metal ion complexes with HAs from composted and vermicomposted SS, MSW and animal manures (Kervas et al, 1989; Senesi et al, 1992). The ESR spectra obtained are similar to, but less intense than those measured for metal complexes of soil HAs, and indicate the existence of indigenous Fe^{3+} and Cu^{2+} ions, and often VO_2^+ ions, held in inner-sphere complexes in sites involving carboxylate, phenolate and N-containing groups of compost HAs (Senesi, 1990). Similar to soil HAs, compost HAs exhibit a high residual metal binding capacity toward added metal ion probes such as Fe^{3+} and Cu^{2+} , involving sites of the same nature as those found in indigenous metal-ion complexes (Senesi et al, 1992).

Summary and Conclusions

Proper composting processes appear to stabilize to various extent the raw organic matter contained in wastes of any nature by inducing maturation and humification processes which result in the formation of KS-like materials relatively homoge-

neous in their composition, structure and chemical properties, and similar to native soil KS.

With respect to native soil HAs and FAs, HA-like and FA-like fractions in composted SS, MSW and animal manures are generally characterized by (i) a high molecular heterogeneity; (ii) a low degree of aromaticity and structural polycondensation; (iii) high aliphatic character; (iv) elevated N contents, possibly ascribed to the incorporation of proteinaceous materials; (v) marked presence of partially modified lignin moieties and polysaccharide-like structures; and (vi) low amounts of oxygen containing and acidic, especially carboxylic, functional groups.

With composting, however, a loss of N-containing groups, alkyl chains and carbohydrates, and an increase in oxygenation, carboxyl groups and aromaticity generally occur in FAs and, especially, HAs of organic wastes.

Soil application of mature, stabilized and partially humified organic wastes of any nature and origin affects, to a measurable extent, the composition, structure and chemistry of native soil KS (Senesi et al., 1995). These modifications appear to be more extensive and lasting in the FA fraction than in the HA fraction of an amended soil. In particular, proteinaceous, lignin and aliphatic structures contained in KS of organic amendments are extensively incorporated into native soil KS in forms relatively resistant to further decomposition. With increasing time after amendment addition, however, the observed structural and chemical modifications which have occurred in the amended soil KS become less and less apparent, especially in the HA fraction, with a clear trend approaching the molecular properties typical of native soil KS. This is an important result which supports the fundamental project of recycling partially humified organic wastes as beneficial soil amendments.

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Heavy Metals in Compost and their Effect on Soil Quality

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Abstract

Application of compost to soils is of considerable interest as means of maintaining a suitable soil structure as well as adding organic matter which is lost due to the practice of intensive agriculture. Among the possible negative effects of compost application to cropland is the potential release of toxic heavy metals into the environment, and the transfer to these elements from the soil into the food chain. A thorough evaluation of the effect of heavy metals following compost application may be supported by the knowledge of their behaviour in the soil environment. ‘Low metal compost’ deriving from source separated collection can be regarded as valuable resource in soil management practices because of their nutrient supply and organic matter content, particularly in Mediterranean soils which generally contain very low quantities of humified organic matter

Introduction

The growing production of wastes in the industrialized countries poses the crucial problem of their elimination. This is not only a scientific problem, but also involves economic, political and cultural factors.

The study of the present trends in treatment and their respective importance highlights the relatively limited role played by biological treatments, particularly in Italy after the numerous failures (sometimes premeditated) of many composting plants.

The management of urban wastes in Italy still presents considerable legislative inadequacies. Only a small amount of waste is re-cycled in a controlled way and finds a suitable solution in terms of disposal on the land due to the policy of integrated management being little developed. In this context the amount and quality of the organic matter present in many urban wastes, above all those deriving from some selected uses, justify the choice of a biological treatment, for the production of compost, as a means of exploiting the waste itself. By separating the organic

wastes from the other wastes it is possible to obtain, by means of the right composting process, a material sufficiently rich in humified organic matter to occupy a prime position in the market of organic soil conditioners. In this way the amount of wastes discharged or destined for incineration and landfill is reduced.

To obtain high quality products for agricultural use there is increasing recognition of the need to separate the organic wastes from the other wastes, before reaching the technological plants, if at all possible. In addition, particular attention has to be paid to the arrangement of the transformation processes of the organic wastes collected separately.

Research carried out in the last years have shown that the agronomic value of various types of composts obtained in this way, if used in the same organic amounts is very similar to that of manure. Both compost and manure in fact generally have low coefficients of mineralization as regards nitrogen and their effect on crop yields is not great. These substances alone are therefore not able to satisfy the nutritive needs of crops. However, these considerations may not hold for quality composts, for which it is possible, with an appropriate choice of matrixes, to obtain good levels of fertilizing elements. The compost can contribute decisively to the reintegration of organic matter in the soil. This is of vital importance for Italian and Mediterranean soils, which are generally poor.

As is well-known, the main limitations to the use of biomasses in agriculture are those deriving from the presence of inert substances such as plastics, glass and textiles or from toxic substances such as heavy metals and synthetic organic substances, whereas the lack of stabilisation of the organic matter can be eliminated by a process carried out efficiently.

Among the various types of contaminants, particular attention has been reserved for heavy metals, given that possible organic micro-pollutants are subjected to biodegradative phenomena in the composting process and therefore end up in the finished products only in extremely low concentrations. In addition, the soil, by itself, is able to biodegrade almost all the organic composts in the wastes, whereas the same cannot be said of the heavy metals, which have the tendency to persist and accumulate.

It is therefore necessary for the assessment of the parameters of quality of the compost to consider both the aspects connected to agronomic efficiency and those of environmental compatibility.

Heavy metals in compost

As known heavy metals in compost derive both from the contamination of different kind of wastes which contain high concentrations of these elements, and from the leaching of metallic wastes carried out by organic acids which are produced during composting.

In order to deal with the problem of heavy metals in the compost, it is particularly important to determine the origin of these elements in urban wastes.

Naturally the amount and nature of the wastes vary with geographical and social conditions and therefore there is a notable variability of composition. However, it is possible with a general estimate to consider that the distribution of heavy metals in urban wastes can be roughly evaluated (Rosseaux 1988).

Some metals, therefore, have a precise origin, whilst others are more uniformly distributed in all types of materials. A good example is that of batteries, which represent less than 1% in weight but which can contribute to unsorted urban waste as much as 95% of the total mercury content. The elimination of mercury from most batteries has in fact brought about a drastic drop in the presence of this element in solid urban residues. Table 1 shows some data relative to solid urban wastes produced in France (Amman 1993).

Table 1 Decrease in the Mercury content of solid urban wastes in France

Year	Hg (ton)
1985	270
1988	170
1993	35
1994	25

Based on what has been said, the premise for obtaining a high-level compost is that intrinsically 'clean' biomasses are involved in the composting process. An efficient differentiated recovery of wastes can significantly reduce the hazard presented by heavy metals. In particular it is important to obtain an adequate separation of the organic matter both to make the evolution of the composting process easier and to obtain a high quality final product. The separation at source of the organic fraction, generally, influences positively the metal content of the compost obtained from it (Golueke and Diaz 1991, Spencer 1994). However, it is inevitable that a certain amount of metals will be present also in the compost originating from a sorted collection and the heavy metals, in the presence of fermentable organic matter in the particular leaching environment created following microbial activity, migrate into the biodegradable matrix without any further possibility of being separated.

The total content of heavy metals in the compost is of primary importance. Therefore it is essential that the amount of these elements in the compost destined for agricultural use does not reach thresholds which can damage either soil fertility or the food chain. The chemical species in which a metal is present is also of significant interest from the environmental point of view.

In fact, heavy metals can be present in various chemical forms, as salts (carbonates, sulphites, etc.), bound to organic matter, or in an adsorbed or exchangeable form. The nature of the chemical species depends on the origin of the heavy metals and on the modifications induced by the biological treatments of organic wastes, (Canarutto et al 1991) and can also influence the behaviour of these elements in the soil, above all immediately after the addition of compost.

Heavy metals in soil

While taking into account the important diversity of the various chemical forms of the metals in the compost, it is the soil, above all, which triggers the fundamental processes that determine the passage of these elements into the food chain. The main factors that influence the solubility, and hence the environmental mobility, of heavy metals are: pH, Cation exchange capacity, Organic matter , Water and thermal regime of the soil

The **pH** is probably the most important factor, due to the fact that the activity of a metallic ion in soil solution depends directly or indirectly on the pH. In fact, most ions able to precipitate metals are weak acids which become soluble following protonations and shifting of the metal from the solid phase. In addition, also the specific adsorption sites depend on pH, so that any increase in acidity reduces the number of sites available for the heavy metals. As an example figure 1 shows the amount of Cadmium present in the soil solution, and therefore available for plant nutrition, for different values of pH and total concentration. As can be seen, with equal total concentrations in the soil, the amounts of metal in a soluble form are notably different depending on the pH, which therefore is shown to be a factor of environmental importance even greater than that of the total content of the metal in the soil.

Cationic exchange capacity. The mobility of the metallic ions in many soils is regulated also by the cationic exchange capacity. As is well known, this is the extent of negative charge present on soil particles and is also therefore an index of the soils capacity to adsorb and hold metallic cations. Both organic matter and clay minerals contribute to the cationic exchange capacity. It must be emphasised how the exchange capacity deriving from clays is very little influenced by pH, the contrary of what happens for that deriving from the organic matter. The cationic exchange capacity undoubtedly represents an important parameter in holding metals with bonds of an essentially electrostatic nature.

Still more important is the role played by the **organic matter**, which can interact with the metals, so forming complexes and chelates of varying stability. The complexing ability of the humic substances essentially depends on the content of functional groups containing oxygen, and also on the amino and imino groups.

The use of compost with the contribution of metals in various chemical forms, organic matter of varying structures able to complex them, and with the possible variations of pH induced in the soil, can alter the distribution of the heavy metals in the various complexes and can therefore vary their availability for plants. In fact, the root system of plants is able to absorb not only the free ions present in the soil solution, but can also interact with the weakest metal-organic matter complexes.

Finally, **the water and thermal regime** of the soil influence the redox processes of heavy metals and the more general processes of decomposition of the organic matter in the compost. In this regard the depth of soil working is important as this determines the nature of the contact and of the reactions between the metals and soil constituents at different depths.

In outline, heavy metals in the soil can be considered present in various chemical forms as reported in Table 2.

Table 2 Chemical forms of heavy metals in the soil.

-
- a) simple or complex ions in the soil solution,
 - b) exchangeable ions,
 - c) linked to the organic matter,
 - d) occluded and coprecipitated with oxides, carbonates and phosphates, or other secondary minerals,
 - e) ions in the crystalline lattices of primary minerals.
-

The first three chemical forms are in equilibrium with each other. These are the forms which are effectively available for plant nutrition, and environmentally significant.

The distinction between the various forms is not well-defined. For example, it is very difficult to distinguish adsorption reactions from those of precipitation, or if the adsorption occurs due to the clayey materials or because of the presence of the humic substances, etc. For a real understanding of the danger of these elements, an in-depth assessment of their reactivity in the soil treated with compost is essential. There must be an evaluation of the amount of heavy metals in a mobile and/or mobilizable form, which are able to enter the environmental processes. With this aim it is common in soil chemistry to use methodologies of chemical extraction, that is laboratory trials besides field experiments, in order to identify these metallic species of environmental relevance. Use of sequential extraction with various chemical reagents generally in order of increasing extractive force are considered of greater value than single extractant (Petruzzelli et al. 1989, McGrath and Cegarra 1992).

The main reactions which lead to the distribution of heavy metals in these different pools are: *Hydrolysis* In soil solution metal ions are mainly coordinated to water molecules and thus remain in a free form; however, in the presence of available ligand, the formation of more stable complexes prevails. Hydroxyl complexes are among the most abundant; because heavy metals easily hydrolyse in the normal pH range in soil. The products of hydrolysis can further release more protons from the coordinating water molecules. In fact the formation equilibrium constant indicates the strong influence of the pH, which will be determined both from the soil and the waste characteristics

Complex Formation For a metal ion, in the soil solution, the formation of complexes with an uncharged ligand can progress further until there is a complete displacement of the water molecules, assuming that the coordination number of the metal does not change.

In the soil a particular role is played by the humic molecules in this type of reaction in which the 'donor' atoms are oxygen in carbonyl, carboxyl and hydroxyl groups, nitrogen in amino and azo groups. The addition of compost may also increase the content of some anions such as chloride, nitrate phosphate which are able to complex heavy metals. Moreover compost can contain also organic

molecules which, given the presence of the dissociated functional groups, are capable of forming more or less stable complexes with the metallic ions, more or less soluble in relation to molecular weight, pH and concentration of ligands.

Oxidation Reduction The speciation of heavy metals is also considerably influenced by redox reactions, both of a chemical nature and of micro biological origin. A role of particular importance regarding this type of reaction is played by iron and manganese oxides, which generally occur as mineral coatings and nodules in soils. In general, heavy metals are less soluble in their highest state of oxidation, therefore the capacity of the iron and manganese oxides to oxidise the metals contributes to a decrease in their solubility and mobility in the environment.

Precipitation and adsorption reactions The various chemical species of heavy metals present in soil solution are in equilibrium with those retained on the solid phase. The possibility for ion or soluble complex to remain in solution depends on many factors which include: the concentration in the solution of the metal and of other competing cations; the concentration in solution of ligands and chelating agents able to form complexes; the pH and rH; the nature and quantity of adsorption sites present on the solid phase .

Displacement from solution can occur essentially by means of either precipitation or adsorption. Depending on the process involved, which is strictly connected to soil conditions and to the kind of waste added, there is a variation in the type and intensity of the forces involved which maintain the ions in pools that are more or less immediately available to root absorption, or leaching . It is a typical behaviour of heavy metals to have the possibility of being involved both in normal cationic exchange reactions, (principally connected to the charge characteristics of the ion and to coulombian-type attractions) and also in specific interactions which involve various factors such as the geometry of the adsorption site, ion size and coordination number, hydration energy, polarizability, etc.

The effects on soil quality

Concern regard the heavy metal pollution of agricultural soils is related essentially to crop quality and human health . The most relevant question is to determine if the utilization of compost will produce a deterioration of soil quality by increasing the original content of heavy metals and / or their mobile forms and then their bioavailability with the related effects of phyto-toxicity by changing the interactions with organic matter in the long term.

The addition of compost to soils, particularly if derived from municipal solid wastes, can produce an increase in the concentrations of metals in agricultural soils. This is due to the higher concentrations of metals in the biomass than in most soils. However, once the compost is mixed into the plough layer of non acidic soils, the metals do not leach appreciably and very often they are not in a more bioavailable chemical form even if we do not know what the chemical form of the metals will be in the long term.

Organic matter appears to play different roles in controlling trace metal availability. Immediately following the application of sludge or compost to soil, there is an increase in bioavailability which may be ascribable both to the rapid organic matter decomposition that may release soluble metals (Chaney and Ryan, 1993) and to the incomplete initial mixing of biomasses with soil. This produces a situation of non equilibrium , in which the soil adsorptive properties are not completely effective

Moreover according to the molecular complexity some metal cations such as Cu²⁺, are strongly bound and are thereby prevented from diffusing to roots, while organic materials of different kinds form complexes with heavy metals from which the plant is able to extract trace metals (Petrizzelli et al. 1977, McBride,1994).

The complexes of the heavy metals with the soil organic matter can be subdivided depending on their solubility, which determines their environmental mobility, as reported in Table 3.

Table 3 Complexes between organic matter and heavy metals

-
- a) organic matter of high molecular weight containing aromatic nuclei condensed in polymer complexes, which have a very high affinity for heavy metals and are for the most part insoluble
 - b) organic matter of low molecular weight of recent origin, essentially deriving from the break-up of microbial cells, roots, etc.. They represent the primary units for the formation of humic composts of a higher molecular weight and generally exhibit high solubility
 - c) soluble organic matter, which forms insoluble salts reacting with the metals.
-

One of the most important questions which is now debated derives from the fact that field experiments have shown that with time, the levels of mobile metals added with compost or sludge stabilise at lower values, and bioavailability is reduced. The phenomenon has been ascribed to the adsorptive properties of biomasses such as sewage sludge which can prevent excessive uptake of many of these metals into crops, a protection attributable largely to the added organic matter, but can this protection be considered to be permanent or effective for all toxic metals, also in the long term?

Recent studies concerning the protective effect of sewage sludge starting from the same data reached an opposite conclusion. Chaney and Ryan (1993) stated that the specific metal adsorption capacity added with sludge will persist as long as the heavy metals of concern persist in the soil, but McBride (1995) rejected the argument suggesting that the slow mineralization of organic matter in sludge treated soils could release metals in more soluble forms, (sludge time bomb hypothesis).

The interest in the study of the adsorption of heavy metals has emerged particularly in cases in which waste products, such as sludges or compost , are added to soil. The reason for this interest is that this practice not only does introduce relevant quantities of heavy metals into the soil, but also organic materials which can naturally influence the dynamics of the metals in the soil.

When the soil is treated with organic biomasses the metals are adsorbed not only onto the soil but also onto the organic matter deriving from the waste materials. The increased sorption capacity of the soil can be explained through a preliminary adsorption on soil of organic compounds contained in the sludge , as confirmed by NMR, IR and HPLC measurements performed on the sludge extract before and after interaction with the soil(Petronio et al. 1994) .Such substances, previously adsorbed onto the soil, give rise to new adsorbing sites with a higher affinity for the metals. As an example distribution coefficient of Ni is reported in figure 1.(Petruzzelli et al 1992)

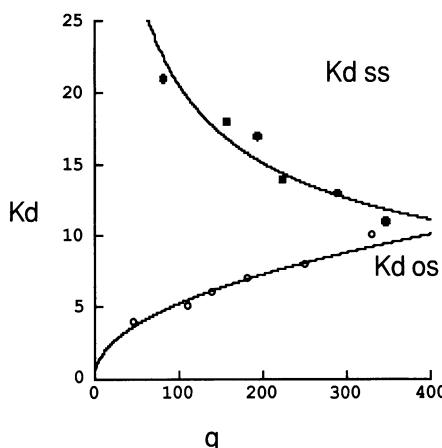


Figure 1 Pattern of Ni distribution coefficient, with (Kd_{ss}) and without (Kd_{os}) sewage sludge, as a function of metal sorbed by the soil q ($\mu\text{mol g}^{-1}$)

At low levels of concentration the metal is for the most part held by the soil treated with sewage sludge , but, as the adsorbing sites gradually become saturated, the distribution of the metal between the solid and liquid phases returns to its initial state in the untreated soil. Analogous behaviour (increase in the amount of metal held by the soil, modification of the type of isotherm) was observed in the case of cadmium, zinc, lead, and copper (Petruzzelli et al.1994).

It is important to stress that the sorption capacity is inversely related to the amount of metal sorbed so that low-metal biomasses are more suitable to provide new sorbing sites. In any case adsorbing capacities decrease with the increase in the 'covering' of the adsorbing surfaces of the soil by the heavy metals.

A similar process can reasonably be hypothesised also in the case of compost addition to soil Compost amended soil shows generally an increase in the adsorptive properties with respect to the heavy metals; (Petruzzelli et al.1990) if this phenomenon is ascribable to the effect of the added organic matter as shown for sewage sludge , the potential dangerous effects could be related to the mineralization of organic, matter which could release adsorbed or complexed metals.

Pluriennal research on the behaviour of compost-applied heavy metals is lack-

ing, and it is consequently quite difficult to develop models able to describe the behaviour of heavy metals in the long term derived from short term experiments. Field experiments which are the most important source of data are carried out with different environmental conditions, plant species, and soil types; moreover, there is a lack of statistical significance between soil content and plant uptake of heavy metals.

Following the cessation of biomasses application it has been generally observed, a fairly constant extractability (Mc Grath 1987) and sometimes a slow change in bioavailability (Davis and Carlton-Smith. 1984). In some cases it has been shown that about 30% of organic matter derived from sewage sludge remained in the soil even if the application had stopped more than 20 years earlier. The residual organic matter can therefore play an essential role in retaining heavy metals ,(and in increasing soil adsorptive properties), and these metals in turn can protect organic matter by exerting a toxic effect against the micro-organisms which are able to decompose humic-like materials (Minnich and Mc Bride 1986).

In any case, it is evident that the characteristics of the soil determine the amount of heavy metals accumulating after addition of compost. It has been estimated that the use of a hypothetical compost with the maximum permissible levels of heavy metals added at the maximum permissible rate by Italian legislation, will reach the Italian limit values of allowable soil concentration after 100, and 256 years of yearly application, for Zn and for Cd respectively (Petruzzelli 1989).

However, to establish whether soil has exceeded the thresholds of metal which can damage the food-chain, the most critical soil parameter is not the total heavy metal content, but the of amount of mobile species. However research is needed to determine if the solubility or activity of these metals changes significantly as organic matter from compost decomposes in the soil.

The amount of heavy metals removed by plants obviously depends on the crop species cultivated, but yield cannot be used as the index of toxicity for metals or compost quality. This is because it is affected by many factors, related to chemical and physical properties of biomasses which can mask metal toxicity for example the beneficial effects of organic matter on soil physical structure and water holding capacity.

Conclusions

The soil has always been the destination of wastes and it has always carried out its function of a natural system able to interact with wastes. In fact, soil organic matter derives from the plant and animal residues introduced every year into the soil. Agricultural practices have always used residues such as manure, straw, etc. Even if in this context the soil has benefited from interaction with residues, there are certain kinds of wastes which produce no beneficial effect for the soil, and can significantly lower the functions of protection that the soil carries out as regards

other environmental areas. It is therefore important that some types of wastes are separated from others in order to avoid negative effects. This is so that homogeneous materials can undergo the most suitable treatment. Knowledge of the distribution of heavy metals in the various types of wastes can supply valid help in prioritising the actions to be undertaken in terms of the sorting of wastes and differentiated waste collection in order to obtain a high quality compost with a limited content of pollutants, integrating this process with those of direct recycling of matrixes which can be reintroduced into productive cycles.

Differentiated sorting of organic wastes can, today, be arranged according to the knowledge of the quality and quantity of wastes on a regional basis. The organic fraction of the solid urban wastes selected, the organic deriving from domestic uses, markets, catering sectors, agricultural foodstuffs industries, are possible examples of organic wastes with a low content of pollutants which can be used for the production of quality compost.

We should now know that such a valuable resource as the soil should be used in this generation without restricting the requirements of future generations. This means avoiding any activity which might damage irreversibly the soil quality. Nevertheless at present, beyond biomass utilization, atmospheric deposition, additives in animal feed, uncontrolled discharges of industrial residues, etc., are increasing the level of heavy metals in agricultural soils. Knowledge of the chemistry of heavy metals in soils treated with biomasses means that this environmental problem can be faced on a scientific rather than emotive basis, recognising that it is necessary to accept the existence of these elements in the environment.

Therefore, today it is possible to correctly deal with the legislative aspects of the problem, for the non-polluting use of a material such as compost, in which many elements of fertility can be found and whose production in the context of the vast problem of waste disposal represents an environmentally correct option. In the likelihood of a more restrictive legislation in the future the aim to be reached is no longer that of keeping within the limits established by the environmental norms, but to obtain a product attractive for wide sectors of the market.

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Occurrence of Microorganisms Pathogenic for Man and Animals in Source Separated Biowaste and Compost – Importance, Control, Limits, Epidemiology.

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Abstract

The utilization of biowaste is an important factor for relief of the environment. But it should not be ignored that a variety of pathogens can be found in the raw material of biowaste. It is therefore necessary that by the composting technology the guarantee is given that these pathogens are inactivated during the composting process. The pathogens of importance in this respect belong to microbial groups of bacteria, fungi, viruses and parasites. The main role play salmonellas which reach the biowaste with kitchen waste of households, restaurants, canteens etc. Most of this material is of animal origin.

The epidemiological importance of insufficiently treated food scraps and swill has been proved in Germany during the epizootic of European (Classical) Swine Fever in 1993/94. Since no sufficient experiences are available about the tenacity of viruses pathogenic for man and animals in the composted biowaste further investigations are necessary. But generally it can be said that the temperatures required for the inactivation of pathogens in compost which are stipulated in regulations of various countries do ensure that the health of humans and animals is not endangered when the compost facilities are operated in accordance with the relevant regulations.

A further important factor of biowaste composting is the problem of occupational safety. The employees in composting plants are exposed to various harmful influences: dangerous substances, malodors, dust, microorganisms and their toxins, noise. Especially the problem of aerosolized microorganisms like *Aspergillus fumigatus*, other bacteria and viruses and their possible influence on the health of employees and of residents in the surroundings of composting plants are discussed. Recommendations are mentioned for a better outfit of workplaces to improve the protection of employees from microbial emissions. For the protec-

tion of the environment the use of biofilters for purification of waste air is recommended.

Introduction

The collection and utilization of biosolids is an important factor for the success of the so-called 'circle economy' as a component of modern waste management policy. The exploitation precept of the German Waste Disposal Legislation therefore demands the separate collection and composting of the organic raw materials usable for that purpose. To meet the demands of the German legislator a country-wide collection of these residues is necessary. The progress in that field can be proved for Germany with some figures: the capacities of plants for the utilization of biowaste increased from 1985 with 105,500 Mg/a to 804,095 Mg until May 1993, which means that 8 millions inhabitants were linked to collection systems for biowaste. Under consideration of plants which are under construction or in the approval procedure it was calculated that until the end of 1996 ca. 2.4 millions Mg/a of biowaste from 24 millions of inhabitants are obtained and processed (7).

Small scale composting of food and yard waste of households is a traditional method for a useful utilization of residues and offers people an opportunity to contribute to and benefit from part of the solid waste solution. Compared to the municipal collection of biowastes and their utilization the small scale composting on own premises of households turns out as a considerable reduction potential concerning transportation, collection expenditure, size of composting plants and expenditure for marketing of the compost. According to a rough estimate in Germany, by the small scale composting of biowaste of households on their own premises further 5.3 millions Mg/a of compost are produced, which results in a total amount of 7.7 millions Mg of compost in one year. This has to be considered for calculations of the further need of large scale composting facilities to prevent oversized planning (18).

This development, which is in itself encouraging with regard to the relief of the environment, should not make us forget that biowastes do require a discussion from the hygienic point of view, because they may contain pathogens which can endanger the health of man, animals and plants and therefore should not be contained in the final products of biowaste processing. This is the legal consequence of the principle in 10 of the new German 'Law on the Avoidance, Utilization and Disposal of Wastes' (coming into force 7 October 1996), which stipulates that wastes have to be disposed of in such a manner that the welfare of the general public is not impaired. An impairment exists especially when the health of man is affected, animals and plants are endangered and waters and soil are harmfully influenced.

This principle is a commitment for the fields of medical, veterinary and phytohygiene to expertly advise the population and waste disposal enterprises that endangerment of the environment by pathogenic microorganisms is prevented.

The duty to advise people begins already in the household with the storage of biowaste and continues from collection and processing to the utilization of the final products.

Occurrence and Importance of Pathogenic Microorganisms in Biowaste

The organic residues may contain pathogens from the groups of bacteria, viruses, parasites and fungi. The species and their numbers are unlimited. Table 1 shows a selection of pathogens which possibly may occur in household wastes.

From the facultatively pathogenic agents, which cause only disease in immunocompromised individuals, the obligatory pathogenic agents have to be distinguished on principle. For reasons of medical and veterinary hygiene special attention must be given to the occurrence and quantity of the obligatory pathogenic agents, because a potential general danger emerges from them which does not fall in the individual liability of the processing enterprise and utilizer of the systems, raw materials and final products. For that especially salmonellas have to be considered as pathogens, because after the utilization of a salmonellas containing compost in agriculture epidemiological circuits can emerge and cause a certain risk of infection for the utilizer. Besides salmonellas some other bacterial pathogens can occur in the raw material (Table 1). Viruses of importance for livestock are primarily the causative agents of Classical (European) Swine Fever, Aujeszky's Disease and Newcastle Disease which, as has been proved, are transmitted via food wastes. Other viruses pathogenic for animals can during the viraemic state settle in meat, organs and bones. In the case of European Swine Fever it is known that the virus can be found already in the bone marrow before the disease is diagnosed during meat inspection. Further viruses can occur in bedding of pet animals, baby diapers or in grass cuts which are soiled with dog or cat feces. It is still not very good understood what the epidemiological significance of viruses in compost is like. Endangering of man was considered rather unlikely because viruses cannot multiply outside of living cells. Our own recent research has shown that airborne viruses can be detected in aerosols within composting plants (11).

Table 1 Possible Occurrence of Microorganisms Pathogenic for Man and Animals in Biowaste of Households (1, 4, 8, 10).

Bacteria	Viruses
<i>Salmonellas</i> , <i>E. coli</i> , <i>Enterobacter</i>	Entero-, Hepatitis-A-, Poliomyelitis-, Coxsackie-, ECHO-, Reo-, Adeno-, Parvo-, Pestiviruses
<i>Yersinia</i> , <i>Streptococci</i> , <i>Proteus</i> .	
<i>Pseudomonas</i> , <i>Klebsiella</i> , <i>Citrobacter</i>	
Parasites	Fungi
<i>Taenia</i> , <i>Ascaris</i>	<i>Aspergillus</i> and others

Since salmonellas can be found in nearly every sample of biowastes from households it can be concluded that they have the greatest significance of the bacterial pathogens. In own investigations we isolated salmonellas from raw biowastes of three composting plants, in dependence on the number of samples, between 72 % and 100 % (12). Other authors reported a range of variation between 0 % and 33 %. At random counts of the numbers of salmonellas proved amounts of below 10 to 106 cfu/g wet weight (3, 12, 14). Basically one has to start out from the assumption that each pathogen which is excreted by man and animals can appear in the raw biowaste. The same is valid for the resting forms of parasites, though their epidemiological significance in this context is low. But it can play a certain role in small scale food and yard waste composting, because of the usually very low temperatures in these systems.

As an important representative of facultatively pathogenic microorganisms the fungi *Aspergillus fumigatus* is considered. It can be isolated not only from raw biosolids and compost but also from all other organic materials. Their epidemiological significance has recently been very intensively discussed by various authors (4, 5, 6, 9, 17, 20, 21).

Conditions and Procedure Parameters for Elimination of Pathogens in Biowastes

Prerequisite for the inactivation of pathogens during and by the composting process is the observance of necessary parameters like temperature, exposure time, water content, aeration and pH-value by the technology used. Critical points of windrow composting are the outer parts of the walls, because they are influenced by the ambient temperature. Therefore the technique for turning of the windrows must ensure that also the material of the outer walls is transported into the interior of the windrow to guarantee that it is also exposed to the necessary temperature and time for the reliable inactivation of pathogens.

The necessary temperature/time requirements which are provided in various countries are differing only marginally (Table 2). But all authorities which have issued these regulations seem to be convinced, that - if the composting processes are properly managed – the sanitation of the final compost product is ensured.

Of all regulations listed in Table 2 those of the U.S.EPA seem to be the most complicated as a whole, because they include all processing techniques for 'biosolids', which 'are a primarily organic solid product produced by wastewater treatment processes that can be beneficially recycled'. Apparently these regulations are also valid for biowaste which is not a derivative of wastewater treatment processes. Due to the difficulties in interpreting the Part 503 Rule, EPA decided to publish at least two voluminous explanatory notes (20, 21), one of which is called 'A Plain English Guide to the EPA Part 503 Biosolids Rule', which makes one understand how more difficult it is for people, who do not have English as native language, to interpret these rules.

A main difference between the US-regulations and e.g. those in Germany is the fact that in Germany the composting system is tested for its hygienic efficiency already as prototype. For that purpose so-called 'germ-carriers', which are infected with *Salmonella senftenberg* W 775, are inserted into the process and pass through the system. No salmonellas should be detectable at the end of the process. New composting plants which are no prototype have to be tested within 18 months after beginning of their operation with the same method as the prototypes. Both controls have to be done twice and in case of not enclosed windrow composting, one test must be made in winter between December and February. In approved composting plants the produced compost is tested once a year for salmonellas. In plants with an input below 10,000 Mg/a one composite sample per 1,000 Mg, at least three composite samples, and in plants with an input of more than 10,000 Mg/a one composite sample per 2,000 Mg, at least five composite samples have to be investigated. These yearly controls must ensure that no salmonellas can be found in 25 g of the composite samples.

Table 2 Temperature/Time Requirements for the Hygienic Control of Biowaste Composting Plants in various Countries

Country		Time/Temperature Relations
Austria		> 60 ° – 65 °C for altogether at least 6 days
Denmark		> 55 °C for at least 2 weeks
Germany (Draft)	Open windrow	> 55 °C for at least 2 weeks, or 65 °C for at least 1 week
	Enclosed windrow, In-Vessel Techniques	> 60 °C for at least 1 week
Italy (4)		> 65 °C for 2–3 consecutive days, final material must be biologically stable to prevent pathogen regrowth
Switzerland		> 55 °C for at least 3 weeks, or > 60 °C for at least 1 week, or a temperature/time combination of equal standard
United States CFR Part 503 Sewage Sludge Biosolids		
Processes to significantly reduce pathogens (PSRP)		> 40 °C for at least 5 days for windrow composting: > 55 °C for 4 hours during these 5 days
Processes to further reduce pathogens (PFRP)	Static Pile or In-Vessel	> 55 °C for at least 3 days
	Windrow	> 55 °C for at least 15 days with at least 5 turnings

To test the composting plants for their sanitizing effect on phytopathogens other test microorganisms are used: tobacco mosaic virus (TMV), *Plasmodiophora brassicae* (Pb) and, as a trial, tomato seeds. The ulterior motive for that is to find out whether TMV and Pb could be substituted by tomato seeds. The testing of prototypes of composting systems is performed in the same manner as described for the tests with pathogenic bacteria, with the only difference that the product of approved composting plants is controlled not once a year but only every third year with the described method using 'germ carriers'. The involved phytopathologists made that proposal because according to their opinion it is not possible at present to isolate phytopathogenic microorganisms reliably from a big mass of compost and at justifiable costs (19).

Epidemiological Considerations

In Germany in 1993/94 an epizootic of European (Classical) Swine Fever (ESF) raged and - due to the questionable no-vaccination policy of the European Union (EU) – caused damages of ca. 1,5 billion Deutsch Marks. In this context the question was discussed whether this disease could be spread by compost made from biowaste. Having sufficient knowledge about the heat resistance of the causative virus the scientists could calm down the public, that under normal conditions the virus is inactivated by the temperatures which emerge during the composting process (Table 2). Only one uncertainty was left and that is the fact, that the virus very early after infection is settling in the bone marrow of pigs who do not yet show clinical signs of illness and therefore are slaughtered without recognizing their disease during meat inspection and thus the meat is processed for human food and reaches the households and catering enterprises and from there as scraps and other food wastes the composting plants. There is no experimental evidence yet available on the inactivation of ESF-Virus which occurs in bones or pieces of them and the transmission of the disease via compost which is used in agriculture or professional gardening for instance to wild boars. Respective research is urgently necessary. But all in all there is no evidence available that infectious diseases of people or animals were caused by contact with composts in an epidemiological or epizootological scale. This could possibly be interpreted as an indirect proof of the efficiency of the internationally stipulated rules for the temperature/time relations during the composting processes.

Occupational Health Problems of Composting

Since several years the question of possible adverse health effects which employees of composting plants and persons living near a composting facility might experience, has to an increasing extent vehemently been discussed in the public. Therefore the German Ministry for Research and Technology in 1991 established

in the framework of the program 'Labor and Technology' a joint research project called 'Estimation of Health Risks for Employees in Waste Disposal by Microbial Emissions and Development of Occupational Safety Measures'. Involved in this study were institutes of four different universities. One institute investigated the emission of fungi and dust, another one of thermophilic actinomycetes and a third one of bacteria and viruses in biowaste composting plants, sorting plants for valuable materials or municipal solid waste, waste incineration plants and sanitary landfills. The results of these investigations were analyzed and evaluated by an institute for occupational medicine (5, 17, 20).

It is not possible to discuss all the results in this paper. But it should be mentioned, that – to our knowledge for the first time – also intensive virological studies were made in such a variety of waste disposal facilities which resulted in the isolation of various types of Coxsackie-B-, ECHO- and Herpes-simplex-Viruses. The linkage between the occurrence of these viruses and a possible risk of infection for humans remains to be elucidated by further epidemiological studies. The results, however, indicate that, besides of an increased dust and germ concentration in such facilities, there is substantial evidence of increased viral contamination as well (11). The internationally discussed threshold limit values for the microbial content and the endotoxin concentrations of bioaerosols published by a Swedish researcher (total germ count 10,000 cfu/m³ air, gram-negative bacteria 1,000 cfu/m³ air, endotoxins 0,1 µg/m³ air) were included in the discussion of the results of that study. The results of the German joint research project were presented, discussed and evaluated in two conferences, together with reports of scientists from Austria, Denmark and Switzerland (5, 17; 11, 15).

One of the leading German scientists for medical hygiene summarized the results of these and other studies and drew the following conclusions (13). Numerous investigations are concurrent with the result that the pollution of the air with microorganisms in the waste disposal facilities is higher than normal. On the other hand the medical knowledge about the necessary infective doses are rather sketchy. In other words: an air pollution with microorganisms exceeding the normal bounds does not inevitably result in disease. This at present unsolved dilemma naturally questions the establishment of limit values in recommendations or ordinances. Each establishment of such values therefore is arbitrarily, especially because epidemiological investigations are lacking. This also applies for the establishment of standard values since at present the measuring methodology for airborne microorganisms is not standardized. The range of variations of the determined numbers of microbes is very large with deviations of more than the power of two. Any establishment of limit values in this situation would be just as arbitrarily. In spite of these present methodological difficulties of course everything possible has to be done to protect the staff in composting and other waste disposal plants from diseases. How this can be achieved is described elsewhere (17, 5, 11, 15, 9, 20, 21).

Also in the USA considerable efforts have been made in recent years by various working groups to answer the question: 'Do bioaerosols associated with the oper-

ation of biosolids or solid waste composting facilities endanger the health and welfare of the general public and the environment?' In an impressive and substantial report of nine scientists, which was reviewed by another nine scientists, the report "Bioaerosols associated with composting facilities" was published in autumn 1994 (9). Among others the report comes to the conclusion that the available epidemiological studies of both the workers and the general population are inadequate solely to determine whether or not significant risk exists from exposure to bioaerosols.

Both, the European and the US scientists elaborated recommendations for further research which is needed to fill the gaps in the insufficient knowledge of this important area of occupational and public health (17, 2, 5, 16, 11, 15). Within the bounds of this paper more details about these recommendations cannot be given with regard to time and therefore the reader must be referred to the literature cited.

To bridge the time until final conclusions can be drawn from further investigations, practical recommendations were given for various work-places in composting facilities to improve the conditions for the workers e.g. in the delivery and sorting area, composting area (windrow, in-vessel), screening and curing area by minor technical changes. These can help to reduce the microbial emissions. A further important aim for the future should be to automate technical processes in the plants to such an extent that areas which are considered to be precarious from an occupational health point of view, can be kept free of human labor (5, 11, 15, 17). The protection of the environment from bioaerosols and noxious odors would further be improved by the use of biofilters in plants with encased windrow or in-vessel composting.

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Phytohygienic aspects of composting

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Abstract

The majority of plant pathogens do not survive exposure to conditions prevailing during composting of infested plant residues. The most resistant pathogens are heat-resistant viruses and biotrophic root-infecting fungi. Most soil-borne viruses need nematodes or fungi for infection of the host plant. Since the vectors are destroyed during composting when properly performed, the product is not infectious. Apart from a few viruses, e.g. tobacco necrosis virus (TNV), virus particles in compost are not picked up by vectors that are resident in compost-amended field soil. Tobacco mosaic virus (TMV) is not completely inactivated. Since it can be directly transmitted to the plant root, i.e. without a vector, compost from infested residues should not be used in susceptible crops. Data on survival of other heat-resistant viruses that are mechanically transmitted are lacking.

Survival of biotrophic fungal pathogens was only studied for *Plasmiodiophora brassicae* and the virus vector *Olpidium brassicae*. Although the results are not consistent, it is tentatively concluded that these fungi are eliminated after exposure for one day to compost at 60 °C and a moisture content of 40%. Concerning trade of plants in compost-amended substrates within the EC countries, research on survival of composting by quarantine pathogens mentioned in Council Directive no 77/93/EEC is needed.

Among the factors involved in inactivation, heat is considered to be the main factor in composting under predominantly aerobic conditions and toxic agents in decomposition under anaerobic conditions.

The present sampling techniques and detection methods for plant pathogens in compost do not allow a reliable analysis for the evaluation of infestation of the finished product. An alternative is defining the conditions required for sanitation that should be maintained during the process for sanitation.

Introduction

Use of compost as a soil conditioner in agriculture or as a constituent of potting or container media in horticulture implies two requisites for plant disease control. First, the product should be free of pathogens. Secondly, its application should not stimulate pathogens that are already present in the soil or in other substrates supplied with compost. The subject of this review is confined to the first aspect and focuses on the risk of spreading plant pathogens when using compost. As compost is applied to soil, the discussion will be mainly on the soil-borne pathogens.

Occurrence of pathogens in compost depends on whether they occur in the starting material and on the efficacy of sanitation during the composting process. Populations of pathogens often occur in high numbers in senescent plant tissue, where resting structures are formed for survival during absence of the host plant. They enter the composting system in high numbers when crop residues constitute a major component of the starting material. The crop residues include remains of field and greenhouse crops (in particular those on soilless cultures are set free in large quantities) and fruit and vegetable remains in the organic fraction of household and garden waste. Due to the recent trend in collecting organic waste separately from other solid wastes, the amount of material to be composted is increasing in many countries.

The literature on sanitation during composting has been reviewed earlier (Golueke, 1982; Hoitink and Fahy, 1986; Bollen, 1985, 1993). Since the last review, only a few data can be added. This paper provides an overview of the susceptibility of plant pathogens of various types to composting and a discussion of the mechanisms involved. Although anaerobic digestion of organic waste is not considered as a form of composting (Zucconi and De Bertoldi, 1987), the few data on inactivation in an anaerobic environment are discussed also. This is because it may help us to understand the elimination of pathogens in windrows and other systems of composting where anaerobiosis occurs inside the bulk material.

Pathogen survival

Infection of crops grown on soil or other substrates amended with compost can be caused in various ways. Sources of pathogens are infested soil, compost or planting material. Moreover, the plant-substrate system can be infested from outside after the compost was added. Once a disease appears, it is often impossible to determine where the pathogen came from. In only a few examples, infested compost is irrefutably proven to be the source (Serfontein et al., 1991).

With the present sampling and detection methods, it is impossible to examine the finished product unless levels of infestation are extremely high. Therefore,

emphasis is on process evaluation rather than on product control (Marciniszyn and Gottschall, 1995). Data on pathogen survival are derived from experiments where samples of infested soil or plant material placed in perforated metal containers, in nylon fabric nets, or in glass vials were exposed to the composting process together with the bulk material. After composting, the samples are assayed for presence of viable pathogens by inoculation of test plants or by growing susceptible host plants on substrates to which the samples have been added or by using various laboratory techniques.

Nematodes

Data on pathogen survival show that nematodes are sensitive to composting. This applies also to cyst-forming species and root-knot nematodes that are more resistant to adverse conditions in soil, like dehydration and chemicals, than most other nematodes. Cysts of the potato cyst nematode, *Globodera rostochiensis*, are destroyed also by agents involved in anaerobic decomposition of crop residues (Sevidy, 1966; Turner et al., 1983). In a system with a high rate process for composting of mixed household waste, the root-knot nematode *Meloidogyne incognita* var. *acrita* in tomato was killed in each of eight experiments (Menke and Grossmann, 1971). The same was found for *M. incognita* from paprika in windrows for composting of kitchen and garden waste (Herrmann et al., 1994).

Nematodes are more sensitive to heat than most other plant pathogens (Fig. 1). Although only a few studies on the fate of nematodes during composting of infested crop residues were made, the results support the conclusion that a properly prepared compost including a heat phase and a maturation phase is free of plant-infecting nematodes.

Viruses

About one-sixth of the plant viruses are claimed being soil-borne (Hiruki and Teakle, 1987). These viruses infect the host plants via roots, bulbs or corms. They are found in most soils used for horticulture or agriculture. Even in plant nurseries, where more attention is paid to plant health than in production farms, soils are often infested. A survey including 55 Swedish plant nurseries revealed that tobacco necrosis virus (TNV) and tobacco rattle virus (TRV), both known as pathogens of a wide range of host plants, occurred in 31 and 19 nurseries, respectively (Rydén and Eriksson, 1978).

For a few heat resistant viruses, literature data on their resistance to composting are inconsistent. Tobacco mosaic virus (TMV) was detected in compost made from infested tobacco plant residues after composting for six weeks at 50 to 70°C (Hoitink and Fahy, 1986). Extracts of compost strongly reduced its infectivity, but complete inactivation was not achieved (Bartels, 1956). On the other hand, in

windrows with a mixture of biowaste and chopped wood Herrmann et al. (1994) found that TMV had lost its infectivity completely, even in samples where the maximum temperature achieved was below 65°C. As will be discussed below, heat is only one of the factors involved in inactivation. Moreover, in this study infectivity of the samples was assessed by using test plants as the criterium for survival of the virus. As the authors mention themselves, the inactivation might have been a reversible one (adsorption, without destroying the virus molecule) in stead of an irreversible one where the virus is destroyed. Evidence for the occurrence of a reversible inactivation of TMV in compost extracts was obtained by Bartels (1956).

TRV is another virus of which survival is poorly understood. It was destroyed in compost heaps where temperatures remained far below the lethal level, but in another study it retained its infectivity under a severe composting regime. One of the host plants is tulip where the virus causes white streak disease. In static piles of peeling waste of flower bulbs, where the highest temperatures recorded remained below 60 °C, the virus was shown to be eradicated in a serological test using ELISA (Bollen et al., 1986). On the other hand, in a system with a high rate process for composting of municipal waste, Menke and Grossmann (1971) found survival after exposure of infested plant material to composting for 6 days at temperatures up to 68 °C. The product was still infectious in five out of six samples.

A third heat resistant virus is TNV. The virus is associated with diseases of economically important crops, e.g. Augusta disease of tulip, stipple streak of bean and necrosis of cucumber. Its infectivity rapidly declined in compost heaps at a temperature of 54 °C and the virus could not be detected any more after 4 days (Lopez-Real and Foster, 1985).

Transmission of the virus from compost-amended soil to the plant root

Evaluation of the risk of using compost that is not free of viruses depends on the type of transmission of the virus involved. Transmission is either by a vector or direct (mechanical). Most soil-borne viruses need a vector, that can be a nematode or a fungus.

Nematode-transmitted viruses.

About 20 plant viruses are known to be transmitted by nematodes (Hiruki and Teakle, 1987). One of them is TRV that is transmitted by free-living nematodes of the genera *Trichodorus* and *Paratrichodorus*. The virus has many hosts including economically important crops as potato and tulip. As mentioned above Menke and Grossmann (1971) demonstrated its resistance to composting.

Although pertinent data on resistance of the nematode vectors are lacking, it is very unlikely that they survive composting since plant parasitic nematodes are very sensitive to heat. In routine analyses including many samples of aerobically

produced compost, they were never found in properly prepared compost (Baltussen, unpublished).

The question arises what happens when a virus-infested compost is applied to soils that harbour the vector nematodes. Species that transmit viruses are parasites that feed on living plant roots, but not on microorganisms or dead substrate like compost. The cell wall is penetrated with a stylet, whereafter the cytoplasm of the attacked cells is ingested and at departure of the feeding site the stylet is drawn back into the oesophageal lumen. When moving from one root to another the stylet does not touch the soil and so it is very unlikely that it becomes infected with virus particles.

Fungus-transmitted viruses.

The fungal vectors are obligate plant parasites that survive in soil as resting spores, heavy-walled structures that are resistant to adverse conditions. The resting spores can be infected with the viruses that survive for long periods within the resting spore. All fungal species involved have in common that they infect the plant root by zoospores that move through the soil and infect the plant root. The zoospores that emerge from virus-infected resting spores carry the virus particles and together with the contents of the zoospore the virus enters the plant root. The number of viruses known to be transmitted by fungi is steadily increasing (Campbell et al., 1995).

In the discussion on phytohygienics of compost three examples are most relevant: beet necrotic yellow vein virus (BNYVV) transmitted by the fungus *Polymyxa betae* and causing rhizomania disease in sugar beet, and TNV and lettuce big vein virus (LBVV) both transmitted by *Olpidium brassicae*. Resistance to composting of *P. betae* is not studied so far, but *O. brassicae* is more resistant than the nematode vectors (Bollen et al., 1989). This vector is, however, less resistant to heat than the viruses. Again, the question arises if compost infested with virus and not with the vector constitutes a threat to the crop. The situation is more complicated than with nematode vectors. It depends on the virus-fungus combination whether the zoospore of a vector in the compost-amended soil can acquire the virus from the compost. Maraite (1991) distinguished two types of transmission. In the first type, the virus is acquired when the zoospores are formed inside the infected host plant or in the resting spore, but not from soil when moving from one root to another one. The virus particles occur only inside the zoospore. This is the case with transmission of BNYVV by *P. betae*. In the second type, the virus particles can become attached to the flagella and the surface of the zoospore when it is swimming in soil water. With infection of the root the flagellum with virus particles is retracted into the cyst formed from the zoospore and the whole content is emptied into the plant cell. An example is the transmission of TNV by *O. brassicae*. Therefore, application of TNV-infested compost implies a risk and that of BNYVV-infested compost does not if it is free of the vector.

Mechanically transmitted viruses.

These viruses can infect the roots via wounds. A growing root has always wounds, either made by soil inhabitants or during formation of side roots. Infection without vectors is well established for TMV with tomato and tobacco as its most important hosts and for tomato mosaic virus (ToMV). Both viruses are very stable. In plant debris in soil their infectivity is retained for a year or more (Migliori and Marrou, 1970; Lanter et al., 1982). The factors determining survival in soil are comprehensively discussed by Kegler et al. (1995) and a major factor is adsorption to soil particles, that highly differs from soil to soil. Resistance of TMV to composting is discussed above and, as the virus does not need a vector, use of compost in susceptible crops implies taking a risk.

Bacteria

The few studies on the fate of plant pathogenic bacteria in compost heaps show that composting effectively sanitizes crop residues infested with these pathogens. *Erwinia amylovora*, causing fire blight in pear trees and ornamentals, was destroyed when the infected shoots were exposed to the composting process for 7 days at 40 °C or more, but not at lower temperatures (Bruns et al., 1993). Two other bacteria were even less resistant, i.e. *Erwinia carotovora* var. *chrysanthemi* and *Pseudomonas phaseolicola* in chrysanthemum cuttings and bean leaves, respectively (Hoitink et al., 1976; Lopez-Real and Foster, 1985).

Anaerobic digestion of crop residues creates also adverse conditions for survival. *Clavibacter michiganense*, the pathogen causing bacterial canker in tomato, was destroyed in a digester fed with tomato waste and run at 35 °C (Turner et al., 1983).

The data available suggest that it is very unlikely that properly prepared compost is infested with bacterial pathogens.

Fungi

In studies on sanitation during composting, fungi received more attention than other pathogens. Most fungal pathogens were rapidly inactivated. This applies also to species that form sclerotia as resting structures, e.g. *Sclerotium rolfsii* (Yuen and Raabe, 1984), *Sclerotinia trifoliorum* (Dittmer and Weltzien, 1988), *Verticillium dahliae* and *Sclerotium cepivorum* (Bollen et al., 1989) and *Sclerotinia sclerotiorum* (Herrmann et al., 1994). Although sclerotia are known for their resistance to adverse conditions and for their longevity in soil, they are unable to endure the temperatures that prevail in compost heaps during peak heating.

The biotrophic fungi that form heavy-walled resting spores are less easily eradicated. They are obligate root-infecting parasites. The resting spores are resistant to drying and heat and survive for many years in soil. As a rule, in compost heaps exposure to 60 °C under moist conditions should be maintained for several hours to kill the resting spores. An example is *Olpidium brassicae*, the vector of viruses

in lettuce and other crops (Bollen et al., 1989). In research on phytohygienes, elimination of *Plasmodiophora brassicae* has been given much attention because it is a serious threat for cabbage growing and compost is utilized on cabbage fields. Moreover, the fungus can easily be detected with chinese cabbage as a highly susceptible test plant. Under controlled conditions, where the process could be run at a given temperature and moisture regime, Marciniszyn and Gottschall (1995) found that it survived exposure to composting yard waste for 18 days at 50 °C under moist condition. Literature data are very inconsistent and were discussed in detail in a previous review (Bollen, 1993). The extremes were survival in sites of compost heaps where 65 °C was recorded for 3 weeks (Ylimäki et al., 1983) and complete elimination after 24-hour exposure in compost at 54 °C (Lopez-Real and Foster, 1985). Apparently, other factors than temperature can be involved in elimination of the fungus and they will be discussed below.

For at least four other biotrophic fungi information on the fate of their resting spores in compost heaps is needed, viz. *Synchytrium endobioticum*, the pathogen causing potato wart disease, *Spongospora subterranea* causing powdery scab in potato, *Polymyxa betae*, the vector of BNYVV, and *Olpidium bornovanus* (syn. *O. radicale*), the vector of cucumber necrosis virus (CNV) and melom necrotic spot virus (MNSV). The latter virus causes serious problems in cucumber grown in soilless cultures. In areas with these cultures, crop residues from greenhouses are the major raw material in compost heaps.

Fungi are highly sensitive to conditions prevailing during anaerobic digestion as has been shown for *Fusarium oxyporum* f.sp. *dianthi* causing wilt in carnation (Turner et al., 1983) and *Sclerotium cepivorum*, the white rot fungus in onion (Bollen, 1993). It merits further study to learn whether it also applies to the biotrophic parasites with heavy-walled resting spores.

Pathogens mentioned in special requirements for trade of plants and adhering soil within the European Community.

Export and import of plants in soil or substrate mixtures occurs on a wide scale for woody and herbaceous ornamentals. Use of compost in container media and potting mixtures implies that special attention should be given to pathogens mentioned in the Council Directive of the EC no 77/93/EEC and its amendments (last amendment 95/4/EC of 21-02-95). The main soil-borne pathogens whose introduction into and spread within all member states is prohibited are the potato cyst nematodes, *Globodera rostochiensis* and *G. pallida*, the bacteria *Clavibacter michiganensis* ssp. *sepidonicus* and *Pseudomonas solanacearum* causing ring rot and brown rot in potato, respectively, and the potato wart disease fungus *Synchytrium endobioticum*. With properly prepared compost problems with the nematodes or the bacteria are not likely to occur. Information on sensitivity of *S. endobioticum* to composting is lacking thus far. Because of severe control measures and quarantine regulations, spread of this pathogen is restricted to some regions. Until more data on its survival are available it is advised to avoid the use

of compost prepared from crop residues and household waste from infested regions in container media.

A few EC countries (DK, IRL, UK and the Azores) include BNYVV, the rhizomania virus, in the list of 'quarantine agents'. Since the virus and its fungal vector are common features in soil and sugar beet residues in most other countries, a study on its survival during composting is urgently needed.

Mechanisms of inactivation and environmental factors involved

Inactivation and destruction of pathogens is caused by 1) heat generated during the first phase of composting, 2) toxicity of decomposition products, 3) enzymatic breakdown and 4) microbial antagonism. The mechanisms operate at the same time and inactivation will often be achieved by interactions, e.g. exposure to sub-lethal temperatures enhances pathogen's susceptibility to toxic agents and conversely. Moisture content and acidity are the major environmental factors determining the ultimate effect on the pathogens.

Inactivation or destruction by heat

The differential sensitivity to heat of the various pathogens is dealt with in a previous review (Bollen, 1993) and the data are summarized in Fig. 1. In conclusion, the quantity of heat generated during the first phase of aerobic composting of crop residues and organic household waste exceeds the level that is needed for thermal kill of most pathogens. The quantity of heat required for complete elimination of a pathogen depends on the number of propagules of its population.

For a few common biotrophic fungi, data on their heat resistance are either inconcistant or lacking. This information is urgently needed for prediction of their inactivation and also for the choice of the most adequate test pathogen in the assessment of sanitation during composting. At present, Marciniszyn and Gottschall (1995) are using resting spores of *P. brassicae* for evaluation of sanitation. With inactivation of this pathogen by far most plant pathogens are covered. It is aimed at to include also TMV in the sanitation test.

Effect of moisture conditions on thermosensitivity.

The influence of moisture was already demonstrated in 1926 by Glynne who found that treatment of resting sporangia of *S. endobioticum* at 70 °C for 1 h in water was enough to kill them, but treatment at the same temperature for 20 h was survived when dry. Increased resistance under dry conditions is the rule and was demonstrated several times, e.g. for *Sclerotinia sclerotiorum* (Herrmann et al., 1994) and the potato cyst nematode *G. rostochiensis* (LaMondia and Brodie, 1990).

Occurrence of dry pockets in composting material is probably the main cause of pathogen survival in heaps or windrows where eradication was expected on the basis of the temperatures reached. Marciniszyn and Gottschall (1995) postulate that moisture content of the material should be 40% at least.

Effect of acidity on thermosensitivity.

Although much information exists on effect of substrate pH on growth and survival of pathogens, the interaction with heat resistance has rarely been considered. From literature data, Herrmann et al. (1994) concluded that heat resistance of TMV decreases with increasing alkalinity. This is especially so at Ph-values > 8 which are often measured, although the optimum levels for composting are within the range of Ph 5.5-8.0. However, in the first phase of composting – where the virus is exposed to high temperatures – acid conditions initially prevail due to decomposition of carbonaceous plant material by acid-forming bacteria. Subsequently, pH level rises because of protein degradation associated with release of ammonia (Zucconi and De Bertoldi, 1987).

Inactivation by toxicity of conversion products

Destruction or loss of infectivity of pathogens in compost heaps or digesters where temperatures required for thermal inactivation were not attained is attributed to the activity of toxic conversion products or to direct breakdown of pathogen structures by the microflora. Evidence for involvement of toxic compounds is mainly derived from observations with decomposition under anaerobic conditions. Because of the intensive microbial activity during the initial stage of composting oxygen demand is high. Within the bulk material anaerobiosis will, at least temporarily, be the rule rather than the exception.

The products associated with decomposing crop residues that are claimed to be toxic to pathogens are mainly volatiles. In subtropical regions, solarization as a method of soil disinfection is practised by covering the wetted soil with plastic sheets or sprayable mulches. Solarization was shown to be more effective when the soil is amended with crop residues before mulching. It creates an environment that is similar to that in compost heaps in that decomposition occurs at elevated temperatures under semi-anaerobic conditions. Gamliel and Stapleton (1993) found that in heated soil previously amended with cabbage residues a wide range of volatiles were generated. High levels of aldehydes and isothiocyanates were correlated with reduced populations of *Pythium ultimum* and *Sclerotium rolfsii*, two common fungal pathogens with a wide host range. Reduction was appreciably higher in heated than in nonheated amended soil. Production of fungitoxic volatiles during decomposition of residues of other crops in soil was reported by Berestetsky and Kravchenko (1984). Spore germination of *Verticillium dahliae* was more inhibited than that of the saprotrophic fungi tested and bacterial growth was stimulated, suggesting selective toxicity.

A few fungal pathogens, e. g. *Phytophthora cinnamomi*, are killed after exposure to relatively high concentrations of ammonia (Gilpatrick, 1969). In the first stages of composting of crop residues rich in nitrogen, ammonia probably contributes to sanitation. Supporting experimental data are lacking so far.

During composting of hardwood bark products are formed causing lyses of zoosporangia and zoospores of root-infecting *Phytophthora* species (Hoitink and Fahy, 1986).

Products formed under anaerobic conditions affect pathogens of various types. As mentioned above, in digesters with crop residues the nematode *G. rostochiensis*, the bacterium *C. michiganensis*, and the fungi *F. oxysporum* f.sp. *dianthi* and *S. cepivorum* were destroyed at temperatures of 32–35 °C. The toxic agents were not identified. Under low redox potential pathogens may be more sensitive to toxic agents. Anaerobiosis itself can also reduce viability of some fungal pathogens.

The role of anaerobiosis in sanitation is well illustrated with farm-scale composting of peeling waste of flower bulbs. Conditions for proper composting are poor. The bulk material is compact and contains much adhering sand. The heaps are large and they are turned only once. Temperatures rarely rise above 45 °C. Nevertheless, relatively heat-resistant pathogens as the formae speciales of *F. oxysporum* causing bulb rot in lily, daffodil and tulip were destroyed, even at sites within the heap where temperatures did not exceed 35 °C. Although the heaps were provided with perforated tubes for aeration, the oxygen content of the air at 30 and 70 cm inside the heap was 14 and 1 %, respectively, at the end of a 32-week composting period. Evidence for involvement of toxic conversion products was obtained by exposing chlamydospores of *F. oxysporum* f.sp. *lili* to percolation water collected from a heap made from fresh residues of bulb crops during an early phase of composting (Bollen and Volker, unpublished). Exposure for only one day was enough for loss of viability due to lysis.

Microbial breakdown of viruses

Enzymatic degradation is probably one of the mechanisms involved in inactivation of viruses. Viruses in decomposing plant residues are exposed to the proteolytic activity of the microflora. Data on susceptibility of virus proteins to conditions prevailing in compost heaps are lacking. Although TMV protein is quite resistant to proteolytic digestion, studies on the fate of the virus in soil showed that its degradation is associated with a high microbial activity (Van Winckel, 1974; Cheo, 1980; Kegler, 1995). Repeated addition of TMV accelerated its degradation in soil and it was suggested that aerobic bacteria were involved (Cheo and Nickoloff, 1980).

Presence of high populations of a strain of *Bacillus subtilis* in soil reduced infection of host plants by TRV (Kegler et al., 1993). It is not known if enzymatic action is involved. *B. subtilis* is a common species among the mesophilic microflora in compost during the maturation phase.

Inactivation by microbial antagonism.

Microbial antagonism is the principal factor involved in disease suppressive properties of mature compost. The main effect is an increased level of fungistasis due to competition between the pathogens and the compost microflora (Hoitink et al., 1993). To a lesser extent mycoparasitism and amensalism by formation of anti-fungal substances are involved. During maturation, the antagonism is established when the compost is recolonized by the mesophilic microflora. The increased fungistasis implies that spore germination and mycelium growth are suppressed, but not that pathogen structures that survived during the heat phase are destroyed. Experimental evidence for lysis by amensalism or mycoparasitism during the maturation phase is lacking thus far.

In compost heaps where samples with infected roots were exposed to part of the entire process, *O. brassicae* and *P. brassicae* were destroyed during the heating phase but survived the long-lasting maturation phase without loss in viability (Bollen et al., 1989). This is easily understood as the heavily-walled resting spores of these biotrophic pathogens are not liable to antagonism and mycoparasitism. However, the same result was found for *F. oxysporum* f.sp. *melonis* which is more sensitive to antagonism.

In conclusion, substantial evidence for a role of microbial antagonism that is often claimed as contributing to destruction of pathogens in compost heaps (e.g. Herrmann et al., 1994) has not been established so far.

Evaluation and conclusions

Although the great majority of the pathogens tested so far do not survive under conditions prevailing during composting of infested plant residues, a few of them may escape. Critical pathogens include heat resistant viruses, a few biotrophic fungi and a few strains of *Fusarium oxysporum*.

In most studies on its survival, TMV was not completely inactivated. For infection of the plant root, the virus does not need a vector that is destroyed during composting. Therefore, it is a threat to susceptible crops on soils amended with compost. The virus has only a limited number of host plants and residues of infected crops should not be used. A few other soil-borne viruses do not need a vector either, but data on survival are lacking.

Survival of most heat resistant viruses that need a vector for transmission to the plant root is without risk for a crop where compost is used. The vectors are sensitive to composting, if properly done, and those that are resident in soil cannot pick up the virus from the compost. However, TNV can be acquired from the substrate by its vector. In spite of its heat resistance, the few studies on its survival showed that the virus was readily inactivated, apparently by other factors than heat. Because of its occurrence in economically important crops, further research is needed before generalizations can be made.

Of the biotrophic fungi only *P. brassicae* and the virus vector *O. brassicae* were studied for survival. Although the results are not consistent, it is tentatively concluded that these fungi are eliminated after exposure for one day to 60 °C in compost with a moisture content of at least 40%. Use of compost in container media or other substrates for growing plants for trade within the European Community requires special attention to pathogens listed in Council Directive no 77/93/EEC. Strangely enough, the only fungal pathogen among the most emphasized 'quarantine agents', *S. endobioticum* causing potato wart disease, has not been included in survival studies. Survival of another biotrophic fungus, *P. betae*, being the vector of the 'quarantine agent' BNYVV, has not been studied either.

Among the factors involved in inactivation heat is considered to be the main factor in composting under predominantly aerobic conditions and toxic agents in decomposition under anaerobic conditions. Although toxic agents greatly contribute to pathogen kill in compost heaps, heat generation is the best parameter used for estimating sanitation, as temperature can be monitored much easier than evolution of toxic metabolites.

The present sampling techniques and detection methods for plant pathogens in compost do not allow a reliable analysis for the evaluation of infestation of the finished product. The most adequate way is defining the conditions required for sanitation that should be maintained during the process. Currently, Marciniszyn and Gottschall (1995) are attempting to define these conditions using *P. brassicae* and TMV as test pathogens. Residues of many host plants enter the compost heap and with them a great number of pathogens. It will be impossible to define conditions that exclude any risk. However, with the choice of the two pathogens mentioned by far most pathogens will be covered.

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Canadian National Compost Standards

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Introduction

Canadians dispose of about 22 million tonnes of waste each year. Approximately 25% of this waste is leaf, yard and food waste that could be composted. Canada is committed to attaining its goal of 50% waste diversion by the year 2000 relative to a 1988 base year. In addition to reducing the amount of waste going to landfills, composting is one way to return nutrients and organic matter to soil. This makes compost a valuable product for landscaping, horticulture and agriculture. In light of these benefits, large scale composting facilities are being operated by industries and municipalities.

With the introduction of these compost operations and the growth of composting as a waste/resource management practice, standards for the safety and quality of compost help protect: public health, the environment, and the composting industry. Standards will help ensure that compost products are safe, thereby enhancing consumer confidence. This should promote the use of organic materials as a resource rather than a waste. The view that standards are beneficial is shared by several stakeholders, including representatives of the composting industry, compost user groups and regulators. The following information will demonstrate how different Canadian stakeholders (Government of Canada, Provincial Governments and industry) have collaborated to draft national compost standards, and the consensus achieved to date.

Background

Several bodies across Canada are mandated to regulate compost and/or write compost standards. These bodies include the Government of Canada, provincial and territorial governments, and the Standards Council of Canada (SCC)¹. Within the Government of Canada, the Department of Agriculture administers the Fertilizers

¹The SCC coordinates voluntary industry standardization activities in Canada, and represents Canada in the International Organization for Standardization (ISO).

Act that provides for the regulation of fertilizers and supplements sold in Canada. It therefore regulates compost when sold either as a soil amendment or as a product with plant nutrient claims. The Provinces and Territories regulate the disposal and beneficial reuse of wastes, hence they regulate the production and use of compost. The SCC establishes industry standards that allow products that meet their standards to bear seals reflecting high quality.

At present, among the federal and provincial regulators, different sets of standards exist for several aspects of compost. Additional standards for compost safety and quality were previously being developed by these agencies and the SCC. To work towards harmonization, stakeholders met, in January 1993, to discuss and evaluate existing and anticipated compost standards, and the general status of the regulatory situation pertaining to compost. As a result, the parties agreed to coordinate efforts in an attempt to develop compost standards that provide a significant level of national harmonization, while being flexible enough to accommodate different (i.e., regional) groups, interests, and issues.

The process:

At the January 1993 meeting, it was agreed that the creation of harmonized national standards for compost quality should be pursued, and that initial efforts should focus on five core criteria for quality and safety, namely: foreign matter, maturity, organic contaminants, pathogens, and trace elements. Note, however, that the SCC industry standards will consider these five core criteria as well as additional criteria related to product quality e.g., organic matter content.

Also established, was that the different parties had slightly different mandates and objectives.

- The Provinces have a goal of reducing the amount of waste disposed by 50% by the year 2000. They will develop quality guidelines for compost based on the experiences and knowledge of several regulatory agencies and advisors. This process allows all provinces and territories to benefit from the work previously done in other provinces, and encourages the adoption of the same standards in all provinces and territories.
- The Government of Canada's Fertilizers Act and Regulation require that fertilizers and supplements be safe and efficacious and properly labelled. These products must be safe for humans, plants, animals and the environment, and efficacious for every purpose they represent. Through their random sampling and analysis and special investigations of regulated products, such as compost, they must be able to determine compliance of products with established standards.
- The objective of the SCC is to publish voluntary industry standards for compost, to help protect the environment and promote growth in the industry. It was recognized that the different mandates and objectives, as described above, require that three separate documents be produced upon completion of the project, including:

- Provincial Guidelines (for use by provinces and territories adopting regulations for compost)
- A Trade Memorandum describing compost standards adopted under the authority of the Government of Canada's Fertilizers Act and Regulations
- SCC voluntary industry standards

Finally, it was concluded, that a good framework for compost standards should involve two categories of product (e.g., A and B). Category A compost being appropriate for any application, such as in agriculture, home and garden uses, horticulture operations, etc. Category B compost may require some form of controlled use; managed by individual provinces and territories.

Given the multitude of agencies and stakeholders represented, two compost standardization committees were established: a Provincial Committee and a SCC Committee. The Provincial committee consists of representatives from every province and territory, a group leader from the Government of Canada (Department of Environment), and advisors from other Federal Departments (Department of Agriculture, Department of Health, Department of Industry) and the SCC. The SCC Committee is balanced by representatives from user groups, industry, and special interest groups including experts from across the country and the Government of Canada (Department of Agriculture and Department of Environment). To facilitate correspondence and continuity between the two committees, both have representation from the Department of Environment, Department of Agriculture and the SCC.

Discussion papers were developed by the Government of Canada on the five core criteria (foreign matter, maturity, organic contaminants, pathogens, and trace elements). The discussion papers were distributed to all Provincial and SCC members to stimulate and initiate discussions. Both committees have worked from these papers throughout the project. The Government of Canada (Department of Environment) coordinated the input for modifications to the papers, recommendations for standards, arguments for recommendations, etc., and passed them through all members of both committees. As such, the two committees worked individually but also worked together.

Described below are the consensus points achieved. The significant level of harmonization between the Provinces, the SCC, and the Government of Canada is demonstrated.

The Standard:

Applicability/feedstock:

Canada, being one of the largest countries in the world is extremely geographically, culturally and economically diverse. Due to the large diversity, different policies exist within the provinces. As such, individual provinces and territories may need to adopt policies to accommodate their individual conditions and require-

ments. For example, provinces have differing needs with regard to the use of sewage sludge and other materials as a compost feedstock. Because of these differences the Provincial guideline will apply to compost produced from municipal solid waste or other feedstock as determined by the individual Provinces.

The Government of Canada and the SCC are developing product standards, therefore there is no restriction on feedstocks, but compost may be subject to additional requirements, on a case by case basis, depending on feedstocks.

Foreign matter:

Provincial

A compost shall be virtually free of foreign matter that may cause nuisance, damage or injury (to humans, plants or animals) during or resulting from its intended use. It shall contain no sharp objects measuring over 3 mm in any dimension and no foreign matter greater than 25 mm in any dimension.

SCC

Foreign matter is a serious industry concern as consumers will not purchase compost containing visible inert contaminants. The SCC committee decided to create a third category for foreign matter, a Category AA that would not contain any visible foreign matter. The criterion is as follows:

The compost shall be virtually free of foreign matter that may cause nuisance, damage or injury (to humans, plants or animals) during or resulting from its intended use. It shall contain no sharp objects measuring over 3 mm in any dimension, and:

	Category AA	Category A	Category B
Foreign Matter Content (% of total oven dried weight)	$\leq 0.1\%$	$\leq 0.5\%$	$\leq 1.5\%$
Maximum Size (mm) 25	12.5	12.5	

GOVERNMENT OF CANADA (Department of Agriculture)

A compost shall be virtually free of foreign matter that may cause nuisance, damage or injury (to humans, plants or animals) during or resulting from intended use. It shall contain no sharp objects measuring over 3 mm in any dimension.

FUTURE NEEDS

- define sharps;
- develop a protocol for testing of sharps

Maturity:*Provincial*

The PROVINCIAL guideline will provide the following list of maturity tests:

1. – C/N ≤ 25
- Oxygen uptake < 150 mg O₂/kg organic matter (volatile solids) per hour
- Germination of cress (*Lepidium sativum*) seeds – not suppressed

OR

2. – Upon standing, compost will not reheat to greater than 20°C above ambient temperature

OR

3. – Reduction of organic matter must be > 60% by weight

OR

- If no determination of maturity is made the compost must be cured for a six (6) month period. The curing pile must be in a state that permits aerobic biological activity but does not reach the thermophilic stage in any section.

SCC

Category A and B compost must pass two of the following three tests:

- C/N ≤ 25
- Oxygen uptake < 150 mg O₂/kg organic matter (volatile solids) per hour
- Germination of cress (*Lepidium sativum*) seeds – not suppressed

GOVERNMENT OF CANADA (Department of Agriculture)

A product must be mature at the time of sale.

The Government of Canada will recognize the SCC proposal for testing of maturity:

- C/N ≤ 25
- Oxygen uptake < 150 mg O₂/kg organic matter (volatile solids) per hour
- Germination of cress (*Lepidium sativum*) seeds – not suppressed

FUTURE NEEDS

At present, no single test of compost maturity is reliable and scientifically valid by itself, hence the preference for more than one test. Therefore, further research to develop a single test would be useful.

Organic Contaminants

PROVINCIAL, SCC & Government of Canada (Department of Agriculture)

Compilation, review and evaluation of research is required in this area. There is no supportive rationale for inclusion of a standard for organic contaminants at this time; however, this position will be modified as scientific findings dictate.

With regard to PCBs, this position is based in part on evidence that plant uptake of PCBs from soil occurs to only a limited extent.

Pathogens

Provincial

The compost must undergo treatment criteria using a recognized Process to Further Reduce Pathogens (PFRP) or other process recognized as equivalent by regulatory agencies. In certain circumstances, provinces may wish to specify pathogen limits in addition to or in place of the PFRP requirement. In this regard, it is recommended the following be applied:

fecal coliforms < 1000 MPN/g of total solids

salmonella sp. < 3 MPN/4g total solids

SCC & GOVERNMENT OF CANADA (Department of Agriculture)

For all compost:

fecal coliforms < 1000 MPN/g of total solids

salmonella sp. < 3 MPN/4g total solids

Trace elements

Provincial

TRACE ELEMENTS	CATEGORY A Maximum Trace Element Concentrations within Product * (mg/kg dry weight)	CATEGORY B Maximum Trace Element Concentrations (mg/kg dry weight)	Maximum Cumulative Trace Element Additions to Soil kg/ha
As	13	75	15
Cd	3	20	4
Co	34	150	30
Cr	210	—	—
Cu	100	—	—
Hg	0.8	5	1
Mo	5	20	4
Ni	62	180	36
Pb	150	500	100
Se	2	14	2.8
Zn	500	1850	370

* Based on the cumulative trace element additions to soil and assume an application rate of compost containing up to 5% nitrogen at 4.4 tonnes of compost/ha per year for 45 years.

The proposed Category A limits have been established using the higher of: British Columbia's Class 1 compost regulations, and Alberta's, Ontario's and Quebec's 'background' trace element levels in soil. British Columbia's regulation for Class 1 compost is derived from the 'best Achievable' approach with well-managed source separation programs. Alberta's, Ontario's and Quebec's 'background' levels were calculated by taking the arithmetic mean of available analytical data and adding three standard deviations of the mean. For distributions that are 'normal', 99% of all sample of uncontaminated soils will have trace element concentrations below these limits.

The proposed category B limits are taken directly from standards enforced by the Government of Canada under the Fertilizers Act (Trade Memorandum T-4-93). Currently limits for Cr and Cu do not exist in the Fertilizers Act. In calculating the limits for these elements consistent with the other nine elements the limits would be: Cr = 210 kg/ha and Cu = 150 kg/ha for the maximum cumulative trace element additions to soil and Cr = 1060 mg/kg and Cu = 757 mg/kg for maximum trace element concentrations within the compost product.

The Government of Canada (Department of Agriculture) will begin a consultation process for adopting these limits for Cr and Cu. The Provinces will re-evaluate these parameters once their review is complete.

SCC

The SCC is proposing the same trace element levels as the Provinces with the following additions:

- Levels for Chromium and Copper have been added to Category B:

	Maximum Trace Element Concentrations within Product mg/kg	Maximum Cumulative Trace Element Additions to Soil kg/ha
Cr	1060	210
Cu	757	150

GOVERNMENT OF CANADA (Department of Agriculture)

The trace element limits for compost as described in Trade Memorandum T-4-93 have existed for over 10 years and are not expected to be changed at this time. These limits are reflected under Category B in the above table. Department of Agriculture is considering a proposal to add to T-4-93 limits for chromium and copper as follows:

	Maximum Trace Element Concentrations within Product mg/kg	Maximum Cumulative Trace Element Additions to Soil kg/ha
Cr	1060	210
Cu	757	150

All conditions described in the existing Trade Memorandum T-4-93 apply to these values.

Sampling and analytical methods

Sampling and analytical test methods are currently being developed. A compilation, description and preliminary evaluation of compost sampling protocols and methods of analysis, (from Canada, USA and Europe) were drafted and used as a basis to adopt standard sampling and analytical methods. It is expected that this will be complete by the summer of 1995.

Future action

With the above consensus points, the Provincial guidelines, the SCC voluntary industry standard, and the standards enforceable under the Government of Canada's Fertilizers Act are being written. A national consultation of the SCC standard is complete and the SCC standard revised accordingly. It should be obvious from the information provided that the standards expected to be adopted by the different bodies, namely the Provinces, the SCC, and the Government of Canada, will be harmonized to a great extent. With the application of these standards, composting can become a resource management practice for organic materials rather than principally a waste management solution. This will also help secure composting as a beneficial soil management alternative for the Canadian environment, while helping to ensure the high quality and safety of compost available to Canadians.

Ninhydrin Reactive Nitrogen of CHCl₃ Fumigated and Non Fumigated Compost Extracts as a Parameter to Evaluate Compost stability

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Abstract

Three compost, from widely different composting processes (a garden compost and two municipal plants for solid waste treatment), were investigated for their biomass C and ninhydrin-N content at different stages of the composting period. Biomass C in all the 3 compost reached a maximum at the end of the thermophilic phase, maintained a high content throughout the mesophilic phase and then decreased with a trend that roughly parallels temperature.

Biomass ninhydrin-N showed a regular decreasing trend during the whole composting period. A similar behaviour was observed for non fumigated ninhydrin-N. This parameter, reflecting the release of extracellular enzymes and the intensity of ammonification processes, could represent itself a useful parameter to evaluate compost stability.

The ratio between biomass C and ninhydrin-N increased in the first month of the process and decreasing afterwards to values within the range normally found in soils (14-33), suggesting a change in the composition of microbial population during composting process.

The percentage of biomass ninhydrin-N respect to total N, showed lower values in stabilized compost respect to compost in the early stage of decomposition.

The trend observed in the 3 different composting processes, suggests that a low C_{bio}/nin-N_{bio} together with a ninhydrin-N_{bio} content about 1% of the total N would indicate a well stabilized compost.

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Introduction

The concept of soil microbial biomass was introduced by Jenkinson in 1966 and represented a kind of holistic approach very much in contrast with the soil microbial studies carried out in those years (Powlson, 1994). The novelty of the concept was that, for some purposes, it is not necessary to identify microorganisms responsible for single processes, but the whole soil microbial community can be considered as a single entity (Jenkinson and Ladd, 1981; Jenkinson, 1988). This enables the evaluation of the flux of energy and material through the soil population, which is necessary for studying the global cycles of C, N and S and for the formulation of mathematical models of organic C and N turnover (Jenkinson, 1990). The approach allows the use of an easily determined sensitive biological marker for predicting long term effects of agricultural practices and heavy metal pollution assessment (Powlson et al., 1987; Chander and Brookes, 1992). Chloroform fumigation lysis the cells of microorganisms and makes part of the cell constituents, probably part of the cytoplasm, extractable by 0.5M K₂SO₄. The amount of organic C extracted from soil after fumigation minus the amount of C extracted from a non fumigated blank, is proportional to the amount of microbial biomass C, and can be used to calculate the latter by means of an appropriate correction factor (Vance et al., 1987). This method has been widely applied to soil of all types, including soils which had recently received easily degradable substrate (Ocio and Brookes, 1990). In the case of compost, measuring microbial biomass C and its related parameters (total N, ninhydrin reactive N) can help to evaluate the effects of changing process strategies and possibly the degree of compost maturity in commercialized products. Composting substrates, however, are very different from soil and the application of methods developed to analyze soil microbial biomass C and N is not straightforward. This work represents a first attempt to investigate the possibilities offered by this kind of approach for the characterization of composting processes.

Materials and methods

Three different composting processes were considered: a garden compost made with grass cuttings in a manually turned pile and two municipal plants for solid waste treatment. In the first plant (MSW 1) grinded and sieved wastes are suspended in water to eliminate flosses and then pressed to bring moisture to 60%. After piling indoor the material is ventilated and passed through a first thermophilic stage which lasts for about 15 days. The compost is then carried outdoor, turned, piled and ventilated. Temperature increases again up to 75 °C (2nd thermophilic stage) and then decreases to ambient temperature in 1–2 weeks. In the second plant (MSW 2) glass is separated by means of a centrifugal separator; wastes are then piled under cover for 70 days and subdued to alternate cycles of ventilation and aspiration. The thermophilic phase lasts for about 20 days.

Fumigation and extraction

Each sample (containing 25 g of compost on an oven-dry basis) was fumigated in a dessicator with ethanol-free CHCl_3 for 24 h in the dark. After fumigant removal, the compost was extracted with 200 ml K_2SO_4 0.5 M for 30 minutes and then filtered through a Whatman n° 42 filter paper. Non fumigated portions were extracted as above at the time fumigation commenced (Vance et al., 1987).

Biomass C and biomass ninhydrin-N determination

Organic C in the extracts was determined by digestion with $\text{K}_2\text{Cr}_2\text{O}_7$ 0.75N and titration of the excess dichromate with FeSO_4 0.2N. Biomass C (C_{bio}) was calculated from the relationship Biomass C = 2.64 E_c where E_c is the difference between C extracted from the fumigated and non-fumigated samples.

Ninhydrin-reactive N in the K_2SO_4 extracts was determined according to the method proposed by Joergensen and Brookes (1990). Ninhydrin reagent (1.25 ml) was added to 0.75 ml of the extract and the solution was heated for 20 min in a vigorously boiling water bath to form a purple complex with α -amino N containing molecules. Subsequently the absorbance of solutions was read at 570 nm against a water blank. Biomass ninhydrin-N ($nin\text{-}N_{\text{bio}}$) was calculated from: $nin\text{-}N_{\text{bio}} = nin\text{-}N$ in extracts of fumigated compost minus ninhydrin-N in extracts of non-fumigated compost.

All results are expressed on an oven-dry compost basis and are the means of triplicate determinations

Results and discussion

Peak levels of microbial biomass C were reached in all the three composting processes examined at the end of the thermophilic phase and maintained throughout the mesophilic phase (fig. 1). This is in agreement with the general trend of bacterial, fungal, and thermophilic actinomycetes populations determined by microscopy counts. In compost MSW 1 there is a second biomass C peak which coincides with the onset of the second thermophilic phase. Afterwards in all composting processes microbial biomass C decreases with a trend that roughly parallels temperatures.

The concentration of ninhydrin reactive N in K_2SO_4 extracts of non-fumigated samples during the thermophilic phase is about five times that found during the following stages. This is due to the release of extracellular enzymes and to the intense ammonification which occur during the early stages of substrate decomposition. The high concentration of ninhydrin reactive N in non fumigated extracts represents a problem as the accuracy of the estimation of the ninhydrin-N content of microbial biomass is affected by the size of the difference of fumigated minus non fumigated soil in relation to the values from non fumigated samples. However

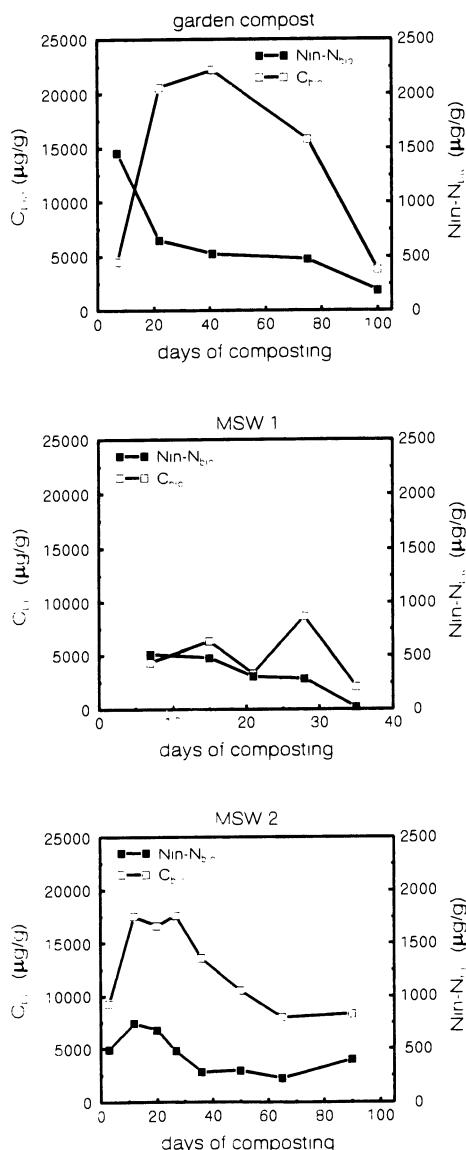


Figure 1 Microbiomass C (C_{bio}) and ninhydrin reactive N ($\text{Nin-N}_{\text{bio}}$) during composting

the 0.5M extractable ninhydrin-N of non fumigated extracts shows a regular decreasing trend and could represent itself a possible parameter to evaluate the degree of transformation and stabilization achieved (fig. 2).

In soil ninhydrin reactive N (essentially α -amino N and ammonium N) released by CHCl_3 fumigation is strongly related to soil biomass C (Joergensen and Brookes, 1990). During composting the ninhydrin reactive N of the microbial biomass has a widely different trend than microbial biomass C (fig. 1).

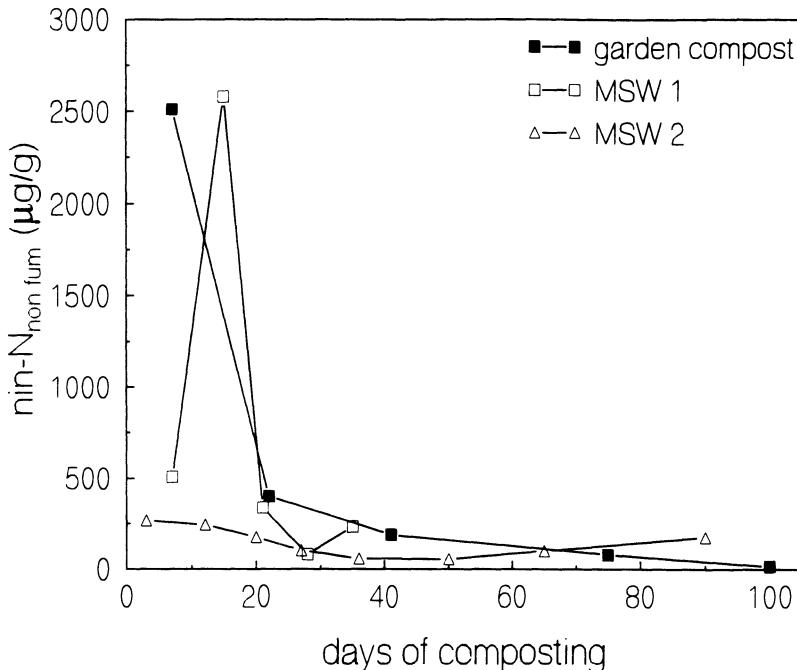


Figure 2 Ninhydrin-N extracted from non fumigated compost samples

The ratio between biomass C and ninhydrin-N, which is constant from a specific soil, is related to changes in microbial populations (Miller, 1994): both bacteria and actinomycetes have a 5:1 protoplasmatic C/N ratio, whereas fungi have a 10:1 ratio (Alexander, 1977). In all the three composting processes examined this ratio increases during the first month of composting (fig. 3) reflecting a change in the chemical composition of microbial biomass due to the succession of different microbial populations. Afterwards, during the curing phase, this ratio decreases to values ($C_{bio}/nin\text{-}N_{bio} = 20$) that are well within the range (14–33) normally found in soil (Joergensen and Brookes, 1990). Although the composting process of MSW 1 is considered complete after 35 days, it is immediately evident that this compost is still, on the contrary, at a rather early stage of decomposition.

The trend observed in the three widely different composting processes examined suggests that a low $C_{bio}/nin\text{-}N_{bio}$ together with a ninhydrin-N_{bio} content around 1% of the total nitrogen (fig. 4) would indicate a well stabilized material.

The analysis of ninhydrin-N reactive nitrogen of fumigated and non fumigated compost could therefore be useful for the characterization of composting processes. Further work is however necessary to optimize and adapt the analytical methods used for soil to the study of composting processes. In particular to validate the use of this parameters to evaluate compost stability it will be necessary to test the behaviour of poorly composted materials and end products after long periods of storage at low humidity.

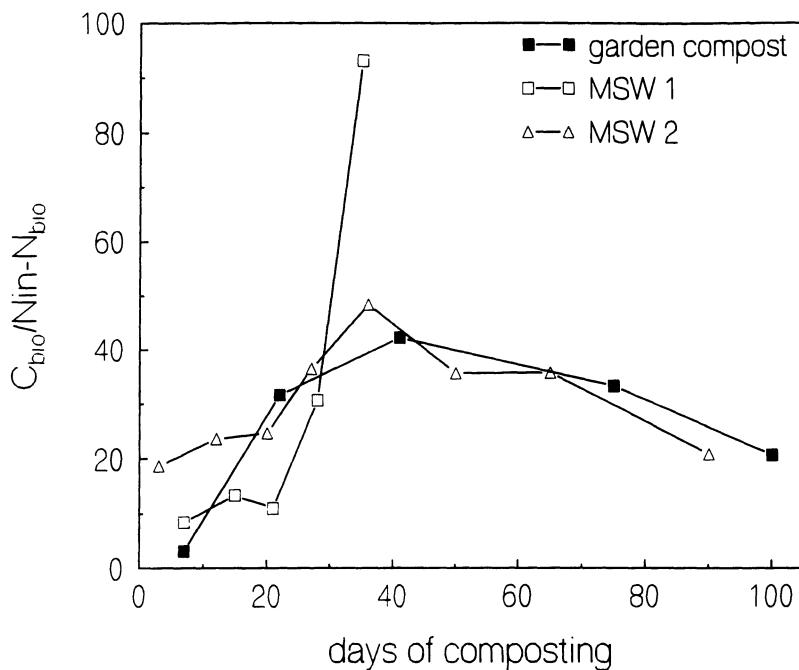


Figure 3 Ratio between microbial biomass C (C_{bio}) and ninhydrin-N ($\text{Nin-N}_{\text{bio}}$) during composting

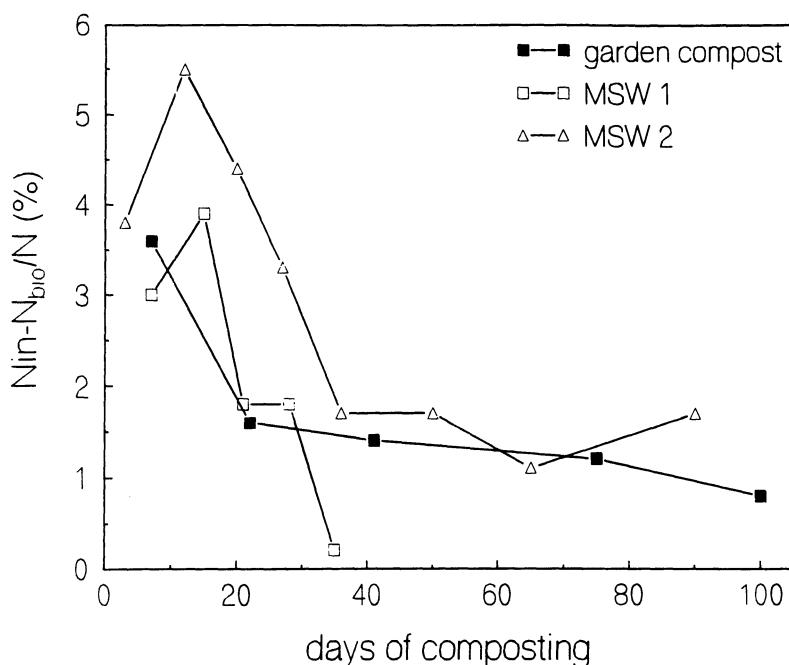


Figure 4 Ninhydrin reactive N ($\text{Nin-N}_{\text{bio}}$) of microbiomass as percentage of total N

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Impact of Composting Type on Composts Organic Matter Characteristics

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Abstract

Three MSW-composts (C1, C2 and LC2) originating from separately collected organic household wastes were studied. C1 and C2 had undergone a traditional windrow composting with different maturation times. LC2 was a lumbricompost: the first 2 months of maturation had been replaced by an earthworm digestion. Composts organic matter was characterized at different levels. (1) Global carbon and nitrogen balances were determined in water or alkaline extracts and in acid hydrolysates. (2) Gross chemical fractionation was performed to estimate organic compounds like fats, resins, water soluble compounds, hemicellulose, cellulose, proteins and ‘lignin-humus’. (3) Biomolecules were more precisely analyzed with colorimetric methods: carbohydrates, amino acids and phenols. Some of the phenolic compounds were identified by HPLC. Organic matter characteristics were related to the degradability of the composts, assessed by carbon mineralization. In all the composts, a labile pool of organic matter could be characterized, as well as an important humified fraction. It appeared that maturation time (7 or 3 months) and lumbricomposting few influenced the studied organic matter properties.

Introduction

Municipal solid waste (MSW) composting is a developing orientation of solid waste management. Agriculture utilisation of composts as organic amendments is an important way to valorize it and to recycle the organic matter. A minimum compost quality is required: acceptable level of organic and mineral contaminants, and optimal level of compost maturity. A pragmatic strategy to reduce the contaminant level in the MSW-composts is the homesorting of the fermentable organic matter of the municipal solid waste. The maturity level of the compost

directly depends of the composting process. Many tests have been proposed to assess the maturity or stability of the organic matter in the composts. Very efficient ones are the laboratory incubations coupled with respirometric measurements. They supply a direct biological evaluation of compost stability involving degradation processes similar to those occurring in the field. However, these methods are very time consuming. An alternative is the use of the chemical assessment of the compost stability. Chemical composition and properties of compost organic fraction give informations about their degree of stabilisation in relation to the content of the labile organic constituents (for a review, see He et al. 1992). The analysis of organic C and N after different extraction and fractionation methods are used also (Ashworth 1942; Gonzales-Prieto et al. 1993). In this way, important information can be given by the proportion of water soluble C and the ratio humic to non-humic compounds. The non-humic fraction of the organic matter has been studied (Morel et al. 1985), but most researches have dealt with the humic fraction, using nowadays recent techniques such as electrofocusing (Garcia et al. 1993; Ciavatta et al. 1993), pyrolysis-gas chromatography (Garcia et al. 1993) and IR (or FTIR) and NMR spectroscopy (Inbar et al. 1990; Giusquiani et al. 1989).

The objectives of this work were to evaluate comparatively the nature and the chemical and biological stability of composts resulting from different composting process.

Materials and methods

Composts and soil

The composts were made from the organic fraction of the municipal solid wastes of Bapaume (France). The waste material was collected in summer and has undergone a windrow fermentation followed by a windrow maturation of 7 and 3 months for C1 (older compost) and C2 (younger compost), respectively. The lumbricompost LC2 was composted as C2, but the first two months of maturation consisted in an earthworm digestion. The composts were air dried and passed through a 2 mm sieve. Some of their main characteristics are presented in Table 1. A soil organic matter was used as reference. The soil was sampled in the surface layer of a bare experimental plot in Grignon (Paris area, France). The soil was a *typic Eutrochrept*, its clay and loam contents were 22% and 73%, respectively. The soil was air dried and passed through a 2 mm sieve. Other soil characteristics are in Table 1.

Chemical characterisation of the organic matter

Gross fractionation of the organic constituents. Gross chemical fractionation of the compost organic matter was realized by successive extractions (Stevenson, 1965). Ether, alcohol and hot-water respectively extracted fats + waxes, resins and

water soluble compounds. Then, the hemicellulose and the cellulose were evaluated by sugar analysis after hydrolysis of the compost residue with 2% HCl for the hemicellulose, then with 80% H_2SO_4 for the cellulose. The final non hydrolysable residue contained proteins, determined by nitrogen measurement, and a 'lignin-humus' fraction, calculated by subtracting the protein value from total organic matter in non hydrolysable residue.

Table 1 Soil and composts main characteristics (results are expressed on a dry weight basis)

Soil	C1 (7 months maturat&on)	C2 (3 months maturat&on)	LC2 (lumbri- compost)
pH – water	7.3	8.5	8.7
Organic C (%)	1.08	16.87	13.72
Organic N (%)	0.13	1.34	1.45
C/N ratio	8.3	11.3	9.5

Analysis of the biomolecules. Content of free and total carbohydrates, phenolic compounds and aminoacids were colorimetrically determined after water extraction and specific hydrolysis described later on. All the hydrolyses were done on duplicate samples of 1 g dispersed in 50 ml of specific reagent at 150 °C in hermetically closed Pyrex bottles. For the carbohydrates, the hydrolysis was realized with 1 N H_2SO_4 during 6 h, and colorimetric measurement using the anthrone method (Brink et al. 1960); the results were expressed as equivalent of C-glucose. For the α -aminated nitrogen, the hydrolysis was realized with 3 N HCl during 24 h, and colorimetric measurements with the ninhydrin reagent (Moore and Stein 1954) of the sum of N-aminoacids and N-ammonium; the results were expressed as equivalent of N-leucine. For the phenolic compounds, the hydrolysis was realized with 2 N NaOH during 4 h, and colorimetric measurements using the Folin-Ciocalteu method (Singleton and Rossi 1965). The identification of the individual phenolic compounds was done by HPLC analyses. NaOH-hydrolysates were acidified with H_2SO_4 until pH 1 and phenolic compounds in the supernatant were extracted three times with 10 ml ethyl acetate. Extracts were pooled and evaporated under vacuum, and the residue was redisolved in 2 ml HPLC solvent A (see below). Chromatography was done using a Nova-Pak C18 4.6 x 250 mm column (Waters), with UV detection at 275 nm. The gradient program was solvent A (10% methanol, 2% acetic acid, 88% water) from 0 to 15 min; then linear gradient between 100% solvent A and 100% solvent B (98% methanol, 2% acetic acid) from 15 to 40 min. Sample injection volume was 100 μ l and eluent flow 1 ml min⁻¹.

Organic matter mineralisation during laboratory incubations

The laboratory incubation experiment has been described previously (Serra-Wittling et al. 1995). Briefly, 50 g of soil and 25 g of composts mixed with 25 g of sand were separately incubated during 6 months at 28 ± 1°C in sealed jars. Their

water content was adjusted to 95 % of the water holding capacity and it was kept constant during incubation. The evolved CO₂ was trapped in 10 ml of 0.5 N NaOH and periodically analyzed using colorimetric method (Chaussod et al., 1986) on an autoanalyzer (Skalar).

Organic matter solubility in different extractants

Water soluble organic matter: 20 g of soil and 2 g of compost were shaked in 100 ml of 0.025 M K₂SO₄ during 24 h. Water extracts were then recovered by centrifugation (8000 g, 15 min). The pellets were resuspended in 100 ml of 0.025 M K₂SO₄ and autoclaved for 16 h (121°C, 100 kPa). The autoclave extracts were recovered by centrifugation.

Alcalino soluble organic matter: 20 g of soil or 2 g of compost were shaked in 100 ml of 0.1 N NaOH during 2 hours. The alcalino soluble organic matter was separated from non alcalino soluble (or humin) by centrifugation. In an aliquote of the supernatant the humic acids were separated from the fulvic acids by precipitation of the former by addition of 2 N H₂SO₄ until pH 1.5 and centrifugation.

Hydrolysable organic matter: 10 g of soil and 1 g of compost were hydrolysed in 50 ml of 3 N HCl at 150°C in hermetically closed Pyrex bottles. After 24 h, hydrolysates were recovered by centrifugation.

All extractions were performed in triplicate on the soil and the composts before and after incubation. Total carbon in the extracts was determined using a DC 190 analyzer (Dohrmann), the HCl hydrolysates excepted, for which a TCM 480 (Carlo Erba) was used. Total nitrogen was measured by the persulfate oxydation method (Cabrera and Beare 1993). In all the extracts besides the autoclave extract, the organic N content was calculated by subtracting the initial soil and compost mineral N, from the total N in the extract, and the mineralized N after incubations.

Results and discussion

Organic matter characterisation

The table 2 shows the results of the gross fractionation of the organic constituents of the composts. The water soluble compounds represented 13 to 23% of the total organic matter. These values were within the range of results published by Gonzales-Prieto et al. (1993) for MSW composts, but was 10 fold higher than found by Garcia et al. (1993). The most important component of the composts was the 'lignin-humus' fraction, and corresponded to 45 to 54% of the total organic matter, high proportion compared to the ranges found by Gonzales-Prieto (1993). This fraction decreased with compost maturation time or with lumbri-composting. Simultaneously, the water soluble fraction increased. Humic materials were present in high quantities in the composts; but they still contained large amounts of lignin (Gonzales- Prieto et al., 1993). Lignin is very recalcitrant to

microbial degradation, and its proportion increases during composting, whereas labile organic matter as polysaccharides, hemicellulose and cellulose are reduced (Riffaldi et al. 1986). Stevenson (1965) considered that the water soluble fraction corresponded to soluble polysaccharides but without any analytical identification. However, this fraction may contain other hydrosoluble compounds. On the other hand, the soluble polysaccharides may not come directly from cellulose and hemicellulose depolymerisation, but rather from microbial production (Morel et al. 1985) or earthworm secretion in the case of the lumbricompost (Martin and Marinissen 1993). The non water soluble polysaccharides (hemicellulose and cellulose from vegetal residues) represented less than 10% of the total organic matter of the different composts. The relatively high amount of proteins (10.1 to 13.7%) may also be from microbial origin. Fats and resins represented less than 5% of the organic matter.

Table 2 Gross fractionation of the composts organic matter (in % of total organic matter).

	Composts		
	C1	C2	LC2
Fats	5	4	2
Resins	1	2	3
Water soluble compounds	22	13	22
Hemicellulose	6	4	6
Cellulose	3	4	4
Proteins	10	14	12
'Lignin-Humus'	45	54	48

Table 3 reports the amounts of some biochemical compounds in the water extracts and the hydrolysates of soil and composts. Low values were always found in the water extracts. The water soluble proportion of carbohydrates, expressed as percent of the total organic carbon, was generally higher in composts than in soil, but the hydrolyzable carbohydrate proportions were higher in the soil than in the composts. They represented about 5% of the compost organic matter. Morel et al. (1985) also reported that organic matter of mature composts contained 4 to 10% of hydrolyzable carbohydrates. This C fraction could be related to the hemicellulose and cellulose fractions obtained in the gross fractionation (Table 2). It confirmed that compounds other than polysaccharides must have been extracted with hot water during the gross fractionation.

Table 3 Biochemical characterisation of the soil and the composts

	Carbohydrates (C-glucose in % TOC)		Phenolic compounds (C-gallic acid in % TOC)		Amino acids + NH ₄ (N-leucine in % org N)	
	Water-soluble	Hydro-lysable	Water-soluble	Hydro-lysable	Water-soluble	Hydro-lysable
Soil	0.1	6.8	0.2	2.4	0.0	81.5
C1	0.3	3.9	0.3	3.7	0.6	66.4
C2	0.2	3.3	0.2	3.4	0.1	58.2
LC2	0.1	4.2	0.1	3.2	0.0	57.4

Important proportion of amino-acids + NH_4^+ , expressed in relation to the total organic nitrogen, has been already found in this soil (Menasseri, 1994). This N fraction was also high in the composts compared to those reported by Grünklee et al. (1993) and Gonzales-Prieto et al. (1993) who found that about 40% of the organic N was hydrolysable in amino-acids and NH_4^+ .

The relatively high proportion of phenolic compounds in the composts compared to the soil is to be related to the large 'lignin-humus' fraction of the composts (Table 2), that produced phenolic subunits after hydrolysis. Individual phenolic compounds were semi-quantitatively identified by HPLC (Table 4). Cinnamic acids (p-coumaric, ferulic), phenolic aldehydes (vanillin, syringaldehyde) and phenol carboxylic acids (vanillic, syringic) came from lignin and humic compounds formed during lignin degradation. Other compounds like p-hydroxybenzaldehyde and p-hydrobenzoic acid could come from lignin degradation or microbiological metabolism. No important differences were observed in the phenolic distribution between the soil and the composts, besides the relative higher content of vanillic and syringic acids in composts than in soil. Lignin depolymerisation and degradation by oxidative process during humification or composting produces first cinnamic subunits, then the corresponding aldehydes and finely the corresponding acids. Indeed, the ratios syringic acid / syringaldehyde and vanillic acid / vanillin can be considered as indices of oxydative transformation (Haider 1992). These ratios (Table 4) were lower in the soil than in the composts, indicating that the progress of the oxidative process were higher in composts than in soils.

Table 4 Identification of phenolics compounds in the soil and composts (expressed in % of the total area of identified pics on the chromatograms).

Phenolic compounds ^a	Soil	C1	C2	LC2
p-hydroxybenzoic acid	26	10	15	16
p-hydroxybenzaldehyde	8	6	8	8
Vanillic acid	7	19	14	16
Vanillin	15	15	13	13
Syringic acid	17	31	30	31
Syringaldehyde	6	5	3	4
p-coumaric acid	13	8	10	9
Ferulic acid	9	4	5	4
Syring. acid / syringald.	2.8	6.0	8.7	8.5
Vanillic acid / vanillin	0.5	1.3	1.1	1.2

^a Phenolic compounds listed in the order they appeared on the chromatogram

Biological assesment of the organic matter stabilisation

The kinetics of organic C mineralization were used to estimate the organic matter potentially mineralizable in the soil and composts. The cumulative amounts of C-CO₂ produced was described using first order kinetics: C-CO₂=C_o(1-e^{-kt}), with C-CO₂, the cumulative amounts of C-CO₂ produced at time t (in per cent of total organic C); C_o, the potentially mineralizable carbon (in per cent of total organic C)

and k the rate constant of mineralization (in day⁻¹). The potentially mineralizable organic carbon, C_o represented a larger proportion of total organic C (TOC) in the composts (20.7 to 22.4% of TOC, Table 5) than in the soil (7.6% of TOC). The mineralization was also faster in the composts. The larger rate constants of mineralization for the composts than for the soil indicated a more easily mineralizable organic matter in the composts. Saviozzi et al. (1993) reported a C_o of 12.5% for a MSW-compost, but this parameter concerned the mineralization of compost added to soil, and not a compost alone like in our experiment. Differences of time maturation between C1 and C2 composts did not modify the correponding C_o. Lumbricomposting did not modify the potentially mineralizable carbon but increased the rate constant of mineralization, which could be related with the increase of the carbohydrates and water soluble compounds observed previously. Additional mineralisation experiments of the composts, after a long storage of 1.5 to 2 years showed that C_o and the rate constant of mineralisation decreased of 20 to 25% (Table 5). Mineralization occurred during storage and reduced the degradable C.

Table 5 Estimated parameters of the first order kinetic model used to describe the organic C mineralization: C-CO₂=C_o(1-e^{-kt})

	C _o (% of initial TOC)	k (day ⁻¹)	R ²
Soil	7.6	0.008	0.973
C1	22.4	0.013	0.997
C2	21.5	0.014	0.994
LC2	20.7	0.016	0.992
Old C1 ^a	17.5	0.010	0.997
Old C2	18.4	0.010	0.998
Old LC2	15.4	0.012	0.999

^a old C1, C2 and LC2: C1, C2 and LC2 after 2, 1.5 and 1.5 years storage, respectively

Chemical assessment of the organic matter stabilisation

The results of three different chemical fractionations of the TOC are presented in Figure 1: the extractability of organic C in water, either in cold water or after autoclaving; the hydrolysable organic matter and the extractability of the humified organic matter. These extractions can give informations about chemical stabilisation and humification of the organic matter. Moreover, it can be assumed that the most easily extractable materials will be the most easily biodegradable. Thus, the water extracts can be related to the potentially mineralizable organic carbon. The C extracted in cold water is obviously the easiest organic C to be mineralized. The C extracted after autoclaving could be an estimation of the organic matter potentially mineralizable. The organic C extracted by acid hydrolysis would include the organic pool extracted after autoclaving and also extract another pool of organic matter coming from the hydrolysis of biopolymere structures or insoluble organometallic complexes. Both fractions are used as indices of soil nitrogen availability (Smith and Stanford 1971; Juma and Paul 1984; Giroux and Sen Tran 1987). The

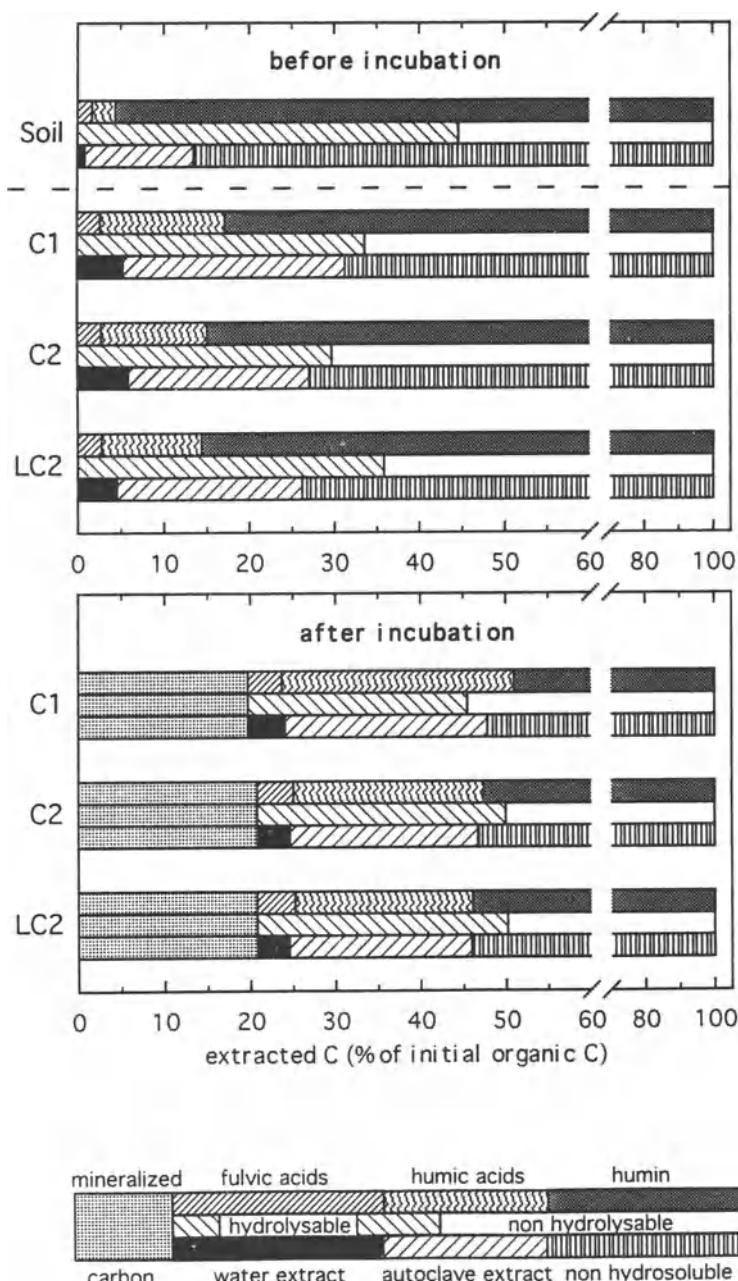


Figure 1 Carbon repartition in the different soil and composts extracts before and after incubation. Results are expressed in percent of initial organic carbon.

alkaline extraction gives informations about the humification level of the organic matter.

The total water extracted C represented 28 to 32% of TOC in the composts but only 14% in the soil. The easily mineralizable organic pool would be twice larger in the composts than in the soil, confirming the different C_o estimated during the incubations. Among this organic pool, the most labile organic C extracted in cold water was also more important in the composts (6% of TOC) than in the soil (2% of TOC). Gonzales-Prieto et al. (1993) also reported water soluble fraction containing 3 to 14% of compost TOC. The acid hydrolysis solubilized the largest proportion of carbon in the soil (45%) and the composts (30 to 35%). The alkaline solvant extracted more organic carbon in the composts (14 to 17%) than in the soil (4%), with a larger proportion of fulvic acids in the alkaline extract for the soil than for the composts. The humic fractions extracted were low compared to those of Giusquiani et al. (1989), but similar to those of Riffaldi et al. (1983), Garcia et al. (1993) and Gonzales-Prieto et al. (1993). The fulvic fraction represented always less than 5% of the TOC. Humic acids could be determined by difference between the total alkaline extract and the fulvic acids. Humic acids predominated over fulvic acids, as pointed out by Gonzales-Prieto et al. (1993). The humification ratio (C of humic acids/C of fulvic acids) was 1.6 for the soil and ranged between 4.2 and 5.5 for the non-incubated composts, as found by Inbar et al. (1990) for mature composts.

After incubation, 20% of the TOC were mineralized in the 3 composts. The C_o from mineralisation experiments could be related to the organic C extracted in cold water or by autoclaving, which was about twice higher in the composts compared to the soil. It could also be attributed to the humic fractions 3 to 4 fold higher in the composts than in the soil, as Saviozzi et al. (1993) found a positive correlation between C_o and the sum (C of humic acids + C of fulvic acids). The water and hydrolysable extracts decreased during incubation. However the non extractable fractions (non hydrolysable, non hydrosoluble and humin) observed the most important decrease. The successive extracted fractions were not independent. It could be assumed that the extractable C was mineralized meanwhile transformations of the previously non extractable C allowed to keep more or less constant the extractable pools. The humified organic matter increased during incubation. Humic substances are synthetized during composting (Saviozzi et al. 1988, Inbar et al. 1990) and may therefore also appear during incubation. The humification ratio was about 1.2 times higher in the incubated composts, confirming that humification took place in the composts during incubation. This agrees with the decrease of the C/N ratio observed during incubation (decrease of 5.7 to 5.1, 5.5 to 4.0 and 5.4 to 4.1 for C1, C2 and LC2, respectively), that indicates a higher degree of humification in the incubated composts. No differences were observed between the composts.

The persulfate oxidation method for total nitrogen determination was compared to the classical Kjeldahl mineralization. The results were comparable (data not shown), except for the acid hydrolysates, where the persulfate method overesti-

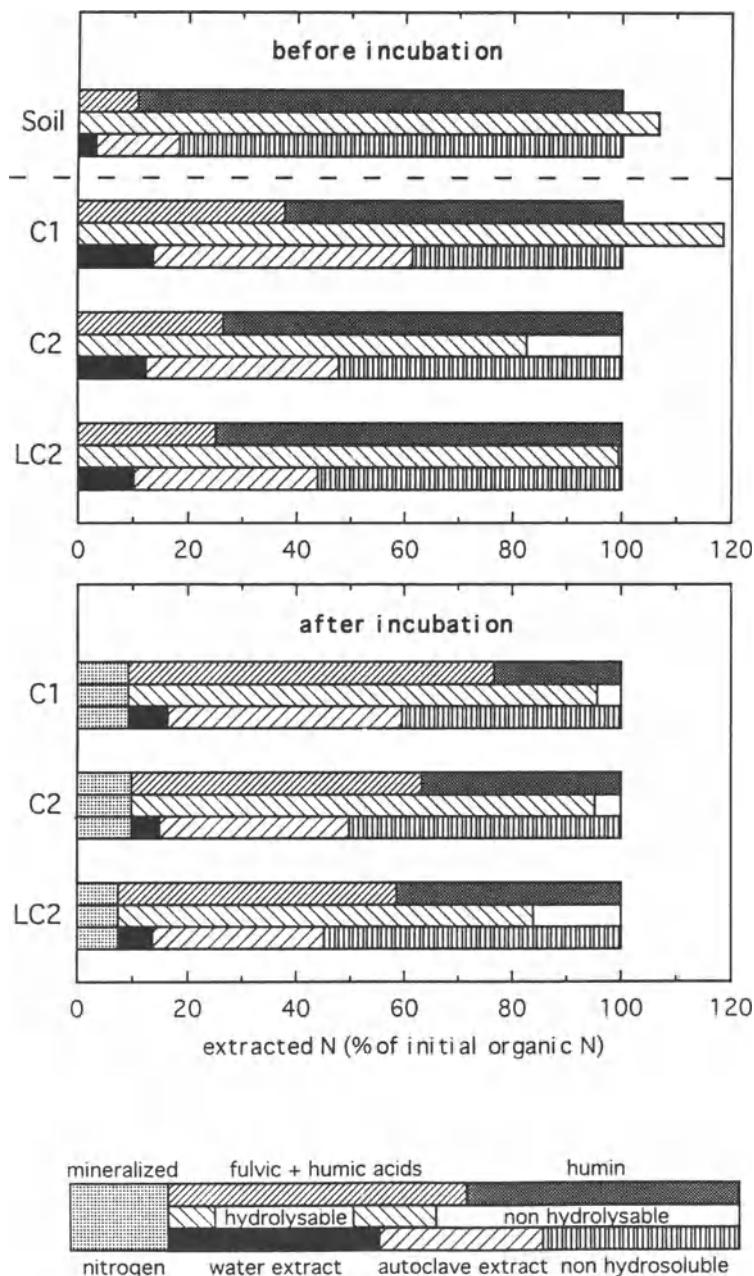


Figure 2 Nitrogen repartition in the different soil and composts extracts before and after incubation. Results are expressed in percent of initial organic nitrogen.

mated the nitrogen content of 25 to 30%. Cabrera and Beare (1993) also reported problems in the N recovery with the persulfate method with high Cl concentrations. The N repartition in the different extracts was similar to C repartition (Figure 2): water extracts (3 to 16% of organic nitrogen) < autoclave extracts (15 to 44%) < acid hydrolysates (even if overestimated). For these 3 extracts, no obvious influence of composts incubation could be shown. The alkaline extractable nitrogen was lower in the soil (11%) than in the composts (25 to 38%) and was twice higher after incubation.

In summary, chemical characterisation of 3 composts with different maturation time and process was performed with different extraction procedures as well as with fractionation and biochemical characterization of organic matter. The compost organic matter exhibited different properties than the soil's one. Composts were characterized by a larger labile fraction of organic matter than in the soil and a more humified organic matter. This was in agreement with the higher mineralization capacity of composts evaluated by incubation experiments. Moreover, these experiments showed that humification occurs during incubation. No significant difference could be found between the 3 composts. Composting type did not seem to have any influence on the organic matter properties studied. This confirmed that, for mature composts, composting leads to a quite homogeneous composition of organic matter, irrespective of the initial material and the composting process (maturation lenght, earthworm digestion) (Garcia et al. 1993).

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Respirometric Techniques in the Context of Compost Stability Assessment: Principles and Practice

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Summary

Knowledge of the degree of organic matter decomposition (maturity or stability), both during the composting process and in the final, marketed product, is essential for; effective process control, beneficial use of composts, and the development of composting itself as a reliable waste management option. A wide range of parameters have been proposed to meet this need, but a simple, reliable and rapid test still remains to be found. The most promising parameter seems to be the change in microbial respiration which occurs during composting.

In this study a respiration test is proposed, the SOUR (specific oxygen uptake rate) test, that utilises a dissolved oxygen (DO) meter to measure changes in the oxygen concentration of an aqueous compost suspension, at 30°C. The test takes advantage of the improved technology in the Clark-type polarographic DO probe routinely used in the wastewater field. A fully automated experimental procedure is described and the evolution of SOUR during composting of; sewage sludge, a poultry manure mixture and mechanically separated MSW is reported.

The SOUR values correlated highly significantly ($r=0.94$) with results from another respiration test recently proposed by Iannotti *et al.*, (1993), which also makes use of the DO meter, but measures the drop in oxygen concentration in the air space over a compost sample (solid phase) in a sealed container. Both tests indicated increasing stability with compost age. Analysis of other stability indicators confirmed the value of volatile solids in certain circumstances, while the information revealed following the optical density of compost water extracts was very limited.

Introduction

Evaluation of compost stability, both during the composting process and in the final, marketed product, is essential for; effective process control, beneficial use of composts, and the development of composting itself as a reliable waste manage-

ment option. The stability of compost determines the extent to which readily biodegradable organic matter has decomposed. It identifies the actual point reached in the decomposition process and represents a gradation on a recognised scale of values which give a comparable indication of the process of decomposition (LAGA, 1984).

The desired degree of stability depends on the use of the compost; for example horticulture, plant nurseries, the home gardening market etc., require well stabilised composts, whereas other uses, such as mushroom production and hot beds in greenhouses, require fresh compost (Morel *et al.*, 1985; Inbar and Chen, 1993). Stability is closely related to phytotoxicity (Zucconi *et al.*, 1985) and affects the potential for pathogen regrowth (Finstein *et al.*, 1987), and plant disease suppressiveness (Hoitink and Grebus, 1994). In addition, to evaluate different composting systems, process efficiency has to be assessed in terms of the stabilisation achieved in the final product (Stentiford, 1993).

A wide range of parameters have been examined for the determination of compost stability (Nicolardot *et al.*, 1986; Jimenez and Garcia, 1989; Mathur *et al.*, 1993a; He *et al.*, 1992), but a simple, reliable and rapid test still remains to be found.. Most of the methods proposed are based on monitoring, throughout the composting process, certain physical, chemical and biological parameters, whose change is a result of the metabolic activity of the micro-organisms involved. The variation of these parameters during composting, usually follows a similar tendency, irrespective of the nature of the organic matter, but the values attained at the end of the process depend largely on the feedstock.

A suitable stability test should be quantitative over a wide range of conditions and adaptable to a wide range of composting materials and processes. The equipment should be reliable, inexpensive and readily available, and procedures should be simple to perform, not requiring specialised personnel.

The most promising parameter to monitor the progress of the composting process and subsequent product stability, seems to be the change in microbial respiration activity (Usui *et al.*, 1983; Haug and Ellsworth, 1991; Zimmerman, 1991). As composting progresses, less substrate is available to the microorganisms and this is reflected in their respiratory activity; the respiration rate in a mature compost is significantly lower than that in the starting raw material, and is similar to the endogenous respiration rate.

Respiration rate may be measured as: i) heat released by a compost sample under controlled conditions (LAGA, 1984; Zimmerman, 1991)- this test is simple and inexpensive, but, due to the high specific heat of water, results are affected by even small variations of the moisture content of the sample; ii) carbon dioxide produced by a compost sample in an air-tight vessel- CO₂ is trapped in an aqueous solution of alkali and analysed gravimetrically or titrimetrically (Forster *et al.*, 1993). This procedure is inexpensive, but requires some analytical skills and does not differentiate between aerobic and anaerobic processes; iii) oxygen consumed by solid compost samples (Morel *et al.*, 1985; Wilson and Dalmat, 1986) or compost slurries (Usui *et al.*, 1983; Haug

and Ellsworth, 1991; Zimmerman, 1991; Robinson, 1991).

Respirometers designed to measure O₂ consumption can be placed into two general categories: those in which the partial pressure of O₂ continuously decreases, and those in which it is maintained at a more or less constant level (electrolytic respirometers). For aerobic systems, measuring the oxygen consumed is the most reliable and widespread method.

While oxygen respirometry produces satisfactory results, which have been validated with plant assays and other tests (Nicolardot *et al.*, 1986; Iannotti *et al.*, 1993), most of the methods make use of sophisticated and expensive instruments (eg. electrolytic respirometers).

This study proposes a stability test, the SOUR (Specific Oxygen Uptake Rate) test, that utilises a dissolved oxygen (DO) meter to measure changes in the oxygen concentration of an aqueous compost suspension. The test takes advantage of the improved technology in the Clark-type polarographic DO probe, widely used in the wastewater field. The method avoids rate limitations due to imbalanced pH, lack of nutrients or insufficient moisture, and measures the maximum microbial activity that could be supported by the amount of biodegradable organic matter in the sample. In addition, handling slurries rather than solid samples is simpler and more convenient.

Materials and Methods

Composting materials and processes

Three composts were examined, representing a diversity of substrates and different composting strategies.

Sludge compost samples were obtained from the Thames Water composting facility at Little Marlow, Buckinghamshire, England. A mixture of 6·8 parts of primary and secondary sludge and 1 part wheat straw (w/w) are composted in windrows for three weeks, with a turning frequency of about twice per week. The temperature in the core of the windrows typically reaches 50°C in the first 2–3 days and is sustained at this level for the full composting period. Material from windrows of different age (0, 3, 7, 14, 21 days) was taken immediately after turning, and combined samples (three locations per pile) were collected from piles approximately 2, 6, and 18 months old.

The MSW compost was prepared from the organic fraction of mechanically separated MSW using the ASP method with temperature feedback control, set at 65°C (Walker, 1994). The poultry manure compost was prepared in 200L plastic bins, manually turned twice per week. The initial mixture consisted of 30% poultry manure, 32% peat, 10% bark chips, 10% garden compost and 18% diesel oil (Stidwell 1994).

Chemical and physical analysis

The number of the subsamples ranged from 2–4 depending on the material and the parameter analysed. Moisture content (%_{ww}) was determined after drying in a ventilated oven at 105°C for 24h. Volatile solids content was determined from the percentage loss of mass of dry solids on ignition at 550°C for 3h. Electrical conductivity, pH and nitrogen content were determined according to MAFF/ADAS (1986).

Compost water extracts (two subsamples for each sample) were prepared by shaking a suspension of wet compost in distilled water (1:10 dry weight/volume) in a mechanical shaker for 1h. The suspensions were centrifuged and the supernatant passed through glass-fibre GF/C and 0.45µm membrane filters successively. Extracts were analysed for COD (APHA, 1992) and optical density at 280, 465 and 665nm (Mathur *et al.*, 1993b).

Respirometry

The rate of oxygen consumption was measured for: i) aqueous compost suspensions (SOUR test); and ii) compost samples in the solid phase, after adjusting their moisture content at approximately 60% (Dry Specific Oxygen Uptake-DSOUR test). The oxygen uptake rate was determined by following the changes in oxygen concentration with time, in the suspension or in the air space on top of the solid sample in a sealed container, respectively. Oxygen concentration was determined with a membrane-covered, polarographic Clark-type, dissolved oxygen (DO) probe, linked to a data logger/controller.

In both tests the compost samples (two replicates per treatment) were placed in a water bath, at 30°C. This temperature lies at the lower end of the optimum temperature range for the activity of compost microbiota (McKinley and Vestal, 1984; Kuter *et al.*, 1985). It was chosen because although, according to their specifications, the DO probes could be used up to 45°C, above 30°C some noise was often present in the signal (Robinson, 1991; Lasaridi, 1991).

Aqueous phase respiration - SOUR test

The SOUR test is based on the BOD test, routinely used for water and wastewater quality monitoring, adapted for more active solid materials such as compost.

A fresh sample of 3–12g, depending on the activity, of sieved (7 mm sieve) compost and 500ml distilled water were mixed in a food blender for about 30s, and placed in a 500ml Duran bottle, in a water bath held at 30°C. 12ml of phosphate buffer and 5ml each of the CaCl₂, FeCl₃ and MgSO₄ nutrient solutions made up per Standard Methods BOD test procedures (APHA, 1992), were used. The 'recipe' was similar to that recommended by Haug and Ellsworth (1991) and was designed to ensure that nutrients or pH are not limiting.

The DO probe was placed in the bottle, its sensor being at a depth of 5–6cm

below the surface. The suspension was continuously stirred by means of a magnetic stirrer and periodically aerated using a small fish-tank air pump, to replenish the oxygen consumed by the microorganisms. The electronic control system was adjusted to provide a repeating sequence of 20 minutes aeration followed by 15 minutes measurement of the oxygen concentration in the bottle, for about 24 hours.

The DO concentration data, expressed as mg/L, were analysed using EXCEL. For each measuring interval (15min) the first four readings (2min) were discarded, as they usually reflected a supersaturated state of the suspension, and a linear regression was performed for DO concentration versus real time, which gave the slope value $|S|$ (mgO₂/L/min). The correlation coefficient r^2 exceeded 0.98. The *maximum slope value /S_{max}* was used for the calculation of SOUR, expressed as mgO₂/gVS/h according to the equation:

$$\text{SOUR} = (60 * |S|_{\text{max}} * V_s) / (m * DS * VS)$$

where:

$60 =$ factor change from minutes to hours

$V_s =$ volume of the suspension (L)

$m =$ mass of the compost sample (g, wet weight)

$DS =$ fraction of dry solids (from 0 to 1.0)

$VS =$ fraction of volatile solids (from 0 to 1.0)

Typically the rate of oxygen demand increased for several hours, reaching a maximum within 2 to 14 hours, younger composts requiring generally less time. The time required before maximum activity was reached was found to depend on the age of the compost, the nature of the waste and the time elapsed between sampling and testing. Some tests were prolonged for 60 hours, to investigate if peaks in microbial respiration occur after the usual 24h of testing, but only lower, secondary peaks were observed. The variation of oxygen uptake rate with time during a typical SOUR test is presented in Figure 1.

A major concern with the SOUR test was that, as the DO probe was not sealed into the bottle, the liquid sample was subject to some natural reaeration during the phase of oxygen consumption measurement, limiting the accuracy of the method. To estimate the rate of the atmospheric oxygen diffusion to the sample through the exposed surface, under the experimental conditions, a reaeration test was performed.

Distilled water, in which disinfectant was added to a 110 ppm Cl⁻ concentration, to prevent microbial growth was de-aerated by bubbling into it nitrogen gas. The change of oxygen concentration with time, under the same experimental conditions as in the SOUR test, was followed until oxygen saturation was reached (about 16h). The overall oxygen mass transfer coefficient, K_a , was 0.25h⁻¹, resulting in a <5% error in the consumption of oxygen as measured in the SOUR test.

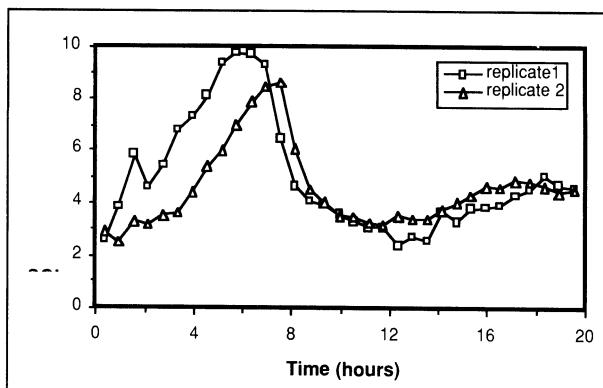


Figure 1 Variation of the specific oxygen uptake rate with time, during the SOUR test of a 2 months old sludge-straw sample. The respiration rate follows the typical pattern of microbial activity in a batch reactor, where aerobic conditions are maintained (Gaudy and Gaudy, 1980). The maximum rate of oxygen uptake reflects the maximum activity that the organic matter in the sample could support and gives its SOUR value.

Solid phase respiration-DSOUR test.

The respirometric method proposed by Iannotti *et al.* (1993) was followed, for comparison with the SOUR test. Compost was sieved (7mm sieve) and adjusted to a moisture content of approximately 60% (w/w). Samples corresponding to about 35g dry weight, were placed in 500ml conical flasks and aerated overnight (about 16h) at 30°C. A DO probe was sealed into the flask and monitored the change in percent oxygen in air over a 2-h period. The DSOUR (mgO₂/gVS/h) was calculated by the equation:

$$\text{DSOUR} = -(60 \cdot S \cdot C \cdot V_a \cdot D) / (m \cdot DS \cdot VS)$$

where:

S = slope of relative O₂ uptake rate (change in % oxygen saturation per minute)

C = volume fraction of O₂ in air; usually 0.21

V_a = volume of air in flask (ml)

D = oxygen density (g/L) at experimental conditions (303.15K, 100% water vapour saturation in air); 1.1816 g/L

Results and discussion

Temporal changes in moisture content (not shown), volatile solids, pH and electrical conductivity (table 1) were typical for the substrates and the composting systems used (Haug, 1980; Robinson, 1991; Hirai *et al.*, 1983; Garcia *et al.*, 1992). Moisture content in all trials was not limiting for microbial activity. The volatile solids reduction, calculated on the basis of the initial ash content (Stentiford and

Pereira-Neto, 1985) was 61.2% in 18 months for the sludge compost (44.0% in the first 60 days), 46.4% in 64 days for the poultry manure mixture and 62.3% in 35 days for the MSW compost. The low values obtained for the sludge and manure composts in the first two months, reflect the low biodegradability of the other materials used in the mixtures. The further volatile solids reduction in the sludge compost should be attributed to the decomposition of lignocellulosic materials in straw, which is slower than that of sludge (Lynch, 1993). Pieces of straw could be easily distinguished in the 0-60 days old samples, but not in the 6 and 18 months old ones which had a dark colour and an homogeneous texture.

The pH of the 0 and 3 days old sludge samples was low, indicating that anaerobic conditions had developed during transportation to the laboratory. However, this did not seem to affect the respiration rate in either the SOUR or the DSOUR test. Electrical conductivity did not change greatly during the process. It was higher for the MSW compost, although higher values have often been reported (Iannotti *et al.*, 1994). They also found a highly significant negative correlation between conductivity and composting time which was not observed here.

Compost stability, as determined by both wet and dry respirometry (Fig. 2 and 3), increased with age, for all composts. Values are expressed per gVS rather than per g total solids, to provide a more uniform basis. Otherwise, a sample with high inorganic content (e.g. sand) would exhibit a low rate of respiration, even if its organic matter was unstable.

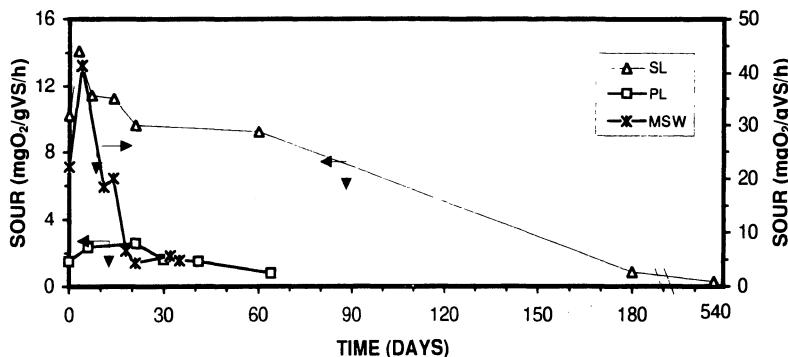


Figure 2 Variation of SOUR with time during composting of: sewage sludge (SL), poultry manure (PL), and organic fraction of municipal solid waste (MSW).

In all composts and with both methods, an increase of the respiration rate was observed during the initial stages of decomposition (Fig. 2). The increase was more pronounced with the MSW compost, where SOUR rose from an initial value of about 20, to peak around 40 mgO₂/gVS/h on day 4, coinciding with the maximum aeration demand (Walker, 1994). As composting begins, large organic molecules are broken down to smaller, soluble ones and temporarily more substrate becomes available to the microorganisms (Biddlestone and Gray, 1987), enhancing their activity. An initial increase in the soluble organic carbon was also noticed by Iannotti *et al.* (1994) and resulted in a peak in biomass (Herrmann and Shann, 1993).

The initial SOUR values varied considerably between the three composts following the order MSW>sludge/straw> poultry manure mixture. The same range of values has been observed by Robinson (1991) for sewage sludge composts (initial values between 4 and 20 mgO₂/gVS/h) and Lasaridi (1991) for source separated MSW (initial values between 25 and 50 mgO₂/gVS/h). The low respiration rate of the poultry manure mixture reflected the high percentage of slowly biodegradable materials, such as peat and woodchips, in the mixture. The presence of diesel oil slightly enhanced microbial activity compared with the control (not shown here), (Stidwell, 1994). The variation of the SOUR for different substrates was wider in the initial stages of the process and narrowed with time. A mature compost should be expected to exhibit an SOUR lower than 1 mgO₂/gVS/h, although higher values may not necessarily indicate instability for MSW composts. As with most stability indicators, SOUR can monitor changes occurring during composting, differentiate between the stages of the process and indicate stability for specific substrates, but 'stability values' may vary among composts of different origin.

Table 1 Changes in chemical parameters of the three composts with composting time

Age (d)	% Volatile solids	pH	Conductivity ($\mu\text{S}/\text{cm}$)	% TKN	COD (mg/gVS)*
<i>Sludge and straw compost</i>					
0	75.0±2.0**	4.78	1670±90**	3.71±0.32**	17.3±1.0**
3	68.2±3.9	5.63	1590±75	ND	ND
7	70.3±0.64	7.06	1460±72	1.96±0.28	14.6±0.3
14	68.8±0.28	8.09	2300±84	1.96±0.22	23.0±0.4
21	59.7±4.1	7.62	876±69	1.26±0.31	15.4±2.6
60	62.7±1.6	8.48	1160±82	1.88±0.26	17.5±0.8
180	57.1±2.0	6.10	2240±93	1.82±0.22	15.1±1.0
540	53.8±0.73	7.07	2130±88	ND	3.0±0.4
<i>Poultry manure mixture</i>					
0	80.8±4.0	7.79	ND	0.75±0.08	86±14
6	80.5±2.1	8.20	ND	0.78±0.12	50±4
21	81.0±0.71	6.75	ND	0.76±0.09	98±14
30	78.9±0.58	5.91	ND	0.68±0.07	54±11
41	74.3±2.1	5.98	ND	0.70±0.13	89±10
64	69.3±3.2	6.48	ND	0.70±0.11	ND
<i>Mechanically separated MSW compost</i>					
0	71.5±5.4	6.20	4050±700	1.85±0.11	ND
4	65.8±5.1	5.19	ND	ND	ND
11	71.1±6.0	6.28	4750±750	1.82±0.09	ND
14	61.9±5.3	6.62	ND	ND	ND
18	53.4±5.0	7.65	5500±780	ND	ND
21	63.3±4.2	7.33	6270±690	1.89±0.13	ND
32	43.5±4.9	7.58	ND	ND	ND
35	48.8±5.2	7.26	ND	1.79±0.10	ND

*COD analysed for 1:10(dw/v) water extracts.

**Population standard deviation (n=4 for VS and COD, 3 for pH and conductivity and 2 for TKN)

ND: not determined

The low pH of the 0 and 3d sludge samples did not seem to inhibit respiration when using the SOUR test, in contrast with concerns expressed about the effects of

low pH on microbial activity (Kubota and Nakasaki, 1991; Iannotti *et al.*, 1994). The experimental protocol of the SOUR test is such as to avoid rate limitations due to restrictive pH, nutrient imbalance or insufficient water content.

The SOUR test measures the maximum rate of respiration that the sample could potentially sustain, rather than the expected oxygen demand under conditions of actual use in the soil. This is demonstrated in Fig. 3, where the variation of the SOUR and DSOUR with compost age for the sludge/straw compost is presented. The two respiration rates followed the same pattern of change with compost age and their correlation was highly significant ($r=0.94$). However, their values were remarkably different, the SOUR being more than 6 times higher than the DSOUR in the first three weeks of composting. This difference, narrowed with compost age and practically vanished for the 18 months old compost, which exhibited an SOUR of $0.28 \text{ mgO}_2/\text{gVS/h}$ and a DSOUR of $0.27 \text{ mgO}_2/\text{gVS/h}$.

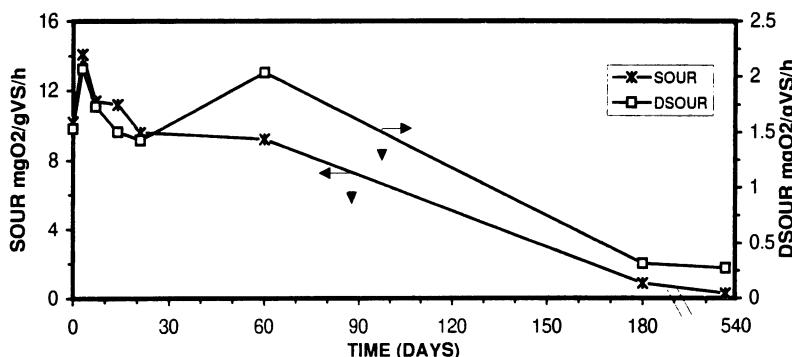


Figure 3 Variation of SOUR and DSOUR with time during windrow composting of sewage sludge

The high correlation coefficient between the two tests indicates that they reflected the evolution of the compost organic matter (i.e. its stability) in an equivalent manner. The biochemical transformation of the organic matter in the compost is carried out by microorganisms whose metabolic activity occurs in the water soluble phase (Hirai *et al.*, 1983). In the SOUR test, respiration rate is measured in an environment where there is intimate contact of substrate, microorganisms and oxygen. All the soluble organic matter in the sample becomes immediately available to the microorganisms and the increase of readily available food promotes their growth and reflects into their activity. In the DSOUR test microbial activity occurs in a thin water layer that surrounds the compost particles and is limited by the rate of substrate solubilisation and oxygen transfer at the water interface (Haug, 1980). As compost ages and there is less food available, these transfer rate limitations become less important and the difference between the SOUR and DSOUR values narrows.

Pearson product moment correlation coefficients (Table 2) revealed that respirometry (for both the intact sample and its aqueous suspension) and volatile solids were highly significantly ($p\leq 0.01$) correlated with compost age, for all three composts, which is in agreement with the findings of Iannotti *et al.*, 1994, Garcia *et al.*, 1992 and Inbar *et al.*, 1993. The COD of the water extracts correlated ($p\leq 0.01$) with age

for the sludge compost, but not for the poultry manure mixture, possibly because of the highly differing degrees of biodegradability of the raw ingredients and the presence of diesel oil, while pH correlation with time was highly significant for the poultry manure mixture and the MSW compost, but was not significant for the sludge compost. Electrical conductivity correlated with age at the 0.01 and the 0.05 significance levels, for the MSW and the sludge composts, respectively. The nature of the composted wastes seemed to influence the latter parameters more than the composting process itself, which limits their value as stability indicators.

None of the parameters based on the optical properties of the water extracts (Fig. 4) had a highly significant correlation with compost age. The change in the optical density of compost extracts has been widely used for the evaluation of the progress of the organic matter decomposition and the degree of maturity (Mathur *et al.*, 1993b; Chen and Inbar, 1993; Morel *et al.*, 1985), mainly because of the simplicity of the method. However, the degree of success varied and results were contradictory. In this work, the information on compost stability and maturity, provided by the absorbance of compost water extracts at the UV and visible spectrum range, was very limited.

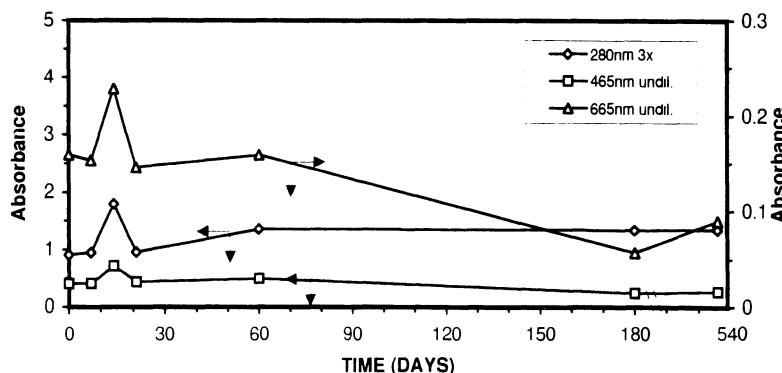


Figure 4 Variation of optical density of 1:10 (dw/v) water extracts at 280nm (3x dilution), 465nm and 665nm (undiluted) with time during composting of sewage sludge.

Table 2 Pearson product moment correlation coefficients (*r*) between compost age and various chemical and biological properties of the examined composts.

Technique	<i>r</i>		
	Sludge compost	Poultry manure mixture	MSW compost
VS	-0.75**	-0.72**	-0.88**
pH	0.07	-0.73**	0.78**
conductivity	0.45*	ND	0.96**
COD (mgO ₂ /g dry wt)	-0.88**	-0.10	ND
COD (mgO ₂ /g VS)	-0.88**	0.16	ND
SOUR	-0.85**	-0.65**	-0.79**
DSOUR	-0.80**	ND	ND
280	0.24	ND	ND
465	-0.59*	-0.45	ND
665	-0.63*	0.33	ND
E4/E6	0.20	-0.57*	ND

* and ** represent significance at the 0.05 and 0.01 levels, respectively. ND: Not determined

Conclusions

The two respirometric methods gave comparable results and were good indicators of compost stability for all three composts examined. The rate of respiration may reveal far more about the stability of a compost sample than any other test. In this respect, the SOUR test offers the additional advantages of simplicity and convenience and avoids rate limitations due to insufficient sample moisture or drying.

The value of the volatile solids analysis as a simple, non-specific indicator of the decomposition progress was confirmed, while the information provided by the optical density analysis of compost water extracts was very limited.

Since the ultimate criterion for compost stability is its effect on plants, it is suggested that plant growth bioassays are carried out, to associate, for various composts, values of the oxygen uptake rate with specific levels of compost stability.

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Different Location of Acid and Alkaline Phosphatases Extracted From a Compost of Urban Refuse.

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Summary

The study of the molecular location of acid and alkaline phosphatases in a compost of urban refuse was initiated after their extraction using 0,05 M pyrophosphate at pH 9 and in the presence of 1 M KCl to modify its ionic strength. The extract was divided by ultrafiltration in cell-bound (UF_3 fraction with $\phi>0,45\text{ }\mu\text{m}$) and exocellular enzymes: UF_{23} with $\phi<0,45\text{ }\mu\text{m}$ and mol. wt. $>100\text{ kD}$; UF_{22} with $100<\text{mol. wt.}<30\text{ kD}$; UF_{21} with $30<\text{mol. wt.}<10\text{ kD}$ and UF_1 with mol. wt. $<10\text{ kD}$. Thereafter UF_3 was divided by sonication in their intracellular (E_i) and membrane-bound components (E_m), and after solubilization with Triton X-100 in enzymes located outside (E_{mp}) and inside the membrane (E_{ms}).

The highest activity of acid phosphatase appeared in the UF_3 fraction, its extraction being unaffected by the introduction of KCl in the extractant. The UF_3 fractionation located the acid PA in the membrane-protein fractions (E_m). Alkaline phosphatase was predominant in the fraction UF_{23} showing 86% of the activity displayed by all the fractions; the increase in the ionic strength reduced this activity in UF_{23} (-68%) increasing the activity in UF_{22} (5,2% to 24,2%). In UF_3 , the alkaline phosphatase had an intracellular localization (E_i fraction) showing 90% of the activity displayed by UF_3 .

Different mechanisms of stabilization for compost enzymes were postulated: acid phosphatases may be associated to membranous components of living or dead microbial cells with low solubility in the pyrophosphate extractant and alkaline phosphatase may form a soluble complex enzyme-organic matter of high mol. wt. dissociable at high ionic strength.

Introduction

The amount of urban waste in European countries is increasing constantly and it needs to be disposed off in landfills or via incineration. However, public acceptance and the costs of the these waste disposal methods are the main problems for the authorities. For the next decade a new hierarchy for waste management has been established in several European countries: 10% of waste must be avoided; 50% reclaimed; 25% incinerated; and 15% landfilled. Composting of household waste, or a significant fraction thereof, is an essential part of the proposed integrated waste management system, being a technology that is a key for achieving the goal of 50% by the year 2000 (Van Belle, 1992). The organic fraction of Municipal Solid Wastes (MSW) may reach 60–70% in weight and is the most hazardous fraction to dispose of because it undergoes microbial transformations causing soil, water and air pollution. Composting is the only way to transform this fraction into an organic fertilizer (De Bertoldi, 1992).

The organic C content in most composts is about 30% on dry-wt.; this high content of organic matter makes compost a very attractive soil conditioner to increase soil organic matter content. Contents of the main plant nutrients N and P in composted MSW are considerably higher than those in most agricultural soils, but the N and P availability are low. Only 10–15% of total N and up to 15% of P is available in both the first and second years after soil application (He *et al.*, 1992). Microorganisms influence the transformation of the organic matter of a waste either during composting or when it is added fresh to the soils. Thus, the activity of phosphatases transforms the organic P into soluble phosphate making it bioavailable for plants or microorganisms. It might also be considered as an indicator of the organic matter evolution and of the degree of stabilization reached in the composting process (García *et al.*, 1993).

Sodium pyrophosphate has been successfully used in extracting soil-bound exocellular enzymes like phosphatase, urease and proteases (Nannipieri *et al.*, 1980). The fractionation by ultrafiltration of extracted soil-enzymes allowed their partial purification and characterization (Nannipieri *et al.*, 1988). The aim of this work is to extract compost-phosphatases, determine their localization and the mechanism involved in their association with the organic matter or microorganisms of the compost.

Material and methods

Raw material.

Samples of Municipal Solid Waste (MSW) were collected from the dumping place of Burgos town (Castile, North-Center of Spain). After six months of composting, the samples were carried to our laboratory and stored in closed polyethylene bags at environmental temperature until their pretreatment. This MSW was

screened to pass a 2 mm mesh to discard the inert components and 150 g of the light fraction was ball-milled with fifty balls of agate. The final product was stored frozen at -20°C. The physical and chemical properties were: Ashes 77,7%, density 2,53 kg.l⁻¹, dry matter 96,5%, pH (1:5 in distilled water) 7,78, oxidizable organic matter 23,46%, Total N 0,576 gN.Kg⁻¹ (dry weight basis), Total P 0,376 gP.Kg⁻¹ (dry weight basis) and Total K 0,48 g K₂O.Kg⁻¹ (dry weight basis). Total heavy metals in µg.g⁻¹ (dry weight basis) were: Fe 17.947; Cd 9,5; Pb 187,4; Cr 221,5; Mn 271,7; Cu 236,9 and Ni 660.

Enzyme assay.

Acid and alkaline phosphatase activities in extracts were assayed using 110 mM *p*-nitrophenyl phosphate (*p*NPP) and *p*-nitrophenol (*p*NP) liberated by the enzymatic hydrolysis measured colorimetrically at 410 nm in alkaline medium. Acid phosphatase was assayed using 0,2 M citrate buffer at pH 5 (Moss, 1984) and alkaline phosphatase with 0,1 M 2-amino-2-methyl-1-propanol with 1 mM ZnSO₄ and 2 mM MgSO₄ at pH 10,5 (Bretaudiere and Spillman, 1984). For analysis in solid samples of MSW, modified universal buffer (MUB) was used in accordance with (Tabatabai and Bremner, 1969).

Soluble proteins were measured by the Folin method (Lowry *et al.*, 1951). Triplicate assays were made for all determinations and two controls in which the substrate was added after the incubation, were run for each sample.

Enzyme extraction.

5 g of MSW and 100 ml of 0,05 M Na₂H₂P₂O₇ at pH 9 were mixed in a 250 ml centrifuge bottle. This suspension was sonicated in an ice bath for 10 min (maximum interval of 2 min) at 70 Watt. Then agitated for 5 h with a vibratory movement (200 osc.min⁻¹) at 4°C. The MSW-extract was removed by centrifugation for 30 min at 21.000 g (at 4°C) and the solid particles discarded by filtration.

Molecular fractionation of enzymes.

MSW-extract was fractionated by ultrafiltration with tangential flow (Minitan System, Millipore). 50 ml of extract and 200 ml of distilled water, added continuously to a constant volume of extract, were passed through a 0,45 µm membrane plate (Filter Millipore, type HVLP). The retained solution -called UF₃- was diluted to 50 ml with distilled water to preserve the initial volume of extraction; this fraction contains mainly the cell-bound enzymes. The filtrate was passed through a membrane with a 10 kD exclusion limit (Filter Millipore, Type PTGC), concentrating it initially to 50 ml and adding 300 ml of distilled water to remove the smallest mol wt compounds, a sufficient volume to obtain 50 ml of a salt-free extracellular fraction called UF₂. Salts and compounds with mol wt <10 kD were accumulated in the last filtrate and after concentration in a rotary evaporator under

vacuum at 40°C to 50 ml, we obtained the UF₁ fraction with a residual enzymatic activity.

In subsequent experiments, filter plates with 100 and 30 kD of retention were interposed (Filter Milipore type PTHK and PTTK, respectively). They led to a division of the UF₂ fraction into three new molecular fractions: UF₂₃, with Ø<0,45 µm and mol wt>100 kD; UF₂₂ with 30< mol wt <100 kD and UF₂₁ with 10< mol wt < 30 kD.

The UF₃ fraction was sonicated for 5 min, at 70 Watt in an ice bath, then centrifuged for 1 hour at 30.000 g (at 4°C). The supernatant, containing intracellular enzymes, was the E_i fraction; the pellet obtained was resuspended in 50 ml of distilled water and this fraction was called E_m, comprising the membrane-bound enzymes. Furthermore, the same pellet was dissolved in a solution of Triton X-100 (1% v/v in distilled water) and after 10 min of vibratory agitation at 4°C, two new fractions of E_m were obtained by centrifugation (1 h at 30.000 g and 4°C): the supernatant –E_{mp}– with the enzymes located on the outer part of the membrane, and the pellet suspended in distilled water –E_{ms}– with the enzymes located on the inner side of the membrane. Both fractions were ultrafiltered at 10 kD to obtain the enzymatic protein free of Triton X-100.

Results and discussion

Phosphatase activity (PA) was initially measured for solid samples of MSW-compost using MUB covering a wide range of pHs. Two peaks of activity with different intensity appeared at pH 5,5 and 10,6 revealing the existence of a slight presence of acid PA ($0,871 \mu\text{mol pNP.(g dry MSW)}^{-1} \cdot \text{h}^{-1}$) and an important amount of alkaline PA ($21,538 \mu\text{mol pNP.(g dry MSW)}^{-1} \cdot \text{h}^{-1}$). These values of alkaline PA were higher than the mean values of PA found for organic rich soils and similar to those found for rhizosphere soils or soil organic fractions with the highest mineralization rates (Rojo *et al.*, 1990).

In a previous work, the use of a low concentration of sodium pyrophosphate (0,05 M), an alkaline pH, and the sonication of the mixture extractant/MSW was found optimum to reach the maximum extraction of enzymatic activities including acid and alkaline phosphatases (Rad, 1992). The values of PA displayed in the extract corresponded to the extraction of 4% of acid PA and 1,7% of alkaline PA of the MSW-compost PA although, after ultrafiltration of the extract, the whole PA in all the molecular fractions showed a higher percentage of extraction: 68,9% for acid PA and 35,5% for alkaline PA (Table 1). The exhaustive ultrafiltration of extract with distilled water as solvent gives the complete pyrophosphate elimination, a strong inhibitor of PA (Nannipieri *et al.*, 1988), and the real amount of extracted phosphatase might be measured.

The distribution pattern of acid and alkaline phosphatases between the molecular fractions was very different (Figure 1). Acid PA had an homogeneous distribution by all the fractions prevailing in the cell-bound fraction UF₃. While, alkaline

PA concentrated their activity in the exocellular fraction of highest mol. wt. UF₂₃ that also showed the main amount of extracted proteins. The highest specific activity for both enzymes appeared in the UF₂₂ fraction in which the least protein content appeared.

Table 1 Molecular fractionation of acid and alkaline phosphatases extracted from a compost of Municipal Solid Wastes (MSW) by 0,05 M sodium pyrophosphate at pH 9.

SAMPLE ^a	Protein ^b	Acid PA		Alkaline PA		r (Alk/Ac) ^c
		PAc	SPAd	PAc	SPAd	
Extract	6,372	0,035	0,005	0,363	0,057	10,37
UF ₃	0,370	0,199	0,538	0,592	1,600	2,97
UF ₂₃	2,569	0,150	0,058	6,615	2,575	44,10
UF ₂₂	0,130	0,123	0,944	0,399	3,063	3,24
UF ₂₁	1,756	0,128	0,073	0,101	0,058	0,79
E _i	0,021	0,086	4,127	0,536	25,720	6,23
E _m	0,307	0,129	0,420	0,020	0,065	0,15
E _{mp}	0,010	0,161	15451	0,001	0,096	0,01
E _{ms}	0,042	0,125	2,999	0,000	0,000	0,00

^aExtractant: 0,05 M Na₂H₂P₂O₇, pH 9, 5 h vibratory agitation, 5 ml.g⁻¹ of ratio Extr/MSW; molecular fractions: UF₃ ($\varnothing > 0,45$ mm), UF₂₃ ($\varnothing < 0,45$ mm and mol. wt.>100 kD), UF₂₂ (100>mol. wt.>30 kD), UF₂₁ (30>mol. wt.>10 kD), E_i intracellular enzymes, E_m membrane-bound enzymes, E_{mp} outer-membrane-bound enzymes and E_{ms} inner-membrane-bound enzymes.

^bProtein in mg.(g dry MSW)⁻¹

^cPhosphatase activity (PA) in mmol pNP.(g dry MSW)⁻¹.h⁻¹

^dSpecific phosphatase activity (SPA) in mmol pNP.(mg protein)⁻¹.h⁻¹

^eRatio alkaline/acid phosphatase activities for each fraction.

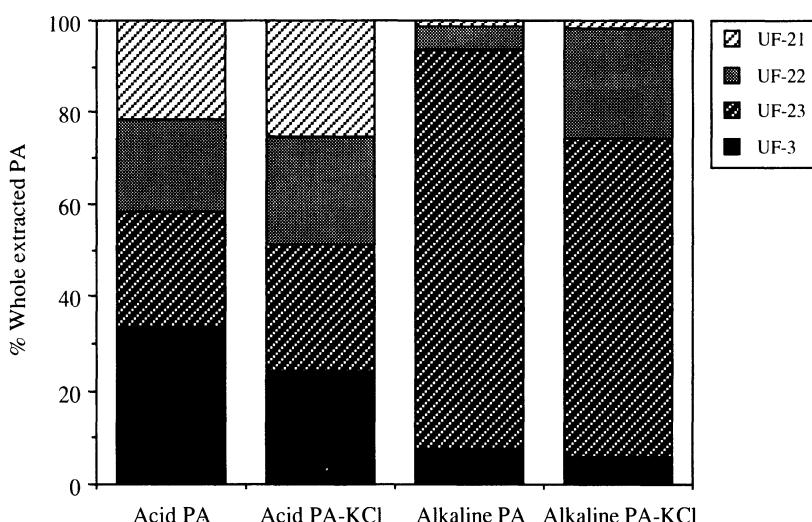


Figure 1 Molecular distribution of acid and alkaline phosphatases extracted from a compost of Municipal Solid Waste (MSW) with 0,05 M Na₂H₂P₂O₇ at pH 9 with and without 1 M KCl. Molecular fractions: UF3 ($\varnothing > 0,45$ mm), UF23 ($\varnothing < 0,45$ mm and mol. wt.>100 kD), UF22 (100>mol. wt. >30 kD), UF21 (30>mol. wt.>10 kD).

Fractioning of cell-bound compounds revealed the intracellular character of alkaline phosphatases (E_i) and the association of acid phosphatases to membranes (E_m fraction) in the UF_3 fraction. The treatment with a detergent such as Triton X-100 led to a net increase in enzyme expression for both fractions, the solubilized material (E_{mp}) or the insoluble material

(E_{ms}). Proteins of the E_m fraction were solubilized by this treatment, but they were lost in the detergent elimination by ultrafiltration at 10 kD, because they were low mol. wt. compounds. The low amount of proteins in the intracellular fraction supposed the maximum specific activity for intracellular alkaline phosphatase.

The introduction of 1 M KCl in the extractant had no effect on the total extracted acid PA but strongly diminished proteins in the extract (~37%) and in the whole extracted alkaline PA (~35%). These changes were also found in the distribution of proteins and enzymes in the molecular fractions (Table 2). The main amount of extracted proteins were present in UF_1 (mol. wt.<10 kD) with a net increment of 104%; the highest reduction appeared in UF_{23} and UF_{21} fractions (~88% and ~80% respectively).

Table 2 Molecular fractionation of acid and alkaline phosphatases extracted from a compost of Municipal Solid Wastes (MSW) by 0.05 M sodium pyrophosphate with 1 M KCl at pH 9.

SAMPLE ^a	Protein ^b	Acid PA		Alkaline PA		r (Alk/Ac) ^c
		PA ^c	SPA ^d	PA ^c	SPA ^d	
Extract	4,032	0,038	0,009	0,186	0,046	4,89
UF_3	0,094	0,146	1,551	0,296	3,144	2,08
UF_{23}	0,303	0,161	0,531	3,385	11,159	21,02
UF_{22}	0,131	0,142	1,086	1,202	9,193	8,46
UF_{21}	0,345	0,153	0,443	0,077	0,223	0,50

aExtractant: 0,05 M Na₂H₂P₂O₇, 1 M KCl pH 9, 5 h vibratory agitation, 5 ml.g⁻¹ of ratio Extr/MSW; molecular fractions: UF_3 ($\varnothing > 0,45$ mm), UF_{23} ($\varnothing < 0,45$ mm and mol. wt.>100 kD), UF_{22} (100>mol. wt. >30 kD), UF_{21} (30>mol. wt.>10 kD).

bProtein in mg.(g dry MSW)⁻¹.

cPhosphatase activity (PA) in mmol pNP.(g dry MSW)^{-1.h-1}.

dSpecific phosphatase activity (SPA) in mmol pNP.(mg protein)^{-1.h-1}.

eRatio alkaline/acid phosphatase activities for each fraction.

The first consequence was the extraction of most purified enzymes clearly stated by their specific activities. The presence of KCl reduced the activity of acid PA in UF_3 and increased their presence in UF_{21} . In alkaline PA, the activity of UF_{23} was decreased with a parallel increment in UF_{22} ; in the percentile expression, the sum of both against the whole extracted enzyme remained constant (Figure 1).

The different behaviour found for acid and alkaline phosphatases in MSW-compost may be related with their different origin and the existence of several stabilization mechanisms for these enzymes. Nakas *et al.* (1987) reported for a grassland soil, that bacteria were the highest producers of exocellular phosphatases -acid or alkaline, fungi only produce in general acid phosphatases and in an order of ten to a hundred times less. García *et al.*, (1993) related that alkaline PA diminished with composting although their stability was increased by the association of

free enzyme with humic matter formed in the composting process.

The localization of alkaline PA is predominantly exocellular, the main fraction of PA appearing in UF₂₃, fraction with the highest mol. wt. molecules. This portion of enzyme may be associated with soluble organic matter of the compost forming an active enzyme complex, similar to the humus-enzyme complexes found in soils. The presence in UF₂₂ of an important amount of enzymes with high specific activity may correspond with the soluble enzyme. Microbial phosphatases have two subunits with a similar mol. wt. for both acid and alkaline forms; thus, acid phosphatase produced by *Neurospora* has 42 kD and alkaline phosphatase from *E. coli* 43 kD (Fasman, 1989). The increase in the ionic strength of extractant by KCl addition produced the breakdown of this complex diminishing the activity in UF₂₃ and increasing the presence of free enzyme in UF₂₂.

For soil exocellular enzymes, the association with colloidal humic matter is one of the most important mechanisms of stabilization (Burns, 1986). This association may be done through physical entrapment of the enzyme in the matrix of humic acid or by the formation of stable hydrogen or covalent bonds (Ruggiero and Radogna, 1988). These humus-enzyme complexes show a remarkable stability against the denaturalizing conditions of soil: pH, salinity, thermal variations or proteolysis (Boyd and Mortland, 1990). Chromatographing soil pyrophosphate extracts, Nannipieri *et al.* (1988) found that higher mol. wt. complexes (>100 kD) were more resistant to thermal denaturation and proteolysis than the small complexes (<100 kD) because of their high content of carbohydrates. Martens and Frankenberger (1991) found that glycoproteins present in exocellular soluble or insoluble polymers excreted by fungi and bacteria for colonizing the surrounding microenvironment, displayed remarkable enzymatic activities like alkaline phosphatases. In compost the association of these polymers with soluble humic matter may constitute a stable exocellular activity that remains active for a long period of time being the responsible of the mineralization of organic P, during the composting or after soil addition.

Conclusions

1. The MSW-compost may be seen as a good alternative to peat or other organic substrates for horticulture because of its high content in organic matter, its important amount of nutrients such as organic N and P and the presence of an enriched medium of hydrolytic enzyme activities that make possible the slow and biochemically controlled release of these nutrients.
2. In MSW-compost enzymes are synthesized by different microorganisms and their location and persistence varies widely. Compost enzymes may be extracted in 0,05 M pyrophosphate at pH 9 in high yields. Alkaline PA was mainly an exocellular enzyme with a high persistence due its association with soluble humic matter of compost, while acid PA was a cell-bound enzyme, linked to membranes or cell fragments with less persistence in the composting process.

3. The association humus-alkaline PA in MSW-compost was through ionic or hydrogen bounds being dissociated by the increase in the ionic strength of the extractant by the addition of 1 M KCl. The molecular pattern distribution of acid PA was unaffected by KCl addition.

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Biological Parameters to Estimate the Effect of Biogenic Waste Composts on Plant Growth in Pot Trials

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Abstract

About 80 different biogenic waste composts were tested by new or modified conventional microbiological methods (oxygen-consumption, DMSO-reduction, Eh- and pH-drop during anaerobic incubation, reference method: self-heating-capacity) to determine the state of maturity and the effect of composts on plant growth in pot-trials. The progress in ripening of composts could be proved well by oxygen-consumption, pH-drop and self-heating-capacity, while DMSO-reduction and Eh-drop reflected maturity only with restrictions. A satisfactory prediction of plant-growth (dry-matter-production of oats) after compost-application with the help of the biological parameters was scarcely possible, only pH-drop showed a somewhat higher correlation. It was found out, however, that the effect of compost on plants could be estimated well by making use both of the C/N-ratio and of biological parameters.

Introduction

An essential criterion for application of composts in agri- and horticulture is - besides the contents of nutrients and pollutants – the maturity. Conventional methods for determining the ripeness of composts (e.g. self-heating capacity (LAGA 1984)) often do neither reflect the general status of the material nor its effect on plant growth. Moreover some methods demand several days for carrying out. Therefore it was tried to develop and modify biological procedures to evaluate the maturity of composts reliably and in a relatively short time.

The theoretical basis of all biological methods is founded on the presumption that the unriper composts are the higher is the availability of degradable C-compounds and the microbiological activity.

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Material and Methods

1) Composts: The tested composts came both from compost plants in the whole of Bavaria and out of composting experiments. They differed in kind and mixture ratio of raw materials (biogenic household wastes, plant residues), additional substances (mature compost, clayey soil, lime, mineral powder, bacterial preparations), age, pile size, kind and frequency of turning the pile, technical equipment and buildings of the compost plants. Model-composts which are represented graphically to prove maturity progress (Figs. 1 – 4) are characterized in table 1.

Table 1 Raw material, turning intervals and pile size of model composts

Compost designation	0	60	80	I	+N	dly	4wk	lrg
Plant residues %	0	60	80	60	60	60	60	60
Organic house-hold waste %	100	40	20	40	40	40	40	40
Turning interval (d)	3	3	3	3	3	1	28	7
Additional substances	–	–	–	bacteria, CaCN_2	–	–	–	–
Sectional area of pile	triangle	triangle	triangle	triangle	triangle	triangle	triangle	trapeze
Hight of pile (m)	1.5 – 1.8	1.5 – 1.8	1.5 – 1.8	1.5 – 1.8	1.5 – 1.8	1.5 – 1.8	1.5 – 1.8	4
Width of pile (m)	2.5 – 3.0	2.5 – 3.0	2.5 – 3.0	2.5 – 3.0	2.5 – 3.0	2.5 – 3.0	2.5 – 3.0	7 – 8

These model-composts were analyzed for three times during composting (3, 8 and 13 weeks). Together with composts from Bavarian compost-plants there were about 80 different composts being examined by the following methods:

Biological methods for determining maturity:

Oxygen-Consumption:

By advancement of the methods described by Nicolardot (1986), Morel (1986) and Kohmann and Fischer (1993) microbial activity was measured as pressure-drop as a result of absorbing the CO_2 released by the microorganisms with NaOH. For this purpose compost (<10 mm) was brought up to a water-tension of 25 - 35 hPa and was filled in a perforated flower-pot on the basis of 250 g dry matter in a way that the maximum distance between the innermost of the compost and the surrounding gas-atmosphere amounted only to 2.5 cm. Thus advantageous conditions for gas exchange should be created. Then the compost was put in a pressure-tight vessel together with 10 g NaOH and 10 ml H_2SO_4 (30 %) and incubated by 38°C. NaOH was placed at the bottom of the vessel so that the CO_2 (high density, sinking down) produced by the microorganisms could be caught immediately. H_2SO_4 was put on the top of the compost to bind ammonia (low density, rising upwards) to avoid pressure changes which are not due to the CO_2/O_2 -system. Before incubation started the vessel-atmosphere had been enriched with O_2 .

Pressure-decrease was logged continuously with a data-logger and calculated as O₂-consumption in mg per g compost dry-matter and hour.

Dimethylsulfoxide-(DMSO)-Reduction/Dimethylsulfid-(DMS)-Production

To employ this enzyme-activity-method (Alef 1991), which predominantly is used for mineral soils so far, compost had to be sieved (<10 mm), ground (<6 mm) and sieved again (<2 mm). 8 g of compost fresh-matter were filled into flasks (118 ml volume), added with 4 ml DMSO-solution (3,5 %), closed gas-tightly and incubated in a water-bath (40°C). After 3 hours an aliquot of the flask's gas atmosphere was taken and the DMS produced by microorganisms was analyzed in a gas chromatograph. Furthermore a part of the samples was not added with DMSO-solution but with DMS to determine the DMS-absorption of the composts (Zehner et al. 1992).

Redoxpotential- and pH-drop during anaerobic incubation

This method is founded on the assumption that in compost-suspensions the redox-potential (Eh) and the pH are the more decreasing during anaerobic incubation the higher is the quantity of available C-compounds and the activity/reducing capacity of the present microorganisms (Flessa 1990, Jakob 1970, Jann et al. 1959, Yamane and Sato 1968). For this purpose compost (<10 mm) on the basis of 40 g dry-matter was submerged with distilled, boiled water in a ratio of 1: 6,25. This suspension was incubated in a water-bath by 40°C and Eh, pH and temperature were measured each hour. Between the measurements the flasks were screwed up to avoid O₂-infiltration.

Pot-trials

The composts were given on the basis of 1,2 g N_t to oat which was cultivated in a silty loam soil of pH 6,1 in Mitscherlich-pots. At the end of the trial dry-matter and N-uptake of the plants were determined. Detailed informations of the pot-trial are given by Ebertseder et al. (1994).

Results

Determination of the progress of maturing:

All methods reflected the process of maturing more or less well as proved in a experiment with modell composts of defined mixture of raw materials and regular turning-intervals. The most evident graduation of increasing maturity depending on the time of composting was given by oxygen-consumption and pH-drop during

anaerobic incubation (Figures 1 and 2). The youngest composts (3 weeks) showed the highest oxygen-uptake and the lowest pH, the oldest composts (13 weeks) behaved exactly in the opposite manner. Composts in the age of 8 weeks were situated between the values of young and old composts, often hardly different from the 13-week-old material. The greatest difference in all cases existed between young and middle-old samples.

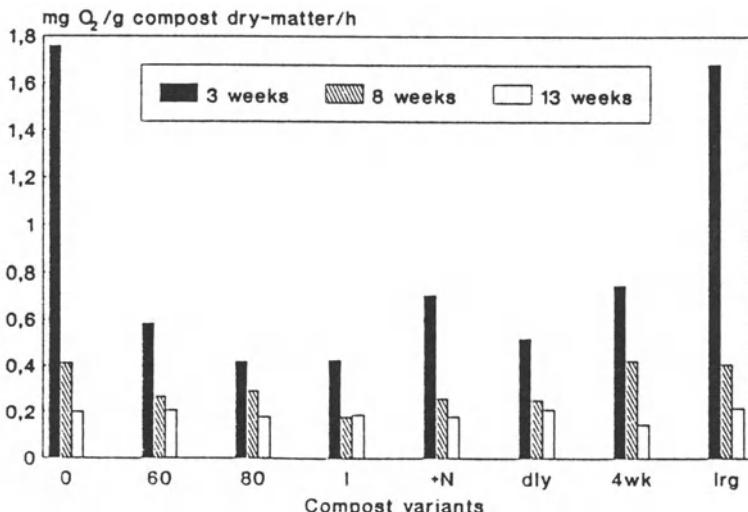


Figure 1 Oxygen-consumption of different composts depending on time of composting (3, 8 and 13 weeks)

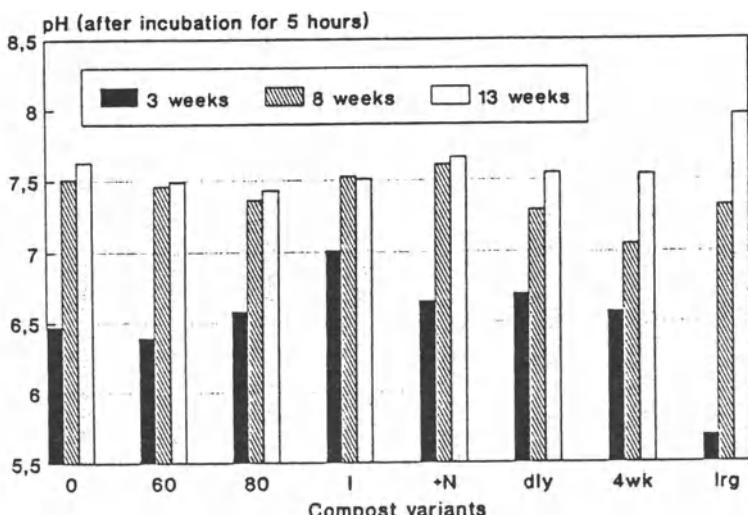


Figure 2 pH after anaerobic incubation (40°C) of different composts depending on time of composting (3, 8, 13 weeks)

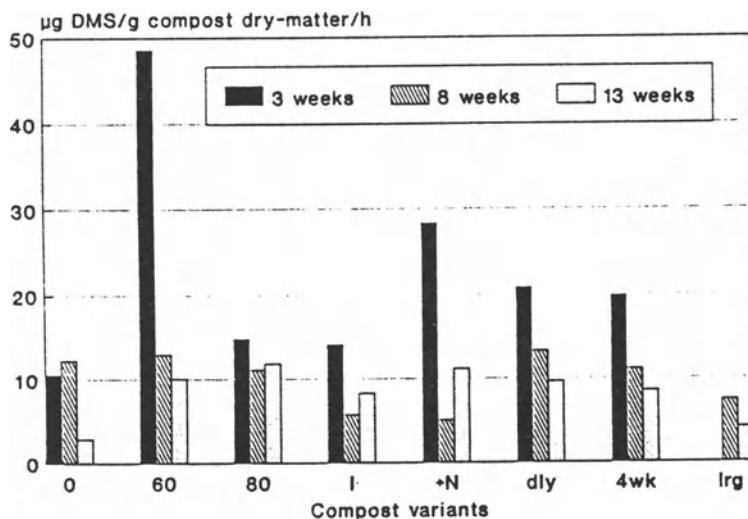


Figure 3 DMS-production of different composts depending on time of composting (3, 8 and 13 weeks)

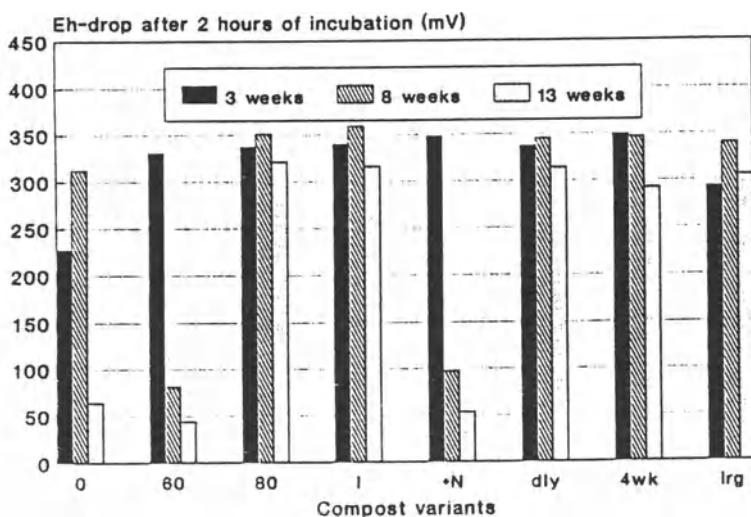


Figure 4 Eh-drop after incubation (40°C) of different composts depending on time of composting (3, 8 and 13 weeks)

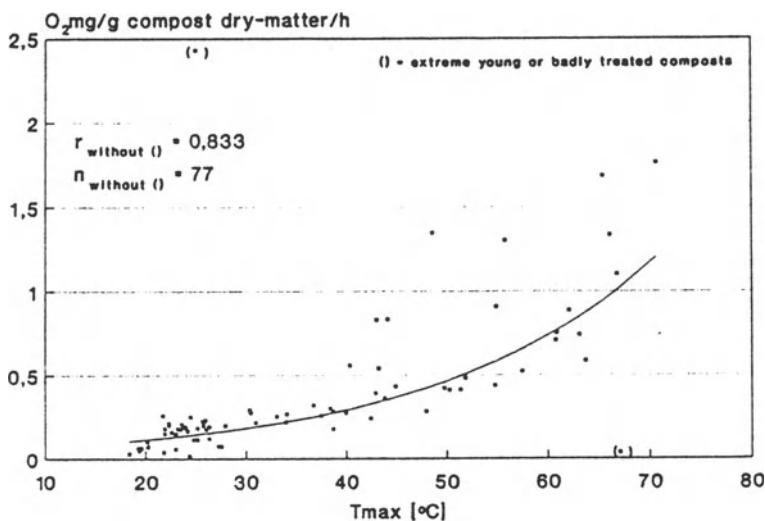


Figure 5 Relationship between self-heating-capacity (T_{\max}) and oxygen-consumption of different composts

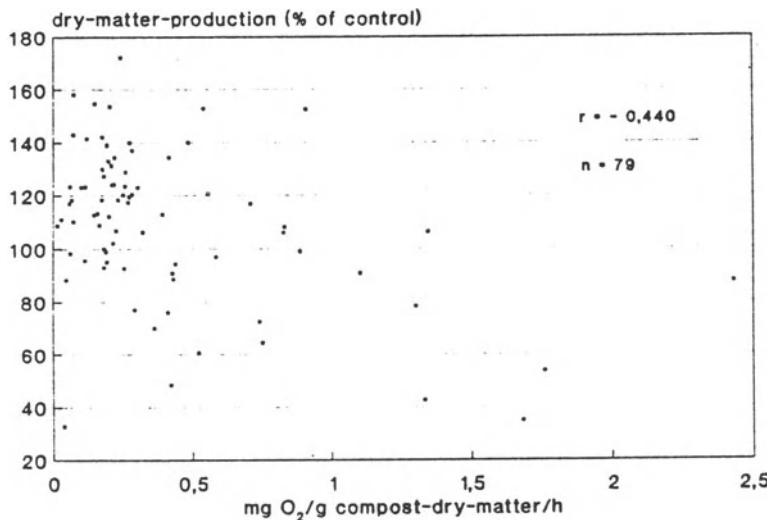


Figure 6 Relationship between oxygen-consumption of composts and their effect on dry-matter-production of oats

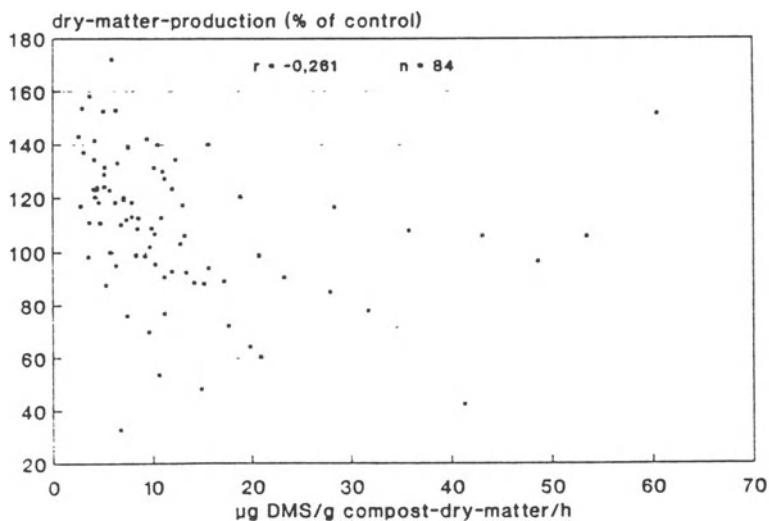


Figure 7 Relationship between DMS-production of composts and their effect on dry-matter-production of oats

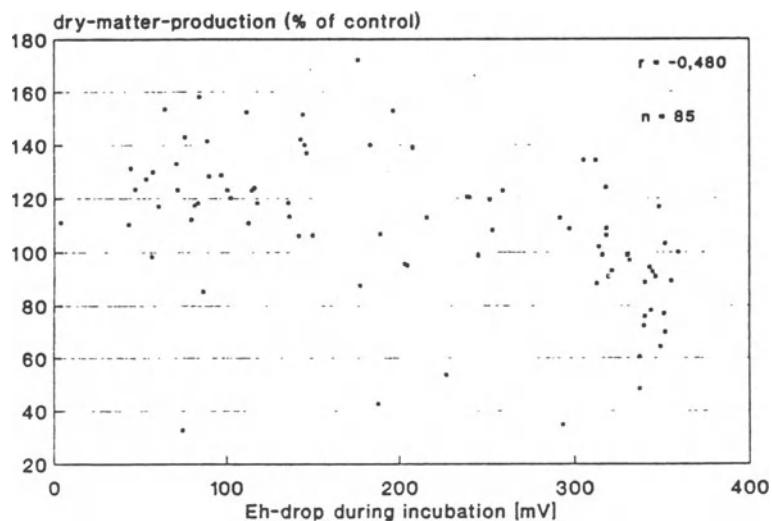


Figure 8 Relationship between Eh-drop of composts and their effect on dry-matter-production of oats

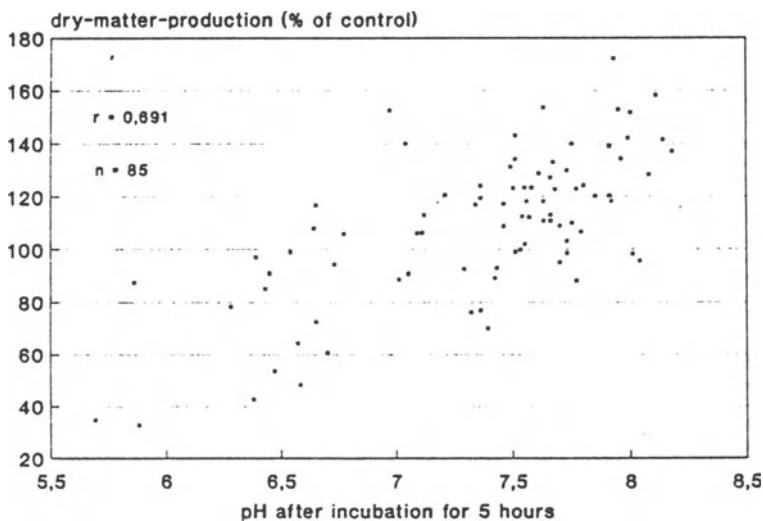


Figure 9 Relationship between pH (after incubation) of composts and their effect on dry-matter-production of oats

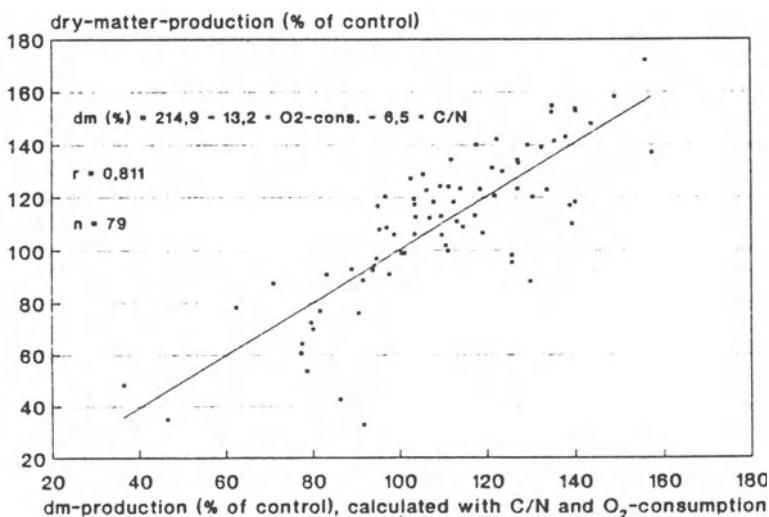


Figure 10 Real and calculated dry-matter-production of oats after compost application in pot trials

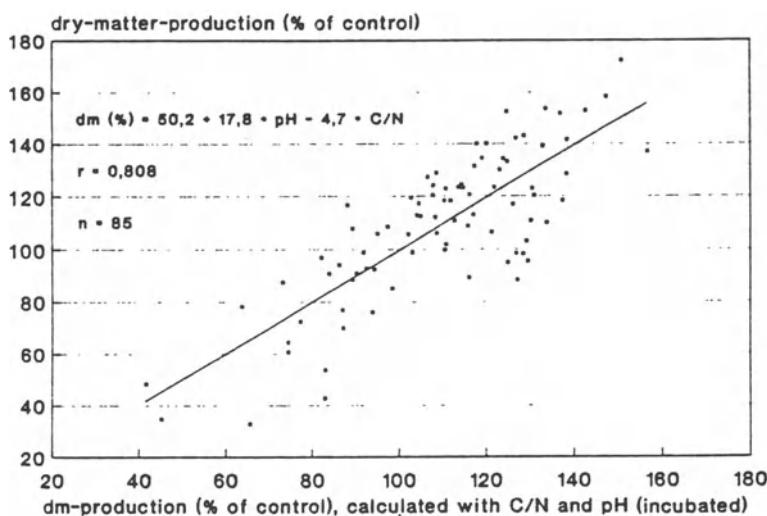


Figure 11 Real and calculated dry-matter-production of oats after compost application in pot trials

Measurements of DMSO-reduction and Eh usually proved that young composts had higher values than old ones, but sometimes the differences between the material of the three sampling times were small or inverse as one would have expected (Figs. 3 and 4). Even with regard to the fact that DMS was partly absorbed by the compost samples (3 - 9 µg DMS/g compost dry-matter during 3 hours) the results were not changed substantially.

DMSO-reduction and Eh-drop showed only weak relation to the three other methods, which correlated among themselves relatively well, for example oxygen-consumption and the self-heating-capacity, the most wide-spread maturity test in Germany (Fig. 5).

Prediction of the effect of composts on plant growth in pot trials:

Contrary to the possibility to determine the process of maturing with biological methods it was almost impossible to predict the effect of composts on plant growth in a satisfactory manner. There was only low correlation between nearly all biological maturity parameters and the dry-matter-production of oats - even oxygen-consumption, which showed a clear relation to the duration of composting couldn't predict the effect on plants (Figs. 6 – 8). Composts with high microbiological activity could both cause high yields (up to 150% of the control) and low yields (ca. 40% of the control). On the other side there were composts with low activity which resulted in serious negative yields compared with the control. Only pH after 5 hours of anaerobic incubation brought about a closer correlation to plant growth (Fig. 9).

One opportunity to improve the estimate of compost behaviour in pot-trials was

to use biological parameters and the C/N-ratio of composts supplementarily. Thus one was able to predict the effect of composts with high reliability (Figs. 10 and 11).

Discussion

Though some microbiological methods are more or less able to prove the progress of maturing in dependence on time they evidently cannot produce universally valid results because there is a great influence of raw material and procedure of composting (see figs. 1 – 4). However it would be conceivable to use biological parameters related to single compost plants with relative invariable raw materials and constant technique of composting.

Reasons for partial divergences between the single biological methods probably are the different mechanisms which are tested respectively (Forster et al. 1993). While self-heating-capacity and oxygen-consumption reflect a general ability to dissimilate C-compounds the other methods determine more or less specific properties of composts: DMSO-reduction is a method for measuring the activity of a group of enzymes (Alef 1991). Despite the statement of

Alef (1991) that more than 95 % of soil-microorganisms are capable of reducing DMSO to DMS perhaps it is possible that the microflora in composts reacts somewhat different concerning this enzyme activity. Undoubtedly the conditions in composts vary strongly from soils as DMS produced by biogenic waste compost samples can exceed soil DMS-production by the factor 2000 (own measurements, not yet published). The decrease of pH as a consequence of anaerobic incubation is a combined effect of the presence and availability of C-compounds, the kind of produced organic acids and the buffering capacity of composts. Nearly the same is true for Eh, the buffering capacity presumably being the result of a complex system of redox-effective compounds (e.g. nitrate, Fe- and Mn-oxides and -ions, humic-acids (Ziechmann 1972, Schachtschabel et al. 1982)). Moreover it is to be supposed that the activity of some of the organisms is partly reduced under the extreme conditions being necessary for measuring pH and Eh (anaerobiosis, 40°C).

Therefore it met up to the expectations that self-heating-capacity and oxygen-consumption were closely correlated (only two composts deviated extremely, see Fig. 5) while it was a little bit surprising that pH after 5 hours incubation showed a high correlation with oxygen-consumption, too ($r = -0,814$; $n = 78$). Inspite of the different mechanisms being active in both methods they seemed to be very similar ultimately and proved the course of maturing best. DMSO-reduction and Eh however reflected maturity only with restrictions. Latter method apparently detected phenomena not being directly involved in the ripening process. Moreover in all composts with low pH (< 7,5) at the beginning of the incubation, Eh dropped substantially only after a lag period. Hence in these composts Eh failed in determining maturity while it was possible with the pH-method, which

indicated only little progress in composting by low pH-values. DMSO-reduction possibly behaved similar to other enzyme-activity methods, which were on a low level in young or badly treated composts as Abd-el-Malek et al. (1976) and Herrmann and Shann (1993) had ascertained. Therefore low activity found out with the DMSO-method in some cases possibly wasn't due to increased maturity but to unfavourable conditions in the composting process (e.g. 3 week old compost 0 in Fig.3: no structure material). Generally in young composts enzymic activities can be small though oxygen-consumption may be high (Abd-el-Malek et al. 1976).

Last but not least, one reason for a certain unreliability of biological methods to prove maturity is the fact that during composting there can be sudden changes in microbial activity (Iannotti et al. 1994). This would mean that values measured by biological methods need not reflect the general status of composts and their maturity but indicate only an actual condition perhaps affected by turning, irrigating et cetera.

One essential cause for the relative failure of biological methods to predict the effect of composts on plant growth however, is the fact that these methods give no information about the quantity of usable nutrients, nitrogen in particular, but only determine microbial activity. So it could be that there are concomitantly high activity and a large N-pool. This pool presumably is able to supply both the microorganisms and the plants. This would mean that some composts in spite of 'low maturity' (= high activity) produce good plant growth. This hypothesis is supported by the results brought about by including the C/N-ratio to explain the behaviour of composts in pot-trials (Figs. 10, 11), because the C/N-ratio provides information about both C- and N-contents. A further conformation of this interpretation was given by Ebertseder et al. (1994) who found out that plant growth showed best correlation to C/N-ratio in the K_2SO_4 -extract of composts but not to the C- or N-concentration alone.

Conclusions

Measurements of microbiological activity can provide only supplemental information about maturity of composts and their effects on plant growth. For that reason they should not be used as sole methods but only in combination with other chemical parameters, e.g. C/N-ratio of the solid phase of composts. In further investigations, which are not completed yet, is to be examined, whether other methods, for example analysis of the N-status of composts (determination of different N-fractions of compost-samples after drying and extracting under varied conditions) allow better evaluation of composts than the biological methods which are presented in this publication.

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Parameters to Estimate the Nitrogen Effect of Biogenic Waste Composts

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Abstract

Efficient strategies for using composts in agriculture demand for parameters to estimate their nitrogen effect (mineralization, immobilization) in soil. To find such a parameter different extraction methods (water extract, K_2SO_4 extract, hot water extract) were carried out on 81 different biogenic waste composts. Besides this selfheating capacity, total organic carbon and total nitrogen were determined. The results of compost analysis were correlated with nitrogen uptake by oat in two pot trials. Selfheating capacity did not correlate with the nitrogen effect of the composts. The C/N ratio of the solid phase of composts was considerably well related to N uptake by oat and is therefore an important quality criterion of composts. But the correlation was found to depend on the similarity of raw materials and management of composting. All in all the best correlation to N uptake by plants was given by the total organic carbon to total nitrogen ratio of K_2SO_4 extracts ($C/N_{K_2SO_4}$). The correlation coefficients were almost the same in both pot trials. $C/N_{K_2SO_4}$ is therefore proposed to be a good parameter to estimate the nitrogen effect of composts. This is further supported by results from field trials.

Introduction

The use of waste composts on agricultural soils demands high compost qualities. One major aspect of compost quality is its nitrogen effect (mineralization, immobilization) in the year of application which is influenced by the microbial availability of compost nitrogen and carbon. Parameters to estimate the influence of compost on nitrogen turnover in soil are necessary, to avoid yield losses by nitrogen immobilization, to increase the utilization of compost nitrogen and to optimize the nitrogen nutrition of plants through mineral fertilization.

Although many methods to measure compost stability have been proposed

(Jiménez and Garcia, 1989, Senesi, 1989, Gallardo-Lara and Nogales, 1987, Garcia et al., 1992, Forster et al., 1993) the influence of this compost parameters on the nitrogen dynamics in soils fertilized with compost were scarcely investigated. Therefore, the aim of this study was to find parameters that predict the nitrogen effect of composts measured in pot trials. For two reasons the investigations were concentrated on C and N fractions soluble in aqueous extracts: first, the methods should be easily practicable for routine analysis and second, more important, the turnover of organic and inorganic nitrogen compounds by microorganisms occurs in the water soluble phase.

Materials and methods

Pot trials:

Two pot trials (A and B, Mitscherlich pots, 6.0 kg airdried soil) with composts from different sources were carried out in a vegetation hall. Composts were mixed at an amount equivalent to 1.2 g N/pot with a silty loam soil (pH 6.1) which was well supplied with other nutrients. Oat was cultivated in the pots (four replicates per treatment). The water content of the soils was kept near 65 % of the maximum water-holding capacity by irrigating daily with distilled water. The oat was harvested at the end of flowering. Dry matter yield and N uptake were measured.

Field trials:

In two field trials running 1992 and 1993 on brownearth soils derived from loess-loam (sandy to silty loam) composts were applied at an amount of 510 kg N/ha in spring just before sowing of maize. The aboveground parts of maize plants were harvested in September. Dry matter yield and N uptake were determined.

Composts:

All composts originated in general from organic household and garden waste as well as plant materials from public grounds. The composts were sieved through a 10 mm sieve.

In pot trial A fourty different composts were tested which came from 15 different compost plants all over Bavaria. They differ widely in kind and mixture of the raw material, additional substances (e.g. mature compost, clayey soil, lime), age and management of composting (e.g. pile size, kind and frequency of turning the pile). In pot trial B the tested composts came from a composting experiment. The compost piles in this experiment differed mainly in the mixture ratio of raw materials, frequency of turning, influence of climatic conditions and pile size. Compost samples were taken from each pile 3, 8 and 12.5 weeks after the begin-

ning of composting. On the whole these 41 compost samples were much more similar than the ones of pot trial A mainly because of the same raw materials (only different mixture ratio) and the same sampling dates for all piles.

Compost analysis:

The selfheating capacity (Jourdan, 1988) of compost was measured in Dewar-flasks (1,5 l) at room temperature. The maximum temperature (T_{\max}) was determined as a standard criterion on compost maturity (Bundesgütegemeinschaft Kompost, 1994). Total nitrogen content (N_t) was analysed by Kjeldahl method and total organic carbon content (C_t) by $\text{Cr}_2\text{O}_7^{2-}$ -oxidation. The mineral nitrogen content (N_{\min} , $\text{NH}_4\text{-N}+\text{NO}_3\text{-N}$) was measured in an 0,01 M CaCl_2 -Extrakt (w/v=1/10) by steam distillation. Soluble C and N fractions were determined in three different aqueous extracts:

- water extract (40 g fresh weight of compost were shaken in 200 ml dest. water for 1 hour at room temperature),
- K_2SO_4 extract (0,5 M K_2SO_4 instead of dest. water) and
- hot water extract (boiling 40 g fresh weight of compost in 200 ml dest. water for 1 hour under reflux).

All extracts were centrifuged (20 min., 1200 rpm), filtered through 0,45 µm membrane filter and deepfreezed. Ammonium, nitrate and Kjeldahl nitrogen content of the extracts were determined by steam distillation, desolved organic carbon by a TOC analyzer (TCM 480, Carlo Erba Instr.). The total nitrogen content was calculated: $N_{\text{extract}} = \text{Kjeldahl-N} + \text{NO}_3\text{-N}$.

Statistics:

Correlation (Pearson correlation coefficients) and regression analysis between the N uptake of oat (means of four replicates) and the parameters from compost analysis were performed by SAS.

Results and discussion

To examine the nitrogen effect of composts the nitrogen uptake by plants is more suitable than their yield. On the one hand the influence of other factors than nitrogen availability is stronger on yield than on nitrogen uptake. On the other hand nitrogen that becomes available at the end of the growing period (only about 8 weeks in this pot trials) may not lead to higher yields but to higher N uptake.

In figure 1 the maximum temperature of selfheating is plotted against the difference in N uptake of compost fertilized and unfertilized plants in pot trial A. Obviously there is no correlation at all. Therefore selfheating capacity is not a suitable parameter to calculate nitrogen availability of composts for plants. This

is noteworthy because selfheating capacity is the standard method for compost maturity in Germany (Bundesgütegemeinschaft Kompost, 1994).

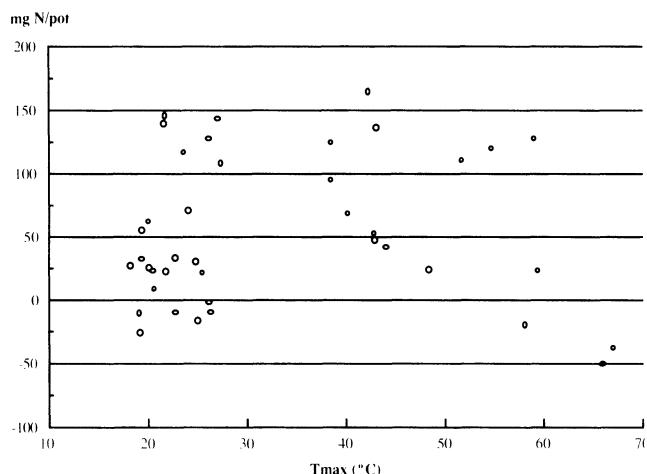


Figure 1 Relation between selfheating capacity of composts and the N uptake by oat calculated as difference between compost fertilized and unfertilized treatments in pot trial A

The different carbon and nitrogen fractions of the composts in pot trial A were closer related to the nitrogen uptake by plants than selfheating capacity (Tab. 1). The soluble nitrogen fractions were higher correlated with the nitrogen effect of these very different composts than the soluble carbon fractions or the total carbon and nitrogen contents. The highest correlation coefficients, however, were found between nitrogen uptake and the diverse carbon to nitrogen ratios. This is due to the fact that carbon availability as well as nitrogen availability plays an important role for nitrogen turnover.

Table 1 Correlations between parameters of compost analysis and the N uptake of oat (pot trial A, n=40)

	N uptake	N uptake	N uptake
T _{max}	-0,00	C _{K2SO4}	-0,16
C _I	-0,36*	N _{K2SO4}	0,43**
N _I	0,21	C _{hotwater}	0,08
N _{min}	0,61***	N _{hotwater}	-0,48**
C _{H2O}	-0,08	C _I /N _I	-0,66***
N _{H2O}	0,40*	ln C _I /N _I	-0,67***

The best prediction of nitrogen availability to plants in this pot trial permitted the C/N ratio of the K₂SO₄ extract (C/N_{K2SO4}). The prediction could be improved by transforming C/N_{K2SO4} to logarithm (ln C/N_{K2SO4}) as shown in figure 2.

It should be noted that for the calculation of the C/N ratios of these aqueous extracts their total nitrogen content was used. Therefore these ratios are different from the carbon to organic nitrogen ratio in water extract which was proposed by

Chanyasak and Kubota (1981) and Saviozzi et al. (1987) as a good parameter for compost maturity. Although the carbon to organic nitrogen ratio of water extract was found to correlate with plant growth too (Hirai et al., 1986), the inorganic nitrogen must be included because it is primary available to plants and microorganisms. The importance of the inorganic nitrogen for the nitrogen effect of composts is clearly shown by the relatively high correlation coefficient between N_{min} and nitrogen uptake of oat in table 1.

Obviously distilled water is too weak a solvent for extracting the readily bioavailable organic and inorganic fractions because of the relatively low correlation coefficient between its C/N ratio (C/N_{H_2O}) and the nitrogen utilization by plants. Water extracts contain on the average only 90 % of the nitrogen of the K_2SO_4 extract, especially due to lower ammonium content. Whereas the average carbon content was almost the same in the two extracts. On the other hand boiling water may be too strong a solvent compared with the concentrated K_2SO_4 -solution (average N content 180 %, average C content 270 % of K_2SO_4 extract). Therefore the water and the hot water extraction were excluded from the analysis of the compost samples in pot trial B (see lower correlation coefficients, table 1).

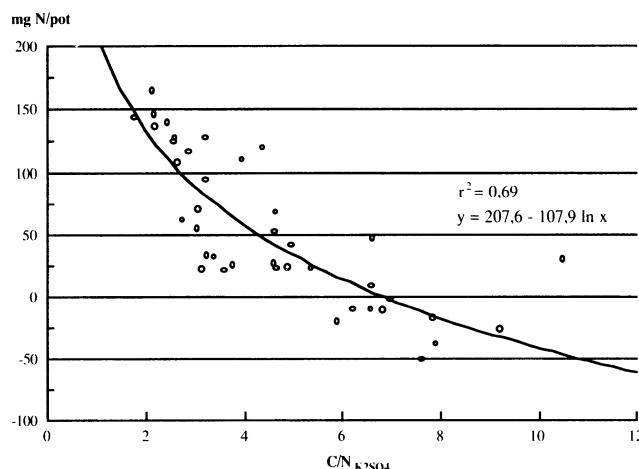


Figure 2 Relation between C/N ratio of K_2SO_4 extract of composts and the N uptake by oat calculated as difference between compost fertilized and unfertilized treatments in pot trial A

Table 2 Correlations between parameters of compost analysis and the N uptake of oat (pot trial B, n=41)

	N uptake	N uptake	N uptake
T_{max}	- 0,40**	$C_{K_2SO_4}$	-0,25
C_t	- 0,10	$N_{K_2SO_4}$	0,04
N_t	0,67***	$C/N_{K_2SO_4}$	- 0,74***
N_{min}	0,14	$\ln C/N_{K_2SO_4}$	- 0,76***

The correlation coefficient between the C/N ratio of the solid phase (C/N_t) and the nitrogen uptake by oat in pot trial B was very high (Tab. 2) compared to pot trial A. This is in agreement with findings that only if very similar composts (especially in raw material) were used C/N_t can be accepted as an indicator of compost maturity (Hirai et al., 1983; Jiménez and García, 1989). Nevertheless the C/N ratio of the solid phase can be considered as an important quality criterion of composts as has been pointed out by several authors (Watanabe and Kurihara, 1982; Jiménez and García, 1989) since its correlation to N uptake was also rather high in pot trial A. But the only use of the C/N ratio of the solid phase for estimating the nitrogen effect of composts without taking into account other factors may in many cases lead to mistakes in fertilizing strategies with compost application.

Compared to pot trial A, the similarity of the composts in pot trial B also led to an improvement of the correlation coefficient between the selfheating capacity (T_{max}) and the nitrogen uptake by plants. In contrast no soluble nitrogen fraction (N_{min} , $N_{K_2SO_4}$) correlated with the nitrogen effect of the composts in this trial neither did the soluble carbon ($C_{K_2SO_4}$). The C/N ratio of the K_2SO_4 extract ($C/N_{K_2SO_4}$), however, was almost as suitable to predict the nitrogen effect of the composts as in pot trial A (Figure 3).

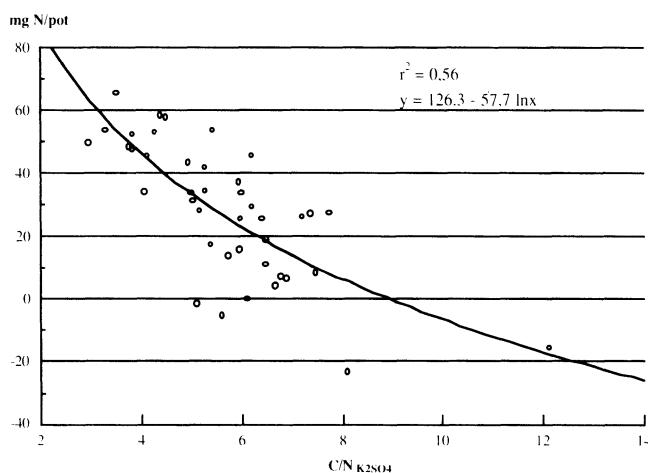


Figure 3 Relation between C/N ratio of K_2SO_4 extract of composts and the N uptake by oat calculated as difference between compost fertilized and unfertilized treatments in pot trial B

In both trials (Figures 2 and 3) composts with a C/N ratio of the K_2SO_4 extract below 5 - 6 increased the nitrogen uptake of plants due to the supply of inorganic nitrogen or the mineralization of organic nitrogen from compost. On the other hand composts with $C/N_{K_2SO_4}$ higher than 6 led to the risk of nitrogen immobilization.

All in all the ratio of total organic carbon to total nitrogen of the K_2SO_4 extract seems to be a good parameter to estimate the short-term nitrogen effect of composts in the year of application. Yet it only can be completely accepted if a satis-

fying correlation consists in field trials too, because most often the standardized conditions of pot trials differ strongly from that in field. Till now only a few data from field trials with maize are available but they seem to support the results of the pot trials (Figure 4).

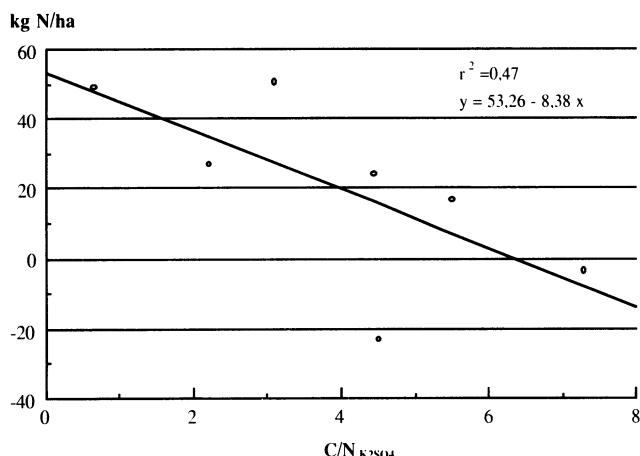


Figure 4 Relation between C/N ratio of K₂SO₄ extract of composts and the N uptake by maize calculated as difference between compost fertilized and unfertilized treatments in two field trials

Conclusions

1. The selfheating capacity is not related to the short-term nitrogen availability after compost application on agricultural soils. Therefore it is not a suitable parameter to estimate the short-term utilization of compost nitrogen by plants.
2. The ratio of total organic carbon to total nitrogen (C_t/N_t) of composts (solid phase) is relatively well correlated with their nitrogen effect in soil. However, the correlation between C_t/N_t and nitrogen availability in compost fertilized soils depends on their raw materials and management of composting. Therefore it can not be used as the only parameter for calculating the potentially for plants useable compost nitrogen in the year of application.
3. The ratio of total organic carbon to total nitrogen of the K₂SO₄ extract (C/N_{K2SO4}) is proposed to be a good parameter to estimate the nitrogen effect of composts. It correlates well with the nitrogen uptake by plants in the year of application and is widely independent of raw materials and management of composting. Composts with C/N_{K2SO4} lower than 5 - 6 lead to a positiv nitrogen effect whereas with higher C/N_{K2SO4} values the risk of nitrogen immobilization increases.

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Biowaste Compost and Heavy Metals: a Danger for Soil and Environment?

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Abstract

The paper presents several scenaria for heavy metal accumulation. The heavy metal balances are based on the average background levels in Austrian arable soils, the current limits for compost in Austria as well as the proposals discussed within the European commission on standardization ‘Soil Improvers and Growing Media’(CEN/TC223). Additionally balances are calculated based on Viennese biowaste composts. It is shown that, using the values discussed in CEN/TC223, the soil limits relevant in Austria and Germany (except for Zn) will be exceeded significantly after only 50–100 years.

On the background of references for the ecotoxic significance of soil contamination the validity of the standards and upper limit values established in Austria or in Germany for universally utilizable soils [Cd 0.1 –1.5; Cr 100; Cu 80 – 100; Hg 1.0; Ni 50 – 60; Pb 100; Zn 150 – 300 ppm d.m.l] is proved.

This leads to the demand that the functionality of agricultural soils has to be maintained in the long run; specifically, the input of heavy metals stemming from organic fertilizer applications should be minimized. Based on the results, suggestions for a reasonable application of biowaste compost as soil improver in arable systems are made.

Introduction

The main factor that must be addressed in limiting heavy metals in the environment is their ecotoxic impact. Due to the fact that organic soil improvers such as compost and fertilizers perform higher heavy metal contamination than the soil, an accumulation at least within the uppermost 20 cm of the soil may occur. Today it is well proven that the acid extraction with aqua regia shows an uncertain correlation with mobilization and availability of heavy metals as well as the uptake rate

by plants. A lot of research has been done on this issue, and heavy metal limits for arable soils have been revised on the base of the better knowledge about mobilization and transfer in soil and plants considering that a number of soil properties are relevant for heavy metal dynamics for an ecological risk evaluation. Concerning the risk assessment for a safe continuous application of compost we face a wide range of variations that reaches from NOAEL based policy of 'no need for international agreements' and voluntary restriction to stringent limitations down to 2–3 t/ha*a maximum application rate.

Since the soil represents a dynamic equilibrium a justifiable strategy in the sense of a sustainable agroecological humus management has to be discussed.

Scenaria of heavy metal accumulation in soil by application of biowaste compost

Background levels

It can be generally stated that caused by the introduction of separate 'source' collection of the organic fraction of household wastes and garbage wastes from municipal greens the heavy metal contents in compost were diminished by the factor 2 to 10 as related to M.S.W. compost. On the other hand the actual concentrations still exceed average soil values by the factor 0,5 to 3. Thus an accumulation of heavy metals by spreading compost on arable land may not be avoided.

Table 1 compares heavy metal background levels in soils and composts related to location and source. Results of Austrian, German and Swiss investigations are listed in table 2. The data make clear that the results correspond very well if the collection system is conducted properly incorporating the latest advances in logistic and technology. Although if differences in the quality between biowaste and park waste compost are reported, so far this fact did not lead to a significant distinction (Stöppler Zimmer et al., 1993). The examination of the frequency distribution shows, that due to the unsymmetric data distribution mode values (50 percentile) occur to be 10 – 30 percent beneath the mean values. (Amlinger, 1993; Fricke et al, 1991)

Table 1 Average heavy metals in Austrian soils, urban garden soils in M.S.W. compost, biowaste compost (ppm D.M.)

	Austrian soils ^a frequent range	Urban soils ^b mean	M.S.W. compost ^c mean	Biowaste compost ^d frequent range	Soil limit Austria ^d
Cd	0,1 – 0,3	0,69	4,87	0,1 – 1,5	1
Cr	20 – 40	48	50	20 – 60	100
Cu	20 – 30	81	379	20 – 100	100
Hg	0,05 – 0,1	0,71	2,95	0,1 – 0,7	1
Ni	20 – 40	27	38	10 – 40	60
Pb	20 – 30	20,6	875	40 – 150	100
Zn	60 – 80	273	1431	100 – 400	300 (200)

^aAichberger 1989 ^bBrüne 1986 ^cMüller 1985 ^dStöppler Zimmer et al. 1993 ^eÖNORM L 1075

Tab.xx Heavy metals in biowaste and garbage compost in Austria, Germany and Switzerland

ppm d.m.	Vienna **		Austria national	biowaste **	Germany park waste **		Bavaria	Switzerland * national		Kanton Zürich	Kanton Aargau
	1) n=69 mean	2) n=32 mean	3) n=151–167 mean	3) n=38 mean	4) n=52–64 median	5) n=58–134 mean		6) n=27 median			
Cd	0,59	0,6	0,84	0,72	0,39	< 1		0,4		0,51	
Cr	23,4	25	36	28	17,0	32		22,6		24	
Cu	52,0	79	47	35	26,0	51		40,0		40	
Hg	0,25	0,23	0,38	0,28	0,13	—		—		0,07	
Ni	21,1	20	21	19	11,0	23		16,2		13	
Pb	78,0	68	83	63	44,0	134		55,6		61	
Zn	197,2	254	249	117	90,0	276		153,6		173	

1) Amlinger (1993) * attention(!): extraction not with aqua regia
 2) Goller (1995) but with HNO₃!!! This leads to lower values.
 3) Fricke et al. (1991) ** related to 30% organic matter
 4) Jauch and Fischer (1991) 5) Candinas et al. (1988)
 6) Anonymous (1992a) 7) Kuhn and Arnet (1990)

Heavy metal load and dosage limits

Within the CEN-technical committee 223 ‘Soilimprover and Growing Media’ WG2 (‘Safety’); 3 ways to determine ‘safe’ limit values for potential toxic elements (PTE’s) are considered which vary according to the viewpoint adopted:

1. Risk assessment based on No Observable Adverse Effect Levels (NOAEL)
2. Precautionary limitation or No Net Degradation
3. Hybrid systems that utilise toxicity assessments without quantifying risk

Typical for the NOAEL approach is the US EPA sewage sludge regulation (cited in Anonymous 1994a). The risk assessment is based on a number of pathways (scenarios), that are used to model the impacts of heavy metals on man and environment. Accepting the limitations for the yearly sludge dosage in CH, AUT and FRG (1,6 – 2,5 t/ha*a D.M.) the NOAEL exceed the maximum load in the mentioned countries by 1.5 to 4 times. Table A1 presents the wide range of heavy metal limits in Europe. The most precautionary approach we find in NL, B and DK whereas in E, I and F the load regulations still range at M.S.W. levels of the early 1980s.

Since limit values per se are not able to guarantee a safe application system directives integrate the limitation of the yearly dosage per ha. Within AUT, FRG and CH the agreement about what is found to be ‘safe’ is well prooved (table A2). Following the internal discussion in Austria we are faced with three defferring regulations: 1) ÖNORM S2200 (Anonymous 1993); 2) Fertilizer Rule 1994 (Anonymous 1994b); 3) Sewage Sludge Rule in Lower Austria 1994 (Anonymous 1994c) (table A3). Applying the mentioned Fertilizer and the Sewage Slugde Rule after a transitional period until 2004 the maximum heavy metal dosage will be drastically reduced to 1/2 – 1/10 of the current guidelines.

How to calculate potential accumulation

Most of the European directives related to sewage sludge or organic fertilizer limiting the heavy metal deposition on soils derive those data from maximum values in the substrate and calculate the amount of the substrate that may be spread on the field per ha and year.

At the first glance it seems opportune to calculate the heavy metal accumulation on the basis of pure metal loads in gramm per ha and year. Depending on organic substance ratio and the total mass that is distributed this method leads to a mistake which shouldnt be neglected.

The following formula introduces the undegradable ash ratio related to the organic matter content of the soil that is increasing the root penetration layer. Table 3 illustrates the the difference deriving from the two calculation methods when applicated to compost and sewage sludge.

The change of heavy metal concentration in the soil is calculated according to the following equation:

$$C(s;na) = \frac{\{Ms \times Cso\} + \{[Mco \times na] \times Cco\}}{Ms + [Mco; na \times na]}$$

$C(s;na)$ heavy metal concentration in the soil after n years of continous compost application (ppm d.m.)

Ms Soil weight per ha related to the horizon concerned (tons)

Mco average yearly applied mass of compost within the referred period (na) calculated on the basis of actual soil organic matter (t/ha d.m.)

na number of years within the referred application period

Cso background heavy metal concentration in the soil (ppm d.m.)

Cco heavy metal concentration in the compost, related to the content of soil organic matter (ppm d.m.)

Scenaria for heavy metal balance

The calculations are based on

- background concentration in soil; average values in Austria (Amlinger et al., 1990)
- average airborne deposition and Cd-impact by phosphatic fertilizer
- average export data for heavy metals without erosion losses
- potential enrichment by biowaste composts

The following 5 scenaria varying heavy metal concentrations in compost related to 30% organic matter and the amount of yearly application have been assumed:

- (1) 75%-il Values of the Viennese biowaste compost; *10 tons per ha and year [75%-il / 10t]*
- (2) Limit Values Class II; *dosage according to n ÖNORM S2200 in Austria [KI.II / S2200]*

- (3) Limit Values Class II (ÖNORM S2200); *10 tons per ha and year [Kl.II / 10t]*
- (4) Limit Values Class II (ÖNORM S2200); *dosage according to Fertilizer Rule from 2005 [Kl.II / F.R.2005]*
- (5) Limit-proposal in CEN/TC223/WG2 (Anonymous 1994a) based on EC-sewage sludge directive/upper limit; *10 tons per ha and year [EC/U.L./ 10t]*

Table 3 The heavy metal accumulation in the soil after 100 years of application of compost.(30% OM in D.M.) or sewage sludge (60 % OM in D.M.) using the two calculation methods (ppm d.m.)

Background Soil	Compost CL. II / S2200 ¹⁾			Sewage sludge CL. III / 2,5 t ²⁾			
	Limit	Formula	H.M. dosage	Limit	Formula	H.M. dosage	
Cd	0,3	1,0	0,66	0,87	8,0	1,04	1,04
Cr	30	70	53	80	500	71	72
Cu	25	100	57	76	500	68	68
Hg	0,1	1,0	0,48	0,63	8,0	0,81	0,80
Ni	30	60	44	60	100	37	38
Pb	25	150	64	79	400	62	62
Zn	70	400	177	223	2000	240	240

1)Assuming the maximum compost dosage per ha and year according to ÖNORM S2200 Class II (Anonymous 1993)

2) Assuming the maximum heavy metal load per ha and year according to sewage sludge directive in Lower Austria Class III until 2004 (Anonymous 1994c)

Airborne deposition rates/ha.a according to Köchl (1987), Isermann (1992), Anonymous (1993a), Anonymous (1993b), see table 4.

Table 4 Average airborne deposition of heavy metals/ha and year

metal	Cd	Cr	Cu	Hg	Ni	Pb	Zn
deposition (g/ha*a)	3.5 (+2.1*)	20	75	1	20	130	500

* input by phosphatic fertilizer (Isermann, 1992)

For **heavy metal export**, the available data refer to uptake by plants, surface erosion (not considered in the presented balances) and leaching rate (cited from Köchl 1987; Isermann 1992; Anonymous 1993a) (Table 5).

Based on 30% organic matter in the compost d.m.it is assumed an degradation down to the soil organic matter of 3.5% when applied to the soil.

In table 6 heavy metal accumulations for the period of 100 years and the percentage attainment of the soil limits are calculated on the basis of the data given in the scenarios (1), (2) and (5).

Table 7 shows the number of years of continuous compost application required, to reach the Austrian limit values.

Table 5 Export and balance of heavy metals in g/ha.a (without deposition by compost)

metal	plant 1	export in g/ha.a by			balance in g/ha.a	
		erosion*	leaching	total 1+2+3	with erosion	without erosion
Cd	2	2.6	1.5	6.1	-0.5	+2.1
Cr	20	260		280	-260	0
Cu	41	217		258	-183	+34
Hg		0.87		0.87	+0.13	+1
Ni	18	260	12	290	-270	-10
Pb	19	217	3.7	240	-110	+107
Zn	298	607	115	1020	-520	+87

* Cd export by erosion is documented as 45% of the total (after Isermann, 1992). This is equivalent to 0.289% of the background concentration in 20 cm of the upper soil horizon. The same percentage was used to calculate the heavy metal export of all metals by erosion.

The data clearly show that - based on the conditions of the scenarios described in this paper - in a period of 100 years the limit values of soil will only be exceeded if compost with a heavy metal level according to [EC/U.L./ **10 t**] is used (except Zn). Soil limits for Cd and Pb are already exceeded after 47 and 51 years, respectively.

Using the Austrian limits of ÖNORM S 2200 (1993) [**Kl.II / 10t**], the 70% level of the soil limit is not reached in any case .

Table 6 Heavy metal concentration (ppm D.M.) and percentage attainment of the Austrian soil limits within 100 years assuming the scenarios (1), (2) and (5).

Soil limit	Soils	Austrian		75%-il / 10t		CL.II / S2200		EC/U.L./ 10t	
		Conc.in 100 y	% of S. L.						
Cd	1.0	0.3	0.49	49 %	0.66	66 %	1.8	180 %	
Cr	100	30	32	32 %	53	53 %	952	95 %	
Cu	100	25	38	38 %	57	57 %	92	92 %	
Hg	1.0	0.1	0.18	18 %	0.48	48 %	0.9	90 %	
Ni	60	30	29	49 %	44	73 %	59	97 %	
Pb	100	25	50	50 %	64	64 %	173	173 %	
Zn	300(200)	70	120	40 (60)%	177	59 (89)%	199	66 (100)%	

Table 7: Attainment of Austrian heavy metal soil limits in years assuming the scenarios (1) - (5).

	75%-il / 10t		Kl.II/F.R.2005		CL.II / 10t		CL.II / S2200		EC/U.L./ 10t	
	Conc. Comp.	Years								
Cd	0.65	374	1	248	1	248	1	194	5.5	47
Cr	29	3565	70	582	70	535	70	306	262	107
Cu	60	600	100	462	100	321	100	238	262	111
Hg	026	1069	1	316	1	316	1	239	2.9	112
Ni	20	—	60	447	60	299	60	217	129	104
Pb	96	304	15	365	15	191	15	191	552	51
Zn	226	456	400	342	400	236	400	215	515	179

Ecotoxicological assessment

Based on a number of investigations, the ecotoxicological relevance of the above calculations will be proved. Table 8 lists some data concerning the uptake of heavy metals by plants as well as relevant limit values.

Table 8 Data and standards relative to heavy metal uptake by plants

	1 pH limit of higher availability	2 Transfer- coefficient soil⇒plant ***	3 Normal plant values ppm d.m.	4 Harvest related toxicity limits in plants ppm d.m.	5 Limits in food ppm f.m.	6 Limits in fodder ppm f.m.	WHO maximum weekly uptake (70 kg)
Cd	6.0	0.01 – 10	<0.1 – 0.5	2.5 – 10	0.1 – 0.2*	1.0	490 µg
Cr	4.5	0.01 – 0.5	<0.1 – 1.0	1 – 2	–	–	–
Cu	4.5	0.01 – 2.0	2 – 20	15 – 20	–	50	–
Hg	4.0	–	2.6 – 86 ppb	0.5 – 1.0	0.3 – 0.5	0.1	350 µg
Ni	5.5	0.01 – 0.5	0.1 – 2.0	20 – 30	–	–	–
Pb	4.0 – 4.5	0.001 – 0.5	0.1 – 10	10 – 20	0.3 – 0.5**	40	3.5 mg
Zn	5.5	0.01 – 10	2 – 100	150 – 200	–	250	–

* fruit: 0.05; spinach: 0.5 ppm ** kale: 2.0 ppm *** ppm in plants/ppm in soil (d.m.)

1 Anonymous (1988); 2 Sauerbeck und Styperek (1988); 3 Maier et al. (1993); 4 Sauerbeck (1983); 5 Anonymous (1989); 6 Hecht (1982)

A considerable number of investigations describe the dynamics of mobilization and availability of heavy metals in relation to specific soil properties.

Referring to Anonymous (1988), the sorption of heavy metals is mainly carried out by

- adsorption at exchange compounds
- chemical precipitation
- organic sorption.

The strength of specific sorption at hydroxylised Fe-, Al- und Mn-oxides follows the order Cd<Ni<Zn<<Cu≤Pb. Due to the soil organic matter the order of sorption by metalo-organic complexing agents is Zn<Co<Ni<<Pb≤Cu. Both forms of sorption are closely related to pH.

Herms and Brümmer (1984) showed that the availability in soils with low humus level and between pH 3-6 decreases by the order Cd>Zn>Cu>Pb. In soils with a high level of high molecular organic matter of high stability at low pH range, the immobilization decreases in the order Cu>Cd>Zn>Pb.

The mobilization by soluble organic complexing compounds follows the order Cu>Cd>Zn>Pb

This phenomenon may be accelerated by phases of intensive microbial decomposition of organic matter (e.g. degradation of fresh manure).

Furthermore the application of chlorides as compounds in mineral fertilizer may increase the availability of Cd.

On the whole, Cd and Zn – but also Cu and Ni – must be given particular consideration due to the pH dependence of desorption and transfer coefficient soil : plant > 1.

Considering Cadmium's accumulative toxicity and its relatively higher mobility in soil and plants the significance of soil limits are described. Table 9 lists plants that reach a transfer ratio for Cd>1.

For Cd, particularly in soils with pH < 6.0 and low sorption capacity, the possibility of accumulation in leaves and root occurs (Sauerbeck and Styperek, 1988). Field forage plants are thus subject to considerable impact.

Table 9 Transfer coefficient for Cd soil \Rightarrow plant > 1 (after Lübben and Sauerbeck, 1992)

Crop	Leek	Carrot	Radish	Leaf lettuce	Leaf celery	Spinach	Celery root
T.C. Soil \Rightarrow Plant	1,20	1,29	1,61	3,21	3,73	5,34	7,09

A soil level of 2 ppm d.m. may lead to a Cd concentration in spinach of 1.5 ppm f.m., i.e. three times the German limit value (0.5 ppm f.m.)

Horak et al. (1994) discuss the joint effect of increasing heavy metal concentrations in soils, and describe the accumulation of Cd in the grain of wheat as well as a negative effect on microbial parameters in the soil even if the Cd level in the soil is moderate.

Table 10 Cd impact as a combined effect with the heavy metals Cu, Ni, Zn and V on the contents in the grain of wheat and on microbiological soil parameters (Horak et al., 1994)

Böden (pH-Wert)	Cd in soil aqua regia ppm d.m.	Cd in soil NH_4^+ - acetate ppm d.m.	Contents in grain of wheat ppm d.m.	Inhibition of respiration in % of control	Inhibition of arylsulfatase activity in % of control
Control*	0.2 – 0.3	0.03 – 0.07	0.05 – 0.11	—	—
A (7.5)	2.2	0.37	0.4	30%	29%
B (6.9)	2.3	0.50	0.92	35%	60%
C (7.7)	2.6	0.20	0.38	28%	70%

* range of the soils A, B and C

As a result of the joint effect of Cd, Cu, Ni, Zn and V, toxic effects were already found at Cd values of 0.28 ppm d.m. extracted by ammonium acetate. This refers to a value of 1.9 ppm d.m. in a weakly acidic, somewhat humous, silty sandy soil using acid extraction.

A Zn:Cd antagonism as widely is reported was not confirmed: no suppression of Cd uptake was observed with increasing Zn concentrations in soil.

The evaluation of a total of 25 long-term field studies (Sauerbeck and Styperek 1988) led to the following results:

Zn, similar to Cd, showed the highest uptake rates, particularly in the vegetative parts; this also holds true for monocotyledonous plants. Soil values of 300 ppm were sufficient to exceed the phytotoxic Zn concentration of >200–300 ppm in the plants. In acidic soils low in clay, toxicologically disturbing plant concentrations were already attained in dicotyledonous plants at soil values of 100 ppm.

The situation is similar for Cu. Soil concentrations of 100 ppm (limit value in Austria and Germany) in sandy soils are enough to lead to a phytotoxically critical

accumulation of 20 ppm in dicotyledonous plants (i.e., sugar beets).

In a 5-year study programme on the impact of municipal wastes on soil, soil organisms and plants (Sauerbeck and Lübben 1991), the limit values of Cd in food are compared with the concentrations actually attained in plants in relation to soil levels.

Table 11 clearly demonstrates that:

- 1) the Cd concentrations in grain of wheat, leaf lettuce and leaf celery frequently reach or go beyond the food limit value;
- 2) the frequency of these violations increased with the degree of soil contamination.

Based on those determined soil values above which the food limits could be exceeded, it is evident that the derived reference values for Cd in aqua regia extracts were distinctly below the 3.0 ppm d.m.

Table 11 Percentage of samples with Cd levels exceeding the food limit values (ZEBS) in relation to soil concentration (after Sauerbeck and Lübben 1991)

Soil concentration mg/kg d.m. ZEBS:	Wheat grain	Oat	Radish	Carrot	Spinach	lettuce Leaf	Leaf celery
	0.12	0.12	1.0	1.0	5.0	1.0	1.0
0.0 – 0.3	22	22	0	0	0	67	44
0.3 – 0.5	25	50	17	0	8	33	83
0.5 – 0.75	50	25	0	0	19	75	63
0.75 – 1.0	63	50	25	0	0	100	100
1.0 – 1.5	82	67	33	17	17	100	100

ZEBS = Food limit value in mg Cd/kg d.m. (Anonymous 1989)

According to Stadelmann et al. (1984), the **microbial activity** of various soils reacts – as do plants – in accordance with the key factors pH, clay content and non-living organic matter content. The sensitive parameters are:

- bacteria number
- bacterial growth
- bacteria spectrum
- C mineralization

A research study, carried out in Germany between 1986 and 1990 (Sauerbeck and Lübben 1991) made following conclusions about the effect of heavy metals on soil fauna and soil microbiology:

Microorganisms impacted by higher heavy metal concentrations exhibited an elevated respiration and had a correspondingly increased maintenance energy requirement. *'Their biochemical enzyme activities, i.e. their ability to catalyse metabolic processes – were in part considerably reduced'*. Accordingly, the soil microflora used a greater part of its food substrate for cell repair than breaking down biomass. In addition, an impaired growth of cyanobacteria and chlorophytes as well as a reduction of atmospheric–nitrogen–fixation through cyanobacteria was registered.

In laboratory experiments in which soils were treated with heavy metal salts, the basal respiration, along with the activity of various enzymes, was significantly reduced at soil heavy metal concentrations which were only 50% of the limits in effect in Germany in 1992.

Although the details remain to be proven, Sauerbeck and Lübben (1991) conclude that the heavy metals are primarily responsible for the often considerable impairment of soil organisms.

The *feeding activity of the soil fauna* decreased at high heavy metal concentrations; values at the allowed limits (FRG ABfKlärVo 1982) revealed a certain impairment of this fauna.

In a test soil mixture including sludge contaminated with heavy metals, damage to earthworms (much as on the microbial level) was registered at soil concentrations only 50% of the maximum values specified in Germany up to 1992.

Since heavy metal concentrations in the range of the original upper limits negatively affected at least a few species, the 5-year study on the behaviour of the soil flora and fauna prompted the authors to recommend a *reduction of the soil limit values for Cd (originally 3 ppm) to 1.0-1.5 ppm, Zn (originally 300 ppm) to 150-200 ppm and Cu (originally 100 ppm) to 80 ppm d.m.*

Conclusions

Limiting heavy metal loads for compost, a reasonable effect in terms of a sustainable agroecological approach can only be expected when deposition of heavy metals on the field is determined as well.

Though the separate collection of organic wastes led to significant decrease of the heavy metal load in the composts, a precautionary approach should still remain the guideline to any soil management. The results of ecotoxicological investigations concerning mobility, soil-plant transfer ratio and the impact on soil biotas have justified the current soil limits which we find in Austrian but also in most of the European countries. This leads to the demand that the functionality of agricultural soils has to be maintained in the long run; specifically, the input of heavy metals stemming from organic fertilizer applications should be minimized. Exceeding toxicologically determined heavy metal limit concentrations within periods of 45 - 100 years by applying too highly contaminated soil improvers does not appear to be a reasonable strategy.

Second we need an adequate mathematical method to evaluate the enrichment of the soil with heavy metals stemming from compost products. When we use the pure metal deposition per ha and year and thus not taking into account the continuous increasing soil substance it is evident that we obtain too high and incorrect accumulation rates.

A restrictive limitation following a 'no accumulation' policy which leads to maximum compost applications of 2-3 tons/ha*a often argues on the basis of fear and is not scientifically proved. This would imply the impracticability of an rea-

sonable compostmanagement in agriculture. So we should not ask just for a compromise between the interests of 'chambers and lobbies'. Risk assessment must be scientifically well founded and has to reflect the current state of knowledge. This approach can provide a safety framework taking into account the difficulty of controlling and improper implementation.

Concluding our considerations on the basis of 10 years experience with biowaste compost especially in Austria, Switzerland and Germany we recommend the following elements for an 'safe' strategy in the use of compost:

- heavy metal limits for compost based soil improvers as defined in ÖNORM S2200 if used in agriculture
- standardisation of heavy metal data on the basis of 30 % organic matter within directives and rules
- limitation of the yearly compost application and thus heavy metal deposition to avoid an attainment of soil limit values earlier as within 200 years
- establishment of international (european) product and application specific quality standards as an important tool of environmental protection
- knowledge of the heavy metal background soil level. Examinations may be repeated every 10 years or after 100-150 t d.m. compost application
- declaration in accordance with national or international compost regulations
- recommendations for the safe use

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Table A1 Limits for Composts & Soil Improvers in several European countries (ppm d.m.)

Metal	Limits for Composts & Soil Improvers in Europe (ppm D.M.)										Sew. Sludge U.S. ^g EU ^f EC / U.I. E.P.A. NOAEL Soil impr. Sew. Sludge	
	AUT ^a KL. I 1993	AUT ^a KL. II 1993	FRG ^b RAL GZ 251 1992	FRG ^c M10-LAGA 1992	CH ^d VLACO 1992	BELG ^e SoV 1993	NL ^e KIWA 1993	DENMARK ^e before from AFNOR 1995	FRANCE ^e DPR 1995	ITALY ^e planned	SPAIN ^e	
Cd	0,7	1,0	1,5	2,5	1,0	1,0	1,0	1,2	0,8	8	10	5,1 39
Cr	70	70	100	200	100	—	70	50	—	—	750	262 1200
Cu	70	100	100	200	100	90	60	—	—	—	600	1750 1500
Hg ^g	0,7	1,0	1,0	2	1,0	1,0	0,7	0,3	1,2	0,8	8	2,9 17
Ni	42	60	50	100	30	20	20	45	30	200	200	129 420
Pb	70	150	150	250	120	120	100	120	100	800	500	552 300
Zn	210	400	400	750	400	280	280	200	—	—	2500	4000 2800

* 500 ... Cr III: 10 ... Cr VI

a Austrian heavy metal limits class I and class II for compost according to 'ÖNORM S 2200' (Anonymous, 1993)

b German limit values according to RAL GZ 251 (Anonymous, 1992b)

c. Proposal for non food application according to Merkblatt 10 (M10) of the LAGA (Länderarbeitsgemeinschaft Abfall Working group 'Biowaste' (Thomé-Kozmiensky, 1994))

d Swiss heavy metal limits for compost according to 'Stoffverordnung 1992' (Anonymous, 1992b)

e cited in Jopski (1993)

f Proposal in CEN/TC223 'Soil Improvers and Growin Media' Working Group 2 'Safety' based on EC-sewage sludge directive / upper limit (Anonymous, 1994a)

g US EPA Rule 503 sewage sludge distribution and marketing limit values, cited in Anonymous (1994)

Table A2 Application Limits to Compost (t.D.M. / ha * a) and limiting dosage of heavy metals (g / ha * a) in Austria, Germany and Switzerland

Metal	AUT			FRG			CH		
	ÖNORM S 2200 ^a	AbfKlärV ^b & RAL-GZ 251 3)	M10 ^d non food	M10 ^d food	SToV ^c				
amount KL. I t/ha*a	dosage KL. II t/ha*a	amount g/ha*a	dosage t/ha*a	amount g/ha*a	dosage t/ha*a	amount t/ha*a	dosage g/ha*a	amount g/ha*a	
Cd	21,43	15	15	16,5	5	12,5	10	15	
Cr	21,43	21,43	1500	1500	5	1000	10	1000	
Cu	21,43	15	1500	13,3	5	1000	10	1000	
Hg	21,43	15	15	13,3	5	10	10	10	
Ni	21,43	15	900	6,7	333	500	10	500	
Pb	21,43	10	1500	10	1500	1250	10	1500	
Zn	21,43	11,25	4500	10,4	4167	5	3750	10	
						4000	10	4000	

^a Austrian heavy metal load regulation class I and class II for compost in 'ÖNORM S 2200' (Anonymous, 1993)^b According to the heavy metal load regulation in the German sewage sludge directive (Anonymous, 1992d) and the German limit values according to RAL GZ 251 (Anonymous, 1992b)^c Proposal for non food application according to Merkblatt 10 (M10) of the LAGA (Länderarbeitsgemeinschaft Abfall Working group 'Biowaste' (Thomé-Kozmienky, 1994)^e Swiss limits for compost application in 'Stoffverordnung 1992 (StoV)' (Anonymous, 1992c)

Table A3 Application limits according to load regulations in Austrian norms and rules

Metal	Application limits according to load regulations in the Austrian norms and rules		Application limits according to load regulations in the Austrian fertilizer rule 1994 ^a						Applications limits according to load regulations in the sewage sludge rule in Lower Austria 1994 ^b											
	until 2004: arable land &		from 2005: arable land & pasture / horticulture / orchards		until 2004: pasture / horticulture / orchards		from 2005: pasture / horticulture / orchards		until 2004: arable land &		from 2005: pasture / horticulture / orchards		until 2004: arable land & pasture / horticulture / orchards		from 2005: pasture / horticulture / orchards		until 2004: arable land & pasture / horticulture / orchards		from 2005: pasture / horticulture / orchards	
Cl. I	Cl. II	amount ^c t/ha*a	H.M. dosage	amount ^c t/ha*a	H.M. dosage	amount ^c t/ha*a	H.M. dosage	Cl. I	Cl. II	amount ^c g/ha*a	H.M. dosage	Cl. I	Cl. II	amount ^c g/ha*a	H.M. dosage	Cl. I	Cl. II	amount ^c g/ha*a	H.M. dosage	
Cd	21,43	15	15	28,6	20	20	14,3	10	10	7,2	5,0	5	28,6	20,0	20	7,1	5,0	5	5	
Cr	21,43	21,43	1500	17,9	17,9	1250	9,0	9	625	4,5	4,5	315	17,9	17,9	1250	1,8	1,8	125	125	
Cu	21,43	15	1500	17,9	12,5	1250	9,0	6,3	625*	4,5	3,2	315**	17,9	12,5	1250	10,7	7,5	750	750	
Hg ^g	21,43	15	15	28,6	20	20	14,3	10	10	7,2	5,0	5	28,6	20,0	20	7,1	5,0	5	5	
Ni	21,43	15	900	17,9	12,5	750	9,0	6,3	375	4,5	3,2	190	6,0	4,2	250	1,5	1,05	63	63	
Pb	21,43	10	1500	17,9	8,3	1250	9,0	4,2	625	4,5	2,1	315	14,3	6,7	1000	3,6	1,7	250	250	
Zn	21,43	11,25	4500	23,8	12,5	5000	11,9	6,3	2500*	5,4	3,2	1125**	23,8	12,5	5000	17,9	9,4	3750	3750	

* if actual annual load for Cu and Zn is declared the load limit for the distribution on arable land may meet the level of the period until 2004
 ** if actual annual load for Cu and Zn is declared the load limit for the distribution within pasture / horticulture / orchards may meet the level of the period until 2004
 *** load and Amount of annual Compost application on pasture land is to be halved

1) (Anonymous, 1994b)

2) (Anonymous, 1994c)

3) Maximum amounts of compost that may be applied calculated on the base of heavy metal limits according to ÖNORM S 2200 class I and II (ANONYMOUS, 1993) and Austrian limitation for heavy metal deposition in fertilizer rule 1994 (ANONYMOUS, 1994b) & sewage sludge rule in Lower Austria 1994 (ANONYMOUS, 1994c)

Polychlorinated Dibenzo-P-Dioxins and Dibenzofurans – Level of Contamination and Dynamic in Bio- and Yard Waste Composting

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Abstract

The mean level of PCDD/PCDF found in biowaste compost in Germany was found to be 14.8 ng I-TEQ/kg dm while the median value is 11.3 ng I-TEQ/kg dm – at a standardised content of organic matter (om) of 30 %. The concentrations ranged between 2.5 and 79.2 ng I-TEQ/kg dm for the standardised om content (30 %). The frequency distribution ranged from 7.49 to 17.5 ng I-TEQ/kg dm (upper and lower quartile).

74 % of the compost analysed had PCDD/PCDF levels less than 17 ng I-TEQ/kg dm which is the limit value established in the Baden-Württemberg Compost Regulation. This limit value of 17 ng TEQ/kg dm for compost is derived from the Germany Sewage Sludge Ordinance assuming an annual application of 10 Mg dm/ha (1 ha = 100 m * 100 m)

Early results which reported an 8-fold increase of the TEQ in compost were not confirmed by later experiments. Laboratory as well as full-scale experiments for composting yard and biowaste showed an increase of hepta- and octa-PCDD during the composting process. As the HpCDD and OCDD only have very low toxicity equivalency factors (TEF) the increase of the overall toxicity equivalent (TEQ) is not more than 2 ng I-TEQ/kg dm.

It was demonstrated that the concentrations of the lower chlorinated PCDD/PCDF decreased during the composting process. The same experiments showed also that, generally, furans seem to be more susceptible for degradation.

Laboratory experiments have shown that dioxins can be formed from chlorophenols as precursors.

On the basis of current knowledge it does not seem to be necessary to study the formation of PCDD/PCDF during biological processing of yard and biowaste in more detail and to stop composting as a means for organic waste management and fertilization of agricultural soils.

Introduction

In order to guarantee the use of yard waste and biowaste compost it is necessary that the compost produced meets quality requirements set by compost users. Generally it should be the case that compost can be applied in all fields of plant production in proper quantities. Therefore, compost quality is a key factor in compost marketing.

While the contamination of compost through undesirable materials such as glass or plastics and through heavy metals was the focal point in the past, nowadays contamination of compost through organic contaminants is of increasing concern. Publications presenting experimental results which show that PCDD/PCDF is newly formed during the composting process (ÖBERG et al., 1990 and 1993) resulted in an increased interest in these pollutants.

Legal framework

Currently there are no binding statutory limits regulating the tolerable level of organic contaminants in compost.

For the first time the revision of the Sewage Sludge Ordinance introduced maximum levels for organic contaminants in 1992 (ABFKLÄRV, 1992). The following classes of compounds are included in this regulation:

- six polychlorinated biphenyls (PCB 28, 52, 101, 138, 153 and 180)
- polychlorinated dibenzo-p-dioxins (PCDD)
- polychlorinated dibenzofurans (PCDF)
- adsorbable organic halogenated compounds (AOX).

The tolerable levels of contaminants listed in Table 1 are relevant for sewage sludge, for amendments used to upgrade the sludge and for the mixture produced (ABFKLÄRV, 1992). There are no guidelines or limits for these organic contaminants regulating the tolerable level in soil after sewage sludge application (see Tab. 4: 'Recommendations / guidelines for agriculturally and horticulturally used land' provided by the German Federal Health Office (BGH) and the German Federal Environmental Agency (UBA)).

Table 1 Limits for organic contaminants in sewage sludge and mixtures containing sewage sludge (AbfKlärV, 1992)

Organic contaminants		Concentration	
6 PCB's (# 28, 52, 101, 138, 153, 180)	per single compound	0.2	mg/kg dm
PCDD/PCDF (I-TEQ)		100	ng/kg dm
AOX		500	mg/kg dm

The limits established in the Sewage Sludge Ordinance are based on an application rate of 5 Mg dry matter (dm) within a three year period. Long-term trials established to evaluate the use of biowaste compost in agriculture and horticulture

(VOGTMANN et al., 1989; KEHRES, 1991) have shown that the annual application of 5 to 10 Mg compost (dm) on a medium soil is sufficient to ensure a satisfactory supply of nutrients and organic matter (om) as well as to generally improve soil quality. This results in a compost application which is three to six times higher than that of sewage sludge. Subsequently, if the 100 ng I-TEQ/kg dm limit for PCDD/PCDF established in the Sewage Sludge Regulation is applied for compost, the toxicity limits have to be reduced by the same factors to 33 and 16.7 ng I-TEQ/kg dm (based on an organic matter content of 30 %), respectively (FRICKE et al., 1992).

The German state of Baden-Württemberg established limits for contaminants in biowaste and yard waste compost by means of a Compost Regulation (UMINBW, 1994) which passed state parliament in summer 1994 (Table 2). The regulation is applicable for biowaste and yard waste compost as well as for anaerobically treated organic waste materials. Other composts originating from various waste materials such as composted bark are not subject to this state regulation. The same applies for every kind of home composting which includes also agricultural and horticultural enterprises. The limitations on application rates are only applicable where yard waste or biowaste compost is supplied to agriculturalists or horticulturalists and/or where it will be used.

Apart from absolute permissible levels of contaminants in the compost, the regulation also establishes limits on the basis of compost application rates. In each case the limits are based on an organic matter content of 30 % in dry matter (see Table 2). Contrary to the Sewage Sludge Ordinance (AbfKlärV, 1992) there is no guiding aggregated value for adsorbable organic halogenated compounds (AOX) due to analytical problems and in addition minimal overall knowledge. The Baden-Württemberg Compost Regulation has been in force since July 1st, 1994.

Table 2 Limits for organic contaminants in biowaste and yard waste compost as established in the Baden-Württemberg Compost Regulation (UMinBW, 1994). values are based on a standardised organic matter content of 30 %

Organic contaminant	Content	Loading at an application rate of
PCDD/PCDF	17 ng I-TEQ/kg dm	10 Mg dm/ha*a
PCB (congeners 28, 52, 101, 138, 153 & 180)	per congener: 0.033 mg/kg dm	170 µg I-TEQ dm/ha*a 0.33 g dm/ha*a in total: 0.2 mg/kg dm

Due to unavoidable variations of analytical results, measured contaminant concentrations are acceptable as long as they do not exceed the guiding values for PCDD/PCDF (measured as I-TEQ) and the relevant PCB-congeners by more than 30 %. This would result in a situation where the PCDD/PCDF-limit of 17 ng I-TEQ/kg dm would not be violated by a measured concentration of 22 ng I-TEQ/kg dm (UMinBW, 1994).

The draft version of the LAGA Information Sheet M10 contains the following statement on organic contaminants which has been comprised by the sub-working group 'Quality Criteria for Compost and Recommendations for its Application':

'Since chlorinated organic compounds, generated for example by incineration, are ubiquitous today, a certain level of background contamination of waste and residual materials with chlorinated benzenes/phenols and also by dioxins/furans is unavoidable.

Table 3 Range of dioxin contamination (ng BGA-TEQ/kg dm) found in soils in Germany as of 15.5.1991; compiled from data ascertained by the Federal States (BLAG, 1992).

Area and location		Average (ng/kg TEQ)	Range of averages	Minimum value	Maximum value	Number of samples	Sampling depth
Soil in rural areas (background contamination)	Forest soil	5	1.4 – 14	0.04	46	33	a)
	Forest litter	35	7 – 56	0.3	140	41	
	Grass land	3	0.6 – 7	0.04	10.7	95	1 State 0 – 5 cm 4 States 0 – 10 cm
	Arable land	2	0.2 – 5	0.01	7.7	178	0 – 30 cm
	Other	5	2 – 7	0.03	35	34	0 – 2
	(1 State)						
	Sewage sludge amended soil	5	3 – 7	0.025	21	46	Grass land 0 – 10 cm Arable land 0 – 30 cm
	Forest soil	2		0.8	7.4	48	1 State 0 – 5 cm 1 State 0 – 10 cm
	(1 State)			(1 State)			
	Forest litter	10			75.1	29	
Soil in urban areas which is contaminated by diffuse sources	Arable land	2.8			32	98	0 – 30 cm
	Grass land	3.8		0.5	100	223	1 State 0 – 5 cm 2 States 0 – 10 cm
	Residential area	9			30	10	
	(1 State)						
	Parks and play grounds			5	1,594	126	1 State 0 – 10 cm 1 State 0 – 5 bzw- 0 – 40 cm
	Soil from allotments	12		2.5	27.3	86	1 State 0 – 30 cm 1 S. 0 – 5 a. 0 – 40 cm
	Other	32		8.6	73.0	(1 State)	
	(1 State)			(1 State)	(1 State)		
	Waste incineration plants	43		0.01	202	118	b)
	Landfills			0.8	188	5	
Soil in the vicinity of known dioxin sources	Abandoned industrial sites			3	200,000		1 State 0 – 10 cm 1 S. 0 – 5 a. 0 – 40 cm
	Chemical Industry	8	5 – 13	0.05	1,658	57	1 State 0 – 10 cm 1 S. 0 – 5 a. 0 – 40 cm
	Metal works			0.07	4,958	262	c)
	Road traffic	10	10 – 20		200	30	1 State 0 – 5 cm 1 State 0 – 30 cm
	Other therm. processes	65	1 – 160	0.02	800	47	d)
	Other chem. processes	7		0.05	89	27	1 State 0 – 10 cm 1 State 0 – 10 cm

a) 1 State 0 – 4 cm; 2 States 0 – 5 cm; 1 State 0 – 12 cm; 1 State 0 – 15 cm (depending on soil profile)

b) 1 State 0 – 10 cm; 1 State 0 – 5 or 0 – 30 cm; 1 State 0 – 40 cm

c) 1 State 0 – 5 cm; 2 States 0 – 10 cm of which 1 State sampled additionally 10 – 30 cm; 2 States 0 – 30 cm

d) 1 State 0 – 5 a. 0 – 40 cm; 3 States 0 – 10 cm; 1 State 0 – 25 cm; 1 State 0 – 30 cm

Numerous analyses of yard waste and biowaste compost showed that their PCB and PCDD/PCDF content is obviously within the range of the current unavoidable background contamination level (see Table 4). Therefore, presently there is no reason for setting limits for the tolerable levels of organic contaminants in compost.

Table 4 Recommendation and reference values for land use and remediation of contaminated soil. Established by the Joint Working Group DIOXINS (BLAG, 1992).

Level of contamination ng I-TEQ/kg dm	Recommendation / measures
< 5	Target. any kind of use is possible without prior evaluation
≥ 100	Guideline value to exchange soil on playgrounds
1,000	Guideline value to exchange soil in residential areas (disposal of the contaminated soil according to LAGA guidelines on disposal of flyash from waste incinerators)
10,000	Guideline value to exchange soil in any location (disposal of the contaminated soil or clean-up; in both cases minimum emission has to be ensured)
Guide lines for agriculturally and horticulturally used land:	
5 – 40	Cultivation of foodstuffs is not restricted. Critical land uses (e.g. grazing cattle) should be avoided if increased levels are found in the agricultural or horticultural products
40	Limitations on the cultivation of certain foodstuffs and feedstuffs. Unlimited cultivation is only recommended for plants with minimum dioxin transfer, e.g. corn

Analysis of municipal yard waste and biowaste compost showed the following range of concentrations:

- PCDD/PCDF 5 – 40 ng I-TEQ/kg dm
- PCB 0.01 – 0.1 mg/kg dm for each congener (28, 52, 101, 138, 153, 180).

As a preventative measure, at least once a year composted material from each plant has to be analysed for organic contaminants such as

polychlorinated biphenyls (PCB) and
polychlorinated dibenzodioxins and dibenzofurans (PCDD/PCDF)

and the results have to be presented to the authorities. If the measured concentrations of these contaminants exceed the level of background contamination known so far, the relevant authority will decide on the necessity of further measurements and the appropriate steps to be taken. This applies also where there is reason for suspicion that the use of compost input material originating from heavily contaminated areas will raise the level of contaminants.'

All data on dioxin contamination in soil have been summarized in the 1992 report of the Joint Working Group on DIOXINS (BLAG, 1992) (Table 3). According to these data, soil samples from uncontaminated areas (mainly Baden-

Württemberg and Bavaria) showed PCDD/PCDF concentrations below 5 ng TEQ/kg dm. High concentrations have been found in forest soil with figures amounting to 46 ng TEQ/kg dm and in forest litter where as much as 140 ng TEQ/kg dm were measured (BLAG, 1992). Concentration in urban areas range between 10 and 30 ng TEQ/kg dm while they can be as high as 100 ng TEQ/kg dm in industrial areas. In close proximity to known dioxin point sources concentrations might exceed 100 ng TEQ/kg dm; in certain cases as much as 30,000 ng TEQ/kg dm have been found.

The German Federal Health Office and the Federal Environmental Agency presented recommendations and reference values for land use and renovation of contaminated soil at the dioxin symposium in Karlsruhe in 1990 (BGA, 1992). The translation of these recommendations into action is the task of each German State.

In January 1992 the State of Baden-Württemberg passed a decree on dioxin and declared that the guiding values on the use and renovation of contaminated soils will be in force as long as there are no new reliable data available.

PCDD/PCDF content of yard waste and biowaste compost

The contamination of biowaste and yard waste with organic pollutants and the variation of contaminant concentrations during the composting process has been evaluated for the first time by FRICKE et al. (1989) as part of the research project 'Bio-bin Witzenhausen'. Further analyses were conducted in 1990/91 and 1994 (see Table 5 and Figure 1). These results are presented and evaluated on the following pages.

Table 5 Organic contaminants (ng I-TEQ/kg dm) in biowaste and yard waste compost, the organic matter content is standardised to 30 % (dm)

	Mean	Median	Central frequency distribution
Biowaste compost 1)			
Sum Chlorophenols	748	721	726 – 759
PCDD/PCDF 2)	12.1	11.8	7 – 15.8
PCDD/PCDF 3)	14.8	11.3	7.49 – 17.5
Yard waste compost			
PCDD/PCDF 4)	10.6	7.5	4.7 – 13.7

- 1) Generally, biowaste was amended with yard waste
- 2) PCDD/PCDF: of 22 mean values which are based on 27 single analysis (FRICKE et al., 1993)
- 3) PCDD/PCDF: of 36 mean values which are based on 101 single analysis
- 4) PCDD/PCDF: of 27 mean values which are based on 64 single analysis

Data from 101 single PCDD/PCDF analyses examining samples from 36 different composting plants have been evaluated and were comprised in a review (FRICKE, 1994). These data revealed an average content of PCDD/PCDF in biowaste compost in Germany of 14.8 ng I-TEQ/kg dm while the median showed a value of 11.3 ng I-TEQ/kg dm – at a standardised organic matter (om) content of 30 % in

both cases. The concentrations were between 2.5 and 79.2 ng I-TEQ/kg dm for the standardised om content (30 %). The central frequency distribution ranged from 7.49 to 17.5 ng I-TEQ/kg dm (upper and lower quartile). Figure 1 demonstrates the distribution of the PCDD/PCDF concentrations found. 74 % of the PCDD/PCDF analysis measured less than 17 ng I-TEQ/kg dm which constitutes the limit established by the Baden-Württemberg Compost Regulation. This figure also represents the analogous application of the Sewage Sludge Ordinance to compost at an annual application rate of 10 Mg dm/ha (see chapter 2).

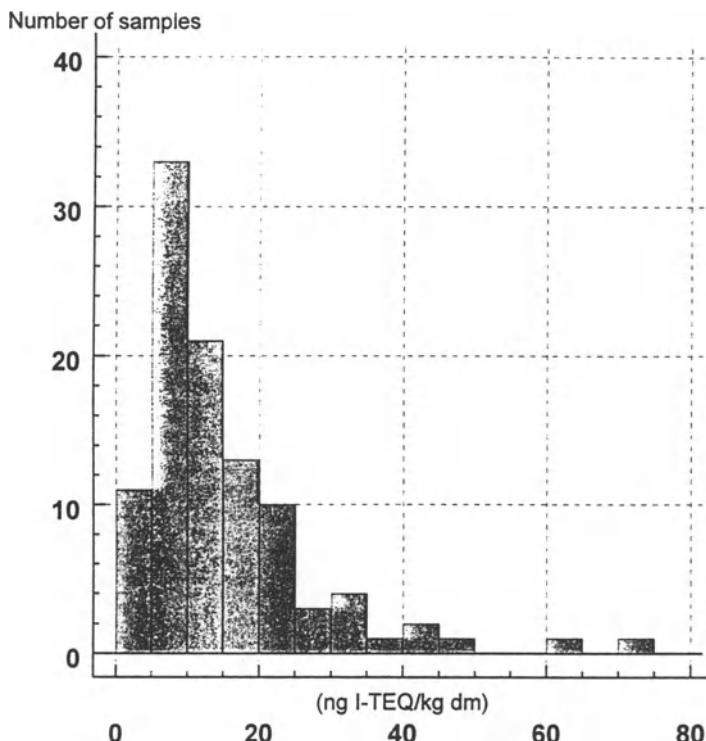


Figure 1 Number of samples of PCDD/PCDF-contents found in biowaste compost (101 analysis)

Samples originating from the composting plant in Witzenhausen (Germany) showed comparatively high PCDD/PCDF concentrations, averaging 16 ng I-TEQ/kg dm. However, it was not possible to find a plausible reason for the observed level of contamination. According to EINZMANN (1992) and KUMMER (1992), there is no correlation between the content of dioxins in compost and the amount of dioxin deposited through dust sedimentation.

Although the review mentioned above differentiated between yard waste and biowaste compost and also between the input materials it was not possible to determine significant differences between yard waste and biowaste compost. Biowaste is mixed and co-composted with yard waste in more than 90 % of the relevant

composting plants. Therefore, generally speaking, biowaste compost in fact is composted biowaste plus yard waste.

Analysis performed by KRAUSS (1991) showed similar results: non-separated household waste: 38 ± 22 ng I-TEQ/kg dm, biowaste compost: 14 ± 9 ng I-TEQ/kg dm, yard waste compost: 11 ± 8 ng I-TEQ/kg dm. Further research in this field has been conducted by EINZMANN (1992), KEHRES (1990), KUMMER (1992) SCHAFER et al. (1993), SCHMIDT and ECKSTEIN (1991), WAGNER (1990), WILKEN et al. (1990).

Regional pollution levels

Contrary to expectations the 1991 evaluation of compost analysis revealed no significant difference in dioxin contents between biowaste compost originating from urban and from rural areas (FRICKE et al., 1992). Compost input materials which show a relatively high level of contamination are collected in both, conurbations and completely rural areas. Although, there is a tendency for biowaste compost originating from Bavaria to show lower PCDD/PCDF concentrations than compost being processed elsewhere in Germany.

PCDD/PCDF congeners

Yard waste and biowaste compost show an almost identical PCDD/PCDF homologue distribution, i.e. that the PCDD/PCDF profiles are almost identical in both composts (KRAUSS, 1991; WILKEN et al., 1990). The highest concentration found is for octachlorodibenzodioxin (OCDD) followed by heptachlorodibenzodioxins (HpCDD) (Figure 2).

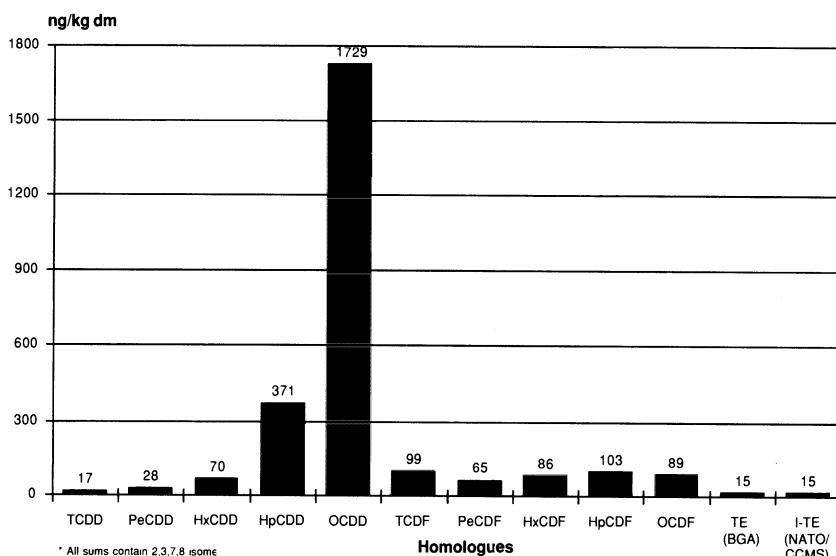


Figure 2 PCDD/PCDF-content (sums of homologues) in biowaste compost. Number of samples analysed = 62, figures represent the standardised organic matter content of 30 % in dm.

Table 6 PCDD/PCDF-concentration (ng I-TEQ/kg dm) of different compost input materials for both, the original as well as for the standardised (30 % in dm) organic matter content (EINZMANN, 1992)

Input material	PCDD/PCDF concentration (ng I-TEQ/kg dm)	
	Original organic matter content	Organic matter content standardised to 30 % (in dm)
Lawn clippings (rural area)	4	16
Leaves (rural area)	4	17
Wood chips	5	11
Bark	3	16
Kitchen paper	4	17

Figure 6 demonstrates that the same applies to the various compost input materials such as leaves, grass, wood chips etc. (EINZMANN, 1992). This gives rise to the assumption that PCDD/PCDF contained in various composts is derived from similar sources. Furthermore, this result is an indicator for the ubiquitous background contamination – without a specific pollution source.

Figure 3 shows the contribution of various PCDD/PCDF congeners (single isomers and homologues) on total I-TEQ values. As can be seen 1,2,3,4,6,7,8-HxCDD and OCDD are the single most contributing congeners to the toxicity equivalent. All in all PCDF make up 54 % of the total I-TEQ value while PCDD contribute slightly less (46 %).

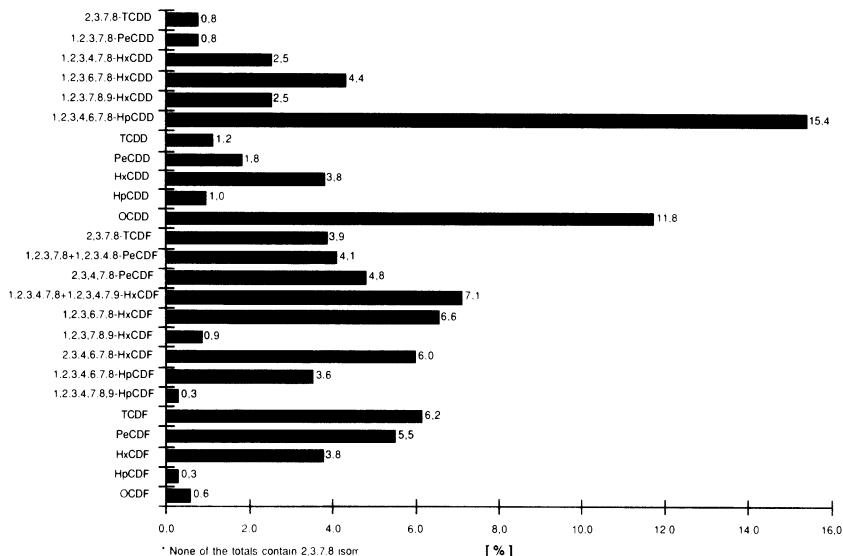


Figure 3 Proportion of single PCDD/PCDF isomers and homologous groups on the TE (BGA) found in biowaste compost. Number of analysed samples = 62, figures represent the standardised organic matter content of 30 % in dm.

Seasonal variation

A number of research projects showed that the concentration of dioxins found in compost varies from season to season (EINZMANN, 1992; KUMMER, 1992; SCHÄFER et al., 1993). This has been observed in particular with high-chlorinated PCDD/PCDF. The PCDD/PCDF content measured increased until summer and decreased again afterwards. The same holds true for the toxicity equivalent; the I-TEQ was 2,5 times higher in summer than in winter.

Origin

According to KRAUSS et al. (1994) the reason for different contamination levels of biowaste compost seems to be mainly due to varying degrees of PCDD/PCDF deposition in different geographical areas. The authors showed that particle bound deposition of PCDD/PCDF is almost the sole cause for the current concentration of these pollutants in the soil. The reason for the dominant effect of particle bound PCDD/PCDF deposition on the contamination level of raw materials for composting is seen in the high PCDD/PCDF concentration in dust particles. The authors above also demonstrate that the congener profile of deposited dust is dominant in source separated organic waste materials and not the congener profile found in the air – which is dominant in forest soil.

Formation of PCDD/PCDF during composting of biowaste and yard waste

Hitherto, PCDD/PCDF have been seen as substances resulting only from anthropogenic activities. Recently however, there is evidence that PCDD/PCDF are formed in biological processes, too (EINZMANN, 1992; KRAUSS et al., 1994; ÖBERG et al., 1990; SCHÄFER, 1993; SIEVERS and SCHACHT, 1994).

Experiments conducted by KRAUSS et al. (1994) showed that the content of HpCDD, OCDD and 1,2,3,4,6,7,8-HpCDD increased significantly during the composting process (Table 7). The authors detected increases of HpCDD and OCDD depending on the prevailing composting conditions, in particular on the temperature. A concentration of chlorophenols between 15 and 30 g/kg can result in an increase of toxicity by as much as 2 ng I-TEQ/kg dm (standardised at 30 % om). However, these findings from laboratory scale experiments could not be confirmed with samples originating from a commercial composting plant. With respect to changes observed in the homologue profiles and congener patterns, identical results were obtained in the laboratory trial and with samples from composting plants.

KRAUSS et al. (1994) conclude from their experiments that the maximum increase of toxicity is in the range between 0 and 2 ng I-TEQ/kg dm. According to the same authors there are distinct indications to show that the formation of PCDD/PCDF from chlorinated phenols are facilitated by prolonged periods of high composting temperatures (above 70°C).

Table 7 Concentration and absolute amount of PCDD/PCDF found in the input material, during the composting process and in final biowaste compost (KRAUSS et al., 1994)

	1 Input n=5* (ng/kg)	2 Composting process n=1 (ng/kg)	3 Output n=4 (ng/kg)	4 Input (4,822 g) (ng)	5 Composting process (3,485 g) (ng)	6 Output (2,231 g) (ng)
TCDD	0.8	1.1	1.8	4.0	4.0	4.0
PeCDD	0.7	0.8	1.9	4.0	3.0	4.0
HxCDD	3.4	5.5	7.0	16.0	19.0	16.0
HpCDD	23.8	57.5	134.9	115.0	200.0	301.0
OCDD	68.2	207.7	375.7	329.0	724.0	838.0
Total PCDD	96.9	272.5	521.2	467.0	950.0	1163.0
TCDF	3.4	4.0	5.8	16.0	14.0	13.0
PeCDF	1.8	1.9	3.3	9.0	7.0	7.0
HxCDF	4.8	4.0	6.3	23.0	14.0	14.0
HpCDF	14.5	18.9	20.4	70.0	66.0	45.0
OCDF	24.2	30.0	36.2	117.0	105.0	81.0
Total PCDF	48.7	58.8	71.9	235.0	205.0	160.0
2,3,7,8-TCDD	< 0.1	< 0.1	< 0.1	—	—	—
1,2,3,7,8-PeCDD	< 0.1	< 0.1	< 0.1	—	—	—
1,2,3,4,7,8-HxCDD	0.2	0.1	0.2	0.7	0.5	0.4
1,2,3,6,7,8-HxCDD	0.7	0.8	1.4	3.2	2.9	3.1
1,2,3,7,8,9-HxCDD	0.2	0.2	0.4	1.1	0.8	0.9
1,2,3,4,6,7,8-HpCDD	15.2	38.7	96.3	73.4	135.0	214.8
2,3,7,8-TCDF	0.6	1.0	0.8	2.7	3.9	1.8
1,2,3,7,8-PeCDF	0.2	0.2	0.2	0.8	0.8	0.5
2,3,4,7,8-PeCDF	0.2	0.3	0.4	1.1	1.0	0.9
1,2,3,4,7,8-HxCDF	0.2	0.3	0.4	0.9	0.9	0.9
1,2,3,6,7,8-HxCDF	0.2	0.3	0.3	0.9	0.9	0.6
1,2,3,7,8,9-HxCDF	< 0.1	< 0.1	0.1	—	—	0.3
2,3,4,6,7,8-HxCDF	0.2	0.1	0.3	0.8	0.5	0.6
1,2,3,4,6,7,8-HpCDF	3.9	6.1	5.8	19.0	21.2	12.9
1,2,3,4,7,8,9-HpCDF	0.3	0.3	0.3	1.4	1.1	0.6
I-TEQ (NATO/CCMS)	0.6	1.1	2.0	3.0	4.0	4.5

* One out of six values has been omitted for calculating the average

The Hamburg Department for the Environment also evaluated the formation of dioxins during the composting process. The experiment, conducted at the composting plant in Hamburg-Bergedorf comprised the periodical analysis of biowaste right from the input material through to the finished compost (SIEVERS and SCHACHT, 1994). The composted biowaste had PCDD/PCDF levels of 11.2 ng I-TEQ/kg dm while the input material measured only 7.3 ng I-TEQ/kg dm (in both cases standardised to 30 % om). These results are within the range of the dioxin contents usually found in compost produced in the composting plant Hamburg-Bergedorf (SIEVERS and SCHACHT, 1994). The changes in toxicity, particularly those associated with HpCDD and OCDD and also with furans, observed during the composting process are detailed in Table 8.

HpCDD and OCDD increased during the composting process while the level of hepta CDF and OCDF remained constant. During these experiments concentrations

of the relevant dioxins and furans increased mainly during the intensive decomposition stage while concentrations tended to decrease again during the later curing period. The results obtained in Hamburg indicate that additional OCDD and 1,2,3,4,6,7,8-HpCDD are generated during the composting process. However, since both of these compounds have comparatively low toxicity equivalency factors (TEF for OCDD: 0.001 and for 1,2,3,4,6,7,8-HpCDD: 0.01). These two congeners contribute only about 1 ng I-TEQ/kg dm to the PCDD/PCDF content in compost.

Table 8 Dynamic of HpCDD, OCDD, HpCDF, and OCDF concentrations (ng I-TEQ/kg dm) during the composting process (mean values normalized to the standardised organic matter content of 30 % in dry matter) (SIEVERS and SCHACHT, 1994)

Sampling date	29.04.93 input material	17.05.	07.06.	31.08.	11.10.93 compost, unsieved	Increase, compared to input (%)	Increase, compared to compost %
1,2,3,4,6,7,8-HpCDD	117	143	161	172	156	33	25
OCDD	797	1,212	1,566	1,532	1,381	73	42
1,2,3,4,6,7,8-HpCDF	47	64	58	59	51	8,5	8
OCDF	103	132	134	112	99	4	-4

Two research projects which investigated the formation of PCDD/PCDF during biological processes have been conducted at the Institute of Ecological Chemistry, University of Bayreuth, Germany. WAGNER et al. (1990) conducted laboratory experiments and investigated the enzymatic formation of PCDD/PCDF from Chlorophenols with various peroxidase activities. At a small municipal composting operation SCHÄFER (1993) took samples at certain intervals during the composting process and analysed for dioxins.

The input material consisted of a biowaste : yard waste mixture (3 : 1, v/v) which was processed in a covered hall with an open front. This project involved the analysis of 32 samples for their PCDD/PCDF content. The samples were also analysed for heavy metals in order to determine the degradation of organic matter during the composting process and to estimate the possible increase or decrease of PCDD/PCDF.

As observed before, the increase of toxicity equivalents in the final compost was due to higher levels of HpCDD and OCDD. On average the homologue concentrations increased by a factor ranging from 1.52 to 2.37 and 2,3,7,8-substituted the congeners increased 1.48 to 1.88 fold.

With the financial support of the State Government of Hessen and the Werra-Meißner-County, the Fa. Ingenieurgemeinschaft Witzenhausen in co-operation with the University of Kassel, Department of Ecological Agriculture in Witzenhausen, conducted experiments to study the degradation of PCDD/PCDF, PCB, polycyclic aromatic hydrocarbons (PAH), hexachloro-cyclohexane (HCH), and chlorinated hydrocarbons (CHC) (EINZMANN, 1992).

The results for PCDD/PCDF are shown in Figure 4 (EINZMANN 1992). The PCDD/PCDF contents represent the mean of 4 replicates and the contamination levels found after a composting period of 6 and 12 weeks, resp., were adjusted according to the observed loss of organic carbon during the composting process

(calculation based on the content of ash and phosphorus).

Figure 4 shows the concentration of all homologues for the summer and the autumn experiment. As can be seen, both experiments gave more or less identical homologue profiles with a predominance of HpDD and OCDD. The HpDD and OCDD levels of the summer compost were found to be significantly higher ($P < 0,01$) than the respective ones measured in autumn. The statistical comparison of the PCDF contents did not reveal a significant difference between the summer and autumn experiments.

The concentration of 1,2,3,4,6,7,8-HpDD and total HpCDD increased significantly during the composting process in both the summer and autumn. The autumn experiment also showed an increase of the 1,2,3,4,7,8,9-HpDF content. The TEQ levels decreased slightly during the summer composting process and increased during the autumn composting test. However, there was no statistical difference. It was not possible to prove that the PCDD/PCDF content – expressed in toxicity equivalents (TEQ) – increased during the composting process.

Summer

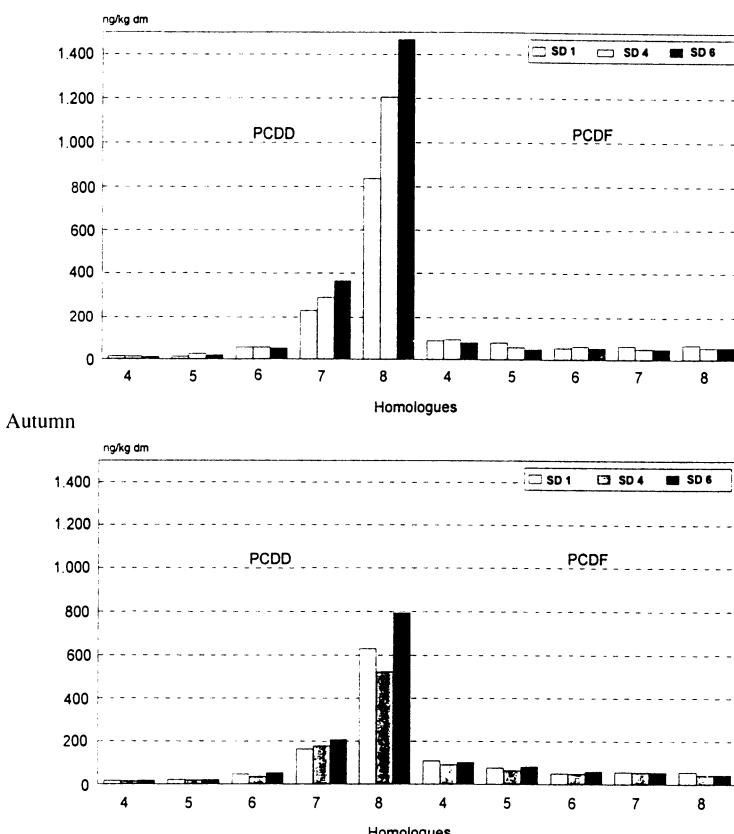


Figure 4 Content of PCDD/PCDF homologues groups in biowaste compost during a summer and autumn composting period. (SD 1 = sampling date = beginning of the composting process, SD 4 = after a 6 week composting period, SD 6 = after a 12 week composting period) (FINZMANN, 1992)

Table 9 Time required to increase the dioxin content in the soil by 1 ng TEQ/kg (FIEDLER et al., 1994)

Pathway	Concentration, Depth of application	Time frame
Atmospheric deposition	10 pg/m ² ·d, 30 cm	115 years
	10 pg/m ² ·d, 10 cm	38.5 years
	30 pg/m ² ·d, 30 cm	38.5 years
	30 pg/m ² ·d, 10 cm	12.8 years
Sewage sludge	50 ng/kg dm, 30 cm	10 years
Compost	14 ng/kg dm, 30 cm	30.3 years

A quantitative estimate of PCDD/PCDF being introduced into the soil through various pathways

In this chapter we used a simple model to calculate the increase of dioxin levels in soil via three different pathways. These examples are useful to demonstrate the importance of the various pathways – atmospheric deposition, application of sewage sludge and compost (Table 10). In this model it is assumed that biological and photolytic degradation of PCDD/PCDF in the soil is negligible (FIEDLER et al., 1994).

PCDD/PCDF background contamination of the soil:	4 ng TEQ/kg dm
PCDD/PCDF content of sewage sludge:	50 ng TEQ/kg dm
PCDD/PCDF content of compost:	14 ng TEQ/kg dm
Application rate for sewage sludge:	5 Mg dm/ha every 3 years
Application rate for compost:	10 Mg dm/ha every year
PCDD/PCDF deposition (rural area):	12 pg TEQ per m ² ·d
Specific weight of soil:	1.4 g/cm ³
Depth of application (grassland / arable land and garden):	10/30 cm

Pathway 1 – Atmospheric deposition:

An atmospheric deposition rate of 10 pg TEQ/m²·d results in an additional input of $10 \text{ pg} \cdot 365 \text{ d} = 3.65 \text{ ng TEQ}$ per square meter and year. The mass of cultivated soil (30 cm) per m² amounts to $1 \text{ m} \cdot 1 \text{ m} \cdot 0.3 \text{ m} \cdot 1.4$ (specific weight) = 420 kg. This means that each year 3.65 ng TEQ are added into 420 kg of soil, which is equivalent to 8.7 pg TEQ/kg soil (dm).

Based on this calculation it will take 115 years to increase the dioxin content by 1,000 pg = 1 ng TEQ on arable land. If the soil is cultivated only to a depth of 10 cm (= 140 kg soil/m²), the level of contamination in the topsoil amounts to 26 pg TEQ/kg soil (dm). In this case the deterioration of the contamination level by 1 ng TEQ would take 38.5 years. A higher rate of deposition amounting to 30 pg TEQ/m²·d = 11 ng/m² p.a. will result in an additional load of 26 pg TEQ/kg soil (dm). If the soil is cultivated to a depth of 30 cm it will take 38.5 years to increase the present dioxin contamination by 1 ng/kg TEQ while it will take only 12.8 years for grassland (depth of 10 cm).

Pathway 2: Application of sewage sludge

The application of 5 Mg sewage sludge (dm) per ha is associated with a dioxin load of some 250,000 ng TEQ. The dioxin is blended with 100m*100m*0.3m*1.4 = 4,200 Mg of soil which results in an increase of the contamination level by 300 pg TEQ/kg soil (dm) every three years or by 100 pg TEQ/kg soil (dm) annually. Consequently, the original dioxin content is increased by 1 ng TEQ/kg soil (dm) within 10 years. It is a known fact that, before the sewage sludge regulation has been in force sewage sludge has been applied in higher quantities than those recommended nowadays. In some cases this has resulted in an additional contamination which exceeds 100 ng TEQ/kg soil (dm).

Pathway 3: Application of compost

The application of 10 Mg compost (dm) corresponds to an introduction of 140,000 ng TEQ into 4,200 Mg soil (depth: 0.3 m) which is equivalent to 33 pg TEQ/kg soil (dm). Therefore, it will take 30.3 years to increase the present dioxin contamination by 1 ng TEQ/kg soil (dm).

Pathway 4: Application of plant protection agents

Analysis by the German Federal Institute for Agriculture and Forestry showed that pesticides containing 2,4,5-T or Dichlorprop as the active agent placed on the German market in the late 1970's and the 1980's contained up to 5 g 2,3,7,8-TCDD. Under the assumption that the pesticide is contaminated with 10,000 TEQ/kg 2,4,5,-T and this amount is applied on an area of 1,000 m² the dioxin content in soil will be increased by 25 pg TEQ/kg soil by a single application. However, 2,4,5-T originating from earlier production contained, on average, 2 mg 2,3,7,8-TCDD. According to the calculations above this would mean that a single application would result in a 100 times higher increase. Therefore, it might be possible that arable soil can be contaminated with high amounts of dioxins since the early 1970's.

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The Influence of Composts and Mineral Fertilizers on the Heavy Metal Concentration and Transfer in Soil and Plants

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Utilization of biogenic waste compost

Regarding the safety of waste management systems for composting the worst possible situation of non-marketability of large quantities of compost is often anticipated. First of all, it should be pointed out clearly that biogenic waste compost - produced from separately collected kitchen and garden waste – has a considerably higher standard concerning its quality than total solid waste compost, and problems in marketing as they occur in waste and waste/sludge compost can therefore not at all be applied to biogenic waste compost.

Against the utilization of biogenic waste compost, potential users have not raised any doubts up to now, so there are no real objections against the use of biogenic waste compost in agriculture. It is known that for various reasons the need for compost in agriculture may be low – one reason is that the costs of spreading are very high; but considering the aspect of the safety of waste management systems agricultural utilization of biogenic waste compost could be of great importance as a mean for dealing with surpluses – if there ever may be some.

In principle, the utilization of compost could serve various aims:

- part of cultural substrates,
- soil replacement and soil improvement,
- fertilization,
- improvement of soil fertility,
- protection against soil erosion,
- technical utilization as for example air filters and noise protection.

Fertilization

When using compost as fertilizer for crops, the required quantity of compost results

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- from the plant nutrient content in compost, whereby especially the amount of nitrogen, which is
- available in the vegetation period, and its effects during the following years have to be considered,
- from additional manuring (farm yard manure, green manuring, crop rotation),
- from the essential nutrients for the respective crops,
- from the soil quality of the respective site.

Assessment of biogenic waste compost

Desirable characteristics and nutrient contents

Today, the positive influence of compost on the soil fertility – its improvement of important physical, chemical and organic soil parameters – is undisputed and therefore, the utilization of compost as a substance for soil improvement is widespread.

In order to assess the utilization of biogenic waste compost in agriculture and horticulture, the plant nutrient content is checked first of all (table 1). However, it has to be considered that compost is a multi-nutrient manure which should be used in limited quantities. It has also to be paid attention to this restriction in case of a monetary assessment of the desirable nutrient contents of compost.

The following characteristics and effects are relevant for the utilization of biogenic waste composts in crop management:

- the high content and availability of plant nutrients in compost,
- the replacement of the soil humus which is mineralized,
- the buffer effects in the soil,
- the improvement of the cation exchange capacity, aeration, water retention, physical stability etc. of the soil; the reduction of the erosion hazard and the risk of soil sealing; the „feeding function“ of soil organisms and the increase in the number of soil organisms,
- the in a certain way preventive and partially direct protective action against an infestation of crops particularly with fungal diseases (phytosanitary characteristics of compost),
- the positive influence on the nutritional quality of the produced vegetable crops,
- the possibility to reduce the utilization of synthetic fertilizers and peat products which are disputed – seen from the ecological point of view

Undesirable components

The often raised doubts concerning the utilization of biogenic waste compost are true in the areas of heavy metals and organic harmful substances.

Table 1 Desirable characteristics and nutrient contents of biogenic waste compost (Vogtmann and Fricke, 1989)

parameter	dimension	span	mean value
dry matter	% fresh matter (fm)	55 – 65	60
water content	% fm	35 – 45	40
volume weight	g/l fm	500 – 800	700
maximum water capacity	Vol.-%	40 – 60	55
water-soluble salt content	g/l fm	2.0 – 6.3	3.5
pH		7.0 – 8.0	7.6
nitrogen (N_{tot})	% dry matter (dm)	0.8 – 1.7	1.2
$N\text{-NO}_3$	mg/l fm	10 – 300	80
phosphorus (P_{tot})	% dm	0.3 – 0.5	0.4
$P_2O_5\text{tot}$	% dm	0.6 – 1.2	0.8
P (CAL soluble)	mg/l fm	220 – 870	440
P_2O_5 (CAL soluble)	mg/l fm	500 – 2000	1000
potassium (K_{tot})	% dm	0.7 – 1.4	1.2
$K_2O\text{tot}$	% dm	0.8 – 1.7	1.5
K (CAL soluble)	mg/l fm	1500 – 4000	3000
K_2O (CAL soluble)	mg/l fm	1810 – 4820	3610
magnesium (Mg_{tot})	% dm	0.6 – 1.2	0.8
$Mg O\text{tot}$	% dm	1.0 – 2.0	1.3
calcium (Ca_{tot})	% dm	2.5 – 5.5	4.0
$CaO\text{tot}$	% dm	3.5 – 7.7	5.6
organic matter	% dm	25 – 40	33
C/N-ratio	% dm	10 – 20	15

Heavy metals

In our own research (Fricke et al., 1992) average heavy metal contents of biogenic waste composts have shown relatively large fluctuations (table 2). So, according to the expectations, it has to be assumed that geologically-pedologically different soil types as well as anthropologically caused contamination of soils and organic waste materials exist between the individual regions in Germany and therefore, also in the heavy metal contents of composts.

The average heavy metal contents of biogenic and vegetable composts are low. However, in our case the results have shown that nine bio-composts are not able to meet the requirements for keeping the seal of quality of compost'. Following the first examination, the reason for exceeding the guide value in three cases seem to be caused by high geological resp. pedological soil types. In the three other cases this seems also to be caused by increased soil contaminations, but in these cases they are caused anthropologically. Outstandingly high contents of non organic substances in the organic raw material should be the reason for the increased heavy metal contents in two of the composts.

These findings show that regular examinations of biogenic waste composts regarding their heavy metal contents are essential in order to reach a „protection of soils against contaminations with harmful substances“ (Poletschny, 1992). In this connection it should also be pointed out that the total load of harmful substances applied through the compost has to be considered. In order to find the maximally possible quantity of heavy metals allowed, it is advisable to apply the rule which is given in the German Sludge Decree.

Table 2 Heavy metal content in biogenic waste compost related to the original organic substance and standardized to 30 % organic matter in the dry matter (mg/kg dm)

element	mean value ^a	median	frequency centre	number of samples above the guide value ^b	using the limits of the guide value ^b %
Pb	77.64	69.00	54.79 – 94.65		
Cd	0.78	0.61	0.45 – 1.00		
Cr	33.73	25.00	11.90 – 44.30		
Cu	43.24	38.37	29.79 – 48.79		
Ni	19.13	17.29	11.69 – 25.30		
Zn	232.82	211.18	168.75 – 279.00		
Hg	0.33	0.21	0.15 – 0.44		
standardized to 30 % organic matter in the dry matter					
Pb	83.07	75.88	53.27 – 99.76	4	55.4
Cd	0.84	0.68	0.42 – 0.97	8	56.0
Cr	35.83	27.34	20.26 – 44.30	2	35.8
Cu	46.76	40.66	30.33 – 59.33	2	46.8
Ni	20.48	18.64	12.49 – 26.48	2	41.0
Zn	249.60	228.57	177.16 – 307.34	5	62.3
Hg	0.38	0.22	0.15 – 0.45	3	38.0

a number of means on average 52, based on 490 separate analyses

b guide values according to the German Federal Compost Quality Association

Field trials

In 1986 and 1987, two experiments with different crop rotations were started in the research centre of the Department of Ecological Agriculture at the University of Kassel in Neu-Eichenberg. In experiment 1 an intensively fertilized purely field vegetable crop rotation of white cabbage (1987), carrots (1988), potatoes (1989), beetroots (1990) and celeriac (1991) was performed. The heavy metal determination was performed using the Zeeman Atomic Absorption (Zaas) technique. Statistical analyses were conducted with Anova, average values were compared with the Duncan multiple range tests.

In this experiment compost applications lead to a superior quality of the plant products with regard to desirable and undesirable nutrients in the N-fraction and also to the storage quality of the products. Sensory evaluations showed a similar trend. Crop yields were comparable for the NPK and the compost treatments in the third year of the experiment.

The main concern regarding bio-compost utilization in agriculture and horticulture are heavy metals. During this five-year-experiment significant differences only occurred between the cadmium contents (table 4). It is noticeable that the plant values of the two biogenic waste compost treatments are lowest and are significantly different to both NPK-treatments and to OCF (organic commercial fertilizer). The absolutely highest soil-value for the control (no fertilizer) could be connected with the low cadmium export through the harvest.

Table 3 Fertilizing regimes in a field vegetable trial

treatment	application quantity 1991 [kg/ha] resp. [t/ha]	compost quantity 1987 - 91 [t/ha]
V1 control	without fertilizer	
V2 NPK 1	80 kg N as Ammonium nitrate (AN) 80 kg P ₂ O ₅ as Superphos 240 kg K ₂ O as Patentkali	
V3 NPK 2	160 kg N as AN, rest like V2	
V4 biogenic waste compost 1 (BWC 1)	80 t biogenic waste compost from the project „Green Garbage Bin Witzenhausen“	310 FM, c. 205 t DM
V5 biogenic waste compost 2 (BWC 2)	40 t biogenic waste compost like BWC 1 80 kg N as Horn meal 80 kg P ₂ O ₅ as Hyperphos 120 kg K ₂ O as Patentkali	145 t FM, c. 84 t DM
V6 farm yard manure compost 1 (FYMC 1)	50 t manure compost	210 t FM, c. 84 t DM
V7 farm yard manure compost 2 (FYMC 2)	50 t manure compost 80 kg N as Horn meal 80 kg P ₂ O ₅ as Hyperphos	210 t FM, c. 84 t DM 120 kg K ₂ O as Patentkali
V8 organic commercial fertilizer (OCF)	80 kg N as Horn meal 80 kg P ₂ O ₅ as Hyperphos 120 kg K ₂ O as Patentkali	

Table 4 heavy metal contents in the soil and in vegetables (celeriac) in experiment 1

treatment	cadmium (mg/kg DM)		copper (mg/kg DM)		zinc (mg/kg DM)	
	soil	plant	soil	plant	soil	plant
control	0.31 b*	0.383 abc*	13.6	13.3	62.1	32.8
NPK 1	0.20 a	0.528 c	13.6	12.6	62.4	34.1
NPK 2	0.20 a	0.483 c	12.9	11.5	63.2	33.3
BWC 1	0.22 a	0.308 ab	12.8	14.2	63.3	34.7
BWC 2	0.26 ab	0.305 a	14.2	14.9	66.0	37.1
FYMC 1	0.26 ab	0.408 abc	14.2	15.2	59.3	35.1
FYMC 2	0.25 ab	0.398 abc	14.1	13.9	64.7	34.3
OCF	0.28 ab	0.455 bc	13.8	13.9	61.2	37.6

* results are significantly different with different letters ($p < 0.05$)

In experiment 2, which was not as intensively fertilized as experiment 1 and more close to the manuring practice of ecological agriculture, the crop rotation was as follows: field vegetable (beetroots 1986), winter wheat (1987), potatoes (1988), spring wheat (1989), grass-clover (1990 – 91) and again field vegetable (white cabbage 1992). Compost was used only specifically before planting the field vegetables (table 5).

Table 5 Fertilizer treatments (selection, 1992) and total quantities of the compost applied from experiment 2

treatment	application quantity 1992 [kg/ha] resp. [t/ha]	compost quantity 1985 – 92 [t/ha]
V1 control	without fertilizer	
V7 NPK	180 kg N as AN 125 kg P2O5 as Superphos 300 kg K2O as Patentkali	
V10 farm yard manure compost (FYMC)	47.5 t	107.5 t FM, c. 43 t DM
V12 biogenic waste compost (BWC)	60 t biogenic waste compost from the project „Green Garbage Bin Wittenhausen“	120 t FM, c. 80 t DM

Concerning cadmium similar results were obtained to those in experiment 1: The Cd-content in plants with mineral fertilizer applications were significantly higher compared into all other variants (table 6). Furthermore, a higher absorption of nickel and zinc could be demonstrated. All in all, soil values are lower than the values for the multi-functional exploitation of soils given from Kloke (1991). The same applies on the whole to the plant values which are in no way a health risk.

Table 6 Heavy metal contents in the soil and in vegetables (white cabbage) in experiment 2 (all values in mg/kg DM)

treatment-	lead		cadmium		copper		nickel		zinc	
	soil	plant ¹	soil	plant	soil	plant	soil	plant	soil	plant
control	21	0.060	0.18	0.0175 a ²	11	1.65	14	0.25 ab ²	50	11.88 a ²
NPK	17	0.030	0.22	0.035 b	11	2.01	14	0.33 b	49	17.48 b
FYMC	19	0.025	0.22	0.0175 a	11	1.59	13	0.27 ab	54	10.65 a
BWC	19	0.013	0.24	0.0175 a	10	1.47	15	0.21 a	50	11.13 a

1 statistically not analysed because 8 from 16 treatments were lower than the limit of the analytical procedure

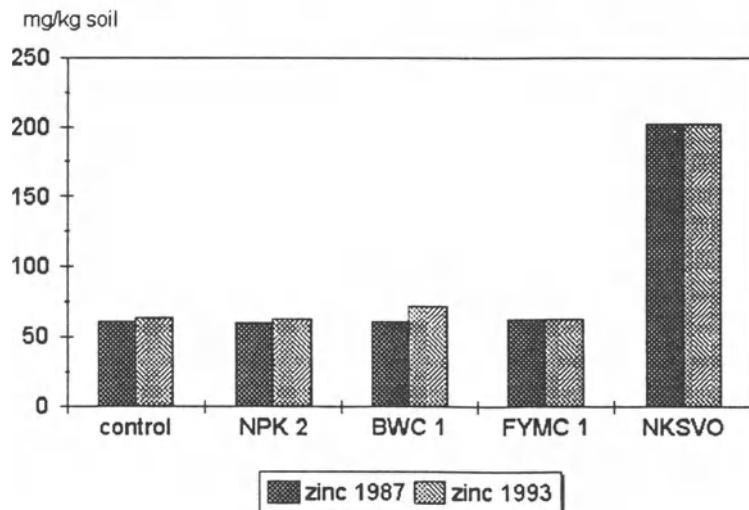
2 values with different letters are significantly different ($p < 0.05$)

If one looks at the total period of 7 years of compost application, no increase in either zinc or cadmium content in the soil can be seen (figures 1, 2).

The transfer of cadmium from the soil to the plants tested is extremely low and shows an advantage for both compost types applied (BWC, FYMC) (figure 3).

The experiments show that even a very intensive medium-term fertilization with biogenic waste compost does not significantly increase the content of relevant heavy metals in soils and plants. As far as cadmium is concerned, the compost application obviously has a remarkable positive influence on the transfer from the soil into the plant. So, the cadmium values of the mineral fertilized plants were in both experiments significantly higher than those of the plants fertilized with biogenic waste compost.

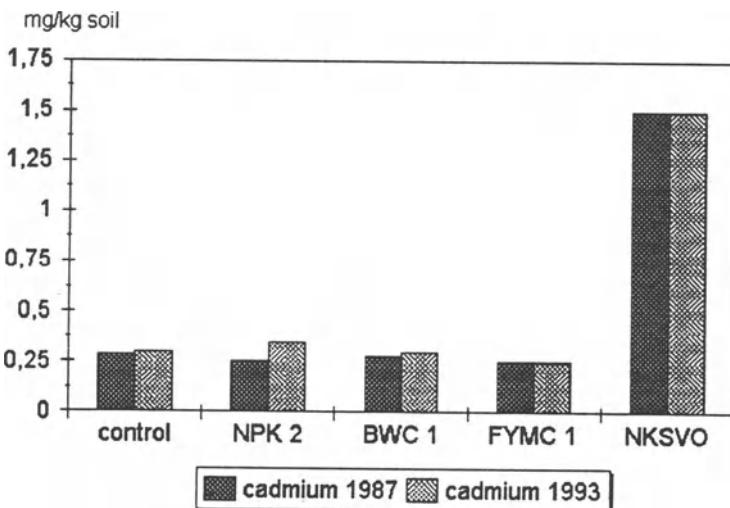
Zinc contents in the soil at the beginning of the experiment (1987) and at the end of the experiment (1993)



NSD = limit New Sludge Decree; no significant difference between years and treatments

Figure 1

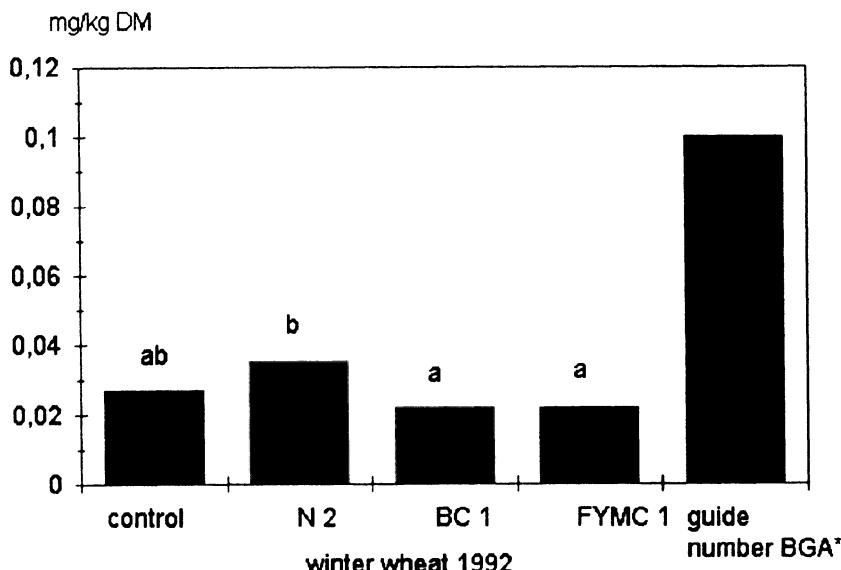
Cadmium contents in the soil at the beginning of the experiment (1987) and at the end of the experiment (1993)



NSD = limit New Sludge Decree; no significant differences between years and treatments

Figure 2

Plant contents of cadmium in winter wheat 1992



* guide numbers of BGA refer to FM; bars with the same letter are not statistically significant (-)

Figure 3

Conclusions

Bio- and plant composts have a high quality standard. Due to their determining characteristics they can be used profitably and in optimal quantities in all fields of crop management. Only in the field of substrate production the relatively high salt content in bio-compost can lead to a limitation of the quantity used.

Although the average heavy metal contents of bio- and plant composts can be considered as low, the total heavy metal load applied with the composts has to be taken into account. If the amount of compost applied annually is limited to a maximum of 10 t dry matter no problem with compost, which meets the German Guide Values, can be considered.

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A3 Round Table on Legislation

U.S. Environmental Protection Agency Regulations for Compost Production and Use

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Abstract

Composting is an excellent tool for stabilizing and facilitating the subsequent utilization of organic waste materials, (e.g., biosolids, municipal solid wastes (MSW), farm wastes and certain industrial wastes. Associated with compost production and utilization are various concerns. These concerns pertain to the ability, during processing and storage, to minimize odor and bioaerosols and to adequately destroy pathogens; and, prior to utilization, the ability to produce compost with sufficiently low pollutants contents, maturity and stability for intended end-uses.

Rules and guidance can help assure good compost processing and the best and fullest use of these compost products. This paper will describe the approach the U.S. Environmental Protection Agency (EPA) took in developing its 40 CFR Part 503 biosolids rule which includes requirements for composting and use of biosolids-containing composts. The paper will also discuss the applicability of the Part 503 rule to composts that do not contain biosolids.

Introduction

The transformation of organic waste materials into compost facilitates recycling and public acceptance. The challenge is to facilitate this transformation by the employment of good processing procedures that produce a finished compost with sufficient quality for the intended end-use. EPA has developed a comprehensive rule that protects public health and the environment when biosolids are used or disposed and the rule includes requirements for the production and use of biosolids-containing composts. This rule is found in 40 CFR Part 503 and is known as the Part 503 rule for short. The paper will discuss:

- aspects of composting and utilization that can benefit from guidance and/or rules,
- a description of the approach and important features of the risk assessment processes used during the development of the part 503 biosolids rule,

- the rule itself,
- the applicability of the Part 503 rule to the composting and utilization of compost products that do not contain biosolids, and
- a brief discussion of how rules can impact the processing and potential useability of compost products.

Compost Processing and Utilization Potentially Benefiting from Guidance or Regulation

There are a number of considerations about compost processing and end-use that would be helped by regulation or guidance. EPA has thus far chosen to regulate only those aspects of compost processing and use that are necessary for the protection of public health and the environment and not those aspects pertaining to nuisance potential or useability of the end-products. Guidance, and not necessarily regulations, is needed to facilitate processing with minimal neighborhood annoyance. Similarly, guidance is needed for producing compost products that are not only useful but also have been designed for even higher and better end-uses. Table 1 summarizes these needs.

Development of the part 503 Rule: EPA's Approach

EPA chose to develop the part 503 rule based upon scientific risk assessment. The results of the assessment provided a basis for determining acceptable environmental change when biosolids were used or disposed (USEPA 1995). Change is inevitable when you add anything to soil. Chemical fertilizer and animal manure additions are not exceptions.

Proposed Part 503 Rule. EPA began the process in a very conservative manner. The proposed rule was designed to protect the *most exposed individual* (MEI) from pollutants in land-applied biosolids. The MEI was defined as the most exposed individual (person, animal, or plant) that remains for an extended period of time at or adjacent to the site where maximum exposure occurs. *Worst-case* estimates of the potential for exposure were assigned to the MEI which resulted in the regulatory limits in the proposed rule being very stringent.

Critical Comment. Experts were highly critical of the risk assessment EPA used as a basis for developing the proposed Part 503 rule. They were critical of the use of an MEI as the target organism to be protected, the very conservative assumptions, and the overly stringent models. The commenters showed that the use of the MEI was so unrealistic that such an individual would not exist; and, hence, any assessment of risk to a nonexistent organism would not be meaningful. As an example, one of the MEIs in the proposed Part 503 rule (for exposure pathway 1F [now exposure pathway 2]) was the following hypothetical home gardener:

Table 1 Compost processing and Product Utilization Steps Benefiting from Guidance or Regulation

ITEM	DISCUSSION
<i>Pollutants EPA Rule*</i>	Applies to Composts Containing Biosolids See Table 3
Heavy Metals	
Pathogen Reduction	Class A (USEPA 1994B). Most common temperature requirements are 55°C for a minimum of 3 days for static aerated pile and within-vessel configurations and 55°C for 15 days with a minimum of 5 turnings for windrows. Testing for fecal coliform or Salmonella sp. is also required.
Vector Attraction Reduction (VAR)	(USEPA 1994B). Most common VAR requirements are for a minimum 14 days of aerobic treatment with an average temperature of >45°C and the temperature generally above 40°C
Organic Pollutants	Organic compounds were evaluated in the biosolids risk assessment; limits were established but not placed in the final rule (See Table 4).
<i>Processing Guidance</i>	
Bioaerosol Control	Not currently regulated. Use operational techniques to minimize bioaerosols release (Millner, et. al. 1994).
Odor Control	Odors (Walker 1992) are the primary reasons that composting operations get into trouble. Odors stimulate concerns about all other issues associated with composting such as bioaerosols, water pollution, dust, traffic, etc.
<i>Utilization Guidance</i>	
Degree of Growth Suppression	Growth suppression could be caused by soluble salts, improper available C/N ratio, or acid imbalance. Useability depends upon the sensitivity of the crop.
Oxygen Uptake or CO ₂ Evolution	A good routine testing procedure for determining how well the operation is doing at each step of the process. The testing is reflective of degree of compost maturity and potential for odor production by the 'finished' product (Walker 1992).
Aesthetic Appearance	Amount of plastics, glass, etc in 'finished' product.
Nitrogen	Agronomic Rate [required by the Part 503 if the compost produced for use is not EQ**]. None-the-less good practice dictates nutrient management.

*EPA Part 503 rule applies to any compost containing biosolids. For the degree of applicability to other composts see discussion in the text.

**EQ refers to biosolids that have low pollutant contents, are Class A with respect to pathogens and meet vector attraction reduction requirements.

- who raised and consumed essentially all of his or her own food for 70 years in a biosolids-amended garden,
- whose biosolids-amended garden soil contained the maximum cumulative permitted application of each of the evaluated pollutants for that 70-year period,
- whose food harvested from the garden had the highest plant uptake rate for the 70-year period for each of the pollutants as calculated using data from salt studies, and
- who consumed food growing in that garden for 70 years, being simultaneously both male and female and was always at the age and physiological state for maximum ingestion and adverse impact of the pollutant, (e.g., pregnant; an infant; a teen-age male; and deficient in dietary calcium, iron, and phosphate, etc.).

Final rule. Because of the many difficulties experienced with the MEI approach, EPA developed a new paradigm for conducting risk assessment (Habicht 1992).

This paradigm involves the protection of a **highly exposed individual** (HEI) and the use of a combination of high-end and mid-range assumptions in models and algorithms used to conduct the risk assessment for the final Part 503 rule. In contrast to the MEI, EPA considers the HEI as representative of that subset of the population of actual individuals at higher risk. The HEI attempts to be representative of a real individual. Consider the data, models and assumptions used for protecting the highly exposed home gardener again via Pathway 2 during the revised risk assessment and development of the final Part 503 rule. In this risk assessment:

- the home gardener HEI raised and consumed up to 60 percent of his or her own food for a 70-year period in a biosolids-amended garden,
- the biosolids-amended garden soil contained the maximum cumulative permitted application of each of the evaluated pollutants for the 70-year period,
- the food, that was harvested from the garden, had the uptake slopes for biosolids pollutants determined using the geometric mean of relevant data from field studies with both acid and neutral biosolids-amended soils, and
- the food consumption was apportioned among several different age periods during the 70-year life of the HEI gardener who was of reasonable health and dietary sufficiency.

A Different Approach for Developing Rules

Some rule makers have followed a very different policy-driven rather than risk assessment-based approach. Such an approach often allows only small incremental increases of pollutants from the use or disposal of biosolids over background levels of pollutants already present in the environment. Such an approach is often not associated with an attempt to determine the extent or acceptability of environmental change.

The close to zero change/zero risk philosophy, taken to its ultimate end, often predicts that background levels of pollutants in the environment are harmful. Rarely, if ever, is this prediction substantiated by field research. Without this knowledge of real field data, policy-driven decisions or unrealistic worst-case assumptions (as were made in the risk assessment for the proposed Part 503 rule) would preclude the recycling to land of our valuable organic waste resources. The application of such logic to the normal agronomic practices that make use of chemical products and animal manures could, without valid field verification, also suggest that these practices were too risky to be continued.

EPA and other Federal Agencies in the United States *did* pay attention to years of field research and experience. And, as a result, have adopted policies that encourage and promote the beneficial use of biosolids (USEPA 1994A). The minimal risks associated with the outstanding benefits that have accrued from biosolids recycling to land have been reaffirmed by the intensive multi-year Federal effort to develop the science-based 40 CFR Part 503 rule. Many of the significant steps in this comprehensive process are outlined in Table 2.

Table 2 Steps in the Development of the 503-rule

March 1984	• List of 200 pollutants
May 1984	• Experts select 50 pollutants for further study and identified exposure pathways
1984 & 85	• EPA conducts worst-case hazard profile assessment
1985	• Science Advisory Board approves risk assessment methodology; did not check data selection, assumptions and models
1986 – 88	• EPA conducts risk assessment protecting MEI and using worst-case data, assumptions & models
Feb 1989	• Proposed Part 503 Rule
July 1989	• Peer Review of Part 503, points out scientific reasons for over-stringency in proposed rule
Jan 1990	• Establishment of expert team to assist EPA with revision of rule
1990	• EPA selects new data, assumptions and models and begins revised risk assessment
Nov 1990	• EPA publishes National Sewage Sludge Survey (NSSS) results and announces possible changes to the rule
1990 – 92	• EPA continues risk assessment protecting HEI and using field data, modified assumptions & models; incorporates comments on NSSS notice
1992	• Internal Agency-wide review by EPA
Feb 1993	• EPA publishes final Part 503 rule
Feb 1994	• EPA publishes minor amendments to Part 503 rule
1994 – 95	• EPA considers 4 provisions of Part 503 rule remanded by court
1994 – 95	• EPA begins ecological, study on specific issues identified for additional study during development of Part 503 rule
1994 – 99	• EPA identified 32 more biosolids pollutants for regulatory consideration by year 2000. Current analysis is narrowing the focus for consideration to dioxins and PCB's

The Rule

Because of the many benefits and very low risks associated with biosolids recycling, the Part 503 rule was written in a manner that encourages the beneficial use of biosolids. Moreover, the Part 503 rule was written in a manner that is reasonably straight forward and self-implementing. The rule includes standards for each use or disposal practice.

What a Standard Includes. A Part 503 standard includes general requirements, pollutant limits, management practices, operational standards, and requirements for the frequency of monitoring and recordkeeping, and reporting (USEPA 1994B). For the most part the self-implementing requirements of the Part 503 must be followed even without the issuance of a permit.

Ceiling Concentrations. All biosolids applied to land must meet the ceiling concentrations for pollutants listed in the first column of Table 3. The ceiling concentrations are the maximum concentration limits for the regulated heavy metals. Ceiling concentrations for pollutants are policy-based limits that were set at the 99th percentile of EPA's National Sewage Sludge Survey (USEPA 1990). This

limit is important because the rule was developed using data from biosolids field experiments rather than from pure salt studies in the risk assessment. Biosolids with the highest concentration of pollutants (>99th percentile) do not as effectively bind those pollutants. Hence, uptake of metals from soils amended with these 99th percentile biosolids is more like that observed from metal salt-amended soils than from soils amended with less pollutant-concentrated biosolids.

Table 3 Pollutant Limits (USEPA 1994B).

Pollutant	Ceiling Concentration Limits for All Biosolids Applied to Land (milligrams per kilogram)	Pollutant Concentration Limits for EQ and PC Biosolids (milligrams per kilograms)	Cumulative Pollutant Loading Rate Limits for CPLR Biosolids (kilograms per hectare)
Arsenic	75	41	41
Cadmium	85	39	39
Chromium*	3,000	1,200	3,000
Copper	4,300	1,500	1,500
Lead	840	300	300
Mercury	57	17	17
Molybdenum**	75	—	—
Nickel	420	420	420
Selenium ⁺	10	36	100
Zinc	7,500	2,800	2,800
From Part 503	Table 1 Section 503.13	Table 3 Section 503.13	Table 2 Section 503.13

*Chromium may be deleted from the rule based on court remand reconsideration.

**All molybdenum were limits except the ceiling concentration limits were deleted from the rule pending reconsideration.

⁺Selenium limits may be changed pending court remand reconsideration.

Pollutant Concentration (PC) Limits or Cumulative Pollutant Loading Rates (CPLR). Biosolids applied to land must also meet either PC limits or CPLR's (Table 3, second and third columns, respectively). The biosolids risk assessment process involved characterizing the risk from 14 different pathways by which humans, animals, and plants could become exposed to pollutants of concern from the use of biosolids. Algorithms were formulated to mathematically represent these pathways. Calculations were made for each pathway to determine levels of pollutants that would not cause toxicity thresholds or cancer risk levels to be exceeded. The risk assessment deliberations including policy and risk management decisions, involved in the biosolids risk assessment process, are discussed in EPA's Guide to the Part 503 Risk Assessment (USEPA 1995).

For each pollutant evaluated, EPA chose the pathway with the lowest calculated permitted pollutant level as the regulatory limit. For example, for arsenic the lowest limit was found in exposure pathway 3 and for copper the lowest limit was found in exposure pathway 8. All of the selected pollutant regulatory limits are shown in Table 4.

Table 4 Most Limiting Pathway for each sludge pollutant

Sludge Pollutant	Highly Exposed Individual	Most Limiting Pathway*	Regulatory Limit RSC**, ug/g
<i>Pollutants Remaining in the Final Part 503 Rule</i>			
Arsenic	Biosolids eaten by child	3	43
Cadmium	Biosolids eaten by child	3	39
Chromium ⁺	Phytotoxic plant	8	3000 ⁺
Copper	Phytotoxic plant	8	1500
Lead	Biosolids eaten by child	3	300
Mercury	Biosolids eaten by child	3	17
Molybdenum ⁺⁺	Animal eating feed	6	18 ⁺⁺
Nickel	Phytotoxic plant	8	420
Selenium	Biosolids eaten by child	3	100
Zinc	Phytotoxic plant	8	2800
<i>Pollutants Deleted from the Final Part 503 Rule**</i>			
Aldrin	Eating animal fat/milk	5	2.7
Dieldrin	Eating animal fat/milk	5	2.7
Benzo(A)Pyrene	Biosolids eaten by child	3	15
Chlordane	Biosolids eaten by child	3	86
DDT/DDD/DDE	Eating fish	12	120
DimethylNitrosamine	Biosolids eaten by child	3	2.1
Heptachlor	Eating animal fat/milk	5	7.4
Hexachlorobenzene	Eating animal fat/milk	5	29
Hexachlorobutadiene	Eating animal fat/milk	5	600
Lindane	Biosolids eaten by child	3	84
PCB's	Eating animal fat/milk	5	4.6
Toxaphene	Eating animal fat/milk	5	10
Trichloroethylene	Biosolids eaten by child	3	10,000

*The regulatory limit for each pollutant was based on the exposure pathway found to be the most limiting for that pollutant.

**The RSC is the calculated concentration limits for pollutants in biosolids that do not cause endangerment of public health or the environment.

⁺This metal may be deleted from the rule because its previous inclusion was not risk-based.

⁺⁺Only ceiling limits for molybdenum now in rule pending better data for risk assessment.

*+Pollutant deleted because (1) it was not present in NSSS studied biosolids, (2) it was only present in biosolids at levels about 10 to 100 times below the pollutant limits calculated by risk assessment for biosolids to be protective of public health and the environment, or (3) the pollutant has been banned by EPA and is no longer being manufactured or used in the United States.

The organic pollutant ‘regulatory’ limits, also shown in Table 4, were calculated but were not included in the Final Part 503 rule. This is because reevaluation has shown that the low levels of these organic pollutants, now occurring in biosolids, do not pose significant risks to human health or the environment. Deletion of organic pollutants from the final Part 503 rule was based upon meeting any one of the three following criteria:

- The pollutant has been banned or restricted for use by EPA, or is no longer manufactured or used in the manufacturing of a product in the United States, or
- The pollutant is detected infrequently (i.e., ≤ 3 percent) in biosolids, based on data from EPA’s National Sewage Sludge Survey, or
- The pollutant limit identified in EPA’s risk assessment conducted for the final

Part 503 rule is not expected to be exceeded in biosolids that are used or disposed, based on data from EPA's National Sewage Sludge Survey.

Pathogens and Vector Attraction Reduction (VAR). Biosolids must meet either Class A or B pathogen requirements plus site restrictions and one of 10 vector attraction reduction requirements (USEPA 1994B).

Equally Protective Options for Land Application. The Part 503 rule provides several options for governing the land application of biosolids. All these options are equally protective of public health and the environment. There are fewer requirements for the highest quality biosolids. Such biosolids are often produced by composting or heat drying.

Exceptional Quality Biosolids (EQ). EQ is a term used to characterize biosolids that meet low-pollutant (second column in Table 3), Class A pathogen reduction (virtual absence of pathogens) limits, and VAR requirements in the Part 503 rule. These high quality biosolids are the least cumbersome to use. Once having met the stringent requirements, their use *is not subject to further regulatory oversight* including the absence of further monitoring or keeping track of land-applied biosolids pollutants. Once produced, EQ biosolids are considered an unregulated product like chemical fertilizer, peat, or animal manure. However, as with any other soil conditioning and fertilizing product, sound nutrient management practices should be followed.

The risk assessment, conducted to develop the acceptable EQ pollutant limits, involved the assumption that, under a possible but highly unlikely worst-case scenario, a one-time application of 1000 metric tons per hectare of biosolids (over a two-foot thick layer of biosolids on the surface) would occur (USEPA 1995). It is reassuring to note that experience and field research over the past several decades have shown virtually no observed adverse effects from repeated use of such EQ biosolids.

Applicability of the Part 503 Rules to Other than Biosolids Composts

The applicability of the Part 503 rule to the production and use of composts from other than biosolids-containing materials depends on the degree of similarity between the compost process, the compost products and their use. Ryan and Chaney 1992 have indicated that there is considerable similarity. Hence, the production and use of such composts will ultimately be required to meet similar standards, or, at least similar methodology will be used to develop the applicable standards. An understanding of the methodology that would be needed to develop such standards and its data requirements would be highly beneficial.

For the most part MSW composts products contain fewer inorganic pollutants than biosolids composts (Walker and O'Donnell 1991). The primary exception is

the content of lead (Table 5). What needs to be determined for fuller confidence in the direct applicability of the Part 503 rule standards to non-biosolids-containing composts is to learn their degree of similarity to biosolids-containing composts with respecting to pollutant binding capability, (i.e., with respect to the contents of iron, aluminum and manganese oxides as well as phosphates). Also, we need to verify that the levels of toxic organic compounds in non-biosolids-containing composts are sufficiently low (compared with the ‘regulatory’ levels calculated during the Part 503 risk assessment) so that routine monitoring for these compounds would not be necessary.

Table 5 Heavy Metals in MWSW Compost from Operating Facilities (Walker and O'Donnell 1991).

METAL	MSW COMPOSTS					
	AGRISOIL	FAIRGROW	FILMORE*	ST CLOUD	SUMTER	BIOSOLIDS
	ug/g biosolids (dry weight basis)					
Cadmium	4.1	3.4	2.9	2.2	5.0	6.9
Chromium	20.5	223	12.8	33.5	—	119
Copper	256	285	101	180	250	741
Mercury	2.4	4.0	1.2	1.8	—	5.2
Nickel	34	77	15	28	27	43
Lead	124	496	82	185	290	134
Zinc	607	1008	329	390	580	1202

*Combined MSW and Biosolids Compost

**Mean biosolids metal contents from the National Sewage Sludge Survey

Examples of Rule Impacts (Walker, et. al 1995)

Irrespective of the requirements in the Federal part 503 rule, individual states within the United States have their own rules for biosolids. By law their requirements may be more stringent than the Part 503 rule. How successful biosolids recycling becomes depends in part upon the degree of adoption of a risk-based rule such as the Part 503 rule. Lets trace for a moment what has actually happened in several states and Sweden where different regulatory approaches and policies have been in effect.

Maryland, Ohio, and Wisconsin. These states have long well-established programs with attitudes, rules and guideline provisions that have encouraged biosolids recycling. About 90 percent of all biosolids are beneficially used on land in Maryland, 55 percent in Ohio and 95 percent in Wisconsin.

New York and New Jersey. These states historically had their major biosolids producers dumping the biosolids into the ocean or causing it to be incinerated. There was little perceived need nor desire until recently to even study the use of biosolids, particularly in New York State. There has been a mind set that since the biosolids come from humans and industries in major cities they must be foul, toxic

and damaging to public health and the environment. As a result in New York State there is only about 11% within-state usage of biosolids. And, nearly all of New York City's biosolids have had to be used out-of-state as far away as Texas and Colorado.

Likewise, stringent laws were developed to govern the use of biosolids in New Jersey, particularly since the State is so populated. Even though most stakeholders in New Jersey endorse the beneficial use of biosolids, there have been significant difficulties just in complying with the complexity of the rules as they had existed, let alone attempting to gain public acceptance. Hence, New Jersey historically had about 10% of its biosolids used within state. More recently New Jersey has been more proactively encouraging biosolids recycling and is now actively considering adopting the provisions of the Part 503 rule so that the benefits of recycling can be more fully realized. Currently, about 32% of New Jersey's biosolids are being used beneficially.

In General. In many states a majority of citizens support recycling. However, a problematic view of some regulatory officials has been that biosolids rules must be very stringent because of perceived high risk and/or lack of trust that the vast majority of biosolids generators and land applicators will follow rules and will be environmentally responsible. Public support for biosolids recycling is also dampened when the proposed use happens to be nearby. In part, because of such stringency, New York City has faced per pound costs for managing its biosolids up to as high as the per pound costs for purchasing frying chickens. *All of this concern, stringency and associated extra costs are remarkable considering the high degree of benefit and very low risk associated with using biosolids (USEPA 1994A).*

The United States EPA vs. the Swedish Biosolids Use Rules. In Sweden the use of biosolids was once quite acceptable. Now, the use of biosolids has been banned by the Farmers' Organization, because food industries refuse to accept agricultural products derived from croplands fertilized by biosolids. The reason for the ban is that biosolids are believed to contain 'environmentally hazardous' substances (Hellstrom and Dahlberg 1994). Such limited perception misses the fact that every food grown even in a pristine environment contains potentially hazardous substances, but are not hazardous unless pollutant levels are such that critical exposure thresholds are exceeded. The point is that it is relatively easy to manage the use of biosolids and foods so that permitted levels of potentially hazardous substances do not exceed critical levels and become environmentally hazardous.

For those few areas in Sweden where biosolids use is being permitted, the already stringent Swedish rules have become much more stringent. Very few biosolids in the United States can meet the Swedish rules, even though a majority are of very good quality; and even the Swedish biosolids are even having considerable difficulty meeting their rules.

Hellstrom and Dahlberg 1994 present an intriguing theory of how *environ-*

mental worry and the promotion of environmental worry limits biosolids recycling (see Figure 1). Environmental worry causes the public to lose, but benefits others by providing politicians with control and power, environmental management companies with profits, and environmentalists and researchers with funding to continue lobbying or research efforts. Following directly from 'promoted' environmental worry is that it does not matter how little of a 'hazardous' substance is left after treatment, there always is something left to worry about, (i.e., the public sees this independently of how much effort has been put into causing the wastes to contain lower levels of pollutants). The authors state that the way out of this dilemma is partially dependent upon risks being characterized and the public being informed in a reliable way — such as the approach being followed in the United States.

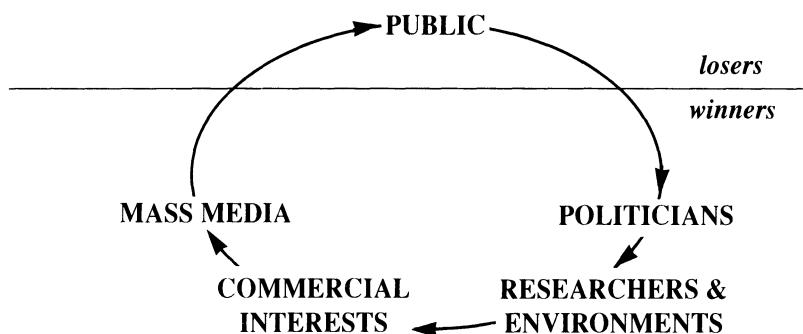


Figure 1 Groups influencing and benefiting from environmental worry (Adapted from Hellstrom and Dahlberg 1994)

Opportunities for Designer/Tailor Made Wastes (Walker 1995A & B)

The way rules are written, interpreted and implemented can have a major impact on the practices and costs associated with beneficially using biosolids. Where rules permit, there are a number of opportunities for creative uses of wastes.

Knowledge gained from basic research as well as practice is paving the way for creative uses of waste materials that arise either directly from various municipal and industrial waste treatment processes or from combinations or special treatment of waste materials to give them desirable characteristics. This knowledge also leads directly to improved methods of overcoming other environmental problems. The proper use of these waste products helps achieve the goal of sustainable farming. The production of tailor-made waste products creates opportunities for new jobs in both rural and urban areas. Several examples follow:

- Metal bioavailability can be managed. The bioavailability of metal pollutants in a waste material such as wastewater sludge biosolids is reduced due to matrices

components like oxides of iron, aluminum and manganese, humic acids from the biosolids organic matter, and phosphates (Chaney and Ryan 1992). Dewatering biosolids with an iron salt such as ferric chloride enhances its ability to reduce bioavailability of metal pollutants.

- On-going research is suggesting that biosolids, which are added to soils contaminated by lead-containing paints or past automotive emissions, can reduce the soil lead bioavailability and hence help protect children who ingest soils (Heneghan, et. al. 1994).
- Research by Hoitink et. al. 1992 has demonstrated and the potting industry has adopted the use of specially prepared compost to suppress plant root disease.

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A4 Use of Compost

Suppression of Plant Diseases by Composts

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Abstract

Composts offer unique opportunities to examine fundamental interactions between plant pathogens, biocontrol agents, soil organic matter and plant roots. These organic amendments can be prepared reproducibly and have the potential to provide consistent biological control of plant diseases. Foliar as well as root pathogens may be affected by composts. Unfortunately, many factors control these beneficial effects. Heat exposure during composting kills or inactivates pathogens if the process is monitored properly. Biocontrol agents with the exception of *Bacillus* spp. also are killed by this heat treatment, however. Thus, biocontrol agents largely must recolonize composts after peak heating. The raw feedstock, the composting environment, as well as conditions during curing and utilization affect the potential for recolonization of composts by biocontrol agents and the induction of disease suppression. In practice, controlled inoculation of compost with biocontrol agents has proved necessary to induce consistent levels of suppression.

The stability of composts is another factor to be considered. Immature composts serve as food for pathogens. Their populations increase in fresh organic matter even if it is colonized by biocontrol agents. In mature composts, biocontrol agents inhibit or kill pathogens and induce suppression of disease. Excessively stabilized organic matter, on the other hand, does not support the activity of biocontrol agents. Disease develops in such highly mineralized organic matter. Finally, salinity and the rate of release of plant nutrients, particularly the amount of nitrogen released, affect suppressiveness. As a result, timing of compost application relative to planting of crops is another factor to be considered.

Introduction

During the 1960's, nurserymen across the United States explored the possibility of using tree bark as peat substitutes to reduce potting mix costs. Early during the

utilization of bark composts, improved plant growth and decreased losses caused by *Phytophthora* root rots were observed as side benefits in the nursery industry. Today it is recognized that control of such root rots with composts can be as effective as that obtained with fungicides (Hardy and Sivasithamparam, 1991; Hoitink et al., 1991; Ownley and Benson, 1991). Therefore, the ornamentals industry relies heavily on composts for control of diseases caused by these soilborne plant pathogens. In field agriculture, similar results have been obtained (Hoitink and Fahy, 1986; Lumsden et al., 1983; Schüller et al., 1993).

Composts must be of consistent quality and maturity to be used successfully in biological control of diseases of horticultural crops, particularly if used in container media (Inbar et al., 1993). Respirometry is one of several procedures that can be used to monitor stability of composts (Iannotti et al., 1994). Variability in this quality parameter is one of the principal factors limiting its utilization. Maturity is less important in ground bed or field agriculture as long as the compost is applied well ahead of planting to allow for additional stabilization. Lack in maturity frequently causes problems here as well, however.

Effects of chemical properties of composts on soilborne disease severity often are overlooked (reviewed in Hoitink et al., 1991). Highly saline composts enhance *Pythium* and *Phytophthora* diseases unless they are applied months ahead of planting to allow for leaching. Compost prepared from municipal sewage sludges that are of low carbon to nitrogen ratio aggravate Fusarium wilt. On the other hand, composts from high C/N materials such as tree barks suppress Fusarium diseases. It has been recognized for decades that high ammonium and low nitrate nutrition aggravates Fusarium wilts. The ammonium nitrogen releasing sludge compost perhaps for this reason enhances these Fusarium diseases.

Survival of biocontrol agents during composting

The composting process often is divided into three phases. The first phase occurs during the first 24–48 hr as temperatures gradually rise to 40–50°C and sugars and other easily biodegradable substances are destroyed. During the second phase, when high temperatures of 55–70°C prevail, cellulosic substances that are less biodegradable are destroyed. Thermophilic microorganisms predominate during this part of the process. Plant pathogens and seeds are killed by the heat generated during this high temperature phase (Bollen 1993, Farrell 1993). Compost piles must be turned frequently to expose all parts to high temperature and produce a homogeneous product free of pathogens and weed seeds. Unfortunately, beneficial as well as detrimental microorganisms are killed during the high temperature phase of composting. Therefore, suppression of pathogens and/or disease is largely induced during curing as biocontrol agents recolonize composts after peak heating.

The third or curing phase of composting begins as the concentration of readily biodegradable components in wastes declines. As a result, rates of decomposition and heat output and also temperatures decline. At this time, mesophilic microor-

ganisms recolonize the compost from the outer low temperature layer into the pile.

Bacillus spp., *Enterobacter* spp., *Flavobacterium balustinum*, *Pseudomonas* spp., other bacterial genera and *Streptomyces* spp., as well as *Penicillium* spp., a host of *Trichoderma* spp., *Gliocladium virens* and other fungi have been identified as biocontrol agents in composts (Chung and Hoitink 1990; Hadar and Gorodecki, 1991; Hardy and Sivasithamparam 1991; Hoitink and Fahy 1986; Nelson et al, 1983; Phae et al., 1990). The moisture content of compost critically affects the potential for bacterial mesophiles to colonize the substrate after peak heating. Dry composts (<34% moisture, w/w) become colonized by fungi and are conducive to *Pythium* diseases. The moisture content must be high enough (at least 40–50%, w/w) so that bacteria can colonize the substrate after peak heating and induce biological control. Water often must be added to composts during composting as well as curing to avoid this problem.

Variability in suppression of *Rhizoctonia* damping-off and *Fusarium* wilt encountered in substrates amended with mature composts in part is due to random recolonization of compost after peak heating by effective biocontrol agents. Compost produced in the open near a forest (field compost), an environment that is high in microbial species diversity, is colonized by a greater diversity of biocontrol agents than the same produced in a closed reactor (Kuter et al., 1983). Field compost is more consistently suppressive to *Rhizoctonia* diseases than the same compost produced in a partially enclosed facility where few microbial species survive heat treatment (Kuter et al, 1983). Curing of compost for months after peak heating solves part of this problem. Frequently, however, *Rhizoctonia* disease is observed for some time after composts are first applied (Kuter et al., 1988; Lumsden et al., 1983). Incorporation of compost in soil several months ahead of planting solves this problem.

To solve the problem of variability in suppressiveness in freshly prepared composts, specific fungal and bacterial inoculants have been developed that when introduced into compost after peak heating, but before significant levels of recolonization have occurred, induce consistent levels of suppression to diseases caused by a broad spectrum of plant pathogens. Patents have been issued to The Ohio State University for this process (Hoitink 1990). In Japan, Phae et al, 1990 isolated a *Bacillus* strain that induces predictable biological control in composts. Their strain survives peak heating.

General versus specific suppression induced by composts.

Two mechanisms of biological control, based on competition, antibiosis, hyperparasitism, and induced systemic resistance in the host plant, have been described for compost-amended substrates. Propagules of plant pathogens such as *Pythium* and *Phytophthora* spp., are suppressed through a mechanism known as "general suppression" (Chen et al, 1988a; Chen et al, 1988b; Cook and Baker 1983; Hardy and Sivasithamparam 1991; Mandelbaum and Hadar 1990; Boehm et al, 1993).

Many types of microorganisms present in compost-amended container media function as biocontrol agents for diseases caused by *Phytophthora* and *Pythium* spp. (Hardy and Sivasithamparam 1991; Boehm et al, 1993). Propagules of these pathogens, if inadvertently introduced into compost-amended substrates, do not germinate in response to nutrients released in the form of seed or root exudates. The high microbial activity and biomass caused by the 'general soil microflora' in such substrates prevents germination of spores of the pathogen and infection of the host, presumably through microbiostasis (Chen et al, 1988a; Mandelbaum and Hadar 1990). Propagules of these pathogens remain dormant and are typically not killed if introduced in compost-amended soil (Chen et al. 1988a; Mandelbaum and Hadar, 1990). An enzyme assay, that determines microbial activity based on the rate of hydrolysis of fluorescein diacetate, predicts suppressiveness of potting mixes to *Pythium* diseases (Chen et al, 1988a; Mandelbaum and Hadar 1990; Boehm and Hoitink 1992). Similar information has been developed for soils on 'organic farms' where soilborne diseases are less prevalent (Workneh et al, 1993).

The mechanism of biological control for *Rhizoctonia solani* in compost-amended substrates is different from that of *Pythium* and *Phytophthora* spp. A narrow group of microorganisms is capable of eradicating sclerotia of *R. solani*. This type of suppression is referred to as 'specific suppression' (Hoitink et al, 1991). *Trichoderma* spp, including *T. hamatum* and *T. harzianum*, are the predominant hyperparasites recovered from composts prepared of lignocellulosic wastes (Kuter et al, 1983; Nelson et al, 1983). These fungi interact with various bacterial strains in biological control of Rhizoctonia damping-off (Kwok et al, 1987). It is of interest that *Penicillium* spp. are the predominant hyperparasites recovered from sclerotia of *Sclerotium rolfsii* in composted grape pomace, a high in sugar content waste (Hadar and Gorodecki, 1991). *Trichoderma* spp. were not recovered from this compost. The composition of the parent product, as expected, thus appears to have an impact on the microflora in composts active in biological control.

Organic matter decomposition level versus suppressiveness.

The decomposition level of organic matter in compost-amended substrates has a major impact on disease suppression. For example, *R. solani* is highly competitive as a saprophyte (Garrett, 1962). It can utilize cellulose and colonize fresh wastes but not the low in cellulose mature compost (Chung et al, 1988). *Trichoderma*, an effective biocontrol agent of *R. solani*, is capable of colonizing fresh as well as mature compost (Nelson et al, 1983; Chung et al, 1988). In fresh, undecomposed organic matter, biological control does not occur because both fungi grow as saprophytes and *R. solani* (the pathogen) remains capable of causing disease. Presumably, synthesis of lytic enzymes involved in hyperparasitism of pathogens by *Trichoderma* is repressed here due to high glucose concentrations in fresh wastes (de la Cruz et al, 1993). The same may well apply to antibiotic production

which plays an important role in biocontrol. In mature compost, where concentrations of free nutrients are low (Chen et al, 1988a), sclerotia of *R. solani* are killed by the hyperparasite and biological control prevails (Nelson et al, 1983). The foregoing reveals that composts must be stabilized adequately to reach that decomposition level where biological control is feasible. In practice, this occurs in composts (tree barks, yard wastes, etc.) that have been 1) stabilized far enough to avoid phytotoxicity and 2) colonized by the appropriate specific microflora. Practical guidelines that define this critical stage of decomposition in terms of biological control are not yet available. Industry presently controls decomposition level by maintaining constant conditions during the entire process and adhering to a given time schedule.

Excessively stabilized organic matter, the opposite end of the decomposition scale, does not support adequate activity of biocontrol agents. As a result, suppression is lacking and soilborne diseases are severe, as in highly mineralized soils where humic substances are the predominant forms of organic matter (Worknek et al, 1993). The length of time that composts incorporated in soil support adequate levels of activity for biocontrol has not yet been determined. Presumably, it varies with soil temperature and the type of organic matter from which the compost was prepared. Loading rates and farming practices of course also play a role.

We have studied this 'carrying capacity' of soil organic matter in potting mixes prepared with sphagnum peat to bring a partial solution to this problem (Boehm and Hoitink 1992, Boehm et al, 1993). Sphagnum peat typically competes with compost as a source of organic matter in horticulture. Both the microflora and the organic matter in peat itself can affect suppression of soilborne diseases. The literature on that effect is reviewed briefly here, therefore.

Dark, more decomposed sphagnum peat, harvested from a foot or greater depths in peat bogs, is low in microbial activity and consistently conducive to *Pythium* and *Phytophthora* root rots (Boehm and Hoitink, 1992). On the other hand, light less decomposed sources of sphagnum peat harvested from near the surface of peat bogs, is less decomposed, has a higher microbial activity (FDA activity) and suppresses root rot. The suppressive effect of light peat to *Pythium* root rots is of short duration, however (Boehm and Hoitink 1992; Tahvonen 1982; Wolffhechel 1988). Light peats are used most effectively for short production cycles (6–10 week crops), such as in plug and flat mixes used in the ornamentals industry. Composts have longer lasting effects (Boehm and Hoitink, 1992; Boehm et al, 1993).

The rate of hydrolysis of fluorescein diacetate (FDA) predicts suppressiveness of peat mixes and of compost-amended substrates to *Pythium* root rot (Boehm and Hoitink, 1992). As FDA activity in suppressive substrates declines to $< 3.2 \text{ g FDA hydrolyzed min}^{-1} \text{ g}^{-1}$ dry weight mix, the population of *Pythium ultimum* increases, infection takes place and root rot develops. During this collapse in suppressiveness, bacterial species composition changes (Boehm et al, 1993). A microflora typical of suppressive soils, which includes *Pseudomonas* spp. and other rod-shaped Gram negative bacteria as the predominant rhizosphere coloniz-

ers, is replaced by pleomorphic Gram-positive bacteria (e.g. *Arthrobacter*) and putative oligotrophs (Wu et al, 1993). The microflora of the conducive substrate resembles that of highly mineralized niches in soil (Kanazawa and Filip, 1986).

Non-destructive analysis of soil organic matter, utilizing Fourier Transform Infra Red spectroscopy (FT-IR) and Cross Polarization Magic Angle Spinning -¹³Carbon Nuclear Magnetic Resonance Spectroscopy (CPMAS - ¹³C NMR), allows characterization of biodegradable components of soil organic fractions (Inbar et al, 1989; Chen and Inbar, 1993). CPMAS - ¹³CNMR allows quantitative analysis of concentrations of readily biodegradable substances such as 'carbohydrates' (hemicellulose, cellulose, etc.) versus lignins and humic substances in soil organic matter (reviewed in Chen and Inbar (1993). In a preliminary report, Wu et al, (1993) showed that the 'carbohydrates' decline as suppressiveness is lost. During the same time, bacterial genera capable of causing biological control are replaced by those that cannot. Biocontrol agents inoculated into the more decomposed substrate are not able to induce sustained biological control of Pythium root rot. Thus, biocontrol of this disease is determined by the 'carrying capacity' of the substrate which regulates species composition and activity and, this in turn, the potential for sustenance of biological control.

Compost for control of foliar diseases

During the past decade, a series of projects have been published on the control of plant diseases of above ground plant parts with compost water extracts (Weltzien, 1992). Steepages often are prepared by soaking mature composts in water (still culture; 1:1, w/w) for 7–10 days. The steepage is filtered and then sprayed on plants. Unfortunately, efficacy varies with composts, batches of steepages produced, crops and the disease under question. Sackenheim (1993) utilizing plate counting procedures, has shown that aerobic microorganisms predominate in these steepages. The microflora includes strains of bacteria and isolates of fungi already known as biocontrol agents. A number of enrichment strategies, that include nutrients as well as microorganisms, have been developed to improve efficacy of the steepages.

Control induced by compost steepages also has been attributed to systemic acquired resistance (SAR) induced in plants by microbes present in the extracts (Weltzien, 1992). The recent work by Sackenheim (1993) on grape does not support this assumption, however. A factor that has been entirely overlooked but could play a role in efficacy of steepages is the condition of soil organic matter and the associated microflora in the soil in which treated plants are produced. Soils naturally suppressive to soilborne plant pathogens (e.g. compost-amended soils) harbor active populations of biocontrol agents (Boehm et al, 1993). Several of these rhizobacteria and fungi can induce protection to foliar pathogens in the leaves of plants (Wei et al, 1991; Maurhofer et al, 1994). Thus, further research may show that plants produced in suppressive soils not only have less root rot but could also

be less prone to attack by vascular wilt and foliar pathogens because SAR genes are turned on. Such plants might also respond better to compost steepages.

Disease suppression – future outlook

Success in biological control of diseases is possible only if all factors involved in the production and utilization of composts are defined and kept constant. Most composts are variable in quality. Therefore, composted bark and light sphagnum peat remain the principal organic components used for the preparation of potting mixes or soils naturally suppressive to soilborne plant pathogens. Composted manures, yard and food wastes steadily are gaining in popularity, and offer the same potential (Gorodecki and Hadar, 1990; Grebus et al, 1994; Inbar et al, 1993; Marugg et al, 1993; Schüller et al, 1993).

The general suppression phenomenon, based on present concepts, at best covers those diseases caused by pathogens suppressed through microbiostasis. Microbial activity in a mix, based on the rate of hydrolysis of fluorescein diacetate, is one procedure that now can be used effectively to determine suppressiveness to *Pythium* and *Phytophthora* root rots. This procedure by itself, however, does not predict how long the effect will last. The potential for biodegradable carbon in a mix to support an active and effective microbial biomass determines that phenomenon. CPMAS ^{13}C NMR spectroscopy predicts this property for peat. The same basic information will have to be developed for composts and other sources of organic amendments. Predictive utilization of composts for disease control will remain an art until more quantitative guidelines are developed.

Controlled inoculation of composts with biocontrol agents is a procedure that must be developed on a commercial scale to induce consistent levels of suppression to pathogens such as *R. solani* (Hoitink et al, 1991; Phae et al, 1990; Grebus et al, 1993). Recently, tree bark was proposed as a food base for the culture of biocontrol agents and as a carrier of such agents for use in agricultural applications (Steinmetz and Schönbeck, 1994). This new field of biotechnology is in its infancy, however. Major research and development efforts will need to be directed into this approach to disease control. Recycling through composting increasingly is being chosen as the preferred strategy for waste treatment. This also applies to farm manures. For this reason, composts are becoming available in greater quantities. Peat, on the other hand, is a limited resource that cannot be recycled. Future opportunities for both natural and controlled-induced suppression of soilborne plant pathogens, using composts as the food stuff for biocontrol agents, therefore appear bright.

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Formation and properties of humic substance originating from composts

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Abstract

Composting enables a detailed evaluation of the humification process of various organic wastes within a short period of time (3 to 6 months). Humic substances (HS) constitute a large fraction of the organic matter (OM) in compost, and they are its most active fraction due to their effects on soil ecology, structure, fertility and metal complexes, and plant growth. The formation and properties of HS extracted from various composts such as municipal solid waste (MSW), grape marc (GM), composted separated cattle manure (CSM), sewage sludge (SS), wood compost (WC) and other organic wastes were studied. Degradative and non-degradative techniques (FTIR, DRIFT, ¹³C-NMR) were used to study the transformation of HS during composting of the various organic wastes. Time-course studies of composting some of these wastes showed an increase in the relative amount of humic acid (HA) (from 18% to 45% of OM in CSM compost and from 5% to 20% in MSW compost), whereas the formation rate of fulvic acid (FA) was inconsistent. A humification ratio (HR – the ratio of HA/FA) was used to evaluate compost maturity. Values of 0.9 to 3.4 and 3.0 to 9.2 were typical for immature and mature composts, respectively. Another humification index (HI) used to define compost maturity was calculated as the ratio between non-humified fraction (NHF) and the humified fraction (HA+FA). A HI decrease during composting represents the formation of HS. Elemental- and functional-group analyses indicated only minor differences between HA extracted from composts at various stages. Moreover, these values fell into a wide range, similar to that of soil HA. The ¹³C-NMR spectra of the HA exhibited strong bands representing aliphatic structures in various composts (50% of total C in CSM, 30% in MSW and 61% in GM) and a lower level of aromatic components (37% in CSM, 22% in MSW and 22% in GM). The FTIR spectra showed similar trends of strong aliphatic and carbohydrate components. Both techniques provided more qualitative information indicating that HA extracted from mature compost exhibits more aromatic structures and carboxyl groups and less carbohydrate components than that from immature compost.

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Studies on the effects of HS on plant growth showed stimulative effects. Typical response curves indicated enhanced growth with increasing HS concentration in solution, followed by decreases in growth at higher concentrations. In soils, the addition of composts was found to stimulate growth beyond that provided by mineral nutrients, presumably because of the effects of HS.

Introduction

Composting can play useful role in global waste management due to the increasing amount of decomposed organic materials such as animal excreta, municipal solid waste (MSW) and sewage sludge (SS) in modern society. Composting has been defined as a controlled microbial aerobic decomposition of heterogeneous raw waste passing through a thermophilic phase with a temporary release of phytotoxins, followed by the production of CO₂, H₂O, minerals and stabilized organic matter (OM) containing a high amount of humic substances (HS). The importance of HS to soil ecology, fertility and structure and their beneficial effects on plant growth (Chen and Aviad, 1990) have caused an increase in the use of compost as an amendment to soils or as a substitute substrate for peat in container media (Avnimelech et al., 1993; Chen et al., 1992; Hoitink, et al., 1993). HS originating from compost form within a shorter period of time than soil HS, therefor better understanding of the chemical and physical characterization and transformation of the compost HS is necessary to study the differences in the formation period. Moreover due to the increase interest in compost as substitute to peat in container media it is essential to study the interactions of HS in the compost-plant system.

The objectives of this article were (1) to compare the rate of decomposition of OM in various composts; (2) to study the rates of formation and decomposition of HS– humic acid (HA), fulvic acid (FA) and the non-humic fraction (NHF), in various composts; (3) to use humification parameters as maturity indexes; (4) to characterize compost-derived HA using elemental– and functional-group analyses and spectroscopic measurements; (5) to study the effects of compost-derived HS on nutrient solubility and plant growth.

Humic Substance Content

Among the chemical criteria used to characterize compost maturity, HS content is one of the most common. The amounts of HS fractions in various composts at various stages of composting are reviewed here. The main trends of several humification parameters over a period of 140 days of composting of wastewater sludge and straw mixtures are shown in Fig. 1 (Saviozzi et al., 1988). The following humification indexes (HI) were used to defined compost maturity: (1) HS- amount of total humic substances (HA, FA and NHF) as percent of OM; (2) HA- amount of humic acid as percent of OM; (3) FA- fulvic acid as percent of OM; (4) HR- the

HA/FA ratio; (5) amount of the humic materials (HA+FA); (6) HI- the ratio between the NHF and the HA+FA fractions (Sequi et al., 1986); (7) HAp- humic acid percent of HS.

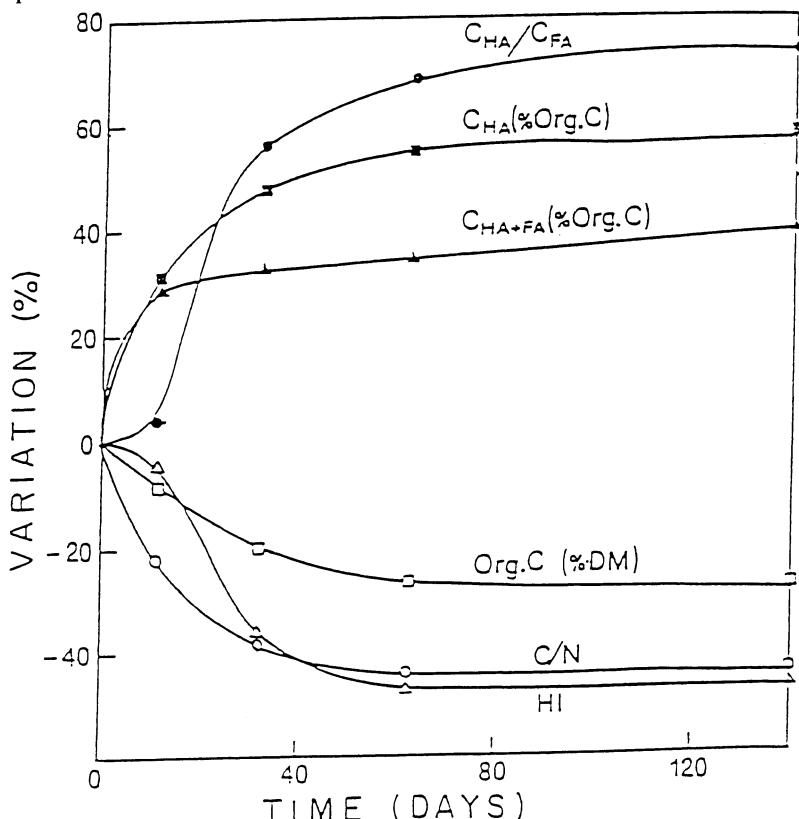


Figure 1 The major relative trends of several humification parameters (expressed as percentage of variation) during 140 days of sludge-straw composting (after Saviozzi et al., 1988).

Total HS content follows different trends during the composting of different composts. HS content does not vary during composting of MSW (Sugahara and Inoko, 1981; Das, 1988; Jimenez and Garcia, 1992). These authors found that alkaline extraction of MSW compost at various stages of composting gives a steady value in the range of 19 to 22% of OM. A possible explanation for the presence of HS in the early stages of composting and for the stability of the HS content in MSW compost could be the relatively high content of NHF. Therefore HS in MSW compost cannot be used as an indicator of maturity. In contrast, during the composting of CSM, HS content doubled (from 377 to 710 g/kg OM). The different trends between the composts can be explained by the relatively high amount of HA in CSM (46% of OM), whereas both HA and FA fractions in MSW compost amount to less than half of the total OM. The trend in HA levels during composting is similar in all composts, its content increasing during composting and reaching up to 46% and 48% of OM in CSM and poplar bark compost, respectively (Roletto et

al., 1985; Inbar et al., 1990). In MSW compost, HA increased from 7% – 8% in the raw material to 12% – 14% in mature compost (Jimenez and Garcia, 1992). While the levels of HA increases the amount of FA usually decreases and the HA/FA ratio is therefore often used as an indicator of maturity. This trend of an increasing HA/FA ratio from fresh to composted OM has been reported for poplar bark (Roletto et al., 1985), farmyard manure (FYM), urban refuse (Saviozzi et al., 1988), CSM (Inbar et al., 1990) and MSW (Sugahara and Inoko, 1981; Das, 1988; Jimenez and Garcia, 1992; Gonzales et al., 1993). The value of the HR differs for various wastes but it generally increases by more than 80% during composting, indicating a high degree of OM polymerization, since more polymerized components are found in the mature compost.

Another parameter indicating the role of HS is the HI (NHF/HA+FA) which decreases during composting due to humification of OM (Saviozzi et al., 1988; Inbar et al., 1990). The trend of decreasing HI from fresh to composted materials is similar in all wastes, but the rate of decrease changes according to the amount of NHF in the waste. The HI of grape marc (GM), containing a high level of sugars, drops sharply during composting, in contrast to the HI in CSM (Inbar, 1989). To summarize a large amount of HA forms while FA level usually decreases. The HI and the HR can only be used as maturity parameters when NHF is separated from the fulvic fraction, otherwise these parameters have no meaning.

Elemental- and Functional-Group Analyses:

The elemental composition, atomic ratios and functional groups of HA extracted from various composts as compared to ‘model’ HA (Schnitzer, 1978) and Leonardite HA are presented in Table 1. The average compositional range of HA extracted from various composts was similar to those of ‘model’ and Leonardite HA. The C content of HA isolated from compost was lower than that of ‘model’ HA, except in the cases of CSM and GM. This parameter does not change during composting (Roletto and Luda, 1987; Inbar, 1989; Garcia et al., 1992). H content was higher in compost HA than in Leonardite or ‘model’ HA, although it was slightly reduced during composting of CSM and GM. N content was also higher in compost HA. The high N and H contents in the composts may be due to the presence of side chains containing those components. The highest contents of N and H were found in MSW compost (Garcia et al., 1989; Deiana et al., 1990; Garcia et al., 1992), which yielded a relatively low C/N ratio as compared to HA formed in soil or during composting of other stabilized wastes. The H/C ratio represents HA aromaticity (a low ratio indicates an aromatic structure). All compost HA had higher H/C ratios than the ‘model’ or Leonardite HA, indicating that aromatic structures in compost HA are less pronounced and therefore compost HA has identified as ‘young’ HA.

The major differences between ‘model’ or Leonardite HA and compost HA were found in the functional-group analysis. Compared to soil and sediment HA,

compost HA contained less fractional oxygen groups (carboxyl, carbonyl and phenolic carbon), due to the relatively short formation time during composting as compared to that required for soil OM transformation. During composting, the carboxyl group content increased (192 to 221 meq/100g in CSM, 176 to 224 meq/100g in MSW, 184 to 264 meq/100g in SS). The carbonyl group content showed the same trend, whereas that of the phenolic group decreased during composting. The total acidity (calculated as phenolic plus carboxyl groups) behaved differently in the various composts: it increased in composts in which the raw material had a stable structure (wood and cattle manure) but decreased in composts in which the raw materials contained more rapidly biodegradable fraction such as city refuse, yard waste and sludge (Roletto and Luda, 1987; Garcia et al., 1992; Kakezaw, 1992). There were no major differences between the elemental composition of HA from the various composts at various stages of composting and that of 'model' HA (Table 1). In general, the elemental and functional groups were similar to 'young forms' of HA reported in the literature, even though HA amounts increased during composting.

Table 1 Elemental analysis, H/C and C/N ratios, functional groups and E₄/E₆ analysis of compost-derived humic acid (HA).

	CSM ¹	MSW ²	SS ³	WC ⁴	GM ¹	'model' Leonardite ² HA ⁵
C	57.8	52	53	50.58	58.2	56.2
H	5.3	6	5	5.66	5.9	4.7
N	3.8	6.3	4.12	3.53	5.8	3.2
S	1.1	0	nd	nd	0.66	0.8
H/C	1.11	1.4	1.17	1.34	1.21	1
C/N	16.6	11.7	13	16.9	14.2	20
Total acidity (meq/100 g)	346	498	626	439	413	670
COOH (meq/100 g)	221	225	264	247	271	360
Phenol OH (meq/100 g)	126	273	362	192	142	390
C=O (meq/100 g)	NA	252	288	276	nd	nd
E ₄ /E ₆	7.8	7.1			9.4	4.8

¹ Inbar, 1989

² Garcia et al., 1992

³ Garcia et al., 1989

⁴ Kakezawa et al., 1992

⁵ Schnitzer, 1978

The E₄/E₆ ratio was higher in compost HA, indicating a lower molecular weight than that of 'model' HA (Chen et al., 1977). Elemental and functional group analyses of FA have been reported in only a few works (Roletto and Luda, 1987; Pandey, 1992). The compost FA had lower C and N contents but higher amounts of O and carboxyl groups than HA, and the overall elemental and functional groups extracted from compost were similar to 'model' FA (Schnitzer, 1978; Roletto and Luda, 1987; Pandey, 1992).

Infrared Spectroscopy (FTIR, DRIFT)

Infrared spectroscopy was used to characterize the HS. FTIR and DRIFT spectroscopy served as qualitative tools to characterize the chemical groups and bands of the HA complex structures. Sugahara and Inoko (1981) investigated HA extracted from city refuse at various stages of composting by IR spectroscopy and found that the aliphatic C-H and C-O stretching decreased while the carboxyl COO⁻ increased during composting. The main absorbance bands were: a broad band at 3400–3300 cm⁻¹ (H-bonded OH groups); a slight shoulder at 3085–3075 cm⁻¹ (aromatic C–H stretching); two peaks at 2930 and 2850 cm⁻¹ (aliphatic C–H stretching); a slight shoulder at 1730–1715 cm⁻¹ (C=O of carboxyl, C=O of ketonic carbonyl); a well-pronounced peak at 1610–1655 cm⁻¹ (aromatic C=C stretching); a sharp peak at 1540–1560 (amide II); a peak at 1460–1450 cm⁻¹ (–CH deformation of –CH₃ and –CH bending of CH₂); a peak at 1420 cm⁻¹ (aromatic ring stretch); a peak at 1400–1350 cm⁻¹ (aliphatic C–H bending); a peak at 1270–1220 cm⁻¹ (aromatic C–OH and –C–OH stretch and OH deformation of –COOH); a peak around 1100–1020 cm⁻¹ (C–O stretch of polysaccharides). The interpretations of the IR spectra are based on Inbar et al. (1990), Niemeyer et al. (1992), Deiana et al. (1990), Sugahara and Inoko (1981), Garcia et al. (1992), Roletto and Luda (1987) and Stevenson (1982).

HA spectra from the various mature composts studied here exhibited similar features: all showed a strong aliphatic nature with aromatic structure and peptide bonds, along with relatively low carboxyl content, similar to young type III HA extracted from fresh soil OM (Stevenson and Goh, 1971). HA extracted at several stages during the composting of various wastes exhibited only minor changes. The main ones consisted of slight reductions of the aliphatic and polysaccharide bands during composting of SS and MSW (Sugahara and Inoko, 1981; Garcia et al., 1989, 1992), whereas during composting of CSM, no changes were observed; during the composting of GM there was a relative increase in aliphatic carbon and a decrease in polysaccharides. The minor changes in HA extracted from CSM during composting are presented in Fig. 2.

CPMAS ¹³C-NMR Spectroscopy

The use of NMR spectroscopy to study HA has gained prominence over the last few years. Wershaw (1985) showed that although NMR analysis is only applied for a short time, it can provide more definitive structural information than other methods. The ¹³C-NMR spectra were divided into the following regions (Hatcher et al., 1983; Malcolm, 1989): 0–50 ppm (alkyl C-methyl, methylene and methine groups), 50–60 ppm (methoxyl C), 60–70 ppm (alcohol), 70–98 ppm (C–O, C–N), 98–112 ppm (anomeric C), 112–145 ppm (aromatic C), 145–163 ppm (phenolic C), 163–190 ppm (carboxyl groups), 190–215 ppm (carbonyl C). The 0–112 ppm region was calculated as aliphatic C, 60–112 ppm as polysaccharide C, 112–163

ppm as aromatic C. Total aromaticity was calculated by expressing aromatic C (112–165 ppm) as percentage of aliphatic C (0–112 ppm) plus aromatic C. CPMAS ^{13}C -NMR spectra of HA extracted from CSM is presented in Fig. 3.

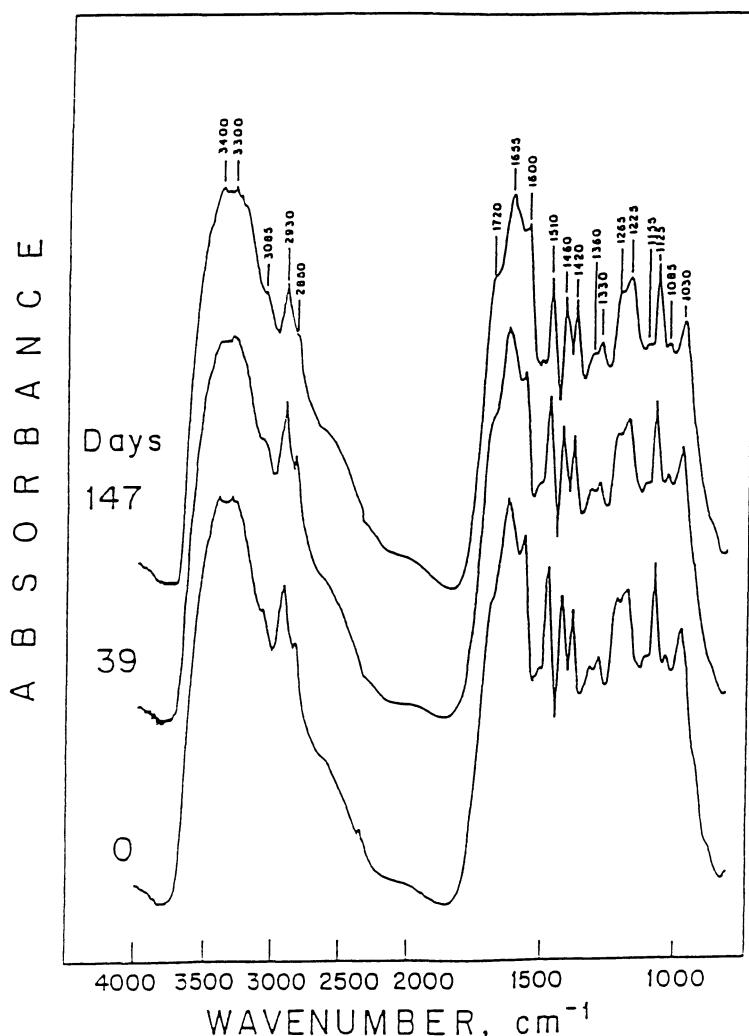


Figure 2 FT-IR spectra of HA extracted from separated cattle manure at three stages during composting (after Inbar, 1989).

There were only minor differences between the spectra of HA from the fresh and composted manure (12% increase in carboxyl content; 8% increase in aromatic carbon and 8% decrease in alkyl carbon), similar to the FTIR spectra (Inbar, 1989). During the composting of MSW, changes in HA structure were observed: the HA aromatic carbon increased by 39% while the aliphatic carbon content decreased by 19% (Garcia et al., 1992). Opposite changes occurred in GM HA: while the alkyl region increased, the aromatic carbons decreased, indicating highly

oxidizing conditions (Inbar, 1989). The main differences between HA extracted from various composts are present in Table 2. CSM HA seemed to be more aromatic and less aliphatic than MSW and GM HA. The higher aromaticity of the CSM HA can be explained by the high lignin content in this compost (61.5% of dry weight), whereas GM and MSW contain more easily biodegradable OM. These differences in HA structure lead to the conclusion that the raw materials components influence not only the time of composting but also the formation of HS.

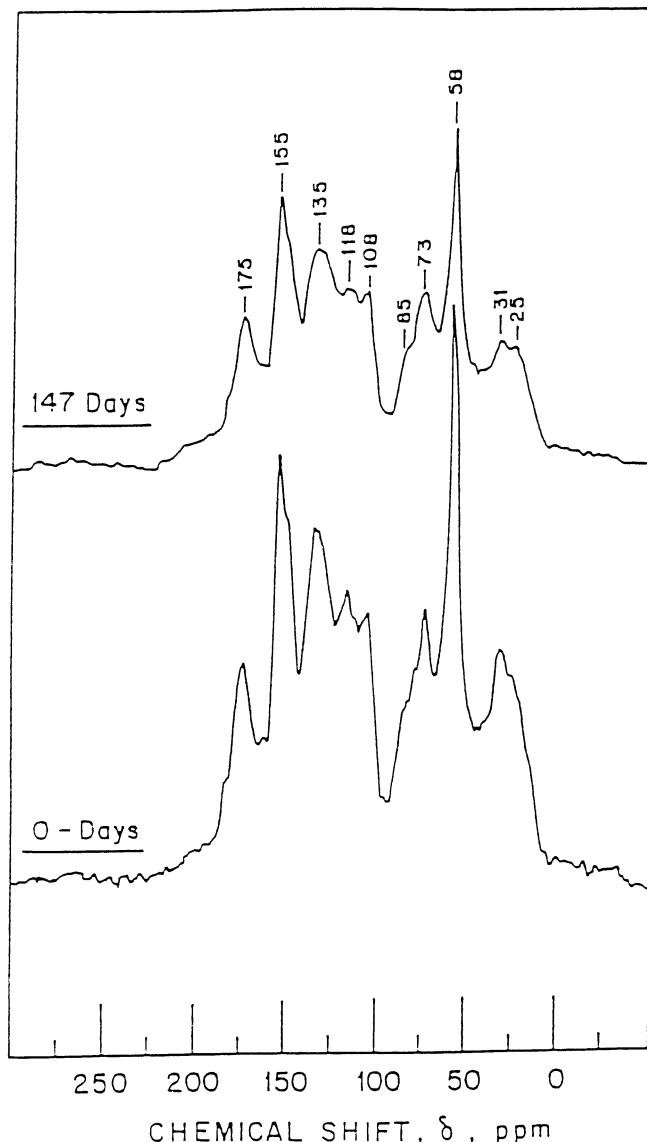


Figure 3 CPMAS ^{13}C -NMR spectra of HA extracted from separated cattle manure at the beginning and after 147 days of composting (after Inbar, 1989).

Table 2 Carbon distribution in humic acids (HA) extracted from CSM, GM and MSW (as determined by ^{13}C -NMR).

		CSM ¹	GM ¹	MSW ²
Aliphatic C	% of total C	50.4	61	67.3
Aromatic C	% of total C	37.1	22	18.8
Carboxylic C	% of total C	10.6	15	10.2
Aromaticity	% of total C	42.4	27	21.8

¹ Inbar, 1989² Garcia et al., 1992

Humic Substance Effects on Plant Growth

Applying OM as a fertilizer increased plant yield to a higher level than that resulting from the application of the same level of inorganic fertilizer, presumably because of the effects of the HS. In soils, the addition of compost can stimulate growth beyond that provided by mineral nutrient supplements alone (Senesi, 1989; Chen et al., 1994). This improvement can be explained by direct short-term fertilizer effects and some indirect effects. Table 3 presents the typical effects of HA stimulation on wheat growth when given in water or nutrient solution. Addition of FA to the nutrient solution yielded an atypical response curve whereby cucumber root and shoot weights increased with increasing FA concentration up to a FA concentration where shoot and root weights decrease. Chen et al. (1994) found the same trend in melon shoots and roots with increasing concentrations of HS originating from a water extract of CSM. Both experiments showed that higher OM levels result in decreased growth, possibly resulting from a suboptimal concentration of free micronutrients in solution due to an excessive amount of chelators (HS). Complexation of transition metals, such as Cu, Zn, Fe and Mn by HS has been the focus of numerous publications. The solubility of most of the micronutrients in their inorganic forms is limited in soil or nutrient solution. The presence of HS may contribute to improved availability of these elements (Chen and Aviad, 1990). HS not only increased the solubility of Fe in solution but they also affected Fe transport from roots to shoots. Chen et al.'s (1994) work on HS extracted from CSM indicates that residual concentrations of Fe, Mn and Cu in nutrient solutions that were equilibrated at pH 6.5 and 7.0 increased with increasing concentrations of added OM. With regard to plant nutrition, this data suggests that at low pH, HS may not exhibit beneficial effects, but at pH 7.5 or higher, a high concentration of HS is required to maintain micronutrient availability. The stimulation of ion uptake by the addition of HS led to the proposal that these materials affect membrane permeability related to surface activity of the HS. Another phenomenon related to CSM and GM HS is hormone-like activity (Chen et al., 1994). When mung-bean cuttings were placed in nutrient solutions containing OM extracted from CSM, GM and Leonardite, root weight and number were significantly higher as compared to the control. This result supports those of other plant growth assays, in which HS added to a nutrient solution enhanced root formation activity, which

could be considered an auxin-like activity. To summarize, the effects of HS on plant growth can be divided into direct and indirect, as follows (Chen and Aviad, 1990):

Table 3 The effects of 50 humic acid (HA) in water or Hoagland's nutrient solution on wheat growth (after Vaughan and Malcom, 1985).

Culture medium	Plant organ	Fresh weight, mg/plant	Stimulation, %
Water	Root	93	0
	Shoot	185	0
Water + HA	Root	146	57.5
	Shoot	252	36.2
Hoagland's	Root	182	96.3
	Shoot	342	84.9
Hoagland's + HA	Root	203	119.0
	Shoot	390	110.8

Direct effects:

1. Effects on membranes resulting in improved transport of nutritional elements
2. Enhanced protein synthesis
3. Hormone-like activity
4. Enhanced photosynthesis
5. Effects on enzyme activity

Indirect effects:

1. Solubilization of microelements (Fe, Zn, Cu and Mn) and some macroelements (K, Ca, P)
2. Reduction of active levels of toxic elements
3. Enhancement of microbial populations

Conclusions

1. The level of HS formation reached a maximum within 90 to 120 days of composting without forced aeration.
2. HS level increased with composting time in CSM and wood compost (WC), but remained steady in MSW compost.
3. HA level increased in CSM, WC, MSW and SS composts.
4. FA level remained steady in CSM and decreased in MSW composts.
5. NHF level decreased with composting time.
6. Elemental- and functional-group analyses indicated only minor differences between HA extracted from composts at various stages of composting.
7. Values of C, H and S in HA derived from various composts were similar to

- those found in soils. However, the N levels were higher in compost-derived HA and the C/N ratio was therefore lower.
8. Total acidity, -COOH and phenolic OH levels were lower in HA derived from composts than the average numbers from soil HA.
 9. FTIR and NMR spectra of compost-derived HA were similar, regardless of composting time.
 10. FTIR and NMR spectra of compost-derived HA exhibited high levels of polysaccharides and aliphatic structures.
 11. Biological activity of compost-derived HS resembled that of soil-derived HS.
 12. Plant-hormone-like activity attributed to HS does not involve auxins, cytokinins or abscisic acid.
 13. Growth enhancement of plants in nutrient solution and soils by HS may be attributed to the maintenance of Fe, Mn, Cu and Zn in solution at sufficient levels. This effect is pH-dependent, its effectiveness decreasing with increasing pH.
 14. The commonly cited conclusion (including 1992 publications) stating that: 'Stimulatory effects in nutrient solution of HS can't be ascribed to a supply of elements' may be incorrect.

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Waste Research at the IRNAS, CSIC

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The agricultural and livestock sectors are of great significance in the region of Andalusia (South of Spain) (Table 1). Important quantities of agricultural and agroindustrial residues are generated by these activities, frequently causing environmental problems. These residues contain organic matter and nutrients and could therefore be recycled and used as fertilizers or amendments, with or without a previous treatment (composting, concentration). For some of these wastes, recipes for compost mixes, such as olive oil wastewater based compost, have been developed by private companies. Afterwards, laboratory and field experiments have been conducted to study the best conditions for their agricultural use and their degradation process in the soil (González-Vila *et al.*, 1992, Martín-Olmedo *et al.*, 1994). In other cases, such as those of the vinasse based composts, both the compost fabrication and its use have been studied previously to the marketing stage (Díaz *et al.*, 1993, Madejón *et al.*, 1994). Our first research projects at IRNAS dealt with the properties and reuse of municipal solid waste (MSW), and are still in progress.

Table 1 Some figures showing the importance of the agricultural sector in Andalusia and Spain (Ministerio de Agricultura de España, 1993)

Final Agricultural Output (1991)				
Spain/EC	%	Agriculture		15
		Livestock		10
		Agriculture + Livestock		13
		Agrofood Industry		10.5
Working Population in Agriculture in Spain				
Land Distribution in Spain (1991)		Arable land	Grazing land	Woodland
Spain	1000 ha	20089	6438	15858
Andalusia	1000 ha	4175	708	2655
Andalusia/Spain	%	21	11	16
				15
Livestock Distribution (1992)		Cattle	Sheep	Goats
Spain/EC	%	6.3	25	23
Andalusia	1000 heads	516	3144	1169
Andalusia/Spain	%	10.4	12.8	41.2
				10.8

Table 2 shows a list of the most intensively studied wastes at the IRNAS. The topics covered for these wastes include the monitoring of the performance of various treatment systems (concentration, aerobic and anaerobic treatment), the study of the composting process and the study of land treatment or land utilization with treated and untreated wastes. In many of these studies, special attention has been paid to the interaction phenomena in the system waste-soil-plant-water. Some usual aspects studied in this context are shown in Figure 1.

Table 2 Some residues studied at the IRNAS

Waste use	Treatment/Recycling	Research (1)	Selected References	Actual (2)
Sugarbeet Vinasse	Concentration Anaerobic treatment Use of effluents	***	Cabrera <i>et al.</i> , 1987 González-Vila <i>et al.</i> , 1992 Martín-Olmedo <i>et al.</i> , 1995 Murillo <i>et al.</i> , 1993 Díaz <i>et al.</i> , 1993	E D E F
Concentrated Vinasse	Direct land reuse	***		
Olive mill wastewater	Co-composting with cotton gin trash, olive press cake, grape marc and use as fertilizer Several treatment systems Land utilization of anaerobic treated effluents Direct land treatment Composting and use	*** *** *** *** ***	Madejón <i>et al.</i> , 1994, 1995 Cabrera <i>et al.</i> , 1987 López <i>et al.</i> , 1992 González-Vila <i>et al.</i> , 1992 López, 1992 Martín-Olmedo <i>et al.</i> , 1995a,b	D D D E
Olive mill wastewater + olive press cake (from new system)	Composting	*		F
Wheat straw Extracted eucalyptus leaves	Composting Use of compost	*** **	Almendros <i>et al.</i> , 1987 Murillo <i>et al.</i> , 1990	N D
MSW	Composting and use	***	Cabrera <i>et al.</i> , 1989, 1991 Fernández <i>et al.</i> , 1987 González-Vila <i>et al.</i> , 1982, 1985 Murillo <i>et al.</i> , 1989a, b, 1991 Troncoso <i>et al.</i> , 1983	
Sewage sludge	Composting	***	Hernández <i>et al.</i> , 1990	E

(1) * Starting; ** In progress; ***Advanced or finished

(2) N, without application; F, probable use in future; D, developed for use but not used or used in few cases; E, extensive use

Municipal Solid Waste (MSW)

Since 1965, several composting plants have been established in Sevilla and nearby cities. The Sevilla urban compost plant, the biggest in Andalusia, was closed some years ago, but now the Government is encouraging new plants for Sevilla (1300 ton day⁻¹ of MSW) and other municipalities. Most of the compost produced in these

plants is applied to the rice paddies in the Guadalquivir delta and to vineyards.

Some research projects on wastes in the IRNAS dealt with the properties and effects caused by MSW on soils and plants. Compost from the Sevilla composting plant was often employed in these studies which were focused on:

1. The characterization of the organic matter of the composts (González-Vila and Martín, 1985; González-Vila *et al.*, 1982, Fründ *et al.*, 1987; Almendros *et al.*, 1987a, 1991) and the fitting of techniques and analytical procedures.
2. The effects of the agricultural use of composts in the soil organic fractions, mainly the humic acids (González-Vila and Martín, 1987) and the soil lipids, which exercise a considerable influence on the physical and biochemical soil properties related to its fertility level (González-Vila *et al.*, 1985).
3. The effects of the compost on the soil nutrient contents, such as phosphorus (Cabrera *et al.*, 1991), potassium (Murillo *et al.*, 1991) and heavy metals (Cabrera *et al.*, 1989).
4. The effects on the soil physical properties (Fernández *et al.*, 1987).
5. The response of various plant species to compost addition (Hernández, 1989; Hernández *et al.*, 1992; Murillo *et al.*, 1986, 1989a, b, c, 1995; Troncoso *et al.*, 1983).

Vinasse

Vinasse (V) is the wastewater obtained from the distillation of alcohol after the alcoholic fermentation of sugarbeet molasses. Normal vinasse has high BOD (20–70 g L⁻¹) and high salt content (EC 25–30 dS m⁻¹) (Table 3). In Spain, ca. 10⁶ m³ per year of normal vinasse are produced.

Until a few years ago, sugarbeet vinasse was kept in evaporation ponds, which can cause pollution of ground water, a strong smell, appearance of insects and other nuisances. The first studies on vinasse at the IRNAS dealt with the pollution of wells surrounding the vinasse ponds. Following this investigation, sugar companies decided to treat vinasses.

Table 3 Characteristics of sugarbeet vinasses

		Normal	Concentrated
pH		4.3–5.0	4.6–5.3
Dry matter	% w/w	10.6–15.3	25–63
Org. matter	% w/w	7.4–11.1	23–40
N–Kjeldahl	% w/w	0.5	1.7–3.3
P (P ₂ O ₅)	% w/w	0.01	0.1
K (K ₂ O)	% w/w	0.7	2.2–4.6
Ca	% w/w	0.25	0.3–1.0
Mg	% w/w	0.16	0.3–0.7
Na	% w/w	0.4	1.3–2.8

Plants for anaerobic treatment were designed and the effluents of these plants

were used in fertirrigation (Cabrera *et al.*, 1987). These studies showed decreases in crop yields due to low P supply and salt accumulation in the soil treated with vinasse. A few factories installed systems for the anaerobic treatment but some others installed systems to produce concentrated vinasse which shows better properties for its recycling (Table 3). Concentrated vinasse (CV) is being used as fertilizer and for animal feeding, but the high salt content of the vinasse produced in the south of Spain limits use for a second time.

The experiments carried out with CV applied to several crops showed that moderate doses of CV (<9000 kg ha⁻¹) did not cause any damage to germination and seedling performance (López, 1992; López *et al.*, 1993; Murillo *et al.*, 1993a). Concentrated vinasse (P supplemented) applied in deep fertilization produced yields similar to, or even higher than those obtained with mineral fertilizers (López, 1992, 1993; Murillo *et al.*, 1993b). These yields are related to the high nitrogen mineralization rate of vinasse (López, 1992; Martín-Olmedo *et al.*, 1995a).

Soils treated for 3 years with CV showed a moderate increase in their fertility levels (López, 1992), particularly in organic-N which is slowly released over time (Martín-Olmedo *et al.*, 1995a). No salt accumulation in treated soils was found after three consecutive years of application, despite the high salt content of vinasse.

No significant changes were observed in the humic fractions and lipid content of treated soils (2 years). However, analyses by GC-MS of the lipid compounds occurring in the subsoil layer in bound forms, revealed that some hydrophobic components had accumulated (González-Vila *et al.*, 1992).

The concentrated vinasse is also being co-composted with other abundant by-products produced in Andalusia, mainly to facilitate its incorporation into the soil, which presents some problems due to its high viscosity. The composting process was studied (Díaz *et al.*, 1993) and the compost was employed in greenhouse and field trials with excellent results particularly in the fertilization of sugarbeet and cotton (Madejón *et al.*, 1994, 1995). Some communications on this subject are presented at this Congress (see Madejón and Díaz).

Olive oil mill wastewater

The disposal of olive vegetation water (OWW) from olive processing industries is a problem in many Mediterranean countries for similar reasons to those mentioned above for vinasse: its high organic load (BOD 10–100 g L⁻¹, COD 40–200 g L⁻¹) and salt content (E.C. 8–22 dS m⁻¹).

Several treatment systems for OWW have been proposed or employed with different success. Cabrera (1995) reviewed the situation of OWW treatment in Spain.

The chemical characteristics of the OWW organic matter were studied by Sáiz-Jiménez *et al.* (1987) focusing on their lipidic fractions which contain non-stabilized hydrophobic constituents.

In the case of OWW, recipes for compost mixes of the sludge obtained after dessication of the wastewater in ponds and other agricultural residues were developed by private companies. Such composts are welcomed by farmers. The phytotoxicity that OWW presents, due to its polyphenols, disappears with composting. So, composts of OWW do not inhibit the germination of plants such as cress or ryegrass (Cabrera *et al.*, 1990) as OWW does.

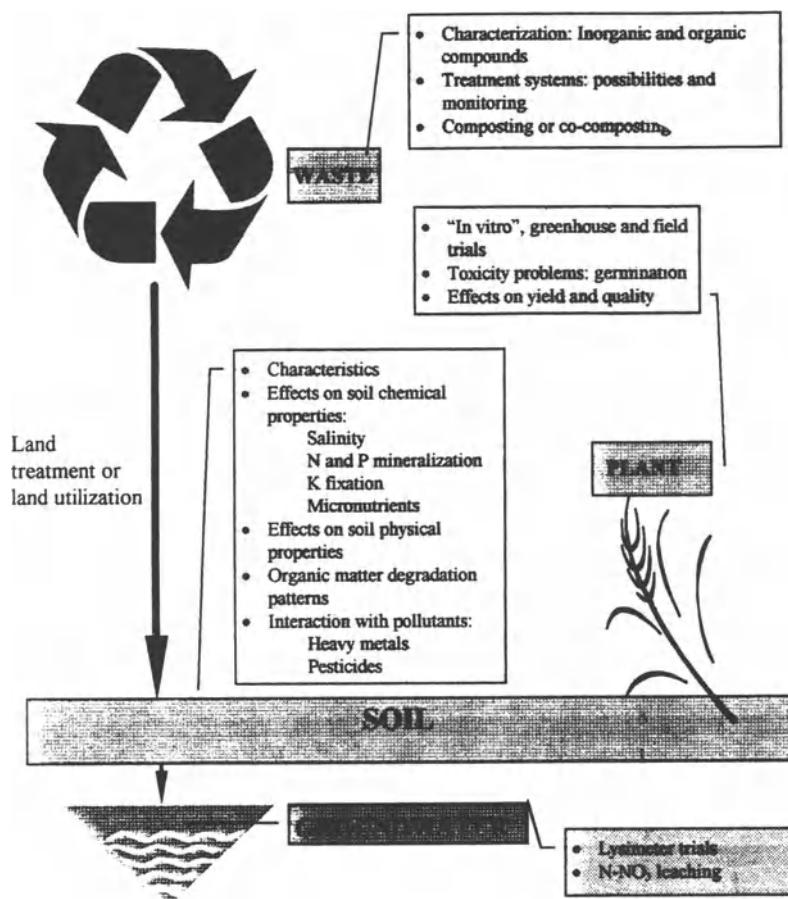


Figure 1 Interaction phenomena in the system waste-soil-plant-water

Succesive applications of composts have been proved advantageous for the fertility status of soils, increasing their organic matter and N contents (López, 1992; Martín-Olmedo *et al.*, 1995a, b) which are usually very low in semiarid regions.

The effect of composts upon the organic fraction of agricultural soils have also been studied by Gonzalez-Vila *et al.* (1992).

The application of OWW composts did not cause an imbalance in the nutritional status of ryegrass, barley, corn and sugarbeet. Although low Mn and Zn

content were detected, they were above the sufficiency level (Cabrera *et al.*, 1990; López, 1992).

Land treatment of OWW is an alternative disposal procedure, especially for small factories which can not afford more expensive treatment methods. For loading rates lower than 500 L m⁻² year⁻¹, in carbonate rich soils, no effects of the treatment up to 1 m soil layer were detected (López *et al.* 1992, 1995).

In water courses or soils, OWW forms soluble chelates with oligoelements and heavy metals, especially Mn and Zn, facilitating their dissolution and mobility. The interaction between them and the composition and stability of the compounds formed have been intensively studied (Cabrera *et al.* 1984, 1986; Bejarano, 1995; Bejarano and Madrid, 1992; Madrid and Díaz-Barrientos, 1994a, b).

The enforcement of EC directives on wastes in addition to the great general preoccupation with the environment and the development of biological farming systems will enhance the use and research of wastes, and especially composts, in the South of Spain.

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Compost as a Source of Organic Matter in Mediterranean Soils.

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Abstract

An overview of the relationship involved between climate, vegetation and soil in the Mediterranean Basin is presented. According to the criteria established by the legend of the Soil Map of the World (FAO-UNESCO, 1974 & 1988), the main characteristics of dominant soils in the area are analyzed. As well, soil problems associated to actual land uses or land uses changes are considered.

Low organic matter content is one of the common features of Mediterranean soils. Organic waste reuse through soil system for different land purposes seems to be the best way to improve soil organic matter contents. When organic wastes are composted these practices contribute to eliminate non polluted organic wastes with public health safety and environmental advantage.

Mediterranean site

From a geological history and geographycal point of views, the Mediterranean Area represents the borders of an relict island of the former Teathys Sea.

Taking into account climatological conditions used to establish different terrestrial ecological formations, Mediterranean Biome is present in a discontinuous small surface (about 1.2%) from the biosphere which geographical occurrence is represented in whole Continents. For each area the border line depends on the Mediterranean climatic criteria employed.

The Mediterranean Basin around the Mediterranean Sea is the most extensive area (more than 60% of total biome surface) being present in Europe, Africa and Asia.

The other areas are more homogeneously distributed, but they are small ones: S-W and S of Australia (20%), California (10%), Central Chile (less than 5%) and S-W of South Africa (3%).

Deacon 1983, indicated that it is purely fortuitous that the present-day landscapes of Mediterranean-type ecosystem have become positioned between lati-

tudes 30° and 40° on the globe; any similarities in geological history and substrate are also fortuitous. Similarities in climate however, are not due to chance but to the simetry of the atmospheric circulation.

The Mediterranean climate extent is represented in the Map of the World major Climates, FAO-AGLS 1991 (Figure 1).

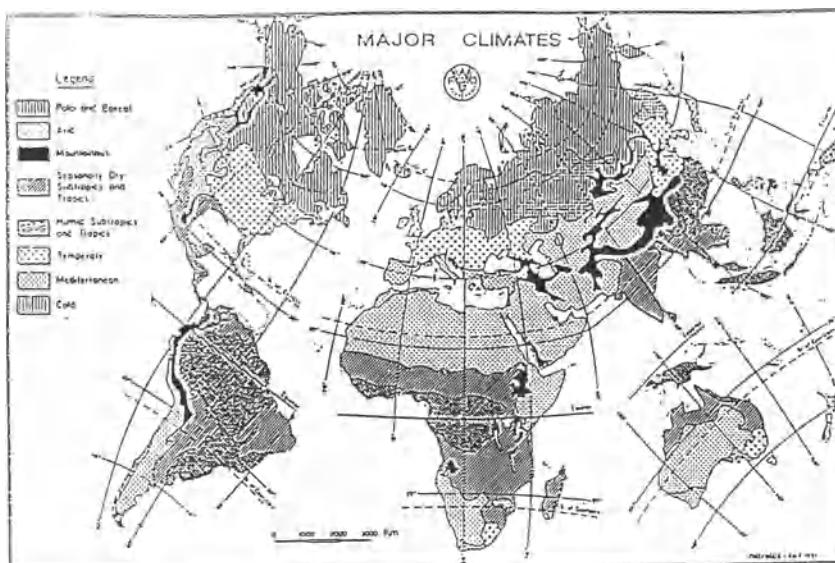


Figure 1 Major climates (FAO/AGLS, 1991)

According to Le Houérou 1991, the Mediterranean Basin is integrated by countries or parts of countries having a Mediterranean type of climate neighbouring the Mediterranean Sea, but not necessarily adjacent to it. This area occupies a land surface of some 13 million Km² (Figure 2).

Climate, vegetation and soil in Mediterranean Basin

The Mediterranean climate is characterized by hot, dry summers and generally rainy winters, often with maximum rainfall in autumn. Frost risk is generally limited to very short periods.

The most singular climate characteristics are the low mean annual rainfall and the summer drought. The lenght and intensity of the dry season is a good indicator of moisture stress, which in turn is reversely related to the length of the growing season. Several climatic index, calculated using rainfall, temperature and potential evapotranspiration, had been employed to have more information about these climatic conditions.

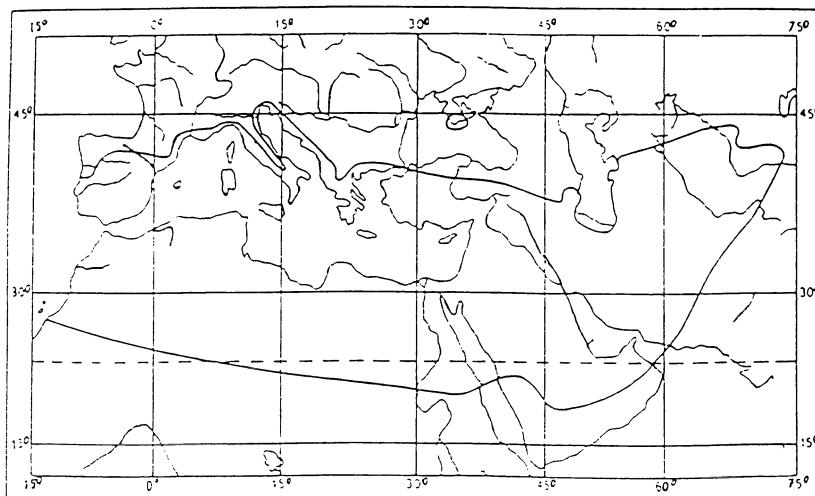


Figure 2 Geographical distribution of Mediterranean climates in the basin (Le Houérou 1991, after Daget 1977)

Owing to the landscape form, often very sharp because of the mountain chains, rainfall and temperature vary considerably, depending on the exposure and the relief itself. In the mountain region annual rainfall usually exceeds 1000 mm, and in the intermountain basins, on the contrary, the annual is many times below 500 mm. Climate not only determine natural vegetation and agricultural crops, but also is one of the major features controlling the soil development.

The regional distribution of some major soil-types can be related to the climatic conditions. Therefore, in the legend of the Soil Map of the World (FAO-UNESCO 1974), and in the revised legend (FAO-UNESCO 1988) climatic characteristics are not used as diagnostic properties in the definition of major soil groupings and soil units. On the other hand, the units description of the Soil Map of the European Communities (CEC 1985) often includes references to the soil moisture and temperature regimes, using terminology taken from Soil Taxonomy System 1975. According to this system, the typical soil moisture regime for the Mediterranean area is the xeric, but because relief and latitude changes, soil moisture vary from udic to aridic; the temperature regime is thermic. Soil temperature and soil moisture regimes are important properties which affect soil behaviour and crop production.

The multiplicity of the regularity that determine the actual world soil cover has now become obvious. Soil spatial variability, diversity and distribution are now recognized to be the result of a combined change of soils and soil forming factors (climate, biota, parent material, relief, hydrology, human-induced forces, paleo-

geography, duration of soil formation). The study of the global soil cover enabled the recognition of 'pure lines' of spatial soil changes: climate-induced, biota-induced, etc. Generalizing the vast empiric knowledge of soil geography it is possible to distinguish 'pure line' spatial changes. They influence the soil cover in combination, however, some of them may have a dominant effect (Dudal et al 1990).

The parent material from which soils are developed have different composition and origin but calcimagnesian materials are dominant in Mediterranean Basin. The soil forming processes are often linked with migration and accumulation of clay, calcium carbonates or more soluble salts as gypsum. When slopes are pronounced or conservation practices for agricultural systems are not employed, erosion is a limiting factor for soil development.

Mancini 1966 said, in a communication 'On the elimination of the term –Mediterranean– in Soil Science' that soils from this area are not different from others with similar characteristics. More than a half of major soil groupings, established in the legends of Soil Map of the World by FAO-UNESCO (1988) are represented in Mediterranean Basin.

The most important features of dominant Mediterranean soil-type are summarized –according to FAO-UNESCO 1974 & 1988, and previous discussions made by CEC 1985, Griesbach 1993 and Sánchez-Díaz 1993 – as follows:

Fluvisols. Young alluvial soils, which have gained new discharges of fine materials in irregular intervals of time, have fluctuations of organic matter content with depth.

They are important soils for agriculture, occurring on a leveled topography along major rivers. They are suitable to a wide variety of crops and are highly productive, particularly when irrigated.

Some times they present salinity irregularities, in those cases and when they have not some other diagnostic horizons, are named *Solonchaks*. This soils are used in some places for the culture of rice and cane.

Regosols. Young soils from unconsolidated materials often occur on steep sloping land or they are course textured, having no diagnostic horizons other than an ochric or umbric A horizon. When they are course textured soils, they are called *Arenosols*.

Topography, structural stability, erosion and moisture stress are the main limitations, although the finer textured ones are fertile for many crops. When topography is suitable they are used for intensive cereal and fruit production and are also associated with coastal dunes or recent sand deposits in desert. Peaches and citrus are grown with sprinkler irrigation. Hilly and mountainous areas are largely devoted to extensive livestock production from rough grazing or remain under forest.

The shallow soils as *Lithosols*, *Rendzinas* and *Ranker* from FAO-UNESCO 1974, has been grouped as **Leptosols** by FAO-UNESCO 1988.

Lithosols are very shallow soils over rock that often occur on steep to very steep slopes. They are largely present in all Mediterranean countries. These soils should be left under natural vegetation to prevent erosion and conservation measures should be taken when they are damaged. Forest and controlled extensive grazing are the recommended land uses.

Renzinas are soils rich in humus contents, shallow over limestone and often high in gravel contents that occur generally in hill areas. When slopes are moderate to gentle intensive agriculture (olives, figs, wines, barley, vegetables, winter pastures) is possible. Cultivation of plants sensitive to chlorosis should be avoided.

Vertisols. Soils with high expandable clay contents, are very hard and crack when dry and sticky and plastic when wet.

They have great agricultural potential but because of their peculiar physical properties, special management practices are required to secure sustained agricultural practices. Due to their poor workability they are less suitable for sustenance agriculture and, except under mechanization and irrigation, they are best for grazing.

Because climatic criteria is not longer used to define soil units (FAO-UNESCO 1988), the soils developed in aridic moisture regime as *Xerosols* and *Yermosols* with a weak or a very weak oeric A horizon respectively. (FAO-UNESCO 1974) are not included. New major groupings of *Calcisols* and *Gypsisols* have been introduced (FAO-UNESCO 1988) to distinguish soils in which accumulation of calcium carbonate or gypsum, or both, are the dominant soil forming process. They occur dominantly under arid and semiarid conditions.

In both, *Xerosols* and *Yermosols*, the oeric horizon often lies on a calcic horizon where the calcium carbonate accumulation is frequently so intensive that a continuous cementation is due and a petrocalcic horizon is developed. Instead of calcium carbonate, gypsum accumulation horizon or a gypsic horizon could also be present. The indured layer at shallow depth form Petric units for *Calcisols* and *Gypsisols*. These layers can be a serious limitation for use and has to be taken into account when any kind of farming is planned.

When petric horizon and argic B horizon are lacking, Haplic units for *Calcisols* and *Gypsisols* are present. Haplic *Calcisols* are the most frequent because the presence of a cambic B horizon is very common. They are mostly irrigated and devoted to cereals and vegetables in addition to wines and olive trees.

When they have an argilic B horizon they are *Luvic Calcisols* and were formed on past wetter climatic conditions.

Cambisols. Soils having a cambic B horizon which is well structured present adequate supplies of nutrients and water holding capacity. They suffered either a partial (Calcaric *Cambisols*) or total loss of carbonates (Eutric *Cambisols*), in this case with a high base saturation. These properties are favorable for root development.

Calcaric units occur in the driest part of Mediterranean climates. In North

Africa they are generally on gently undulating terrain. Land use results in winter cereals and extensive grazing. Olives and fruits are grown and less frequently citrus because they may suffer from chlorosis. In Andalusia and West Anatolia these soils are associated with a hill and mountainous topography and are often stony. They are devoted to cereals, fruits, wines, rough grazing or forestry. The major limitations are severe moisture stress and slope because they are susceptible to erosion.

Eutric Cambisols are present on different topography level: valley, hilly to mountainous. Land use vary according to climate, topography and stony degree, consist on arable cropping, sheep production from low yielding pastures and some fruit cultivations.

Luvisols. Soils with argic B horizon. In general are not calcareous but are still very rich in bases. They represent the most developed soils in the Mediterranean area.

Cromic unit is the most extensive, and it develops in various parent materials being limestone the predominant one. Calcic Luvisols are derived from calcareous materials. There is an important agricultural limitation when a shallow petrocalcic horizon is present.

Luvisols had been used since time for agriculture because its fertility, now degraded due to long intensive cultivation, deforestation and overgrazing. They are still extensively used for a wide variety of crops.

Other soil groupings can also be present under special conditions in several localities. Some examples are: *Andosols*, *Gleysols*, *Solonetz* or *Podsols*. *Anthrosols* are present in areas of heavy pressure of human activities.

Main soil distribution by Mediterranean countries and the most important constraints (Table 1) for each one had recently been summarized by Griesbach 1993.

Land use and Land use Changes in Mediterranean Basin

In Mediterranean Basin important surface is used for agricultural purposes and agricultural activity is usually combined with livestock and forest exploitations. Agro-silvo-pastoral systems are traditionally employed since ancient times. The main crops are olives, grapes, almonds, figs and cereals. With irrigation, dominant crops are fruit trees and vegetables. Natural vegetation consist of sclerophyllous forest (evergreen oak, chesnut and pistachio), and thorny thickets (maquis degrading into garigues). Coniferous are used many times for revegetation.

Mediterranean woodland and tropical sevanas have in common long dry season and the duration of water deficit period is critical, during summer for the former and winter for the latter (Harlan 1992). Today the human race is nourished by such plants and its origin appears to be in the Near East.

The land use system in Mediterranean Basin has considerably changed during the last forty years because of technological development, socio-economical con-

ditions and associated environmental pollution problems at the north side. According to Skouri 1993, the evolution can be summarized taking into account two groups as follows:

At the north of Mediterranean Sea:

- Reduction of cultivated areas and increase of specialized crops, as fruit trees and vegetables, extremely productive by monoculture.
- Abandonment of cultivated and pasture land in marginal areas compensated by reforestation, it has been high in France, Spain and Portugal (23, 19 and 15% respectively) from 1965 to 1985 (Le Houréou, 1991).
- At the south of Mediterranean Sea:
 - The evolution takes an opposite direction as in the north countries. Agricultural surfaces still increases at the expense of forest and pasture lands, so during 1961/65 and 1981/85 the agricultural land increased respectively 1265 x 103 ha in Morocco and 281 x 103 ha in Tunisia. (Allaya et al, 1988).
 - Tree crops, basically olives, and cereals have been extended considerably on arid zones of these countries, particularly in Tunisia.

During the last years in both sides of Mediterranean Sea, irrigation had been the most important change of land use. The total coverage of irrigated land increased since 1965 to 1982 by almost 50%, (Sánchez-Díaz, 1993). The irrigated areas are in general limited by water resources and irrigation is responsible for salt accumulation in soil. (Szabolcs, 1991). Salinization may occur also as a result of salt mobilization during summer by evapotranspiration.

The transformation of traditional methods of agricultural use to intensive mechanised systems and increased grazing pressure on marginal soils has been exacerbated by growing population whose ever increasing consumptive needs have contributed to environmental pollution. As well, great land use conflicts in coastal lands are present and as a result severe impact is done due to competition between touristic urbanization, industry and agriculture. (Coccossis, 1991). The impact of tourism is not only strong on a narrow belt of less than 5 Km from the touristic urbanization, but it also contributed quite significantly to the exponential increase of forest and shrubland fires that occur each summer (Le Houérou, 1990).

Changes in land use are the result of changes in the size and distribution of population, technological innovation and economic restructuring, social organization and policy (Coccossis, 1991).

Increasing aridity is the major problem associated to Mediterranean region if climatic change should occur. Agriculture and horticulture will become less reliable, however, if is presumed that new technologies will provide the necessary adaptations to cope with greater climatic instability and increasing physiological stress due to salinization. The outstanding feature for agriculture, will be that the area will become virtually frost-free, removing one of the major risks involved with fruit tree cultivation (Hekstra, 1990).

In a general sense Mediterranean area could be considered as a fragile ecosys-

Table 1 Main soil constraints (%) in Mediterranean countries after Griesbach 1993, from FAO World Soil Resources Map.

	Drought	Steepy	Shallowness	Wetness	Coarse text.	Fertile	Na toxicity	Peat	Miscell. land	No problem
Albania	0	30	9	2	3	0	0	0	1	54
Algeria	51	4	17	0	17	0	0	1	0	10
Cyprus	0	23	17	3	0	10	0	3	0	44
Egypt	61	3	0	1	17	0	0	1	0	17
France	0	7	12	15	9	0	0	0	2	55
Greece	0	36	5	1	2	2	0	0	0	54
Israel	56	4	4	0	1	14	0	0	1	20
Italy	0	24	10	3	3	0	0	0	0	57
Lebanon	19	30	13	0	0	11	0	0	0	27
Libya	66	1	5	0	21	0	1	0	0	6
Malta	0	5	15	0	0	0	0	0	0	80
Morocco	55	9	2	2	2	3	0	1	0	26
Spain	2	20	16	5	2	2	0	0	0	53
Syria	81	2	1	1	0	5	0	0	0	10
Tunisia	44	11	11	1	11	3	0	6	0	13
Turkey	31	22	10	1	1	1	2	0	0	31

tem because is intensively affected by human activities (erosion, overgrazing and fire, likewise pollution in same zones) and also due to the desertic conditions border limit. Therefore, desertification is a degradative process also identified in this area.

Soil Organic Matter Status and Needs in Mediterranean Soils

Dark colour soil in surface horizons means in general high organic matter content (mollic A horizon). The most dominant surface horizon in Mediterranean soils is ochre A horizon which is too light in colour to be a mollic horizon. This is probably due to organic matter imbalance between mineralization and humification by ploughing.

As well, the rainfall concentration during cool periods (autumn-winter-spring), when temperatures and insolation are least favorable for plant growth, have an unfavourable effect on soil organic matter production. This prevents the surface development of deep organic horizons or/and rich organic matter content. The major natural environmental hazard is also drought under natural conditions, because it prevents biomass production to guarantee organic supply for organic horizons development.

It is well known that there is a relationship between soil physical properties and its amount of organic matter. The most likely affected properties by increasing organic matter content are aggregate size distribution and stability, bulk density, water economy and thermal regime. The effects are largely dependent on kind of organic material, soil attributes as texture and biological activity, and climate conditions.

Arable soils, especially those associated with cereal production have suffered a severe decline in soil organic matter. Without residues in arable fields organic matter content decreases, soil temperature soar, crusting problems are aggravated, runoff and erosion accelerated, moisture infiltration less uniform, soil biological activity declines, soil compaction is favored and soil degradation processes are progressively augmented. Additionally failure to retain crop residues in cropped fields and the burning of crop residues after harvest, common practice in many Mediterranean places, adversely affect soil fertility because nutrients are not recycled.

Organic wastes have long been recognized as one of the best methods to maintaining fertility, productivity and soil organic matter. On a intensively exploited agricultural land as Mediterranean region is, the value of organic wastes goes far beyond their value as a source of plant nutrient.

Nowadays, many different kinds of organic wastes are produced in our society. A lot of them can be reused through the soil system as amendment, when the content of potentially toxic elements or compounds, and pathogenic organisms is low or neglectable. To take advantage of organic matter quality and to avoid undesirable effects on vegetables, some treatment is necessary previous land reuse.

Composting process is essentially a stabilization process which works similarly to the organic residues transformation in soil. The process reduce also the vitality of weed seeds in manures and suppressive effects of compost on soil pathogens have also been found.

The large spectrum of organic materials, the different treatment processes and the singularities of plant operations, produce compost which varies widely in their composition and properties. Usually composted materials have less available nutrients than fresh ones, for this reason they have to be considered more as an amendments than a fertilizers.

The potential pollution risk for crops, food chain, soil and environment makes necessary to establish guidelines to regulate its utilization. In addition to potentially pollutants, the most hazardous factors for agricultural purposes included in some waste compost are excessive salt content and absence of maturity.

When compost with a highly degradable organic matter content is applied to arable land immediately biological activity increases and biomass nitrogen immobilization occurs.

It is well known that after several land applications of wastes the residual organic matter increases in soil, so long time effects are expected. For that reason and considering the economical cost yearly application are not recommended, better 2-4 years intervals.

In many cases the use of organic wastes provides the only means of establishing a suitable plant cover in hostile soil environments such as severely eroded or denuded areas, mine spoils or chemically degraded emplacements. Compost could also be a good material for this purpose and the worse quality of compost is the most adequate for this purpose. The compost application as a filling material in quarry places and building roads is also widely recognized.

The use of compost obtained from many different materials as soil amendment or for land reclamation is dependent primarily on their availability close to the site being used. The transport costs are usually the limiting factor. Land use for different purposes has to be selected according to the compost quality, this include both the content of pollutant and the stabilization degree of its organic matter. For a better land uses of compost, probably guidelines should be done for a Mediterranean area.

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- SZABOLCS I. (1991). Salinization potential of European Soils. In 'Land use changes in Europe'. Brouwet et al (ed). Kluwer Academic Publishers. NL. Table 1. Main soil constraints (%) in Mediterranean countries after Griesbach 1993, from FAO World Soil Resources Map.

Utilizing Composts in Land Management to Recycle Organics

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Abstract

Florida ranks fourth among states in the USA in population (about five percent of the total), but produces about one-tenth of the solid waste (about 18.4 million Mg annually in 1992). Perceived problems with landfills and incineration are encouraging composting as an environmentally benign way to recycle organics that cannot be reused in better ways. Potentially about 10 million Mg of organics could be composted to produce 3.6 to 5.4 million Mg of compost. Recycling this volume of material will occur only if research can demonstrate beneficial utilization. Thus, the University of Florida and several cooperators initiated a statewide research program to determine the benefits or problems with applying composts in the production of major crops grown in the state. Composts made from mixed municipal solid waste or source-separated wastes (e.g., yard trimmings, mixed waste paper, refuse derived fuel) with or sans biosolids were applied to soils planted to citrus, pines, various vegetables, turfgrass, sod and container grown woody ornamentals.

Results indicate that metals in composts are not accumulated in plants at a level of concern to human health, nor do they occur at levels that exceed recommended soil loadings. The most serious problem identified is ‘nitrogen rob’ in plants immediately planted in soil treated with unstable and immature composts. Crops grown in soils with stable composts usually benefitted from the application—e.g., potato, tomato and watermelon yields increased 30% or more, water deficits delayed in turfgrass, expensive organics replaced in container media, nutrient and pesticide leaching attenuated, root density and extension increased, soil-borne root diseases reduced, soil water storage increased, corn silage yields increased. Data indicate that recycling waste resources has value associated with returning organics to soil, and it helps communities solve waste management.

Introduction

Economically affordable and environmentally acceptable methods to manage municipal solid wastes (MSW) continues to be a high priority issue for communities. With average per capita generation at 2 kg per day, 188 million Mg of MSW resulted in the U.S. during 1993 (U.S. Environmental Protection Agency, 1994). The amount of waste generated annually in the USA has more than doubled in the last 30 years as the capacity to handle these wastes has declined in many areas (USEPA, 1994b). Numerous landfills have become full and others have closed because of more stringent regulations governing their design and operation. Both economical and perceived environmental problems associated with air emissions and ash have also restricted the combustion option for handling wastes.

In Florida, the problem is even more acute since the per capita MSW generation has grown to an average of 4.3 kg per day in 1993, over twice the national average (Florida DEP, 1995). Thus, the total MSW collected in 1993 was 21.4 million Mg. While recycling and waste reduction have increased over the last seven years, Florida's population growth has caused the MSW collections to increase. Because of shallow groundwater tables and other features of the Florida environment, there are now requirements that landfills be lined and meet rigorous management specifications. Similarly, criteria for siting and operating waste-to-energy facilities have slowed the development of additional combustion capacity. Both of these methods of handling wastes have become expensive. For example, the average landfill tipping fee in Florida averaged \$46.15 Mg⁻¹ in 1993 (Florida DEP, 1995).

The search for safe and effective ways to manage MSW is causing some communities to consider composting. Composting is becoming more attractive as a waste management option because it can handle up to 30 to 60 percent of a community's MSW stream (USEPA, 1994b) and is perceived to be a safe and environmentally benign way of recycling. Biological decomposition that occurs during composting reduces the volume by about 50 percent and results in a product potentially useful in agriculture, horticulture and silviculture. Many communities have targeted yard trimmings since they are the largest, cleanest and easiest fraction to collect separately and compost. In Florida, of the 44 composting facilities operating, 29 facilities compost yard trimmings only (Florida DEP, 1995). Nationally about 2,200 facilities for composting yard trimmings were operating in 1991 (Goldstein and Glenn, 1992), while 21 were processing MSW. Numerous other composting facilities are in various stages of planning and/or development.

In Florida, significant quantities of composts are being produced, while there is a potential to produce about 5 million Mg annually from the biodegradable fraction of the MSW stream. Successful recycling of the composts will only occur if beneficial uses can be demonstrated through research. Shiralipour et al. (1992) summarized the research results from around the world and concluded that there was considerable promise for compost utilization. To develop data specific to the types of composts being produced and the species of crops grown in Florida, a statewide research and demonstration program was begun in 1991. These projects

supplement the growing number of projects (Table 1) being conducted throughout the USA as identified by survey and review of databases. Additional information on these projects is available in Smith (1994, 1995) and the U.S. Department of Agriculture's Current Research Information System (USDA, Cooperative State Research, Education and Extension Service, CRIS Manager, Washington, D.C.).

Florida's research and demonstration program

The University of Florida's Center for Biomass Programs has coordinated the development of a statewide program that has interfaced a number of sponsors and cooperators (e.g., Florida Departments of Environmental Protection, and Agriculture and Consumer Services, Water Management Districts—St. Johns, South and Southwest Florida, Procter and Gamble in cooperation with The National Composting Council, Palm Beach Solid Waste Authority in cooperation with the American Forest and Paper Association, Keep Florida Beautiful, Inc., Bedminster Bioconversion, Inc., Reuter Recycling, Inc., Amerecycle, Inc., Sumter and Broward County Public Works Departments, Wood Resource Recovery, Inc., Enviro-Comp, Inc., the Florida Center for Solid and Hazardous Waste Management and several farmers and growers). The several contributing research projects were conducted in Departments and Research and Education Centers of the University of Florida's Institute of Food and Agricultural Sciences (Smith, 1994, 1995).

Table 1 Compost utilization and demonstration projects in several U.S. states.

Crops Evaluated	Compost Type ¹	Location ²
Acer, Quercus, Pinus	MSW	Connecticut
Alfalfa	MSW, composted landfill waste	New Mexico
Broccoli, lettuce, marigold and salvia flowers	MSW, YT, MSS/YT	California
Christmas trees, nursery container stock, corn, soybeans	MSW	Wisconsin (4)
Citrus	MSW	Florida (2)
Corn	MSW	Minnesota
Corn	Mushroom compost, dairy manure, poultry manure, packing house waste	Pennsylvania
Corn, lettuce, marigolds, geraniums, other nursery stock, bedding plants	fish waste, ground fish/alder sawdust, groundfish/hemlock–fir sawdust	Washington
Corn, radish, turfgrass, maple and linden trees	commercial composts, sawdust, composted sawdust	Missouri
Corn, turfgrass	diary manure, farm/yard compost, anaerobically digested SS, lime-stabilized dewatered SS	New Hampshire
Corn, wine vineyard	MSW, SS + woodchips	New York
Cowpea	SS	Washington
Forage grasses, corn, wheat, ryegrass	dairy manure, SS, commercial fertilizer	Washington
Fushia, bedding plants	MSW	Maryland
Horticultural plants	YT, wood waste, Compost (not specified)	Florida (3) Hawaii
Horticultural plants (not specified)	MSW	Minnesota
Horticultural plants (not specified)	Humus (not specified)	Michigan
Hybrid poplar trees, corn, fescue	Spiked compost (not specified)	Iowa
Lettuce, fescue, wheat, potatoes, peanut, burley tobacco	MSW	North Carolina (2)
Lettuce, potatoes, tomatoes, corn, fescue, beans	MSW	Washington
Marigold, radish, tomato, melon seeds	Zebra mussels with poultry litter, sawdust and peat	New York
Nursery plants	yard debris, SS, MC	Oregon
Peach and apple trees	YT MSW	Alabama South Carolina
Philodendron, Lantana, Schefflera, Oleander, Jessamine, West Indian Mahogany, Live Oak	MSW, SS + YT Mixed waste paper, RDF, RDF residuals, YT—all co-composted with SS	Florida (2)
Potatoes	YT	Florida

Table 1 Continued

Crops Evaluated	Compost Type ¹	Location ²
Red winter wheat	SS	Colorado
Rudbeckia, rhododendron, azalea, taxus	wood chips + SS	Connecticut
Seasonal greenhouse crops	Organic wastes (not specified)	Connecticut
Small grains, corn, vegetables	poultry litter or dairy manure composted with newspapers, leaves and/or cafeteria waste	Maryland
Sorghum	MSW, cattle manure	Kansas
Soybeans, cotton, wheat animal manures	gin trash, municipal wastes,	Arkansas
Spinach, cucumbers	MSW	Maryland (2)
Strawberries, blueberries, apples, landscape flowers, wildflower sod	MSW, SS and woodchips, leaf, agricultural (chicken manure, cranberry pomace)	Massachusetts (2)
Sugarcane and kenaf	MSW, sugarmill waste	Louisiana
Sugarcane, bermudagrass	MSW, papermill sludge + wood ash, gypsum	Louisiana (2)
Sunflowers, durum wheat Sweet corn, okra, squash, cowpea and unspecified vegetables	MSW, coal combustion residues YT	Maryland Florida (2)
Tomato	black polyethylene, recycled paper, hay, YT Blue crab scrap compost	Virginia Tomatoes Florida
Tomatoes, black beans, cowpeas	polyethylene film mulch, MSW, SS, wood chips	Florida
Tomatoes, eggplant, peppers lettuce, broccoli, cauliflower, squash	MSW, MSW/SS, MSW	Connecticut Florida (2)
Tomatoes, peppers, cucumbers	Mixed waste paper, RDF, RDF residuals, YT—all co-composted with SS	Florida
Tomatoes, watermelons	MSW, MSW + SS, poultry manure	Florida
Turfgrass	CW products	Pennsylvania
Turfgrass, corn	MSW	New Hampshire
Turfgrass, Kentucky bluegrass	MSW, MSW + SS	New York
Turfgrass/Sod	MSW MSW + SS/YT	Florida (2)
Viburnum, ligustrum, azalea, pittosporum	MSW, YT	Florida
Wheat, sorghum, cotton, soybeans, corn	Not specified.	Georgia

¹ Municipal Solid Waste (MSW), Yard Trimmings (YT), Sewage Sludge or Biosolids (SS), Refuse Derived Fuel (RDF), Composted Waste (CW), other materials are not abbreviated if specified.

² Number of separate experimental sites is in parentheses.

Composts were derived from various feedstocks employing an array of processing procedures (Table 2).

Crops chosen for the test program ranged from high value/low volume to low value/high volume (crop value/compost utilization potential). The crops chosen (Smith, 1994) usually received one application of compost and the cropping cycles imposed. In Florida, two vegetable crops are frequently planted in one year. For the case of turfgrass, greenhouse experiments were done to arrive at rates to field test. Container grown ornamentals were either in greenhouses, shadehouses or on outdoor surfaces.

Table 2 Composts from various feedstocks and processing systems tested in the Florida utilization program.

Amerecycle (also Sumter County Public Works Department	Mixed municipal solid waste—uncovered turned windrows
Bedminster Bioconversion by covered turn windrows	Mixed municipal solid waste—Eweson drum followed
Broward County Public Works	Yard trimmings co-composted with biosolids—uncovered static piles
Enviro-Comp	Yard trimmings—uncovered turned windrows
Palm Beach Solid Waste Authority	Biosolids co-composted with yard trimmings, mixed waste paper, refuse derived fuel (RDF) or RDF residuals—covered, agitated and aerated beds
Wood Resource Recovery	Yard trimmings—uncovered static piles

Results

One lesson quickly learned was that unstable and immature compost would cause nitrogen rob. When such compost was applied and a crop planted immediately, evidence of suppression was apparent for 40–60 days. Laboratory and field experiences showed that for composts with C:N ratios greater than 20, nitrogen fertilizer should be applied or planting delayed for 6 to 10 weeks to permit the compost to stabilize in situ (Eichelberger, 1994 and Obreza and Reeder, 1994).

In two tests with citrus, MSW compost was soil-incorporated at 0, 50 and 100 Mg ha⁻¹ and planted with seedlings. Soil water contents at both sites were significantly greater where the composts were applied, although the only growth response was a trunk diameter increase at one site after six months. The compost treatments increased total root length and appeared to alter root distribution by increasing the root density in the 15–30 cm soil depth. In other experiments, citrus inoculated with Phytophthora, a soil-borne root disease, caused less root density reductions when compost was applied. Tree diameters were increased by compost regardless of disease infestations (Graham, J. Unpublished report, University of Florida, Lake Alfred, FL Citrus Research and Education Center).

Compost from the same source was also applied at three rates (100, 200 and 300 Mg ha⁻¹) to a cleared forest site and in a site supporting a six-year old slash pine forest. The cleared site was planted to slash pine. Wood chips (300 Mg ha⁻¹), fertilizer and zero treatment comparison plots were included. Because of intense competition by 'weed species,' deer grazing and/or predation by insects, the seedlings did not survive. After two years the high rate compost treatment in the

established forest increased tree growth by 50 percent over the control. The growth responses to the wood chip and fertilizer applications indicated that about half the response was to improved water relations and half to improved nutrition when soil moisture and plant chemistry data were considered.

Yard trimmings compost was applied in three successive years to plots planted to corn with cumulative rates of 534, 672 and 806 Mg ha⁻¹. Both surface mulch and soil incorporation was tested. Regardless of method, corn silage yields were increased by 1.8 to 2.3 Mg ha⁻¹ over the untreated control. Increasing the soil organic matter resulted in over 5 ha-cm of additional stored water in the soil profile.

When 134 Mg ha⁻¹ of yard trimming compost were incorporated in the soil in November, planted to potatoes in March and harvested in May, potato yields were increased 30 percent. There was no evidence that soil pests were affected by treatment.

Biosolids/yard trimmings co-compost was applied to peppers and other vegetables. In no case did this compost cause nitrogen rob problems when applied at 134 Mg ha⁻¹. In fact, at first harvest pepper yields were as good with compost alone as with full fertilizer. The best treatment after all harvests was the compost treatment with half the normal fertilizer applied. Pot experiments suggested that the biosolids/mixed waste paper co-compost gave similar results as the biosolids alone composted with the yard trimmings. Field experiments are now in place to confirm the greenhouse results.

Several experiments have been completed with two vegetable crops per year. One of these involved two sources of MSW compost and chicken manure. Where tomatoes were planted following 67 and 134 Mg ha⁻¹ of immature and unstable compost, plant growth was suppressed for the first six weeks. Thereafter growth was rapid where compost was applied, but not enough to restore all the growth loss. Subsequently, watermelons were planted and yield increases of 30 and 50 percent, respectively, occurred where the composts were applied.

In another tomato/watermelon cropping sequence, it was demonstrated that comparable yields could be obtained with 75 percent of the recommended N and P fertilizer rates. Quality improvements were also noted as there were increased yields of extra-large tomatoes.

Peppers in a rotation with tomatoes treated with MSW compost at 67 and 134 Mg ha⁻¹ gave similar results. Pepper sets planted in soil receiving immature and unstable compost were suppressed, while the crops of tomatoes planted afterwards had a 30 percent yield increase with more large fruit.

In both of these experiments, soil organic matter was increased as was water-holding capacity. The soil in the beds covered with plastic mulch showed a more uniform moisture content across beds provided drip irrigation. We hypothesize that the compost caused the water to disperse throughout the bed from the point source emitter. In addition to the increased yield and improved quality of tomatoes and peppers, lower rates of irrigation were adequate to sustain the crops where compost was applied.

Contrasting with the experiments on acid sandy soils, compost was also applied to tomatoes rotated with squash on marl soils. With tomatoes, stable and mature MSW compost resulted in delayed earliness (fewer red fruit at first harvest), increased large and marketable fruit yields and decreased cull yields. For the squash following tomatoes, marketable yield increased linearly with increasing compost rates at the low irrigation rate. At the high irrigation rate, compost additions prevented yield reductions. Total yields of squash were increased 17 and 24 percent respectively, over controls with no compost by the 67 and 134 Mg/ha-1 compost treatments. Yields of large fruit were increased 45 and 75 percent over the control (no compost) by the two rates of MSW compost.

Turfgrass measured several months after planting into pots treated with MSW composts showed improved growth and color. Even though the turfgrass was fertilized regularly, grass clippings contained higher concentrations of N, P and K with compost treatments. The composts either helped retain the applied fertilizer or released the elements by mineralization. The pot experiments were used to determine that 30 percent MSW compost to soil by volume was the optimum for growth, color and nutrient retention. Higher compost rates were associated with detectable nutrient leaching. Also at rates of compost up to 30 percent, when pesticide leaching was observed, the MSW compost incorporation greatly reduced the quantity of pesticide leached.

Using these results, MSW compost was applied at the 30 percent rate to a soil and turfgrass established. The compost extended the period between irrigation and wilting by 7 to 10 days. Wilting was delayed even though 1 to 3 cm more water were used by the grass cover. Field tests using the 30 percent rate revealed that the compost would delay wilting under field conditions while producing greater weights of clippings and improved appearance.

Limited experiments were conducted using compost as a mulch to prevent evaporative water losses or to suppress weeds. MSW composts, especially if immature and unstable, tend to seal the surface and/or become hydrophobic and prevent water from infiltrating the soil. MSW composted only 1 to 3 days produces extractables that significantly reduce the germination of seeds. Our researchers are trying to use these phenomena to control weeds and prevent moisture loss in order to replace expensive plastic mulch. The strategy involves allowing the compost mulch to be subsequently incorporated into the soil for in situ stabilization.

Several woody species were grown in containers with MSW compost or biosolids/yard trimmings co-compost comprising the media (100 percent compost) or replacing the peat fraction (40 percent by volume) in the control mix. While each of the species (*Nerium oleander*, *Philodendron selloum*, *Eugenia uniflora*, *Murraya paniculata*, *Schefflera arboricola* and *Lantana camara*) displayed different response patterns, the compost treatments generally resulted in superior growth than on the control. The notable exception was *Murraya paniculata* where the standard (control) generally produced taller plants with greater biomass.

Similar experiments were conducted with *Ficus benjamina*, *Jasminum volubile*, *Chrysalidocarpus lutescens*, *Schefflera arboricola*, *Philodendron selloum*, *Hibiscus*

rosa-sinensis and *Nerium oleander* with medium from biosolids/yard trimmings co-composted with either biosolids, mixed waste paper, refuse derived fuel (RDF) or RDF residuals. Partial data from these species show similar results as in the other experiments with there generally being better growth when the co-compost percentage in the media increased, with 100 percent compost frequently being the best treatment.

Composts from MSW sources were used to replace the peat in media for growth of other woody species (*Viburnum odortissima*, *Ligustrum japonicum*, *Rhododendron* sp.). At 20 percent compost, plant growth and root development were similar or greater than the growth of these species in the peat control media. Higher compost levels led to physical problems relating to media drainage during early months. If carried longer than 4 to 5 months, the problem was overcome and improved water relations resulted. With *Rhododendron*, iron chlorosis occurred when alkaline compost was incorporated, but it was easily corrected by incorporating sulfur into the media or applying a folier spray containing iron.

The composts from the several sources were analyzed for total and water soluble nutrients and heavy metals and incubated to assay stability and maturity (Eichelberger, 1994). Except for copper in compost from the refuse derived fuel residuals, elemental levels were less than permitted by the Florida Department of Environmental Protection. Incubation of composts in the soil did not mineralize elements at levels of concern. Using CO_2 release as an indicator, immature composts would stabilize within 100 days. Because most composts have neutral to alkaline pH's, they increase the soil's capacity to immobilize elements (especially in acid soils). Plant tissues (including edible portions of tomato and watermelon) from crops grown on compost amended soils were analyzed for heavy metals. Rarely were elevated levels detectable and when increases were measured, they were small and well below levels of concern for human health (Ozores-Hampton et al., 1994).

Summary

Composting is becoming increasingly attractive as a solid waste management option. Because of problems associated with landfilling and incinerating and the rapid increase in solid waste generation in Florida, composting is being widely considered. However, for composting to succeed, utilization opportunities must be developed through research and demonstration programs. Such programs are necessary for determining the agronomic value for the purpose of defining how to price composts in the marketplace and for helping allocate societal values for capturing the environmental benefits of recycling organic wastes by composting.

The University of Florida launched a statewide program to explore the use of composts from a variety of feedstocks used in a broad array of cropping schemes in diverse environments. Prominent among these crops are corn, peppers, tomatoes, watermelons, squash, potatoes, turfgrass, several container grown woody

ornamentals, citrus and slash pine.

In several cases, substantial yield improvements were documented suggesting that composts can be used beneficially. Elemental analyses showed that compost from usual municipal sources were below environmental agency standards set for safety and that plants did not accumulate levels of concern to human health. When immature and unstable composts were applied and crops planted, immediate 'nitrogen rob' occurred. This growth suppression could be avoided by applying N fertilizer or delaying planting for 6 to 10 weeks. In no other case were there deleterious effects observed when the proper treatment was determined experimentally.

Simple calculations suggest that agricultural, horticultural and silvicultural uses of compost could easily assimilate compost quantities potentially available in Florida. Recycling composts is environmentally sound and contributes in the long-term to a sustainable agriculture.

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Effect of Compost–Fertilizer Blends on Crop Growth

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Abstract

Two growth chamber studies were conducted to determine whether compost–fertilizer combinations or blends were equal to or better than nitrogen (N) fertilizer alone for tall fescue (*Festuca arundinacea*) growth and N uptake. A sewage sludge compost(SC) or a compost made from both sewage sludge and municipal refuse (MC) was added on the basis of total N to Sassafras soil at rates equal to 17, 33 and 50% of the N requirement of fescue. The remaining N was supplied by NH_4NO_3 or urea. All combinations were compared to 50 to 100% fertilizer application rates and to each other. After approximately 150 days, fescue N uptake from the 83% NH_4NO_3 ;17% compost N blend equalled that from 100% NH_4NO_3 treatment which was not different from 83% NH_4NO_3 . The 67% NH_4NO_3 ;33% MC blend equalled the 83 and 100% NH_4NO_3 alone treatments. The 67% urea:33% sewage sludge compost N blend equalled the 83 and 100% urea alone treatments. Because compost N is only partially mineralizable during the first year, the equality of compost:fertilizer blends to fertilizer alone suggests that ingredients other than N are benefitting the fescue. The studies presented herein suggest that the ability of compost in blends to substitute for a fraction of the fertilizer requirement is both compost and fertilizer dependent. The data suggest that blends with urea would be successful in substituting for one–third of the N fertilizer required by fescue.

Introduction

Composting of organic wastes results in a final product that can be stored, easily handled and uniformly applied to land for beneficial use as a low–analysis fertilizer and soil conditioner. Because most composts contain relatively low levels of nutrients (1–2% N, less than 1% P) as compared to complete fertilizer, and because mineralization rates of the macronutrients generally are low, the compost application rate necessary to satisfy the complete N or P requirement of a crop is

large, usually 40 to 100 mt/ha (Hornick et al., 1984). Mineralization of macronutrients in composts is generally low because the final C:N ratios of composts are above 10. Mattingly (1956) found that the nitrification rate of 18 different composts was 9.3 to 10.6% of the total nitrogen after 13 weeks. Tester et al. (1977) in a greenhouse study found that sewage sludge compost with a final C:N ratio of 17 had a N mineralization rate of approximately 10%, i. e., 10% of the organic N in the compost is available to plants during the first year.

There are several reasons to amend soils with composts at low to moderate rates as opposed to the rate needed to fulfill the N requirement of the crop. The volume of compost equal to the N requirement demands several application trips across the field. The volume may not be available when needed or storage of large volumes near the site of application may not be possible. Most importantly, the addition of non-nutrient ingredients such as heavy metals to soils may result in an unacceptable accumulation that would reduce the value of the land for safe production of food. Several countries have annual and maximum accumulations of trace nutrients that reduce the application rates below that of the N requirement of the crop (DeBertoldi et al., 1990).

Blending residues or composts with fertilizer is an appealing alternative which (a) uses residues at lower rates, (b) reduces the amount of inorganic fertilizer applied to soils, and (c) reduces the accumulation of non-nutrient ingredients in soils. Studies were initiated to find combinations or blends of composts and fertilizers which would be equal to the inorganic N fertilizer requirement of tall fescue.

Methods

Sassafras soil (Typic Hapludults) was air-dried, crushed and passed through a 2 mm sieve. A sewage sludge compost (SC) or a compost made from both sewage sludge and municipal refuse (MC) was added on the basis of total N to Sassafras soil at rates equal to 17, 33 and 50% of the N requirement of tall fescue (*Festuca arundinacea*). The remaining N was supplied by NH_4NO_3 (N) in the first study. The sewage sludge compost was blended with NH_4NO_3 or urea (U) in the second study. Both composts were oven-dried at 70 C overnight and the MC compost was ground with mortar and pestle and then sieved through a 2mm sieve. Moisture determinations were done on a sample of sieved materials at 100 C overnight.

Table 1 contains the characteristics and the amendment rates of the composts. The municipal solid waste compost (MC) was a mixture of sewage sludge and municipal refuse and was composted by the Fairfield-Hardy process (Haug, 1980). The sewage sludge compost (SC) was made using the static aerated pile method mixing undigested sewage sludge with wood chips as a bulking agent (Willson et al., 1980).

Eighteen hundred g of soil was amended with four rates of compost to provide 0, 16.7, 33, or 50% of the total N requirement of fescue. The remaining N require-

ment was provided by NH_4NO_3 only (first study) or NH_4NO_3 or urea (second study). Fertilizer alone treatments were included in which the fertilizer provided 100, 83.3, 67, or 50% of the N required. Phosphorus was added as CaHPO_4 to all pots at rates of 300 mg kg^{-1} P in the first study and 200 mg kg^{-1} P in the second study. All pots were amended with K (as K_2SO_4) at 300 mg kg^{-1} in the first study and 200 mg kg^{-1} in the second study. Magnesium (as MgSO_4) was added to all pots at 125 mg kg^{-1} in the first study and at 75 mg kg^{-1} in the second study. A micronutrient solution containing Zn^{2+} , B^{3+} , Cu^{2+} , and Mo^{6+} was also added to all pots. Calcium oxide (2.65 g/pot) was added as the lime treatment to increase uniformly the soil pH to 7.0. The soil, dry amendments, and micronutrient solution were hand-mixed in large plastic bags, placed in pots, brought to 0.33 bar moisture, and equilibrated for at least 48 hr before being planted to Kentucky 31 tall fescue (300 seeds/pot). Treatments were replicated at least three times and as many as six times for some compost-fertilizer blends.

Table 1 Information on compost characteristics and amendment rates.

Component	Sewage Sludge Compost (SC)	Sewage Sludge/Refuse Compost (MC)
Total N	2.2%	1.2%
Total P	1.1%	0.9%
Moisture	36%	55%
Amendment rate @ 17% N addition	2.1 t ha ⁻¹	4.8 t ha ⁻¹
Amendment rate @ 33% N addition	4.3 t ha ⁻¹	9.9 t ha ⁻¹
Amendment rate @ 50% N addition	6.5 t ha ⁻¹	15 t ha ⁻¹

Pots were watered every other day and moisture was readjusted weekly to 0.33 bar. The temperature of the growth chamber was maintained at 25 C during the 16 hr of illumination and at 20 C for the 8-hr dark period. Relative humidity was maintained at 70%. The fescue was clipped to a 2.5 cm height four times over 150 days in the first study and three times over 120 days in the second study. Dry weight was determined by drying in a forced-air oven at 70 C. Dried clippings were ground using a Udy Cyclone Sample Mill. Ground samples were analyzed for total N and P content by block digestion and Lachat QuikChem AE methods. All blends were compared to 50 to 100% NH_4NO_3 (300 kg N ha^{-1}) application rates and to each other in the first experiment and 50 to 100% NH_4NO_3 or urea (150 kg N ha^{-1}) in the second experiment. Statistical testing of differences was done using 'PROC MIXED' procedure (SAS Institute, 1990).

Results

The first study compared two composts (SC and MC) in blends with NH_4NO_3 (N designations in figures) and the second study compared one compost (SC) in blends with urea (U) or NH_4NO_3 . The objective was to determine if blends with equal total nitrogen contents were equivalent to 100 % fertilizer. Increasing the amount of NH_4NO_3 fertilizer increased yields and N uptake of fescue. The 83%

and 100% N fertilizer rates were not significantly different indicating that the 100% rate of 300 kg ha^{-1} may have been excessive. Combinations of SC or MC with fertilizer also increased yield and uptake of N as the blend contained increasing amounts of N fertilizer (Fig. 1). Statistical tests indicated that for SC blends, 50 and 67% yields and N uptake were lower than the 83% blend and 100% fertilizer rate. Yield and N uptake for the 50% blend were significantly lower than the 83% blend and 100% N fertilizer. However, N uptake from the 67% or MC67 blend was not significantly different from the 100% fertilizer blend. These data suggest that the MC:fertilizer blend of one-third compost N and two-thirds NH_4NO_3 -N provides the same amount of mineral N to fescue as 100% fertilizer.

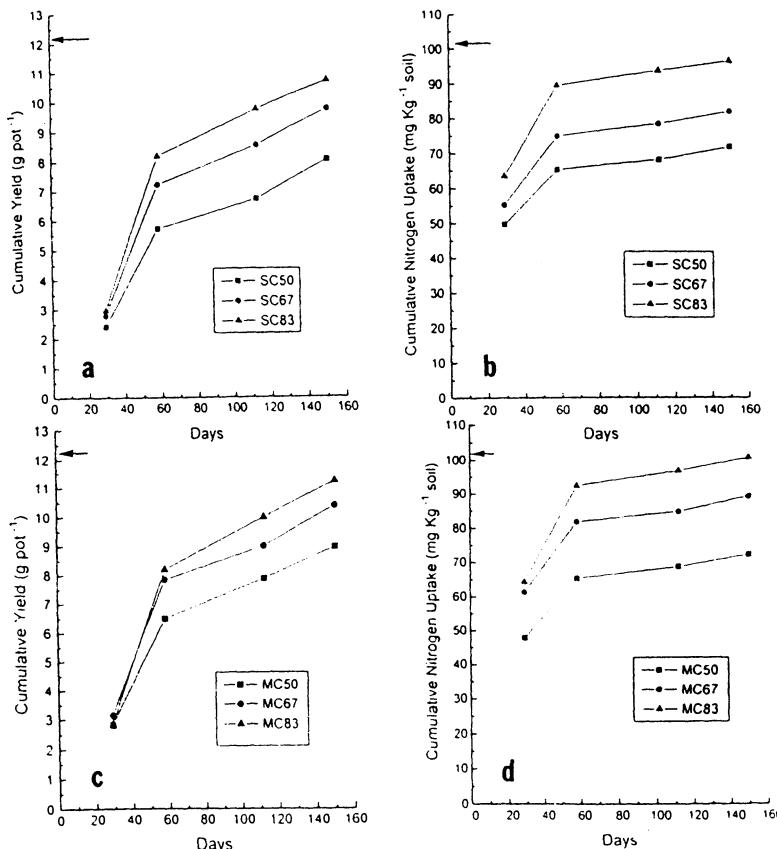


Figure 1. Cumulative yield and N uptake of fescue grown on compost-fertilizer blends. SC=sewage sludge compost; MC=municipal refuse-sewage sludge compost. The arrow designates the 100% NH_4NO_3 yield or N uptake value.

In the second study, sewage sludge compost plus NH_4NO_3 (NC) blend was again included. Cumulative fescue yields from the NC blends were similar to the first study with the exception of the magnitude of yield and uptake (Fig 2). In the second study, the 100% N amendment rate was 200 as opposed to 300 kg ha^{-1} . The NC67 blend was significantly lower than the N100 treatment. The NC blends did not equal the yield or N uptake of fescue from 100% NH_4NO_3 fertilizer.

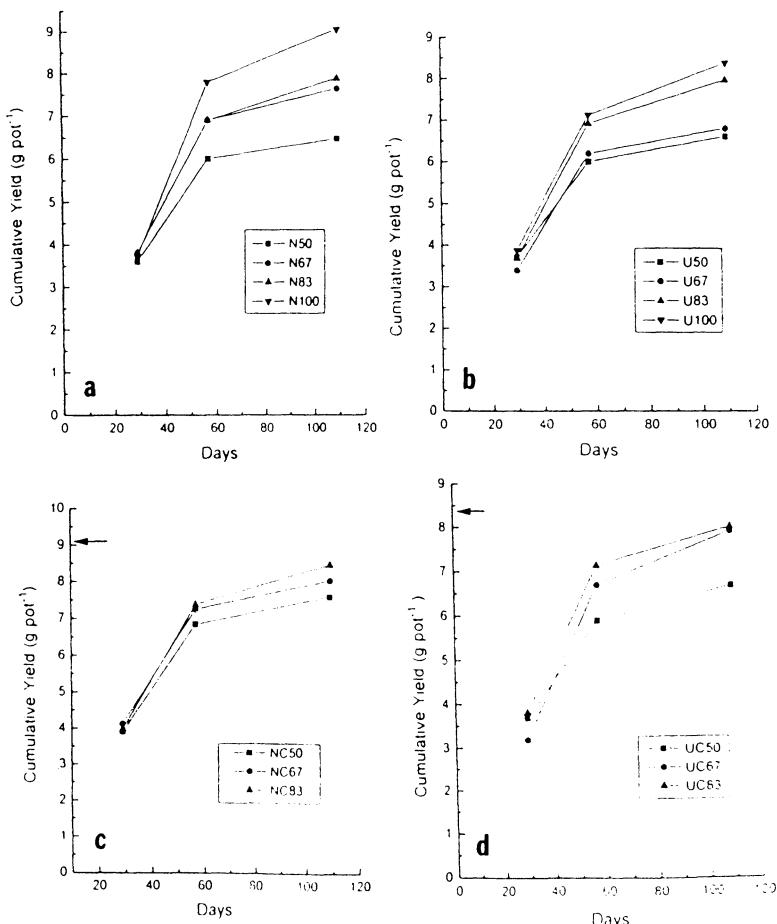


Figure 2. Cumulative yields of fescue grown on $\text{NH}_4\text{NO}_3(\text{N})$ or urea(U) alone (a & b) or on blends of sewage sludge compost and $\text{NH}_4\text{NO}_3(\text{NC})$ or urea(UC) (c & d). The arrow designates the 100% fertilizer yield value.

The response of fescue to urea was similar to that seen with NH_4NO_3 (Fig 2b). The yields were slightly but not significantly less than NH_4NO_3 fertilizer treatments. The blends with urea were different from NH_4NO_3 blends in that UC67 and UC83 were not significantly different from the U100 treatment (Fig 2d). These data suggest that blending sewage sludge compost with urea in which one-third of the N comes from compost results in as high a yield as the 100% urea amendment.

The N uptake results were different from the yield in the second study (Fig 3). In the fertilizer alone treatments, N83 and U83 were not significantly different from the N100 or U100 (Fig 3a and b). These data suggest that the amount of mineral or available N for plant uptake is the same at 100% or 83% of the 200 kg N ha^{-1} rate. The N uptake data for the blends containing NH_4NO_3 indicated that only NC83 was equal to N100 (Fig 3c). The blends containing 67% urea (UC67) and 83% urea (UC83) resulted statistically in the same N taken up by the fescue as

U100 (Fig 3d). These data suggest that blends with urea provide more plant available N to fescue and a blend which contains one-third compost N and two-thirds urea N will equal the yield and N uptake provided by 100 % urea.

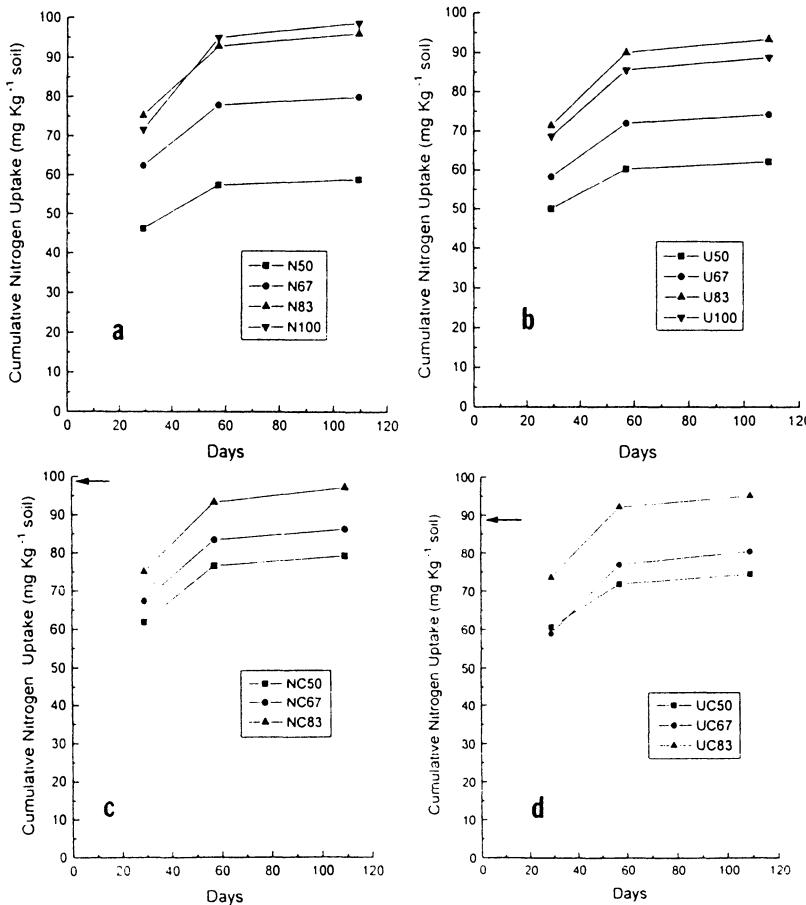


Figure 3. Cumulative N uptake of fescue grown on $\text{NH}_4\text{NO}_3(\text{N})$ or urea(U) alone (a & b) or on blends of sewage sludge compost and $\text{NH}_4\text{NO}_3(\text{NC})$ or urea(UC) (c & d). The arrow designates the 100% fertilizer N uptake value.

Discussion

The data reported here suggest that one-third of the N requirement of tall fescue can be provided by compost. However, the source of the compost and the type of N fertilizer affected the results. In a study comparing two composts, the sewage sludge/refuse compost (MC) could substitute for one-third of NH_4NO_3 while sewage sludge compost (SC) could not. In the study testing two fertilizers blended with the same sewage sludge compost, blends with NH_4NO_3 resulted in essentially the same data, i. e., the 67% blend was significantly different from the 100%

and 83 % blends. The blends with urea resulted in higher yields and N uptake than blends with NH_4NO_3 with UC67 equaling the 100% urea fertilizer rate.

The blends are equal in total N to fertilizer treatments, but are not equal in mineralizable or plant available N. Compost N is only partially mineralizable (<20%, Parker and Sommers, 1983, 10%, Tester et al., 1977). Yet the N uptake data suggest that blends with one-third compost N and two-thirds fertilizer N provide N to fescue equal to 100% NH_4NO_3 or urea alone. Either compost improves the N efficiency of fertilizer or the opposite is true. Another possibility is that the benefit from the blends may be a result of other ingredients in the composts such as trace metals.

The maturity of the compost would affect the N availability to the crop with a less mature compost providing less N. Fertilizers may differ in stimulation of soil or compost mineralization. Incubation of soils from pots after the final harvest in the second study indicated that blends with urea mineralized at a higher rate (based on carbon dioxide) than blends with NH_4NO_3 (data not presented). Further studies on blends are required to determine the reason for greater N availability from blends than from fertilizer alone.

Sustainable agriculture practices strive to reduce chemical inputs while maintaining profitable yields. Returning residues or adding composts to soils is one technique to reduce chemical input. Adding wastes at high amendment rates such as that equal to the N requirement of the crop may not be practical and may even be damaging to the soils. An alternative solution is to add the composts at low to moderate rates and make up the difference with N fertilizer. Sikora and Azad (1993) showed that composts made from industrial wastes could substitute for one-third of the fertilizer N requirement for wheat. The studies presented herein suggest that the success of blends to substitute for a portion of the fertilizer requirement of a crop is both compost and fertilizer dependent. The data suggest that blends with urea would be successful in substituting for one-third of the N fertilizer required by fescue.

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The Influence of Compost and Sewage Sludge on Agricultural Crops

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Summary

Compost, liquid and dewatered sludge from a sewage purification plant were spread each year on a three-course rotation (maize- wheat and sugarbeet) at two rates, with or without an extra inorganic NP supply. Sludge application was compared with a mineral fertilisation based on 4 rates of urea. In the first 6 years no toxicity to plants grown in compost or sludge plots was observed, even at the highest application rate (15 t DM ha^{-1}). Sludges gave crop yields similar to those obtained with the highest rate of urea; compost yielded as the best inorganic fertilisation, which often corresponded to the lowest inorganic fertilisation. Most of the results of the organic materials could be ascribed to their N-NH₄ content. The N in compost showed the lowest utilisation by crops (about 20% of urea-N), the highest in liquid sludge (30%) and intermediate values in dewatered material (27%). Because of negative effects of N relative to wheat lodging and quality of beet sugar, the disposal on agricultural land of liquid sludge requires particular care, whilst the application of dewatered sludge or compost appears much safer to crops.

Introduction

Each year the municipal sewage purification plants of Emilia Romagna produce an average of 278,000 tons of sludge (52,000 t DM), 48% of which are disposed on agricultural land. This material is used by farmers as fertiliser, but the effects on crop and soil of its continuous spreading have been experimented very little in our environment. With the aim to obtain a better knowledge of the problem we are carrying out a long term study on the agronomic efficacy and environmental hazard of the disposal on farm land of the sludge and compost from a sewage purification plant. Of this research the first 6 years' results regarding crops are discussed in this paper, whilst data on the risk of soil pollution are reported elsewhere.

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Materials and methods

The research, which started in 1988 and is still in progress, takes place at the 'M. Marani' Experimental Farm, near Ravenna, on fields on the plains in which three course rotations are carried out in such a way that all the three crops are grown each year. The crops are maize (*Zea mays L.*), wheat (*Triticum aestivum L.*) and sugarbeet (*Beta vulgaris L.*). Sludge application is compared with mineral fertilisation. The inorganic dressings consist of 4 increasing rates of urea (0- 33- 66 and 100% of the recommended input, i.e. 180, 120 and 300 kg N ha⁻¹ for wheat, sugarbeet and maize, respectively) plus a unique superphosphate supply (100 kg P₂O₅ ha⁻¹ for maize and wheat and 150 for sugarbeet). The organic fertilisations, which are applied each year on the same plots, consist of a factorial combination of the following treatments:

- 1) Three types of waste material: liquid sludge, dewatered sludge and compost.
- 2) Two application rates: 7.5 and 15 t DM ha⁻¹ yr.⁻¹, the first of which corresponds to the maximum amount allowed by the Italian legislation for soils with pH> 7.5 and CEC> 15 meq 100 g⁻¹.
- 3) With or without an extra application of urea and superphosphate at rates which are fixed so as to reach the highest NP supply with mineral dressing.

Table 1 Main characteristics of the effluents applied. Means of 6 years.

	An. method	Liquid sludge	Dewatered sludge	Compost
Dry matter (%)	IRSA (a)	3.27	24.18	57.52
Total N (% dry wt)	APHA (b)	5.96	4.20	2.83
NH ₄ ⁺ -N (% Total N)	IRSA (a)	33.2	15.7	13.1
P (% dry wt)	APHA (b)	1.66	1.56	1.19
K (% dry wt)	IRSA (a)	1.74	0.75	1.10
Org. C (% dry wt)	G.U. (c)	31.5	28.8	24.5
pH	IRSA (a)	7.76	7.88	6.98

(a) IRSA, 84-86. 'Metodi analitici per i fanghi. Parametri chimico-fisici'. Quad. 64, Roma.

(b) American Publ. Health Ass., 1985, 'Standard methods for the examination of water and wastewater'.

(c) Gazzetta Ufficiale Italia suppl. 196, 23/8/1989, 'Approvazione dei metodi ufficiali per i fertilizzanti'.

All organic materials, whose main characteristics are reported in table 1, derive from the same purification plant of mixed (municipal and industrial) wastewater with a potential of 90,000 population equivalent. Liquid sludge is the anaerobically digested effluent stored in a tank for at least 3 months. Dewatered material is produced by a horizontal belt filter and is stored in open air. Compost is obtained from dewatered sludge mixed with straw (9:1 w/w sludge-straw) treated in a windrow system for at least 2 months and cured for a further 1-1.5 months. Sludge spreading is performed in the fall, before soil tillage, phosphate fertiliser is applied in presowing whilst urea is top dressed on crops in two fractions. All crop residues, except for sugarbeet leaves, are removed from the field. The experimen-

tal plots (49 m^2) are distributed in three adjacent fields according to randomised block designs with four replications. The soils at the experimental site are silty-loam and their main characteristics are reported in table 2. Their pH and CEC are higher than the thresholds authorised in Italy for sludge application ($\text{pH} > 5$ and $\text{CEC} > 8 \text{ meq } 100\text{ g}^{-1}$).

Table 2 Soil characteristics assessed at the start of the experiment. Analytical methods according to SISS (1985): 'Metodi normalizzati di analisi del suolo', Edagricole, Bologna.

	Average	C.V. %
Sand (%)	23	44.2
Silt (%)	55	13.4
Clay (%)	22	43.6
pH in H_2O	7.8	4.7
Organic matter (%)	1.6	11.3
N-Total (%)	1.2	13.7
Available P (ppm)	16	35.5
Exchangeable K (ppm)	177	30.4
CEC (meq 100 g^{-1})	13.9	14.8

Results

During the first two cycles of rotation the spreading of sludges and compost neither caused phytotoxicity symptoms on crop nor showed the adverse effects on crop emergence which were found by other Authors (e.g. Coker, 1978). During the experiment slight influences of climate on the performance of fertilisers were observed; thus the discussion of results will concern the averages of data collected over the 6 years. Moreover it will be focused only on wheat and sugarbeet because both mineral and organic fertilisation had scarce effects on maize (table 3).

Table 3 Effects of mineral and organic fertilisation on maize grain yield (t ha^{-1} 85.5% DM). Means of 6 years. Sludge and compost values are means of the two rates and mineral integration.

Urea N kg ha^{-1}	Maize yield	Effluent	Maize yield
0	9.59	Liquid sludge	9.71
100	9.80	Dried sludge	9.69
200	9.65	Compost	9.58
300	9.76		
L.S.D. (0.05)	0.17		n.s.

Wheat

Urea increased wheat yield up to the first rate (60 kg N ha^{-1}); higher N supplies gave lower yields (table 4) mainly due to the intensifying of plant lodging, which was particularly severe in the years: 1989–90–91 and 94. On average, organic materials gave yields similar to those obtained with the highest rate of mineral

dressing. The best production was observed for compost without mineral integration. The application rate had no significant effect while the addition of urea to sludges and compost was always found to be negative. Both mineral and organic fertilisation improved the vegetative growth of the plant and favoured lodging (table 5). This phenomenon showed a linear response to urea application rates and was particularly increased by liquid sludge.

Table 4 Effects of fertilisers on wheat grain yield ($t \text{ ha}^{-1}$ 87% DM). Means of 6 years. Sludge and compost values are averages of two application rates.

Urea N kg ha^{-1}	Effluent	Mineral integration	
		NO	YES
0	6.13	Liquid sludge	6.10
60	6.81	Dried sludge	6.25
120	6.55	Compost	6.46
180	6.10		5.77
L.S.D. (0.05)	0.43		0.25

Table 5 Effects of mineral and organic fertilisation on plant height, crop biomass and lodging of wheat. Means of 6 years. Sludge and compost values are means of the two rates and mineral integration.

	Plant height (m)	Aboveground biomass ($t \text{ ha}^{-1}$)	Wheat lodging (%)
Urea N (kg ha^{-1})			
0	0.72	12.4	1.5
60	0.75	13.7	6.5
120	0.76	13.6	24.5
180	0.76	13.8	35.8
L.S.D. (0.05)	0.02	0.8	10.0
Liquid sludge	0.77	13.8	41.1
Dried sludge	0.76	13.6	35.9
Compost	0.75	13.4	28.4
L.S.D. (0.05)	0.01	n.s.	4.4

Table 6 Effects of urea rate and organic fertilisers on the Harvest Index (%) of wheat. Means of 6 years. Sludge and compost values are averages of the treatments with and without mineral integration.

Urea N kg ha^{-1}	Effluent	Application rate ($t \text{ DM ha}^{-1}$)	
		7.5	15
0	44.6	Liquid sludge	38.8
60	44.2	Dried sludge	40.9
120	42.5	Compost	42.9
180	39.1		38.2
L.S.D. (0.05)	1.7		1.2

Wheat lodging may have been the major cause of the low values of crop Harvest Index (grain dry weight as % of the total plant organic matter) observed for high N supply (table 6). Organic fertilisation resulted in H.I. often lower than the highest rate of urea. Liquid sludge gave the lowest percentages; the best H.I. was observed for compost, but the superiority of this material disappeared at the highest application rate.

Nitrogen fertilisation also worsened the kernel unit weight of wheat, which was found to be decreasing with urea N according to a precise linear response. This relation was used to estimate the availability of the nitrogen in sludges to the crop. The results obtained (table 7) indicate that N in the lowest rate of sludge and dried sludge correspond to 30% of N-urea approximately, whilst nitrogen in compost has a lower biological value (26%). Doubling the spreading rate decreased the nitrogen efficacy of all the sludges, but the reduction was slight for compost.

Table 7 Influence of N input with effluents compared with urea N on the weight of individual kernel of wheat. Means of 6 years without mineral integration. The equivalencies were calculated on the basis of the following model: Kernel weight (mg) = 39.21 – 0.046 kg urea-N ha⁻¹; R² = 0.996**.

Effluent	Application rate t DM ha ⁻¹	Actual N input kg ha ⁻¹ yr. ⁻¹	Kernel unit weight mg	Urea-N equivalence kg N ha ⁻¹	%
Liquid sludge	7.5	456	32.8	193	31
	15	912	30.6	186	20
Dried sludge	7.5	320	34.8	95	30
	15	640	32.2	153	24
Compost	7.5	214	36.7	55	26
	15	428	35.0	92	22

Sugarbeet

Fertilisation improved root yield but the negative correlation with sugar content reduced its effect on sucrose production (table 8).

Table 8 Effects of mineral and organic fertilisation on root yield, sugar content and quality of sugarbeet. Means of 6 years. Sludge and compost values are means of the two application rates and mineral integration.

	Root yield t ha ⁻¹	Sugar yield t ha ⁻¹	Sugar content %	Sugar quality (% / °Brix)
Urea N (kg ha ⁻¹)				
0	51.3	8.39	16.2	85.4
40	51.8	7.99	15.4	85.0
80	56.5	8.80	15.5	84.7
120	59.8	8.73	14.6	84.0
L.S.D. (0.05)	4.9	n.s.	0.5	0.8
Liquid sludge	59.8	8.34	14.1	82.2
Dried sludge	57.2	8.30	14.5	83.3
Compost	53.4	8.17	15.3	84.2
L.S.D. (0.05)	2.6	n.s.	0.4	0.4

The yields of roots and sugar obtained with sludges were similar to those measured with mineral fertilisers. On average, root yield caused by liquid sludge was equal to that of the higher rate of urea while compost yielded 6 t ha⁻¹ less. Sugar content and quality showed a linear decrease with urea N input. Sugar concentration was influenced by both the rate of sludge application and the addition of min-

eral fertilisers (table 9): the lowest values were observed with the highest amount of liquid sludge; the highest percentages with compost, whose performance was not influenced by the application rate.

Table 9 Effects of organic fertilisation at two rates and with or without mineral integration on sugar content of sugarbeet (%). Means of 6 years.

Effluent	Appl. rate (t DM ha ⁻¹)		Mineral integration	
	7.5	15	NO	YES
Liquid sludge	14.4	13.7	14.0	14.1
Dried sludge	15.0	14.1	14.8	14.2
Compost	15.2	15.3	15.5	15.0
L.S.D. (0.05)	0.4		0.3	

The integration with mineral fertilisers had slight effects on liquid sludge efficacy but enhanced the negative effects of dewatered sludge and compost on sugar content.

The purity of beet sugar (table 10) was markedly worsened by sludge application: the poorest sugar quality was observed with liquid sludge at the higher rate, whilst the negative effects of compost were scarce and little influenced by the amount supplied.

The influence on sugar quality was mainly due to the content of undesirable elements, like Na, K and amino-N, which was particularly high following sludge spreading and heavy urea dressings (table 11).

Because of the linear responses, in sugarbeet the availability of sludge N can be evaluated on the basis of the production of aboveground biomass (table 12) and amino-N sugar content (table 13).

Table 10 Effects of organic fertilisation at two rates and with or without mineral integration on sugar quality (% content / °Brix) of sugarbeet. Means of 6 years.

Effluent	Appl. rate (t DM ha ⁻¹)		Mineral integration	
	7.5	15	NO	YES
Liquid sludge	82.9	81.5	82.4	82.0
Dried sludge	83.8	82.7	83.3	83.3
Compost	84.3	84.1	84.8	83.5
L.S.D. (0.05)	0.5		0.5	

Table 11 Effects of mineral and organic fertilisation on the content of undesirable elements in sugarbeet pulp. Means of 6 years. Sludge and compost values are averages of the two application rates and mineral integration.

Urea N (kg ha ⁻¹)	Amino-N meq 100g ⁻¹ sugar	K meq 100g ⁻¹ sugar	Na meq 100g ⁻¹ sugar
0	3.24	4.86	2.47
40	3.88	4.64	2.72
80	4.38	4.87	2.77
120	4.98	4.86	3.05
L.S.D. (0.05)	0.55	0.33	0.45
Liquid sludge	5.80	5.19	4.04
Dried sludge	5.21	4.84	3.67
Compost	4.68	4.94	3.13
L.S.D. (0.05)	0.27	0.18	0.25

Table 12 Influence of N input with effluents compared with urea N on the aboveground biomass (tops) of sugarbeet. Means of 6 years without mineral integration. The equivalencies were calculated on the basis of the following model: Biomass ($t\ ha^{-1}$) = $18.52 + 0.083\ kg\ urea-N\ ha^{-1}$; $R^2 = 0.998^{***}$.

Effluent	Application rate $t\ DM\ ha^{-1}$	Actual N input $kg\ ha^{-1}\ yr^{-1}$	Top biomass $t\ ha^{-1}$	Urea-N equivalence	
				$kg\ N\ ha^{-1}$	%
Liquid sludge	7.5	456	30.8	147	32
	15	912	31.1	151	17
Dried sludge	7.5	320	26.6	97	30
	15	640	30.3	138	22
Compost	7.5	214	21.5	36	17
	15	428	24.5	72	17

Table 13 Influence of N input with effluents compared with urea N on the amino-N content of sugar. Means of 6 years without mineral integration. The equivalencies were calculated on the basis of the following model: Amino-N (meq $100g^{-1}$ sugar) = $3.26 + 0.014\ kg\ urea-N\ ha^{-1}$; $R^2 = 0.999^{***}$.

Effluent	Application rate $t\ DM\ ha^{-1}$	Actual N input $kg\ ha^{-1}\ yr^{-1}$	Amino-N meq $100g^{-1}$	Urea-N equivalence	
				$kg\ N\ ha^{-1}$	%
Liquid sludge	7.5	456	5.00	122	27
	15	912	6.38	218	24
Dried sludge	7.5	320	4.59	93	29
	15	640	5.62	165	26
Compost	7.5	214	3.79	37	17
	15	428	4.21	66	16

In both instances the nitrogen in compost showed a lower efficacy (17% of urea N) than liquid effluent (27 – 32%) and dewatered sludge (29 – 30%). Moreover, doubling the application rate significantly reduced the availability of N in liquid and dried sludge, but did not affect the utilisation of compost N.

Conclusions

As usual, the effects of sludges on crops observed in the present research can mainly be ascribed to the available nitrogen supplied to the soil by their spreading (Genevini, 1991, Steffens & Benedetti, 1993). The estimated utilisation of N in compost (17 – 26% of urea-N) was similar to the availability of cattle and pig slurry applied in the fall (15 – 20%) (Unwin *et al.*, 1986, Beauchamp, 1983, Spallacci, 1991) and its efficacy in dewatered and liquid sludge was found to be even higher (27 – 31%, respectively). In accordance with Adams (1973), Boschi *et al.* (1981) and De Haan (1984) for compost and liquid sludge the equivalence with urea-N appeared comparable with their NH_4 content. The drastic reduction of N availability brought about by doubling the rate of sludge can be accounted for by a higher volatilisation from heavy spreading of liquid material (Unwin *et al.*, 1986 and Beauchamp, 1986). The utilisation of nitrogen of dewatered sludge was found similar to its availability in liquid sludge and higher than that of compost. This result, also reported by Hall & Williams (1988), could be explained by a faster release of this element from the organic fraction compared to compost

(Beauchamp, 1983); in addition by lower losses by volatilisation both during and soon after spreading than from liquid sludge due to a lower percentage of mineral N in the dried effluent. In the research the effects of nitrogen on crops were mainly negative (increase in wheat lodging and worsening of sugarbeet quality as found by De Haan, 1984). In these conditions the major problems were caused by liquid sludge, particularly at the highest application rate. Dried material gave intermediate results. Compost showed the best performances: its application to land, even at a rate which is double that allowed by Italian legislation, always appeared safe to crops. The addition of mineral fertilisers to sludges and compost was found to be unadvisable because it was useless or even negative to crop yield.

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Compost from Selected Organic Wastes as a Substitute for Straw-bedded Horse Manure in *Agaricus Bisporus* Production*

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Abstract

Compost from selected organic waste (vegetable waste from fruit and vegetable market and pruning residues) was used alone and in mixture (25% of volume) with a substrate from straw-bedded horse manure, normally used in mushroom farms, for the cultivation of *Agaricus bisporus* (common white mushroom). The composting process lasted 20 days. After this period the mature material was transferred to the culture room. The substrate from straw-bedded horse manure was used as a control.

The compost was found to be suitable for the cultivation of *A. bisporus*. The production of beds with the compost from selected organic waste alone was 18.34 kg/m², the beds where this compost formed 25% of the volume was 23.21 kg/m² and the beds with the compost from straw-bedded horse manure alone was 24.93 kg/m². No differences were observed in the quality of the mushrooms from the three different substrates.

Introduction

All human activity which produces goods and services also produces waste and the disposal and/or recycling of this waste has for some years aroused a great deal of social and economic interest.

In Italy, the quantity of solid urban refuse and similar waste produced by the catering sector, the agroindustrial sector and the commercial sector linked to the sale of food products is around 50 million tons, 20 million produced by civil activities and 30 million by production. Thirty percent of this material is made up of animal and vegetable organic waste.

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The composting process makes it possible to control the transformation of appropriately pretreated organic waste to render it suitable for use in agriculture. However many composting experiences have failed to give satisfactory results due to the poor quality of the final product and the absence of a suitable commercial approach (Ferrari and Galli , 1990; Picci and Ferrari 1991). Some agricultural sectors, although they require large quantities of organic substances have been not well explored as potential users of the compost. Most waste materials contain large amounts of cellulose, hemicellulose and lignin which can support the growth of edible mushrooms. Various biologically recycled wastes (municipal, agricultural and industrial wastes) have been studied with different results for mushroom production in other countries (Chang and Miles, 1989; Dergham *et al.*, 1991; Rinker, 1991; Senyah, 1988; Tasnadi, 1988; Tolentino, 1987).

The European farms which produce *Agaricus bisporus* at an industrial level, use large quantities of straw-bedded horse manure which is the starting material for the cultivation of these mushrooms. This material is not easy to find and is generally expensive, especially due to the high transport costs. The replacement, even partial, of straw-bedded horse manure with compost obtained from the treatment of organic waste would provide an effective commercial outlet for the compost and probably reduce the cost of mushroom production.

One preliminary study (Govi *et al.*, 1993) demonstrated that the compost obtained from the selected collection of solid urban waste had characteristics which made it suitable for the cultivation of *Agaricus bisporus*. The need to make a few changes to the composting process to obtain a final product more suitable for use in mushroom farms was also highlighted on this occasion. This paper reports the results of subsequent investigations.

Materials and methods

The trial was carried out in two distinct stages. The first took place in the AMIA composting plants at Rimini, the second in the 'Fungospergola' mushroom farm at Anzola Emilia (Bologna), where the compost was used as a substrate for cultivating *Agaricus bisporus*.

Compost production

In 1989, AMIA started an experimental selected collection of organic waste from large users on the basis of the following assessments: a) the predominance of the organic fraction in solid urban refuse, especially in summer when in the city of Rimini alone more than 1500 hotels and 400 firms in the food sector are in full activity as well as the fruit and vegetable market; b) the poverty of the soil around Rimini as regards the organic fraction, makes the addition of humus essential; c) the presence in this area of numerous agricultural/food industries with wastes of a predominantly organic nature; d) the availability of approximately 1000 tons/year

of pruning residues produced by AMIA from the public parks and trees. The organic waste treatment plant consists of three functional units:

- 1) Material reception area, consisting of three hoppers, one for storing the waste collected from canteens and agricultural industries, one for woody residues and the last for biological sludges.
- 2) Area where the substrate is prepared; here the waste material is supplied to a mixer in the required proportions, making it possible to determine the value of the C/N ratio and the humidity value.
- 3) Bio-oxidation area, where the substrate is placed in an area equipped for the forced ventilation of the windrow, regulated by a computerized monitoring system.
- 4) Refining area, where the mature material undergoes screening to eliminate any large impurities.

In the spring of 1993, a mixture was placed in the bio-oxidation area consisting of the following materials:

– vegetable organic waste from the fruit and vegetable market	68% (in weight)
– residues from the pruning of the city trees	25%
– biological sludge from water treatment plants	7%

Chicken manure (7%) and calcium sulfate (6%) were added to the mixture, since these materials are normally used in mushroom beds as integrators of the straw-bedded horse manure substrate. While the material remained in the maturation section, daily samples were taken from the heap to check the organic matter oxidation progress. In particular, the following parameters were checked: temperature, one of the most important for the final product quality, C/N ratio, humidity, pH, ashes.

At the end of the process the mature compost was passed through a screen to remove the large pieces. The screened product, characterized by pieces measuring 20 mm, was analyzed to determine the presence of heavy metals and then immediately transported to the mushroom farm where the next stage of the experiment took place.

Production of Agaricus bisporus

As soon as the material arrived from the Rimini composting plant it was placed in the culture room containing 12 overlapping beds, divided into two groups of 6 each, separated by a corridor. Each bed measured 30 m² and contained 100 kg/m² of substrate. Four beds were prepared with the horse manure compost normally used in the mushroom farm for the production of *A. bisporus* and used as a control. This material had undergone a fermentation process. Four other beds were prepared with the compost coming from the AMIA composting area and the four remaining beds were filled with a substrate consisting of 25% compost from selected organic wastes and 75% material from straw-bedded horse manure. These percentages refer to volume. At the end of the filling stage, the controlled heating

(pastorization) began by delivering steam to the culture room which created a compost temperature of between 55 and 65°C for a few hours. After this, the temperature decreased gradually until it stabilized after about 10 days at around 30°C. At this point the fungal mycelium was added with a commercial product (1 litre/q substrate). We used *A. bisporus* strain 333 (Champion, France) which has excellent quality features (large fruit bodies with white compact flesh); this strain has very particular nutritional requirements and is less resistant than other strains to attacks by pathogens. This made it possible to make a better assessment of the treatments. Cropping began 22 days after spawning and continued for 44 days. In the seven flushes the mushrooms were collected separately from the three different media.

The weight data were evaluated statistically according to the Student-Newman-Keul test.

Results

Compost production

Figures 1, 2 and 3 show the patterns for temperature found at three different depths in the heap, for the C/N ratio, humidity, ashes and pH.

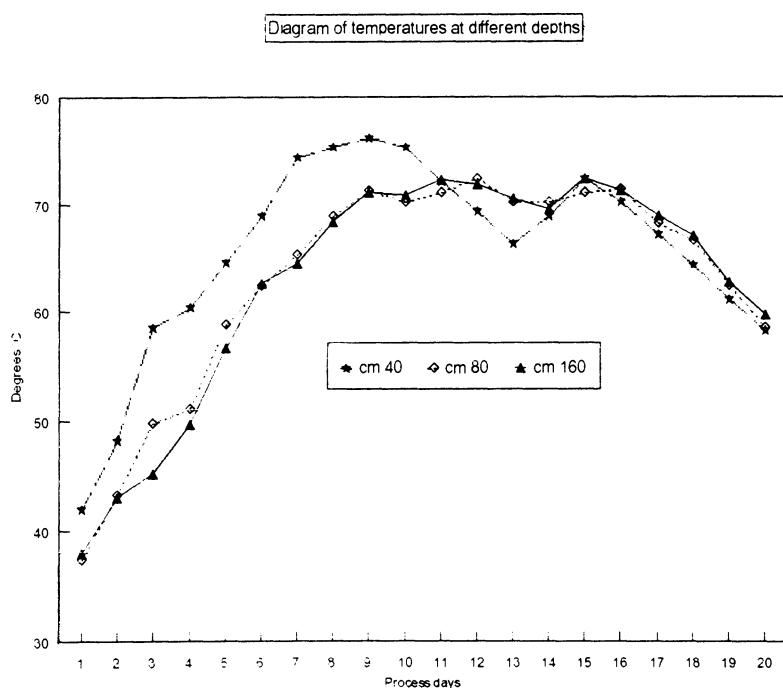


Figure 1

An examination of the graphs reveals that the duration of the bio-oxidation stage was reduced from the normal 45-60 days to 20 days, since the values for these parameters after this period were suitable for use in the mushroom farm. The high

temperatures, beyond 60°C which developed in the heap during the process days guaranteed a sufficient reduction in the harmful micro-organisms, in particular Schizomycetes, strong antagonists to the development of *A. bisporus* (Picci and Ferrari, 1992). The compost was then immediately transferred to the culture room and distributed in the beds, where it underwent the subsequent routine stages adopted for mushroom cultivation.

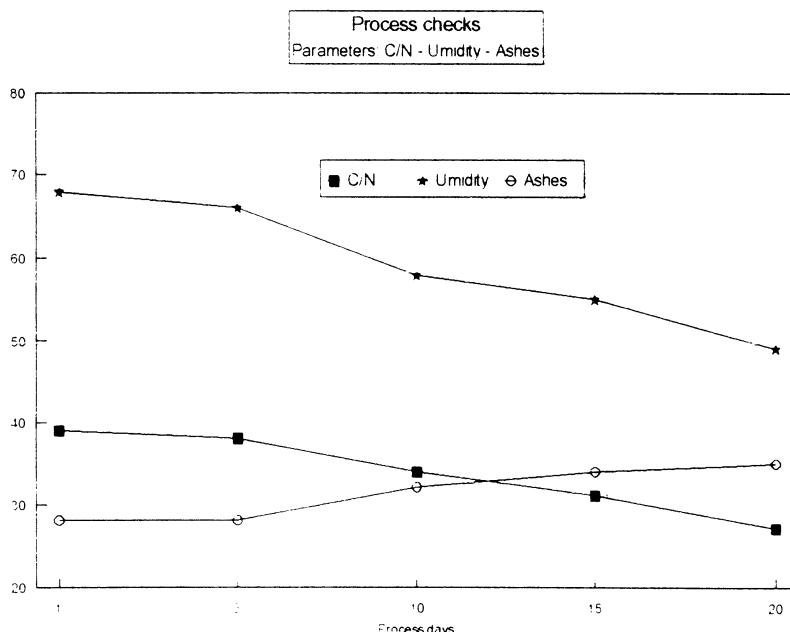


Figure 2

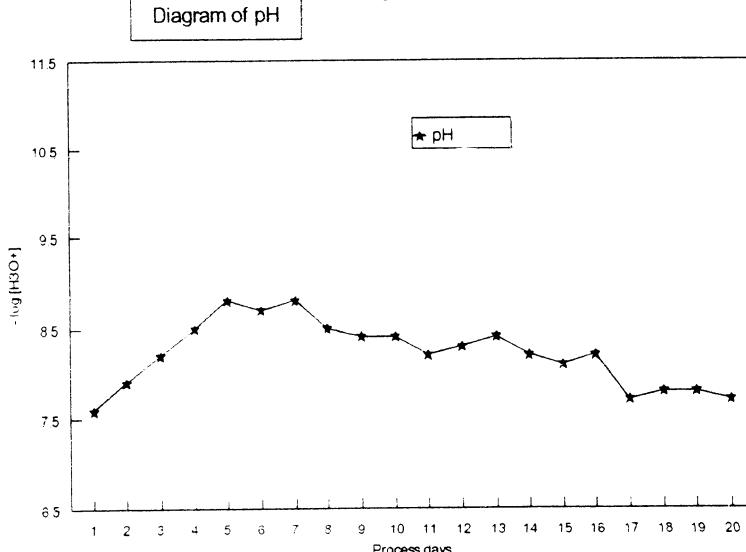


Figure 3

Figure 4 shows the results of compost analysis performed on a sample collected immediately before use in the mushroom bed. As can be seen, the Cd, Ni, Pb, Cu, Zn, Hg contents had low values, well below the legal limits (D.P.R. 915/82 and subsequent decision 27/07/84); this is due to the selection of the organic matrices at the time of collection.

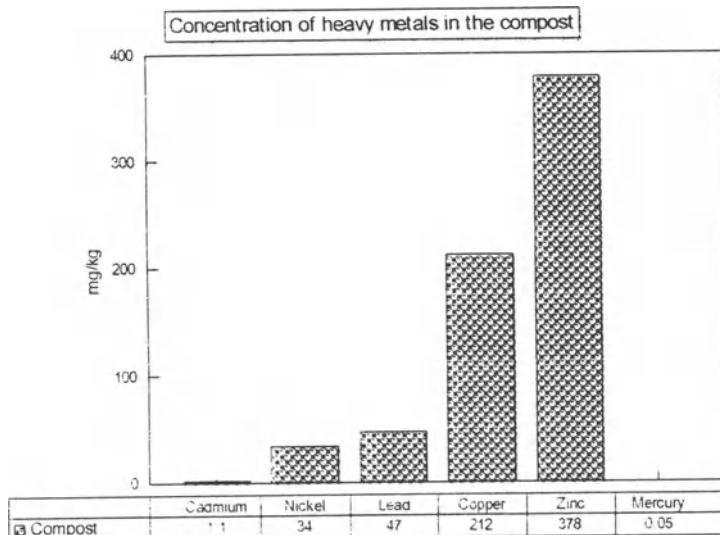


Figure 4

A. bisporus production

Table 1 shows the production of *A. bisporus* obtained with the three treatments in the different flushes expressed as kilograms of fresh carpophores per unit of substrate surface.

An examination of the results shows that the production of the beds containing just the compost from straw-bedded horse manure, normally used in mushroom cultivation and used here for control, and that of the beds in which 25% of the horse manure compost was replaced by compost obtained from selected collection of waste were similar, while the production of the beds containing just the compost from selected organic waste showed a different and opposite trend to that of the previous two.

In the first flush the production of the beds with standard compost alone (control) was the highest (2.97 kg/m^2), statistically lower the production with 25% organic waste plus 75% horse manure (2.09 kg/m^2) while the beds with 100%

organic waste had the lowest (0.61 kg/m^2). In the second flush, the production of the beds with horse manure alone and horse manure plus organic wastes were almost identical (7.03 and 7.08 kg.m^2), while the beds with 100% organic waste were even less productive (1.67 kg/m^2). In the subsequent flushes there was an increase in the productivity of the beds with 100% organic waste compost which, especially in the sixth and seventh flush produced significantly more than the others. When the culture room was emptied, the beds containing 100% organic waste compost were still producing carpophores.

Table 1 Yield of each flush and total yield expressed in kg of fresh mushrooms per square meter of substrate

Flushes	TREATMENTS		
	Control	25%w + 75%hm	100%w
FIRST	2.97 c	2.09 b	0.61 a
SECOND	7.03 b	7.08 b	3.38 a
THIRD	5.16 c	4.97 b	3.01 a
FOURTH	2.41 b	3.05 c	1.67 a
FIFTH	3.45 c	2.41 a	2.67 b
SIXTH	1.80 a	1.71 a	3.69 b
SEVENTH	2.11 a	1.90 a	3.11 b
Total	24.93	23.21	18.34

Different letters on the same line indicate significant difference for $p=0.05$ according to the Student-Newman-Keul test

w = substrate from selected organic waste

hm = substrate from straw-bedded horse manure

control = substrate from straw-bedded horse manure

The same table gives a summary of the total production with all three types of substrate. In the beds containing just horse manure compost, the production of *A. bisporus* carpophores was 24.93 kg/m^2 , the beds containing 25% organic waste compost produced 23.21 kg/m^2 , whereas the beds containing 100% selected organic waste compost produced by the AMIA composting plant in Rimini produced 18.34 kg/m^2 .

The quality of the mushrooms from the three different types of substrates were very similar. No significant differences were observed in colour, shape or size of the carpophores of *A. bisporus* which, regardless of the treatment, showed the typical white colour with a firm flesh.

The presence and diffusion of polluting micro-organisms, especially fungi, in the casing layer and biotic or abiotic carpophore malformations were within the normal limits and no differences were observed between the treatments.

Conclusions

This study demonstrated the possibility of using compost produced from the selected collection of vegetable organic waste from the fruit and vegetable market in the cultivation of *A. biporus* as a supplement to straw-bedded horse manure or

as an alternative substrate, although with a lower production.

The farms which produce mushrooms might therefore be an important sector for the use of this compost. The cultivation of *A. biphorus* in Italy has reached significant proportions: 110,000 tons in 1994. Since it takes on average four kilos of straw-bedded horse manure to produce one kilo of mushrooms it is possible to consider how much organic material from selected waste collection can be recycled in mushroom beds with obvious benefits especially for the environment. Furthermore, the reduction of the duration of the composting process might also involve a saving for the companies which produce the compost.

Further investigation is however necessary to examine an even more productive use of the compost in the mushroom growing sector.

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Use of Composted Societal Organic Wastes for Sustainable Crop Production

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Abstract

Composted organic wastes are increasingly pointed out as alternative to chemical fertilisers for crop production. This paper reports on a trial using sewage sludge compost and municipal solid waste compost at two rates (50 or 100 ton/ha) and two systems of application (incorporation to soil or as surface mulch) for the production of wheat (*Triticum aestivum*) in two consecutive growing seasons: spring (var. Canon) and winter (var. Mercia). Additional treatments were: Nitram (ammonium nitrate, 34.5% N) at 75 or 150 kg of N/ha and a null control. The different treatments were applied in a single dose, in the first season; the objective being the observation of possible residual effects in the second year. There was no statistical difference between the two compost, regarding release of nutrients to soil, biomass production, grain yield and grain quality. Composted societal wastes showed to be able to sustain crop production at levels of quantity and quality similar to those obtained from chemical fertiliser (Nitram, ammonium nitrate, 34.5% N). Results for rates of mineral nutrients at soil level throughout the experiment allow us to conclude that composted societal organic wastes provide nutrients to plants in a balanced way, providing high yields with low risks of soil and underground water pollution. Results for these trials indicate that the residual benefits from compost use for consecutive crops are minimal and, thus, compost should be used as a long term strategy for improving soil fertility, with applications of low doses –up to 50 ton/ha– prior to drilling of each crop or as surface mulch after that.

Introduction

The increasing concern over the environmental implications of the traditional processes of waste disposal added to the growing demand for organic inputs for the agricultural sector, act as the main catalysts for the growing interest in compost pro-

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duction and use (Duggan & Wiles, 1976, Blum, 1992, Lopez-Real, 1994). Compost quality, and in consequence its marketability, is closely linked to the quality of the feedstock material for the composting process. Source separated municipal solid wastes and sewage sludge from residential areas produce a high quality compost with market appeal (Golueke & Diaz, 1991, Epstein *et al.*, 1992, Richard *et al.*, 1993). The mineral composition of composts are a reflex of the material or materials from which they derive, providing there are not significant losses in the composting process (Lopez-Real, 1990, Buchanan & Gliessman, 1991). The availability of nutrients such as N, P and S, is closely related to the maturity of the compost. Well stabilised composts will release nutrients at slow rates, while fresh materials, with high C/N, C/P and C/S relation, will demand nutrients from the soil to complete their decomposition, leading to a competition between soil microorganisms and plants for those elements (Gallardo-Lara & Nogales, 1987, Senesi, 1989). In addition to macro nutrients, composted organic wastes are a rich source of essential plant micronutrients as B, Cu, Zn and Fe (Mays *et al.*, 1973, Epstein *et al.*, 1992). When prepared accordingly to suitable technical systems which will lead to their stabilisation, composted organic wastes directly ameliorate soil chemical, physical and biological factors related to its fertility and, therefore, enhances the soil ability to promote sustainable crop production in the long term (Dick & McCoy, 1993, Piccolo *et al.*, 1992, Zucconi & De Bertoldi, 1986).

This paper reports on a two years trial using sewage sludge compost and source separated municipal solid waste compost for wheat (*Triticum aestivum*) production at Wye College Farm, Southeast England.

Materials and methods

Source separated municipal solid waste (MSW) from the village of Wye and sewage sludge (SS) from non industrial areas in Southeast England were composted under controlled conditions at the Wye College-Composting Unit. The soil was a loamy-clay, with total N = 0.28%, pH = 8.1, CEC = 19.4 me/100g and organic matter content of 4.0%. The average chemical characteristics of the two composts are as follows:

Table 1 Chemical characteristics of the two composts

Compost	Total N%	Organic C	P (mg/kg)	K (mg/l)	Mg (mg/l)	Ca (mg/l)	pH
SS	2.76	18.9 %	18,200	1,340	169	2,073	6.8
MSW	1.81	10.9 %	5,660	2,090	104	458	7.2

Spring wheat (*Triticum aestivum*, var. Canon) followed by winter wheat (*Triticum aestivum*, var. Mercia), were planted under eleven treatments:

SS Compost - 50 ton/ha incorporated (SS50i)

SS Compost - 100 ton/ha incorporated (SS100i)

SS Compost - 50 ton/ha as surface mulch (SS50m)

SS Compost - 100 ton/ha as surface mulch (SS100m)

MSW Compost - 50 ton/ha incorporated (MSW50i)

MSW Compost - 100 ton/ha incorporated (MSW100i)
 MSW Compost - 50 ton/ha as surface mulch (MSW50m)
 MSW Compost - 100 ton/ha as surface mulch (MSW100m)
 Nitram (Ammonium nitrate, 34.5% N) – 75 kg N/ha (N75)
 Nitram (Ammonium nitrate, 34.5% N) – 150 kg N/ha (N150)
 Null Control

Spring wheat was drilled in late March/1993, all 'i' treatments were applied just before drilling and incorporated at 150 mm depth. The mulch treatments were applied 24 hours after drilling. Nitram doses were divided in three applications: after drilling, at GS21, and at GS32.

For the winter wheat, drilled in late September/1994, no further application of the treatments was done, in order to evaluate the effect on plant development of any residual nutrients still in soil. In both cases, samples from soil and plants were collected throughout the experiments for nutrient availability and growth parameters evaluation. At harvest, values for total grain yield were recorded and adjusted to 14% moisture content, and grain samples were kept for quality assessment. Soil samples were analysed for NO_3^- -N, NH_4^+ -N, P, K, Mg, and Ca (ADAS, 1988). Grain quality was assessed for: Thousand Grain Weight, Falling Number (Perten, 1964) and Total Protein (Kjeldhal extraction).

Results and discussion

*Spring Wheat (*Triticum aestivum*, var *Canon*) – 1993*

Results from soil chemical analyses show that composted societal wastes released to soil quantities of nutrients which were proportional to their content in the different compost and the rates of application. Levels of nitrogen (Figure 1) in soil indicate that composted sewage sludge and source separated municipal solid waste can be used as source of nitrogen for spring wheat production, for the study site. Due to high soil pH, NH_4^+ -N, was not find in any sampling.

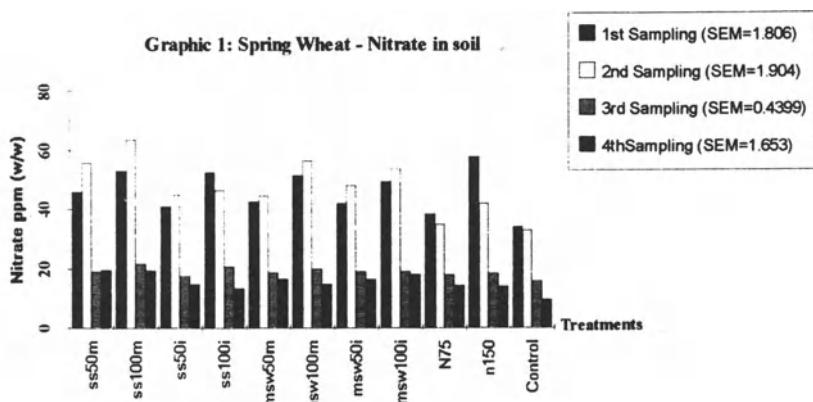


Figure 1 Spring Wheat – Nitrate in soil

Soil chemical analyses show that both composts were able to significantly increase levels of Phosphorus (Figure 2), and Potassium (Figure 3) throughout the experiment. As Ca and Mg occur in soil at high levels compost amendment did not show any effect on those elements, in the short term of the trial.

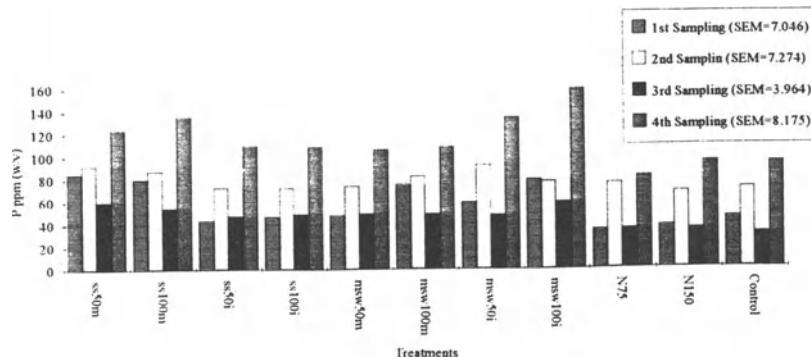


Figure 2 Spring Wheat – Phosphorus in Soil in soil

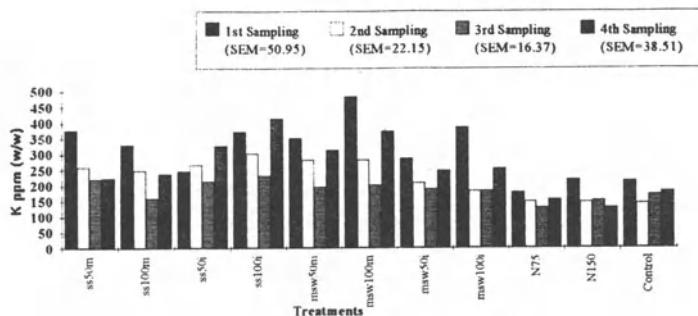


Figure 3 Spring Wheat – Potassium in soil

Composted societal organic wastes, for the present study, showed to be source of essential macro-nutrient to soil and plants at levels that had a positive impact in grain yield (Figure 4). Compost treated plots produced grain yields comparable to those which received mineral nitrogen as fertiliser. All treatments gave positive response when compared to the Control. Results for both composts are not statistically different ($p>0.05$), and there is no difference regarding method of application (incorporation or surface mulch). MSW compost at 50 ton/ha produced lower yield than the higher rate for both methods of application. With the exception of the Control, all treatments produced yields within the range expected for organic spring wheat, var Canon, from the National Institute of Agricultural Botany – NIAB (~ 5,000 kg/ha).

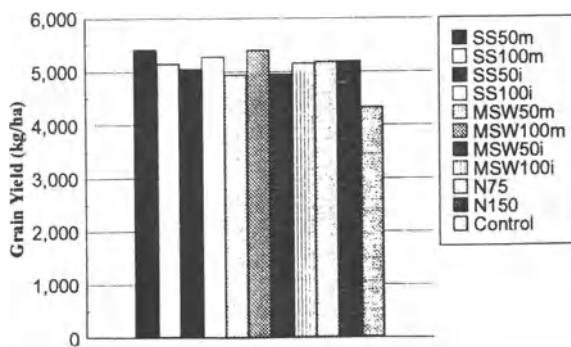


Figure 4 Spring Wheat – Grain Yield (SEM=101.3)

As far as grain quality is concerned, it has been observed that:

- a) with the exception of SS100i, all organic treatments resulted in high Thousand Grain Weight, being statistically ($p<0.05$) different from N150, which produced the smaller grains. As expected, the Control, producing low yield, resulted in high TGW. It is important to highlight that in the compost plots high production, did not bind grain size. There was no statistical difference between the two composts and their method of application (Figure 5).

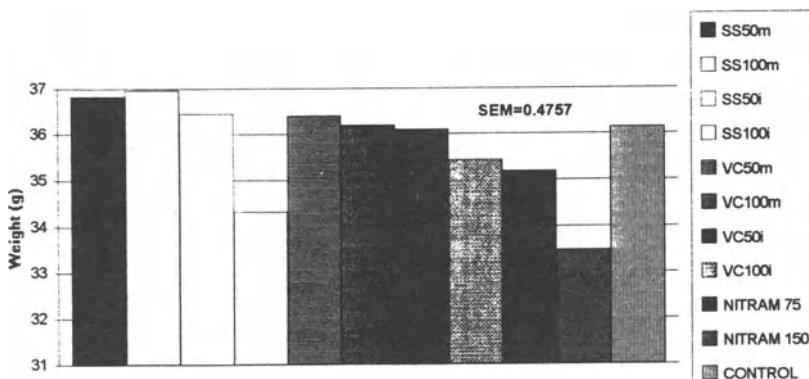


Figure 5 Spring Wheat – Thousand Grain Weight

- b) N150 produced the higher Grain Crude Protein Percent (CP%) of all treatments. For the compost plots, the '100i' treatments resulted in better results, with minimal difference among the others. Overall, both the mineral and the organic treatments resulted in higher GCP% than the control (Figure 6)
- c) Falling Number (Perten, 1964) is a standard method for the determination of alpha-amylase activity in flour, its results are applied to segregate grain suitable for the bakery industry and for feedstuffs purpose. The optimum amylase

activity is found in values between 250–300. Results over 300 mean low amylase activity, indicating a sound wheat, which will produce dry bread crumb and reduced loaf volume. All treatments resulted in values for FN between 250–300. The higher FN was for N150 (Figure 7).

When compared to a well established and highly productive system of cereal production, mineral nitrogen fertilisation, the use of composted societal organic wastes have shown to be able to produce yields which were similar in quantities and, in some extent better in quality. Compared to results for the Control, composts clearly produced overall better results.

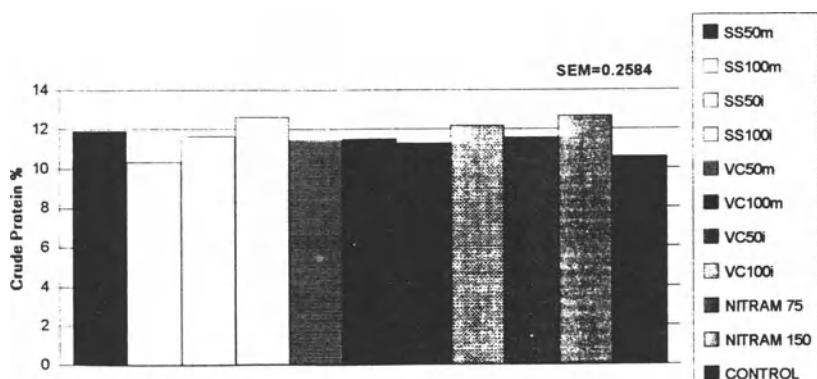


Figure 6 Spring Wheat – Grain Crude Protein

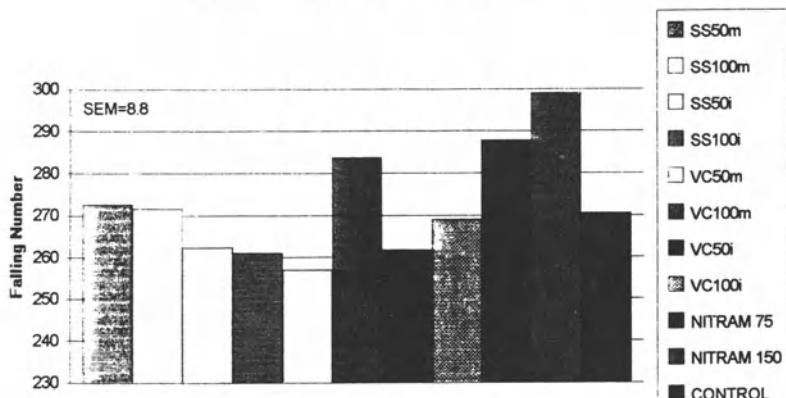


Figure 7 Spring Wheat – Grain Baking Quality

Winter wheat (*Triticum aestivum*, var. *Mercia*) – 1993/94

The same set of variables analysed for the spring wheat were assessed for the winter crop. Levels of nitrate in soil were much lower than in the previous season, but increased throughout the experiment for all treatments, probably due to the min-

eralisation of that element from the original soil organic matter pool and from the composts applied in 1993. Orthogonal contrasts for levels of NO_3-N , revealed that: a) there is no statistical difference between composts and between methods of application; b) compost treated plots had higher levels of nitrate in soil, compared to N75, N150 and the Control (Figure 8).

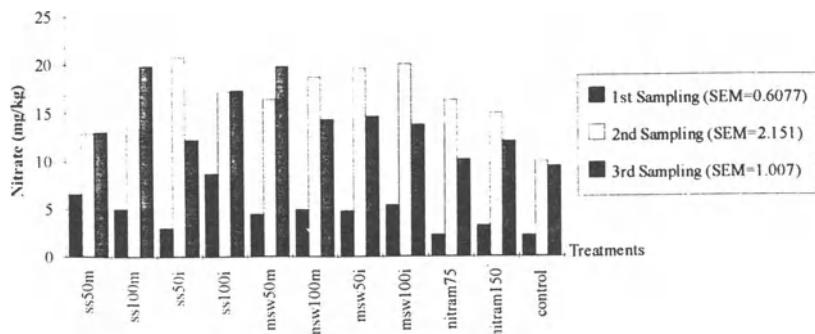


Figure 8 Winter Wheat – Nitrate in soil

Phosphorus also declined from the last sampling for the spring wheat (1993) to the first sampling in this trial, when no statistical difference was found among treatments. It is assumed that most P has been converted to the soil organic fraction, for in the second sampling an increase was observed in soil P content for almost all treatments. As expected compost treated plots showed an overall higher P content in soil than N75, N150 and the Control (Figure 9).

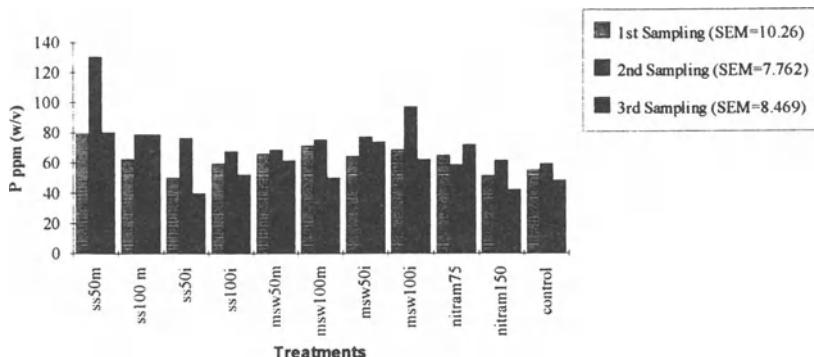


Figure 9 Winter Wheat – Phosphorous in soil

As far as levels of Potassium in soil are concerned, plots which received compost showed higher values, when compared to N75, N150 and the Control (Figure 10). There was no statistical difference between the two composts. At this stage,

differences in the quantities applied did not appear to have any influence in K content in soil.

The higher soil residual nutrient content in the plots treated with compost did not produce increasing grain yields, when compared to the plots which received mineral fertilisation and the Control plots. Overall production was very low – between 2,745 kg/ha for SS100i and 3,490 kg/ha for MSW100i – when compared to NIAB expected yield for that wheat variety in the region.

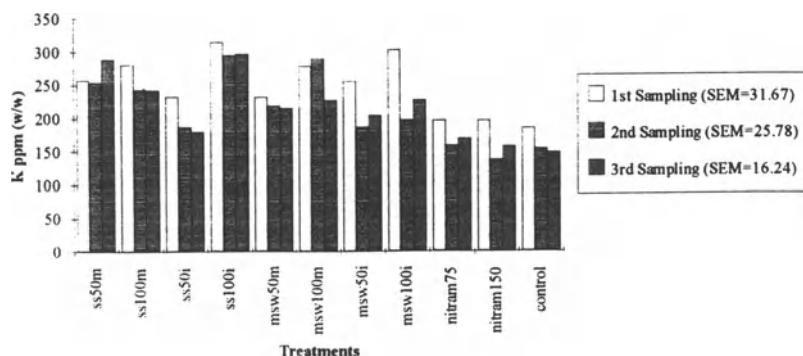


Figure 10 Winter Wheat – Potassium in soil

Regarding grain quality, there were no statistical ($p<0.05$) differences among the treatment means for Grain Crude Protein, Thousand Grain Weight and Falling Number. Levels of crude protein were very low, between 8.75% for MSW100i and 9.35 for SS50i. Mercia is a wheat variety with high Falling Number, and values for this trial were between 329 for SS50m and 345 for MSW100m.

As far as weeds are concern, there has not been observed any effect on weed population from compost application in both crop seasons.

It is clear, from the results above for the study site, that winter wheat did not benefit from the residual nutrients remaining in soil after compost application in the spring, even at higher doses. Despite the differences in composition, sewage sludge compost did not differ from municipal solid waste compost in releasing nutrients to soil and enhancing crop performance.

Conclusions

Environmental and economic pressure on conventional methods of waste disposal led to the return of composting to the agenda. The potential use of compost in agriculture, though, is directly dependent on its quality (Q), which is function of the feedstock material (F), composting process (P) and compost maturity (M): $Q = f(F, P, M)$.

This research has shown that good quality compost is able to enhance crop pro-

duction even in a very fertile soil. Composted organic societal wastes are source of macronutrients in quantities enough to sustain wheat production at levels comparable to those obtained with the use of mineral fertilisation and superior to the null Control. As compost at high doses (100 ton/ha) did not produce significant marginal increases in production, applications of up to 50 ton/ha are suggested in order to avoid luxurious build-up of nitrogen in soil with potential risk of underground water contamination. Under other circumstances, for example soils with low organic matter and/or low fertility, higher applications could be favourable for some time. In the long run, rates of application may be reduced as soil fertility is expected to increase with the constant use of composted organic materials (Allievi, 1993; Maynard, 1993).

As nutrients remaining from one crop season to the following one are not sufficient to promote satisfactory yields, it is possible to suggest, from the results obtained, that regarding management practices compost application should be done at drilling of each new crop, either incorporated to soil or as surface mulch. There are not statistical differences between the two methods of compost application, thus the use of one or the other will depend on the dynamics of each individual farm.

In addition to meeting the demand from organic farmers for a reliable and constant source of compost, composted societal organic wastes may be of great importance for less developed regions which struggle against low fertility soils and are heavily dependent on imports to supply their fertiliser needs. Compost production, being a low-tech process can provide a safe disposal of wastes with the additional benefit of an ever renewable source of nutrients for sustainable agriculture in the developing world.

Further research is needed to assess the effects of composted organic wastes on soil chemical, physical and biological aspects, crops quantitative and qualitative production, weeds population dynamics and the environment, in the long term.

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Effects on the Content of Organic Matter, Nitrogen, Phosphorus and Heavy metals in Soil and Plants After Application of Compost and Sewage Sludge*

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Abstract

This paper summarises the results of six years application of compost and sewage sludge on the content of the heavy metals in crops and on the content of organic matter, total nitrogen, available phosphorus and extractable heavy metals in soil. The trial was carried out on a three course rotation including winter wheat, sugar beet, maize; all the crops in rotation were grown each year. The soil was a silt loam with an average pH of 7.8 and an average CEC of 13.8 meq/100 g.

The experiment consists of treatments with compost from sewage sludge and straw, liquid and dewatered anaerobic digested sewage sludge, at two rates (7.5 and 15 t of dry matter ha⁻¹year⁻¹) and of four treatments with only mineral fertilizers.

The application of organic materials determined an increase of the Zn content in grains and in root and an increase of Cu in sugarbeet root. The other investigated heavy metals (Cd, Cr, Ni, Pb) have not shown significant differences in crops. The increase of the application rate had no effect on the concentration of heavy metals in plants; the application of liquid sludge resulted, some years, in a higher accumulation compared to dewatered sludge and compost. After six years of sludge and compost application, the soil showed an increase in organic matter, total nitrogen, available phosphorus, in extractable Zn and Ni. This increase was higher with the higher rate of application and, for Zn and P, with liquid sludge dressing.

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Introduction

The utilization of sewage sludge on land can be a correct way of disposal, because in this way farmers can be provided with a useful amount of organic matter, nitrogen and phosphorus. The efficiency of nitrogen supplied with sludge and compost was also evaluated in these trials and the results after six years of application are reported elsewhere (Baldoni et al., 1995). The content of organic matter in sludge and compost is 35–75% of dry matter, and their application can maintain, and in some conditions improve, the stock of soil humus (Del Zan, 1989; Johnston, 1980; Levi Minzi et al., 1985). Sewage sludge and compost improve physical and biological properties of soil such as soil porosity and aggregation (Pagliai et al., 1981). They also increase total and available phosphorus in soil (Furrer & Gupta, 1985; Johnston, 1981). The main concern about utilization of sewage sludge and compost on agricultural land is the accumulation of heavy metals in soil and the contamination of crops. Many Authors determined an accumulation of heavy metals in the top soil caused by repeated application of sewage sludge and compost (Barbera, 1987; Chang et al., 1984). The concentration of extractable heavy metals in soil, such as Cu, Zn, Cd, and Ni can be increased by sludge (Andersson, 1984; Kelling et al., 1977). Short term and low rate applications influenced extractable heavy metals, even if their total concentration is not modified by manure. In order to predict the heavy metal uptake by crops, the extractable heavy metal concentration in soil seems to be more useful than total concentration (Paris & Lucianer, 1987), even if the discussion about chemical methods to assess the bioavailability is still on (Kiekens & Cottenie, 1985).

With the aim of protecting the soil and restricting the application of heavy metals with sludge, national regulations were established, following the EU Directive 278/86.

This paper summarizes the results of a six year field trial carried out in the experimental farm 'M. Marani', located in Ravenna (Italy), with the aim of improving the extension service to farmers who are requested to apply sewage sludge and compost on land. The following topics related with sludge and compost application to agricultural land were studied since 1988: fertilizing value of sludge and compost; the accumulation of heavy metals in soil and crops due to application of organic materials.

Materials and methods

The field trial (still underway) involves three crops, maize (*Zea mays* L.) wheat (*Triticum aestivum* L.) and sugarbeet (*Beta Vulgaris* L.) in a three course rotation. All three crops are grown each year. The trial consists of treatments with mineral fertilizers only and treatments with organic materials. In inorganic dressing (N_0 , N_1 , N_2 , N_3), four increasing rates of urea are applied (wheat: 0, 60, 120, 180 kg ha⁻¹ N; maize 0, 100, 200, 300 kg ha⁻¹ N; sugarbeet: 0, 40, 80, 120 kg ha⁻¹ N). P is

applied as superphosphate at the rate of $100 \text{ kg ha}^{-1} \text{ P}_2\text{O}_5$ (wheat and maize) and $150 \text{ kg ha}^{-1} \text{ P}_2\text{O}_5$ (sugarbeet). The organic materials are applied each year on the same plots, following a factorial combination of the following treatments:

1. three types of sludge: anaerobically digested liquid sludge, anaerobically digested dewatered sludge (from belt press), compost obtained from dewatered sludge and wheat straw (rate 9:1 w/w);
2. two application rates: $7.5 \text{ t ha}^{-1} \text{ y}^{-1}$ (R1) and $15 \text{ t ha}^{-1} \text{ y}^{-1}$ (R2);
3. with or without an extra application of urea and superphosphate at rates which are fixed so as to reach the highest NP supply with mineral dressing, considering a sludge N and P efficiency of 20% and 50% respectively.

The landspreading of organic materials is performed before tillage, in the autumn; crop residues, with the exception of sugarbeet leaves, are removed from the field. The experimental plots (49 m^2) are distributed in three adjacent fields, one for each crop. Each treatment is distributed according to a randomised block design with four replications.

The average characteristics of sludge and compost are shown in table 1. Samples were collected before spreading and analyzed for dry matter, volatile solids, organic carbon (Springer Klee), nitrogen (Kjeldahl), phosphorus (metavanadate molibdic complex). Metals were analyzed after mineralization with nitro-perchlorate mixture 3:1 in teflon autoclaves at 160°C for 25' in a microwave oven: Cu, Zn and K (flame atomic absorption); Cd, Cr, Ni and Pb (furnace grafite atomic absorption). DH (degree of humification) was determined according to Ciavatta et al., 1988.

Table 1 Composition of sludge and compost. Average of 6 years.

Parameter	Liquid sludge		Dewatered sludge		Compost	
	Average	Coefficient of variation (%)	Average	Coefficient of variation (%)	Average	Coefficient of variation (%)
DM (g kg ⁻¹)	32.7	21.9	241.8	8.1	575.7	18.0
VS (% DM)	52.0	2.7	49.2	6.1	42.8	14.5
N _{tot} (% DM)	6.0	10.8	4.2	6.8	2.8	17.9
P (% DM)	1.7	8.2	1.6	9.2	1.2	30.5
K (% DM)	1.7	35.1	0.8	8.7	1.1	23.3
C _{org} (% DM)	31.51	12.7	28.81	6.4	24.53	23.9
Cd (mg kg ⁻¹ DM)	2.39	65.1	2.16	45.6	1.86	42.4
Cr (mg kg ⁻¹ DM)	207	33.8	212	28.4	152	27.8
Cu (mg kg ⁻¹ DM)	852	29.4	861	31.9	645	31.3
Ni (mg kg ⁻¹ DM)	258	55.3	253	26.2	208	42.6
Pb (mg kg ⁻¹ DM)	102	61.5	100	46.7	91	46.0
Zn (mg kg ⁻¹ DM)	1456	18.2	1455	21.4	1135	17.0
pH	7.76	1.5	7.88	4.4	6.98	6.3
DH (%)	38.68	5.5	52.71	25.2	68.93	2.4

The soil is mainly a silty loam with the characteristics reported in table 2. Soil samples were collected at the start of the experiment and each year after cropping, before the application of organic materials, from each experimental plot (five sub

samples for each plot). Sampling depth was 40 cm, corresponding to the depth of the soil tillage. The soil samples were analyzed at the start of the experiment according to SISS methods for the following parameters: sand, loam, clay (Pipette method); pH_{H2O}, CEC (BaCl₂ and triethanolamine, pH 8.5), total CaCO₃ (gas volumetric method), active CaCO₃ (Droineau), total nitrogen (Kjeldahl), organic carbon (Walkey Black), available P (Olsen) and exchangeable K (ammonium acetate 1 N, pH 7). Metals were analyzed with the methods adopted for sludge and compost. Available heavy metals were determined according to Lindsay and Norvell, 1978. In the following years (except 1992 and 1993) the extractable heavy metals, nitrogen, organic carbon, available P were determined. A complete set of analysis will be carried out at the end of the experiment.

Table 2 Composition of soil in the first year of experiment. Average of 192 samples.

Parameter		Average
Sand	(%)	23.1
Silt	(%)	54.8
Clay	(%)	22.1
pH		7.75
Total CaCO ₃	(%)	21
Active CaCO ₃	(%)	8.2
Organic matter	(%)	1.60
P _{Olsen}	(mg kg ⁻¹)	16
K _{exchangeable}	(mg kg ⁻¹)	177
N _{tot}	(‰)	1.18
CEC	(meq 10 ⁻² g ⁻¹)	13.82
Cd _{tot}	(mg kg ⁻¹ DM)	< 0.5
Cd _{DTPA}	(mg kg ⁻¹ DM)	< 0.05
Cr _{tot}	(mg kg ⁻¹ DM)	46.3
Cr _{DTPA}	(mg kg ⁻¹ DM)	< 0.2
Cu _{tot}	(mg kg ⁻¹ DM)	68.2
Cu _{DTPA}	(mg kg ⁻¹ DM)	15.16
Ni _{tot}	(mg kg ⁻¹ DM)	43.8
Ni _{DTPA}	(mg kg ⁻¹ DM)	0.58
Pb _{tot}	(mg kg ⁻¹ DM)	14.9
Pb _{DTPA}	(mg kg ⁻¹ DM)	1.77
Zn _{tot}	(mg kg ⁻¹ DM)	78.5
Zn _{DTPA}	(mg kg ⁻¹ DM)	2.30

At harvest, crop samples from all treatments and replications were collected and analyzed (except 1992 and 1993) for the following parameters Cd, Cr, Cu, Ni, Pb, Zn according to the methods adopted for soil and manure.

Results and discussion

Effects of organic materials on crops

The concentration of metals such as Cd, Cr, Ni in wheat and maize grain and sugarbeet root was not significantly influenced by treatments (table 3); Pb was always under the detectable limit (0.2 mg kg⁻¹DM) in all tissues. This result agrees with

findings of other Authors (Kelling K.A. et al., 1977; Paris et al., 1987) and can be related to the soil properties (the low total and extractable concentration of metals, pH, CEC) but also to the low amount of metals added with organic materials (table 4): the first rate always results in an application of metals below the maximum application rate allowed by Italian laws. For metals such as Cd and Pb, not useful for the crop nutrition, application was well below the more restricting standards.

Table 3 Concentration of Cd, Cr, Ni in crops (Average of 4 years).

Metal	Wheat grain	Sugar beet root	Maize grain
Cd (mg kg ⁻¹ DM)	0.05	0.02	< 0.01
Cr (mg kg ⁻¹ DM)	< 0.5	1.11	< 0.5
Ni (mg kg ⁻¹ DM)	1.03	0.64	0.99

Zn showed an increase in grains and sugarbeet root for treatments with organic materials compared to inorganic fertilizers (table 5), in accordance with other experiments (Consiglio et al., 1986; Sauerbeck, 1986). However, the concentration in tissues does not increase over the years, as the lower concentrations were detected after six years of application, according to the findings of other Authors (Tano et al, 1994). Compost determined a trend to a lower accumulation of Zn in grains and in root, but the differences among treatments were statistically significant only some years (table 6), and were not detected after six years of application. Cu concentration shows a slight but significant increase in treatments with organic materials only in sugarbeet root, (table 7), confirming that this element accumulates in root, according to other researches as reported by Genevini et al., 1986. The increase of the application rate of manure and the integration with mineral fertilizers did not show any significant influence on the concentration of heavy metals in grains and in sugarbeet roots.

Table 4 Cumulative amount of elements applied with sludge and compost after six years in comparison with the limits imposed by Italian law.

Parameter	Total amount							
	Liquid sludge		Dewatered sludge		Compost		Legal limit #	
	Low rate	High rate	Low rate	High rate	Low rate	High rate	Lower *	Higher **
Organic carbon (t ha ⁻¹)	14.4	28.8	13.2	26.4	11.2	22.4	—	—
N (kg ha ⁻¹)	2736	5472	1920	3840	1284	2568	—	—
P (kg ha ⁻¹)	756	1512	715	1430	536	1072	—	—
Cd (g ha ⁻¹)	109	218	99	198	85	170	300	900
Cr (kg ha ⁻¹)	9.5	19.0	9.7	19.4	7.0	14.0	—	—
Cu (kg ha ⁻¹)	39.0	78.0	39.3	78.6	29.5	59.0	15.0	45.0
Ni (kg ha ⁻¹)	11.8	23.6	11.6	23.2	9.6	19.2	4.5	13.5
Pb (kg ha ⁻¹)	4.7	9.4	4.6	9.2	4.2	8.4	11.25	33.75
Zn (kg ha ⁻¹)	67.3	134.6	67.3	134.6	52.4	104.8	37.5	112.5

= six years of application.

* = lower limit: limit of application of metals with sludge, in soil where pH < 6, CEC < 15.

** = higher limit: limit of application of metals with sludge, in soil where CEC > 15; pH > 7.5.

Effect of organic materials on soil

Extractable Zn (Zn_{DTPA}) and extractable Ni (Ni_{DTPA}) in soil were influenced by organic materials according to the application rates (figure 1, figure 2).

Table 5 Influence of treatments on the concentration of Zn in crops.

		Zinc		
Crop	Year	Mineral dressing ^{\$}	Sludge and compost ^{\$\$}	Signif.
Wheat grain	1989	54.42	63.96	**
	1990	34.75	42.54	**
	1991	42.12	48.90	**
	1994	36.58	38.11	n.s.
	1989	29.97	30.11	n.s.
Sugarbeet root	1990	23.75	27.92	**
	1991	18.30	22.81	**
	1994	17.14	20.53	**
	1989	30.08	30.92	n.s.
Maize grain	1990	31.49	34.67	n.s.
	1991	40.51	43.11	n.s.
	1994	26.35	27.38	**

n.s. = no significant difference

** = significant difference at the 1% level.

^{\$} Average of treatments with only mineral dressing (N_0, N_1, N_2, N_3).

^{\$\$} Average of two rates of application and 3 types of manure.

Table 6 Effect of the type of manure on Zn in wheat grain and in sugarbeet root.

Treatment	Zinc ($mg\ kg^{-1}\ DM$)		
	Wheat grain		Sugar beet root
	1990	1991	1989
Liquid sludge [§]	47.49	50.21	32.61
Dewatered sludge [§]	42.6	50.73	29.4
Compost [§]	37.55	45.77	28.34
LSD ($P < 0.05$)	4.07	1.47	3.02
Sign.	***	***	*

* , *** = significant difference at the 5%, 0.1% level respectively.

[§] Average of two rates of application.

Table 7 Influence of application of manure on concentration of Cu in crops.

		Copper		
Crop	Year	Mineral dressing ^{\$}	Sludge and compost ^{\$\$}	Signif
Wheat grain	1989	7.46	7.35	n.s.
	1990	5.74	6.25	n.s.
	1991	5.08	5.50	n.s.
	1994	4.75	4.94	n.s.
	1989	14.56	14.37	n.s.
Sugarbeet root	1990	6.34	6.38	n.s.
	1991	6.52	7.52	*
	1994	5.97	6.51	**
	1989	6.43	6.07	n.s.
Maize grain	1990	4.32	4.63	n.s.
	1991	3.24	3.33	n.s.
	1994	2.06	2.03	n.s.

n.s. = no significant difference

* , ** = significant difference at the 5%, 1% level respectively.

^{\$} Average of treatments with only mineral dressing (N_0, N_1, N_2, N_3).

^{\$\$} Average of two rates of application and 3 types of manure.

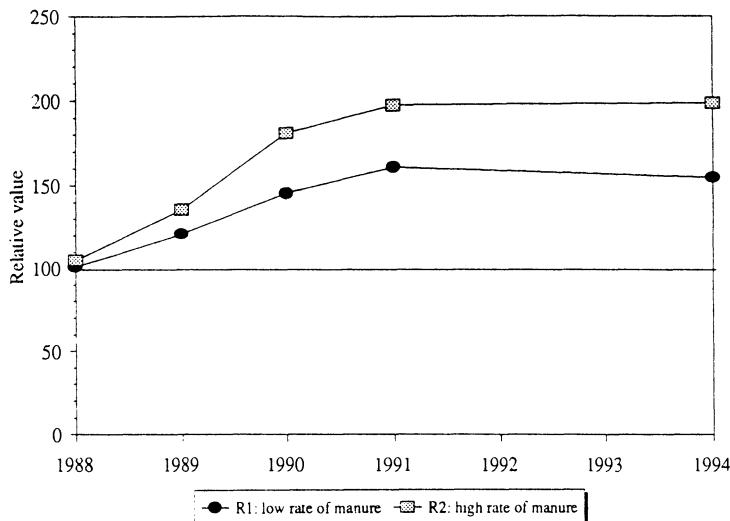
Extractable Zinc in soil

Figure 1 Effect of manure on Zn_{DTPA} in soil compared to mineral fertilizers only (=100). Values for mineral fertilizers are average of four treatments (N₀, N₁, N₂, N₃). Values for manure are average of treatments with sludge and compost without mineral dressing.

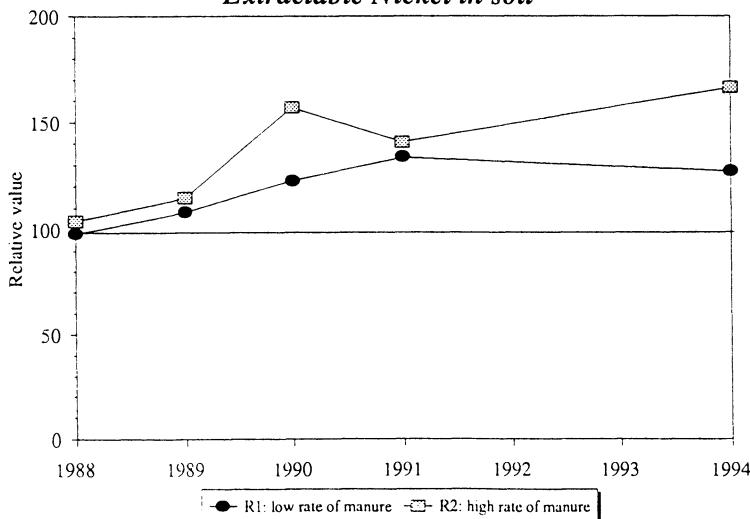
Extractable Nickel in soil

Figure 2 Effect of manure on Ni_{DTPA} in soil compared to mineral fertilizers only (=100). Values for mineral fertilizers are average of four treatments (N₀, N₁, N₂, N₃). Values for manure are average of treatments with sludge and compost without mineral dressing.

After six years, the application of manure determined an increase of Zn_{DTPA} in soil of 55% (R1) and 99% (R2) respectively and an increase of Ni_{DTPA} in soil of 27% and 67% over the application of inorganic fertilizers. The type of organic materials seems to be ineffective for Ni_{DTPA}, while for Zn_{DTPA} liquid sludge determined a significantly higher accumulation compared to dewatered sludge

(which applied the same total amount of Zn) and to compost (table 8). The increase of Zn_{DTPA} following application of manure with relatively high concentrations of this element such as sewage sludge, compost and pig slurry is frequently found by other Authors, also in trials carried out in Italy (Nassisi et al., 1991; Tano et al., 1994). It may be due to the low uptake by crops and to the irrelevant leaching to the subsoil of metals added with sludge (Chang et al., 1984). Rate of application and type of organic materials did not influence the concentration of Cu_{DTPA} in soil even if the total amount of Cu applied was not negligible, ranging from 29 to 79 kg ha⁻¹, probably because of the binding effect of soil organic matter which was improved by application of manure.

Table 8 Characteristics of the soil in 1994 as influenced by six years of treatments.

Treatment	Organic matter (%)	N (%)	P _{Olsen} (mg kg ⁻¹)	Zn _{DTPA} (mg kg ⁻¹)	Ni _{DTPA} (mg kg ⁻¹)
Mineral dressing\$	1.59	1.14	18	2.33	0.45
R1 \$\$	1.68	1.22	23	3.61	0.57
R2 \$\$	1.79	1.32	33	4.63	0.74
Sign.	*	***	***	**	***
Liquid sludge\$\$\$	1.78	1.30	33	4.46	0.66
Dewatered sludge\$\$\$\$	1.71	1.26	25	3.97	0.65
Compost\$\$\$\$	1.72	1.26	27	3.94	0.65
LDS (<i>P</i> < 0.05)			3	0.38	
Sign.	n.s.	n.s.	***	*	n.s.

n.s. = no significant difference

*, **, *** = significant difference at the 5%, 1%, 0.1% level respectively.

\$ Average of treatments with only mineral dressing (N₀, N₁, N₂, N₃).

\$\$ Average of treatments with liquid, dewatered sludge and compost (plots without mineral dressing as integration).

\$\$\$ Average of low rate and high rate of manure (plots without mineral fertilizers as integration).

No increase was detected in the concentration in soil of the other elements, such as extractable Cd, Pb, Cr, even with the high rate of application.

The application of organic materials determined an increase of available P in soil (figure 3), according to the application rate and to the type of waste (table 8). After six years of waste disposal, the increase of concentration of available P in soil treated with the low and the high rate of manure was 28% and 83% respectively over the mineral dressing. Liquid sludge increased the available P in soil more than dewatered sludge and compost (+83% for liquid sludge over +39% for dewatered sludge and +50% for compost), while the latter of the two treatments did not show any significant difference, even if the applied amount of P with compost was about 75% of the amount applied with dewatered sludge. The lower efficiency of dewatered sludge and compost compared to liquid sludge in improving available P in soil may be due to the treatment with aluminium and ferric salts (De Haan, 1980) at the purifying plant, before dewatering.

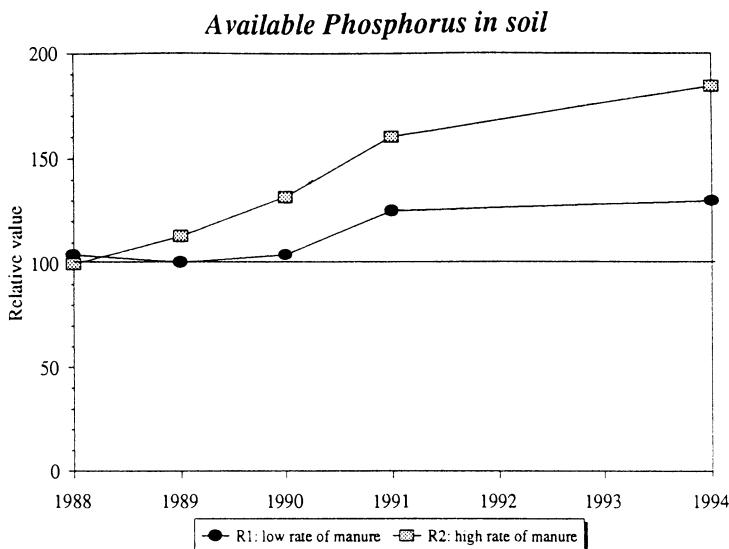


Figure 3 Effect of manure on P (Olsen) in soil compared to mineral fertilizers only (=100). Values for mineral fertilizers are average of four treatments (N_0, N_1, N_2, N_3). Values for manure are average of treatments with sludge and compost without mineral dressing.

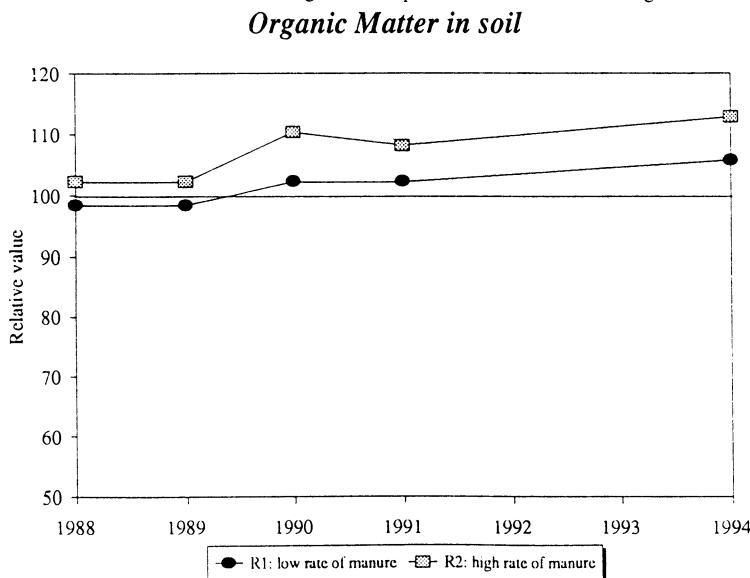


Figure 4 Effect of manure on organic matter in soil compared to mineral fertilizers only (=100). Values for mineral fertilizers are average of four treatments (N_0, N_1, N_2, N_3). Values for manure are average of treatments with sludge and compost without mineral dressing.

Over six years, the applied rates of DM resulted in an application of organic carbon from 11 t ha⁻¹ for the low rate of compost to 29 t ha⁻¹ for the high rate of liquid sludge. Organic matter in soil was improved by treatment with organic materials, according to the rate of application (figure 4). After six years, organic matter concentration in soil treated with the low and the high rate of organic materials

increased by about 6% and 13% respectively over unmanured soil.

This result agrees with results obtained by other Authors, i.e. Andersson, 1984 who found an increase of organic matter with the application of 5 and 10 t DM of compost (municipal solid waste+sludge) and 10 t ha^{-1} DM, while other Authors (Liners et al., 1986), detected an improvement only with massive rates of application.

The type of manure does not influence the status of organic carbon of the soil. Total N shows the same trend of organic matter (figure 5): the content in plots treated with the organic materials was increased by 7% (low rate) and by 15% (high rate) compared to the treatment with mineral dressing only.

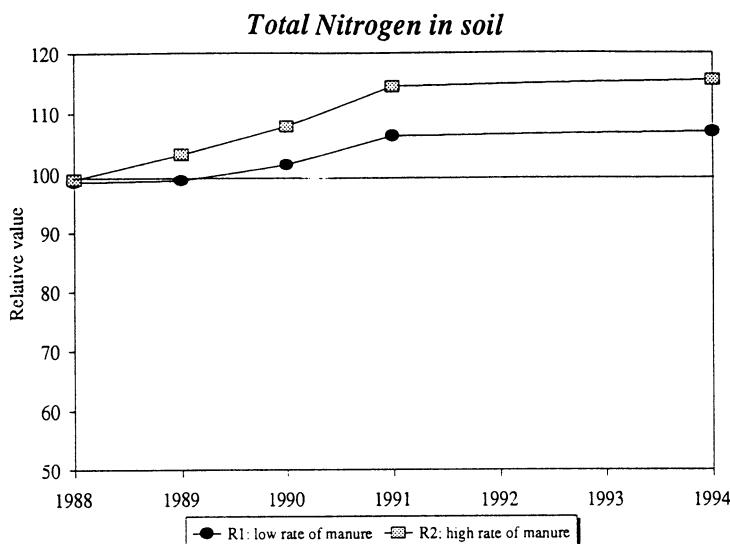


Figure 5 Effect of manure on total N in soil compared to mineral fertilizers only (=100). Values for mineral fertilizers are average of four treatments (N_0, N_1, N_2, N_3). Values for manure are average of treatments with sludge and compost without mineral dressing.

Conclusions

After six years of application of sludge and compost at the rate of 7.5 and 15 t $\text{DM ha}^{-1}\text{y}^{-1}$ the accumulation of heavy metals such as Cd, Cr, Pb does not occur, either in crops or in soil. Zn was increased in grains and in sugarbeet root by treatment with organic materials, Cu in sugarbeet root, but, over the years, the repeated application did not show any fitotoxicity problem, or an increase of concentration in the tissues.

The surplus of heavy metal application compared to plant uptake results in an increase of extractable Zn and Ni in soil according to the application rate, and, for Zn, according to the type of manure, given that liquid sludge increased Zn more than compost and dewatered sludge.

Organic materials proved to have a positive effect on the status of the organic

matter and nitrogen of the soil and increase the concentration of available phosphorus; the increase was correlated to the applied rate, and, in the case of P, resulted higher for liquid sludge than for compost and dewatered sludge.

Neither rate caused problems to plant growth. However the first rate seems to be advisable, because of the slower accumulation of P and of heavy metals, such as Zn, in soil; from this point of view liquid sludge must be used with more caution than dewatered sludge and compost, as Zn and P added with this type of effluent seem to be more effective in increasing the soil concentration of the available forms.

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An Evaluation of Soil Nutrient Status Following the Application of (i) Co-composted MSW and Sewage Sludge and (ii) Greenwaste to Maize

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and ANDY GROENHOF²

Abstract

This paper describes the some of the results of a two experiment conducted to investigate the agronomy and environmental impact associated with the use of (i) co-composted municipal solid waste and sewage sludge (MSW) and (ii) composted greenwaste (GW) on forage maize. The experiment was conducted on a silty loam soil in South West England. In 1994 MSW and GW treatments of 15, 30 and 50 t ha⁻¹ were compared with fertilizer and an untreated control. All treatments were replicated three times. The composts used were significantly different with respect to pH, loss-on-ignition, total potassium and calcium, but not mineral nitrogen or C:N ratio. No significant differences in soil nutrient status were observed between compost types or rates after drilling. The inorganic fertilizer treatment which showed significantly higher levels of mineral nitrogen but not P or K. Patterns of extractable nitrate-N recorded during the summer 1994 were very variable, and only the fertilizer treatment was significantly different from the compost or control treatments, and then not on every occasion. Post-harvest leaching on nitrate-N again showed no consistent pattern between compost types or application rates, while losses from the fertilized plots exceeded all other treatments. It is concluded that at the rates used in this experiment, the nutrients contained in composted MSW and GW can be considered environmentally benign.

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Introduction

Current UK practice for the handling, disposal and recycling of domestic waste varies widely from region to region. The strategies adopted by local authorities and water companies for dealing with municipal solid waste and sewage sludge respectively depend upon geographical, environmental and financial factors. Location of the source as well as the potential outlet for any material exerts the dominant influence, and is often closely related to the economics of disposal or recycling. Landfill continues to play a dominant role in the disposal of MSW, usually in a raw, uncomposted form. However, the economic climate is changing, due in part to the introduction of a landfill tax, announced by the Chancellor of the Exchequer in his 1994 Budget statement. The Department of the Environment (DoE, 1994) noted that agriculture dominates the potential market for MSW compost in the UK, although perceived problems with heavy metal toxicity and pathogenic burdens has limited the uptake by this route. Similarly, recycling of SS to agricultural land is often considered to be a troublesome method of 'disposal' due to concerns relating to long-term heavy metal accumulation and restrictions placed on the water companies by EC legislation (Parkinson, Brown, Jury, O'Neill and Heath, 1994). Source separation of waste products can help to solve some of these problems. For example, separate composting of greenwaste can yield a 'clean' and hence valuable, if sometimes nutrient poor, product.

Composting technology represents an important opportunity to process domestic wastes and so make them more acceptable to the agricultural community. Odours and pathogens can be eliminated, nutrients can be made more 'plant-available' and soil physical benefits can be derived from the composted organic matter (McConnell, Shiralipour and Smith, 1993). Much work has been conducted outside the UK on the agronomic benefits of the application of MSW compost to agricultural land (see for example Mays, Terman and Duggan, 1973; Paris, Robotti and Gavazzi, 1986) but acceptance of these materials by the UK agriculture industry depends in part upon experimental evidence gathered locally. The research work reported in this paper forms part of a series of trials conducted in 1993 and 1994 at the Seale-Hayne Faculty of Agriculture, Food and Land Use, University of Plymouth, to evaluate the agronomic benefits and environmental impact of the application of composted domestic wastes to forage maize. Specifically this paper describes an experiment to compare available soil nutrient concentrations during one growing season, and the losses of nitrate-nitrogen post-harvest. Crop yields for an exhaustion trial using, only MSW, but running over two years are reported elsewhere in these conference proceedings (Fuller, Parkinson, Jury, Vantarakis and Groenhof, 1995)

Experimental details

Location, climate and soil

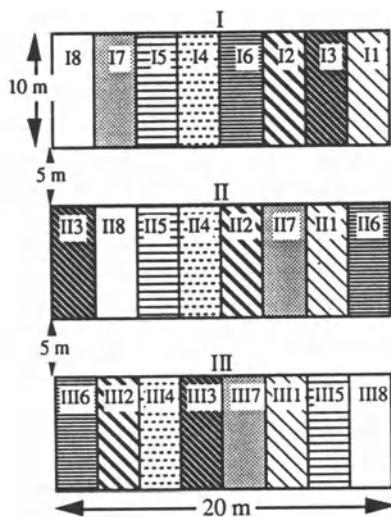
The experiments described in this paper were conducted in South West England, on Seale-Hayne Farm, attached to the Seale-Hayne Faculty of Agriculture, Food and Land Use, University of Plymouth, Devon, UK. Long term mean annual rainfall is 973 mm, and long term mean monthly temperature for the months of January and July is 6.0 °C and 16.5 °C respectively. Weather conditions for the 1994 are given in Table 1. Ground slope over the experimental site ranged from 2 – 5 %. The soil, which is a shallow (400 – 500 mm) silty loam, has been classified as a member of the Denbigh Association (Findlay, Colbourne, Cope, Harrod and Staines, 1984), and using USDA terminology would be described as a dystric cambisol. Soil and site factors combine to cause drainage problems in wet years. These can lead to difficulties when harvesting maize grown on this soil type, which is widespread throughout South West England.

Table 1 Climatic data for the Seale–Hayne experimental site, 1994

Month	Rainfall mm	LTM rainfall mm	Air temp °C	LTM air temp °C
January	151	119	6.0	6.0
February	156	99	4.3	5.4
March	79	77	8.0	7.0
April	54	54	8.3	8.5
May	110	68	10.4	11.1
June	22	57	14.9	14.3
July	21	50	17.6	16.5
August	106	63	16.2	16.0
September	113	75	13.7	14.1
October	125	93	11.5	11.2
November	98	95	11.5	8.1
December	202	124	7.8	6.6
Total	1237	974	—	—

Experimental design

The experiment was carried out on land that was fallow for two years prior to 1994. There were eight treatments, including the untreated control. Treatments were located randomly within each of the three treatment blocks (see Figure 1). Two compost materials, MSW and GW were applied at three rates: 15, 30 and 50 t ha⁻¹ on a fresh weight basis. Fertilizer was applied to plot 7 at a rate of 125 kg N, 27 kg P and 56 kg K ha⁻¹. On an N basis, this is equivalent to c.25% mineralisation of total N in the high rate compost treatment. Composts and fertilizer were applied in early May to plots that had been ploughed and spring tined in April. The plots were harrowed prior to drilling forage maize cv. Cyrano on 31 May. Drilling was late due to unseasonably high rainfall in May. The crop was harvested in early October.



Key to Treatments on Greenwaste Trials

I Block / replicate number

	MSW & Sewage Sludge Compost 50 t/ha		Greenwaste Compost 30 t/ha
	MSW & Sewage Sludge Compost 30 t/ha		Greenwaste Compost 15 t/ha
	MSW & Sewage Sludge Compost 15 t/ha		Fertiliser
	Greenwaste Compost 50 t/ha		Control

Figure 1 Experimental design, showing plot location and dimension

Compost

Two types of compost were used in these trials: co-composted municipal solid waste and sewage sludge, mixed on a 50:50 basis (MSW) and a greenwaste compost (GW). The MSW compost was produced by EcoSci Ltd at Chelston Meadow, Plymouth in 1993. Following composting, the material was screened through a 16 mm sieve to remove the majority of inert materials. The compost had matured considerably prior to use, and has also been allowed to absorb some rainwater, elevating the water content more than was considered ideal. The GW compost was produced several months prior to use from a feedstock of separated garden waste. Both materials were composted in open windrows. Table 2 gives full analytical

details for the MSW and GW composts. All soil nutrient data are reported on an oven-dry soil basis.

Table 2 MSW and GW compost analysis (n=4)

	MSW	GW	Sig. level
pH, 1:2.5 compost:water	7.3	8.0	***
Water content, g g ⁻¹	0.52	0.45	**
Loss on ignition, g g ⁻¹	0.44	0.41	*
Total nitrogen, g kg ⁻¹	15.5	15.1	n.s.
C:N ratio	15.2	14.5	n.s.
Ext. nitrate, mg kg ⁻¹	74.8	71.1	n.s.
Ext. ammonium, mg kg ⁻¹	10.1	2.0	n.s.
Ext. phosphorus, mg kg ⁻¹	11.5	12.7	n.s.
Total potassium, g kg ⁻¹	2.93	17.30	***
Ext. potassium, mg kg ⁻¹	580	2140	***
Total calcium g kg ⁻¹	38.5	34.3	*
Total magnesium, g kg ⁻¹	3.08	3.75	n.s.
Total sodium, g kg ⁻¹	2.75	3.43	n.s.
Total copper, mg kg ⁻¹	485	90	***
Total zinc, mg kg ⁻¹	1040	310	***

Ext. =extractable, n.s. = not significant. *p<0.05, **p<0.01, ***p<0.001

Experimental methods

Detailed soil analysis was carried out one month post-drilling in order to evaluate the impact of contrasting compost materials applied at different rates on soil conditions. Sampling was confined to the surface horizon, 0 – 100 mm. Duplicate samples were taken from each plot, giving six samples per treatment. Analytical methods followed the procedures described by MAFF (1986). Extractable nitrate and ammonia was obtained after shaking with potassium chloride. All results are expressed on an oven-dry basis. Soil solution samples were extracted at two weekly intervals after harvest from ceramic cups installed at a depth of 400 mm below the soil surface at one location on each plot, giving three samples per treatment.

Results and discussion

Initial comments

The application rates used in this trial were chosen in order to evaluate the impact of additions up to an a fresh weight equivalent to the quantities of farm yard manure used in normal agricultural practice, that is 50 t ha⁻¹. Analysis post-application (Table 2) revealed that the MSW compost in particular had a water content higher than ideal. This resulted in lower total dry matter additions to the MSW plots than planned. Nevertheless, the MSW was comparable in composition with the GW compost, as the detailed analysis in Table 2 demonstrates. In terms of total nutrient content, the effect of the composting has been to convert two quite contrasting source materials into much more similar product. Trace element chemistry remains different, as would be expected.

Soil conditions after drilling

Application of composts to soils, even at low rates, is known to modify physical and chemical properties, usually to the benefit of the growing plant (McConnel et al., 1993). Table 3 lists some soil responses to compost and fertilizer application at drilling. In this case, MSW and GW had no significant effect on soil properties except extractable K. GW in particular is a rich source of K, possibly due to the large proportion of woody plant material and 'salty' kitchen refuse in the waste stream. Compost additions did raise soil pH, but not significantly. The effect of the fertilizer is demonstrated clearly in Table 3, with high NH_4^+ and NO_3^- -N being present in soil samples. It is interesting to note that in this experiment the application of compost at rates up to 50 t ha^{-1} did not increase soil extractable nutrient concentrations; this may be due in part to the high water content of the materials, but also reflects the insensitivity of conventional methods to determine 'plant-available' nutrient concentrations. Soil solution nutrient concentrations are often an order of magnitude lower, but can be used as more sensitive indicators of the rhizosphere environment if sampling is possible. In this case the low soil water contents during the summer prevented solution sampling until after harvest when the soils had rewetted.

Table 3 Effect of MSW and GW compost additions on soil conditions, May 1994

Compost rate, t ha^{-1}	MSW			GW			Fert Control LSD	
	50	30	15	50	30	15	0.05	
Bulk density, Mg m^{-3}	0.90	0.93	0.95	0.99	0.88	0.92	0.84	0.90
Loss on ignition g g^{-1}	8.22	8.44	8.29	8.80	8.59	7.86	7.9	8.49
pH	6.23	5.87	6.20	5.87	6.63	5.87	5.67	5.63
NH_4^+ -N, mg kg^{-1}	1.52	4.31	1.03	1.00	1.57	5.28	46.59	1.10
NO_3^- -N, mg kg^{-1}	6.28	7.86	5.02	7.10	7.70	6.41	26.55	4.91
Ext. P, mg kg^{-1}	3.57	3.83	4.70	10.03	4.33	5.81	6.03	4.37
Ext. K, mg kg^{-1}	341	399	427	859	762	421	463	302
								190

Table 4 describes the extractable nitrate concentrations in soil samples taken during the summer months. High values were obtained for all treatments in June and July, due in part to the low rainfall during those months (see Table 1). The large LSDs demonstrate the variability usually associated with mineral N. In consequence, only the fertilizer treatment showed any significant differences from the control treatment.

Table 4 Extractable NO_3^- -N (0–100 mm depth) June – September 1994

Compost rate, t ha^{-1}	MSW			GW			Fert Control LSD		
	50	30	15	50	30	15	0.05		
28 June	21.4	22.7	34.6	32.8	22.6	26.8	33.0	25.7	30.7
26 July	26.2	65.5	28.9	42.0	71.5	31.1	125.2	36.9	78.1
23 August	18.9	14.0	7.6	3.0	20.7	10.2	41.5	8.2	18.6
20 September	3.8	4.5	3.8	4.9	5.1	4.6	5.4	4.2	1.4

Nitrate leaching post-harvest

In order to encourage wider use of compost in agriculture, it is important to be able to demonstrate that these materials are environmentally benign. Heavy metal burdens associated with these materials has been widely discussed, but nutrient losses have received less attention. In Table 5 $\text{NO}_3\text{-N}$ concentrations recorded in soil solution samplers installed 400 mm below the soil surface show that the fertilizer treatment resulted in significantly elevated values. Although the rainfall receipt in September and October was above average, the majority of this rain fell in early September and later October; there was a period of nearly four weeks at the end of September/early October when little rain fell. In consequence, soil solution concentrations were exceptionally high. Previous work measuring $\text{NO}_3\text{-N}$ losses from this soil type under winter wheat production recorded autumn solution concentrations up to 20 mg l⁻¹ (Duller, Parkinson and Fuller, 1994). In order to draw firm conclusions this work must be repeated in future years.

Table 5 Nitrate-N (mg l⁻¹) in soil solution samplers, October – December 1994

Compost rate, t ha ⁻¹	MSW			GW		Fert	Control
	50	30	15	50	30	15	
24 October	8.7	68.7	15.7	47.6	22.0	57.7	300.3
09 November	15.8	53.1	10.0	39.0	31.1	54.5	218.3
22 November	11.0	24.1	2.8	20.6	21.9	21.5	40.1
12 December	12.3	10.6	5.6	16.8	24.3	12.3	51.9
							25.4

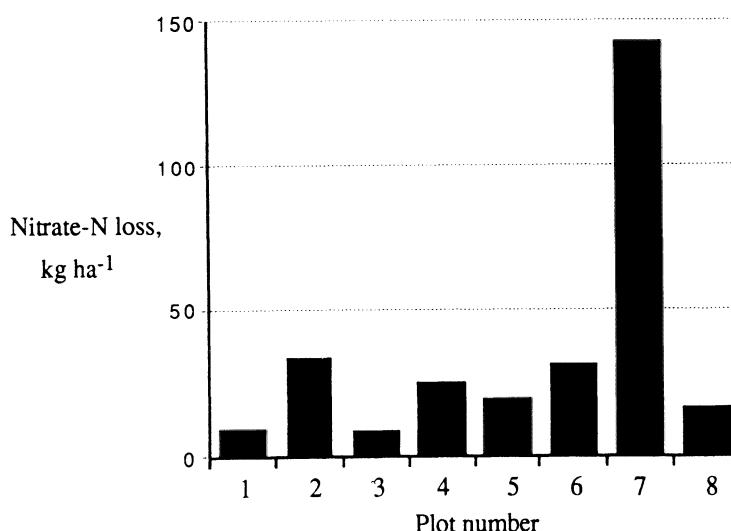


Figure 2 Cumulative nitrate-N losses, October – December 1994

Conclusions

In this experiment, application of composted MSW and GW at rates up to 50 t ha⁻¹ (on a fresh weight basis) resulted in no significant increases in available nutrient concentrations or losses of nitrate-N by leaching post-harvest. Only the fertilizer treatment produced significantly elevated levels of available nutrients and nitrate-N in solutions at the base of the soil profile in the autumn. The environmental conditions during the year and the high water content/age of the compost materials used may well have masked any differences that would have been expected at the stated application rates. As a result, analysis of crop yields (not presented here) showed no significant difference between treatment.

Acknowledgements

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Development of Compost Products

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Abstract

The amount of compost originating from source separated organic household waste in Germany is increasing rapidly. According to estimates of the potential processing capacity based on current building activities and ongoing approval procedures, the biowaste composting capacity will double again within the next two years. This means that the 1996 annual output of bio- and yard waste compost in Germany will amount to some 2,5 million m³. With respect to this development it is necessary to use all sales potentials available to compost marketing. One potential field of compost application for high quality compost which has hardly been recognised so far is that of refined compost products, in particular potting soils, substratum and vegetation layers.

Currently, bio- and yard waste compost is mainly used for soil improvement and fertilisation purposes. For this application quality criteria and plant production requirements have mostly been standardised and laid down in specific regulations (e.g. quality symbol RAL-GZ 251, revised LAGA information sheet M10). In contrast, there is no complete set of quality criteria for compost use in the field of soils and growing media, yet. Some of the criteria have still to be developed while other parameter have to be differentiated more, or the limits have to be made more stringent. The requirements for compost application in such a sensitive area have been laid down in a list of preliminary quality criteria for substratum quality compost. Certain characteristics or contaminant limits for quality criteria applicable to compost which is used in growing media production are currently being established within a research and development project which has been underway since the end of 1993 and is funded by the German Federal Foundation for the Environment and the German Compost Trading Company.

The effect of increasing contents of chloride, sodium, cadmium, copper and zinc on plant development have been evaluated in initial plant production trials using various ornamentals. At a compost application rate of 40 % (v/v) the ornamentals used showed no negative growth effects as long as the heavy metals tested

did not exceed the tolerable level established in the preliminary quality standards for substratum quality compost (equivalent to RAL-GZ 251 limits). In contrast to the results above it was observed that 40 % (v/v) of compost which contained no more than 1.000 g chloride/l resulted already in severely retarded growth of *Primula obconica*, the most sensitive test plant. With respect to the quality criteria 'plant compatibility of compost' it has been evaluated whether results obtained with summer barley (RAL-GZ 251 methodology) are also valid for horticultural production of ornamentals and plants used in landscaping. These initial trials indicated that growth inhibitors contained in compost show a stronger effect on some ornamentals than they do on barley.

Further experiments which are necessary to verify the results obtained so far will facilitate the establishment of detailed standards for substratum quality compost meeting the requirements posed by horticulturists. A list of quality standards defining substratum quality compost and compost based products such as the one being compiled currently, will provide an expert basis for both producers and users of these products. These standards will also bring about the certainty sought after. Suitable raw materials required for the production of compost based media can be supplied by composting plants according to appropriate product diversification measures. Refining of bio- and yard waste compost is very interesting from a potential compost sales point of view and also with respect to the high prices that can be realised. Furthermore, a diverse range of high quality compost represents recycled raw material which is able to aid the reduction of peat contained in soils and growing media today. Hence, the use of compost facilitates active environmental protection in the field of plant production.

The new compost based products can be mainly applied in the following areas:

- Hobby gardening (mainly potting media)
- Building industry (filling material)
- Melioration measures/establishment of green areas (e.g. exchange of contaminated soil)
- Garden- and landscaping industry (e.g. media for roof-gardens, filling material, substratum for tree planting, vegetation layers)
- Public institutions (corresponding to garden- and landscaping industry)
- Viticulture and fruit growing (substrata suitable for the establishment of new fruit plantations and vine yards)
- Commercial horticulture (substrata for seedlings and transplants as well as potting media suitable for vegetable production, growing of ornamentals and tree nurseries)

It applies to all listed areas of use that an innovative development strategy, including quality assurance of the compost based products has to ensure the successful application of the new products in both, plant production and economic terms.

Introduction

The development of compost based products can actually be seen as upgrading of the recycled raw material compost. Refining of compost and the production of compost based potting media and blended soils requires a mixture of selected composts and other materials suitable for this purpose respectively.

Mining and use of peat moss

In the beginning of a discussion dealing with 'compost based substratum' it is necessary to recall some figures which are fairly relevant with respect to the plant production side of the issue. These figures however, are not widely known in the composting industry. Table 1 details the annual amount of peat moss mined in Germany and its use.

Table 1 Amount of peat moss mined in Germany and its use (ZIT, 1992)

Amount of annually mined peat moss	roughly 12 million m ³
Commercial horticultural enterprises (raw material for substratum and soils, application as soil improvement agent)	some 60 %, accounting for 7.2 million m ³
Hobby gardening (used in substrata, potting media, peat based mixed fertilisers and soil adjuvant substances and also as soil improvement agent)	some 20 %, accounting for 2.4 million m ³
Industrially used peat moss (peat based activated carbon)	some 20 %, accounting for 2.4 million m ³
Medical use (mud-baths and mud packs)	a further 0.2 million m ³

Compost production and use

The following figures concern the raw material compost and describe a scenario which is currently familiar while at the same time still cannot really be visualised by many of us:

If organic waste materials are source separated and composted in every city and district it can be expected that some 3.5 to 4 million Mg (5 to 6 million m³) of biowaste and yard waste compost will be produced in 'pre-reunified' Germany and some 5 million Mg (7.5 million m³) in the whole of Germany (Fricke et al., 1991).

Already in 1992 some 508.000 Mg of compost has been produced. This compost can be divided into three categories (see Fig. 1).

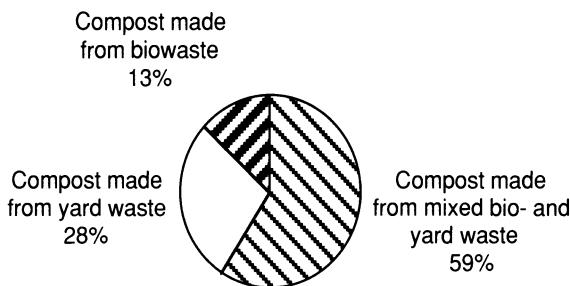


Figure 1 Production of compost originating from source separated organic household waste (1992: 508.814 Mg) (KEHRES, 1993, modified)

In 1992 almost 5 % of German citizens participated in source separation schemes for organic household waste. The quantity of the above mentioned compost, which is relatively high for a participation rate of 5 %, is due to the high proportion of yard waste not collected via the bio-bin but delivered directly to the composting plant (Kehres, 1993). Considering the current phase in which the waste management authorities are implementing resolutions aimed at an increase of the participation rate, and also looking at the potential output of composting plants currently in the planning stage or under construction, it becomes evident that the amount of compost produced will increase to roughly 1.5 – 1.8 million Mg within the next couple of years. At that stage some 45 % of all German citizens will have access to a bio-bin. In general, these figures are confirmed by a more recent inquiry conducted by Feidner und Hangen (1994).

This is enough to help you grasp the figures concerning the amount of compost produced.

However, let's stick with the real life example: Who used the 508.814 Mg of compost produced in 1992?

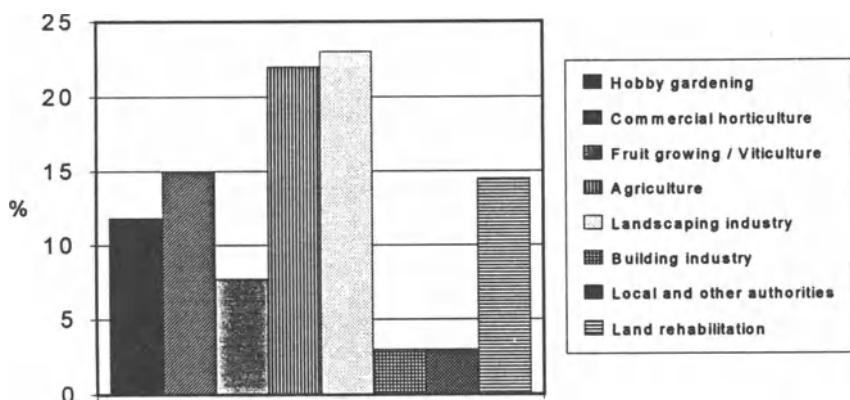


Figure 2 Division of customers using biowaste- and yard waste compost in 1992 (KEHRES, 1993)

The landscaping industry used the highest proportion (23 %) of the available compost. Roughly the same amount of compost was utilised in agriculture. Estimates lead us to believe that only two or three percent of the agriculturally used area is required to utilise, at proper application rates, the forecasted total amount of compost produced in the future. However, there are various reasons such as a high density of livestock, the growing tendency to set aside former agricultural land, statutory limitations, notably the 'Decree on the Use of Fertilisers', and others which limit the use of compost in agricultural production severely (results of market research conducted by Fa. PlanCoTec in 1993, unpublished). This is the reason why it is more difficult to open up this market than the figures cited might suggest (Stöppler-Zimmer und Hauke, 1994).

Based on the current state of the agricultural industry - including the bleak financial situation – it can not be expected that most of the compost will be utilised in agriculture in the long term. This view is based on an inquiry conducted in 1992. According to these findings the agricultural use of compost will remain in the range of 25 % even if the amount of available compost increases (comp. Kehres, 1993).

The use of compost in the areas mentioned (see Fig. 2) can definitely be increased in certain cases by means of well-directed marketing efforts. At the same time additional market shares can be gained by realising the potential of product diversification. The production of specific composts which can be used in substratum production, possibly combined with facilities for the production of substrata suitable for various plant production applications, provides the key to open up a further, economically very interesting potential market for compost. Some two to four million m³ of compost could be utilised in this area if, for example 50 % of peat moss contained in soil improvement agents destined for field application is substituted by compost and if potting mixes and horticultural substratum contain between 20 and 30 % composted biowaste or yard waste (Stöppler-Zimmer und Hauke, 1994).

Potential in marketing substratum quality compost and compost based products

Careful market analysis has to be conducted in order to gain a realistic view of the potential expansion of the market through the production of substratum quality compost or potting media itself. So far, common marketing instruments such as conducting market research and drawing up a marketing strategy have been used only rarely in order to make the current market for compost and substratum more transparent and to provide information for the activities planned.

Market analysis:

Registration and analysis of the current structures and conditions relevant to

the marketing of compost and also compost based substratum and soil with special reference to local soil mixing enterprises and marketing partners.

Marketing strategy:

Description of potential means of sales as well as of a successful marketing policy for composts and compost based products including a conception for product distribution.

With respect to the sales potential of compost suitable for use in substrata it is possible that various options can be developed within the framework of drawing up a marketing strategy. These options might be as follows:

- A soil mixing operation located reasonably close has been found. They are prepared to take composts at reasonable business terms and to use it in their production process. The company sells the compost products on their own account and/or uses existing ways of distribution.
- A soil mixing operation is prepared to produce the desired compost based products but does not see itself in a position to sell these products. Consequently, sales have to be managed by the composting enterprise, either on their own account or through a contractor.
- There is no possibility for refining the compost in an established soil mixing operation. The production and sales of compost based products has to be organised by the composting operation (production and sale by themselves; a contractor (landscaping operation) mixes the products; a sales contract with a compost marketing organisation.).

The more of the above tasks the composting operation performs by itself the higher are the requirements it has to meet. That does not only concern biological and technological aspects but also the area of compost marketing (Stöppeler-Zimmer und Hauke, 1994). However, the additional product line adds another, economically worth while business line to the company and also helps reduce dependency on the sales structures used so far.

Potential use of compost based products

Apart from agriculture, the target group which utilises compost based soil and substratum can be found in almost any area where compost is used for soil improvement purposes (see Fig. 2). However, the requirements concerning compost based products which are set by each area of application, vary greatly (see section 4). Below you will find an overview of the areas where compost based products can be used and the associated purposes. Furthermore, the growing demands on quality aspects of the products will also be described.

Hobby gardening

Potting mixes

Potting mixes make up the largest part of the total quantity of substratum purchased by home gardeners. Some 2 million m³ of potting mix is used annually for filling balcony boxes where summer flowers grow, for repotting indoor plants and for raising vegetable seedlings. With many of these substrata there is no great need for a high degree of structural stability since mostly plants are grown in these media for only a couple of weeks or a few months at the longest.

Soils for graves

The care of graves represents a considerable potential for the use of compost based substratum since planting of flowering plants and the associated application of additional soil is performed several times during the year. Traditionally, only very fine and very dark, almost black substratum is used for this kind of application.

Special purpose container media

It is a distinct phenomena that hobby gardeners are prepared to pay more for some specific areas of gardening such as the establishment of an area for bog-soil plants including planting of rhododendron, than they are paying for ordinary potting soil. However, these special purpose potting media have to meet the specific requirements of each field of application. A low pH-value of the substratum, for example is essential for bog-soil plants. Among private gardeners there is also a demand for other specific products such as substratum used for roof-gardens or for filling large tubs.

3.2 Building industry

In accordance with melioration measures, the building industry also demands substrata for filling purposes which are supposed to be as close as possible to undisturbed soil. Soils and substrata are applied in this field with the purpose of substituting a media, and to level out an uneven surface caused during the construction of buildings, roads or industrial complexes.

3.3 Melioration measures

Areas where substratum is used for melioration measures are more or less identical to those in the building industry. In general, meliorated industrial areas or slagheaps are not intended to be used for agricultural production at a later date. In this type of application the physical characteristics of the soils and substrata used are of importance for achieving the envisaged effect.

Some nature conservation measures might require media with a very low nutrient status.

Garden- and landscaping industry

The garden- and landscaping industry requires very specific materials for a diverse range of applications. Substratum for roof-gardens has to be structurally stable and therefore needs to contain a certain proportion of mineral amendments. Material used for the carrying layer in the construction of sporting and other green fields has to meet clearly defined requirements specifying for example lateral stability and distribution of particle size. If substratum is used as a top soil substitute it needs to be aligned to the characteristics of the existing soil. Structural stability is a particularly important quality criteria where the substratum is used in large containers, in soundproof barriers or in planting holes in disadvantaged locations (e.g. in cities). The same applies to the water holding capacity of substratum if it is used in soundproof barriers or on perforated stones. If the soundproof barriers are sprayseeded it is also possible to use compost amended substratum.

Viticulture and fruit growing

In this area substrata are in demand for application in the planting hole during the establishment of vine yards or fruit plantations.

Commercial horticulture

Tree nurseries

Currently there is an increased demand for nursery plants grown in containers due to the fact that the use of container grown plants entails more flexibility with respect to the planting date than the system where the root ball is dug up. Specialised nurseries grow container plants for use in various areas such as garden and landscaping, fruit growing, viticulture, home gardening and for transplanting to the forest in the case of a forest tree nursery. Substrata used for growing nursery plants in containers are highly diversified media for specific applications.

Vegetable production

Substrata used for the propagation of vegetable plants are as much in demand as potting soils for herbs which are sold in pots. Compost based substratum can also be used for the cultivation of tomatoes, cucumbers or peppers in plastic liners.

Production of ornamentals

This branch of the industry demands substrata for seedling production and transplanting as well as potting media. However, since the production of ornamentals requires very specific container media for different plant species (e.g. substrata with a particularly high pore volume or with an extremely low salt content) is not easily accessible for compost based products. Nevertheless, from an economic view point it is very profitable to market compost based substrata to this branch of

the horticultural industry since the price paid for substrata in this field is comparatively high. Costs for the container media per pot in comparison to the sales price of the plant are several fold of those in other horticultural production schemes.

Characteristics required of substratum quality compost

Requirements posed by compost users

Market analysis which have been carried out by Fa. IGW-Kompostverwertung, Witzenhausen (now Fa. PlanCoTec), showed that potential compost users originating from all sections specified in chapter 3 evaluate the potential characteristics of compost relevant to plant production, quite differently.

Hence, the compost quality requirements described were not limited to characteristics such as the content of heavy metals or organic contaminants but focused also on the compatibility of plants to compost and on the absence of weed seeds and pathogens potentially infectious to plants, animals or humans. The absence of viable weed seeds and plant pathogens in the composted material is rated as important as is the problem of contamination (see Fig. 3).

Practical working horticulturists are also raising questions concerning micro nutrients contained in the compost and are enquiring about the content of specific substances such as chloride, respectively the harmful effects these contents can have on cultivated plants. Another major point of concern for horticultural enterprises is posed by their demand for compost products which always comply with quality standards defined. Only if compost producers pay attention to this requirement, a proper compost application will show predictable effects, hence can be used in horticultural plant production. Due to the difficult economic situation it can not be expected that commercial horticultural enterprises abandon the traditionally used peat based substratum merely for ecological reasons. Therefore, compost based container media have to be produced on the basis of safe recipes and they also have to comply with the high quality standards necessary (Gottschall, 1991).

The compost quality requirements posed by practical working horticulturists are clearly reflected in the preliminary quality standards for substratum quality compost (see 4.2). These preliminary quality standards which have been drawn up by the German Federal Association for Compost Quality (BGK) have been submitted to the German Institute for Quality Assurance and Labelling (RAL) for approval and issuing of a seal of approval.

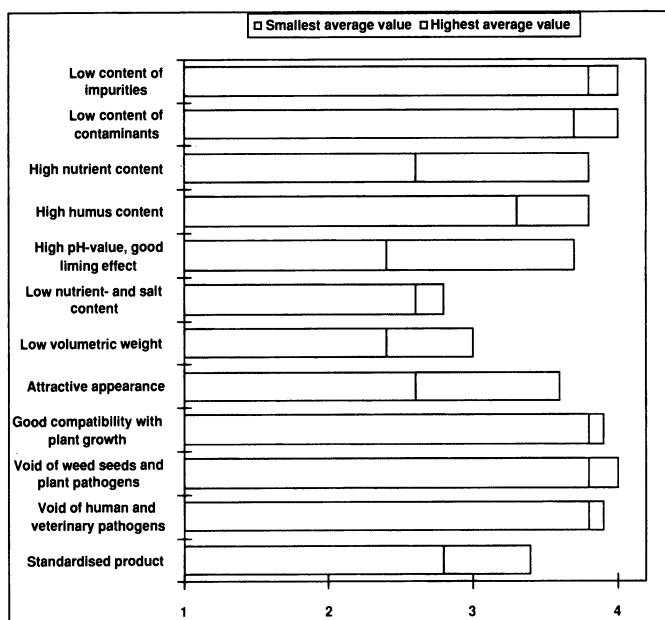


Figure 3 Importance of quality criteria for the major groups of compost users, i.e. agriculture, horticulture, garden- and landscaping, hobby gardening, trading (average of groups, n = 135)

Question: How important are the following quality criteria for you?

Rating: 1 = not important, 2 = of little importance, 3 = important, 4 = very important (results of market analysis, PlanCoTec, 1994, unpublished)

Specific requirements and preliminary quality standards for substratum quality compost

A meeting gathering experts from Weihenstephan Horticultural College, the German Federal Association for Compost Quality, the Institute for Horticultural Education and Research in Hannover-Ahlem and from Fa. PlanCoTec, Witzenhausen took place in 1993 in order to bring together the various requirements posed to compost earmarked for container media production and to draw up a list of characteristics defining substratum quality compost. A proposal for such quality standards was developed at that time and is shown in Table 2 (Stöppler-Zimmer und Hauke, 1994, completed).

Table 2 Preliminary quality standards for substratum quality compost in comparison to quality standards for matured compost established by BGK (RAL quality seal 251)**Table 2a** Declaration/Physical properties/Impurities

Criteria	Requirements	
	Substratum quality compost	Matured compost (BGK)
1. Declaration	Declaration: substratum quality compost type 1 or type 2 and raw materials	Declaration: matured compost and composition
2. Physical properties		
2.1 Density/volumetric weight	Declaration for dry and fresh material (g/l)	Declaration for fresh material (g/l)
2.2 Water content	Damp (advised level: 50 – 60 % (v/v) of maximum water capacity); bulk: max. of 45 % (w/w), bagged: max. of 35 % (w/w), if the organic matter content exceeds 40 % in dm, the water content must not exceed 55 % (w/w)	Bulk: max. of 45 % (w/w) bagged: max. of 35 % (w/w); according to appendix 5 / enclosure 2 of the RAL GZ 251 quality standards higher water contents are permitted if the organic matter content exceeds 40 % in dm
2.3 Particle size	Declaration: fine (ca. 0/8 to 0/12 mm) or medium (ca. 0/16 to 0/25 mm; particle size 0/5 mm always > 50 % (v/v)	Declaration
3. Impurities		
3.1 Glass, metals plastics	> 2 mm – max. of 0,5 % (w/w) in dm none > 5 mm (i.e. < 0,1 % (w/w) in dm) no plastics > 5 mm (i.e. < 0,05 % (w/w) in dm)	> 2 mm – max. of 0,5 % (w/w) in dm
3.2 Stones	2–10 mm – max. of 5 % (w/w) in dm none > 10 mm (i.e. < 0,5 % (w/w) in dm)	> 5 mm – max. of 5 % (w/w) in dm

Table 2b Biological characteristics/Organic matter

Criteria	Requirements	
	Substratum quality compost	Matured compost (BGK)
4. Biological characteristics		
4.1 Germinable weed seeds and plant particles	None, i.e. max. of 0,5 plants per 1 ltr. compost	None, i.e. max. of 0,5 plants per 1 ltr. compost
4.2 Elimination of human, veterinary and plant pathogens	Proof of the sanitary effectiveness of the chosen composting system (assessment of the composting process by means of <i>Salmonella</i> and <i>Plasmodiophora brassicaceae</i> survival rates); for horticultural use, testing of the compost for <i>Plasmodiophora brassicaceae</i>	Proof of the sanitary effectiveness of the chosen composting system by means of providing composting temperature data

4.3 Plant compatibility		
4.3.1 Gaseous phytotoxic	Germination test with cress seeds substances in a closed container (no inhibition of germination, i.e. rate of germination 90 % of germination in control medium)	Not specified ¹⁾ in a 100 % compost medium
4.3.2 Compatibility of compost with plant growth	Biotest growing summer barley in a 50 % (v/v) compost medium (compatible with plant growth, i.e. fresh matter yield 90 % of the yield in control medium)	Biotest growing summer barley in a 25 % (v/v) compost medium (compatible with plant growth, i.e. fresh matter yield 90 % of the yield in control medium)
4.3.3 N-Immobilisation	Evaluation either through a biotest growing summer barley and applying increasing amounts of additional nitrogen (N-balance stable) or through an incubation test according to Zöttl (N-balance stable)	Not specified ¹⁾
4.4 Level of decomposition	Matured compost, decomposition level V (accord. to LAGA M 10)	Matured compost, decomposition level IV or V (accord. to LAGA M 10)
5. Organic Matter	Declaration, > 15 % (w/w) in dm (volatile solids)	20 % (w/w) in dm (volatile solids)

Tab. 2c Chemical properties I, total nutrient content, heavy metals

Criteria	Requirements Substratum quality compost	Matured compost (BGK)
6. Chemical properties I		
6.1 C/N-ratio	Declaration	Not specified ¹⁾
6.2 pH-value (CaCl_2)	Declaration	Declaration
6.3 Carbonates	< 10 % (w/w) in dm	Not specified ¹⁾
6.4 Nutrients (total content)	Declaration N, P, K, Mg, Ca	Declaration N, P, K, Mg, Ca
7. Heavy metals, (mg/kg TS) (acidic extraction (Königswasser), om content adjusted to 30 %)		
7.1 Lead (Pb)	< 150	< 150
7.2 Cadmium (Cd)	< 1,5	< 1,5
7.3 Copper (Cu)	< 100	< 100
7.4 Chromium (Cr)	< 100	< 100
7.5 Nickel (Ni)	< 50	< 50
7.6 Mercury (Hg)	< 1,0	< 1,0
7.7 Zinc (Zn)	< 400	< 400

Table 2d Chemical properties II, extractable nutrient content and heavy metals

Criteria	Requirements only relevant for substratum quality compost *	
	Type 1	Type 2
Mixing component for the production of multi-purpose substratum showing a low nutrient status, maximum content: 20 % (v/v)	Mixing component for the production of multi-purpose substratum showing a low nutrient status, maximum content: 40 % (v/v)	
8. Chemical properties II		
8.1 Salt content, extractable nutrients		
8.1.1 Salt content	< 5.0 g/l (KCl)	< 2.5 g/l (KCl)
8.1.2 NH ₄ -N + NO ₃ -N (CaCl ₂)	< 600 mg/l fm	< 300 mg/l fm
8.1.3 P ₂ O ₅ (CAL)	< 2400 mg/l fm	< 1200 mg/l fm
8.1.4 K ₂ O (CAL)	< 4000 mg/l fm	< 2000 mg/l fm
8.1.5 Mg (CaCl ₂)	Declaration	Declaration
8.1.6 Chloride (H ₂ O)	Limits are currently established	Limits are currently established
8.1.7 Sodium (H ₂ O)	Limits are currently established	Limits are currently established
8.2 Extractable heavy metals		
8.2.1 Zinc (available for plants)	Limits are currently established	Limits are currently established
8.2.2 Cadmium (available for plants)	Limits are currently established	Limits are currently established
8.2.3 Copper (available for plants)	Limits are currently established	Limits are currently established
The establishment of limits for micro-nutrients (Fe, Mn, B) and further heavy metals (available for plants) are currently discussed		

¹⁾ No requirements established

* The BGK guidelines for matured compost (RAL quality seal 251) require only one declaration for the salt content and the content of N, P₂O₅ and K₂O available for plants.

Preliminary results of the R & D project ‘Development of Compost Based Substratum’

The parameter listed in Table 2 clearly define the quality standards which have to be met by substratum quality compost. There is a specific importance attached to each parameter. Currently, many of these limits are either being established or verified within the framework of the research mentioned above and development project which is funded by the German Federal Foundation for the Environment and the German Compost Trading Company. This R & D project facilitates joint research by experts from Fa. PlanCoTec, Witzenhausen (H. Hauke [BSc, Hort.], Dr. H. Stöppeler-Zimmer, R. Gottschall [BSc, Agr.]), from the Institute for Plant Nutrition at the Technical University of Hannover (A. Bucher [BSc, Hort.], Prof. Dr. M. Schenk) and from the Institute for Horticultural Education and Research (LVG) in Hannover-Ahlem (F. Weinhold [BSc, Hort.], Prof. Dr. H.C. Scharpf).

Proportion of substratum quality compost on the total amount of compost produced

Initially it was necessary to establish how much of the compost volume produced can be classified as 'substratum quality' according to the preliminary quality standards. This was achieved by evaluating 334 results of compost analysis which were carried out by Fa. PlanCoTec within the quality testing and assurance programme (RAL GZ 251) established by BGK. These results, all of which represent matured composts material, have been compared with the preliminary quality criteria for substratum quality compost.

Roughly one quarter of the composts examined (precisely 86 out of 334 composts which have all been classified as 'matured') complied with all criteria of the preliminary quality standards for substratum quality compost. Figure 4 shows the proportion of composts which did not comply with the various quality criteria.

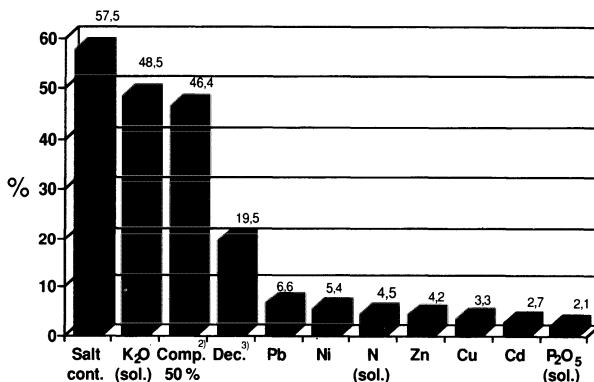


Figure 4 Proportion of matured compost which does not comply to the preliminary quality standards for substratum quality compost (analysis conducted by Fa. PlanCoTec within the BGK quality testing and assurance programme (RAL GZ 251) 1)

1) Matured composts analysed 1992 – 1994 (n = 334)

2) Comp. = Compatibility of plants at a 50 % compost contend

3) Dec. = Level of decomposition

With respect to these figures, in certain cases it seems appropriate to consider whether it is necessary and useful to compost input materials with a low nutrient status separately and to use the compost for container media production.

Plant compatibility of substratum quality compost

One aspect of the above mentioned research project deals with the question of whether the current BGK testing method evaluating plant compatibility is also valid if the compost is used for amendment of container media. This part of the research programme is dealt with by Fa. PlanCoTec. Establishment of whether the

current BGK test gauging growth effects on plants – measured with spring barley – provides results which are also applicable for production of ornamentals and plants used in garden- and landscaping. Suitability of compost to be used in container media was checked by compost amendment of peat based substratum, resulting in growing media which contained 80 % (v/v) and 60 % (v/v) of peat moss. Three ornamentals (pelargonia, begonia and petunia), one agriculturally relevant plant (German rye grass) and the standard summer barley have been grown in these media.

Since the test was meant to show – in alignment with the BGK plant compatibility test – negative short term growth effects induced by compost amendment, fresh matter values of the different plant species were determined after a four week growth period. The results obtained showed that different levels of plant compatibility found in compost which is used for container media production is not reflected in rye grass growth performance. Ornamentals suffered a more severe growth reduction than barley plants at high compost amendment rates, in particular where 50 % (v/v) of compost was used. It became clear that the evaluation of plant compatibility of compost through a growth test with summer barley in media containing 50 % (v/v) compost provides a satisfactory tool for a basic classification of the compost with regard to its use in the various fields of plant production. However, some ornamentals might be more sensitive to compost born growth inhibitors than summer barley. It needs to be stressed that the results presented are based only on one experiment and that further trials are required for verification. In any case, if further experiments confirm our findings it will be necessary to evaluate plant compatibility of substratum quality compost with another plant species than summer barley.

Chloride content of substratum quality compost

Further questions to be answered within the aforementioned co-operational R & D project concern tolerable levels of components which are important quality criteria for growing media and are answered by LVG Hannover. The initial aim of this project section is to establish limits for chloride, sodium and potassium in substratum quality compost. The first trials involving an increased chloride content of growing media have already been conducted. Harmful chloride concentrations have been determined by chlorine addition to both, the input material before composting and the matured compost, amounting up to 3.500 mg chloride / l compost (water extract) and 5.000 mg chloride / l, respectively. The peat based growing media used in this trial contained 20, respectively 40 % (v/v) compost and was limed and fertilised. The effect of various chloride contents on plant growth has been evaluated with pelargonia, petunia, impatiens, begonia and saintpaulia where chloride was added before composting and with pelargonia, petunia and Primula obconica where chloride was added after the composting process.

The trials showed distinct differences in chloride tolerance between the used plant species. Saintpaulia, impatiens, begonia and mainly primula are very sensi-

tive, while pelargonia are more tolerant to chloride and petunia is even unaffected by very high chloride contents. The addition of 40 % (v/v) compost to the growing media resulted in a marked growth depression for sensitive plant species if the compost contained 2.000 or more mg chloride / l. This limit was found to be around 2.500 mg chloride / l compost for more tolerant species and around 3.500 mg chloride / l compost for petunia. Primula which are known for their little salt tolerance showed a marked growth retardation already with a chloride content of 1.000 mg / l compost (amendment rate: 40 % (v/v)). Since chloride is contained in certain fertilisers and might be introduced through the irrigation water, to be on the safe side it is being discussed whether to establish a very low limit for the chloride content in compost used for cultivation of sensitive plant species. It is proposed that in such a case the chloride content should not exceed 600 mg / l if 40 % (v/v) of compost is contained in the media and 1.000 mg / l if 20 % (v/v) of compost is added. Also in this case it needs to be stressed that the results above need to be verified by further research.

Heavy metal content of substratum quality compost

Within the R & D project mentioned, researchers at the Technical University of Hannover are currently in the process of establishing limits for heavy metal contents (cadmium, copper and zinc) tolerable in substratum quality compost. Preliminary results show that no negative growth effects should be expected as long as the content of the heavy metals evaluated does not exceed limits established in the preliminary quality standards for substratum quality compost and as long as no more than 40 % (v/v) of compost is contained in the growing media. These results have been obtained through the cultivation of hybrid petunia which proved to be the most sensitive species of six ornamentals evaluated for their tolerance to the heavy metals cadmium, copper and zinc in a pre-trial. Also in this area of research further trials will be conducted in order to confirm the results obtained.

Development of compost based soils and container media

Compost based products can be used for a wide range of applications. A line of products offering 'compost based soils and growing media' can only be successful economically and in plant production terms if the quality of the compost used is constant and guaranteed and if the various products are mixed according to tested formulae. Furthermore, the production methods applied for blending the different materials is also an important factor.

Procedural steps in product development

Composting plants or soil mixing enterprises are not forced to develop formulae for growing media on their own. The same applies to the optimisation of the pro-

duction process for compost based media. Both of these problems can be handled by specialised institutions or companies. It depends on the objective of the activities planned whether these tasks are contracted out or handled on ones own account. For example, the development of relatively simple growing media used by the garden- and landscaping industry has to be valued differently to the development of non-peat based container media.

Development of single or various growing media requires drawing up of concepts for potential new products (e.g. according to market research or preferences stated by compost producers/soil mixing enterprises depending on the objective of production or the availability of additives). Further tasks to be performed in this respect comprise the evaluation of the composts used, listing and rationing of all components contained in the mixture with reference to their availability and the determination of fertiliser added to the compost based product. Finally the products developed have to be evaluated with respect to each intended area of application.

Recipes for growing media have to be developed on the basis of a list of substratum components and fertilisers which, however, might vary greatly according to the intended use. For horticultural applications substratum quality compost is mainly mixed with components such as peat, clay, bark humus, wood fibre, rice husks, coconut fibre and mineral fertilisers. In addition, mineral components such as lava, sand or recycling products as well as organic mixed fertilisers can be used for blending growing media if they are designed to serve the garden- and landscaping industry. These materials have to be combined with respect to the plant production purposes envisaged and also taking into account the logistical objectives.

Quality assurance of compost based products

With respect to compost based products not only is it important to develop recipes suitable for practical application but also to establish a thorough quality control system for growing media and soils once production is underway. A range of quality criteria which is listed in the preliminary guidelines for substratum quality compost have to be checked. Other specific quality criteria important for growing media assessment which are not listed in the guidelines mentioned such as water capacity and pore volume have to be evaluated, too.

Perspectives for the development of compost based soils and growing media

The development of compost based soils and growing media is the basis for an innovative and future oriented potential in selling compost. This complies fully with waste management legislation which irrefutably requires the utilisation of recycled raw materials. The sale of compost based products opens new economical perspectives for compost marketing since prices realised on the market can vary between 20,- DM / m³ for simple filling material used by the landscaping

industry and as much as 120,— DM / m³ for specialised growing media for ornamentals or roof-gardens. The areas of compost application mentioned are able to absorb a considerable amount of compost. Therefore, the application of this kind of product diversification during production and refining of compost, provides a new and interesting approach in compost marketing activities.

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Political Implications for Integrating Composting into Solid Waste Management in West Virginia, USA¹

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Abstract

The design and implementation of a Pilot Program for composting organics from residential and commercial sources is discussed. This Pilot is perhaps unique in that it not only deals with various political and geographical entities, soliciting the cooperation of the organic material generators but also develops handling systems, a model compost facility, projections for utilization of the finished compost and provision for cost comparison with other waste handling methods.

Introduction – development of a cooperative research effort

Residential collection of organic materials is an uncommon method of managing solid waste in the U.S. There have been numerous pilot programs (Goldstein 1994; Beesley 1992; Riggle 1992; Giles 1992; Hoornweg et al. 1991) and some permanent programs implemented (van der Werf 1995; Glenn 1993). Residential collection is basically at an experimental stage where different programs are being tried, so that there are no standards and a multitude of questions – Will residents separate organic materials?; Will they separate properly?; What type of container is needed?; What participation rates can be expected?; What will be the most cost efficient collection system?

Motivations for diverting organic materials from landfills by residential collection include: (1) achievement of state mandated waste reduction goals; (2) landfill

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bans on yard waste; (3) cost savings; and (4) a reduction of in the potential for groundwater contamination from landfills. In West Virginia, an impending landfill ban on yard waste and the potential for cost effective diversion provide the most important motivations for residential collection by waste haulers. While the cost efficiency of regional composting and collection has been examined elsewhere (Criner et al. 1995), waste haulers are reluctance to implement new collection methods partly because information, applicable to West Virginia, is lacking about collection cost effectiveness. Thus, data are needed from a pilot study in West Virginia to simulate an interest in residential collection. These data include: the organic waste resources available for collection; citizen commitment and participation; collection and handling methodology for efficient operation of a composting site; and utilization of finished compost.

This research project will address these data needs with the following objectives:

1. Demonstrate a residential organic collection and composting system in West Virginia.
2. Determine optimum methods of collection/composting.
3. Determine collection costs of the program.
4. Determine participation/diversions by homeowners and commercial accounts.
5. Develop a utilization strategy for finished compost.

West Virginia University (WVU) composting research has included descriptive (Diener et.al. 1993a,c), economic feasibility assessments (Fritsch and Collins 1993), and development of composting technology (Diener et al. 1993b). Doing applied research on collection and composting in West Virginia, however, requires a cooperative effort between WVU researchers and numerous institutions who have various goals related to management of solid waste (Table I). A cooperative research project requires researchers to accommodate these other goals in order to meet research objectives. The management challenge presented by development of cooperative research efforts in West Virginia is regarded as typical of that facing other researchers in the U.S.

To develop a cooperative research project for a pilot collection program, initial contacts and working relationships must be developed with state regulators, Solid Waste Authority (SWA) representatives, and waste haulers. The Division of Environmental Protection (DEP) has regulatory authority over composting. Site approval and/or permits are required for composting facilities. In addition, regulator support of a project is vital to ensure research funding support from state government. SWAs have planning authority for solid waste in each county and have access to grant funds in West Virginia which can be used to support research. Waste haulers have the primary authority over solid waste management based on exclusive collection rights given by the Public Service Commission. Without appropriate development of any one of these three relationships, a cooperative research project would fail.

In this project, WVU researchers began by conducting a DEP approved train-

ing program for yard waste composting facility operators. Working in cooperation with and obtaining assistance from state regulators developed trust among both parties. Then, a statewide conference on composting was organized in conjunction the Putnam County SWA. The success of these efforts allowed WVU researchers to develop a cooperative grant proposal with the Putnam County SWA for submission to the West Virginia Recycling Act Grant program. Funded by a \$1 per ton tax on landfill disposal, this grant program supports development of recycling and composting programs in West Virginia and can be utilized to support research. Additional assistance in proposal development and support was provided by the WVU Cooperative Extension Service and the West Virginia Graduate College. This grant proposal was funded in February 1995. The waste hauler was recruited last after grant funding was secured so that this individual could be assured of being compensated for participation in the project. The local SWA representatives were responsible for initiating contact to recruit the hauler's participation.

Table 1 Solid Waste Management Institutions in West Virginia.

INSTITUTIONS	FUNCTION	GOALS
Waste Haulers	Collect and transport solid waste	Profit
Solid Waste Management Board	Planning and technical assistance for the county solid waste authorities	Promote recycling, reuse, and composting as a waste management strategies
Public Service Commission	Economic regulation	Assign route/ territory to haulers. Regulate landfill and garbage collection fees
Division of Environmental Protection	Environmental regulation	Protection of soil, water, and air resources
County Solid Waste Authorities	Planning and facility siting: Able to own and operate solid waste facilities.	Develop effective solid waste management strategies for each county
West Virginia University	Education	Promotion of composting as a waste management strategy
	Research	
	Public Service	
Landfill owner/operator	Disposal of solid waste	Profit
Agricultural Landowners	Able to compost manure and urban organic wastes	Profit by increasing the production of soils
Municipal Government	Responsible for waste collection and public health and safety	Least cost management of solid waste

Public relations and recruitment

Previous residential pilot collection projects have involved public-private partnerships which included large waste management companies, local government and the National Audubon Society and Proctor & Gamble (Gottsegen 1994; Beyea 1993). Studies conducted in Santa Barbara (CA), Fairfield (CT), and Pittstown

(NY) have indicated that the educational plan for a source separated waste project is crucial to its success. Each project claimed varying degrees of success attributed to educating the following constituencies: (1) state regulatory officials; (2) local government officials; (3) project committee members; (4) waste haulers; and (5) residents.

Prior pilot projects have designated a coordinator to develop the educational materials for each constituency. These materials included:

- outlines and background information for meetings with state and local officials;
- written materials and outlines for meetings with waste haulers;
- multiple direct mail flyers for residents; and
- press and media releases

Generally, the educational phase of the project takes between 3–4 months regardless of the participating population. The coordinator generally serves as the liaison between government officials, haulers, and the residents. This well-rounded and tactful individual has been responsible for recruiting volunteers from both the public and private sector; conducting hauler and residential meetings; and soliciting donations of goods and services for these meetings.

Educational Plan for Household Participation

The pilot program in Putnam County will follow a similar pattern of education for its household participants. Upon receipt of the Recycling Act grant funding, a press release was issued to local and state news media. Part of the grant funding will be used to hire a local coordinator three months prior to beginning the pilot. Initially, private meetings will be conducted with homeowners associations, garden clubs, city councils, local grassroots environmental groups and other similarly interested parties. The purpose and feasibility of the project will be discussed and citizen input solicited. These preliminary meetings with local leaders will be used to determine what opposition (if any) may occur and to solicit input to mitigate this opposition. These meetings will provide feedback regarding the comprehension and clarity of written materials. All materials will be clearly labeled 'draft' in order to preclude later confusion.

Three public hearings will be held prior to (spring 1995), during (fall 1995), and upon completion of the pilot program (winter 1996). The purpose of these hearings will be to: (1) allow for public input on pilot design; (2) inform the general public and recruit participants; and (3) gain public support for acceptance of permanent site for yard waste composting upon completion of the pilot. Public hearings will be held in a local community center and advertised both in the media and by distribution of flyers in the subdivisions to be chosen for the pilot program.

To simplify the 'chore' of responding, mail back postcards will be used to obtain the names and addresses of residents who are interested in participation. The most important written document in this project will be the list of organic

waste materials accepted and in which bin or bag they should be placed. This instruction sheet will be previewed in the preliminary meetings, at public hearings, and by the hauler for input. A mail survey will be conducted during the pilot to gauge participant perceptions and suggestions about the project.

Recruitment

The 1990 census population of Putnam County is 42,835. This county serves as a 'bedroom' community for two larger counties on either side. A large segment of the population lives in single family homes as part of unincorporated subdivisions and works outside of Putnam County. Both education and household income levels are above state averages. The current recycling opportunities in the county are limited and consist of drop-off sites sponsored by the Putnam County SWA.

Two subdivisions, totaling 240 homes, were chosen for implementation of this pilot. One subdivision, Woods and Irons, was selected because of an ideal geographical layout (straight streets and flat land) and close proximity to landfills and Putnam County SWA office. Many residents in this subdivision have immigrated from areas where recycling was common and environmental awareness was high. These residents were assumed to appreciate the value of a composting pilot and as cooperative as needed to help make such a pilot to succeed. The other subdivision, Woodland Forest, provides socio-economic diversity with its with slightly lower incomes and smaller houses. This subdivision was chosen based on hauler recommendation on the large amount of yard waste generated.

In Woods and Irons, a Garden Club is the most active organization among the residents and was approached initially. Meetings with the officers and club members provided feedback on the educational materials. While the Garden Club members were enthusiastic about the pilot, they desired some anonymity for the residents who did not wish to participate. Since each street in this subdivision has a resident who acts as a block captain, it was decided to distribute pilot participation information initially through these captains so as to maintain the residents' privacy. By training the block captains to do soliciting door-to-door, it is expected to reduce contact time by project members and at the same time to increase participation rates.

The Woodland Forest subdivision of Windfield will be approached through a preliminary meeting with the Windfield city council. Several residents of Woodland Forest serve as council members and this meeting will provide an appropriate forum for gaining community acceptance and input.

Collection program for the pilot study

Full scale programs in the U.S. have used clear plastic bags for collection for the advantages of collection and to discourage contamination (Glenn 1993). Pilot pro-

grams have used primarily plastic bins. In this research pilot, two collection systems will be compared: (1) a large bin for automated collection – 60 or 90 gallons (227.1 or 340.7 liters); and (2) a combination of bins and bags with manual collection. In the combination system, 20 gallon (75.7 liters) are be used for household organic materials and 35 gallon (132.5 liters) kraft bags will be provided for yard waste. The two systems will allow for a comparison of customer acceptability and collection economics. These systems were designed with extensive input from the waste hauler to accommodate his needs and interests.

This collection system will require a weekly, separate pickup on the regular trash collection day. Collection will begin in August and run through the end of October 1995. Both bags and bins will be provided free of charge to participating households before collection begins with no changes in garbage bills during this period.

The collection information to be gathered includes:

- waste generated, collection labor time, and equipment used prior to pilot program;
- collection labor and equipment use estimates under both systems and for the organic and inorganic waste streams during the pilot;
- weights and volume of organic and non-organic waste streams generated each week during the pilot collection both from an individual household and community average standpoint;
- an estimate of contamination and/or customer mis-sorting of the organic waste stream;
- an audit of the entire waste stream for the communities involved.

Prior research on waste generation by the Public Service Commission in Putnam County will be used for the pre-pilot baseline. Total diversion is expected to range from 40 to 50% based on previous research (Glenn 1993). The information collected in this pilot will be used to estimate the cost effectiveness of residential collection. The economic feasibility of composting will be assessed with the costs of composting extrapolated from the pilot program and prior composting costs research (Cook et al. 1994; Halstead et al. 1993; Rynk 1992; Fritsch and Collins 1993).

Siting/operations of the pilot facility

The composting site for this pilot will be on private land which is located close to the landfill used by the waste hauler. This site has been used by the Putnam County SWA to conduct drop off recycling programs.

The WV Solid Waste Management Rules (Title 47 – Series 38) define four types of composting activity permitted in WV:

- a. Non-Residential Activity

- b. Commercial Yard Waste Facility
- c. Sludge Composting Facility
- d. Excluded Composting Activities (Residential and On-Farm Composting)

As a SWA operated site, this pilot compost facility will follow Title 47 – series 38E, ‘Yard Waste Composting Rule,’ effective June 1, 1994, as a ‘*Non-residential Composting Activity*.’ Under Article 3.5, a registration number is required from the DEP, Office of Waste Management, Solid Waste Management Section.

The following siting regulations apply under Article 3.3: ‘Non-residential composting activities shall not be sited or constructed in areas closer than one hundred (100) feet to any regularly flowing stream, perennial stream, pond, lake, wetland or spring; Non-residential composting activities shall have sufficient area and terrain to allow for the proper management of run-on, run-off and leachate; Non-residential composting activities shall not be located within one hundred (100) feet of an adjacent property owner’s boundary line without obtaining prior written permission from the adjacent property owner; Non-residential composting activities shall not be located within one hundred (100) feet of a sinkhole.’

As a Non-residential composting activity, this pilot facility can accept yard waste materials consisting of grass clippings, weeds, leaves, brush/shrub or tree prunings and other acceptable compostable materials which have been approved in writing by the Chief, WV DEP to produce a safe product for use as a soil amendment/soil conditioner. Other acceptable compostable materials may include, but are not limited to, coffee grounds, kitchen scraps, pet and human hair, shredded newspapers, lint and sweepings, wood ashes, fish and poultry carcasses/litter, and animal manures.

The operator will be Putnam County SWA board member Alexandra Dame who has been certified as a yard waste composting facility operator by successfully completing a DEP approved training course.

Assumptions

The pilot program for Putnam County will take organic material from residential, commercial and horse stable sources based on the following assumptions:

- a. Residential participation is estimated at 70%;
- b. Residential waste diversion is for composting will be 45% (Diener et al. 1993a);
- c. Use 2.8 persons/household and a MSW generation rate is 4.82 lb/person/day (WV SWMB 1994);
- d. Use 1 cubic yard organic material/Supermarket/day (uncompacted);
- e. Horse Manure – (feces) use 45 lb/day at 80% M.C. wet basis or 0.750 Ft³/day (White,1993). Use 4.3 Ft³/day/horse with sawdust bedding;
- f. Physical properties of organic material are listed on Table II.

Facility Design

The general design guidelines for the compost facility will be based upon the following calculations: Values from Table II will be used to estimate the initial moisture balance and C/N ratio of the constructed composting windrows.

Table 2 Physical Properties of Organics used in the Pilot Study*.

	Bulk Density lbs/cy	% M.C. wet basis	%N	C/N Ratio
Residential (Mixed food/paper)	350	50	1.2	30/1
Supermarket (mixed food/paper)	350	50	1.5	25/1
Horse manure with sawdust	1000	70	1.0	40/1
Wood chips	500	40	0.10	600/1

* These properties are broad estimates obtained from literature sources. These values are not considered accurate for facility operation, but will be used for the pilot startup until material testing is done during the study.

a. Expected Generation of Organic Materials

1 Residential – Woods & Irons and Woodland Forest subdivisions:

$$300 \text{ Households} \cdot \frac{70\%}{100} \cdot \frac{2.8 \text{ per}}{\text{house}} \cdot \frac{4.82 \text{ lbs}}{\text{person} \cdot \text{day}} \\ \cdot \frac{7 \text{ days}}{\text{wk}} \cdot \frac{\text{cy}}{350 \text{ lbs}} \cdot \frac{45}{100} = \frac{25.5 \text{ cy / wk}}{(19.5 \text{ m}^3/\text{wk})}$$

2 Supermarkets – Kroger, Big Bear, (Teays Valley – Exit, Route #34.)

$$2 \text{ Supermarkets} \cdot \frac{1 \text{ cy}}{\text{day} \cdot \text{market}} \cdot 7 = \frac{14 \text{ cy / week}}{(10.7 \text{ m}^3/\text{wk})}$$

3 Horse Stable – D&M Stables, 3553 Springtown Drive, Charleston, 25306.

$$28 \text{ Horses} \cdot \frac{4.3 \text{ Ft}^3}{\text{horse} \cdot \text{day}} \cdot \frac{7 \text{ days}}{27} \cdot \frac{\text{cy}}{\text{Ft}^3} = \frac{31.2 \text{ cy / week}}{(23.9 \text{ m}^3/\text{wk})}$$

4 Wood Chips – generated from residential brush using a chipper provided by the Putnam County SWA

b. Processed Organics Available for Windrow Construction

1 Residential/Supermarket after grinding

with a 50% Volume reduction – 20 cy

2 Horse manure – 20% Volume reduction – 25 cy

3 Wood Chips at 1/3 substrate volume – 15 cy

60 cy (45.9 m³)

c. Number of windrows required at 100 Ft length

- 1 Volume of a 100 Ft windrow. Cross-sectional area = 2/3 base × height.
Use 10 Ft base, 6 Ft height

$$V \cdot \frac{2}{3} \cdot 7 = \frac{10Ft \cdot 6Ft \cdot 100Ft \cdot cy}{127Ft^3} = \frac{148\text{ cy}}{(113.2m^3)}$$

- 2 60 day windrow capacity requirement – Assume a 50% volume reduction (25% average value)

$$\frac{60\text{cy}}{\text{week}} \cdot 8\text{weeks} \cdot 0.75 = \frac{360\text{ cy}}{(275.4m^3)}$$

- 3 Number of 100 Ft windrows –

$$\frac{360\text{ cy capacity}}{148\text{ cy/windrow}} = 2.40$$

- 4 Total area of the facility will be approximately 5.7 acres (2.3 ha) –
450 Ft (137 m) by 550 Ft (168 m).

d. Facility Construction – (See Figure 1)

- 1 Windrows – 10 Ft x 6 Ft x 100 Ft – 2.4 required (aisle space 20 Ft)
- 2 Location for chipper, tub grinder, brush storage, windrows, tipping/mixing areas for substrates.
- 3 Curing Area – Assume 8 Ft height, 20% volume reduction during curing and 50% volume reduction during windrow composting.

$$(0.5 \cdot 0.9) \frac{60\text{ cy}}{\text{week}} \cdot 8\text{weeks} = \frac{8Ft \times A(Ft^2)}{27}$$

Area Required = 729 Ft² (67.7 m²) or an area of 30 Ft x 25 Ft (9.2m x 7.7 m)

e. Data to be Collected from Pilot Compost Facility:

- Design of model non-residential compost facility utilizing a filter strip to treat small amounts of runoff
- Weight and Volume Reduction of compost substrates
- Composting recipes and operational procedure
- Equipment recommendation/operations/maintenance
- Safety plan
- Odor control recommendations
- Analysis of finished compost
- Utilization of compost

Compost produced in the pilot program will be tested for pH, heavy metals, Carbon/Nitrogen ratio, nutrients, micro-nutrients and soluble salts by the Research Extension Analytical Laboratory in Wooster, OH. Compost will be screened and distributed on-site to participants in bulk form. Bagged samples will be prepared for the Putnam County SWA to distribute as part of public relations information about the pilot.

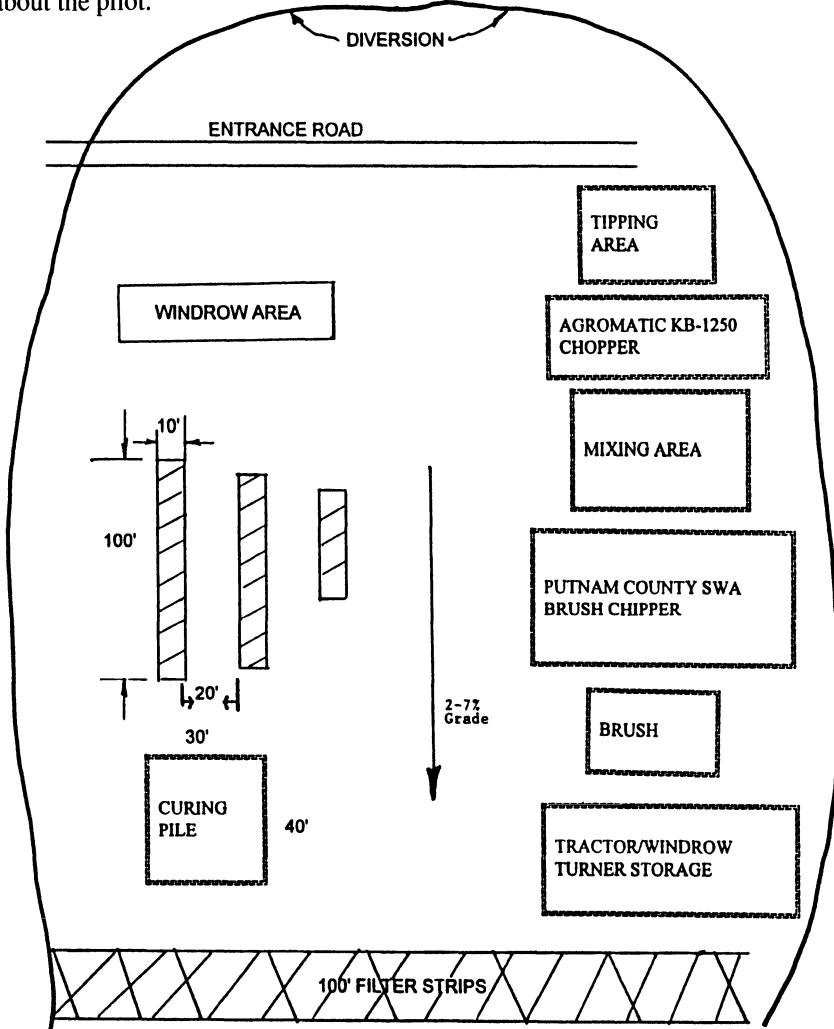


Figure 1 Pilot Compost Facility – Approximately 450' (137 m) x 550' (168 m) or 5.7 acres (2.3 ha).

Implications and outlook

The ultimate goals of this pilot program are to:

- Initiate development of a permanent composting facility to serve Putnam County;

- b Distribute information about this pilot program in order to stimulate interest in residential collection of organic materials in West Virginia;
- c To provide data for the implementation of collection programs and the design of county composting facilities in West Virginia; and
- d Determine conditions under which collection of organic materials can be cost competitive with landfilling.

The authors feel that a permanent facility in Putnam County would be most efficiently operated by a private firm. A private company has already expressed interest in operating such a facility in Putnam County. This pilot will provide information to evaluate the feasibility of this facility and give the waste hauler along with the residents experience with organic material collection. In addition, the equipment purchased during this pilot program (a tractor and windrow turner) will be available from the SWA for lease.

Regardless of the outcome from this pilot program, institutional barriers remain for residential collection in West Virginia. The main barrier is the regulated monopoly status of waste haulers. The PSC grants a monopoly for waste collection and sets garbage fees at a profitable rate. This situation reduces the incentive for the haulers to decrease costs. Thus, waste haulers have little incentive to either open their own composting facility or seek out lower cost disposal sites. Additionally, the stringent state regulations on commercial yard waste facilities in West Virginia lowers the economically viable of these facilities compared to the less regulated non-residential composting activities which can be operated by local governments. These barriers impede the development of a private industry in composting in West Virginia.

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Yard Waste Composting Strategies: Considering Technical Conditions and Organizing Systems

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Yard wastes: a biomass now becoming ‘waste’

a Handling conditions in urban environment

Maintainance of private and public landscaping works produces heavy loads of vegetable materials which sizes, especially in high social standing urban areas, to a major and cumbersome waste treatment and disposal problem. In these situations a ‘rural approach’ for a proper management of yard wastes is definitely lost; the farmer, who has often been called in rural areas to mantain landscape works, is no longer the subject that guides a more or less direct flow to agriculture of yard wastes both for crop uses (mulching, green plowing) and for bedding or animal feeding.

The improvement of economical conditions brings along two opposit effects on yard wastes production and management: on one side a rising attention to the quality of landscaping works and a consequent intensive cultivation of these areas and, on the other end, the reduction in high social standing areas of the population attending to farming. All this in conjunction to an increasing distance between the dense urban areas and the rural ones.

In this situation the straigh relationship between yard wastes production and agrucultural application is definitely lost or could impose excessive organic loads to the residual farming land close to the increasingly congested urban areas; in this context yard wastes lose their attribution of agricultural resource and tend to become objectively a waste: behaviours that cause problems in urban areas are developed (burning, deserting in abandoned areas) and, forgetting the memory of

the natural destination of these materials, they are delivered to the ordinary solid wastes collection system. This fact obviously arises over stuffing problems.

Separate collection and recovery of yard wastes through composting in these situations offers a strategical opportunity for:

- the implementation of a proper management of the solid waste disposal circuit (relieve of the collection, transportation and disposal system; volume reduction of the waste and its improved homogeneity and handling proneness; reduced transportation costs for less bulky material);
- the attainment of important agro-ecological aims for dense urban areas (volume reduction with the consequent reduction of transportations; better control of inappropriate or potential environmentally negative practices as the direct plowing, burning or deserting of these wastes in nearby agricultural areas; offer of soil conditioners and mulching materials for the landscaping operations in urban areas).

In order to what previously pointed out, the problem is primarily suffered in high standing areas: the Central and Northern European Countries, the United States and, in Italy, the Padana Valley area where the urban congested areas are present (the Piemonte, Lombardia and Veneto boundary close to the Alp Chain). In these situations the problem has been already faced or starts to be evident; studies voted to plan and promote yard waste composting activities have brought to evidence a great availability of these materials that, when delivered to the newly started composting operations, often sum up to 30 to 150 kg/person-year (Lechner, 1989; Plebani, 1993; Selldorf, 1995; Kashmanian, 1993; Favoino e Centemero, 1995; ref. tab. 1); the range depends on specific social and inhabitative conditions, the consolidation of recycling habits and the progressive pick up of synergical behaviours of the population such as domestic composting that subtracts materials from the actual flow to the disposal system.

Table 1 International review on unit production of yard wastes

Country	Unit production	Source
Austria	60–180*	Lechner (1989)
Switzerland	69**	Plebani (1993)
Switzerland	50–150*	Selldorf (1995)
United States	150*	Kashmanian (1993)
Italy	30–100*	Favoino, Centemero (1995)

*estimated ** measured

Yard waste becomes an evident overload of the ordinary waste disposal system mainly in spring and summer (Stegmann and Krogmann, 1989) when bagged mowed grass and leaf prunings are easily delivered to garbage containers with an evident increase of the monthly production compared to winter months; in cold periods yard waste is mainly a woody material, therefore burnt for household heating or delivered to the collection areas for cumbersome wastes.

1.b Field implementation: review of causes and situations

Central European Countries have developed since long term the differentiation of biomasses coming from landscaping works; this management strategy has often meant a natural evolution, in the direction of a centralization of the activities, of individual small composting activities (behaviour well common in these areas), to offer a delivery place to yard waste for citizens that find it difficult to handle a domestic composting activity. A system that sees the parallel growing and synergy of domestic and municipal or comprensorial composting has taken place (Lechner, 1989; Charlton, 1994; Selldorf, 1990); it is interesting to underline how the major operations, as far as dimension goes, have always developed out of a natural selection (technical and economical) of the operation of lesser success or capability; these major operations were originally managed according to a minimal technology approach.

In the United States yard waste composting and its strategical importance in the implementation of a composting system, has been neglected since very recent times; it is now living an explosive development in consequence of the 'landfill disposal bans' that are more and more adopted by many States for the yard wastes (Breslin and Tisdell, 1994; Kashmanian, 1993); many times only leaf are forbidden for delivery to landfills due to the fact that most of the lawn mowing is practiced very frequently and without collection of the grass.

While in the United States this field has been developed to reduce the delivery of cumbersome materials to the landfills, in Switzerland, in the Canton Ticino in particular, yard waste composting has been promoted both at domestic and municipal level as an alternative to burning and to control air pollution. With the enforcement of the 1987 Cantonal Law that forbids open fires and promotes vegetable waste composting, yard waste composting has spread with a strong promotion of the individual composting activity; a network of local operations, based on the single town area or small groups of towns has been activated. Along with this network that covers all the territory, major private composting facilities are allowed to meet the material flow in the highly populated areas, close to the major cities and to serve greater landscapers and gardeners; these bigger facilities usually meet better operational standards and make available higher quality composts for professional uses.

The first Italian Regions to promote yard waste recovery and to build up a field strategy and awareness are: Piedmont, that since 1993 has introduced a strong deregulation for composting activities of these organic materials, supporting them in respect of national composting laws that appear to be a much high constraint for simple operations with a sure and reliable environmental outcome; Lombardia, that with the approval of Regional Law n. 21/93 starts the mandatory separate collection of yard wastes for every Public Administration giving recognition to the importance of the quantities involved and to attain the objectives of separate waste collection and waste disposal decongestion. Recently the Veneto Region has shown an increasing interest for the promotion of these activities; yard waste com-

posting is considered a starting action for a systematic introduction of composting in the territory for the recovery of all the selected compostable biomasses; yard waste composting has been ruled in this Region with simplified legislative guidelines in respect both to the administrative and technical compliances. It is expected a near extension of this legislative approach to all the National territory due to the fact that the legislative Decree n. 507/93 on Local Financing has undoubtedly assigned to yard wastes the connotation of urban solid waste assigning the collection and disposal service to the Local Public Administrators; this fact will promote the delivery of selected yard wastes by citizens and private operators increasing the overall recovered quantities and setting up the operational conditions to meet the needed size and minimal economic conditions for well performing operations.

Law initiatives for the system promotion and control

a Considerations on an environmentally safe technology

Technology and process control applied to composting, finalized to an aerobic transformation of biomasses with its humification, stabilization and sanitation, should be choosed and adapted according with the type of material that is handled; from a management standpoint choices should be taken based on the balance between oxygen supply and oxygen consuption during the aerobic metabolism. Let's consider the major factors controlling:

- *oxygen consuption*: it is basically determined by the intensity of the microbial activity which depends on the *C/N ratio* (high C/N decrease the process intensity) and on the *degradability* of the biomass (high protein and sugar content increases process intensity, lignin decreases it);
- *oxygen supply*: it is mainly influenced by the *porosity* of the mean, by the size of the bed of material posed into reaction and by the *external mechanical operations* such as simple turning or the more engineered forced ventilation.

Considering yard waste composting, the main operational aspects to be considered are the following:

- 1) a fairly low intensity microbial process due to the tendentially high C/N ratio and the abundance of low degradable organic matter (cellulose, lignin); this fact carries the need of an expansion of process times but a more natural management of the operations with a 'gradual' active composting time;
- 2) the presence of enough bulking agent in the incoming materials due to the ordinary delivery of tree and brush prunings and other materials such as wood boxes and pallets;
- 3) low constraints in keeping a sufficient oxygen supply in the composted materials in consideration of the fairly low oxugen consumption; it is therefore possible to keep the composting materials in big beds (3 to 4 meters high by 10

meters wide, in the case of windrow) and to operate with extensive procedures (unfrequent turning carried with non specific equipment, such as wheel loaders).

Yard waste composting is therefore connected with an environmentally safe type of process in respect of air, water pollution and disfiguring of landscape (Frilli, 1992). The consistency and bulky characteristics of the raw materials handled allow an efficient natural ventilation during the composting process that prevents anaerobic transformations in the inner bed layers; rotting prevention is therefore achieved with the consequent proper odor control (water vapor and carbon dioxide are the main air emissions of the process). The balance between air and water spaces in the composting materials allows the evacuation of the excessive water along with the natural ventilation; less significant appears also the production of leachate at the base of the composting bed (Fisher, 1991 and others) compared to wet materials composting. Leachates have less polluting characteristics compared to other disposal plants residual waters and are safe from a sanitary standpoint. Last but not least yard waste materials are less attractive for unwanted pests such as flies or rats and this simplifies stockpiling and material handling.

b The need of a strategy: opportunities to promote and qualify the field

All that is pointed out relating to the 'natural' outline of yard waste composting and the environmental safe composting process allows to adopt simplified technologies based on windrows in open air, on unpaved areas, improved surfaces or paved ones; materials can be composted without forced ventilation and with unfrequent turnings. The landscaping of the composting site will therefore be much easier being the operation more similar to an 'equipped area' than an industrial production plant.

Intensive management of yard waste processing can be obviously taken in consideration by the operator: intensive shredding may be used as well as smaller size windrows frequently turned to speed up process performance with the important side effect of a better quality and more homogeneous end product. Simplified production set up are hereby considered as a strategical approach to implement wide range composting both as a territory coverage and as organic material treated.

Yard waste composting in simplified operational and managerial set ups could be a useful mean to reach future more important goals in the picture of waste recycling and recovery; this is particularly true in areas and situations where composting of selected organic wastes is not common yet. The strategy of a temporary decentralization of composting sites may turn out to be the clou to the promotion of the general idea of composting. This goal can come at hand in force of the following factors:

- the possibility to locate immediate, effective and environmentally safe solutions for handling cumbersome flows of wastes; the implementation of centralized operations able to treat greater quantities can therefore be waited and

- promoted referring to these preliminary operations;
- the *build up of public acceptance* of waste recovery spreading over the territory the visible results of a technology aimed to the valorization of resources more than to an alternative to traditional disposal methods;
 - the *selection from the base of qualified operators* starting from the operating fields closer to this type of activity (farmers, gardeners, nursery owners) that will gradually build up know how, opening their operational attitude to other materials than yard wastes or improve the size of their operation to meet product quality and production homogeneity and constancy as the market for compost becomes more and more professional;
 - in situation of rural areas it may be considered the possibility to *implement composting operations in abandoned agricultural set ups* (old barns or warehouses) giving new job opportunities to farmers (Rynk et al., 1992) and locating composting operations in suitable sites that can be expanded and properly sized.

The extensive approach to yard waste composting may lead to a scattering of the operations to be planned and managed according to low technology inputs; every single unit thou, can assume the connotation of a temporary activity in force of the semplicity of the set up that foresees no fixed equipment installed and in many cases unpaved composting pads; it is therefore very important to understand that the decentralized approach to yard waste composting has to be subjected to a natural development both as far as dimension goes and for the range of organic wastes treated by the composting site. The original 'small composting operation' will achieve increasing know how and performances and will be able to process greater amounts of material; new sections will be added to the composting facility and more engineering efforts will be devoted to be able to carry an environmentally safe 'active composting time' in enclosed vessel or with other specific equipment. The natural growth of the more qualified composting operations will be emphasized with the come into force of the selected collection of organic wastes started as a result of the availability on the territory of delivery sites; at the same time the growth of the market of services, the availability of specific composting equipment to rent and the market for compost sale will lead to the completion of a real composting sector.

It is also to be noted how major quantities of yard wastes are handled directly by gardeners and landscape work keepers; these professional operators often dispose of green waste through burning, direct plowing into the soil or abandoning them in residual areas. Others adopt simplified self-composting systems that must be promoted and improved giving to the operators better awarness of the process and of the objectives to be achieved with this activity. The semplicity of the process has to be recognized both from an administrative and a technical standpoint to give a feasible solution to the actual unproper disposal activities. A suitable alternative to this approach will be to provide delivery sites able to meet the following characteristics:

- a short distance from the production sites in consideration of the low specific density of the green waste ($0.15/0.3$) that rises transportation costs; from this point of view the decentralization of the composting sites is a positive aspect;
- tipping fees within a reasonable range in comparison with the actual income provided by the landscaping activity; tipping fees should be considered more as a ‘transformation cost’ compared to a ‘disposal fee’ and operational agreement foreseeing the restitution of the compost produced to the operators should be considered.

c Semplifications of the administrative guidelines and managing standards

The arguments emphasizing the strategical role of decentralized composting have to be sided by a legislative statement that allows the growth of the field in this direction; all this keeping in mind that environmental protection has to be assured also in the great managerial semplification of the operations. The evaluation of both these aspects brings up the need to find some technical and managerial parameters that safeguarding the environmental protection, give a chance to public and private investors to get involved into this type of activities. A praisable statement to apply to environmentally safe waste in all the disposal activities (collection, transportation, delivery, transformation and use of the end product) could be: ‘the law has to guarantee the necessary respect of environmental conditions: the economical and social balance has to define the evolution of the system’.

In these conditions, the system should naturally evolve to bigger operations due to the fact that:

- 1) bigger operations are able to meet better cost reduction;
- 2) bigger operations are able to assure a better quality product with constant characteristics with a consequent improved sellable price (public selfuse or public distribution is the feasible compost allocation for small decentralized activities);
- 3) bigger operations may need yard waste as a source of bulking agent to process other organic wastes; yard waste becomes therefore a needed input to recover other materials.

The question is: ‘which is the level the legislative statements have to rise to allow the semplification of the operations within the environmental safeguard and foreseeing a future aggregation of the same?’

Laws relating to biomass recovery through composting may deal with the following aspects:

- 1) the *permit to receive the waste* (authorization) that appears to be essential only if the activity is considered as a ‘waste handling process’; this is properly applied for all the organic wastes that, as tipped to the plant, give considerable odor or sanitary problems and deserve a strict control such as food left-overs and sludges. If the activity is foreseen as a production of sellable product (pot-

- ting mixtures) or an organic recovery set-up (town owned composting plant with redistribution of the end product to the citizens) it could be appropriate, for yard wastes, the simple communication to the Authorities or a self-certification of the come into force of a trasformation activity (for ex. D.L. 443/93 segg. on residues riutilization in Italy);
- 2) the *permit to use the product*: most national laws tend to liberalize the use of 'quality' compost and the definition of a quality standard is basically the issue nowadays discussed. The chemical analysis requested depends mostly on the type of waste treated by the composting plant and covers a wide range of heavy metals, organic micro contaminant and the sanitization parameters of the organic matter. In the case of decentralized yard waste composting plants, to reduce analysis costs to a value consistent with the budget of these activities, a screening of incoming materials could be adopted and simplified analysis on the end products should inquire only the inorganic pollutant known to be an ordinary problem in these wastes (i.e. lead); this approach has been taken in consideration in recent technical guidelines adopted by Regione Piemonte;
- 3) the *specification of technical guidelines to be followed to handle and process the materials* and all the environmental protection equipment to be installed to be permitted to start composting operations.

Considering the latter point, the environmentally safe characteristics of yard waste composting may very well meet a legislative initiative. Local regulations agree in most cases on the possibility to carry the process in open air in consideration of the very low odor level produced; more discussion is carried on the possibility to carry the process over unpaved surfaces. Paving assures the positive collection of leachates and rain water and leads to the collection of the same in storing ponds; this water can be used to optimize the moisture content within the composted materials. Paving allows neeter composting sites avoiding the organic matter to be mixed with dirt or stones when processed over improved surfaces; it is therefore preferred by operators working for a real commercial valorization of compost. The need for pavement in yard waste composting operations becomes a problem for decentralized plants because of the increase of costs involved and the town planning permits that may reduce the possibilities to build in rural areas; the temporary asset of these units is therefore lost and ceasing the activities to promote a future aggregation in bigger units will be more difficult. In the picture of using yard waste composting as a promotion mean for the whole composting system, mandatory paving of the composting areas may lead to negative effects bound to slow down the start up of new initiatives.

What hereby considered leads to the necessity to *permit decentrated yard waste composting over unpaved surfaces* (that need to be improved for equipment traction with stones or woody materials); this approach finds full environmental approval due to the characteristics of the waste and to the process itself that produces little leachates with very safe analytical characteristics; the nitrate level is usually very low and the sanitation parameters are met by the absence of fecal pathogenous.

The possibility to carry yard waste composting over unpaved surfaces has been adopted by many regional and national legislations (table 2). These indications find a maximum sizing over which paving is requested. The most evident meaning of this approach is that Public Administrations are giving a chance to start operations with little investments, easy location of composting sites and low planning constraints; it is therefore given a chance to gather different activities abandoning the ones that appear less suitable as far as operating conditions and foreseeing a future increased attention to the collection of leachates and rain water as soon as the operations become of a bigger size.

Table 2 Swiss and Italian law prescription on the maximum quantities of yard waste composted on unpaved surfaces

Country/region	limits	other guidelines
Switzerland	100 ton/yr	/
Italy:		
– Lombardia	400 ton/y	only for public institutes
– Piemonte	1.000 ton/yr	surfaces must be paved within 1 year

The chosen dimensional limit depends on the idrogeological local situations (i.e. safeguard of the natural water collection basins for the Swiss situation) but relates greatly on the importance that this promoting action has on the social economical environment in which it is applied. From this point of view it is understandable how the limits are progressively higher for pioneer initiatives (ref. Review of the first American experiences, Goldstein et al. 1992) because this approach will expand the environmental benefits drawn by the start up of composting sites.

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Experiences of Compost Use in Agriculture and in Land Reclamation Projects

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Abstract

Numerous agronomic experiments were set up in fruit and vine growing, using both MSW compost (municipal solid waste not source separated) and BS compost (barks and sewage sludges). Both materials were compared with cattle manure in the field; in planting hole with peat; in mulches with usual under-plant soil management techniques. Compost affected soil porosity, softness, waterholding capacity, and availability of nutritive elements in a positive way. Compost generally improved plants themselves, positively influenced the growth of young apple-trees and vine cuttings, prevented weed development and supported an earlier production in young plants. In some trials with MSW compost, increased heavy metal content in the soil was observed, but that did not happen with BS compost.

The BS compost proved a valid alternative to the soil and organic soil conditioners on the market in the recovery of degraded areas too. In the experiments, compost secured a rapid emergence and regular growth of herbaceous species covering degraded areas. Establishment of a grass sward allowed soil consolidation, reducing soil erosion. The thoroughly environmental safety of tested compost was proved: leaching water and soil tests showed no sign of pollution or eutrophication.

Introduction

Compost, obtained from the controlled bio-oxidative process of the organic fraction of municipal solid waste (MSW) and of other selected biomasses, can be used as fertilizer in natural soils, in farmlands and in land reclamation projects of areas that have suffered man-inflicted damage. In these applications it affords several advantages, associated with its high stabilized organic matter and nutrients content. Compost adding to the soil makes it possible to restore the balance between depletions and replenishments of organic matter in the biosphere (Petruzzelli,

1994). Such actions of organic matter restitution to the soil and additional fulfillment of plants, nutrient requirements are beneficial not only from an agronomic viewpoint, but also in terms of energy supply (Paris and Robotti, 1981; Zucconi and De Bertoldi, 1982).

Following compost application, an increased organic matter and nutrients content was observed in the soils by some authors (Ferreira and Cruz, 1992; Bevacqua and Mellano, 1993; McConnel et al., 1993). Soil physical fertility is also enhanced by the use of compost: in several instances (Ballif et al., 1991; Vigna Guidi, 1992; He et al., 1992) an increase in porosity, structural stability and waterholding capacity was seen as well as a remarkable erosion control.

Regarding crop performance, compost nutritive value is similar to that of cattle manure and its use allows to maintain unchanged quantitative and qualitative crop features (Del Zan, 1989; Beyea et al., 1993; Roe et al., 1993; Baldoni et al., 1994). It has also to be noted that compost is to all intents and purposes an organic soil conditioner and that, in order to fully meet all needs for nutrients, and in particular for nitrogen, of some exceedingly demanding crops, such as corn, integration with mineral manure is necessary (Ferreira and Cruz, 1992; Businelli and Gigliotti, 1994).

As far as concerns its environmental impact, conflicting findings are reported in the literature about the possible actions of heavy metals, depending on the characteristics of the soils used for testing purposes and on the quality of the tested composts. Following compost application an increase in zinc, copper and lead content in the soil and in plants was often observed, whereas changes about other heavy metals turned out to be considerably smaller (Barbera et al., 1989; Zamborlini et al. 1989; Bevacqua and Mellano, 1993; Baldoni et al., 1994; Businelli and Gigliotti, 1994). The heavy metal problem can be overcome by composting only organic matters with a low content of potential pollutants: the use of products with a low heavy metal content did not adversely affect the quality of soils and plants (Petruzzelli et al., 1991).

The existing literature reveals that only accurate analyses and trials, specifically geared to the needs of given soil conditions and crops, can provide invaluable clues as to whether it is worth supplying compost to the soil. On this basis, we also conducted a number of trials, designed to prove the compost impact on soil fertility and plant nutrition and to evaluate its effects on heavy metal dynamic.

Materials and methods

The investigation started in 1986 and is still in progress. It was conducted on several farmlands that were thought to effectively represent the prevailing conditions in the Trento regional district (16 vineyards and 14 orchards in limy soils with a subalkaline reaction) as well as on a number of environmentally damaged areas (ski slopes, deserted roads, abandoned quarries, exhausted landfills). The goal of the experimental study was to assess the agronomic and environmental effects of two compost types:

- BS compost: obtained in the Trento plant through composting a mix of sewage sludges and poplar barks (1:2 ratio in volume);
 MSW compost: obtained from the organic fraction of municipal solid waste mechanically sorted in composting plants; materials from the Schio, Bressanone and Salzburg treatment plants were tested.

The average analytical characteristics of both composts, as well as of the cattle manures and peats used for experimental purposes, are shown in table 1.

Table 1 Analytical characteristics of organic conditioners used in experimental trials.

	Cattle manure	Peat	MSW compost	BS compost
Number	8	6	11	18
Moisture (%)	72.6	64.4	35.2	53.8
pH (1/5)	8.46	5.82	7.89	7.64
El. conductivity ($\mu\text{S}/\text{cm} 1:5$)	2510	620	3800	1260
Ash (% dm)	27.9	19.1	49.6	39.3
Organic matter (% dm)	63.8	75.3	41.2	58.1
C/N	18.4	39.6	19.4	18.3
Total N (% dm)	1.99	1.33	1.26	1.86
P_2O_5 (% dm)	1.87	0.11	0.71	2.39
K_2O (% dm)	1.77	0.10	0.63	0.56
CaO (% dm)	7.58	2.76	8.89	7.41
MgO (% dm)	1.05	0.61	1.99	1.22
B (mg/kg dm)	32	11	67	32
Mn (mg/kg dm)	300	59	424	241
Zn (mg/kg dm)	255	58	1206	572
Cu (mg/kg dm)	53	28	447	206
Pb (mg/kg dm)	30	12	650	89
Ni (mg/kg dm)	10	16	132	20
Cd (mg/kg dm)	1	1	3	2
Cr (mg/kg dm)	28	46	304	61

Both compost types were used according to different operational procedures: in organic fertilization before planting, in planting hole fertilization and in mulching.

Analyses were performed based on the Ipla-Divapra methods (1992) for organic conditioners, on the official methods for chemical analysis of soils (SISS, 1992) and according to Martin Prevel et al.'s recommendations for leaves and fruits (1987).

The results achieved in each one of the investigated areas are reported below.

Use of compost in fruit and vine growing

The results obtained in the different agronomical uses of the two composts used are in the following pages exposed and discussed.

Use of compost on open ground fertilization

Eight trials were conducted (3 on grapevines and 5 on apple trees) to compare the

performance of both compost types in organic fertilization before planting. Our findings show that both composts, used at doses of 40-50 t/ha, exhibit greater fertilizing capabilities than 60 t/ha of cattle manure. When reviewing the soil chemical and physical characteristics 3 years later (table 2), it appears that compost has better conditioning properties than cattle manure: it increases organic matter and nutrient contents and improves the soil physical features (greater porosity, higher available water content).

Table 2 Use of compost in open ground fertilization: chemical and physic characteristics of the soil at the end of the third vegetative period (mean values observed in 8 trials).

	pH	Organic matter % dm	C/N	P ₂ O ₅ av. mg/kg	K ₂ O ex. mg/kg	Available water % dm	Porosity % vol	Stability index %
Cattle manure (60 t/ha)	7.75	3.04b	8.57	63.5b	138b	12.6b	42.1b	33.4b
BS compost (50 t/ha)	7.74	3.78a	8.95	73.7a	177a	13.7a	43.1a	38.9a
MSW compost (50 t/ha)	7.78	3.89a	8.88	69.7ab	175a	13.7a	42.9a	28.1c
Sig. F	ns	**	ns	*	**	**	*	*

(ns=not significant; *=significant with P=0.05; **=significant with P=0.01)

Therefore compost returns to the soil at least some of the nutrients depleted by crops and promotes the conservation of optimal organic matter levels, thus ensuring balanced production and nutritional conditions of plants. As completely stable organic conditioners, such as the tested composts, experience a slow mineralization process, no nutritional imbalances or leaching events were observed, as can occur when using liquid cattle manure, poultry dung and fresh cattle manure.

Compost application into plant holes

Both composts were tested in 6 apple tree varieties versus an untreated control and peat. Conditioners were applied to the root systems of apple tree whips at the time of planting at a dosage of 5 liters per plant. Table 3 shows the growth and production data recorded in the next 4 years.

Table 3 Use of compost in planting holes: vigour and yield of apple trees (mean values observed in 6 trials).

	Shoot radius (cm)				Yield (Kg/tree)	
	1989	1990	1991	1992	1991	1992
Control	1.76b	2.73b	3.54b	4.33	3.63b	8.69b
Peat (5 l/tree)	1.88a	2.83a	3.66a	4.36	4.36a	9.73a
BS compost (5 l/tree)	1.86a	2.85a	3.68a	4.41	4.18a	9.97a
MSW compost (5 l/tree)	1.78b	2.71b	3.52b	4.29	3.60b	8.09c
Sig.F	**	*	*	ns	*	*

(ns=not significant; *=significant with P=0.05; **=significant with P=0.01)

MSW compost proves to be ill suited to this application, offering no greater advantages than the untreated control. Its poor performance in the case of direct appli-

cations onto the plant root systems is believed to be caused by too high pH values and electrical conductivity. On the contrary BS compost had a favourable impact on the crop performance, this being similar to that of peat.

Use of compost for mulching applications

Mulching means to locally distribute a compost layer (50 cm wide and 5 cm thick) upon the ground on plant rows and is meant to control weeds, improve the soil water balance and thermal conditons and to limit erosion. Mulching requires varying amounts of compost depending of the distance between rows: as a rule of thumb a dose between 25 t/ha (rows 5 m apart) and 65 t/ha (rows 2 m apart) is needed.

In total 15 mulching trials were performed (6 on apple trees and 9 on grapevines). Here the two compost types, applied just after the planting, were compared with the conventional techniques of soil management on the rows (mechanical tillage, chemical weeding, black plastic film mulching).

Our findings demonstrate that compost mulch promotes the overall growth of young plans and their early production (table 4 and 5). Mulching turned out to be particularly beneficial in no-irrigated soils and in those with a lower organic matter content, where its favourable effects were largely associated with improved water content and nutritional conditions of soils. An increase in the assimilable forms of nutrients and in the organic matter and available water contents was also seen.

Table 4 Use of compost for mulching purposes: vigour and yield of grapevines (mean values observed in 9 trials).

	Pruning weight (g/vine)			Yield (kg/vine)						
	1987	1988	1989	1990	1991	1992	1989	1990	1991	1992
Control	26 b	101 b	226 b	258	349	358	1.06 b	1.95 b	2.07	2.05
BS compost	39 a	116 a	261 a	263	357	349	1.27 a	2.27 a	2.07	2.21
MSW compost	40 a	121 a	277 a	260	338	364	1.25 a	2.34 a	2.23	1.97
Sig.F	**	*	*	ns	ns	ns	**	*	ns	ns

(ns=not significant; *=significant with P=0.05; **=significant with P=0.01)

Table 5 Use of compost for mulching purposes: vigour and yield of apple trees (mean values observed in 6 trials).

	Shoot radius (cm)					Yield (kg/tree)				
	1987	1988	1989	1990	1991	1992	1989	1990	1991	1992
Control	1.72b	2.30b	3.02b	3.57	4.04	4.43	3.5b	7.2	8.6	12.4
BS compost	1.85a	2.54a	3.30a	3.71	4.10	4.57	4.8a	8.3	9.1	11.2
MSW compost	1.78ab	2.58a	3.27a	3.66	4.08	4.40	4.6a	8.1	8.7	12.5
Sig. F	*	**	*	ns	ns	ns	*	ns	ns	ns

(ns=not significant; *=significant with P=0.05; **=significant with P=0.01)

Our analyses of the soil water content and thermal conditions revealed fairly remarkable findings: the moisture level of compost-mulched soils is steadily and

significantly higher than both in weeded and/or tilled plots and in those treated with plastic film mulching. This achievement is made possible by the permeability of the compost layer which, unlike plastic films, allows to store water supplies in the soil as well as by the lower evaporation losses resulting from the interruption of water capillary rise (Pinamonti et al., 1994). In addition, the compost layer effectively acts as an insulating material and, unlike black plastic film, prevents extreme soil temperature rises, thus minimizing temperature ranges on a daily and on a seasonal basis.

Concerning the desired goal of limiting weeds growing on the rows of apple trees and grapevines using compost mulch, organic matter layers were shown to control weed growth only for a few months' time: thus, their weeding action ends within just one vegetative period. Then chemical weeding also in the mulched strips is necessary, or, alternatively, the covering technique with selected grass species could be applied.

Leaf examinations showed altered nutritional states of grapevines and apple trees in the compost mulched plots, i.e. increased potassium content and decreased phosphorus, calcium and magnesium contents (Pinamonti et al., 1993). These changes can be attributed to the different soil physical conditions (moisture and temperature) and to the different architecture of the root systems. In fact, the control plants showed a different structure in their roots, with a less evident exploration of the top soil and a more significant development in the depth (Pinamonti et al., 1993). The qualitative features of musts and apples, however, were not affected by compost mulching.

Use of compost in land reclamation projects

In this sector only BS compost was tested. A large number of trials were indeed carried out under different conditions: surface application to promote grass covering in dismissed mountain road and ski slopes; field fertilization with ploughing in of the compost in order to enrich extremely depleted soils as part of an environmental reclamation projects of abandoned quarries and exhausted landfills.

Green covering of ski slopes

The trial was carried out on a ski-track of Monte Bondone (Trento), which stretches for a length of 1800 m and slopes of 435 m. The track was set up in the late 1960s and it has caused a complete destruction of the turf. The steep slope and the detrital composition of the ground, classified as calcareous lithosol, impelled an immediate green covering of the whole area, which proved satisfying only in the planer sections of the track. The remaining area, notwithstanding diverse grass and hay mulchings, showed in 1989 a still inadequate turf (covering was lower than 50%).

A portion of 3000 m² of this area, average sloping 35%, was divided in October

1989 into 4 large plots, which were mulched with BS compost at the application rates shown below:

- 2.5 cm layer, equal to 125 t/ha;
- 5.0 cm layer, equal to 250 t/ha;
- 7.5 cm layer, equal to 375 t/ha;
- 10.0 cm layer, equal to 500 t/ha.

Each plot, as well as an untreated adjacent area (control), was sown with a mix of grasses, selected as particularly suitable for mountain areas.

The grasses sown in the compost layer appeared and grew regularly, with no signs of phytotoxicity, nutritional deficiencies or water stress. The vegetation settlement allowed a sound soil covering, so preventing rain from flowing on the soil surface, which effected a positive control of the soil erosion. It should be pointed out that all compost doses applied experimentally had favourable effects on the emergence and development of the sown species and, 4 years later, the mulched areas were covered by 100% and showed a large biomass production, unlike the control parcel, which still remained uncovered by 40–50% (table 6).

The data of leaching water analyses (table 7) give ample assurances about the successful results in terms of environmental protection. Indeed, pH values, electrical conductivity, COD, total phosphorus and ammonical nitrogen in the leaching water, through higher in the mulched area, remained well below the upper limits set by the national law 319/76 regarding the admissibility of sewage into surfacing waters.

Table 6 Turf covering in a grass sowing trial of ski tracks on differently thick mulching layers of barks and sewage sludges compost (data in % of the surface area).

	1990			1991			1992			1993		
	mix	spo	tot									
Control	32	15	47	37	24	61	30	30	60	15	43	58
BS compost (125 t/ha)	81	4	85	89	7	96	79	20	99	68	31	99
BS compost (250 t/ha)	85	3	88	88	11	96	80	18	98	65	34	99
BS compost (375 t/ha)	81	5	86	89	9	99	77	22	99	66	32	98
BS compost (500 t/ha)	84	3	87	89	10	99	80	19	99	69	30	99

mix=present in sown mix species; spo=spontaneous species; tot=total coverage

Table 7 Analytical characteristics of leachate in a green covering trial on ski lopes (samples collected in July through 3 years); all data, except pH and EC, are given in mg/l

	pH	EC µS/cm	COD	P tot.	N amm.	Zn	Cu	Ni	Pb	Cd	Cr
Control	7.10	74	63	0.33	1.08	0.11	0.01	0.17	0.01	0.00	0.01
BS compost	7.39	151	111	1.09	2.45	0.17	0.01	0.14	0.02	0.00	0.01
Sig.F	*	*	**	**	**	ns	ns	ns	ns	ns	ns
Law limits	5.5–9.5	–	160	10.00	15.00	0.50	0.10	2.00	0.20	0.02	2.00

(ns=not significant; * = significant with P=0.05; ** = significant with P=0.01)

Landfill reclamation and recovery of abandoned quarries

In general, these actions are intended to restore the original landscape of the degraded areas and require high quantities of hard-to-find earth. As a consequence inerts of different kinds (gravel, quarry debris, river stones, masonry debris etc.), having extremely poor agronomic properties, are often used. BS compost, if mixed to these materials, makes the soil just fertile enough to host the grass and tree species foreseen in the land reclamation projects.

In order to restore an exhausted landfill near Caldonazzo (Trento), for instance, a 1000 t/ha dose of BS compost had to be admixed to the river stones and the quarry debris forming an approx. 50 cm thick layer on the ground. This mixture compared favourably with a 30 cm thick earth layer: good turf settlement and better root-tacking of the planted species (especially wood types).

A second project included the reclamation of a closed landfill near Borgo Valsugana (Trento). The area involved in the trial (13.800 m²) was first levelled, and afterwards covered with a 1 m thick layer of diverse, very poor materials (e.g. inerts, porphyry processing debris, embankment earth). BS Compost, ploughed in in the 30 cm topo soil in variable rates between 100 and 250 t/ha, meant a considerable chemical, physical and biological enrichment of the site, to be destined to agricultural use, so making possible a rapid settlement of turf and an effective regeneration of an active layer of satisfactory agronomic value.

Heavy metal considerations

The results provided by compost open ground application and mulching in orchards and vineyards (from 30 to 90 t/ha) showed very significant increased in the soil heavy metal content associated with MSW compost, as compared to BS compost (table 8). A large variability was however seen, depending on the pedological, morphological and climatic conditions of the sites. In some instances MSW compost application caused considerable copper, zinc, lead, nickel and chromium increases both in total content and in their assimilable fraction. Under different circumstances the same material induced no significant changes in the soil metal content. Finally MSW compost was hardly ever responsible for manganese and cadmium increases.

Table 8 Heavy metal content in soils conditioned with compost (all data are in mg/kg dry matter weight).

	Zn TOT.	Cu EDTA	Ni TOT.	Pb EDTA	Cd TOT.	Cr EDTA					
Control	92b	25.6b	51.9	24.3b	14.4b	1.16b	63.9b	17.0b	< 3	0.18b	31.5b 0.19b
BS compost	116a	38.1a	63.9	25.4b	15.2b	1.15b	65.5b	17.4b	< 3	0.19b	35.5b 0.19b
MSW compost	123a	41.0a	65.0	40.0a	20.7a	1.72a	95.6a	29.7a	< 3	0.29a	44.3a 0.31a
Sig.F	*	*	ns	*	**	*	*	*	ns	*	***

(ns=not significant; *=significant with P=0.05; **=significant with P=0.01)

In soils naturally abundant or artificially loaded with pollutants, a notable reduction in their assimilable form was observed. This result, which is particularly important for vineyards, these frequently having higher copper concentrations than normal, highlights the ability of the organic matter contained in the compost to fix or chelate some of these trace elements, thereby making them less available to crops.

In plots, where BS compost was applied to the soil, only an increase in the copper and zinc contents, as against the control, was found. Both these, however, in small quantities, are essential to the plant life and, besides, their health and environmental impact is considerably lower than other pollutants, such as cadmium, mercury and lead.

Since plant absorption of heavy metals depends on a large number of factors (pedological soil characteristics, chemical, chemico-physical and biological soil features, climatic conditions, etc.) interpretation of results is frequently difficult. In general in vineyards and orchards receiving MSW compost, significant increases in nickel, lead, cadmium and chromium levels in the leaves were observed (table 9). A similar trend was seen in the musts and apples produced by plants treated with the same material.

Table 9 Heavy metal content of apple tree leaves and fruits receiving a compost treatment (all data are in mg/kg dry matter weight).

	Zn	Cu	Ni	Pb	Cd	Cr
LEAF LAMINAS						
Control	23.2	12.9	1.84	2.60 b	0.052 b	0.72 b
BS compost	22.2	12.1	1.61	2.59 b	0.054 b	0.83 ab
MSW compost	21.0	13.0	1.89	3.30 a	0.071 a	0.91 a
Sig.F	ns	ns	ns	**	**	*
APPLES						
Control	4.53	4.46	0.21 b	0.27 b	0.0060 b	0.16 b
BS compost	3.93	4.13	0.23 b	0.28 b	0.0067 b	0.18 b
MSW compost	4.93	4.73	0.32 a	0.34 a	0.0087 a	0.25 a
Sig.F	ns	ns	**	**	*	*

(ns=not significant; *=significant with P=0.05; **=significant with P=0.01)

Concerning BS compost, the available data reveal definitely lower absorption levels than in MSW compost, so that no hazard exists for the food chain. The analysis of leaching waters collected after compost application in the ski track trial, also demonstrated an excellent degree of environmental safety. The heavy metal content in the leachate did not even change when 500 t/ha of BS compost were applied (table 7).

Conclusions

High quality compost can offer several agronomic advantages: it improves the aggregate stability, enhances the soil porosity and water retention capacity and

minimizes the need of mineral supply. In steep slopes it controls erosion (if applied as mulch) and allows a prompt growth of the grass turf, even in less fertile and deep soils.

In addition, it improves the plant general health conditions, cures or relieves some plant diseases and minimized crop inconsistencies. These beneficial effects are particularly apparent in soils with a low organic matter content and no irrigation.

The growth and production of plant treated with compost are the same as with cattle manure, the amounts of organic matter in the ground and fertilizer remaining unchanged. A high quality compost, applied at the dose of 30 t/ha, is expected to yield a production or fertility-boosting performance equal to 45–50 t/ha of cattle manure.

Based on our agronomic trials carried out, the following final conclusions can be made.

- Compost, as is filled into fruit plant holes at the dose of 5 litre/plant, favourably affects the growth of planted whips. BS compost proved to be more suitable for this purpose than MSW compost.
- BS compost, as part of a pre-planting organic fertilization plan, provides an attractive alternative to cattle manure, due to its longer-acting and more remarkable conditioning properties.
- Compost mulching promotes the growth of young plants and improves the soil water balance as well. Limited to the first year, it controls weed growth only to a slightly lower degree than plastic films and weeding. A longer-lasting effect can be obtained through the controlled planting of grass in the mulched layer.
- BS compost provides an appealing alternative to earth and commercial organic conditioner both for the recovery of degraded areas and for the construction of green areas in city downtowns and neighbourhoods.
- A high quality compost helps protect the environment and ensures wholesome crops. The MSW compost can cause heavy metal deposition, especially nickel, lead, chromium and cadmium, in the soil, in the plants and products. The BS compost had a considerably lesser impact on heavy metal concentrations in plants and crops, due to the smaller amounts of potential pollutants it contains.

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B1 Starting Material

The Importance of Lignocellulosic Compounds in Composting

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Introduction

Composting is the solid state aerobic degradation of organic waste, principally of plant origin. This may be agricultural waste, garden waste or domestic refuse. The latter is included because of the large amount of paper used in packaging and in newspapers and magazines. The common factor with all of these is the high proportion of lignocellulosic material in them. Lignocellulose is the material of which plant cell walls are made and it is the most abundant organic material on Earth. It has been estimated that it represents approximately 50% of the annual global production of biomass, about 5×10^{10} tons (Goldstein, 1981). Composting can produce useful materials from lignocellulosic waste. It can also carry out desirable processes on waste itself and on other materials using the lignocellulosic waste. (Figure 1.)

Substrates

Most of the mass of lignocellulosic material is made of three groups of compounds, celluloses, pectins and lignins. The ratios of these groups of compounds differ in different materials. In herbaceous plant material celluloses and pectins predominate whilst woody material is mainly composed of celluloses and lignins. Paper is largely cellulose plus inorganic fillers (Figure 2).

The celluloses comprise true cellulose and hemicellulose. Cellulose is a β 14-linked polymer of glucose, (14)—D-glucan, with a chain length of about 1000 glucose units. These chains can be aggregated into highly regular micelles to form crystalline regions between which are amorphous regions of less regular arrangement. Because of the length of the cellulose chains single molecules often run from a crystalline region into an amorphous region and *vice versa*. In plant cell walls these amorphous and crystalline regions of cellulose form microfibrils and

cross linking between these microfibrils are hemicelluloses as well as pectins in herbaceous tissue and lignins in woody tissue.

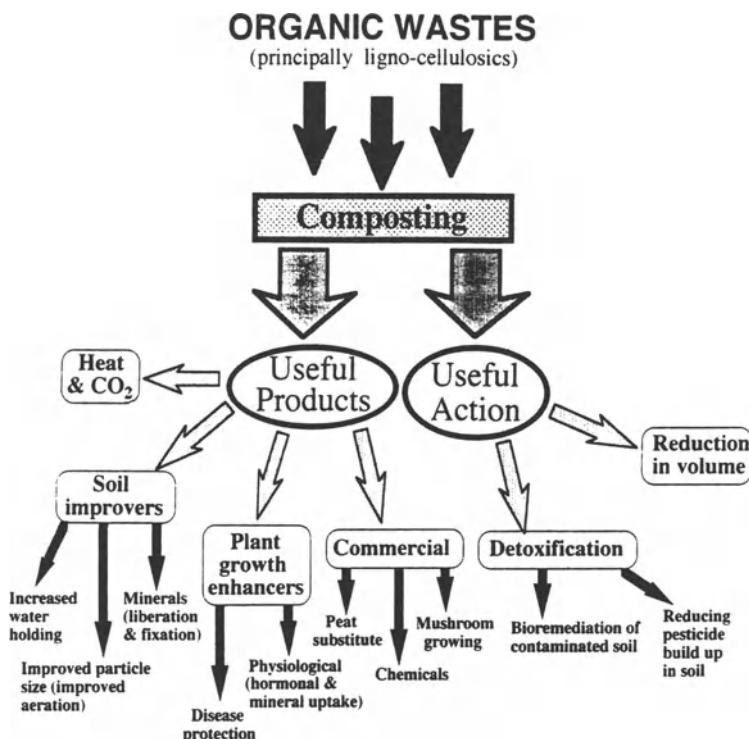


Figure 1 The uses of composting

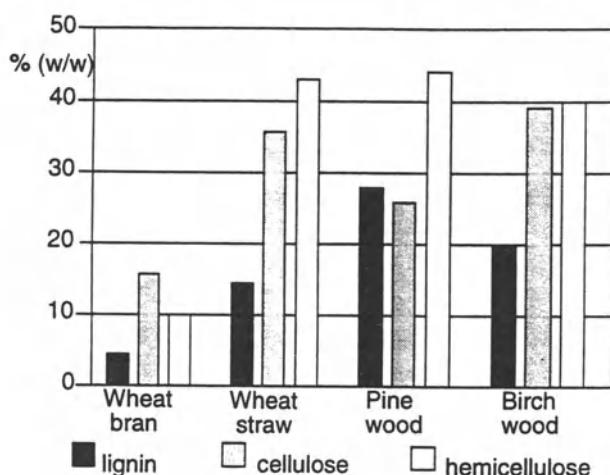


Figure 2 Composition of some lignocellulosic materials (Lynch, 1987b)

Hemicelluloses are a much more heterogeneous than true cellulose. The commonest sugars making up hemicelluloses are the pentoses, xylose and arabinose, and the hexoses, glucose, galactose and mannose. The hemicelluloses formed from them are thus called xylans and arabans (pentosans), and glucosans, galactans and mannans (hexosans). The chains are shorter than in cellulose and may be branched. There is often more than one sugar in a chain and they then have a compound name *e.g.* glucomannan or galactoaraban.

Pectic compounds are also a fairly diverse group differing from hemicelluloses by being composed of chains of uronic acids (sugar-acids). They are basically polymers of 1–4 α-D-galacturonic acid with occasional rhamnose residues in the chain. The commonest member of this group is pectic acid which is about 100 galacturonic acid residues long, with many –COOH groups which can cross link with each other via divalent cations, usually calcium. Other neutral sugars *e.g.* arabinose and galactose may occur in short side chains. Pectinic acid (pectin) is the semi-methyl ester of pectic acid in which some of the –COOH groups are methoxylated to –COOCH₃ and it is about 200 galacturonic acid residues in length. The degree of esterification can vary and the greater the esterification of the carboxyl groups the less cross linking can take place between chains.

Lignin is an extremely complex and variable material which can be 20–35% of the weight of wood. It is a three dimensional aromatic polymer of *p*-hydroxyphenylpropanes cross linked by irregular C–C and C–O–C linkages. Lignins are formed by dehydrogenation of *p*-hydroxycinnamyl alcohols. Lignin from gymnosperms is composed mainly of coniferyl alcohol but lignins from angiosperms (including cereals) are mixed polymers of two or three monomers *e.g.* *p*-coumaryl, coniferyl and sinapyl alcohols. (Figure 3.)

Catabolism

Composting involves the complete or partial degradation of all of these compounds by a consortium of microorganisms, the composition of which changes as the composting progresses. The microorganisms that make up the consortium and the rate of change of composition of the consortium will depend on the substrate and the physical conditions under which composting is taking place. Composting produces heat and as compost is quite a good insulator temperatures may rise to over 60°C. At such temperatures thermophilic organisms, principally actinomycetes, predominate (Goodfellow & Williams, 1983) but at lower temperatures, both before and after the higher temperatures are reached, a wide range of bacteria and fungi are involved in the process of composting.

Although lignocellulosic compounds are resistant to degradation it is present in such abundance that it is rare for the carbon source to be limiting in composting. However, lignocellulosic material does not contain fixed nitrogen and phosphates are also frequently in short supply in material for composting. The growth of degrading organisms is thus normally limited by available nitrogen and phos-

phate which in turn limits the rate of decomposition of the lignocellulosic material. The incorporation of a source of available nitrogen and phosphate into compost e.g. green plant material, animal excreta or proteinaceous food processing wastes, will increase the rate of composting. Despite the apparently nutritious nature of the polymers of which it is composed, no higher animals can themselves produce the enzymes necessary for their degradation of lignocellulosic material and only a limited number of microorganisms can produce such enzymes. Each of the components of lignocellulose requires more than one enzyme for its degradation.

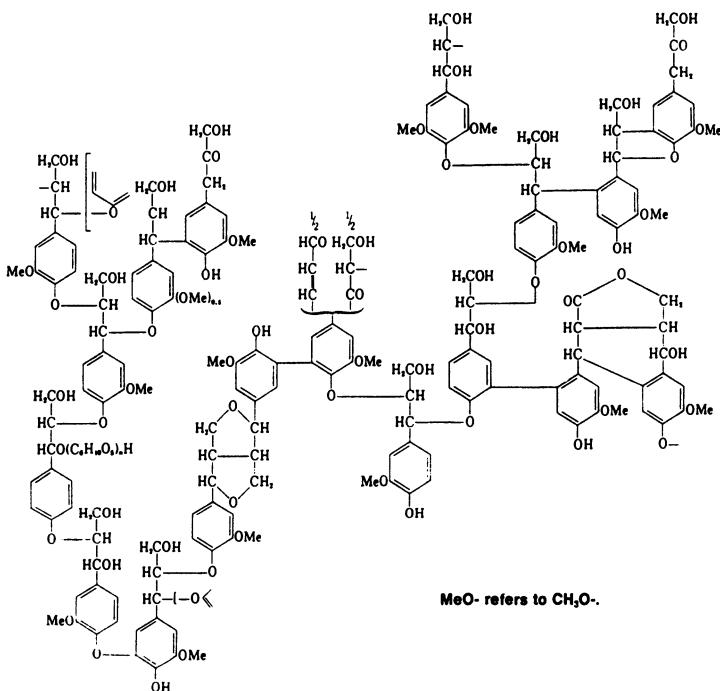


Figure 3 Schematic formula showing units linked in a molecule of spruce lignin (Freudenberg, 1965)

Cellulose is degraded by an endo-(1-4)-D-glucanase (*syns.* endocellulase, C_1) which can attack the amorphous regions of cellulose and the surface of crystalline regions. Because of the regular nature of the crystalline region, bonds cleaved by the endoglucanase are rapidly reformed unless there is the synergistic action of an exoglucanase (*syns.* exocellulase, C_x) which removes a cellobiose unit from the exposed end of the chain. The hydrolysis of cellobiose to glucose requires a third enzyme, β -D-glucosidase (syn. cellobiase).

Pectic substances are more readily attacked by enzymes than cellulose because they do not have crystalline regions and pectinases are produced by a wider range of organisms than are cellulases. The enzymes that degrade pectic substances are of two types, those that attack the polyuronic acid chain (depolymerases) and those that remove the methyl group from pectins to produce pectic acid and methanol

(pectin methyl esterases).

Pectic acid is attacked by a number of depolymerase enzymes which can again be divided into two types, hydrolases which hydrolyse glycosidic linkages and lyases which cleave a glycosidic bond with the formation of a double bond between the C-4 and C-5 of the newly formed end of the chain. There is quite a range of these enzymes which can attack the middle of chains. They include endopolygalacturonase and pectate lyase (polygalacturonic acid trans-eliminase). There are also exo-enzymes which remove uronic acid residues from the ends of chains singly or in pairs and occasionally as trimer. The former are called exopolygalacturonases and the latter exopeptate lyases.

Most depolymerase enzymes are substrate specific and will not attack heavily methylated polymers of uronic acids. Endopectin lyase (*syn. polymethoxyl-galacturonide lyase*) is the only depolymerase specific for highly esterified pectins. Pectin (pectinic acid) being methylated therefore usually requires the action of both a pectin methyl esterase and a pectic depolymerase for its degradation.

Lignin is extremely resistant to chemical and enzymic degradation because of the three dimensional network that the polymers form. Biological degradation is largely by fungi although bacteria can also play a part in association with fungi (Burla, 1995). The most effective lignin degraders are the white rot basidiomycetes, so called because they utilise the lignin from wood leaving the lighter coloured cellulosic material partially undegraded. This results in the wood becoming crumbly because of the lack of cross linking of the cellulose by lignin. Ligninases degrade lignin by both oxidation and hydroxylation. Oxidation can cause the cleavage of the backbone of the polymer or it can be of the phenols and benzyl alcohols which make up the polymer. (Figure 4.) Hydrolysis can be of benzylic methylene groups within the polymer (Harvey *et al.* 1985, Shoemaker *et al.* 1985). Ligninases can be inhibited by the phenolic residues they liberate but compounds such as veratryl alcohol can enable a metabolic pathway to operate that further metabolises these phenols and overcomes this inhibition (Burla, 1995).

Applications

Many of these phenolics and phenolic breakdown products will auto-polymerise to form humic compounds which are even more resistant to degradation and form a valuable part of soils improving their structure and mineral retention.

The microbial manipulation of lignocellulosic materials is not limited to the aerobic process of composting. Anaerobic processes range from the fermentation of silage to methane production from municipal waste in suitably constructed landfill systems. It is possible to produce a compost-like material from lignocelluloses by anaerobic fermentation (Nyns, 1987) though phytotoxic organic acids are easily produced under these conditions (Lynch, 1987a).

The process of composting has a number of attributes. It is a low technology procedure and it can cope with a wide range of input materials. Already different

composting conditions have been employed for different purpose. These range from open systems such as turned piles or static piles with forced ventilation and temperature and moisture control to closed systems with vertical or horizontal reactors either stationary or rotating (De Bertoldi *et al.*, 1985). Using variations on the basic procedure composting can be used to produce a range of useful products and the process itself can have beneficial actions (figure 1). The production of different useful materials and beneficial actions are not mutually exclusive. Sometimes several useful materials may be produced whilst at the same time the action of composting itself can be useful.

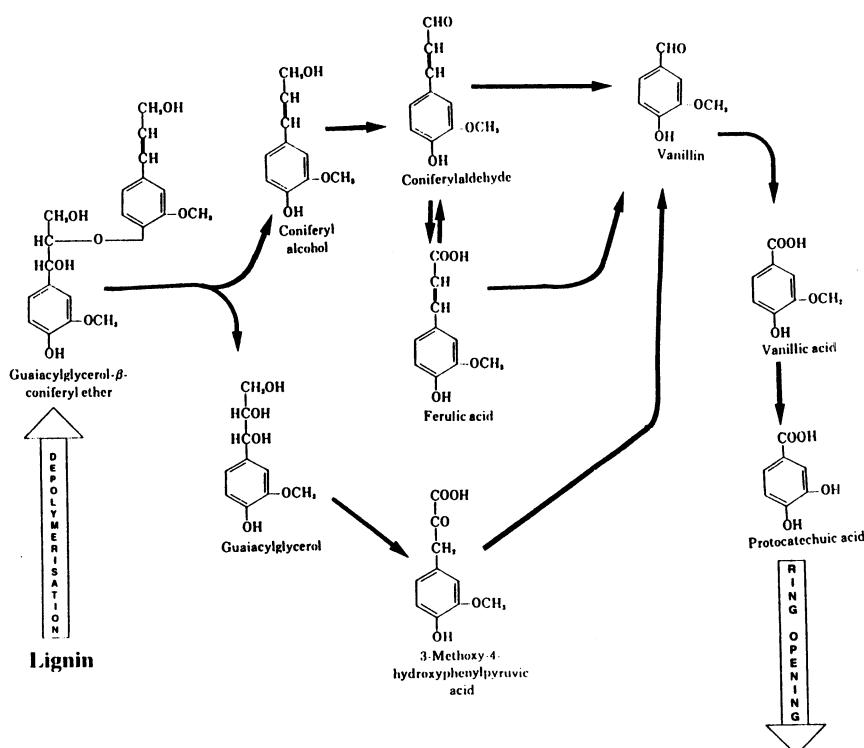


Figure 4 The conversion of a complex ether to a polyphenolic acid in the degradation of lignin

A classic example of this was in the construction of hot-beds of composting straw and horse manure under the benching of Victorian greenhouses to produce heat, carbon dioxide, and compost which could later be used as a plant growth medium in the greenhouse or as a soil conditioner for outside beds. An update on this procedure was the use of stacks of composting straw bales sealed in polythene through which air was blown into the greenhouse to enhance the carbon dioxide level and stimulate plant growth (Lynch 1987 b). As straw is a good insulator it is likely that a considerable amount of heat was recovered and the air blown into the greenhouse was warmed as well as enriched with carbon dioxide.

The very high carbon to nitrogen ratio of lignocellulosic wastes means that many bacteria produce complex polysaccharide gums as an extra-cellular product whilst scavenging for nitrogenous materials. These complex polysaccharides have a high water holding capacity reducing fluctuations in soil water content and together with the complexes resulting from lignin breakdown assist in the retention of minerals and reducing leaching from the soil by absorbing ions in a freely exchangeable manner as well as binding some of them to its reactive functional groups. These gels also hold soil particles together improving soil crumb structure which enhances aeration and reduces soil erosion (Cheshire 1979). Thus the incorporation of lignocellulosic breakdown products *i.e.* compost, into soil improves plant growth by increasing the soil's water holding potential, increases oxygen penetration and improves its mineral content and retention. The breakdown of complex organic material during the process of composting can also liberate minerals in a form available for uptake by plants and thus further improve the nutrient status of the soil.

The large amount of organic carbon available from lignocellulosic material means it is possible for the B.O.D. of its breakdown to be high enough for oxygen to become limiting and other oxidised compounds may then be used as terminal hydrogen acceptors. If nitrates are used in this way it is possible for nitrogen to be lost from the system either as dinitrogen or as ammonia (either directly or as dinitrogen by subsequent oxidation).

There is however evidence that under certain conditions the nitrogen content of compost can be higher than that of the original organic waste and that this process can be enhanced by inoculation with a suitable combination of organisms (Rice & Paul, 1972, Yoneyama *et al.*, 1977, Postgate & Hill, 1979, Lynch & Harper, 1983 & 1985). This means nitrogen fixation has occurred. Nitrogen gas (dinitrogen) makes up nearly 80% of the air but because of the stability of dinitrogen it is not possible for most organisms to use it for protein synthesis *etc*. It requires a large amount of energy for the necessary cleavage of the nitrogen-nitrogen bond, a prerequisite for the incorporation of nitrogen into an organic compound. Thus large amounts of ATP must be used by a nitrogen fixing organism. More ATP is synthesised during respiration if oxygen is the terminal hydrogen acceptor (electron donor) and in the absence of any terminal hydrogen acceptor (fermentation) very little ATP is synthesised for each molecule of sugar used. Aerobic respiration would therefore appear to favour nitrogen fixation. However the nitrogenase enzyme is inhibited by oxygen. This therefore presents physiological problems for any nitrogen fixing organism. Either it must separate the processes of ATP synthesis (respiration) and nitrogen fixation or use something other than oxygen as a terminal hydrogen acceptor and use more carbohydrate to synthesise each molecule of ATP or use very much more carbohydrate and synthesise its ATP fermentatively. All these strategies are used by different organisms but surprisingly they are all prokaryotic organisms. Despite the apparent advantages for nitrogen fixation of the compartmentalisation that occurs within eukaryotic cells there is no eukaryotic organism that can fix atmospheric nitrogen.

Because of the high energy requirement for nitrogen fixation and the more efficient use of energy sources by aerobic respiration it would be expected that inoculation of lignocellulosic material with an aerobic nitrogen fixer such as *Azotobacter vinelandii* would be the most effective way of increasing nitrogen availability and accelerating the composting process. Although in axenic culture *Azotobacter vinelandii* can fix twenty times as much nitrogen per day as can *Clostridium butyricum* it is the latter that has been shown to be effective in nitrogen fixation in the composting of straw (Veal & Lynch, 1984, Lynch & Harper, 1985). There are a number of possible causes for this. For an inoculum to be effective in an environment containing other organisms it must be capable of successfully competing with them. *Azotobacter* may not be a successful competitor in this situation. One possible reason for this is that the high B.O.D. in active compost could lower the oxygen level enough to affect the success of *Azotobacter*, another reason could be that it is sensitive to some of the antimicrobial by-products of the competing organisms in the compost.

Lynch & Harper (1985) increased nitrogen fixation in composting straw by over 60% by inoculating with *Trichoderma harzianum* and *Enterobacter cloacae* as well as *Clostridium butyricum*. Inoculation with *C. butyricum* and *E. cloacae* alone did not significantly increase the nitrogen content of the compost and the effectiveness of these organisms at fixing nitrogen was related to the cellulolytic capability of the fungal partner in the consortium. *Trichoderma* was shown to be a vigorous producer of a range of cellulases which together could degrade native cellulose liberating soluble carbohydrates whilst the *Enterobacter* produced copious quantities of extracellular gums. Together these provided *Clostridium* with a carbon source and a suitable micro-environment within the gum for nitrogen fixation. (Tables 1 & 2.)

Table 1 Cellulolytic activity of fungal isolates on sterilized straw and cellulose agar. Both assays were of 4 weeks duration. (Lynch & Harper 1985)

		Mass loss from straw (mg g ⁻¹)	Clearing of cellulose agar (mm)
<i>Acremonium persicinum</i>	(IMI 284720)	305	4
<i>Botryotrichum piluliferum</i>	(IMI 284721)	145	0
<i>Penicillium corylophilum</i>	(IMI 284722)	69	0
<i>Penicillium hordei</i>	(IMI 284723)	125	5
<i>Penicillium janthinellum</i>	(IMI 284724)	240	6
<i>Sordaria alcina</i>	(IMI 267236)	267	5
<i>Trichoderma harzianum</i>	(IMI 284726)	250	11
<i>Trichoderma harzianum</i>	(IMI 275950)	238	10
<i>Trichoderma longibraciatum</i>	(IMI 284728)	236	15
<i>Trichoderma viride</i>	(QM 9414)	75	0

Table 2 Effect of inoculants on the decomposition of straw and on nitrogen (N_2) fixation. (Lynch & Harper 1985)

	Percentage loss of mass	N gain (mg g ⁻¹)
Uninoculated	8.1	1.24
<i>Clostridium butyricum</i>	8.6	1.04
<i>Enterobacter cloacae</i>	8.5	1.27
<i>Penicillium corylophilum</i>	9.9	1.40
<i>Sordaria alcina</i>	18.5	1.13
<i>Trichoderma harzianum</i>	16.6	1.34
<i>C. butyricum + E. cloacae</i>	12.4	1.30
<i>C. butyricum + E. cloacae + P. corylophilum</i>	11.7	1.53
<i>C. butyricum + E. cloacae + S. alcina</i>	16.8	1.94
<i>C. butyricum + E. cloacae + T. harzianum</i>	17.3	2.02
lowest significant difference ($p=0.05$)	3.3	0.43

Coincidentally *Trichoderma spp.* have been shown to be some of the most effective organisms in the bio-control of plant pathogens (Henis, 1984) and *E. cloacae* has been shown to be effective in controlling the damping-off of lettuce caused by *Pythium spp.* (Hadar *et al.* 1983). This consortium thus not only produces compost with increased nitrogen available for plant growth it also has a disease protection activity. Other organisms present in compost have also been shown to be effective bio-control agents against plant pathogens (e.g. *Fusarium oxysporum*, *Pyrenopeziza lycopersici*, *Pythium ultimum*, *Rhizoctonia solani*) making it an attractive ingredient for potting soils (Alvarez 1995). Its other characteristics make it a possible substitute for peat in many horticultural situations (Verdonck *et al.*, 1987).

The production of chemicals by solid state microbial cultures (controlled composting) is still in its infancy but already lignocellulosic materials such as wood sawdust, chopped straw or ground corn cobs are being used as a combination support and substrate for the production of useful chemical. In these cultures carbon-nitrogen ratio and particle size of the input material is controlled. The latter will affect both its water holding capacity and aeration. Aeration, moisture content and temperature are all controlled during culture and additional nutrients may be added to produce a fed-batch system. (Abdullah *et al.*, 1985, Kumar & Lonsane, 1987a, 1987b & 1990, Desgranges & Durand 1990, Pastana 1995). Controlled solid state culture methods may also be used to enhance the nutritional value of lignocellulosic material as an animal feed (Wood & Lynch 1984).

Enormous quantities of crudely composted plant material and animal waste are used as manure in agriculture. However the largest use of controlled composting to produce a commercial product is in the production of mushrooms (*Agaricus bisporus*). About four million tonnes of prepared compost are used annually world wide to produce about one million tonnes of mushroom. Improvements in procedure and control of composting together with improved culture conditions for the growth of mushrooms have increased yields from 100kg of mushrooms per tonne of compost to 250kg per tonne. Research on improved composting for mushroom

production is continuing. Much of this work is on self sterilization or Pasteurisation procedures to reduce the risk of disease in the mushroom crop as well as methods of increasing the rate of composting and improving the quality of the compost by the addition of nutrients (Flegg 1985).

The process of composting can in itself be useful in accelerating the breakdown of toxic materials. This can be before their release into the environment or as a method of bioremediation. The composting of straw with *Phanerochaete chrysosporum* a white rot fungus has been used to produce a material capable of degrading polyaromatic hydrocarbons and chlorinated phenols. The bioremediation of 6,400 m³ of soil has been carried out at a disused timber treatment plant in Finland using this compost mixed with the soil. Within two years 90% of the chlorinated phenols with which the soil was contaminated was degraded (Holroyd, 1995).

As there are strains of *Trichoderma spp.* that are effective in degrading cyanide (Lynch *et al.* unpublished) a similar procedure could be used to detoxify cyanide containing soil from old industrial sites such as gas-works. Such sites are often contaminated with phenolics and other aromatic chemicals so a combined culture for bioremediation may be a possibility.

Probably one of the most important but least glamorous roles for the process of composting is in the reduction in the volume of waste. Organic material degrades relatively slowly under the anaerobic conditions of landfill. This is especially true for lignocellulosic material. The large amount of space that is needed to accommodate the waste produced by an industrial society is becoming increasingly difficult to find. Therefore even if because of the nature of the waste material composted, the end result is not commercially valuable the massive reduction in volume that can be achieved by composting is in it self valuable.

The process of composting can be seen to be able to produce several useful materials and destroy or reduce nuisance materials. Traditionally the process has been relatively uncontrolled with variable input materials, no defined inoculum and crudely controlled conditions. Despite this the process has worked well. However if composting is to achieve its full potential it is going to be necessary to understand fully its microbiology and biochemistry so that the input material, inoculum and conditions can be optimised for each of the various desired objectives.

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Composting of Agricultural Wastes

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Abstract

The application of composting technology for the processing of agricultural wastes is reviewed. This paper covers the historical background of composting in agriculture and assesses the role of current composting technology and its relevance to farm wastes. The impact of ecological concerns over potentially polluting farm wastes is considered as more important a factor in promoting agricultural waste composting as the potential value of the compost end product.

Introduction

The wastes of agriculture constitute the largest component of wastes produced in society. Agricultural waste in the European Union exceeds one billion tonnes per annum – three times greater than sewage sludge output and six times greater than that produced in the urban domestic sector (MSW). (Ferrero & Hermite 1985). However over the last decade (1985–1995) of some 780 papers published on composting over one third are concerned with municipal solid waste and less than 10% directly related to the composting of agricultural wastes. (Science Citation Index). Such an anomaly not only exists in the field of research but is found also in the real world where the impact of the composting process on these wastes is minimal in the agricultural sector of many countries. This anomaly has occurred because the recent upsurge of interest in composting derives from its application as a pollution control mechanism rather than as a perceived vehicle for the recycling of nutrients for the maintenance of soil fertility (Gray et al 1971). This paper briefly reviews the application of the technology of composting to agricultural wastes (excluding the highly specialised area of mushroom production) and argues that its future in this sector may very well follow the same route as its application in the urban sector – that is primarily as an environmental protection measure and secondarily as a soil improver and nutrient supplier. The latter aspects will be dealt with by other papers at this conference highlighting the long standing problem of cost effective agricultural acceptance of the end product of the process – the compost.

Historical background

A type of 'composting', in a simple and traditional form, has been practiced by farmers and gardeners throughout the world for many centuries. Vegetable matter and animal manures were placed in piles or thrown into pits and allowed to decompose through natural microbial activity until ready for agricultural use. This process usually required six months to a year and traditionally involved no control, except perhaps covering the mass with soil, or turning it once or twice during the year. The composting of human faecal waste – night soil – together with other vegetable and animal manure wastes has been practiced in China for centuries and has been considered the key in supporting high population densities and in maintaining soil fertility and structure over some 4000 years. The 'pit manure' composting method involved layering of a green manure (or aquatic weed) with rice straw, animal manure and river silt together with superphosphate, in circular or rectangular pits of up to 10m³. After wetting a top layer of mud is applied to conserve moisture, maintain uniform temperature and avoid nutrient loss. The materials are turned three times at monthly intervals followed by re-establishment of anaerobic conditions. Other forms of composting in China follow a similar pattern with variations such as placement of bamboo poles for 'aeration' initially, followed by sealing with mud or silt.

Undoubtedly such practices for dealing with organic wastes have a long heritage in China and certainly represent a level of manipulation and 'processing' above that of simply stacking the organic wastes in the field or the yard, in which, providing the conditions of adequate moisture, aeration and nutrients existed, spontaneous self heating occurred – in much the same way as occurs today with animal manures piled up in the fields awaiting a convenient time for its spreading (disposal?). The latter system would in no way qualify as a method of *controlled* composting. Many of the wastes then, and indeed now, would be disposed of by direct application to land if this was conveniently available. The use of organic wastes, in this manner, for maintaining soil fertility by European farmers dates back to at least the Middle Ages. Some form of basic composting may have been carried out with these wastes, in addition to their direct application to the land (Gotaas 1956).

Increasing populations and their gradual urbanisation led to problems of waste disposal that could not be met by absorption onto the land. With the need to produce more food for the growing population agricultural science developed new farming techniques culminating in an understanding of plant nutrition that obviated the need for organic materials produced by society. This led initially to the importation of concentrated organic manures (e.g Peruvian guano) and ultimately, following the pioneering work of Lawes and Gilbert at Rothamsted, England, to the development of superphosphate and nitrate fertilizers. The age old link between societal organic wastes and soil fertility was broken. Plant nutrition and fertility could be supplied by inorganic means – the traditional outlet for these ever increasing wastes had largely gone. Wastes then became 'managed' by land

dumping or by burning and eventually by the application of biological processes, aerobic and anaerobic, including of course composting – but as a mechanism of waste reduction and not production.

The conflicts outlined above have led to a chequered recent history for the process of composting and its application. Interest in the process and its potential has fluctuated considerably – most notably in the twentieth century. This is due, in part, to the fact that the process is a natural one and has a long successful pedigree of empirical use with the scientific understanding of the mechanisms involved only relatively recently being addressed. Indeed the origins of an early *scientific* understanding of composting come from the agricultural sector. The arousal of interest in composting in the West almost certainly stemmed from a visit to China, Japan and Korea in 1909 by Professor F.H. King of the USDA (King 1927). His writings on the recycling and composting of agricultural, human and other organic wastes profoundly influenced Sir Albert Howard, a British economic botanist (and former staff member of Wye College) employed by the Colonial Indian Government. Howard, in collaboration with others, systematized the procedure by which individual farmers and gardeners had for centuries reclaimed organic matter. His composting method, the Indore method, was named after the locality in which he was working. Heaps of waste were constructed either on the surface or in pits and placed in layers of carbon material interspersed with nitrogen containing manures. These heaps were turned perhaps two or three times over a six month period. The leachate was recirculated to moisten the heaps (Howard 1933).

The Indore heaps were almost certainly aerobic for only a short period after piling and after each turn, but anaerobic during most of the remainder of the composting period. The process, with modifications, was extensively used in India (Bangalore process), Malaya, East and South Africa – the primary objective being the effective treatment and use of human and animal wastes for agricultural purposes. The rudiments of an understanding of the process were finally being addressed – the need for high temperatures to effect sanitation of the waste, to increase degradation rates, the combination of carbon and nitrogen, the maintenance of moisture content and the recognition that aeration was important. During this period the work of Waksman in the States on aerobic decomposition of vegetable residues and stable manure indicated the influence of temperature and the roles of individual groups of microorganisms on organic breakdown (Waksman 1939). Further developments in an understanding of the science of composting arose thereafter from the challenges of urban sector wastes – municipal solid and sewage sludges. The key investigations by teams at Beltsville and Rutgers (Finstein 1986) have provided us with a better understanding of the composting process based upon knowledge of the microbial ecology of the composting ecosystem. These insights into the composting process are of course valid for any organic waste substrate and applicable equally to agricultural wastes as any other.

Agricultural Wastes

Agricultural organic wastes arise at a number of different points in the chain of animal and plant, food and fibre production. The list of agricultural wastes appropriate for composting is almost endless. In an agricultural context animal manures and crop residues essentially covers all the major substrates likely to be encountered. Composting has even been successfully employed for the disposal of abattoir wastes and whole dead chickens (Sims et al 1992). It would indeed be difficult to find an organic waste of agricultural origin that has not been tested at some time for its 'compostability'. Other wastes with agricultural links arise from the allied food and fibre processing industries though as they are by this stage 'off farm' they are often classified as agro-industrial wastes. The reprocessing of such wastes back at their origin, the farm, is not of course precluded and has been an area that has seen significant advances in recent years throughout the world. Once again disposal has been the driving force. Lists of these and other wastes with their basic chemical characteristics is available in the literature (Rynk 1992).

It is unusual that a given waste material has all the characteristics required for effective and efficient composting and it is therefore usual to blend several wastes together to obtain the correct levels of C:N ratio, moisture, density and pH, a situation that can be easily attained in a mixed farming operation where the high nitrogen containing manures tend to form the central substrate adjusted by additions of an appropriate carbon crop residue. However, the development of intensive agricultural systems in some countries has left us with a legacy of high concentrations of animal wastes (often in a liquid form and with a low solids content and therefore not amenable to composting) in certain areas and high levels of carbon (straw) residues in others. It is in such a scenario that the once favoured nutrient laden wastes suddenly become a waste disposal problem and a potential threat to the environment through BOD levels, ground water contamination, ammonia emissions, odours and pathogenic loadings. Composting of agricultural wastes where the appropriate mixtures and blends are not available therefore requires importation of off-farm site organic wastes preferably a problem waste from another farm or agro-industrial site alluded to above or alternatively other organic wastes from another sector of society. The plausibility and possibilities of such a scenario are clearly limited and may be precluded by transportation costs.

The types of agricultural wastes available for composting are legion. As already stated in the introduction the quantities of agricultural waste produced in this world are staggering. Tables (1) and (2) indicate the colossal levels of waste output for crop residues and animal wastes from different regions of the world. Participants at this conference will not need reminding that very little of these wastes are processed by composting – the majority being recycled by direct application to farmland in the traditional manner. The technology for processing such materials by composting is of course available and the choice of system will depend as much on socio-economic factors – waste disposal costs, pollution

costs, infrastructure (land, buildings, appropriate equipment, labour etc) – as on the biological requirements of nutrients, moisture etc mentioned earlier.

Composting Techniques

There is now considerable information available in the literature on the different types of composting techniques that may be applied for the processing of organic wastes. These have been defined in many different ways depending on whether the technique is interventionary or non-interventionary (Stentiford 1993), open or enclosed (De Bertoldi et al 1985) or fits a range of operational control parameters related to the ecology of the composting ecosystem (Finstein & Hogan 1993; Miller 1993; Lopez-Real & Vere 1991). Broadly speaking composting operations, in actual practice, fall into four main categories:

- windrow composting
- aerated windrows
- aerated static pile (+/- temp feedback control)
- In-Vessel composting

Table 1 Residues of the main agricultural crops in 1000 t (1983 data)

Product	Africa	Asia	L.Amer	N.Amer	Europe	World
Wheat	12,047	226,678	27,195	124,970	266,770	678,187
Rice	12,015	606,476	23,586	11,929	2,753	657,187
Barley	4,398	19,128	1,482	28,651	100,802	205,962
Maize	22,201	100,157	51,742	218,437	73,264	465,801
Oats	354	1,562	1,452	13,460	22,964	60,697
Millet	12,470	27,392	190	–	3,122	43,217
Sorghum	12,603	30,502	22,793	41,083	1,050	100,377
Roots	54,989	146,142	25,775	14,017	115,533	355,945
Oilseed	8,910	80,196	15,968	30,690	48,848	181,629
Legumes	8,314	50,700	41,100	78,075	17,907	192,920
Sugarcane	9,592	48,835	64,746	25,250	49	131,008
TOTAL:	157,893	1,337,768	276,029	586,562	653,062	3,133,008

Table 2 Animal waste output for different world regions (MT volatile solids)

Product	Africa	Asia	L.Amer	N.Amer	Europe	World
Cattle	189.6	403.8	337.2	201.8	274.1	1,439.6
Pig	1.1	36.7	7.8	9.2	26.0	78.7
Horse	13.2	20.5	7.8	3.5	1.7	43.1
Chicken	8.2	33.2	12.3	9.4	27.6	87.7
Sheep	18.9	32.3	7.8	2.0	22.5	114.0
TOTAL:	231.0	526.5	372.9	225.9	351.9	1,763.1

All of these systems have, and are being used, for the composting of agricultural wastes. The aerated and in-vessel systems are likely to be operating in situations

where high concentrations of these wastes are available (feedlots; food processing centres etc) and in some instances are sited off-farm and even linked with a co-composting operation involving other societal wastes – garden/yard, MSW or sewage sludges. By far the commonest approach on the farm will be the use and adaptation of the windrow composting technique due to its simplicity of operation and the ease with which this can be adapted to farm operations and use of farm equipment and the materials handling expertise of farm workers.

All of these techniques have been described in detail specifically for the farm/agricultural setting in the excellent publication edited by Rynk(1992). The windrow composting technique is of course an eclectic derivative of the Indore and mushroom composting technologies with implicit recognition of the composting process as an *aerobic* system however crudely achieved. That aeration is a key factor in successful composting is surely fundamental to understanding the process – and yet we are still bedevilled in the literature to references and whole papers published on that oxymoron – anaerobic composting . Confusion and incorrect field practice may arise when we begin to allude to simple stacks of crop residues or manures as a form of *passive composting* – thereby giving this a status of processing that it does not deserve – even if subsequently the approach is discredited(Rynk 1992). Miller (1993) has claimed that the application of composting has been impeded by the 'mythology' that composting is a 'natural process' and that control can be left to default or by system designs that give priority to materials handling. The latter is too often the operational case in the farming scenario. Agriculturalists and practising farmers should be made aware that such systems are not true aerobic composting operations but rely upon slow ,low temperature degradation primarily through the anaerobic pathways leading to the production of environmentally unacceptable gases – including methane and hydrogen sulphide – often together with contaminating leachates. Environmental concern over the production of greenhouse gases and malodorous volatile compounds is certainly increasing and the implementation of rigourous control legislation in the metropolitan and urban sectors on these issues will undoubtedly extend in time to the countryside and the agricultural sector.

In common with the composting of other organic wastes the correct processing of agricultural wastes by any of the aforementioned techniques will result in a safe and potentially useful end product for either direct use on the farmland or for sale into the horticultural industries. Naturally the same problems that occur with urban and industrial wastes are also pertinent the processing of agricultural wastes. A number of these relate to the nature of the waste itself icluding:

- pathogenic organisms (human; phytopathogenic)
- heavy metals (copper, zinc, in feeds)
- pesticides etc

others relate to the operational process itself including:

- odour
- dust

- noise
- aerosols

In general these constraints are less evident in the farming situation than elsewhere. The problems of dealing with pathogens, heavy metals and pesticides has been vigorously examined in composting research over the past decade. Operational criteria are now well established to overcome the problems in the waste itself and should not preclude the use of composting on the farm (Hoitink & Keener 1993). Heavy metal contamination in feeds cannot of course be 'source segregated' as a solution and composters of manures emanating from poultry or pigs must be aware from the outset that levels of copper and zinc will be high in the final product.

Composting of any waste high in nitrogen will lead to high losses of nitrogen in the form of ammonia whether the waste is sewage sludge(Witter & Lopez-Real 1988) or animal manures (Martins & Dewes 1992). Entrapment of the ammonia, representing a valuable loss of nitrogen is difficult or with materials such as natural zeolites too expensive(Bernal et al 1993). Ammonia is now recognised as an important catalyst in the acid rain complex therefore ammnia generated from composting operations is as ecologically negative as its volatilization following the spreading of slurries and manures on the field. Further research into this aspect of composting is urgently required.

In many ways the farm is an ideal site for composting and unlikely to cause public offence through noise, odour, dust or aerosols. Indeed many of us have been arguing for a number of years that on-farm composting is an ideal opportunity for farmers to diversify into green recycling and to utilise a few acres of their land in order to receive gate fee income and help to solve farm and urban wastes through co-composting (Rynk 1992 ;Lopez-Real & Haymes 1994). Though such enterprises are not available to all farmers they may serve to show how effective composting can be and in this way help to promote the wider use of the process for agricultural wastes in general.

Conclusions

Interest in the application of composting to organic waste problems has fluctuated throughout the twentieth century. It is clear that we are currently enjoying a phase of positive interest in the process throughout all sectors of society. Without doubt the major catalyst for this interest, over the past five to ten years, has been growing concern over the environmental impacts of other waste management procedures – from sea dumping to landfill and incineration. The same pressures have not been so great in the agricultural sector though this has now begun to change. Where intensive agriculture is practised there is more and more concern about the treatment of the concentrated quantities of manures and crop residues. The practise in the UK of incinerating the six million tonnes of surplus cereal straw , by burning off

the residues in the fields, has recently been banned – not through a scientific appraisal of the value of the residues but through public pressure from the polluting effects of burning fields. It is legislative changes such as these that have dramatic impacts on the role that composting can play in the processing of wastes from all sectors of society. The arguments in favour of composting as an ecological imperative for the treatment of wastes, including agricultural wastes, needs stating and more research evidence support. This paper has not dealt with the end product, the evaluation of which is the theme of another session at this conference.

Over the past decade there has been a growing interest in the uses of composts from organic wastes, most notably in the container industry. The use of composts in agriculture is difficult to discern and even more difficult to quantify. The quantities of wastes available are enormous, the technology is available – the farmer however needs convincing of the value of the process over and above existing methods of disposal and use. Is it better to compost than to plough directly in? If composting has been introduced it is rarely because of a demand for peat alternatives or soil fertility needs. In the light of these new pressures and constraints composting is being seen as an effective treatment process for polluting materials resulting in a potentially useful but, undeniably, environmentally safe end product. We are still, however, bedevilled with the ogre of cost effectiveness, and potential sales of the product assume a greater importance than the environmental and ecological benefits of the process – removal of organic waste from landfills and muck-heaps, leading to an elimination of methane (a powerful greenhouse gas) and a reduction in the threat of groundwater contamination. One can only conclude and concur with Blum(1992) that the economic rationality which is the dominant feature of post-industrial society, will (one day) give way, and the priority of an ecological rationality be established.

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Seven Decades of Sludge Compost Marketing

KATHRYN KELLOGG JOHNSON – Kellogg Supply, Inc.

In the early 1920's, H. Clay Kellogg, Sr., a surveyor by profession, was working at a dry river bed in Santa Ana, California. He noticed luxuriant vegetation growing along the bank. Observing that this growth seemed to result from the sludge in which it was growing, he took some of the black material home to experiment.

The results were amazing. His plants flourished like the vegetation along the river bank. Friends, neighbors, and passersby admired his beautiful yard and asked him what secret formula he used to foster such fantastic growth. It wasn't long before he decided to make a business out of selling this organic sludge.

Making the product marketable in those days was difficult. The sludge was pumped to small lagoons. When it was dry enough to handle, the material was picked up with pitchforks. The processing was done by hand. The larger cakes, sometimes a foot in diameter, had to be crumbled with the handle of a shovel powdered by two strong arms.

From the drying beds, it was carried to a holding pile where horses again were used to pull huge 'Fresnos' of the material to the screen and grinder for further processing. Pulverization was all that was needed to produce fertilizer in bulk which is how it was sold to the large agricultural users in the Southern California area.

He called the material Nitrohumus and today it remains one of Kellogg's very popular trademarks.

Introducing sewage sludge to the 'old-time' farmers as a beneficial part of their soil preparation wasn't easy. In the 1920's it was widely believed that land could only produce crops for a short time and then the land was left fallow. There was so much available farm land that the farmer commonly farmed the land until yields dropped and then he would move on to another piece of land. Amending or replenishing soil fertility was unheard of.

Kellogg took advantage of this belief and began to acquire old 'depleted' orange groves for trade. He scraped enough money together to buy 10 acres and treated it with Nitrohumus. When it had begun to yield a healthy amount of crops he would swap the 10 acres of performing groves that had been treated with Nitrohumus for more depleted acres.

By the time he acquired 1,000 acres the other farmers had discovered the secret. They understood what was happening. The Nitrohumus was restoring fertility to the land. So they began buying the Nitrohumus, instead of trading away their land.

In 1925, Mr. Kellogg organized a fertilizer business he named Kellogg Supply Company. The demand for his product increased. In 1929 he signed a contract to purchase and remove sludge from drying beds of Los Angeles City and County agencies.

Today, 70 years later, Kellogg and the Los Angeles County Sanitation Districts still have a contract for Kellogg to purchase sludge. LACSD is one of the largest sanitation Districts in the world serving 78 cities, 4.7 million people, treating nearly 1/2 billion gallons of waste water a day. It's the residual from this waste water which KSI purchases and uses an ingredient in its line of soil amendments and fertilizers.

Kellogg utilizes 350 tons/day of LACSD biosolids, mixing it with 700 yards carefully selected bulking agents fibers. Bulking agents serve several purposes, they create the appropriate air spaces for the compost mass, supply carbon, control odors, decompose consistently and result in the high quality of product Kellogg needs.

Kellogg is constantly searching California for suitable bulking agents and experimenting with green waste, woodwaste, straw, agricultural wastes, and manure. The majority of bulking agents are woods that were formerly going to landfills or being burned for fuel. Materials range from discarded Christmas trees to furniture and from the muck of race track stalls to ground up movie sets from studios such as Warner Bros. and Paramount. Kellogg's buys a variety of soft woods with a particle size of approximately 1 centimeter.

The biosolids and wood are placed in windrows approximately 240 meters long and 2 meters high. We construct windrows with a ratio of 1.5 yards of wood to 1 wet ton biosolids. Using the SCARAB technology we mix the biosolids and bulking agents immediately. Kellogg has utilized the SCARAB technology for over 20 years. It mixes in a manner that allows the nitrogen and carbon to be thoroughly blended. Heat is generated almost immediately in the windrow. After only 10 days the temperatures in the rows reach over 55° C. Temperatures are maintained for 15 days during which the row is turned 5 times. This helps to control weed seeds, odors, moisture content and product consistency. The compost remains in windrows for approximately 60 days and then Kellogg transports it for further curing, blending, screening, and finally bagging.

Testing

At the end of 30 days Kellogg sends samples of the compost to LACSD from each row for indicator organisms to assure that no pathogens have survived the process.

Microbiological Monitoring
Total Coliform
Fecal Coliform
<i>Salmonella</i> sp.
Viable <i>Ascaris</i> sp.
Virus

After 15 days of high temperatures the coliform count, for example, is well below 1 MPN/g . KSI finds that for a quality product the material should be maintained in the high temperature zone for 30 days and turned nearly every other day. The compost is also tested for metals.

Metals Monitoring	
Pollutant	Monthly Average Concentration (Milligrams per Kilogram)
Arsenic	41
Cadmium	39
Chromium	1200
Copper	1500
Lead	300
Mercury	17
Molybdenum	*
Nickel	420
Selenium	36
Zinc	2800

¹Dry weight basis
*No Limit

Many of the metals are beneficial. In fact, several *nutrients*, essential to plant growth are present in Nitrohumus and all biosolids.

Today industry experts agree that 16 essential plant nutrients contribute to plant growth. Biosolids contains all 16. Naturally chelation of the nutrients allows the effective nutrients to remain in the root zone longer.

Of the 16 essential elements *Carbon*, *Hydrogen*, and *Oxygen* are taken primarily from the air and water. The other 13 are normally absorbed from soil by the plant roots.

Primary

Nitrogen, Phosphorus, and Potassium

Secondary

Calcium, Magnesium, and Sulfur

Micronutrients

Zinc, Iron, Manganese, Copper, Boron, Molybdenum, and Chlorine

Biosolids compost acts as a time release capsule of nutrients for healthy plants.

The nutrients and microbes have a synergistic effect which is beneficial for roots of plants

Biosolids and plant growth

The organisms contained in compost that contains biosolids contribute to the decomposition of organic residues and the release of plant nutrients, provide formation of soil humus from organic materials, improve soil physical properties through humus formation, release plant nutrient elements from insoluble inorganic soil minerals by humic acid, fixate Nitrogen, provide improved plant nutrition through increased microbial activity and provide antagonistic action against plant pathogens.

Some beneficial properties of humus derived from biosolids include the slow-release nitrogen, phosphorous and sulfur nutrients, improved soil structure, improved micro nutrient element nutrition of plants through chelation reactions, solubilized plant nutrient elements in soil minerals, a high exchange capacity for plant nutrient cations, growth-promoting effects exerted by certain components, heat absorption and earlier spring growth facilitated by the dark color of humus, increased water-holding capacity, increased water-use efficiency, improved soil buffer capacity, reduced toxicity of natural toxic substances and pesticides and a higher and more varied microbial population, which favors biological control and fixates Nitrogen.

Truly composted biosolids is a relatively more stable or humidified product than soils amended with peat, etc. This composted biosolids contains more stabilizers or soil aggregating substances, organic acid functional groups associated with humic polymers, enzymes stabilized by linkage to the large humic molecules, and root-or growth-promoting substances.

During the continued slow decomposition, plant nutrients – especially nitrogen - are slowly released in an available form. The ability of the soil to hold nutrients such as calcium, magnesium and potassium is also increased.

Soil-binding substance synthesized by microorganisms during decomposition of the organic materials are important in the building of soil structure. Soils that have good structure have improved drainage, thus allowing for better root growth. Humus-enriched soils also contain an increased amount of available moisture for root absorption.

Marketing

Nitrohumus is marketed as a high quality, high priced amendment to a wide range of customers; from home gardeners and landscapers who purchase the products at Kmart, Walmart, Home Depot, Sears, and Target, to name a few, to large landscape contractors who utilize Kellogg's soil amendments to establish turf in the

Los Angeles Coliseum, the Rose Bowl, and many other ball parks.

What has kept Kellogg's growing in the 1990's is the ability to meet the growing demands of our customers. As the population in southern California grows and becomes more diverse, so we find the demands for products grow and become more diverse.

To meet these increasing and changing needs Kellogg offers a variety of products in hundreds of different and sizes. Some contain biosolids, others do not, but all provide a complimentary role to the marketing biosolids compost.

Product names

Organic Soil Amendments:

Nitrohumus®, Gromulch®, Topper®, Amend®, Azalea-Camellia Mix®
Peat Moss, Leaf Mold, and Steer Manure

Wood Products:

Redwood Compost, KRA®, Decorative Bark, and Xerimulch®

Horticultural Products:

Potting Soil, Perline, Orchid Mix, Basket Moss, Peat Moss, Cactus Mix, Sand, Orchid Bark, African Violet Potting Mix, and Charcoal

Commercial Fertilizers:

Superphosphate, Urea, Ammonium Phosphate, Hydrated Lime, Gypsum, Bone Meal, Blood and Bone Meal, Sulfate of Potash, Cottonseed Meal, Soil Sulphur, Calcium Nitrate, Iron Sulfate, Hoof and Horn Meal, and Aluminum Sulfate

Kare Fertilizers:

Citrus-Fruit Trees, Camellias-Azaleas, New Plantings, Roses and Flowers, Tomatoes and Vegetables, and Blooming Plants

Organic & Specialty Products

All Purpose 8-8-4, Big Six®, HI-K®, pH Acidall®, Gyspote, Sulfate of Ammonia, Kwik Lawn Food, and Wintergreen Lawn Food

PAX Specialty Products

Fungicide Insecticide Fertilizer (F.I.F.), Weed and Feed for St. Augustine & Bermuda, Lawn Food Pellets, Total for Lawns, Weed and Feed Pellets, All Purpose Fertilizer

Conclusion

For 70 years Kellogg has been successfully composting and marketing biosolids based compost. the success can be attributed to a commitment to produce products of the highest quality which consistently meet or exceed the customers expectations.

Kellogg employs a Thermophilic windrow composting process utilizing the Scarab technology for windrow turning.

Customers range from the home gardeners who buy Kellogg product at retail garden shops and large 'chain stores' such as Home Depot, Walmart, K-Mart, Sears, and Target to landscape contractors who utilize Kellogg's biosolids based products for projects as large as the Los Angeles Coliseum, Dodger Stadium, the Rosebowl, Hearst Castle, Disneyland, the Tropicana Hotel in Las Vegas, golf courses, and many luscious resorts in the Hawaiian Islands.

In 'Seven Decades of Sludge Compost Marketing' we focus on the trail blazing that Kellogg Supply has done in the field of composting. Some of the same challenges the company faced in the 1920's are now being taken on worldwide by companies, municipalities, and countries that see biosolids composting as an ecological, economical solution to managing this stream of waste.

Throughout the history of the company, the successful wide distribution of these products can be attributed to Kellogg's constant response to their customers needs. As California grew in population and diversity, so did the demand for horticultural and agricultural products. Kellogg has been there to meet those demands and fulfilled those needs with biosolids compost.

Utilizing Scraps From Blue Crab and Calico Scallop Processing Plants¹

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Abstract

Blue crab and calico scallop processing plant scraps have been landfilled, creating waste management problems. Alternative methods of in-plant compacting, anaerobic bioconversion potential, composting, compost marketing, compost crop applications and nematode control using compost were examined. It is feasible to compost blue crab and calico scallop processing plant scraps and there appears to be uses for the final compost products. Composting is a viable alternative to landfilling these processing scraps. Composting is being used successfully to compost blue crab and scallop processing scraps.

Introduction

Processing scraps from blue crab and calico scallop processing plants in Florida have always been landfilled. Since these scraps are highly organic and putrescible, they have created an environmental landfill problem. Various options have been examined to deal with these and other seafood processing plant scrap by-products. These range from specific analyses including dehydration for use as meal along with other handling methods (Cato, 1977; Andree, 1988) and as a feed stuff for swine (Myers, et.al., 1987), to a complete overview of all seafood waste management problems nationwide (Otwell, 1981).

Blue crab scraps produced in Florida annually range from 1,300 to 2,200 tons. Blue crabs yield 20 percent water when cooked, 12–14 percent meat, 35 percent shell (carapace) and 31–33 percent remaining body parts as scraps. Most of the waste management problem occurs in contiguous Dixie, Franklin, Taylor and

¹ An earlier version of this paper, written in late 1990 while the projects were still active, was presented at the Environmentally Sound Agriculture Conference, in Orlando, Florida, April, 1991. This paper updates the earlier version with final results on the blue crab stitic pile and calico scallop composting work, and reports on spin-off projects occurring through 1994.

Wakulla counties of north-west peninsular Florida. In Wakulla county, scraps from blue crab processing plants have represented about one-fifth of the total waste stream landfill volume and consumed about 25 percent of the solid waste budget.

Calico scallop production is normally highly concentrated in Brevard county on the Atlantic coast. Production on a daily, weekly, monthly and annual basis is inconsistent and unpredictable. Typical annual production ranges from 2 to 15 million pounds (edible meat weight), with one recent year reaching 30 million pounds. Processing requires large amounts of water, with the waste product including by-catch from the vessels, processing effluents, shell and raw viscera. Solid waste can represent over 80 percent by weight of the original vessel production. The shells from calico scallop plants have found potential use as oyster cultch and as fill in spoil areas, but the viscera and liquids have been a landfill and treatment problem. Waste alternatives examined included in-plant controls including waste restrictions and segregation, alternative screening and recycling; secondary and innovative secondary treatment facilities; and landfilling or ocean disposal, use as oyster cultch or animal feed, refining current ocean dumping operations and controlling odor, and sludge disposal from treatment facilities.

The Florida legislature in 1988 mandated that solutions to problems created by landfilling blue crab and calico scallop processing plant scraps be found. A number of demonstration projects were conducted after agreement by Department of Environmental Regulation staff, county officials, seafood industry leaders, private consultants and university faculty (Cato, 1989). This paper presents an overview and results of these projects. Topics covered include:

- In-plant methods for blue crab waste control
 - Wet extrusion
 - Compacting
 - Anaerobic bioconversion
- Composting
 - Blue crabs
 - Calico scallops
- Blue crab compost marketing
- Blue crab compost as a soil amendment
- Nematode control using blue crab compost

In-plant methods for blue crab wastes

Three methods were examined to improve in-plant handling of blue crab wastes. These included wet extrusion into a food pellet for aquaculture, compacting and grinding to reduce volume and moisture, and anaerobic bioconversion to produce methane gas.

Wet Extrusion

Blue crab processing scraps were used to produce two types of pellets (Andree and Earle, 1992). Crab scraps were mixed with soybean meal (48% TKN), potato starch and herring oil in two formulas to form a sinking feed pellet. One formula contained 45% crab, 41% meal, 10% starch and 4% oil, whereas the second contained 35% crab, 60% meal, 5% starch and no oil. Without herring oil, pellets did not form properly. The pellets using herring oil were accepted by spiny lobsters during feeding, but molded too quickly for feeding trials with shrimp and catfish. The moisture content of the pellets was high, and they tended to float following storage. This does not appear to be a potential use of crab scraps without additional tests.

Compacting

A custom built compactor patterned after shrimp plant units was used in a crab plant to examine moisture and volume reduction and compatibility of crab scraps as follows: with screens versus without screens; ground (using a hammermill) versus unground; and at variable compression times. Fluids extracted were analyzed for COD, TKN, and ammonia. Compacting was examined as an alternative to reduce waste volume leaving the plant and as a prior step to other handling uses. The volume reduction of crab scraps was highest via grinding alone, at 50%. Compacting without the screens achieved the best volume and weight reductions for both ground (25.0% at six minutes) and unground (28.6% at five minutes) crab scrap. Ground scraps held their compressed form much better (Andree and Earle, 1992).

Grinding using a hammermill appears to be the best method for volume reduction at the plant level, and could be implemented immediately using existing plant manpower. This does not eliminate the waste stream, but changes its form and makes storage easier. Compacting creates excess fluid that could be a problem if discharged into septic systems or wastewater treatment systems. The liquid fraction of the waste stream contained 256 grams per liter of COD, compared to standard sewage wastewater which contains 300 milligrams per liter of COD.

Anaerobic Bioconversion

The characteristics of blue crab scraps for use as an anaerobic bioconversion feedstock in the production of methane gas was also studied. The investigation focused on physical and chemical analyses of the waste and assessment of the ultimate conversion and rate of conversion via biochemical development, along with optimization using bench scale digesters. Sample analysis indicated an average total solid concentration of 335 for the total waste stream, and a volatile solids concentration of 50% dry weight for the total solids. This indicates a very high average ash content (50%) for the waste stream. For the liquid function, comparable results were 10% and 70% respectively.

Composting

Composting projects were conducted to test and implement an alternative to continued landfilling of scrap by-products from blue crab and scallop processing plants.

Blue Crab

Open Windrow: A large scale blue crab composting demonstration project was conducted at the Taylor County landfill utilizing all crab wastes from Taylor, Wakulla and Leon counties for a two month period (Brinton and Gregory, 1992). Eight windrows of materials were composted using a Wildcat™ turning machine powered by a large tractor. A total of 1,067 tons of material were composted, of which 380 tons (36%) were crab scrap. Cypress sawdust (431 tons), wood knots and shives (148 tons) and pine bark (42 tons) were the principal sources of carbonaceous material. The eight windrows of materials were formulated using the following six combinations:

- fresh cypress sawdust and crab scraps
- fresh cypress sawdust and crab scraps treated with phosphate
- aged cypress sawdust and crab scraps
- pine bark and crab scraps
- knots and shives and crab scraps
- yard trimmings, wood chips, crab scraps and manure

All materials tested, with the exception of knots and shives, appeared to have qualities which in the context of a proper mix would be useful or desirable for composting. All compost windrows were analyzed on a scheduled basis to document changes taking place during the composting process. Initial mix moisture content, pH, organic matter content, carbon-nitrogen ratios and ammonium content were all monitored.

Core and surface temperature measurements were recorded every other day throughout the composting term. Fresh cypress sawdust windrows sustained the longest period of active heating, although aged cypress windrows showed higher earlier average temperatures. Heating was measured over a 125 day period although the cypress windrows completed active composting by about the 60th day. Pine bark windrows lost heating ability by about the 50th day as did the knots and shives windrows, although the latter had some of the highest recorded temperatures of all windrows and a higher-than-ambient temperatures for 100 days. Windrows with yard trimmings maintained the lowest temperatures of all windrows, and heated for only 50 days. Periodic rainfall may also have affected the heating times and levels of some sites. All windrows ranged from 21-36 days above 55°C except for the yard trimmings, which had only 3 days above this temperature. On the average, the composts appear stable after approximately 75 days.

All windrows were sampled at the end of composting. They differed from the

initial compost in color, odor and texture. Each was darker, humus-like and fine-crumbly. Average moisture content across all piles was 44%, similar to the initial compost. Even with some rainfall occurring the compost lost water, a desirable result to yield a marketable product. Finished compost data on water content, pH, organic matter content, TKN%, C:N ratios, NH₃, P, K, Ca, soluble salts and CO₂ were also provided (Brinton and Gregory, 1992).

Analysis on the average composition of all the blue crab compost indicated several important facts. A total of 53% of the organic matter was decomposed, or 28% of the total solids. Total nitrogen loss was 46% and 49% of the compost volume was reduced, based on initial versus final volume measurements.

Traditional disposal costs have risen so significantly that a new framework is now available to assess the economic feasibility of composting. A composting operation (in contrast to landfilling) that exists on a break-even basis may be justified. The concept of composting as 'value added' and the potential of using compost as a soil amendment gives rise to new support for the composting option. A limited economic analysis for a proposed compost operation in Taylor County was also provided (Brinton and Gregory, 1992). Economic factors considered were site preparation costs, required equipment, operating costs, sources of raw product, transportation costs, tipping fees, proposed markets and land requirements. Based on the assumptions outlined in the report, total annual costs of a compost operation to produce 5,000 tons of final product would be \$103,000 or \$29.49 per ton of crab scrap handled. Revenues that would be generated from a nominal tipping fee and bulk and bagged compost sales were estimated at \$107,000, yielding a net revenue of \$4,000. Composting of blue crab scrap appears to be a feasible alternative for the area in which the demonstration project occurred.

Static Pile: This demonstration used a 'low technology' approach that has been used for fish scrap composting in Wisconsin. It was examined because of its lower cost and less frequent handling characteristics. Overall, the low technology system of blending coarse chips with crab scraps worked extremely well. Where little turning is done, the mix ratios must be adjusted upwards to reduce the potential for poor aeration and to guard against odor generation (Brinton and Gregory, 1992).

Each day crab scraps were dumped off trucks directly onto the end of an active compost windrow and blended into the windrow. A mixer was used for large loads and a bucket loader for smaller loads. For this method, the proper ratios of coarse bark and chips to crab scrap appear to be 2 volumes wood:1 volume crab scrap. At the end of the compost process, the compost was processed through a tub-grinder which produced a dark humus-like product. This final step was not necessary in the open-windrow procedure which was turned daily.

Laboratory analysis was conducted on the crab scrap compost to provide information on water content, pH, organic matter content, TKN%, C:N ratios, N, P, K and other measures (Brinton and Gregory, 1992). This product should not be viewed as a fertilizer, since the N, P, K ratio was .9-.5-.1, but as a low-grade soil amendment. The final C:N ratio was 25.

Calico Scallops

A total of 96 tons of scallop viscera were composted in early 1991. Complementary materials used included 1,200 yd³ combined of pine-bark, sawdust and tree trimmings, 128 tons of seaweed, 24 tons of rejected citrus pulp, 25 tons of water hyacinth weed and 14 tons of horse manure (Brinton and Gregory, 1992). The viscera was of two principal forms: raw viscera and viscera/shell mix. The principal wood products used were log bark and log chips from a home manufacturing plant and cypress sawdust from a mill.

A mechanical-lift SCAT™ compost turner was used to turn the windrows. This process does not chop to any extent, like the WILDCAT™ machine, but this did not pose a problem due to the nature of the scallop viscera. The compost piles showed a quick rise in temperature after the scallop viscera was added, but did not reach temperatures over 120° F, probably because water became a limiting factor. The SCAT™ turner oxygenated the piles well, which reduced odors, but the intensive lifting and air-exposure of the compost means a lowering of the temperature, which fell by 30° after each turning.

The beginning nitrogen content of the viscera was very high at 14.2%, while that of the viscera shell mix was one fourth that level. The final compost appeared to be somewhat course, because of wood fragments, so the final product was screened. The course yard trimmings piles performed the best, resulting in more than 70% fine material, which is generally preferred for use as a soil amendment and for potting mixes. The course materials are best for mulch-type landscaping operations. The nutrient composition was also changed after screening. The density increased, nitrogen content increased and C:N decreased, resulting in a more stable product. The final analysis for four scallop viscera piles using various sources of the organic materials gave N, P, K values ranging as follows: N, .3 to .5; p, .07 to .13; K, .08 to .9.

Scallop viscera, with and without cracked shells and by-catch, can be readily composted and converted into a soil-humus product. Because of the high BOD of viscera, frequent turnings are needed, or a coarse fraction of wood is necessary. The SCAT™ machine turning technology used provided excellent aeration of the piles and controlled composting adequately.

Compost marketing

Blue Crabs

A marketing program also was developed for the blue crab scrap compost produced by the open windrow method (Greenfield, et.al., 1992). Potential uses such as garden and farm centers, nurseries, greenhouses, landscapers, farmers, organic farmers, golf courses and contractors were examined. A pilot marketing program was established in six north Florida counties and sales of the compost have occurred both in bulk form and bagged for retail outlets. A total of 14 retail outlets

and several public service organizations were involved in the test sales project. By the end of 1990 compost sales totaled \$8,558 (wholesale value). A total of 311 bags (40 pounds each) had been sold, primarily through farm and feed supplies at a wholesale price of \$3.00 per bag. Retail price was \$6.00 per bag. Bulk sales have been 305 cubic yards at \$25 per yard. An estimated 200 cubic yards and 100 bags remain to be sold, but the supply has been controlled to maintain a constant supply to the market (Greenfield, 1991). Adequate demand exists in the six-county north Florida area to annually sell the entire compost production possible from the blue crab scraps of Taylor, Wakulla and Leon counties.

Other forms of use for the static pile produced blue crab compost and for the calico scallop compost are being examined. A free crab compost day was held for the static pile produced compost as a way to measure product acceptability. In a four hour period, 63 vehicles loaded 85,060 pounds of compost which homeowners and gardeners intended to use as potting soil and for other home uses as a soil amendment (The Wakulla News, 1991).

Calico Scallops

The calico scallop compost will be used in demonstration projects as a soil amendment for roadside wildflower growing projects, in home gardens, and as a possible amendment to mixes used to start young citrus trees (Mahan, 1991). This will help establish demand and uses for the compost.

Blue crab compost used as a soil amendment

Blue crab scraps have interesting chemical/biochemical properties, including a high chitin content which may prove effective in immobilizing not only those metals (including Fe, Al, and Cu) contained in the scraps, but also associated trace metals from other compost constituents including sewage sludge. A study to characterize the responses of sorghum/sudan grass to varying applications of raw and composted blue crab scraps, in comparison to fertilized and non-fertilized control treatments in both field and greenhouse tests was conducted (Street, et.al., 1992).

The field plot portion of the test was an unreplicated demonstration effort, comparing the growth, relative yields, and plant composition of traditionally fertilized, raw crab scrap amended, and compost amended plot areas. The green house study was a replicated variable-rate study in which soil and plant composition, and plant yields, were compared for various rates of raw crab scraps, crab compost, traditionally-fertilized and unamended/unfertilized pots. The greenhouse studies included an analysis of both the soil and plants for resultant values of N, P, K, Ca, Mg and B for all treatments, and soil sample and plant analyses for P and N, and plant yield increases were made for the field tests (Street, et.al., 1992).

Raw blue crab scraps seem to offer considerable potential as a soil amendment for crop production at sites where the initial odor and fly problems from unincor-

porated portions are tolerable. They would seem to be acceptable, for example, in relatively remote sites (removed from the vicinity of human residences) where crops of a low-input, low-maintenance nature are being grown. This would include pine-plantation replanting areas, which are common in the Taylor county area. The compost product, though considerably more desirable from an aesthetics standpoint, is of quite-limited value as a nutrient-supplying amendment. Long-term effects on soil organic matter levels, and adequacy of nutrient supply for more slow-growing crops including pine plantations, are other considerations where the compost may be of considerable value but which could not be evaluated via the current studies.

Nematode control using blue crab compost

Chitin amendments when added to soil significantly reduce populations of the soybean cyst nematode, the southern and peanut root-knot nematodes, and the citrus nematode. Chitin is contained in several brand-name materials used to control nematodes, and in crustacean exoskeletons such as blue crabs. Tests were conducted to determine the effect of compost made of blue crab scrap and cypress sawdust on the reproduction of Javanese root-knot nematode (Rich and Hodge, 1992).

Two greenhouse pot experiments were conducted using the 'Homestead' tomato, as were field microplot tests using the 'Rutgers' tomato. All tests used various levels of the Javanese root-knot nematode for inoculation to determine the effect of various levels of blue crab compost on nematode control. In both greenhouse tests, crab scrap compost had a significant effect on both foliar and root weights of tomato compared to the control treatment. The observed increases varied depending on the rate of nematode inoculation and percentage of compost added to the soil. In the field microplot study, no significant differences between compost levels and the control treatment were observed for tomato plant top weights, although a trend toward greater yield was observed in the compost treatments (Rich and Hodge, 1992).

In both greenhouse tests, the 20% compost application rate was the lowest level of compost that produced large reductions in root galling and nematode reproduction. Pure chitin produces results at extremely lower levels (less than 1 percent). The depletion of nitrogenous compounds and reduction of energy sources through composting probably reduced chitin concentrations and the nematode suppressive characteristics of the crab scrap as well. The 20% level of crab scrap compost represents an application rate of over 200 mt/ha, which would not be economical for nematode control in commercial agriculture. The crab scrap compost has the same limitations for nematode control as many other materials containing low C:N ratios. The greatest potential for crab scrap compost with respect to nematode suppression would be for the container grown plants and organic home gardens, where higher loading rates are common.

Blue crab compost and water quality

Agricultural areas in Florida are commonly underlain by sandy, well-drained soils that generally have low organic matter and low moisture retention capacity. Thus, ground water is highly susceptible to contamination from applied insecticides, herbicides, and fertilizer nutrients. Compost made from crab scrap may impact the quality of the ground water in two ways: decomposition of crab scrap may add organic compounds, chemical residues, or trace elements to ground water; and crab scrap compost may provide a means of enhancing the retention and/or degradation of pesticides and nutrients in the upper portion of the soil profile. Early data indicate that arsenic, selenium and manganese in the crab compost could be at significant levels to create a potential hazard, although the work has not been completed (Rich, 1992).

Summary

These projects have been successful. Composting of all blue crab processing scraps in Wakulla County, Florida, have continued since the demonstration projects ended in 1991. This has enabled the industry to continue and solved the county landfill problem. Because of the highly variable nature of the calico scallop fishery, very little product has been produced in Brevard County since 1991. However, the static pile composting procedure has been used in other regions of Florida. For example, during 1994, approximately 80 tons of scallop, shrimp and crab processing wastes have been composted in Franklin County, Florida. Approximately 400 tons of yard trash have been diverted from the county incinerator to the compost project at a total cost savings of \$18,000 (Bill Mahan, personal communication, 1995). The use of composting to recycle seafood processing scraps is a viable alternative.

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Dairy Cattle Slurry and Rice Hull Co-composting

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Abstract

A liquid dairy cattle slurry was composted using rice hull as absorbing matrix and bulking agent. The main results obtained were as follow: **1)** The structure and size of rice hulls as well as their absorption capacity, made it possible to obtain a good composting mixture (moisture: 71.42 %; C/N ratio: 28.80 %; bulk density: 0.429 kg / dm³) **2)** The compost stability was reached after 56 days of composting, obtaining the follow data (% D.M.): ignition loss: 73.00; C/N: 18.36; TKN: 1.98 ; K: 1.84 ; P: 1.13; humified carbon: 4.60 ; respirometric index: 0.88 mg O₂ /gVS x h; dry matter yield: 57.34 %; organic matter yield: 50.05 %, water losses: 56.99 %; airflow-rate: max: 2.96 m³/kg D.M. x day., min: 0.28 m³/kg D.M. , men 0.75 m³/kg D.M. . **3)** The curing phase determined as aspected the reaching of a high compost maturity degree. After 256 composting days the data obtained (% D.M.): ignition loss: 65.89; C/N: 13.52; TKN: 2.51 ; K: 2.00 ; P: 1.27 ; humified carbon: 10.81; dry matter yield: 46.36 %; organic matter yield: 36.91 %, water losses: 63.99 %. **4)** As shown by the organic matter yield, the mixture presented high degradability, in contrast to the literature (Chino et al., 1983). This can be explained by the composting temperature obtained (30 –45 °C) which permitted high cellulose-like material degradation. **5)**The compost data obtained, suggests that two marketable products are obtained: the first after 56 composting days, utilizable in field applications, and the second after 254 days, as substitute for organic substrata (e.g., peat) in greenhouses and on sensitive plants.

Introduction

About 95 % of Italian rice production (190,000 tonnes/year) is concentrated in Northern Italy, especially in the provinces of Pavia, Novara and Vercelli. Refuse from the rice processing industry consists mainly of the hulls, and each year 35,000 tonnes of this material is produced.

Although rice hulls can be used for many different purposes (cooling steel, litter

for poultry breeding, substratum for flower cultivation, furfural extraction, or as fuel etc.), the problem has never been solved of disposing of this waste, even at practically no cost. Research on the subject has mainly been concerned with investigating how far rice hulls could be combined with dairy cattle slurry to make compost, thus making better use of the waste as an amendment, provided the starting material showed a high degree of degradation and good humification. About 34.5 million tonnes of slurry a year is produced in the regions of Piedmont and Lombardy, thus exceeding the real soil requirement by 50%.

Material and Methods

Slurry and bulking agent. We have used a dairy cattle slurry characterized by 4.85% of dry matter (D.M.), 85.32% ignition loss (VS), 51.50% total carbon content (TOC), and 4.90% and 10.51% of total nitrogen (TKN) and C/N.

Rice hulls from industrial processing, were used as the bulking agent. The rice hull contained 12.10 % of moisture, 85.76% ignition loss, 39.12% and 0.92% total carbon and total nitrogen respectively, and 42.42 C/N. Bulk density was 0.180 kg/dm³.

The rice hull was mixed with the slurry at a ratio of 1:2.5 on a wet weight basis (7.5:1 on a dry weight basis). The ratio represented maximum rice hull absorption capacity, with no presence of free water. Total moisture content, ignition loss, carbon content, nitrogen content, C/N ratio and bulk density of blend were 71.42%, 84.52%, 40.63%, 1.41%, 28.80% and 0.429 kg/dm³, respectively.

Composting facilities. A glass and steel cylindrical adiabatic reactor (Mote and Griffis, 1979) with a diameter of 40 cm and height of 50 cm, was used as composting equipment. The reactor was provided with a 'jacket' for thermostatic water circulation. It was possible to monitor the following parameters: O₂ (%) and CO₂ (%) concentration, temperature (°C) and relative humidity (%) in the biomass. The amount of CO₂ (mg CO₂/g SV x h) and NH₃ (mg NH₃/g SV x h), which evolved during the process, were determined by trapping with an acid and basic traps (Mote and Griffis, 1979). O₂ uptake (mg CO₂/g SV x h) was determined by using data from the CO₂ produced and adopting a molar ratio of the O₂ uptake / CO₂ produced of 1:1, reported to be useful for lignocellulose matrices (Haug, 1986 a).

Air was introduced into the reactor through a stainless pipe. The blower had a maximum feeding capacity of 8 L/min; the airflow rates (m³/kg D.M. x day) adopted were 2.96 max., 0.28 min., 0.75 mean.

Composting process. The composting process was divided into two stages. The first stage was designated the 'active composting phase' and was carried out for 56 days within the reactor vessel of the composting apparatus. The second was termed 'curing phase' which was carried out for 197 days after the stage of active composting had been completed, within a cubic-shaped plastic container (40 x 40 cm).

Sampling. During the composting phase, we took 4 samples: on the 1th, 18th,

36th, 56th day. During the curing phase, on 89th, 120th, 148th, 209th, 254th day. About 50 grams of statistically uniform samples were collected each time and used for chemical analysis. The samples were dried at 60 °C under vacuum.

Chemical analysis. The content of volatile solids and ashes was determined by the ignition of a dry sample at 650 °C (ASA,SSSA, 1982), nitrogen, by the Kyeldahl method (ASA,SSSA, 1982).

Dry matter was broken down into its constituents by using different solvents, as reported in the previous work (Adani et al., 1995), obtaining:

- fraction I, soluble in organic solvents (benzene-ethanol 50/50 v/v, and ethanol 96% w/w): lipids, resins, catechols, tannins, part of proteins and part of fulvic acids;
- fraction II, soluble in H₂O and hot H₂SO₄ 5% under reflux for 2 h: emicellulose, part of proteins, sugar, part of fulvic acids;
- fraction III, soluble in H₂SO₄ 72% at 4°C for 24 h: cellulose;
- fraction IV, insoluble in H₂SO₄ 72%: lignin and humic acids;
- fraction V: residue ashes obtained by ignition of the fraction IV.

The difference between total ashes and residue ashes (V) gave the soluble ashes (VI).

The sum of Fractions I + II + III + IV gave the total volatile solids.

Table 1 shows the result in respect of the dry matter breakdown of starting matrices.

Table 1 Dry matter fraction contents of starting matrices (% of D.M ashes-free)

matrix	I	II	III	IV
rice hull	7.98	36.85	37.91	17.19
slurry	14.14	28.42	39.12	20.65

The organic carbon was broken down using the Adani et al.(1995) methods, thus obtaining true humic acids carbon (CHA) as part of the 'IV + V' total carbon, soluble in NaOH + Na₄P₂O₇ 0.1 N solution, but insoluble too pH value below 1.5. True fulvic acids carbon (CFA) were determined as the fraction of the total D.M. organic carbon, soluble either in alkaline or in a dilute acid solution, after purification by chromatography on to a cross-linked polivinylpyrrolidone column (Ciavatta et al. 1989). The sum of CHA + CFA (as a % of D.M.) represented the total humified carbon content (C hum) (Adani et al., 1995).

Material Balance. Assuming the principle of ash preservation during the composting process (Haug, 1986 a), the following equation was used to determine the exact dry matter content (D.M._t) (in units of weight) at a generic time (t):

$$DM_t = VS_t + \text{ashes}_0 \quad (1)$$

in which VS_t represented the volatile solids at generic time (t), calculable using:

$$VS_t = \text{ashes}_0 [(100 / \% \text{ ashes}_t) - 1] \quad (2)$$

Ashes₀ and '% ashes_t' represented the ash contents at the start of the process (in units of weight) and the ashes present at a generic time (t) (as % of the dry matter), respectively.

Knowing, at a generic time (t) the percentage of dry matter, (experimental data) and, by means equations (1) and (2), the dry matter content in units of weight, it was possible to calculate the water content (W_t) as follows:

$$W_t = DM_t \times (\% W_t / \% DM_t) \quad (3)$$

It was obvious that, considering two different time (e.g., t₁ and t₂, in which t₂ > t₁), the relative yield could be calculated with following expression:

$$DM \text{ or } VS \text{ or } W \text{ yield (\%)} = [(DM \text{ or } VS \text{ or } W)_2 / (DM \text{ or } VS \text{ or } W)_1] \times 100 \quad (4)$$

Results

Composting parameters

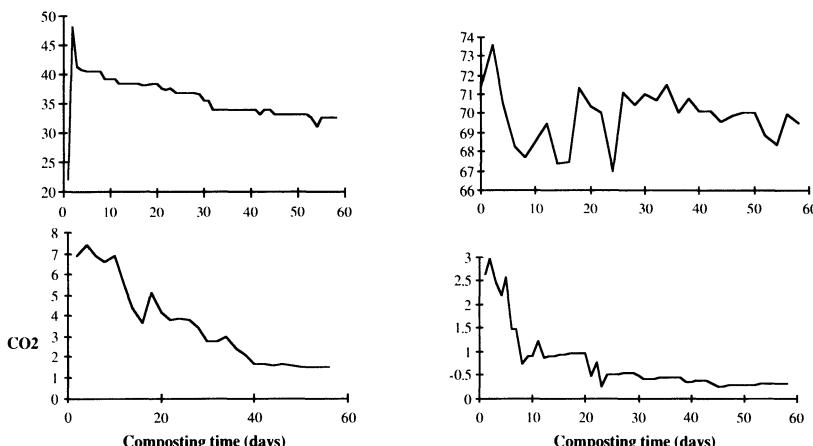


Figure 1 Composting parameters

Fig.1 summarizes the process parameters of the active composting phase and Fig.2 shows their correlation.

The data available had indicated a typical composting process characterized by the highest microbial activity during the first days. Data regarding temperature and CO₂ emitted, which were an indirect measure of microbial activity, confirmed what had been assumed and also pointed to a close interrelationship between them (Fig.2). Consequently, a different daily aeration rate was required (Fig.1), as confirmed by close correlation with the temperature and the CO₂ produced (Fig. 2).

Table 2 presents figures relating to CO₂ and O₂ concentrations and their sum in the biomass, through the active composting phase. The gas concentrations were in a 'optimal' range for composting purpose ([CO₂] ≤ 6 %; [O₂] > 15 %) preserved

from anomalous fermentation (anaerobic fermentation). The fact that a $\text{CO}_2 + \text{O}_2$ total very close to 21 % was obtained confirmed the absence of other gases (derived from aerobic degradation) (MacGregor et al., 1981), which could become toxic to the microbial population (e.g. NH_3).

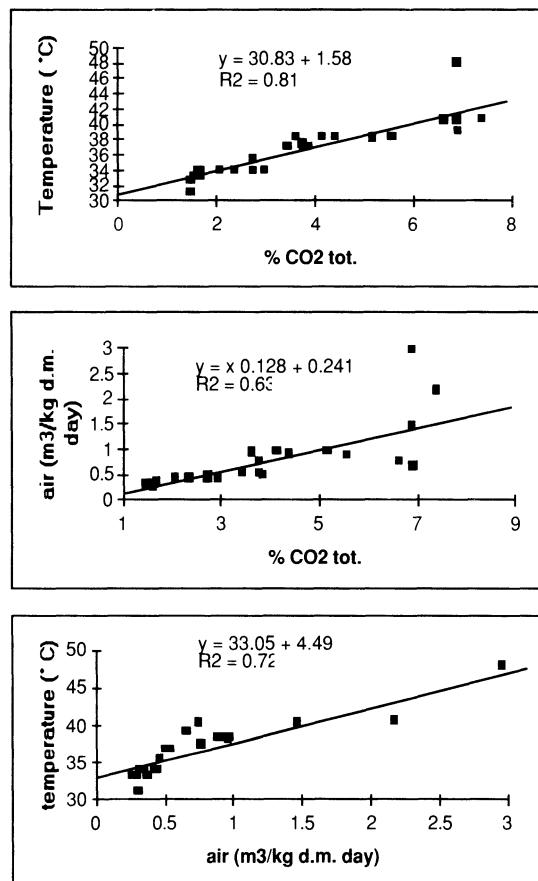


Figure 2 Composting parameters correlation

Table 2 CO_2 and O_2 concentrations during the composting-phase (%).

days	O_2	CO_2	$\text{CO}_2 + \text{O}_2$
0	16.42	2.98	19.40
6	16.71	4.29	21.00
11	16.43	4.75	21.18
16	16.51	4.33	21.00
18	17.07	3.85	21.00
23	15.50	5.50	21.00
27	18.52	2.77	21.29
36	18.51	2.80	21.31
42	19.83	0.58	20.41
48	20.20	0.29	20.49
52	20.55	0.84	21.39
56	21.37	0.00	21.37

Organic matter evolution

Fig. 3 sum up the organic matter evolution. As expected, the process determined a ligno-humic fraction concentration to the detriment of an easily degradable organic fraction (e.g. fats, cellulose, hemicellulose, etc.) (Fig.3), thus confirming the data found in literature (Sana et al., 1989; Ferrara and Vicenzino, 1989). As previously indicated, the first phase of composting was characterized by high degradation values that pointed to the easy degradability of the matrix composted. After only 18 composting days, about 25 %, 13 %, 40 %, 31 % and 0 % of total organic matter fraction I, II, III, and IV respectively were lost. This trend was maintained until the 56th day. At this point, the losses registered were 49.95 % of total organic matter and 51.52 %, 60.41 %, 62.49 %, 10.67 % of Fraction I, II, III, and IV, respectively. The 56th day may be assumed to mark the end of the active composting-phase, corrisponding to which organic matter stability was reached, as confirmed by respirometric compost data (Table 3).

Table 3 CO₂ emitted and O₂ uptake during the active composting- phase

days	mg CO ₂ /g SV x h	mg O ₂ /g SV x h
2	2.80	2.04
18	2.87	2.09
36	1.63	1.19
56	1.21	0.88

Robinson and Stentiford (1993) succeeded in reaching organic matter stability, indicated on the respirometric index as 1.4 mg O₂ /g SV x h, while Iannotti et al. (1993), co-composting poultry waste with MSW, pinpointed an O₂ uptake value of 2 mg O₂ /g SV x h at the start of the process, and values below 0.5 mg O₂ /g SV x h, indicanting the achievement of high stability. Thus an O₂ uptake value of 0.88 mg O₂ /g SV x h could be assumed a real indication of compost stability. The ensuing period (curing phase) produced compost maturation aimed at an increase in humified organic matter, mostly high MW humic acids (Table 4), as reported in literature (Maggioni and Ferrari, 1980; Roletto et al., 1985; Roletto and Cerruti 1985; Godden and Penninckx, 1987).

After 254 of composting days, loss in total organic matter was 63.09 %, while that of Fraction I, II, III and IV were 46.11 %, 71.34 %, 82.17 % and 25.97 %, respectively.

Nitrogen evolution

Nitrogen content, as expected, increased with the composting process (Table 4), due to organic matter degradation and the very low NH₃ losses (Table 4) . Consequently, there was a decrease in the C/N ratio (Table 5).

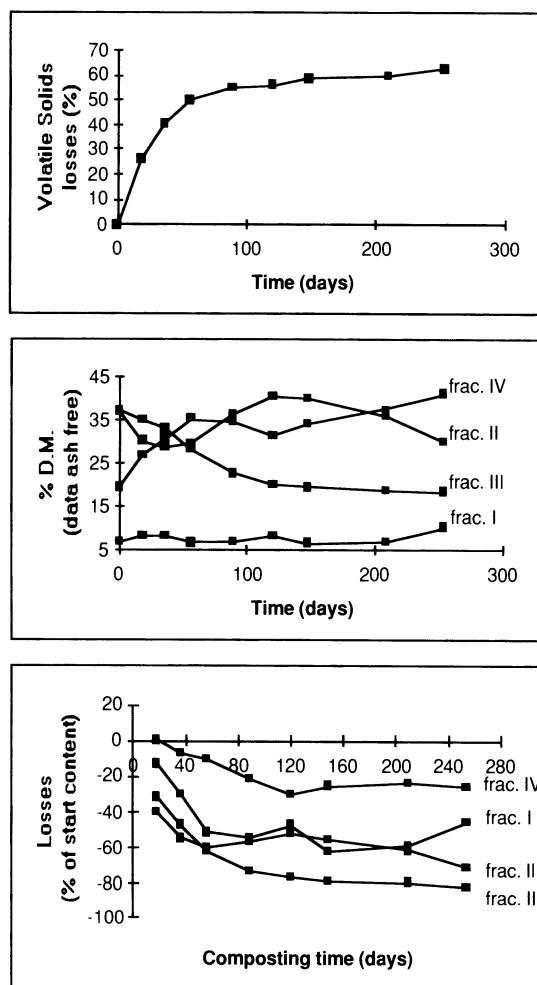


Figure 3 Organic matter evolution during composting process

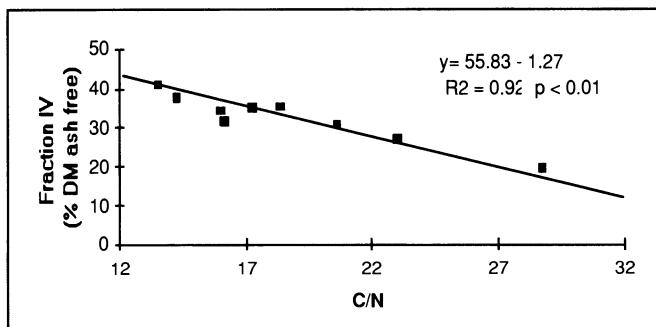
Table 4. Trend in humified organic carbon (C hum) content during all composting process

days	C hum (% DM)	C hum (% TOC)
0	3.29	8.09
20	4.32	11.02
38	3.88	10.39
58	4.60	12.64
89	8.41	23.55
120	8.16	22.92
148	8.62	24.26
209	7.88	22.63
254	10.81	31.85

Table 5 Nitrogen content, C/N ratio and nitrogen loss during composting process

days	TKN (% DM)	C/N	N loss (% TKN)
0	1.41	28.80	0
18	1.70	23.04	6.60
36	1.81	20.61	16.06
56	1.98	18.36	19.46
89	2.07	17.25	21.83
120	2.20	16.18	18.43
148	2.22	16.00	21.99
209	2.36	14.32	17.88
254	2.51	13.52	19.46

Sometimes, the C/N ratio is used as an indicative parameter to determine organic matter maturation, through the composting process, the C/N ratio showed a high correlation with the ligno-humic fraction (Fraction IV) (Fig.4), the latter being utilizable as an organic matter maturation indicator, as already reported in the previous work (Adani et al., 1995) and confirmed by literature (Sana et al., 1989).

**Figure 4** Correlation of ligno-humic fraction (IV) versus C/N ratio

Material Balance

Table 6 shows material balance (dry matter, volatile solids and water) after the 56th and 254th day.

Table 6 Dry matter (DM), volatile solids (VS) and water (W) yield after active and curing composting phase (% of initial weight).

day	DM	VS	W
56	57.34	50.05	34.58*
254	46.35	36.91	n.d.

* considering also the reaction water produced, calculated adopting a H₂O/CO₂ molar ratio of 0.83:1, (Haug, 1986)

Interaction between Water loss, Heat loss and Aeration rate adopted during the active composting-phase

Using the Haug (1986b) procedure, we calculated the theoretical aeration rate necessary to obtain the data on experimental water and heat losses (the complete data

used are given in Table 7). The theoretical aeration rate obtained by water removal was 0.75 ($\text{m}^3/\text{kg DM} \times \text{day}$) and 0.82 ($\text{m}^3/\text{kg DM} \times \text{day}$) by heat removal. These values agreed with experimental data of 0.75 ($\text{m}^3/\text{kg DM} \times \text{day}$) calculated as the mean aeration rate for the 0–56th day period.

Table 7 Data utilized for theoretical aeration rate calculus (W = to water removal; H = to heat removal)

parameter	value	note
temperature inlet (W;H)	20.00 °C	mean of experimental data
temperature outlet (W;H)	37.70 °C	mean of experimental data
air relative humidity inlet (W;H)	70 %	mean of experimental data
air relative humidity outlet (W;H)	100 %	mean of experimental data
air specific humidity inlet (W;H)	0.0147 kg $\text{H}_2\text{O}/\text{kg dry air}$	calculated to 20 °C
air specific humidity outlet(W;H)	0.0428 kg $\text{H}_2\text{O}/\text{kg dry air}$	calculated to 37.7 °C
heat of vaporization (H)	830 kcal / kg H_2O	Haug (1986)
specific heats of water (H)	0.42 kcal / kg $\text{H}_2\text{O} ^\circ\text{C}$	Haug (1986)
specific heats of air (H)	0.24 kcal / kg $\text{H}_2\text{O} ^\circ\text{C}$	Haug (1986)
biomass humidity (start) (W;H)	71.42 %	experimental data
biomass humidity (end) (W;H)	66.20 %	experimental data
water loss during process (W;H)	65.42 %	experimental data
dry matter yield (W;H)	57.34 %	experimental data
volatile solids (H)	0.85 total solids	experimental data
biodegradable volatile solids (H)	0.45 volatile solids	experimental data
heat released by biod.vol.sol. (H)	4100 kcal / kg	Haug (1986)

Conclusion

The main results obtained were as follows:

- 1 The structure and size of the rice hulls, as well as their absorption capacity, made it possible to obtain a good composting mixture, without any need for costly pretreatment prior to use, which suggests a low-technology composting process is feasible.
- 2 As shown by the organic matter yield, the mixture presented high degradability, in contrast to the literature (Chino et al., 1983). This can be explained by the composting temperature obtained (30 –45 °C) which permitted high cellulose-like material degradation, as reported in the literature: McKinley et al. (1985) by co-composting sludge and the lignocellulose fraction, set up the highest microbial activity, at 35 – 45 °C; Regan and Jeris (1970) suggested 25 – 45 °C as the best temperature to cellulose degradation.
- 3 The compost data obtained, suggests that two marketable products are obtained: the first after 56 composting days, utilizable in field applications, and the second after 254 days, as substitute for organic substrata (e.g., peat) in greenhouses and on sensitive plants. Table 8 sums up the characteristics of the products indicated.

Table 8 Chemical characteristic of compost after 56 (A) and 256 (B) composting days (% D.M.)

	VS	TOC	Chum	TKN	C/N	P	K	DM yeld
A	73.00	36.50	4.60	1.98	18.36	1.13	1.84	57.34
B	65.89	33.61	10.81	2.51	13.52	1.27	2.00	46.36

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Field Scale Study of the Effect of Pile Size, Turning Regime and Leaf to Grass Mix Ratio on the Composting of Yard Trimmings

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Abstract

Composting is fast becoming the primary disposal option for leaves and grass in the U.S. due to proposed bans on the land filling and incineration of these wastes. To date, few systematic field scale studies have been done to compare the effects of turning regime, pile size and feed stock mix ratios on the rate of compost production or the properties of finished compost. In this study, leaf, grass and brush mixtures of 4:1:1, 4:2:1, 4:3:1, as well as 4:2:1 and 4:3:1 with staged grass addition, were formed into windrows and piles and composted for 136 days. Using a windrow turner, one series of windrows (#1) was turned seven times every four weeks, while the second series of windrows (#2) was turned once every four weeks. The piles were turned using a front-end loader once every four weeks. Results showed that windrow temperatures rose to 55–62° C in 6 days and remained at this temperature through day 60 and then slowly declined to around 45° C by day 100. Pile temperatures rose to higher levels (68–74° C) and remained above 60° C for 100 days. Windrow oxygen concentrations ranged between 1 and 4% while the oxygen concentrations in the piles fluctuated greatly between 2 and 18%. Organic matter loss was fastest in windrows series #1 and slowest in the piles. The pH of all the treatments rose from neutral to slightly alkaline (pH>8). The bulk density increased by more than 400% for windrows in series #1 but by only 150%, and 100%, respectively, for windrows in series #2 and the piles. The results indicate that turning frequency has a significant effect on bulk density, a slight effect on the rate of organic matter loss, and an insignificant effect on temperature and oxygen concentration. The mix ratio of leaves to grass, on the other hand, had no significant effect on most measured parameters. The composts from

all the treatments were stable after 60 days of composting as indicated by oxygen uptake rates of less than 0.1 mg O₂/g organic matter/hr. None of the composts inhibited seed germination or root elongation as measured by the Cress seed test.

Introduction

Yard trimmings (grass clippings, leaves and brush) account for approximately 18% of U.S. municipal solid wastes. Because of the adverse environmental effects of land filling and incineration, and increasing costs, the U.S. EPA has targeted 25% of the solid waste stream for source reduction and recycling (EPA, 1992). An alternative to the disposal of yard trimmings by land-filling or burning is large scale composting. In this process, leaves or mixtures of leaves, grass, and brush are aerobically decomposed giving a product rich in humus, which can be used to enhance soil fertility (Dick and McCoy, 1993). Yard trimmings are particularly good feed stocks for composting since they are source separated. Yet, grass alone is not an ideal compost feed stock due its tendency to become anaerobic and produce strong and noxious odors (Schulz, 1992).

Large-scale composting facilities often receive high levels of grass and use a variety of different methods to produce compost. However, few systematic studies have been done to compare the effects of grass content, turning regime and pile size on the rate of compost production or the properties of finished compost. In this study the effects of pile size and turning frequency were determined by monitoring the temperature, oxygen concentration, pH, organic matter, moisture content, bulk density, stability, humification and germination index, and nutrient level, during field scale yard composting of yard trimmings.

Methods

Feed stock mixes were prepared from grass, winter stored leaves and chipped brush at a large municipal yard waste composting site near Detroit, Michigan, USA [Southeast Oakland County Resource Recovery Authority, (SOCRRA)]. The characteristics of feed stock mixes used are presented in Table 1. To simulate the large scale composting of yard trimmings as practiced in various parts of the U.S., leaf, grass, and brush mixtures of 4:1:1, 4:2:1, 4:3:1, as well as 4:2:1 and 4:3:1 with staged grass addition, were formed into two series of windrows (#1 & #2) and one series of piles. Using a Scarab windrow turner (Scarab Inc., White Deer, TX 79097), one series of windrows (#1) was turned 7 times every 4 weeks, while the second series (#2) was turned once every 4 weeks. The piles were turned using a front-end loader once every 4 weeks. By preparing the windrows and piles from identical mixtures of leaves, grass, and brush, direct comparisons could be made between different turning frequencies and pile sizes.

The windrows and piles were formed in July 1994, using leaves (collected the

previous fall), fresh grass, and chipped brush. Windrow and pile treatments 1A through 3E are depicted in Figure 1. Initially, treatments A, B, and C received 32 m³ of leaves, 8 m³ of grass and 8 m³ of brush for a total of 48 m³. D treatments received an additional 8 m³ of grass for a total of 56 m³, and the E treatments received 24 m³ of grass for a total of 64 m³. The B and C treatments received one and two additions of 8 m³ grass, respectively, after 4 and 8 weeks to give final L:G:B ratios of 4:2:1 and 4:3:1. The windrows were 4 m wide, 1.2 to 1.5 m high, and 12 to 15 m long. The piles had radii of between 3.5 and 4.3 m at the base, and were 3 m high.

Table 1 Characteristics of initial compost mixes.

Characteristic	Leaf:Grass:Brush ratio (v/v) ^a		
	4:1:1	4:2:1	4:3:1
Moisture Content ^c (%)	62.3 ± 1.3	64.8 ± 0.9	67.5 ± 3.1
pH	7.23 ± 0.21	6.76 ± 0.27	6.96 ± 0.25
Bulk Density ^c (kg/m ³)	159 ± 12	179 ± 17	207 ± 26
Organic matter ^b (%)	69.2 ± 1.5	70.2 ± 1.8	69.5 ± 3.3
C/N ratio	26.4 ± 2.9	25.9 ± 1.6	24.6 ± 1.2
Nitrogen ^b (%)	1.34 ± 0.13	1.51 ± 0.11	1.52 ± 0.04
Carbon ^b (%)	35.0 ± 1.7	39.0 ± 1.0	37.3 ± 1.5
Total Volume (m ³)	48	56	64

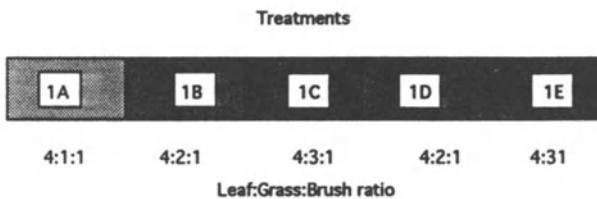
^a-Values are averages and standard deviations for quadruplicate composited samples.

^b-Dry weight basis.

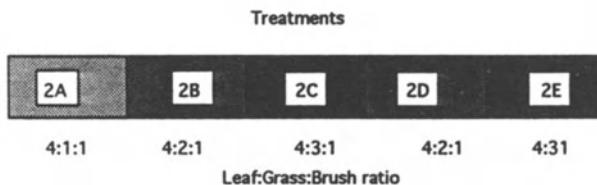
^c-Wet weight basis.

To collect statistically valid data, 0.03 m³ (1ft³) samples were collected from the left side, top and right side of windrows and piles at 0.4 meter and 0.8 meter depths. These samples were combined and mixed to give a composite sample. Triplicate (or quadruplicate) composite samples were collected from each treatment section. The average temperature of windrow and pile treatments was determined by taking four different measurements from the top and side of each treatment at 0.4 and 0.8 meter depths. Oxygen concentrations were measured at the top and side of each treatment at a depth of approximately 0.5 m. On those days when the windrows and piles were turned, oxygen concentration and temperature measurements were made before turning and the samples used for analyses were collected right after turning. The organic matter contents, moisture contents, pH and nutrient levels were determined as described by Michel et al (1993). The 'compost stability' was assessed using the method of Iannotti and Frost (1993). Humification index was determined as described by Ciavatta et al (1991). A galvanic oxygen probe was used to determine oxygen concentrations. Temperatures were measured manually using analog thermometers. Seed germination index was determined as described by Zucconi (1981). Bulk density was measured as described by Schulz (1992).

WINDROW SERIES #1 : Turned seven times every four weeks using a windrow turner



WINDROW SERIES #2 : Turned once every four weeks using a windrow turner



PILES: Turned once every four weeks using a front-end loader

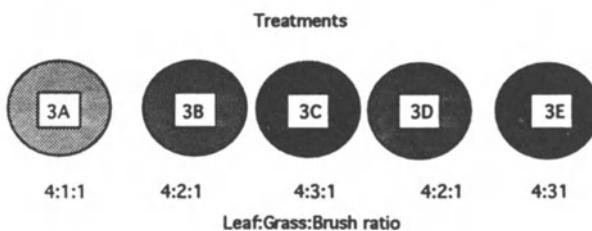


Figure 1 Diagrammatic representation of the experimental setup of windrows and piles. Grass was added in stages after 4 weeks in the B sections and after 4 and 8 weeks in the C treatments. Turning frequencies for each of the windrows and piles are presented in Figure 2

Results

Windrow temperatures rose to between 55° and 62° C in 6 days and remained in this range through day 60. The temperatures declined thereafter, and by day 120 reached 40–46° C in the windrows in series #1, and 48–53° C in the windrows in series #2. In the piles, the temperatures rose to significantly higher levels (68° to

74° C) and remained above 60° C through day 100. The windrow and pile temperatures were not affected by the level of grass in the mixture, by grass addition (sections B and C), or by the turning frequency. These findings suggest that temperatures in the windrows and piles are moderated by convective air flow through the composting mass and not by turning. The piles, which had surface to volume ratios roughly half that of the windrows, presumably had less air flow, less cooling, and, therefore, higher temperatures.

The average oxygen concentrations in the windrows dropped to between 1.5 and 3% within 24 hours of composting and remained in this range through day 81 of composting (Figure 2). In contrast to this, the oxygen concentrations in the piles fluctuated widely between 1% and 18% apparently due to greater heterogeneity in the piles or perhaps due to other factors that are not well understood at this time. The high composting temperatures in the piles may also result in reduced microbial activity leading to decreased oxygen demand and a rise in the oxygen concentrations to near atmospheric levels. Interestingly, neither the mix ratio nor the turning frequency had a significant effect on the oxygen concentrations in the windrows. These results support the idea that convection, and not turning, is the dominant aeration process during windrow and pile composting.

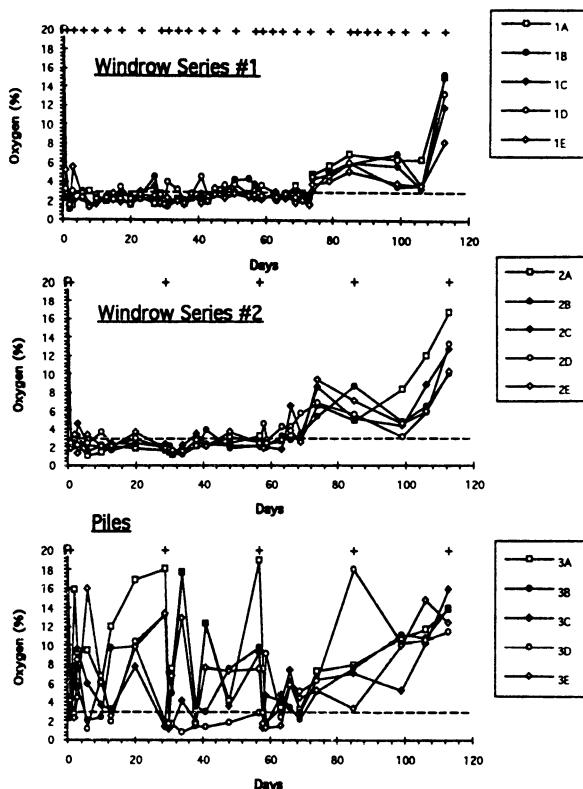


Figure 2 Oxygen concentrations during composting. Treatments 1A through 3E are described in Figure 1. The (+) signs on the top of each panel indicates the days when the windrows and piles were turned.

The organic matter contents decreased faster for windrows in series #1 compared to the windrows in series #2 or the piles (Figure 3). The piles showed the slowest initial rate of organic matter loss. Between 60% and 70% of the organic matter present in all treatments was lost after 136 days of composting. The final organic matter contents were slightly lower in windrows in series #1, than in windrows in series #2 or the piles, but were not significantly affected by the initial L:G:B mix ratio.

The windrows in series #1 and #2 and the piles had initial moisture contents between 62.3% and 67.5% which are near optimal for composting (Table 1). During composting, the moisture contents of all of the windrows and piles gradually decreased, however, there was no correlation between moisture loss and turning frequency, pile size or initial mix ratio. The final moisture contents were between 43% and 58%.

The pH of the windrows in series #1 rose to above 8.2 after 7 days of composting. The pH in the windrows in series #2 reached this level after 36 days and the piles reached it by day 81. Once this pH level was reached all of the sections remained between pH 8.1 and 8.6. The L:G:B ratio had no discernible effect on the pH increase. These alkaline pH values may contribute to nitrogen losses and ammonia odors during composting since above pH 8.2, ammonia nitrogen becomes more volatile.

The compost bulk density, which is inversely related to total compost volume and particle size, was the characteristic most affected by the windrow turning frequency (Table 1). The bulk densities of windrows in series # 1 increased linearly during composting reaching a steady value of between 622 to 662 kg/m³ by day 81 (Figure 3). The bulk densities in windrows in series #2 also increased, but more slowly, reaching between 377 and 427 kg/m³ by day 81 and approaching the bulk density of windrows in series # 1 by day 136. The bulk densities of the piles showed a slower increase reaching 374 kg/m³ by day 136. Thus, turning frequency and turning equipment had significant effects on the compost bulk densities, while the L:G:B mix ratio had little effect on this parameter.

The initial C/N ratios of the three mixes used in this study are shown in Table 1. During composting, the C/N ratio of all of the mixes decreased from around 25 to between 12 and 19 and the total nitrogen content increased slightly due to the overall loss of carbon. All sections lost between 34 to 50% of their initial nitrogen during composting. Grass addition to treatments B and C had no significant effect on the final nitrogen content of the composts probably because of the fact that the decomposed leaves had nitrogen contents similar to that of the added grass. Windrows in series #1 had nitrate levels which were at or below optimum levels for greenhouse planting soils (Warncke and Krauskopf, 1983). Whereas, in less frequently turned windrows (series #2) and piles, the nitrate levels were unacceptably high (>240 ppm) in seven of ten treatments. The results indicate that nitrate levels tend to be lower in frequently turned windrows than in less frequently turned windrows or piles.

The total phosphorous and potassium levels were higher for mixes with higher

levels of grass. Saturation extracts of the final composts showed very low levels of phosphate indicating that most of the phosphorous present was in a bound form that was not readily accessible whereas in the feed stocks the phosphorous was soluble.

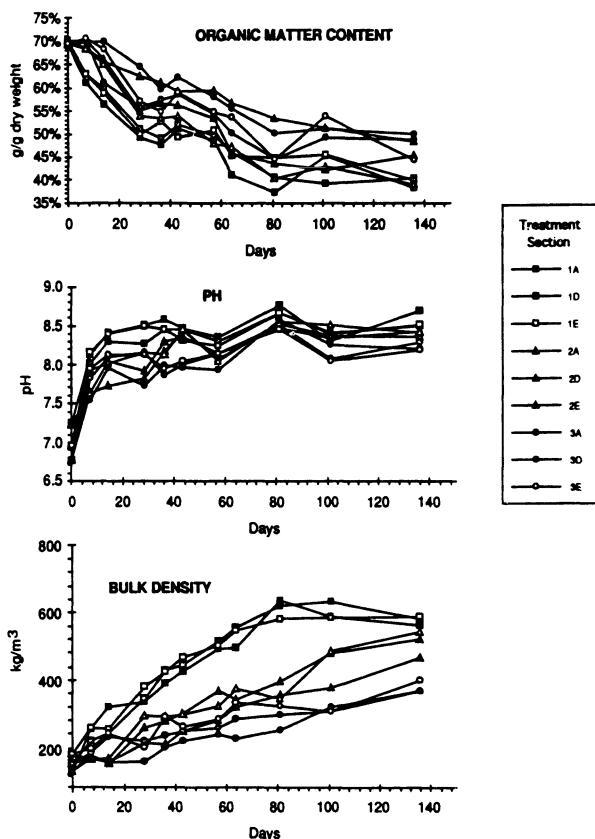


Figure 3 Organic matter content, pH and bulk density in windrows and piles. The treatments 1A through 3E are described in Figure 1. Values are averages of triplicate composite samples as described in Methods.

The total soluble salt levels for all the treatments (except 3E) were below the limit proposed by the U.S. Compost Council for general use compost of 5 mMho. Higher levels of grass corresponded to higher soluble salts contents in the final composts.

The results of compost stability measurements showed that the composts from all the treatments were stable by day 64 in that they exhibited oxygen uptake rates of less than 0.1 (mg O₂/g OM/h). By comparison, the initial feed stock mixes had oxygen uptake rates of between 1.0 and 1.8 (mg O₂/g OM/h). Cress seed germination and root elongation tests showed that the composts had no inhibitory effects.

Although the composts from all the treatments were stable and did not inhibit seed germination, the humification indices (non-humic carbon / carbon from

humic and fulvic acids) were greater than 0.4 in all but two composts (3D and 3E) indicating that the composts were less humified than expected. The amounts of humic acids in compost from the piles and windrows in series #2 were greater than the amount present in windrows in series #1. These results suggest that frequent turning may reduce the level of humic acid formation and humification during composting.

Conclusions

The results of this study indicate that the composts produced using a variety of leaf and grass mixtures, turning regimes and pile dimensions are similar in stability and the extent of humification, but there were some differences in bulk densities, nitrate levels and mineral concentrations. Another difference in the processing methods is the time required to produce a 'finished' compost product. although increasing the rate of composting comes with the trade-off of higher processing costs due to increased turning frequency.

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Optimisation of Anaerobically Digested Primary Sludge as a Composting Substrate.

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Introduction

The treatment of municipal wastewater in Australia results in the production of 250,000 dry tonnes of raw sewage sludge annually (Beavers, 1993). Two types of raw sewage sludge are produced. Primary sludge consists of settled organic matter from primary wastewater treatment. Secondary sludge is microbial matter produced from the activated sludge process in aeration tanks. In Western Australia, both types of raw sewage sludge are anaerobically digested to reduce pathogens, volatile solids and odour. The residual sludge is then blended for use in potting mixes, prior to land application.

Anaerobic digestion of raw primary and secondary sewage sludge does not reduce pathogens sufficiently to allow unrestricted use of the sludge (Beavers, 1993). Although anaerobic digestion reduces odour, the residual sludge is still odorous enough to pose a nuisance. The anaerobically digested sludge attracts vectors such as flies during storage which pose a health risk by spreading the sludge pathogens. The Water Authority of Western Australia (WA WA) wants to improve the quality of the sludge to allow for unrestricted use by further reducing pathogens through composting the sludge. Composting the sludge will also reduce odour and stabilise the organic matter fraction. The requirements for the different classes of sludge are given in Table 1.

Table 1 Classification of requirements for sludge land application (Beavers, 1993).

Class	Composting requirements	Use/Category
A (process to further reduce pathogens)	55 °C for 3 continuous days or 53 °C for 3 continuous days	unrestricted sale including agriculture, landscaping
B (process to significantly reduce pathogens)	minimum of 40 °C for 5 days with 4 hours in excess of 55 °C	agricultural land
C (no pathogen limit set)		Restricted use

Composting a mixture of anaerobically digested primary and secondary sludge amended with sawdust and woodchips on a laboratory scale indicated difficulties in attaining thermophilic temperatures for the required duration to reduce pathogens to acceptable levels (Qiao, In Progress). Apart from insulation effects, the main cause of this is likely to be the lack of bioavailable carbon for the composting microflora since most of this carbon is lost in the form of methane and carbon dioxide during anaerobic digestion (Qiao, In Progress), to 35 for composting (Witter and Lopez-Real, 1987).

The reducing conditions present during anaerobic digestion reduces sulphates in the sludge to sulphides. Composting the sludge oxidises the sulphides back into sulphates to produce sulphuric acid. This is likely to have resulted in acidification which inhibited the process (Qiao, In progress). This acidification is likely to occur during composting of anaerobically digested primary sludge (ADPS) with amendments. Bauxite refining residue (red mud) reduced acidification during composting of this mixture of primary and secondary digested anaerobic sludge (Qiao, In progress). Red mud is a highly alkaline clay consisting mainly of aluminium and iron oxides (Hofstede, 1994).

ADPS has a high moisture content (~80 %) and lacks the porosity to allow for aeration. The sludge moisture content must be reduced to 50–70% and porosity increased (Haug, 1980).

The aim of this research is to optimise ADPS as a composting substrate with amendments in order to further reduce pathogens, volatile solids and odour. This is in context of addressing the following deficiencies of the sludge as a composting substrate (Table 2).

Table 2 Sludge deficiencies as a composting substrate and amendment properties to improve sludge composting.

Sludge deficiency as a composting substrate	Desirable amendments properties
Low bioavailable carbon, low C/N ratio	High carbon content and C/N ratio
Acidification during composting	High pH and buffer capacity
High moisture content	Low moisture content
Poor porosity	Low bulk density (high porosity)

Materials and methods

ADPS and the following potential composting amendments (1) sawdust, (2) chaff, (3) green waste, (4) fine sand, (5) red mud and (6) wastewater skimmings were analysed according to Table 3.

Table 3 Analysis of primary digested anaerobic sludge and amendments.

Parameter	Method
Total oxidisable carbon to Kjeldahl nitrogen ratio (C/N)	sulphuric acid/potassium dichromate digest, colorimetric determination
Moisture content	drying at 105 °C for 8 hours
Bulk density	dividing measuring mass (kg) by measured volume (l)
pH	1 in 10 water extract, Orion pH probe and meter

The analysis provided information (Table 4) on the most suitable properties of each amendment for composting ADPS.

Table 4 Characteristics of ADPS and potential composting amendments.

Amendment	C/N ratio	Moisture content (%)	Bulk density (kg/l)	pH
Chaff	39	12	0.09	5.8
Green waste	55	49	0.26	5.9
Sawdust	467	30	0.28	4.5
Skimmings	91	49	0.89	5.4
Red mud		12	1.38	8.2
Fine sand		0	1.59	7.0
ADPS	7	79	1.09	8.3

Based on the information in Table 4 and the criteria in Table 5, the mixtures of potential amendments with ADPS shown in Table 6 were formulated.

Moisture content and C/N ratio of the composting substrate influence composting. Therefore all mixtures were formulated to achieve the same moisture content of 50 % and C/N ratio of 20. This was to minimise the influence of these parameters between mixtures. The ratio of organic amendments to ADPS was calculated based on information in Table 4 to obtain a C/N ratio of 20. The ratio of sand was then determined for moisture adjustment. Sand was used to adjust moisture content without affecting C/N ratio as it did not contain organic matter. Red mud amended with 10 % gypsum was selected for its alkaline pH and ability to reduce acidification during composting. Gypsum reduces excess alkalinity of red mud (Hofstede and Ho, 1989).

Green waste and chaff were selected primarily as bulking agents as these had a low bulk density. Wastewater skimmings and sawdust were selected primarily for C/N ratio adjustment as these had the high C/N ratios, ideal for raising the C/N ratio of anaerobically digested primary sludge. Wastewater skimmings consists mainly of grease (lipids), which could be a suitable energy source for composting since lipids contain more than twice the energy of combustion as carbohydrates and proteins (Haug, 1980). Sawdust and skimmings have poor structure, the skimmings being a putty like substance. Hence these amendments were used in conjunction with the bulking agents.

Table 5 Relevant characteristics of potential amendments to ADPS.

Potential amendment	Desirable characteristics
Chaff	bulking agent, moisture control, carbon source
Green waste	bulking agent, carbon source
Sawdust	moisture control, carbon source
Wastewater skimmings	carbon source
Red mud	pH buffer capacity and moisture control
Fine sand	moisture control

The mixtures were designed to enable the following comparisons to be made between potential amendments:-

- 1 skimmings and sawdust as carbon sources
- 2 sawdust and chaff as bulking agents/carbon sources
- 3 effect of red mud on composting pH

About 10 kg of material was used for each mixture. The mixtures were:

Table 6 Experimental compost mixtures with ADPS.

Mixture	Amendments and their ratios to anaerobic sludge
I	skimmings (0.38)/ red mud (0.13)/ ADPS (1.0)/ chaff (0.27)/ sand (0.24)
II	skimmings (0.38) / ADPS (1.0) / chaff (0.27) / sand (0.37)
III	sawdust (0.33)/red mud (0.15) / ADPS (1.0) / chaff (0.29) /sand (0.30)
IV	sawdust (0.33)/ ADPS (1.0)/ chaff (0.29)/sand (0.40)
V	skimmings (0.40)/red mud (0.14)/ ADPS (1.0)/ green waste (0.39)/sand (0.43)
VI	skimmings (0.40)/ ADPS (1.0)/green waste (0.39)/sand (0.57)
VII	sawdust (0.36)/red mud (0.15)/ ADPS (1.0)/green waste (0.39)/sand (0.48)
VIII	sawdust (0.36)/ ADPS (1.0)/green waste (0.39)/sand (0.63)

The mixtures were composted using the laboratory composting system developed by Hofstede (1994). Mixtures (I)–(IV) and (V)–(VII) were composted simultaneously. Temperature and the oxygen and carbon dioxide levels in the effluent gas were analysed continuously and the data recorded on a Hyundai 286 PC. Temperature control at 55 °C was facilitated by variation of aeration rates at 1 and 3 l/min by the PC.

The C/N ratio, moisture content, ash content and soluble organic matter was analysed at the start, and then every 4 days. Analysis of pH was initially on a daily basis for the first 7 days, then every 4 days.

Results and discussion

The results in Figures 1 to 4 indicate that thermophilic composting temperatures (55 °C and above) were maintained for longer when wastewater skimmings were used in place of sawdust. This could be due to the lipids in wastewater skimmings providing more energy per mole of carbon oxidised by the composting microflora than carbohydrates in sawdust.

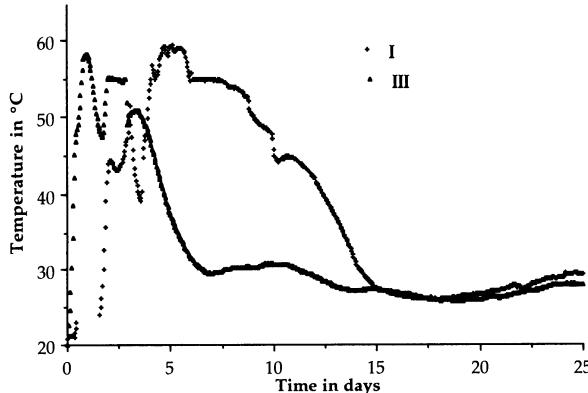


Figure 1 Composting temperature profile of mixtures I and III.

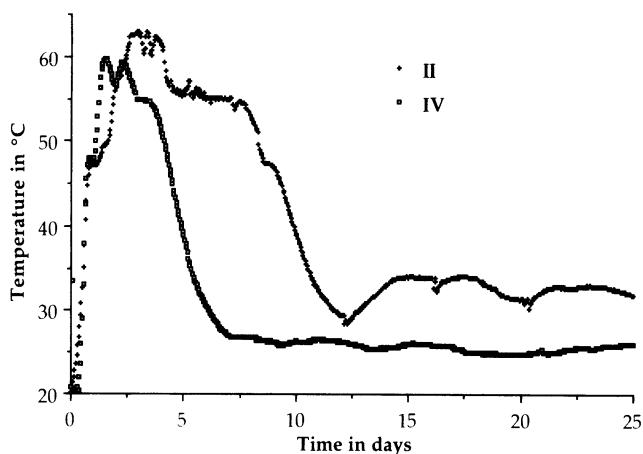


Figure 2 Composting temperature profile of mixtures II and IV.

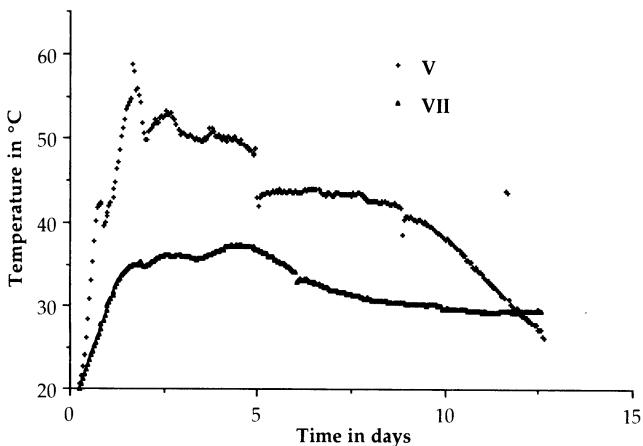


Figure 3 Composting temperature profile of mixtures V and VII.

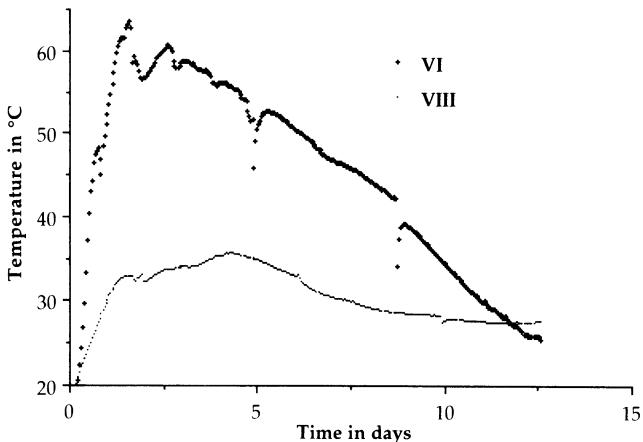


Figure 4 Composting temperature profile of mixtures VI and VIII.

The amount of carbon lost as carbon dioxide per kg organic carbon is shown in Table 7. One mole of carbon is lost as carbon dioxide per mole of lipids or carbohydrates oxidised during composting (Schulze, 1964). The data indicate that more carbon per kg organic carbon was lost as carbon dioxide during composting in the mixtures containing wastewater skimmings than in the mixtures with sawdust. This strongly suggests wastewater skimmings to be a better carbon source for the composting microflora than sawdust.

Thermophilic composting temperatures above 40 °C and 55 °C were attained for longer when chaff was used as a bulking agent (I–IV) in place of green waste (V–VIII) (Table 7). This indicates chaff to be a better bulking agent and/or carbon source than green waste. The green waste used consisted mainly of pine waste. The carbon in pine (softwoods) is lower in bioavailability compared to carbon in other lignocellulosic substrates (Lynch, 1993).

Table 7 Accumulative carbon loss as carbon dioxide during composting.

Day	Carbon in grams			
	I	II	III	IV
5	146	78	36	63
21	482	461	181	268
Day				
	V	VI	VII	VIII
5	164	83	30	45
21	482	454	177	220

Acidification of the sludge occurred during the first few days of composting as seen in Figure 5. However this acidification was not enough to inhibit the process since the pH did not fall below the optimum composting range (pH 5.5 to 8) (Bertoldi and Zucconi, 1987). The pH of all the other mixtures during composting were also within this optimum range.

Red mud increased composting pH and reduced acidification during composting as seen in Figure 5. Red mud had a similar effect on all other mixtures.

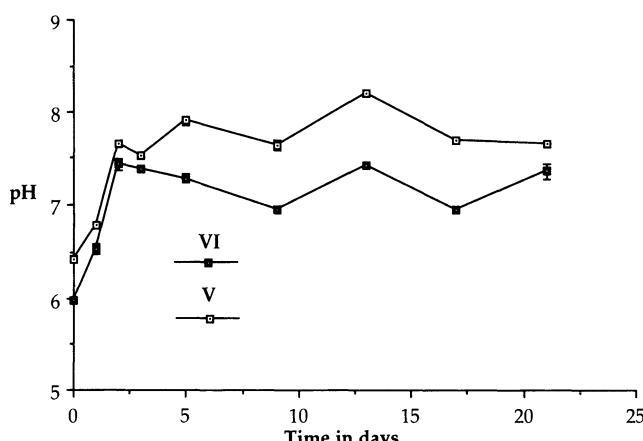


Figure 5 The effect of red mud addition on the pH of mixtures V and VI during composting.

Addition of red mud to the organic waste had the effect of reducing the duration of the thermophilic phase. This is shown in Table 8 where I, III, V and VII contain red mud. The high salinity of red mud (16 g/l) may have inhibited composting microbial metabolism.

Table 8 The duration of the thermophilic phase during composting (days).

Temperature	Duration in days			
	I	II	III	IV
≥ 55 °C	2.2	5.3	0.9	2.0
≥ 40 °C	6.9	8.6	3.8	3.8
Temperature	Duration in days			
	V	VI	VII	VIII
≥ 55 °C	0.2	3.4	0	0
≥ 40 °C	8.2	8.8	0	0

The organic matter content decreased in all the mixtures as a result of respiration in composting. This is inferred by the increase in ash content during composting (Table 9 and 10).

Table 9 Initial composting parameters of mixtures.

Mixture	Parameter			
	C/N ratio	% Moisture	% Ash	Soluble organic matter (mg O/L)
I	18	50.0	45.6	2000
II	18	48.7	47.4	2100
III	19	48.5	44.4	1200
IV	19	49.4	46.5	900
V	16	50.9	59.0	4600
VI	18	51.9	58.4	2400
VII	20	50.6	50.9	1100
VIII	18	50.2	57.2	1100

The reduction in soluble organic matter further indicates the increasing stabilisation of sludge with time (Haug, 1980). The decline in C/N ratio indicates greater carbon loss in relation to nitrogen.

Table 10 Final composting parameters of mixtures.

Mixture	Parameter			
	C/N ratio	% Moisture	% Ash	Soluble organic matter (mg O/L)
I	11	37.9	45.3	1500
II	11	37.7	52.4	1100
III	12	36.0	48.8	1000
IV	12	40.6	49.9	800
V	11	42.0	64.6	1000
VI	11	38.2	64.1	1300
VII	13.5	50.5	59.2	600
VIII	15	49.9	60.4	650

Conclusions

Class A compost could only be produced from ADPS when it was amended with one of the following mixtures: (1) skimmings, chaff and sand, and (2) skimmings, green waste and sand. Class B compost was produced from ADPS by composting with skimmings, chaff and sand with red mud amended with 10 % gypsum.

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The Production of Compost From Agricultural and Municipal Solid Waste.

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The project on which this paper is based is sponsored by Wrekin Council and the work is carried out at Harper Adams Agricultural College in the Crop and Environmental Research Centre and the Agricultural Engineering Department.

The aim of the project catalogued in this paper is to reduce the pollution problems associated with the direct application of agricultural slurries to land and the disposal of municipal organic waste to land-fill. Composting has the potential for reducing the levels of methane gas and harmful leachates produced in the land-fill process and for reducing nitrate pollution from agricultural land. The research programme is detailed below.

1. The production of a feasibility study for the composting of municipal green waste at a large scale central facility. January 1994
2. Small scale compost production from feedstocks including municipal green waste, poultry manure and the separated solids fraction of pig slurries. March to August 1994
3. Assessment of the compost markets (retail and wholesale) and the sales potential for a recycled waste compost. March to October 1994
4. Plant growth trials comparing composts from feed mixtures of agricultural and municipal organic wastes with multi purpose peat based compost. September to December 1994
5. The production of a technical report outlining the results of the previous months' trials, the analyses of the composts produced and the recommendations for further research or production as indicated by the results. December 1994

The initial Carbon:Nitrogen (C:N) ratio is recorded for each feed mixture for composting. The C:N ratio at the 12 to 14 week stage of composting is recorded and used as an indication of compost maturity. Throughout the compost production period temperatures have been recorded regularly and after approximately 12 to 14 weeks of composting a full water available peat compost analysis has been completed for each of the compost mixes. This analysis is carried out using standard procedures making the results easily comparable with the ADAS/MAFF Fertiliser Recommendations.

In an agricultural environment the resources necessary for large scale composting are, in most cases, readily available. Research such as this can open up the route to cooperative composting ventures between farmers and the community. Rural development is an issue of great concern at present and schemes such as this can contribute greatly to its success. On a broader scale waste management plays a part in every walk of life and there is increasing pressure upon the waste industries to clean up their act. An example of this is the Government target for the recycling of up to 25% of all municipal waste by the year 2000. Compostable organic waste comprises as much as 30% of municipal waste arising hence the removal of just a part of this from the waste stream can contribute greatly to this target.

This paper will outline the research findings and enter into some discussion of the problems faced in areas such as finance, location and product consistency.

Summary

A study carried out by the authors on behalf of Wrekin Council suggests that using the windrow system it is feasible to produce a medium grade compost, from municipal green waste / livestock manure mixtures, comparable to peat based products and suitable for general horticultural uses. The second stage of the project was the setting up of small scale compost production using straight green waste and mixtures of green waste with poultry manure and separated pig manure. The results are reported, as are growing trials set up to assess the value of the various composts compared with a peat based multi-purpose compost. The report concludes that whereas the various composts cannot compete with peat based multi-purpose composts for glass-house seed germination or first stage potting they are very suitable as soil conditioners or surface mulches.

Introduction

There are up to six thousand tonnes of green waste collected every year at recycling centres in the District of the Wrekin Council. At present all of this material is land-filled. The Government target of twenty five percent recycling by the year 2000 means that composting has become an option for the recycling of the organic fraction of municipal waste produced. At present it is believed that eleven percent recycling can be achieved by the year two thousand excluding the recycling of organics. If the green waste from the recycling centres is composted this figure is expected to rise to nineteen percent and expansion of the composting scheme to include the organic fraction of domestic waste would take the percentage recycled to a value well in excess of the target.

A large proportion of The District of the Wrekin Council is agricultural land with only one large town. The problem of nitrate pollution of ground water has

put pressure on farmers to reduce the application of fertilizers to the land and as more nitrate sensitive areas are defined the need for an alternative disposal route for manures and slurries has arisen.

The waste disposal problems of both farmers and the local authority may have a common solution in the form of composting. In a region where rural and town communities are in close proximity the logical solution is a central composting facility for the treatment of wastes from both sources.

The benefits of such a facility are considerable. The nature of green waste collected at recycling centres or civic amenity sites is, in the most part, dry and woody with high levels of carbon in the waste, while manures and slurries are wet with poor structure for aeration and high in nitrogen content. The combination of these two different types of waste gives a well balanced feed to a composting system. The equipment necessary for compost production is often expensive and the initial capital investment does not prove to be encouraging for organisations considering composting when a market for the final product is not guaranteed. Most farms are equipped with machinery such as fore end loaders and manure handling grabs which are capable of turning and mixing composting materials. In addition to this the area required for a composting site can be situated on farm with little resistance from nearby residents as the manures produced on site are more of a problem where odours are concerned than the feed materials to most composting facilities.

The project on which this paper is based has examined the possibilities for composting mixtures of municipal and agricultural wastes. Poultry manure and the separated solids from pig slurries were mixed with equal proportions of municipal green waste and a third feed of green waste alone was also prepared.

Small scale composting trials

Materials and Methods

The site selected for the small scale composting trials was a roofed manure storage bay with only one open face. The green waste was delivered in skips to the site and shredded using a small council owned Christmas tree shredder. The manures were produced on the working farm at Harper Adams College in the poultry and pig units. Three compost heaps were set up after preparing the mixtures with a fore end loader. Each heap was formed to approximate a windrow shape. The mass and volume of the feed materials in each compost heap are given in table 1.

Each heap was composted for a period of between 12 and 14 weeks. Temperatures were recorded daily using a modified temperature probe which could be inserted to a depth of approximately 0.3m into the compost heap. Three temperature points on each of the long sides of each heap and one point at each end and in the centre of the heap were selected giving nine temperature readings for each heap daily.

Table 1 Mass and volume of feeds to small scale composting trial.

Heap No.	Component	Mass (t)	Volume(m ³)	Total Wt.	Total Vol. m ³
1	Grn. Waste	0.94	2.35	1.75	3.293
	Poultry	0.81	0.94		
2	Grn. Waste	1.57	3.93	1.57	3.93
3	Grn. Waste	0.88	2.20	1.61	3.23
	Sep. Solids	0.73	1.03		

Grn. Waste – Green waste from recycling centres.

Poultry – Poultry Manure.

Sep. Solids – Separated solids from pig slurries.

The composting material was turned weekly or fortnightly depending on the temperatures achieved. Turning was carried out by hand, using a garden fork and shovel, ensuring that the material was well mixed each time and that the material on the surface was turned into the centre of the reformed heap.

Moisture was added to the compost heaps when appearance and temperature were judged to require it.

Analysis

The carbon to nitrogen ratio of the feed materials to each of the compost heaps was analysed using dry combustion to determine carbon content and the Kjeldahl method for the determination of the total nitrogen percentage.

The initial moisture content of each feed mixture was also recorded.

The composts were analysed for carbon to nitrogen ratio at the 12 to 14 week stage of composting. At this time also, a water available peat compost analysis was carried out for each of the composts to determine the nitrogen, potassium and phosphorous contents, pH and conductivity. The results achieved can be compared with the loamless compost indices given in ADAS Reference 209(Anon. 1994).

Results

The initial carbon to nitrogen ratios and moisture contents for the compost heaps are given in tables 2 & 3. The C:N ratio for compost heap No.1 (green waste and poultry manure) was lower than the optimum range of 26 to 35 (Poincelot 1972) for composting. It is assumed that this is due to the high nitrogen levels found in poultry manure. The C:N value for the green waste feed for heap No.2 was higher than the reported optimum range due to the high wood content of the material. The best balanced feed for composting of those selected was that of heap No.3 (green waste and separated solids from pig slurries), with a value well within the optimum range.

The moisture contents of both heaps 1 & 2 were below reported optimum values of between 50 & 60 percent (Golueke 1972), while heap No.3 had a moisture con-

tent of 60.55% which, although just outside this range, is near ideal for the structure of the mixture.

Table 2 Carbon to Nitrogen Ratio's of feeds to Small Scale Composting trials.

Compost heap No.	Carbon (%)	Nitrogen (%)	C : N Ratio
1	36.62	1.754	20.8
2	50.67	1.370	37.0
3	44.63	1.415	31.5

Table 3 Moisture Contents of Feeds to Small Scale Composting Trials.

Compost Heap No.	Sample Weight (g)	Dry weight	Moisture (%)
1	334.66	234.81	29.83
2	215.64	167.04	22.54
3	286.35	97.25	60.55

The product carbon to nitrogen ratios of the composts produced are given in table 4.

The main findings of the water available peat compost analysis carried out on each of the composts produced in the small scale production trials are given in tables 5 to 8 and the indices referred to in these tables are the ADAS indices for loamless composts from the Fertilizer Recommendations for Agricultural and Horticultural Crops Ref. 209 (Anon. 1994).

Table 4 Product Carbon to Nitrogen Ratios.

Compost heap No.	Carbon (%)	Nitrogen (%)	C : N
1	18.06	1.85	9.8
2	23.5	1.94	12
3	23.4	2.61	9

Table 5 Nitrogen content of composts produced.

Compost Heap No.	Nitrate N (mg/l)	Ammonium N (mg/l)	Total N (%)
1	277	304	1.85
2	3	2	1.94
3	1	3	2.61

Table 6 Potassium content of composts produced.

Compost Heap No.	Potassium (mg/l)	Index
1	3300	9
2	711	7
3	787	7

Table 7 Phosphorus content of composts produced.

Compost Heap No.	Phosphorus (mg/l)	Index
1	325	9
2	84	8
3	37	5

Table 8 pH and Conductivity of Composts Produced.

Compost Heap No.	pH	Conductivity (μS)
1	8.29	850 (Index 6)
2	8.2	202 (Index 1)
3	9.2	439 (Index 3)

Table 9 shows the nutrient values for the multi-purpose peat based compost which is used in the growing trials discussed in the next section.

Table 9 Nutrient value, pH and conductivity of Shamrock Multi-purpose Compost.

	mg/l	
Nitrate N (mg/kg)	72	15.84
Ammonium N (mg/kg)	117	25.74
Water Soluble Potassium (mg/kg)	94	20.68
Slow Release Potassium (mg/kg)	86	18.92
Total Potassium (mg/kg)	180	39.60
Phosphorus (mg/kg)	202	44.44
pH	5.5	
Conductivity (μS)	240 – 370	

(Source: Shamrock Horticulture, Bristol, UK).

Growing Trials

Materials and Methods

The aim of the growing trials was to compare the performance of the composts produced in the small scale trials with that of a peat based multi-purpose compost using various plant species to assess different aspects of plant growth. The composts produced, however, required some pretreatment before commencing with the trials as they were all very dry and had poor water retention qualities. The composts were sieved to <5mm to remove the large particles and treated with a selection of wetting agents. Cress seeds were planted in the wetted composts and the percentage germination and appearance of the cress grown were used as the basis for selecting the most successful wetting agent. Aqua Gro 160 was found to give the highest percentage germination and the healthiest plants and the composts produced in the small scale trials were all treated with this wetting agent before the trials began. A smaller number of plants were planted in the untreated composts in order to assess whether any of the plants were adversely effected by the wetting agent.

The plants selected for the trials were cress, tomatoes (Tiny Tim) and wheat (Mercia). The germination, dry mass yield and root length.

Germination: Fifty cress seeds were planted in each compost and the plants produced were counted after one week.

Dry mass: Tomatoes and wheat grown in each of the composts were dried at 65°C to a constant weight in order to draw a comparison between the mixed waste composts and the multi-purpose compost.

Root length: This was measured using a Delta T scanner for tomatoes and wheat produced in each of the composts.

The general appearance of the plants grown in each of the composts were compared and are discussed in the following discussion.

Results

The tables in this section show the response of the plants selected in the growing trials.

Table 10 Percentage germination of cress seeds achieved in each compost.

Compost Type	Percentage Germination
Green waste, poultry manure + Aq.Gro	0
Green waste + Aqua Gro	100
Green waste + sep. solids + Aq.Gro	88.0
Shamrock Multi-purpose	92.0
Control (No wetting agent)	
Green waste and poultry manure	0
Green waste only	90.0
Green waste and sep. solids	85.0

Table 11 Percentage survival of seeds planted

Compost Type	Percentage survival	
	Tomatoes	Wheat
GW+Poultry+AG	0	0
GW + Aqua Gro	62.5	100
GW + Pig + AG	0	50
Multi-purpose	87.5	87.5
Controls (No wetting Agent)		
GW + Poultry	0	0
GW only	33.3	33.3
GW + Pig	0	33.3

Table 12 Dry mass of roots and herbage for tomatoes grown in trials

Compost	Total Dry Mass (g)	Dry Mass of Roots (g)	Dry Mass of Herbage (g)
Shamrock	2.89	0.93	1.96
GW + Aqua Gro	0.29	0.07	0.22
Green Waste Only	0.87	0.22	0.65

Table 13 Dry mass of roots and herbage for wheat plants grown in trials

Compost	Total DM (g)	Roots DM (g)	Herbage DM (g)
Shamrock	1.09	0.36	0.73
GW + Aq.Gro	0.49	0.10	0.39
GW + Pig + A.G	0.13	0.03	0.10
GW Only	0.70	0.21	0.49
GW + Pig Only	0.06	0.02	0.04

Table 14 Root lengths and diameters measured using Delta T Scan

Compost	Root length	Root Diameter
Tomatoes		
Shamrock M/P	41671 mm	0.41 mm
Green Waste + Aqua Gro	720 mm	0.345 mm
Green Waste only	3863 mm	0.89 mm
Wheat		
Shamrock	7980 mm	0.44 mm
Green Waste + Aqua Gro	8341 mm	0.29 mm
GW + Pig + Aqua Gro	1352 mm	0.25 mm
Green Waste only	490 mm	0.17 mm

GW – Green Waste, Pig – Separated solids from pig slurries, Poultry – Poultry manure,

AG – Aqua Gro 160 wetting agent, Shamrock – Shamrock peat based multi-purpose compost.

Discussion

As already stated the composts produced during the trials were dry in appearance and had very poor water retention properties. A substantial amount of the wood in the mixes was still visible and the coniferous green waste entering the composting process was barely broken down, having altered in colour only.

The manures in the mixes were well broken down and no problems were experienced with odours apart from the release of ammonia when turning the composts in the very early stages.

The carbon to nitrogen ratios of all of the composts were close to the figure of 10 which has been suggested to represent a stable compost, however this theory is unreliable and more reliable methods of stability determination are always being sought (Grasser 1985). Other methods available for stability determination are degree of humification, microbiological assays and spectroscopic analysis.

Green waste and poultry manure compost.

The compost produced from green waste and poultry manure contained amounts of available nitrogen well in excess of all of the other composts produced and the multi-purpose compost. The same was also true for the levels of potassium and phosphorous. During the growing trials this compost achieved 0% germination of all seeds planted. It is possible that the compost was unstable and continued to degrade through the growing trials producing ammonia during the breakdown. Ammonia is phytotoxic in very small amounts and may have been responsible for the failure of the seeds planted to germinate. However, the same effect would also be expected in the compost produced from green waste and separated solids if this were the case and the germination properties of this compost were apparently less inhibited.

Another explanation for the lack of plant growth in the compost produced from green waste and poultry manure is the high conductivity of the material. The material had a higher conductivity than that of most potting composts (400 – 700 μS Neil Bragg, Bulrush Composts) which are generally diluted before use.

Conductivity is a measure of the soluble salts present in the material which, when dissolved, cause an osmotic effect. Osmosis is not a problem when the moisture levels in the material are high, but when there is less moisture present the effect is damaging to roots and seeds (Russell 1988 Ed.).

Green waste compost

The compost produced from green waste had low levels of available nitrogen when analysed, however, during the growing trials it appeared that the compost continued to degrade and produce plant available nitrogen. The plants produced in the trials were stunted and yellower than those grown in the multi-purpose compost but in the later stages the plants remained the same colour while those in the multi-purpose compost became yellow very rapidly. This supports the theory that the compost was unstable and producing nitrogen in available forms throughout the trials although a greater supply of the nutrient would have produced larger more healthy plants. The potassium and phosphorous content of the compost was greater than that of the multi-purpose compost.

Green waste and separated solids from pig slurries compost

The conductivity of this compost was slightly higher than for most seeding and multi-purpose composts (150 – 250 μS Neil Bragg Bulrush Composts). This appears to have been of little detriment to the seeds planted although the germination performance was poorer than that for the green waste compost which had a conductivity within the range for seeding and multi-purpose composts. The available nitrogen in the green waste and separated solids compost was very low when analysed although the total nitrogen content was much higher than the other composts produced. The plants grown in this medium were stunted and very dark green in colour which again suggests an unstable compost where large amounts of nitrogen were being made available during the growing trials. The potassium content was higher than that of the multi-purpose compost and the phosphorous content was slightly lower.

Marketing

The results of surveys of both the general public and garden centres indicated a high level of support for a compost produced from refuse in the local area. The quality of compost expected is equal to that of available peat based composts and the cost would also be expected to be similar. The only problem which became apparent in the marketing of such composts is the fact that the majority of garden centres only stock a certain amount of different composts leaving little room for a new product. A popular option was the sale of refuse derived composts directly from the resource recycling centres where the refuse itself is collected.

Conclusions

It can be concluded from the results produced that a green waste compost would not achieve the quality of those peat based composts available on the market at present though further research into different blends and proportions of agricultural and green wastes could lead to product improvement. Another option in the marketing of green waste compost is its sale as a soil conditioner for which the specifications are more flexible. A fine and coarse grade mulch could also be produced using the more bulky wood fraction of the material. This would reduce the necessity to recycle the larger wood pieces remaining in the compost and prevent a large build up of this type of material within the process.

The use of agricultural wastes can improve the nutrient value of composts produced and further work on the proportions and types of waste available could produce a material which can compete with peat based growing media.

Product consistency is a problem with green waste as the types of material collected vary seasonally. The sale of the product as a mulch or soil conditioner allows for some freedom regarding the consistency of the product but is not as lucrative a market. However, in the case of a local authority the aim is to achieve a self supporting operation and this type of market could quite easily meet the financial requirements for site management and operation particularly if the site is on farm.

The problems of finance and location for a large scale composting facility can be approached more successfully where a joint venture can be established between farmers and the local authority. This type of partnership reduces the requirement for capital investment and reduces the possibility of objections to the site from local residents.

Unfortunately at present in the UK the cost of land-fill in most areas does not encourage composting as the cost of such an operation exceeds gate fees for the material to be land-filled, however new land-fill levies and steadily increasing gate fees are inspiring many local authorities to examine the possibilities of composting.

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Manufacture of Artificial Soil by Composting Coal Fly Ash and Bottom Ash with Poultry Litter

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Abstract

This paper describes the progress of studies of the treatment of coal ash mixed with organic by-products by a compost process as a means of converting ash to a desirable commercial product. Mixtures of fly and bottom ash, broiler chicken litter manure, sawdust and pine bark were successfully composted during the winter of 1994. The recipes and compost procedures for production of the manufactured soils are described. The physical, biological and chemical properties of the manufactured soils are being studied and initial results are presented.

Introduction

The disposal of ash, sludge and other solid by-products from agricultural, industrial or municipal systems has often been a segregated problem in which each waste is independently disposed or utilized. Recycling these by-products as an amendment to agricultural and horticultural soils has rapidly become the avenue of choice because of the vast volume of soil available as a treatment media. Although these by-products have been mixed with natural soils to improve one or more soil characteristics there is often an accompanying degradation of some other soil or soil water characteristic that results in a need to regulate the amount of by-product applied to the soil.

Investigations with natural soils have shown that the addition of coal ash can result in changes in soil physical and chemical structure. Coal ash has been applied to soils to adjust soil pH (liming material), add plant micronutrients, increase porosity in fine textured soils (bottom ash) and increase the percent of fines in a coarse textured soil (fly ash). The degree of success of these efforts has been mixed because of the different ash products used, the soil types amended, application

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practices, and the type of analyses made. Of particular interest is the environmental impact of coal ash on the soil and plant system. Positive impacts are the possible improvements in soil structure and the addition of plant needed nutrients. Negative impacts are the migration of unwanted heavy metal elements into the crop and into soil water systems.

Soil and soil water studies indicate that metal migration from alkaline fly ash was insignificant after three years of weathering. However, warm water soluble arsenic, boron, selenium and chromium were mobile (Bhumbra, et al. 1991). Metal adsorption on coal fly ash was temperature and pH dependent with different optimum conditions for different elements (Viraraghavan, et al. 1991). Column leachate studies defined rapid release of adsorbed metals but could not define long term release through particle decay. Many elements that were expected to be released were below detectable limits. Leachate quality was directly related to coal ash quality (Kuryk, et al. 1985). No reference was made to possible bio-availability of the soil adsorbed elements.

An ideal situation would exist if coal ash and organic by-products were treated to result in a manufactured soil product (MSP) that could be added to or replace a natural soil without concern for deleterious effects. Aerobic composting of mixtures of coal ash and organic waste introduces microbial processes which can change the chemical form and bio-availability of organic and soluble ash constituents. Recent advances in organic matter stabilization through aerobic compost processes have demonstrated that co-mingled wastes from various sources can be advantageously treated (Harrison, 1992, Rynk, 1992). The resulting stable organic product (compost) has desirable horticultural properties but also reflects the elemental character of the raw by-product input. Compost can be improved through selection and mixing of raw by-products to augment desirable and dilute undesirable chemical characteristics.

The opportunity exists to formulate constituent quality and quantity to derive a desirable soil product. The manufacture of artificial soil utilizing mixtures of coal ash and organic agricultural by-products treated by a compost process is a means of reducing the volume of ash stored in landfills. The soil product should have commercial value to warrant the expense of production. This value may derive from avoided storage expense as well as from product sales income.

Objectives

The focus of this study was to develop manufactured soil products from coal ash and organic by-products. Rather than simply mixing ash with compost it was desirable to determine if mixing ash with materials before composting could provide binding of heavy metal elements into organic forms which could reduce their availability for crop uptake. As a first step, this paper describes the development of mixture recipes for composting with coal ash and the preliminary definition of the resulting compost.

Method

Compost ingredients (table 1) were broiler chicken litter manure (for nutrients), pine sawdust (for carbon) and pine bark chips (for bulk and porosity). Coal fly ash provided some organic carbon. Bottom ash provided some structure. Fly ash had been treated to adjust pH toward neutral as a normal management practice by Delmarva Power.

Table 1 Compost Ingredienty Characteristics

Ingredient	Organic Carbon %(dwb)	Nitrogen %(dwb)	C:N ratio	Moisture %	Bulk Density kg/m ³ (wwb)
Broiler litter	32.6	4.06	8	37	609
Pine bark	56.7	0.42	135	42	237
Sawdust	57.7	0.12	481	37	252
Fly ash	3.1	0.04	78	27	800
Bottom ash	0	0	—	na	700

The recipes of optimum mixes of these ingredients were selected using the compost recipe making computer software CRM (Brodie, 1994). Volume based recipes were used to simulate actual field conditions where mixture measurements would be made in truckloads and loader buckets rather than by weight. Six recipes representing a range of from zero to 67 percent fly ash by dry weight were used in the compost trials (table 2). A seventh recipe was developed on site utilizing bottom ash and materials that were left over after constructing the six recipes.

Table 2 Compost Mix Recipes for Coal Ash Trials

trial number	volume ratio* wet wt.	volume % ash wet wt.	% mass ratio* dry wt.	predicted mix C:N ratio	%TKN dry wt.
1	1:1:1:1**	25	31:11:13:45	18	2.4
2	1:2:1:1	20	27:20:11:42	23	1.2
3	1:1:1:1	25	30:11:13:45	19	1.3
4	1:3:3:0	0	30:32:13:45	35	1.4
5	1:1:4:1	14	22:8:36:34	34	1.0
6	1:4:2:3	30	13:18:11:58	35	0.6
7	1:2:3:4	40	11:8:14:67	34	0.5

*Ratio of ingrdients in the order: Broiler litter: Pine bark: Pine sawdust: Coal ash

**Bottom ash used in this recipe; fly ash in all others

The materials were mixed into conical piles using a bucket loader in an open field. The piles were turned, mixed an reshaped with a bucket loader twice a week for the first three weeks; twice in the next month; and then once monthly for six months. After 8.5 months composting was considered complete. The compost was then screened using a 1.27 cm vibrating screen.

The ingredients, representative mixtures and final composts were analyzed for chemical constituents using standard procedures by a contract laboratory. Public

perception of the physical quality of the compost was indicated through comments by randomly selected individuals. Determination of ash compost qualities affecting potential uses will be part of future studies.

Results and Discussion

Four compost mixes (trials 4 to 7) were made in 15 m³ piles on December 28, 1993 in a blowing snow squall with ambient temperature at -4 degrees C. The sawdust was warm and steamy. Rain had wetted the materials beyond the moisture content of the samples taken two weeks earlier. No water was added to the mix during construction because of the weather.. The ash was frozen and in large chunks. Compost piles were made by layering bucketfuls of the individual materials for later mixing by lifting and dropping with a loader bucket. The remaining trials (1 to 3) were made in 20 m³ piles on January 10, 1994 in better weather but, the ash was still frozen. Trial 1 contained bottom ash and trials 2 to 7 were made with fly ash.

Samples from the initial ingredient mixture of trials 4 to 7 were taken after the first mixing. Each sample was a composite of eight sub-samples taken throughout a pile. Chemical analysis of these samples was intended to demonstrate whether the desired C:N ratio was obtained and define the initial heavy metal concentration (table 3). The C:N ratios varied somewhat from the predicted ratio in trials 4, 5 and 7. However, trial 6 showed a C:N ratio almost three-fold greater than the predicted ratio. The variation was a consequence of the materials mixed, the mixing process, and analysis procedures. It was very difficult to obtain true representation from a large volume of heterogeneous materials that were mixed in the field with a bucket loader. Laboratory procedures which grind the large particles to provide a homogeneous sample introduce material into the analysis which may not enter into the compost reaction and may be removed from the final compost by screening. Because of these conditions the analysis of an initial mix may have little value.

Compost temperature was measured at four locations and at two depths in each trial prior to compost mixing during the first twelve weeks of the project. Average temperatures for each trial (figure 1) can be used to describe the compost reaction. All trials eventually produced heat.

Trial 4 contained no ash and was considered the control. The ratios of ingredients provided for an optimum compost mix. The compost temperature increased rapidly considering the cold weather and maintained a temperature near 70 degrees celsius. Trial 5 contained low ash and high sawdust and the temperature response was very similar to trial 4. The high proportion of sawdust provided desirable amounts of available carbon while the low ash content allowed the maintenance of porosity. The recipe of trial 4 included a high proportion of bark chips which may not have been necessary when compared against the response of trial 5.

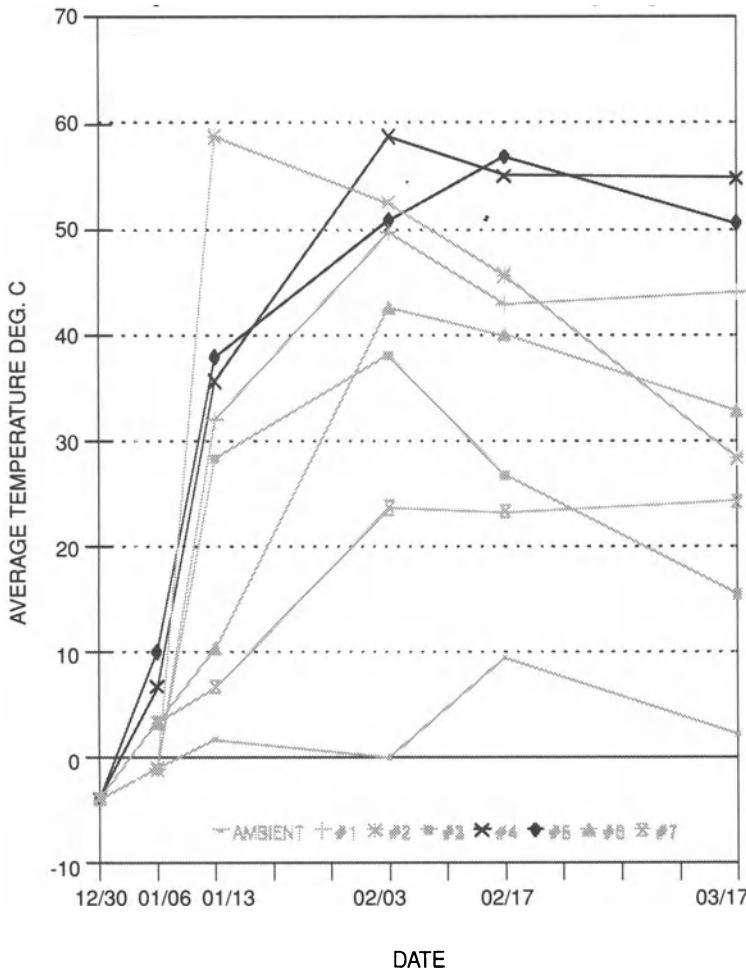
Table 3 Coal Ash Compost Initial Mix Chemical Content

	trial 4	trial 5	trial 6	trial 7
moisture %	56	46	48	42
pH	7.2	7.8	7	7.5
C:N	31.5	47.4	103	41.8
major constituents % dwb				
TOC	52	46	34	23
TKN	1.65	0.97	0.33	0.55
NH4-N	0.55	0.32	0.21	0.21
organic N	1.1	0.65	0.12	0.34
phosphorous	0.77	0.4	0.72	0.47
potassium	1.01	0.38	0.47	0.36
volatile solids	90	78	58	39
other constituents mg/kg dwb				
aluminum	800	5,520	7,300	7,200
arsenic	19.1	31.0	51.6	50.4
boron	20	19	26	23
cadmium	U	U	U	U
chromium	U	15	35	35
copper	166	85	210	114
manganese	203	111	258	124
mercury	0.11	0.16	0.2	0.2
selenium	0.21	4.65	7	8.98
sodium	3,600	1,900	2,700	1,900
sulfur	3,200	3,100	3,100	2,700
zinc	158	94	200	119
U	undetectable			

Trial 7 contained the most fly ash and was slow to heat. A relatively low temperature of around 23 degrees celsius was maintained. Probable cause comes from the high ash content which was frozen at the start. Through most of the winter the ash was very wet and compact which limited porosity and may have limited oxygen concentration in the pile. The wet ash made sticky balls of mixed material. Trial 6, which contained high ash content but with more bark chips than trial 7, was slightly more rapid in heating and maintained temperatures around 40 degrees celsius. The combination of more bark and less ash improved the porosity of the pile which may have improved oxygen availability. Like trial 7, the ash made sticky balls.

Trial 3 contained equal volumes of all ingredients. Temperature increased at about the same rate as the best mixes but slowed at 28 degrees to reach a maximum of 38 degrees celsius then began a rapid decline. This mix had a low C:N ratio and the compost may have simply become carbon deficient. Ash was in sticky balls. Trial 2, identical to trial 3 but with twice the bark chips, showed the most rapid increase in temperature to a high of 59 degrees celsius within the first week after construction. This performance may be in response to the availability of oxygen as a result of the increased porosity compared to trial 3. Temperature constantly declined after this point, possibly in response to the low C:N ratio as in

trial 3. Trial 1 is identical to trial 3 except that bottom ash was used rather than fly ash. Temperature closely followed but was always greater than that of trial 3. The temperature decline also followed that of trial 3 but then leveled. A possible explanation is that the bottom ash like sand allowed the infiltration of rain water to greater depths in the pile which could have stimulated microbial activity. Trial 1 always appeared more moist than the other trials as indicated by hand-squeeze methods. However, percent moisture was not measured during the process.



Compostmix ratios by volume where: p=poultry litter; b=pine bark; a=sawdust; j=fly ash; ba=bottom ash and the trials are: (1) 1p:1b:1a:1ba (2) 1p:2b:1a:1j (3) 1p:1b:1a:11 (4) 1p:3b:3s:0j (5) 1p:1b:4a:1j (6) 1p:4b:2a:3f (7) 1p:2b:3a:4f

Figure 1 Temperature Response of Coal Ash Compost Trials

Generally, all trials had little odor during composting. Odors could be described as woody or earthy. During turning some ammonia odor was perceptible from trials 1, 2 and 3. Trial 1 still had an identifiable chicken manure odor during final

screening. The low C:N recipes used for trials 1, 2 and 3 were expected to produce odor during the first several weeks of composting. However, the cold air may have slowed the compost process as well as dulled the observer's sense of smell. Using low C:N recipes in warmer weather may increase both the odor release and the heat buildup in the compost.

Approximately 3/4 of the large particle pine bark was recovered during screening and can be recycled in new compost mixes. This would indicate that a majority of the carbon in the bark chips did not enter into the reaction and the actual C:N ratio of the mix was lower than indicated either by mixing theory or initial mix chemical analysis.

Table 4 Coal Ash Compost Chemical Content

	trial 1	trial 2	trial 3	trial 4	trial 5	trial 6	trial 7
moisture%	34	28	36	38	30	21	18
pH	8.7	6.9	8.3	6.6	6.2	6.6	6.6
bulk density kg/m ³ wwb	718	718	740	587	652	674	761
Cation Exchange Capacity meq/100g	12.1	13.2	11.8	17.8	17.5	11.4	7.4
C:N	20	16	13	17	21	31	26
major constituents dwb							
TOC	14	12	13	17	14	12	6.6
TKN	0.67	0.72	0.71	0.95	0.67	0.38	0.25
NH ₄ -N	0.14	0.02	0.11	0.06	0.03	0.02	0.02
Organic N	0.53	0.70	0.60	0.89	0.64	0.36	0.23
phosphorous	0.68	0.75	0.81	0.67	0.67	0.42	0.35
potassium	0.32	0.34	0.42	0.35	0.61	0.24	0.19
vs	24	21	23	30	24	20	11
other constituents mg/hg dwb							
aluminum	4,720	7,200	7,300	4,090	5,140	7,600	8,400
arsenic	16	26	38	16	29	41	45
boron	17	26	26	19	22	20	18
cadmium	0.5	0.5	1	1	1	0.5	0.5
chromium	15	30	25	20	15	20	30
copper	157	160	170	148	135	106	79
manganese	196	187	203	208	172	128	110
mercury	0.4	0.16	0.19	0.12	U	U	U
selenium	1.6	7.2	9.1	3.6	7.3	7.3	7.7
sodium	1,400	1,400	1,900	1,500	1,300	900	600
sulfur	5,200	6,200	6,300	8,700	5,700	5,700	5,300
zinc	165	165	170	154	144	111	88

U = undetectable

Results of the metal and nutrient analysis of the screened finished compost are shown in table 4. Screened finished compost had been sufficiently mixed to provide a uniform mass. Samples taken for analysis were considered representative of the mass. Compared to trial 4 which contained no ash, ash compost was: more dense; had a lower cation exchange capacity; contained less organic carbon, nitrogen, and volatile solids; and contained more aluminum. Fly ash compost contained

more arsenic than bottom ash compost and trial 4. Arsenic is an ingredient in broiler chicken feeds and is evident in the manure compost of trial 4. The concentrations of other elements were varied among the trials and represent contributions from all of the ingredients.

Some elements are considered contaminants which affect the usefulness of the compost. Compost contaminant standards vary among states and countries with regulations ranging from the very lax to the very stringent and as much as a ten fold difference in allowable limits of concentration for a single element (Harrison and Richard, 1992). This makes the assessment of compost quality somewhat difficult. Additional studies are necessary to define the bio-availability of these elements.

Mature composts are expected to have a C:N ratio of near 15. The C:N ratios of composts from trial 6 and 7 at greater than 25 are sufficiently high to indicate that the compost process was incomplete possibly because of a nitrogen deficiency.

The production of compost for a specific market requires that the compost meet certain expectations of performance and appearance (Brodie, et.al. 1994). As one measure, the compost was presented to ten people for consumer perception of the product. They were allowed to smell, feel and comment on the screened compost both in a dry and wetted state without knowledge of the origin of the compost. A summary of comments is presented in table 5. In general, people held different attitudes as to what was acceptable or desirable. The gray color was less desirable than the dark brown. The fineness of the compost with high amounts of fly ash was acceptable in the dry condition but produced an undesirable tight mix after wetting. Some believed that the cement like feature would not be a problem when compost was mixed with natural soil. Bottom ash compost was defined as gritty but, generally received good comment.

Table 5 Compost Acceptance

trial	odor dry	color dry	texture dry	odor wet	texture wet	water acceptance	rating overall
1	slight manure	brown -black	sandy	slight manure	mushy friable	fast	2
2	earthy soft	gray hard	powdery puddles	none	firm	slow	5
3	earthy tangy	gray- brown	powdery soft	slight rotten egg	mushy friable	moderate	3
4	earthy	brown	lumpy humus	none	very	fast friable	1
5	earthy gray	dark soft	powdery friable	none puddles	soggy	very slow	4
6	sweet gray	light soft	powdery hard	none slow	tight	extremely	6
7	moldy earthy	light gray	powdery soft	none hard	tight slow	extremely	7

NOTE. words are those of the persons ranking the product – rating 1 desirable to 7 undesirable

Summary

The coal ash compost trials conducted at Indian River Power Station during the winter of 1993–94 showed that mixtures of poultry litter, pine bark, sawdust and coal ash can be composted under difficult winter conditions. Recipes with up to 40 percent fly ash by volume (67 percent dry mass) and 25 percent bottom ash by volume (45 percent dry mass) in piles mixed with a bucket loader produced finished compost in 8.5 months. High ash content reduced the maximum temperature attained by the compost mass as compared to low ash content compost. High ash composts had greater levels of heavy metal concentrations than low ash composts. Composts were given mixed reviews by a panel based on physical properties. Additional studies of ash compost quality are necessary to allow assessment of potential uses; to determine to what extent the ash enters into the reaction, and if the reaction binds chemical elements which might leach from the ash.

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Composting of a Mixture of VFG Waste and used Paper Diapers

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Abstract

Waste disposal in the Netherlands has come under great pressure in recent years. The policy of the Dutch government is directed towards radically restricting on the domestic waste to be dumped on the basis of social, spatial and environmental-protection considerations.

At present, however, paper diapers are thrown into the rubbish bin (grey container) and then dumped or incinerated. The used paper diapers largely consist of pulp and are therefore in principle suitable for being composted together with normal Vegetable, Fruit and Garden (VFG) waste.

Various studies on the compostability of a VFG waste/paper diaper mixture have demonstrated that a good-quality compost can be produced from it.

However, the used paper diaper also contains approx. 15 wt.% plastic film in addition to the compostable material. This plastic diaper film must not end up in the final product. It is therefore anticipated that an adjusted process route will be necessary for composting VFG waste/diaper mixtures.

The Department of Environmental Technology of the Institute of Environmental and Energy Technology (TNO-ME) in collaboration with the Research and Development Department of VAM has carried out a study to develop an adjusted process route for composting VFG waste/diaper mixtures. The point of departure for this adjusted process route is the composting process applied at VAM. The following process steps have been added to this VAM process and studied.

Prior to composting:

- Screening of the VFG waste/diaper mixture over a 60 mm screen to remove all diapers from the VFG waste.
- Grinding of the screen fraction > 60 mm (mixture containing all paper diapers and coarse VFG waste).

After composting:

- Airclassifying/screening of the screen fraction > 25 mm to remove the plastic diaper film.

The results of this study are as follows:

- Mixtures of VFG waste and used paper diapers can be composted without difficulty by introducing additional process steps. The quality of the agricultural compost produced from the VFG waste/diaper mixture via this adjusted process route is good, and the quantity of plastic diaper film in this final product is very low (0.04%) and not visually disturbing.
- The quantity by weight of used paper diaper waste to be dumped or incinerated is reduced by approx. 84% as a result of the composting of the used paper diapers. What remains as waste after composting of the used paper diaper is the plastic diaper film. This accounts for approximately 16% of the weight of the used paper diaper. The plastic diaper film can be separated out as residue to 98% as a result of the introduction of the additional process steps.

In the context of integrated waste treatment in the Netherlands, the benefits resulting from the composting of used paper diapers can also be presented as reduced incineration costs. This can signify a cost saving of up to 10 million guilders per year on the waste treatment of used paper diapers, and a further increase in the future.

Introduction

The Department of Environmental Technology of the Institute of Environmental and Energy Technology (TNO-ME) in collaboration with the Department of Research and Development of VAM has carried out a study on behalf of the Dutch Association of Paper Diaper Manufacturers (Nederlandse Vereniging van Papieren-Luiersfabrikanten) to develop process routes and techniques for composting used paper diapers together with normal Vegetable, Fruit and Garden waste (VFG), followed by the most complete removal possible of the plastic diaper film particles.

Previous studies [1] had demonstrated that a mixture of 90 wt.% VFG waste and 10 wt.% used paper diapers can be composted well and produces a good-quality compost, but that the quantity of plastic diaper particles remaining in the compost that is produced, although low in weight, is assessed as causing a visual disturbance.

The process route tried out in this study was chosen, in consultation with the client.

The basic principles for these process routes are as follows:

- The composting of the paper diapers takes place in one process run-through.
- The paper diapers are reduced in size prior to composting.
- Removal of the plastic diaper film particles takes place after composting.

The following process components were investigated in order to put these basic principles into practice:

- 1 Selective removal of used paper diapers from VFG waste-diaper mixture.
- 2 Grinding of the selectively removed paper diaper fraction.

- 3 Composting of a mixture of VFG waste and used paper diapers.
- 4 Removal of plastic diaper film from compost by screening.
- 5 Removal of plastic diaper film from compost by air classifying.

Selective removal of used paper diapers from VFG waste/diaper mixture

Purpose of process component

In practice, the paper diaper is folded up after use into a kind of plug with the protective plastic film on the outside. Previous research shows [1] that if such diaper plugs are added to VFG waste untreated, the diaper plugs are virtually unaffected after this mixture has been composted and the pulp present in the diaper has not been composted. It follows that before the pulp present in the diaper is composted, the diaper plug must be ground/broken open, so that the pulp becomes available for composting. The grinding of the VFG waste/diaper mixture in its totality is unattractive in terms of energy. An attempt was therefore made to develop a screening step by which the diapers are selectively removed from the VFG waste/diaper mixture and can afterwards be ground/broken open.

The assumed quantities of used paper diapers in VFG waste vary from one study to another. In Germany it has been assumed that paper diapers account for approx. 2.8 wt.% and in Switzerland approx. 2 – 3 wt.% of the VFG waste [1, 2, 3]. In the Netherlands, the National Institute of Public Health and Environmental Protection (RIVM) has published the finding that used paper diapers in VFG waste in practice will amount to between 2.5 and 10 wt.%. In order to be certain that the trials took place at real contents of paper diapers, the composting trials were therefore carried out with a content of 10 wt.% used paper diapers. By opting for the maximum concentration in this study, the effects of this on the composting process are accentuated better.

Screening of VFG waste/diaper mixture

The VFG waste/diaper mixture put together from the separate components was then screened using a mobile drum screen with a screen opening of 60 mm square. The result of this screening step is presented in Figure 1.

The screen oversize (selectively removed paper diaper fraction), 22 wt.% of the original quantity of VFG waste/diaper mixture, was used for performing the grinding trials.

Grinding of the selectively removed used paper diaper fraction

Purpose of process component

The principal purpose of grinding the selectively removed paper diaper fraction is:

To separate the compostable pulp present in the diaper plug as completely as possible from the non-compostable plastic diaper film.

In addition, the following must be achieved after grinding of the diaper fraction: The plastic diaper film remains substantially coarser than the organic compostable material. The purpose of this is to make it possible to screen out the plastic diaper film effectively after composting.

The following are aimed for:

Separation/opening up of compostable diaper portion to 100%.

Plastic diaper film; 100% > 50 mm.

Organic compostable material; 100% < 16 mm.

The grinding apparatus which best approximates this optimum is selected for the continued study.

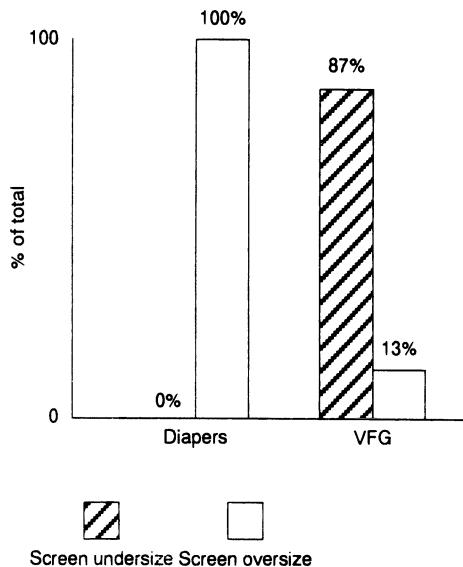


Figure 1 Material distribution over the screen fraction after screening with a screen opening of 60 mm square

Procedure for grinding experiments with diaper fraction

Two groups of mills are selected for the grinding experiments.

The first group of mills are what are known as low-speed mills with a rotor speed < 100 rpm. The action of these mills is based on a cutting principle in which the materials are reduced in size between pairs of knives.

Mills tested are:

- Hammel 450;
- Malin 400*1400;
- Kara;
- Klasmann.

The second group of mills are what are known as high-speed mills with a rotor speed > 500 rpm. The action of these mills is based on an impact/collision principle. Fixed or mobile hammers are mounted on a fast-rotating rotor. The material is beaten/torn apart by these hammers.

Mills tested are:

- Jenz AZ50;
- Jenz HEM 7 and 12;
- Willibald 3500.

All the mills were operated without a screen structure in the grinding chamber. The reason for this was that it is anticipated that grinding capacity would be adversely affected and blockages/smeared may occur. In the case of the high-speed hammer mills JENZ AZ 50 and WILLIBALD 3500, trials were performed at several machine settings. This was done in order to optimize the fragment size of the diaper film.

Assessment of grinding trials with diaper fraction

It is first of all determined during the trials to what extent the mill sufficiently damages/reduces the diaper plugs. If less than 50% of the diaper plugs are visually damaged, the grinding experiment is stopped and the ground product does not undergo further analysis. The mill concerned is not regarded as suitable.

The particle size distribution of the ground products from the mills with which reasonable to complete damage of the diaper plugs was achieved was then determined by screening and the distribution of organic material and plastic diaper film over the fractions was determined by hand picking.

The materials are divided into the following categories in hand picking:

- | | |
|-------------|--|
| film | – this is plastic diaper film without other attached material |
| film + pulp | – this is plastic diaper film with attached or enclosed material (a non-ground diaper also falls into this category) |
| organic | – these are all VFG wastes and the pulp coming from the diaper |
| residue | – this is everything which does not fall under the other three categories and thus contains among other things stone, glass, plastics not coming from diapers and metals |

This analytical data is assessed in relation to two aspects:

- a. The compostable pulp portion of the paper diaper must be separated as well as possible from the plastic diaper film. This is presented as:
percentage opening-up of the compostable diaper portion.
- b. Plastic diaper film must remain coarser after grinding than the compostable organic material. This is presented as:
percentage of plastic diaper film > 50 mm and > 16 mm
percentage of organic material < 50 mm and < 16 mm

The analytical data for the suitable mills is summarized in Figure 2.

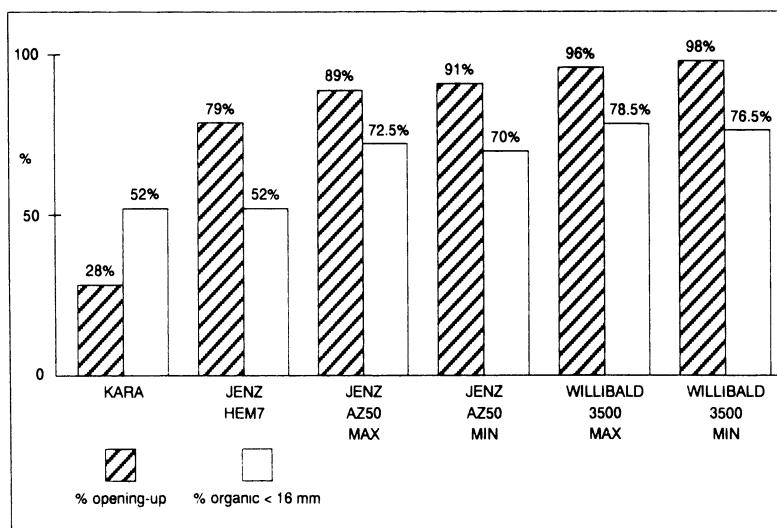


Figure 2 Results of grinding trials on VFG diaper mixture

Conclusions on grinding trials

The percentage opening-up of the compostable diaper portion is the most important assessment aspect. If this is lower than approx. 90%, the ground product still contains too many incompletely damaged diaper plugs. The compostable material present in the diaper plugs will not compost and is removed as residue after the composting process.

The second assessment aspect, the particle-size distribution of the plastic diaper film and the organic material, is secondary to opening-up. The effect of the grinding step can therefore best be assessed on the percentage of organic material present after grinding with a particle size < 16 mm. This portion of the organic material will be completely composted and end up in its totality in the final product.

On the basis of these assessment aspects, the best grinding results are obtained with the Willibald 3500. This grinding mill was also used for the continued study.

Composting of a mixture of VFG waste and used paper diapers

Preparations and method

A composting experiment was conducted by NV VAM in Wijster. Two experimental batches, one with and one without diapers were prepared and offered for composting.

Composting took place in the open air. Both heaps of approx. 50 tonnes each

were set up in the shape of a dike on aeration channels. Composting was carried out using forced (blowing) aeration. The aeration was temperature-controlled and the process data was established using a data-acquisition system. Composting took seven weeks, and the heaps were turned three times during this time.

No re-moistening took place owing to the weather conditions. After composting, the material was screened using a drum screen with 15 mm and 25 mm square openings one after the other. Mass balances were drawn up from the screen oversizes and undersizes. The final product (screen fraction < 15 mm) was examined and tested against the assessment guidelines for VFG compost.

Results

Process

The composting process proceeded normally. Unfortunately an enormous amount of rain fell during this composting trial. This influenced the results to some extent. It was noticeable that the heap with paper diapers suffered virtually no adverse affects from the rainfall, but that the reference heap did suffer such effects. This was evident in the moisture content of the compost and the mass balances.

There are two explanations for the difference between the reference heap and the heap with paper diapers:

- effect of the diapers on the moisture management;
- effect of the grinding step on the moisture management.

The mass balances of the composting trials are presented in Table 1.

Table 1 Mass balances for composting of VFG waste without and with paper diapers

	Reference VFG waste Weight %	VFG waste with paper diapers Weight %
VFG waste 0 – 180 mm	100	90
Used paper diapers		
Heating loss	45.0	53.7
Total after composting	55.0	46.3
Compost 0 – 15 mm	28.7	29.2
Fraction 15 – 25 mm	10.0	7.4
Fraction > 25 mm	16.3	9.7

Quality of the final product compost, < 15 mm

In the composting route now applied for VFG waste with paper diapers, the final product compost contains only 0.04 wt.% of plastic diaper film, which is not visually disturbing.

The final product, the fraction < 15 mm, of both batches was tested against the assessment guidelines for VFG waste.

The data shows among other things that:

- The compost obtained from VFG waste with used paper diapers contains 14% more of the total quantity by weight of the organic material present after composting. This is caused firstly by the pulp coming from the diapers and secondly by the enrichment of the fraction < 15 mm with organic material obtained after grinding of the fraction 60 – 180 mm. This results in a higher yield of agricultural compost per tonne of composted VFG waste.
- The grinding of the fraction 60 – 180 mm before composting does not cause any increase in the content of contaminants and stone in the final product compost, < 15 mm.

Quality of the compost fraction 15 – 25 mm

The plastic diaper film in the compost fraction 15 – 25 mm, obtained from VFG waste with paper diapers, is low (0.35 wt.%). This fraction can therefore be returned to composting in exactly the same way as the reference VFG compost. The fractions 15 – 25 mm of the reference VFG compost and the compost obtained from VFG waste with paper diapers contain almost equal percentages of the total quantities by weight of organic material present after composting.

Residue, compost fraction > 25 mm

The compost fraction > 25 mm obtained from VFG waste with paper diapers contains 98% of the total quantity of plastic diaper films present after composting. The quantity of plastic diaper film, including attached dirt, which remains as residue after the composting of paper diapers is approx. 16% of the paper-diaper weight prior to composting.

The measured percentages of residue in this single trial are:

Reference VFG compost 16.3% of the weight before composting.

Compost obtained from VFG waste with paper diapers 9.7% of the weight before composting.

So the residue obtained after composting VFG waste with paper diapers is 40% less than the residue content of the reference. This is despite the fact that all the plastic diaper films are also contained in this.

In the long term, dumping of the screen fraction > 25 mm is not desirable in view of government policy. This fraction, in addition to approx. 98% of all the plastic diaper film and 70 – 80% of the residual materials, still contains approx. 15 – 30% of all the compostable (organic) material present.

It is therefore appropriate to post-treat the screen fraction > 25 mm with the aim of separating plastic diaper film and remaining material from the compostable (organic) material. In this way, organic material can be returned to composting and the quantity of residue to be dumped can be reduced.

Reducing the quantity of dumped residue by air classifying and screening

The principle of air classifying

The principle of air classifying consists in the separation of particles on the basis of differences in density, shape and size.

Air classifying is a technique in which particles are separated on the basis of their difference in falling behaviour in an air current.

There are many different types of air classifiers. Devices with rectangular, round and zigzag-shaped channels occur. In all types of air classifiers, the mixtures of materials to be separated are brought into an adjustable air current. This air current is across or against the flow of material; combinations of cross and counter-current also occur.

Procedure for air classifying trials

One of the air classifiers used for the trials is a vertical air classifier. The principle of this air classifiers is illustrated in Figure 3.

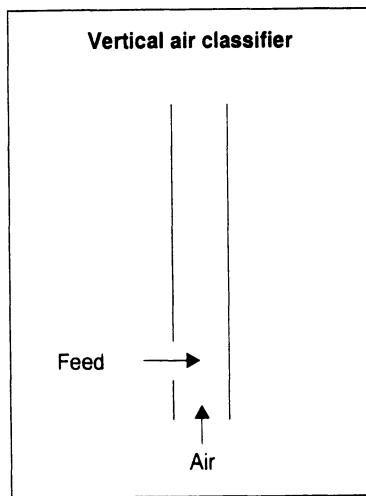


Figure 3 Principle of vertical air classifier

The purpose of the air classifying experiments is to separate the compostable (organic) material as well as possible from the non-compostable materials (plastic diaper film, stone, glass, plastics and so on).

The material used for the air classifying experiments is the residu > 25 mm from the compost obtained from VFG waste with paper diapers. This residu is 9,7% of the weight before composting.

The percentages of the materials in this residu fraction are shown in Table 2.

Table 2 Percentages of the total quantity by weight of a particular material present after composting of a particular material which is present in the > 25 mm screen fraction

	Organic	Plastic diaper film	Remainder
> 25 mm	17.3%	97.7%	80.6%

After composting the following process steps are added to the process route for the composting of VFG waste with paper diapers.

- Vertical air classifying with the screen fraction > 25 mm square.
- Screening of the top stream fraction of the vertical air classifier over 16 mm square.

If the extra process steps after composting are applied, the residue content is decreased from 9.7% to 6.4% of the weight before composting.

The percentages of the materials in this residue fraction (wet) are shown in table 3:

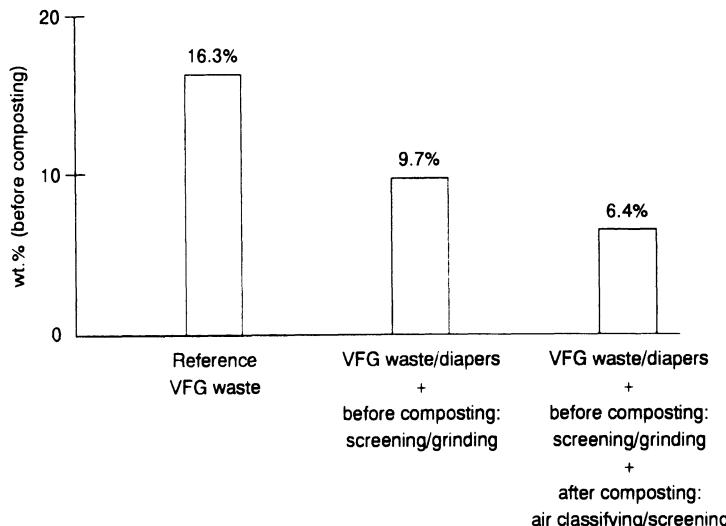
Table 3 Percentage of the total quantity by weight of a particular material present after composting which is removed as residue

Organic	Plastic diaper film	Remainder
9,8%	97,0	79,2

Bij comparing this figures with the figures in table 2 it becomes clear that:

The application of the extra process steps of air classifying and screening after composting thus only make a contribution towards lowering the residue content and the quantity of organic material in the residue. These extra process steps are not necessary for the removal of plastic diaper film and remainder materials.

The residue contents and the percentages of materials in this residue for the reference composting process and the optimized composting process for the composting of VFG waste with paper diapers are presented in overview in Figures 4 and 5.

**Figure 4** Residue contents after carrying out the composting processes

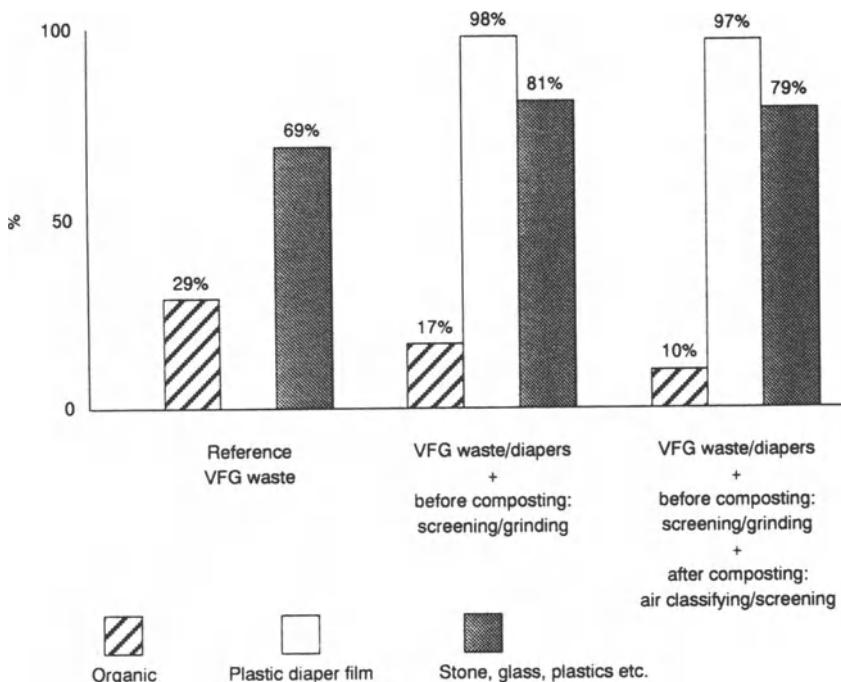


Figure 5 Percentages of the total quantities by weight of a particular material present after composting which is removed as residue

Costs/benefits of the process modification

Costs

The extra process steps added to the VAM composting process consist of:

- The screening before composting of the VFG waste over 60 mm square.
- The grinding of the screen fraction > 60 mm prior to composting.
- The air classifying/screening of the compost fraction > 25 mm after composting.

The costs of these extra process steps have been estimated by VAM at NLG 3.00/tonne VFG waste. The following assumptions have been made:

- Composting unit with capacity of 60,000 tonnes VFG waste/year.
- Investments for extra process steps NLG 700,000.
- Operating costs: NLG 180,000/year.

The costs of dumping and incinerating wastes differ from one municipality to another. The following have been used in the calculations:

- Dumping (excluding storage) NLG 80/tonne waste.
- Incinerating NLG 270/tonne waste.

Benefits

The benefits of the extra added process steps within the composting process chiefly consist in the reduction of dumping or incineration costs. If the quantity of composting residuum to be dealt with is reduced by 1% of the waste weight before composting, the benefits are:

- dumping: NLG 0.80/tonne waste;
- incineration: NLG 2.70/tonne waste.

If it is assumed that the reduction in residue per tonne composted VFG waste varies between 1.5 – 4%, it is possible to calculate what the benefits minus costs are at the present dumping and incineration prices.

This is illustrated in Figure 6.

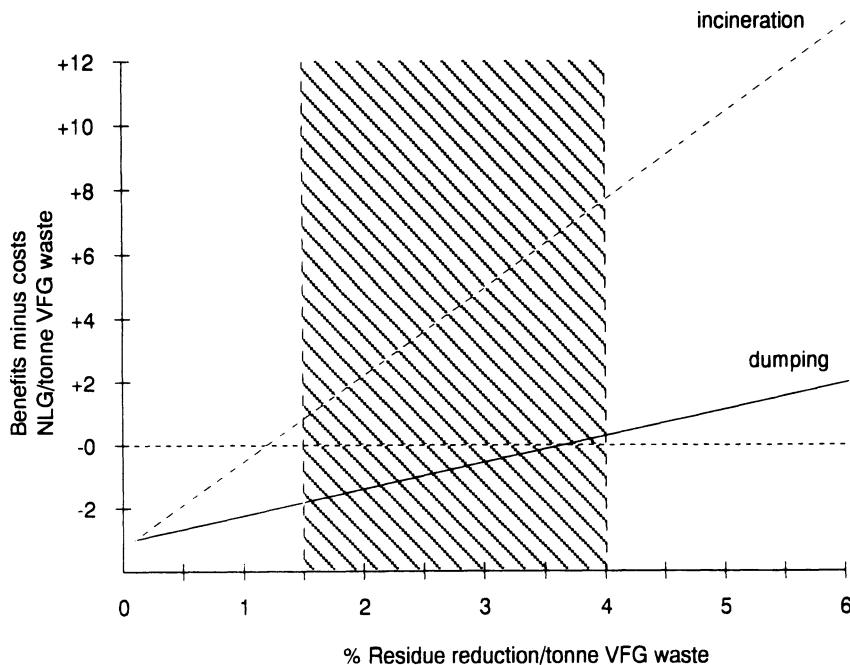


Figure 6 Benefits minus costs versus % reduction in residue per tonne VFG waste

The benefits of composting used paper diapers can also be presented as reduced incinerating costs. The processing of the VFG waste stream is at present NLG 100/tonne cheaper than the incineration of 'residual waste'. In the future this difference will increase further. This means that the composting of used paper diapers

(150.000 tonnes/year) in the future may lead to a real cost saving in waste treatment of 10 to 20 million guilders per year.

Conclusions

Process

Mixtures of VFG waste/used paper diapers (weight ratio 90/10) can be composted without difficulty if extra process steps are added prior to composting. These extra process steps are:

The screening of the VFG waste/diaper mixture with a 60 mm (square) screen. The grinding of the screen fraction > 60 mm (mixture of coarse organic material and all diapers).

The quantity by weight of used paper diaper waste to be dumped or incinerated is reduced by approx. 84% by the composting of the used paper diapers. Approx. 16% of the paper diaper weight therefore remains as waste after composting, in the form of plastic diaper film.

These extra process steps have a positive effect on the composting process of both VFG waste and VFG waste/diaper mixtures. They increase the yield of final product and reduce the residue content per tonne of composted material. This is chiefly caused by the reduction in size of organic compostable material by the grinding step. It is anticipated that the pulp from the paper diapers will also have a favourable effect.

The addition of extra process steps after composting, such as air classifying/screening, is not necessary in order to produce a good-quality compost from the VFG waste/diaper mixture. On the other hand, a quantity of compostable material is recovered from the residue in this way and the residue quantity to be dumped is reduced.

Product quality

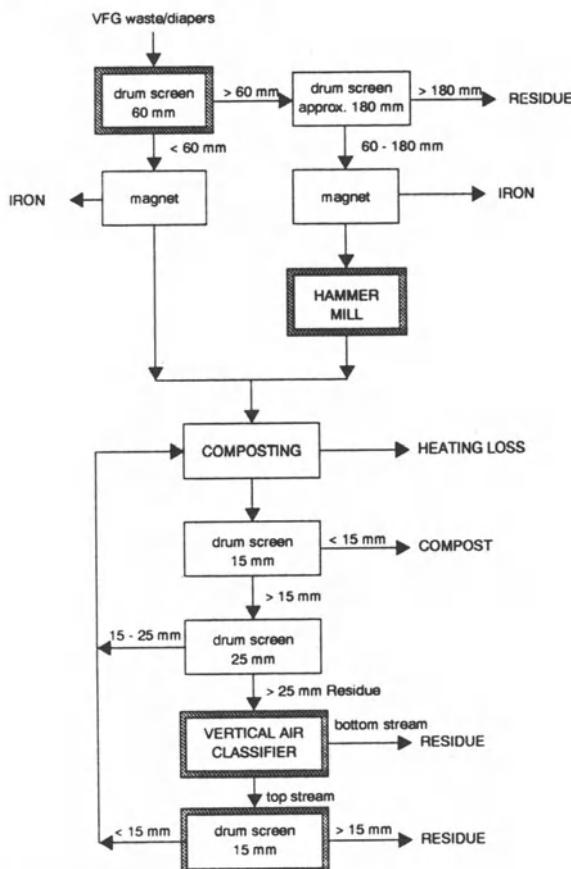
Final product (agricultural compost < 15 mm)

The addition of 10 wt.% used paper diapers to VFG waste does not have any adverse effect on the composition of the compost produced from this, via the adjusted process route. The quantity of plastic diaper film in the final product is very low (0.04 wt.%) and not visually disturbing. In addition, the adjusted process route does not result in an increase in other impurities, such as stone, glass and plastics.

Recycled material (screen fraction 15 – 25 mm)

The quantity of plastic diaper film in the compost fraction 15 – 25 mm, obtained from VFG waste with paper diapers, is low (0.35 wt.%), and this fraction can therefore be recycled without difficulty.

Process diagram for the composting of a mixture of VFG waste and used paper diapers



The boxes with a grey surround are additional process steps.

Residue (screen fraction > 25 mm)

The residue fraction > 25 mm obtained from VFG waste with paper diapers contains 98% of the total quantity of plastic diaper films present after composting.

Product quantity

It is anticipated that as a result of the introduction of a grinding step for the fraction > 60 mm prior to composting, the increase in the yield of final product will be more than 10%, whilst the residue quantity can be reduced by more than 25%.

If the extra process step of air classifying/screening is introduced after composting, a quantity of compostable material can be recovered from the residue, so that the quantity of residue to be dumped can again be reduced by approx. 20%. The quantity of plastic diaper film which is left behind as residue after the composting of paper diapers (screen fraction > 25 mm) is approx. 16% of the paper diaper weight before composting. At a weight ratio of VFG waste/used paper diapers of 90/10, the residue after composting due to the plastic diaper film is therefore 1.6% of the weight before composting.

Costs/benefits

The costs associated with the application of the extra process steps have been estimated at NLG 3.00/tonne VFG waste. Within the composting process, the benefits consist in savings on dumping or incineration costs as a result of the reduction in the residue content. To offset the costs, at the prices currently applicable to dumping and incineration the residue content in dumping must be reduced by approx. 4% and in incineration by approx. 1%.

The benefits of composting used paper diapers can also be presented as reduced dumping or incineration costs.

At a difference in treatment costs between composting and incineration of used paper diapers (150,000 tonnes/year) for example of NLG 100/tonne, a saving of NLG 12,600,000 is attained.

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Processes Regulating Grass Straw Composting

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Abstract

We have been able to successfully compost high C/N ratio materials such as grass straw. The straw composting was examined by using an on-farm windrow approach, different quality straw materials, and different number of turns. Temperatures typical of thermophilic composting ($> 50^{\circ}\text{C}$) were commonly observed in the turned windrow treatments. The magnitude of culturable microorganisms varied little among treatments and windrow depth (30 cm and 100 cm), except that thermophile populations increased in the turned windrow treatments at all depths midway through the 200 day composting process. Hydrolytic enzyme activity showed no definable pattern for all treatments and windrow depths. The loss of lignin fraction C indicated that extensive lignin degradation occurred in all treatments including the control. The increased need for C and reduced requirement of N of the thermophilic biomass and the release of soluble N and ammonium during the mesophilic to thermophilic transition explains the extensive decomposition of high C to N ratio (50–60 to 1) grass straw during windrow composting. Upgrading of agricultural wastes through composting is a viable residue management alternative that may be important for developing sustainable cropping systems.

Key words: lignin, microbial biomass, compost, ryegrass

Introduction

Lignocellulytic crop residues are important components in the maintenance of soil organic matter. The decomposition of lignocelluloses can positively or negatively affect crop production (Smith et al. 1993). The degradation of straw can produce organic acids that are phytoxic to crops, especially seedlings growing in heavy

crop residues (Lynch 1977; Graham et al. 1986). The formation of a thatch layer in blue grass seed cropping systems that retain straw residues often results in the production of smaller and less productive tillers (Canode and Law 1979). Crop residues can act as substrate for host specific pathogens and deleterious rhizobacteria (Cook et al. 1980; Fredrickson et al. 1987). The challenge in crop residue management is to enhance the positive value of plant residue by incorporating it into sustainable cropping systems.

The disposal of plant residues is often difficult due to bulk, low economic value of the material, and costs associated with removal. The disposal problem was aggravated through the elimination of open field burning, a method commonly used to dispose of grass straw residue in the Pacific Northwest. The feasibility of composting high C to N ratio lignolytic plant residues, such as grass straw, without co-composting management (lowering of the C to N ratio) has recently been described in field (Churchill et al. 1995) and laboratory studies (Horwath and Elliott 1995b). During the laboratory incubations, thermophiles required more C and less N to degrade grass straw with an C to N ratio of 50 to 1 or greater (Horwath and Elliott 1995a). The extensive loss of lignin C likely resulted in the increased availability of the cell wall fraction for microbial utilization at thermophilic temperatures.

The recycling of agricultural wastes is an important step in conserving nutrients, soil organic matter, and in establishing sustainable cropping systems. Benefits of compost additions to cropping systems include fertilization, improved physical structure, and control of soil borne pests (Kirchman 1990; Hoitink et al. 1991; Nelson and Craft 1992; Zacheo et al. 1993). This study was conducted to determine the mechanism of the decomposition of perennial ryegrass (*Lolium perenne*) straw in composting windrows as affected by turning. We hope to be able to develop technology of the process for other crop residue by understanding the mechanisms involved.

Materials and Methods

Field Treatments

In August of 1993 after grass seed harvest, threshed straw residue was raked from a 10 ha field and formed into windrows approximately 4 m tall by 6 m wide by 20 m long. Two types of windrows were formed with long straw (threshed straw) and reclipped straw (grass that had regrown to 30 cm in height after the threshing of the first grass crop).

Mature perennial ryegrass straw (7% moisture by dry weight), bailed after threshing, was obtained locally after grass seed harvest. The straw was chopped into 10 to 15 cm lengths, mixed, and stored at 4°C until used. Nylon bags of 22.9 x 30.5 cm dimensions and 0.5 mm mesh size were made using a hot iron to seal the edges of the bag. The bags were fitted with a grommet to hold a nylon rope and

identification tag. Each bag was filled with approximately 28 g (dry wt.) of chopped perennial rye straw and sealed.

The nylon decomposition bags were inserted into the windrows at two depths, 30 cm (shallow) and 100 cm (deep). The straw windrows were turned with a tractor mounted front-end loader to mix and restack the straw residue. The long straw treatment was turned 4 times and the reclip treatment was turned twice (Table 1). The control consisted of long straw and was not turned. The decomposition bags were removed from all treatments during the turning operations and then replaced after turning except those sacrificed for sampling. Four bags were removed from each depth beginning on December 19, 1993 to determine number of microorganisms, enzyme activity, and for the analysis of lignin fraction in the different treatments.

Table 1 Date and number of turns in the LS and RS windrow treatments. Days in field is calculated from December 19, 1993 when first the nylon decomposition bags were removed from the control treatment.

Date turned	Days in field	Windrow Treatment	
		RS	LS
1/13/94	25	X	X
3/30/94	91	X	X
5/3/94	135		X
6/7/94	171		X
Total turns		2	4

Laboratory Studies

Straw samples (1 g dry weight) from the nylon bags were extracted with 100 mL of quarter strength ringer solution on a wrist shaker (Labline Industries, Melrose Park, IL)¹ at maximum speed for 10 min. Serial dilutions were prepared by diluting 1 mL of extract into 9 mL of quarter strength ringer solution. The dilutions were streaked onto specific agar media and incubated at 25° and 50°C. Bacteria cultured at 25°C were plated on half strength tryptic soy (DIFCO, Laboratories, Detroit, MI) containing 1.5% agar. Bacteria cultured at 50°C were plated on quarter strength tryptic soy containing 2.0% agar to avoid spreading of bacteria. Bacterial colonies were counted after 3 days growth. Actinomycetes were isolated on Actinomycete Isolation agar (DIFCO), incubated at 25° and 50°C, and counted after 7 days growth. Actinomycetes colonies were identified under 50X magnification. Fungal propagules were isolated on potato dextrose agar (DIFCO), incubated at 25° and 50°C, after 3 to 5 days of growth.

Straw for enzyme assays was ground with a pestle and mortar after freezing with liquid N. The ground straw (0.2 g dry wt.) was extracted with 2.5 mL of 0.05 M sodium acetate on a wrist shaker for 5 min. The extracts were centrifuged (1300 g, 4°C) for 20 min and passed through a 0.4 µm filter. The extracts (0.1 mL) were combined with 0.15 mL of either 1% carboxymethylcellulose, CMC (Sigma

Chemical Co., St. Louis, MO) or 1% xylan (Sigma Chemical Co., St. Louis, MO) to determine cellulase and xylanase activity, respectively. The extract and buffer was incubated for 1.5 hr at 37°C and analyzed for reducing sugars using the Somogyi-Nelson method (Wood and Bhat 1988). Protease activity was determined by incubating 0.5 mL of extract and 1 mL of 1% Albumin Bovine serum, ABS (Sigma Chemical Co., St. Louis, MO) at 37°C for 24 hr. Hydrolyzed amino acids were determined by the ninhydrin method (Lee and Takahashi 1966). Enzyme activity was expressed as μM of product formed per day.

Straw was incubated at 80% moisture content (dry weight) for 45 days at 25° and 50°C under conditions described previously (Horwath and Elliott 1995a) to determine N mineralization at mesophilic and thermophilic temperatures. The straw (1.8 g dry weight) was extracted with 100 mL of 0.5 M K_2SO_4 on an orbital shaker (400 RPM) for 0.5 hr. The extract was filtered through a Whatman No. 1 and centrifuged (1300 g, 15 min). Inorganic N was determined on a Automated Ion Analyzer (LACHAT Instruments, Milwaukee, WI). Organic N was determined by the ninhydrin method (Lee and Takahashi 1966).

For lignin analysis, straw samples were dried at 70°C, weighed and ground in a Cyclotec mill (Tecator, Höganäs, Sweden)¹ to pass a 0.5 mm opening. Straw C, H and N were analyzed on an elemental analyzer (Perkin Elmer, Danbury, CT)¹. Straw O was determined by difference after correction for ash. Straw lipid, sugars, protein, and soluble polysaccharides was removed according to Horwath and Elliott (1995b). The lignin fraction was determined by a modified Klason lignin method (Horwath and Elliott 1995b). Lignin fraction C, H, and N, was determined in a elemental analyzer. Lignin fraction O was determined by difference after correction for ash content.

Results and Discussion

The composting process is regulated by microbial activity which requires C to supply energy and N to synthesize proteins. A substrate C to N ratio of 25 to 30 to 1 is required to avoid N immobilization and to provide sufficient N for the decomposer community (Biddlestone et al. 1987). Grass straw often has C to N ratios of greater than 50 to 1 and the stem can exceed a C to N ratio of 110 to 1 (Horwath et al. 1995). The grass straw used in the windrow decomposition study had a C to N ratio of 53 to 1 for the LS and control treatments and 60 to 1 for the RS treatment (Table 2). The straw used in the nylon decomposition bags had a C to N ratio of 48 to 1. The high C to N ratio of the straw makes it difficult to decompose in the field and often causes crop growth problems that are poorly understood.

Windrow temperatures exceeding 50°C, typical of composting conditions, occurred in both the LS and RS treatments (Figure 1). Temperatures of up to 70°C were observed at depths of greater than 120 cm during the windrow composting process (D. B. Churchill et al. 1995). The RS treatment had two turns compared to 4 for the LS treatment and achieved higher initial composting temperatures during

the first 2 turns. The LS treatment temperature increased after the last 2 turns and exceeded those in the RS treatment. The control treatment maximum temperature gradually rose from approximately 10°C to 25°C during the composting period in conjunction with seasonal temperature increase. The RS treatment had smaller lengths of straw which produced a higher bulk density and temperature insulating effect and may explain the observed temperature trends.

Table 2 The percent C and N and C to N ratio before and after composting of the control, LS, and RS windrow treatments, and straw in nylon decomposition bags are shown. Standard error of the mean shown in parentheses.

Treatment	C	N	C to N
Initial values			
LS windrow straw ^{1,2}	40.9 (0.5)	0.78 (0.04)	52.6 (3.4)
RS windrow straw ²	42.4 (0.2)	0.71 (0.04)	59.7 (2.8)
Straw in nylon bags ³	43.8 (0.2)	0.92 (0.02)	47.7 (0.9)
Straw in nylon bags after composting			
Control ³	40.9 (0.3)	1.84 (0.16)	24.0 (1.8)
LS ³	41.4 (0.8)	1.94 (0.11)	21.6 (1.4)
RS ³	43.8 (0.7)	1.95 (0.12)	22.7 (1.3)
Deep samples			
Control ³	40.6 (0.4)	2.29 (0.18)	18.0 (1.4)
LS ³	34.6 (0.9)	2.79 (0.12)	12.4 (0.1)
RS ³	40.9 (0.3)	2.35 (0.07)	17.4 (0.6)

1. Control windrow straw treatment has same values as LS windrow straw treatment.

2. n=3

—●— Control

···●··· LS

···●··· RS

3. n=4

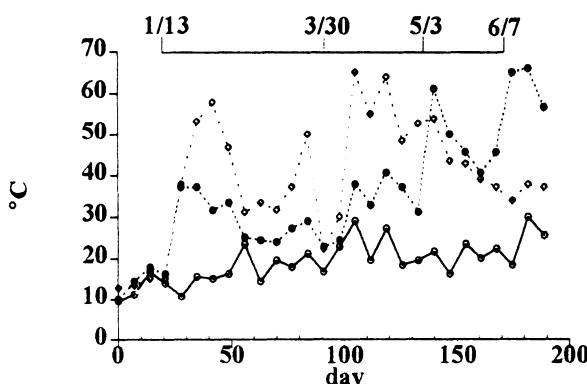


Figure 1 Windrow temperatures (maximum) for the period of December 19, 1993 to July 28, 1994 are shown for the control, LS, and RS treatments. Dates indicate turning of treatments (refer to Table 1 for date of treatment turn).

The difference in windrow temperatures, number of turns, and initial C to N ratio among the windrow treatments had little or no effect on the number of culturable mesophilic organisms in the straw (Figure 2). Mesophilic bacteria were present in the largest numbers attaining densities of 10^8 to 10^9 cfu per g (dry wt.) of straw. Mesophilic actinomycetes and fungi were present in numbers between 10^6 to 10^8 cfu per g straw. During the latter stages of windrow decomposition as the LS and

RS treatments increased in temperature, thermophilic bacteria increased to 10^7 to 10^8 cfu per g straw, and thermophilic actinomycetes and fungi increased to 10^5 to 10^6 cfu per g straw. In the control treatment (data not shown), thermophilic populations of bacteria, actinomycetes, and fungi remained unchanged at 10^3 to 10^4 cfu per g, 10^2 to 10^3 cfu per g, and 10^2 to 10^3 cfu per g straw, respectively. The populations of microorganisms in the perennial rye grass windrows were similar to that observed in wheat and hay composts (Chang 1967; Lacey and Dutkiewicz 1976). The presence of thermophiles in the control treatment indicated that sufficient inoculum existed for decomposition and composting activity.

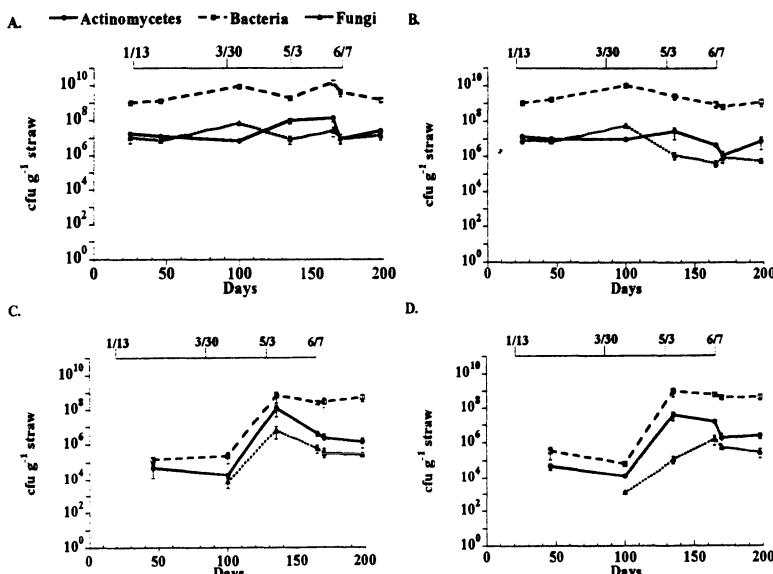


Figure 2 The density of microorganisms is expressed as colony forming units (cfu) and is shown for the LS treatment. The populations of mesophilic microorganisms for shallow and deep samples is shown in Fig. 2A and Fig. 2B, respectively. Thermophilic populations in shallow and deep samples are shown in Fig. 2C and Fig. 2D, respectively. Dates indicate turning of treatments (refer to Table 1 for date of treatment turn). Standard error of the mean shown as hatched line bars, n=4.

Cellulase, xylanase, and protease activity did not present definable patterns (data not shown). The measurement of hydrolytic enzyme activity appears to have limited value in interpreting straw decomposition and completeness or quality of the end product.

Klason lignin increased or remained unchanged in all treatments and depths (Horwath et al. 1994), data not shown). This indicated that little lignin degradation occurred during the decomposition process. The results agreed with composting studies using a variety of substrates (Chang 1967; Inbar et al. 1990). The Klason lignin method underestimates the decomposition of the lignin fraction in laboratory ryegrass straw incubations (Horwath and Elliott 1995b). The Klason lignin method is a gravimetric approach measuring acid insoluble material that is broadly defined as lignin. Precipitation and condensation of other plant components, such as proteins and suberins, can interfere with the Klason method (Obst and Kirk

1988). Oxidation of lignin phenolic and branch chains structures increases the O content of the lignin fraction (Kirk 1971; Chang et al. 1980; Kögel 1986). In addition, the biosynthesis of microbial aromatic compounds during decomposition can interfere with the gravimetric analysis (Flaig et al. 1975; Haider 1991).

The elemental analysis of the Klason lignin fraction revealed extensive C loss and accumulation of O and N (Table 3) and showed that the lignin fraction was substantially altered. We observed a greater or equal loss of lignin fraction C than in previous laboratory incubations of straw (Horwath and Elliott 1995b). The straw residue in the deep LS treatment lost 55% of the original lignin fraction C content (Table 3). The loss of lignin fraction C in the other treatments was 20 to 40% of the original lignin C. Deep straw residue samples lost more lignin fraction C than shallow samples except for the RS treatment which showed equal loss. The increased loss of the lignin fraction C in both depths of the RS treatment and in the deep straw samples of the LS treatment was associated with higher windrow temperatures which indicated the importance of thermophiles in lignin degradation. The increased N content of the lignin fraction was associated with the accumulation of humic substances (Hammouda and Adams 1987). The lignin fraction N content of all treatments increased between 1.5 to 2.3 times the original lignin N content (Table 3). It was shown that treatment and straw type influenced the amount of N stabilized in the organic fraction. The 4 turn LS treatment stabilized more N in organic forms than the control or RS treatments. The differences in the accumulation of lignin fraction N indicated that the treatment conditions used affected the production and quality of the composted end product.

Table 3 The percent of C, H and O remaining in the lignin fraction after 200 d of decomposition in the shallow and deep depths of the straw windrow treatments.

Treatment	C	% element remaining		
		H	O	N
Day 0	100	100	100	100
		Shallow		
Control	86	82	122	197
LS	84	83	158	239
RS	63	54	110	154
		Deep		
Control	67	63	115	152
LS	45	42	101	222
RS	60	51	153	187

Previous laboratory incubations showed that thermophiles mineralized approximately twice as much C and required half of the N than mesophiles during straw decomposition (Horwath and Elliott 1995a). This indicated that thermophiles were C limited, required more C as an energy source to degrade the high C to N ratio straw or more efficiently converted the cellulose and hemicellulose to materials such as gums. Microbial substrate use efficiencies can decline in thermophilic regimes in response to increased metabolic rates and cell maintenance requirements (Amelunxen and Murdock 1978).

The reduced N requirement of the thermophiles is a unique feature of ther-

mophile ecology that enables these organisms to degrade high C to N ratio substrates. The N requirement of thermophiles can also be met during the transition between mesophilic and thermophilic environments. During the transition between mesophilic and thermophilic temperatures in laboratory straw incubations, the accumulation of soluble organic N and ammonium occurred (Figure 3). The increase in soluble N and ammonium may occur as a result of the turnover of the mesophilic population. The increase in available N was 3 times the microbial biomass N content of the thermophilic population and indicated that sufficient N was available for the thermophilic decomposer community (Horwath and Elliott 1995a). In the current study, the increase in thermophiles coincides with the gradual increases in windrow temperature in the LS and RS treatments (Figure 1). The turnover of the mesophilic population during thermophilic activity may be an important mechanism that supplies a limited pool of N for thermophilic microorganism activity. The C to N ratio of the final decomposed straw in the deep samples indicated that the windrow composting treatments produced a completed compost (Table 2). The LS deep treatment produced the lowest C to N ratio material at 12.4 to 1. The RS and control deep treatments had final C to N ratios of 17 to 1 and 18 to 1, respectively. The surface decomposition samples had C to N ratios of greater than 20 to 1 and indicated that the samples were incompletely decomposed or unfinished. We are currently studying the economics of straw composting, its value as a fertilizer amendment, and for the maintenance of soil organic matter. Our intent is to access the feasibility of straw composting for use in sustainable cropping systems.

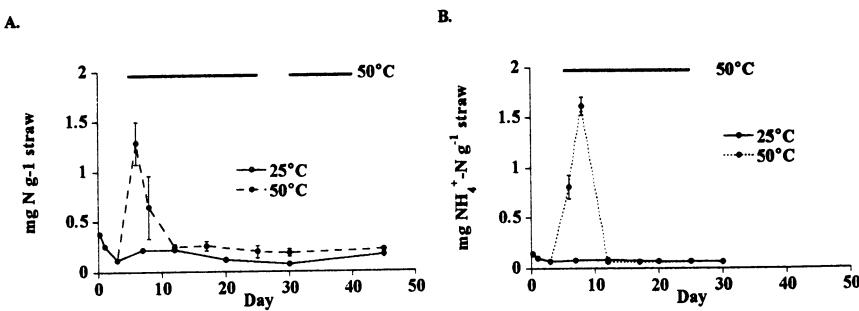


Figure 3 The accumulation of soluble organic N (Fig. 4A) and ammonium (Fig. 4B) is shown for laboratory straw incubations. The horizontal line indicates when the straw was incubated at 50°C. Standard error of the mean shown as hatched line bars, n=3.

Conclusions

The extensive alteration and decomposition of lignin and the reduced N requirement of the thermophilic biomass provided evidence why grass straw composts successfully in the field without the addition of N to lower the C to N ratio. The breakdown of lignin likely increases the availability of cell wall polysaccharide and related compounds for microbial utilization. These field experiments indicated

that lignolytic wastes can be upgraded to form high quality organic amendments with low C to N ratios. It was shown that treatment and straw quality influenced the final C to N ratio of the straw compost and indicates that straw management can be manipulated to form different quality end products. In preliminary field studies, the use of straw compost amendments has shown comparable crop yield to that of fertilizer (Churchill et al. 1995, personal communication). Upgrading agricultural wastes using the described field treatments is an alternative to field burning and traditional in situ residue management techniques that are often associated with residue inhibition and pestilence. These field treatments illustrate viable alternatives that can be integrated into a sustainable cropping system.

Acknowledgment

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Olive-mill Wastewater Bioremediation: Evolution of a Composting Process and Agronomic Value of the End Product.

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Abstract

Olive-mill wastewaters (O.M.W.) were composted with wheat straw in a forced aeration static pile ($7.5 \times 2.5 \times 1.8$ m). To eliminate most of the liquid component and to degrade lignin, the thermophilic phase was prolonged for 5–6 weeks, adding O.M.W. every three days. At the end of the process, the ratio O.M.W./solid substrate was about 10 litres per kg of straw. This paper discusses the bioremediation process from the standpoint of ligninolysis, humification, phenol degradation, phytotoxicity and agronomic value. The end product presented a degree of humification of 78%, and a residual lignin content of 30%. Soluble lignin fraction, made evident during the thermophilic phase, decreased during compost maturation. No phenols or phytotoxicity were detected in the end product. Pot and field experiments performed on maize, rye grass and horticultural plants indicated that bioremediated O.M.W. are able to support partially or totally the nutritional needs of cultures, at the same time improving soil properties.

Introduction

The industry of olive oil extraction produces a great stream of highly polluting effluent, very rich in mineral salts and organic matter. The environmental problem posed by olive mill wastewaters (O.M.W.) can be faced following three main strategies: cleaning, direct disposal on soils or recycling.

Technological approaches to clean O.M.W. have had a limited success. They are generally very expensive and unable to completely solve the problem because of the need to dispose of sludge or other products deriving from the process. Furthermore, neither have rules been established nor has information on the avail-

ability of the cleaning plants been supplied to users by the competent authorities.

The direct disposal of O.M.W. onto croplands is a suitable practice only when permitted by soil conditions (Tomati and Galli, 1992). However, in the E.C. Countries it is illegal to dispose of unremediated wastes because of the risks of contamination of groundwaters. From the standpoint of the environmental protection and energy recovery, many research programmes have been proposed, aimed at realising a market for O.M.W. as fertilisers, as a source for biomass production or for several valuable compounds (Tomati et al., 1995). Among the technologies proposed, composting is the most suitable alternative. The main reasons for this choice are:

- O.M.W. are a very heterogeneous mixture of organic and inorganic compounds which can wholly and economically be transformed by the wide variety of metabolic capabilities of microorganisms growing in them, including halo- and thermotolerant ones;
- Composting requires relevant quantities of water to ensure an adequate moisture to mass. Since O.M.W. contain about 90 – 95 % of water, they can be successfully used to compost lignocellulosic agricultural substrates, which have a high absorbing capacity. Therefore lignocellulose residues can be usefully recycled and returned to croplands as fertilisers. Studies aimed at elucidating the evolution of some parameters involved in the stabilization of O.M.W. mixed with agricultural residues have previously been made (Tomati et al., 1995; Galli et al., 1994). Taking into consideration the nature and composition of the starting mixtures and the aim of our research, this report mainly deals with:
 - the ligninolysis and the humification;
 - the bioconversion of the phenolic compounds of O.M.W.;
 - the evolution of the phytotoxicity;
 - the fertilizing value of the end product.

Materials and methods

Composting was performed in a forced aeration static pile ($7.5 \times 2.5 \times 1.8$ m). The air required for the process was provided by a blower ($0.5 \text{ m}^3/\text{min}$) connected to a series of perforated pipes laid on a slightly sloping concrete slab. About 600 kg of chopped straw were placed over the pipes to form a pile and 600 litres of O.M.W. were then supplied. To ensure a C/N ratio between 35 and 40, 2% urea was added. Temperature was monitored by a system of thermistors placed in the different horizons of the pile and connected to a temperature controller set with an adjustable temperature set point. When the temperature rose over the set point (50°C) the controller activated the blower until the pile temperature decreased. The thermophilic phase was prolonged for 5–6 weeks adding 600 litres of O.M.W. every three days. A ratio of about 10 litres of O.M.W. to 1 kg of straw was reached at the end of the thermophilic phase. Then the mass was turned and submitted to the maturation phase.

Compost analyses

Analyses were performed during the composting process and on the end product. Humic substances were assayed according to Hesse (1971), phytotoxicity according to Zucconi et al. (1981). Residual solid lignin was monitored according to Moore and Johnson (1967), soluble fraction of lignin, extracted according to Crawford et al. (1983), was determined by ^1H NMR spectroscopy on a Bruker AC 200 MHz NMR Instrument. U.V. spectra of solid lignin were performed in dioxan, according to Kirck and Chang (1975) and I.R. spectra by an Infrared Analyzer Ft-IR Perkin Elmer mod. 16F PC, using KBr technique. Elemental composition of lignin and humic acids was assayed by a C/H/N Analyzer Perkin Elmer mod. 240/B; –COOH and –OH groups were determined according to Hesse (1971). Phenols were extracted according to Balice et al. (1965) and detected both at 280 nm and using a ^1H NMR Bruker AMX 600 operating at 600.13 MHz.

Field and pot trials

Field and pot experiments were conducted near Rome on a subalkaline alluvial soil of the Tiber Valley.

Field experiments on maize (*Zea mais* L. hybrid line, Plenus) were carried out on randomized 50 m² plots as follows: 1) Control: Mineral (N=250 kg/ha, P₂O₅=120 kg/ha, K₂O=120 kg/ha) before sowing; 2) Compost 60 Mg/ha, equivalent to 1165 kg of total N and 13 Mg of organic matter, one month before sowing; 3) Compost 60 Mg/ha + Mineral; 4) Compost 60 Mg/ha + 1/2 Mineral; 5) Compost 90 Mg/ha, equivalent to 1750 kg of total N and 30 Mg of organic matter; 6) Compost 90 Mg/ha + Mineral; 7) Compost 90 Mg/ha + 1/2 Mineral. At the emergence time every plot was supplied with 160 kg/ha of urea.

Crop yield and quality were tested together with seed germinability.

Field experiments on rye grass (*Lolium italicum*) were carried out on randomized 8 m² plots previously supplied with a mixture of peat:pozzolana:sand 1:1:1. Treatments were performed as follows: 1) Control: Mineral (N=18 kg/ha, P₂O₅=46 kg/ha); 2) Compost 90 Mg/ha, equivalent to 1750 kg N/ha; 3) Compost 90 Mg/ha + Mineral. The grass was harvested and weighed after 47, 70, 90, 107, 260 and 320 days from sowing.

Pot experiments on maize (*Zea mais* L. hybrid line, Plenus) were performed as follows in 3,5 kg pots: 1) Control: Mineral (doses equivalent to N=250 kg/ha, P₂O₅=120 kg/ha, K₂O=120 kg/ha); 2) Compost, doses equivalent to 30 Mg/ha; 3) Compost, doses equivalent to 60 Mg/ha; 4) Compost, doses equivalent to 90 Mg/ha.

Samples were collected 7, 14, 21, 28 days after sowing.

Nitrate reductase activity was assayed on leaves according to Hageman and Huchlesby (1971); Oxygen consumption was assayed at 28°C by an oxygen monitor YSI mod.240/B on 3 ml of a suspension of rhizosphere soil. Soil polysaccharides were assayed according to Brink et al. (1960).

Pot trials were carried out on Lettuce (*Lactuca sativa* var Romana) and Spinach (*Spinacia oleracea* var Gigante).

Pots containing 3.5 kg of soil were supplied with:

- 1) Control: Mineral (2.3 g of urea/pot, corresponding to 1 g of nitrogen);
- 2) Compost 40 g/pot, corresponding to 0.8 g of N; 3) Compost 80 g/pot, corresponding to 1.6 g of N; 4) Compost 160 g/pot, corresponding to 3.2 g of N.

Crops were harvested after 40 days.

Results and discussion

Lignin degradation and humification

The evolution of ligninolysis was followed monitoring both the residual insoluble lignin and soluble fractions (Galli et al., 1994; Tomati et al., 1995). Ligninolysis occurs during the thermophilic phase (Tab.1). About 70 % of the total amount was degraded by the third week. At this time soluble lignin fractions became evident, as indicated by the broad peaks in the 7.5 – 6.5 ppm region of the ¹H NMR spectra (fig 1), reached the maximum by the 35th day and then decreased as the ripening phase went on.

Table 1 Lignin content and elemental composition of samples collected during the composting process.

Days	Lignin content %	N % d.w.	C % d.w.	H % d.w.	O % d.w.
0	100	0.58	63.00	6.18	30.24
23	30	1.14	65.32	6.14	27.40
35	30	1.76	68.02	5.84	24.38
90	30	3.29	60.96	6.41	29.34

U.V. spectra (Fig.2) and elemental composition (Tab. 1) were performed on residual insoluble lignin extracted at different composting times. U.V. spectra showed alteration of the absorbance centered around 260 and 300 nm. The differences are probably linked to oxidative changes relative to the aromatic carboxyl content. Infrared spectra confirm the above mentioned behaviour.

The humification process started at the end of the thermophilic phase, as compost ripening proceeded (Tab. 2). In this phase humic compounds are produced by the condensation and polymerization of aromatic units and cellular debris. The decrease of soluble lignin fractions could probably be related to the humification process (Fig.1). The chemical characteristics of humic acids, the increase of the ratio between oxygen and carbon and the evolution towards high molecular weights indicate the good level of humification reached during the process (Tab. 2).

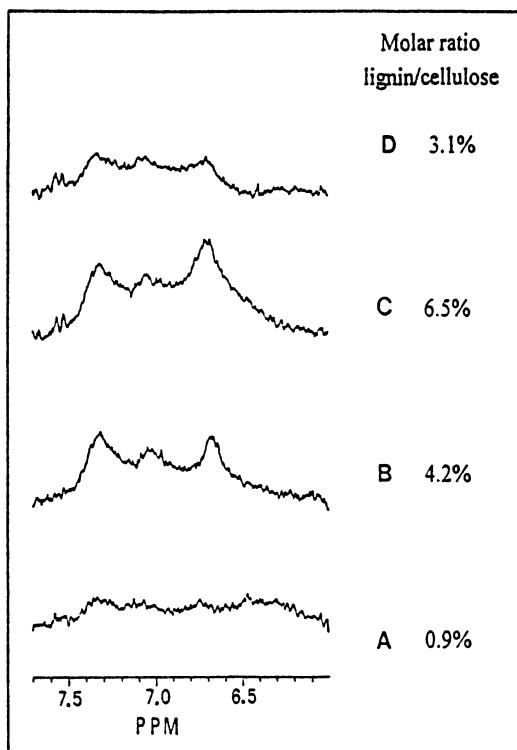


Figure 1 ^1H , 200 MHz, NMR spectra of lignin soluble fractions from O.M.W. -wheat straw mixture after 2 (A), 23 (B), 35 (C) and 90 (D) days from the beginning of the composting process.

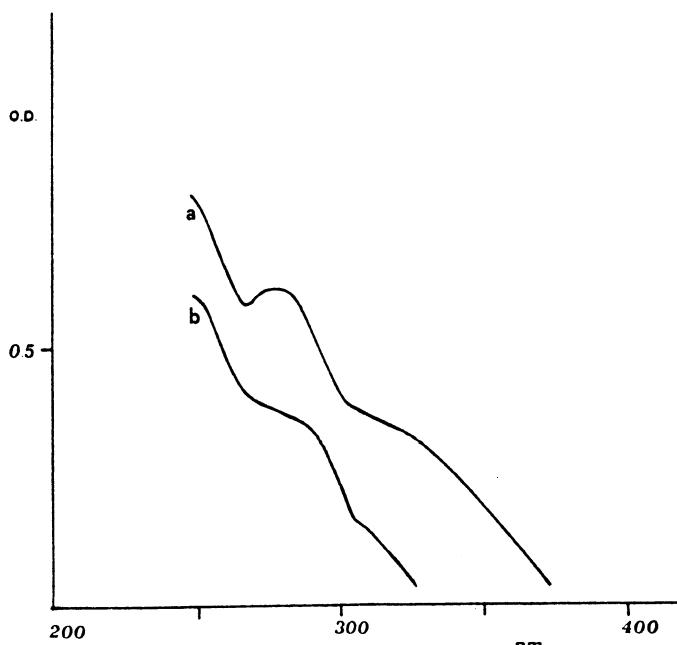


Figure 2 U.V. spectra in dioxan of residual insoluble lignin at the starting (a) and at 35 days (b) of the composting process.

Table 2 Humic acid content, elemental composition and chemical characteristics of samples collected during the composting process. (from: Tomati et al., 1995)

Days	humic acid content %d.w.	N %d.w.	C %d.w.	H %d.w.	O %d.w.	-COOH meq/g	-OH meq/g
35	6.60	3.93	53.87	6.14	34.66	3.42	1.40
63	4.08	4.08	51.16	5.27	38.62	4.06	1.45
90	10.00	4.15	53.53	5.58	36.04	4.02	1.69
110	10.00	4.10	52.26	5.35	37.68	4.55	0.57

Bioconversion of phenolic compounds

On average, O.M.W. contain about 1.5 % of phenolic compounds which are assumed to be responsible for their phytotoxicity. More than 50 different phenols have been detected in fresh waters (Lanzani and Fedeli, 1986). As O.M.W. maturation proceeds, the phenolic pattern rapidly changes as shown by the peaks in the 7.5–6.5 ppm region of the ^1H NMR spectra (Fig. 3). In three week old O.M.W. (Fig. 3B) a phenol with a probable structure $\text{H}-\text{O}-\text{C}_6\text{H}_4-\text{CH}_2-\text{X}$ prevails over the other phenolic compounds. This phenol is present in the fresh O.M.W. in little quantity (Fig. 3A), comparable to that of the other phenolic compounds. Therefore, from the standpoint of compost toxicity, phenol disappearance rather than phenol identification is important. Phenolic compounds are rapidly destroyed during the first three weeks of the composting process. At this time only about 30 % of the total amount was present. ^1H NMR spectra confirm phenol disappearance (Fig.4).

Evolution of phytotoxicity.

O.M.W. are considered a polluting waste because of their high load of organic matter and salts, and the presence of several potentially phytotoxic compounds such as phenols, alcohols, aldehydes and other small organic molecules (Lanzani and Fedeli, 1986).

The phytotoxicity of O.M.W.–wheat straw mixture strongly decreased as shown by the Ig value which passed from 0 (on day 0) to 12.5 (at 18th day) and 75% (at 90th and 140th day). The decrease of phytotoxicity could be related to the growing microflora which destroy phenols and the other small organic molecules. However, there is another aspect which must be taken into consideration, linked to phytotoxicity when compost is supplied to soil. Generally, the end product is not completely stabilized, so phytotoxic compounds can again be released after compost supply to soil. To avoid that, compost must be disposed of about one month before sowing.

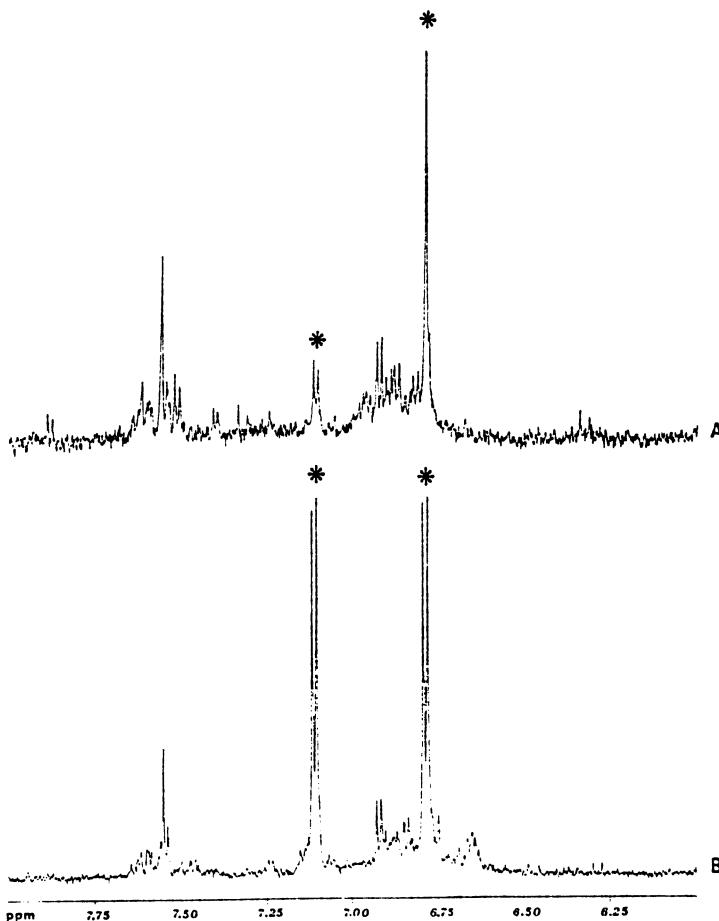


Figure 3 ^1H , 600.13 MHz, NMR spectra of phenols extracted from fresh O.M.W. (A) and 20 day old (B). The vertical expansion of A is multiplied $\times 4$. Resonances with * belongs to a phenol with probable structure H-O——CH₂-X.

Agronomical value of the end product.

The final goal of O.M.W. composting is to obtain a high quality fertiliser, so particular care has been taken to evaluate its agronomic value. Compost composition and its properties make evident its high quality mainly linked to nutrients and humification level (Tab. 3).

Crop yield from field (Tab. 4 and 6) and pot experiments (Tab. 7) lead us to draw the following conclusions: the end product obtained composting O.M.W. with wheat straw reduces, and in some cases removes, the need for mineral manuring as made evident by maize and horticultural plant crop yield and grain quality (Tab. 4,

5, 7); nutrients are available for plants during the whole vegetative cycle of the cultures and are kept in the soil, contributing to long-term fertility. This effect is particularly evident from the experiments performed on rye grass (Tab. 6).

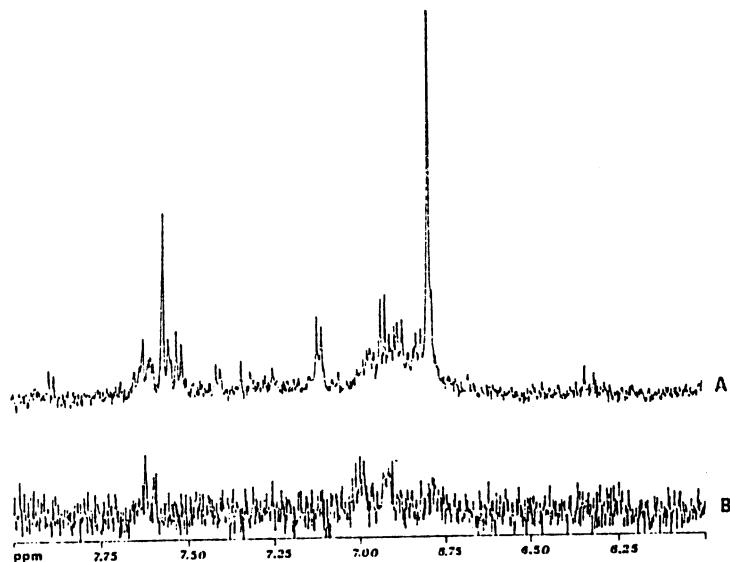


Figure 4 ^1H - 66.13 MHz, NMR spectra of phenols extracted after 0 (A) and 18 days (B) from the beginning of the composting process. The vertical expansion of B is multiplied $\times 8$.

Table 3 Compost analyses at 140 days. (from Tomati et al., 1995)

Humidity	37.3 %
Specific weight	0.345 kg dm $^{-3}$
Maximum water capacity	195 %
Electrical conductivity	9.56 mS cm $^{-1}$
Germination index	75 %
Kjeldhal Nitrogen	3.1 % d.w.
P ₂ O ₅	1.4 % d.w.
K ₂ O	2.1 % d.w.
MgO	1.3 % d.w.
Ca	1.9 % d.w.
Fe	0.5 % d.w.
Zn	0.02 % d.w.
Mn	0.02 % d.w.
Al	0.2 % d.w.
Cu, Cd, Pb, Hg	< 1 ppm
Degree of humification	78.2 %
Humification rate	41.6 %
Humification index	0.28

Table 4 Maize crop yield and seed germination (160 kg/ha of urea was supplied at emergence time).

Treatment	crop yield		germination	
	q/ha	%	days	
Mineral	136	100.0	2.8–3.3	
Compost 60 Mg/ha	136	93.3	3.1–4.3	
Compost 90 Mg/ha	171	100.0	2.5–3.4	
Compost 60 Mg/ha + 1/2 Mineral	128	96.6	2.5–4.0	
Compost 90 Mg/ha + 1/2 Mineral	182	96.6	3.1–3.7	
Compost 60 Mg/ha + Mineral	151	93.3	3.0–3.7	
Compost 90 Mg/ha + Mineral	189	96.6	2.6–3.0	

Table 5 Grain quality of maize (160 kg/ha of urea was supplied at emergence time).

treatment	protein % d.w.	fat % d.w.	ash % d.w.	fiber % d.w.	N-free % d.w.	humidity %
Mineral	7.83	10.15	1.80	2.40	77.82	17.97
Compost 60 Mg/ha	7.30	10.70	1.20	3.80	77.00	14.12
Compost 90 Mg/ha	5.73	8.16	1.30	2.30	82.51	15.53
Compost 60 Mg/ha + 1/2 Mineral	7.52	5.59	1.00	2.95	82.94	18.83
Compost 90 Mg/ha + 1/2 Mineral	8.70	7.22	1.60	2.62	79.86	17.18
Compost 60 Mg/ha + Mineral	7.15	7.67	1.45	2.10	81.63	19.64
Compost 90 Mg/ha + Mineral	7.90	3.22	2.00	3.30	83.58	20.94

Table 6 Rye grass yield (g f.w./8 m²).

Treatment	Days after sowing					
	47	70	90	107	260	320
Mineral	4000 ± 100	3700 ± 89	1600 ± 78	1100 ± 83	1500 ± 75	710 ± 38
Compost	2000 ± 58	4200 ± 72	3200 ± 64	2100 ± 69	2400 ± 73	1350 ± 47
Compost + Mineral	4500 ± 59	6700 ± 58	2500 ± 63	2100 ± 76	2000 ± 58	980 ± 25

Table 7 Lettuce and spinach yield (g f.w.).

Treatment	Lettuce		Spinach	
Control	61.93 ± 8.12		34.91 ± 4.16	
Compost (40 g/pot)	23.92 ± 5.25		12.07 ± 2.82	
Compost (80 g/pot)	63.56 ± 7.26		29.94 ± 5.94	
Compost (160 g/pot)	86.13 ± 6.17		33.27 ± 5.76	

Table 8 Pot trials: rhizosphere oxygen consumption (nmoles O₂/h/ml).

Treatment	days after sowing			
	7	14	21	28
Mineral	128 ± 10	106 ± 9	92 ± 7	77 ± 9
Compost 30 Mg/ha	275 ± 13	133 ± 11	109 ± 8	229 ± 14
Compost 60 Mg/ha	272 ± 13	188 ± 12	153 ± 9	290 ± 13
Compost 90 Mg/ha	77 ± 6	230 ± 13	290 ± 12	488 ± 14

Table 9. Pot trials: polysaccharides in soil (ug/g d.w.).

Treatment	days after sowing			
	7	14	21	28
Mineral	321 ± 8	448 ± 13	449 ± 19	461 ± 34
Compost 30 Mg/ha	679 ± 21	760 ± 18	835 ± 79	810 ± 21
Compost 60 Mg/ha	864 ± 15	1050 ± 14	1666 ± 24	1215 ± 23
Compost 90 Mg/ha	1451 ± 29	1303 ± 64	1778 ± 32	1673 ± 14

Table 10 Pot trials: nitrate reductase activity in maize leaves.
(nmoles NO₂⁻/min/g f.w.)

Treatment	days after sowing			
	7	14	21	28
Mineral	62.97 ± 2.63	14.15 ± 5.01	0.62 ± 0.15	0.0
Compost 30 Mg/ha	61.54 ± 8.99	25.60 ± 5.22	0.39 ± 0.14	0.89 ± 0.15
Compost 60 Mg/ha	57.06 ± 1.81	26.52 ± 1.70	2.63 ± 0.87	0.08 ± 0.02
Compost 90 Mg/ha	55.80 ± 1.69	21.67 ± 0.29	0.86 ± 0.12	0.55 ± 0.06

The following conclusions can be drawn considering some effects on the plant-soil system:

- compost supply improved rhizosphere conditions as indicated by the enhanced oxygen consumption (Tab.8). Improvement of soil condition is generally recorded when humified organic matter is supplied to croplands (Senesi, 1989);
- compost supply increased the polysaccharide content in the soil (Tab.9). Polysaccharides are well-known stabilizing and aggregating agents for soil particles. Moreover, they are able to adsorb many micronutrients, especially metals, the availability of which improves plant development and metabolism (Sandmann and Boger, 1983).
- nitrate content in soil assures an optimum nitrate assimilation as made evident by nitrate reductase activity in maize plants (Tab. 10).

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Agricultural Composting in the United States: Trends and Driving Forces

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Abstract

Agricultural composting is expanding in the United States, with over 7,000 farms currently composting. Based on information collected from the 10 largest producing states for beef and dairy cattle, poultry, and swine, this is largely being driven by the need to find an alternative method to handle livestock mortalities. However, composting is also increasingly being used to recycle crop residues and to improve the handling, marketability, and/or quality of livestock manure. Factors affecting agricultural composting include the availability of land for application of manure or crop residues, proximity of farms to urban areas, environmental policies and regulations, and the support of industry and public agencies via research, education, and financial incentive programs.

In the United States, more farms compost than municipalities, commercial/institutional establishments, and other private sector groups combined (Kashmanian, 1995). The move toward composting is particularly strong within the poultry industry, as many poultry farms have turned to composting to handle their mortalities. However, composting is also increasing among other livestock and crop farms. (In this paper, dry stacking is not considered a form of composting.) There are indications that agricultural composting is more prevalent in certain geographic regions or among certain types of farms. Critical environmental problems are probably a factor in the regional differences, although other contributing factors also seem to be responsible.

To obtain an overview of agricultural composting in the United States, industry, government, and university representatives from the top 10 beef and dairy cattle, poultry, and swine producing states were contacted between January and April of 1995. The representatives provided information about the number of farms composting, the materials composted, composting methods, how the compost is used,

and motivating and impeding factors for farms to compost. In addition, information was gathered concerning composting crop residues. In this case, specific applications of crop residue composting were identified and individuals knowledgeable about the applications were contacted for background information.

The information collected provides insights into the status of composting in U.S. agriculture, including trends, motivating and impeding factors, and research and education needs.

Composting in the Beef and Dairy Cattle Industries

Manure from beef cattle occupying range and pasture land is dispersed by the animals. Therefore, in the beef cattle industry, composting is limited to manure generated at feedlots. Where beef cattle manure is composted (see Table 1), it is usually done in windrows, alone or in combination with locally available materials, such as cotton gin by-products, straw, yard trimmings, newspaper, or biosolids. The compost is typically used on-farm or sold to other farms. In some cases, farmers prefer compost to fertilizer. In other cases, the compost is marketed at retail home and garden centers and nursery outlets, a state highway department, and to landscape a new amusement park and baseball field. A representative from Texas pointed out that when large volumes of compost need to be marketed, it may be better to rely on large bulk markets, such as agriculture.

Dairy farms primarily compost solid manure collected from barns and open lots (containing bedding or partially dried manure), and manure solids, separated from liquid manure collection systems. Composted manure is used for on-farm crop production and sold to neighboring farms or for landscape use. While composting of manure is somewhat novel, composting of separated solids is a long-standing practice among farms with liquid manure handling systems. The composted manure solids are usually recycled for animal bedding.

Nearly all dairy farms that compost employ the windrow method. Separated solids are composted with minimal effort in bins or free-standing piles, receiving one to three turnings simply by moving piles with a bucket loader. Manure is usually composted alone, but also in combination with dry carbon-rich materials, including straw, corn cobs, sawdust, dry leaves, paper, and cardboard. Most dairies that compost do so themselves, but on several dairy farms, particularly the larger ones, a second party performs the composting, such as a commercial composter or neighboring farmer. In the latter case, some dairy farms simply sell or give manure to the composter or even pay the composter to remove it from the farm. Otherwise, the farm retains some involvement in the composting operation, such as providing a composting site on the farm or sharing the revenue from compost sales.

Dairy farms that practice composting are diverse in type and nature, though there may be localized patterns. For example, in Wisconsin, composting is most prevalent among dairy farms that practice rotational grazing. In Iowa, composting takes place mostly on small dairies which use bedding and produce solid manure.

However, in southern California and Idaho, composting occurs primarily on large open-lot farms which need an outlet for excess manure.

Table 1 Estimated Number of Beef and Dairy Cattle Operations Composting Manure in the Top Ten Producing States (as of March 1995)

Beef Cattle: State (a)	Operations Composting	Dairy Cattle State (b)	Operations Composting
California	2	California	(c)
Colorado	20	Idaho	8
Kansas	10–25	Iowa	6
Nebraska	10 (d)	Michigan	19
Texas	10 (e)	New York	12
		Pennsylvania	15
		Texas	5
		Washington	6
		Wisconsin	20
Total:	> 52–67	Total:	> 91

(a): Iowa, Missouri, Oklahoma, South Dakota, and Wisconsin had none reported.

(b): Minnesota had none reported.

(c): According to a state survey, 11.3 percent of California dairy farms compost manure (Meadows and Butler, undated), however this includes dry stacking manure.

(d): One of these operations has some of its manure composted on another farm (included as one of the 10), and composts the rest.

(e): Ten beef cattle feedlots have contracted with five firms to compost their manure.

Composting is a manure management practice for only a small percentage of dairy farms. Nevertheless, it has expanded substantially over the last five years (Rynk, 1994). Most of the representatives surveyed expect dairy manure composting to continue to increase due to more stringent rules for land application of manure, plus increasing opportunities to compost off-farm materials. However, some trends in the dairy industry are unfavorable to composting, including increased use of liquid manure handling systems and a decreased use of organic bedding materials (replaced by sand or stall mattresses).

Composting in the Poultry Industry

Composting in the poultry industry (including broilers, layers, and turkeys), and agriculture in general, is led by the composting of mortalities (see Table 2). Approximately 5,000 farms in the top 25 poultry producing states composted their mortalities as of mid-1994 (Kashmanian, 1995). For the states listed in Table 2, the number of poultry farms composting mortalities increased from 3,603 in mid-1994 to at least 4,645 in early 1995, excluding the Delmarva region (1995 data for Delmarva was not yet available). Composting poultry mortalities has been supported through state, federal, and company cost-share programs, state university extension activities, and the integrator companies. Poultry farms have also adopted composting because it is a voluntary method to address a potential environmental problem, avoiding the use of regulatory methods. One limitation identified for

composting poultry mortalities is that composting bins are designed for normal mortality rates and cannot typically handle excessive bird deaths.

The methods used to compost poultry mortalities are either two-stage composting bins or mini-composting bins for smaller birds and operations. Two-stage composters include a primary stage to initiate the composting process and a secondary stage to complete the process and temporarily store the compost. Mini-composters have a single-stage composting process and do not require turning (Donald et al., 1994; Murphy, 1992-1993). For the states contacted, up to 55 percent of the poultry farms composted their mortalities with mini-composters. Materials added to the composting units include poultry litter (a mixture of poultry manure and bedding) and locally available materials (e.g., straw, peanut hulls, wood shavings, and cottonseed hulls). Hay has been found to be a poor bulking agent for composting poultry mortalities, because it tends to compress and block air flow through the composting pile. Wheat straw tends to work best because it is hollow, providing pathways for air flow. In some places, farms no longer add straw since the litter is dry and contains enough carbonaceous material (e.g., wood shavings). In addition, because straw may not completely decompose, it can 'ball up' when the compost is spread on the field, creating problems. The compost is handled like poultry litter and applied to land on the farm or on other farms. Composting of mortalities uses up to 20 percent of the poultry litter generated on these farms. The compost is often handled on the farms by recycling it into the composting bins.

Table 2 Estimated Number of Poultry Operations Composting Manure and Mortalities in the Top Ten Poultry Producing States (as of March 1995)

State	Operations Composting Manure	Operations Composting Mortalities	Total Operations Composting
Alabama	n.r.	1,000-1,200	> 1,000-1,200
Arkansas	12 (a)	1,150	1,162
California	10 (b)	3-6	13-16
Delmarva (c)	n.r.	1,031 (d)	> 1,031 (d)
Georgia	3	100	103
Maryland	1-10	(e)	1-10 + (e)
Mississippi	n.r.	306	> 306
North Carolina	6-12	590 (f)	596-602
Texas	n.r.	165	> 165
Virginia (outside Delmarva region)	n.r.	300	> 300
Total:	32-47	4,645-4,848	> 4,677-4,895

(a): About 12 farms sell manure each year to a commercial composting company.

(b): Includes two commercial operations.

(c): The Delmarva region includes Delaware, nine Eastern Shore counties of Maryland, and two Eastern Shore counties of Virginia.

(d): Based on mid-1994 data.

(e): Included under Delmarva.

(f): Based on the number of permits issued.

n.r.: None reported.

Where poultry manure is composted, it is done in open or enclosed windrows, or in-vessel. The nitrogen in the manure is sometimes balanced off by adding carbonaceous materials, such as leaves or sawdust, even if bedding material is already mixed in. Composting is chosen to add value to litter and to reduce the volume of the material to be land applied or marketed. In some places poultry manure may have enough value that composting is not considered. The compost markets include use on the farm or by other farms (including in pellet form), fertilizer companies that mix in chemical fertilizer, and landscapers.

Composting in the Swine Industry

Because swine manure is typically collected with water and handled as a liquid, it is considered too wet to be composted. Separation of manure solids is not common among swine farms so the cost and uncertain effectiveness of manure solids separation are barriers to composting swine manure. Nevertheless, a research project at North Carolina State University will study composting of swine manure mixed with peanut hulls, an inexpensive and locally- abundant by-product. The manure will be scraped from floors and collected from manure pits after settling and evaporation remove some of the moisture.

Following research and efforts in the poultry industry to compost their mortalities, there is growing interest in the swine industry to compost mortalities. Missouri has at least 100 swine operations composting mortalities, and 10–12 swine operations compost their mortalities in Indiana. The other top 10 swine producing states, Illinois, Iowa, Kansas, Minnesota, Nebraska, North Carolina, Ohio, and South Dakota, had none reported.

The primary barrier identified to compost swine mortalities is that some states do not allow it, or they allow it only if special permits are obtained by the farm. Since this type of composting is relatively new, several questions remain to be answered before many states approve the practice. For example: will composting swine mortalities work in their state's climate; what happens to the pathogens during composting; what size swine can be composted; can the carcass be composted whole, or should it be cut open or into smaller parts; what recipes work best; are dogs and rodents attracted to the composting piles; is there any leachate from the composting piles; should the composting unit be covered and placed on an impervious surface; and will it work on real farms, under real world conditions?

A number of these questions are being addressed in various research projects. For example, in research at Ridgetown College in Ontario, Canada, composting of whole swine carcasses, including sows over 200 kg killed *Salmonella typhimurium*, *Streptococcus suis*, *Bordetella bronchiseptica*, *Listeria monocytogenes*, *Actinobacillus suis*, and *Actinobacillus pleuropneumoniae*. High temperatures, averaging over 50 C through the winter (when the composting piles were started before the winter), were sufficient to kill these pathogens. Higher temperatures were achieved when sawdust was added as a bulking agent, rather than

straw. The researchers recommend the top layer should have 60 cm of sawdust for insulation or a thickness of 120 cm if straw is used (Morris et al., 1994/1995). In research at North Carolina State University, composting swine mortalities (with wheat straw or peanut hulls as the bulking agent) killed off the Aujesky's disease virus (also known as pseudorabies) and *erysipelothrix rhusiopathiae*, and most of *Salmonella*. Carcasses less than 13 kg were composted whole, while the sows (over 135 kg) were dismembered, with their abdomens opened and diaphragms punctured (Morrow et al., 1995).

State guidelines from the University of Missouri for composting swine mortalities, in combination with proper composting setup and process controls, are considered sufficient to deter dogs and rodents. One composting method developed by the University uses a low-cost, three-sided enclosure made with large round hay bales, 1.5 to 1.8 meters in diameter. The swine carcasses are separated by layers of sawdust 30 cm thick. Using these procedures, little, if any, leachate has been detected in this research. However, if straw is used, a roof may be required to deflect rain water and prevent leaching from the pile. Many farms are using a concrete pad because of its appearance and workability in all weather conditions. The most successful composting has been achieved using sawdust as the bulking agent, 'due to its small particle size, ease of handling, absorbency and high carbon content' (Fulhage and Ellis, 1994). The hay bales have also been tested by the University Illinois, and typically no leaching has occurred.

In a number of cases, research has responded to requests from state agencies and the swine industry. For example, the Missouri Department of Natural Resources (DNR) is concerned with the use of disposal pits, given the state's karst topography, the cost of incineration and its related air pollution concerns, and the lack of renderers. The DNR approached the University of Missouri to develop an alternative approach to handle swine mortalities. The university developed a state standard for composting bins made from treated lumber, concrete, or round hay bales. These systems have worked well for composting whole swine carcasses. The bales are less expensive and consistent with the DNR's interest in having the practice widely adopted by farms. Alternatively, the solid structures are more aesthetically pleasing and/or convenient. As one of the few states with a standard for composting swine mortalities, Missouri currently leads other states in this type of composting.

In Arkansas, the USDA's Natural Resource Conservation Service (NRCS) state office is developing a standard for composting swine mortalities that will be adopted by the state, and distributed to 10 southern states for their consideration. Approximately 10 workshops are scheduled to transmit this information further.

One state regulation limits the size of carcass sections composted to 60 pounds (27.2 kg). In fact, USDA's *Agricultural Waste Management Field Handbook* has a 15-pound (6.8 kg) guideline to maximize surface exposure microbial decomposition and speed up the composting process. On the other hand, swine carcasses weighing up to 295 kg have been successfully composted. The Arkansas NRCS requested an exemption from the 60-pound (27.2 kg) state requirement in its pro-

jects, and composts whole swine carcasses. It believes that farmers would not want to dismember carcasses prior to composting. Approximately five to seven swine producers in Arkansas were composting their mortalities as of early 1995, and approximately 100 more may be composting at the same time in 1996.

In South Carolina, a swine industry trade publication carried a story about the University of Missouri's dead swine composting research. With this information and their general unhappiness with using burial pits and the lack of rendering facilities, and with some counties prohibiting the disposal of swine mortalities in municipal landfills, the state's swine industry approached the USDA's NRCS state office and asked them about dead swine composting. The NRCS office assisted two farms receive trial permits to compost swine mortalities. One farm is using a solid structure under roof and on an impervious surface according to the NRCS Composting Facility Practice Standard, and the other farm is using hay bale enclosures. Carcasses larger than 23 kg are cut down the middle and 'butterflied' open to reduce bloating and increase surface area for microbial activity. Carcasses are encased in sawdust. One finding of this work is that rain water penetrates only 10–15 cm into the outer sawdust layer. No leachate has been observed in the research. However, in case runoff might occur, a vegetative filter strip is used to treat it (Henry, 1995). The NRCS plans to develop a state standard for composting swine mortalities based on this research.

Composting Crop Residues

For many years, crop residues, such as straw and corn cobs, have been composted as amendments for other materials, particularly manure and biosolids. More recently, several crop residues have become the object of composting. Although it is not a widespread practice, composting is being employed in certain locations to process and recycle cull potatoes, grass seed straw, seed screenings, cotton gin by-products, pomace from wineries, and residues from the collection and processing of sugar beets, blueberries, cranberries, and apples. The specific reasons for composting differ with the commodity and local situation, but generally, crop residues are being composted because traditional management methods are no longer acceptable. The following examples typify most applications.

Cull potatoes have been composted on at least six farms in Maine to control the spread of late blight disease from culls spread on the land. The potatoes are composted in windrows with sawdust and/or wood by-products. The composting process destroys the virus causing the disease. The compost has been successfully used as a soil amendment in potato fields.

Straw, remaining after harvesting perennial grass seed, has traditionally been burned in the field. However, field burning has been restricted in some states by public objections to the smoke created. Since 1991, 13 farms in Oregon have composted grass seed straw in windrows without adding a nitrogen source (approximate C/N ratio of 60:1). Support was provided by financial grants from the state

and procedures were developed through research conducted by USDA and Oregon State University. Few growers continue to compost straw because more economical alternatives have developed, such as marketing the straw overseas and leaving finely chopped straw to decompose in the field.

One farm in Idaho is composting alfalfa seed screenings and applying the compost to its crop land. Screenings are the undersized residue separated from marketable alfalfa seeds (weed seeds, pieces of the plant, undersized alfalfa seeds, etc.). The screenings cannot be applied to crop land directly because of the weed seeds and because some pesticides used on the alfalfa seed crop are not approved for food-chain crops. Research conducted by the Idaho Department of Agriculture and Oregon State University has demonstrated that nearly all weed seeds and pesticide residues decompose via composting, although a few species of weed seeds survive. Incineration and landfilling are the only other acceptable methods for handling the screenings.

At least four wineries in California are composting pomace, the residue from pressing grapes. In this case, the reason for composting is to produce compost for use in the vineyard. Although pomace can be directly applied to vineyard soil, compost is preferred as a soil amendment. In addition, vineyards are a highly visible agricultural enterprise and benefit from the positive image that composting creates.

Factors Affecting Agricultural Composting in the U.S.

Based on the comments of the state representatives contacted, the prevailing reason why farms compost is to create an outlet for agricultural residues where traditional handling methods are no longer acceptable, desirable, or economical. In the case of livestock mortalities, composting primarily offers an alternative to burial pits (because of regulatory restrictions and environmental concerns), incinerators (because of odors, emissions, and costs), and renderers (because of availability and cost). Manure and crop residues are most often composted because direct land application is a problem due to environmental concerns, odors, and/or lack of cropland. However, farms also compost to improve the quality of manure and crop residues by reducing the weight and volume, removing undesirable materials (e.g., rocks and concrete), improving physical consistency and field distribution, destroying weed seeds and pathogens, improving storage and transport, or increasing the market value. Although it is not usually the primary reason for composting, many farms gain revenue by selling compost or by composting municipal and industrial by-products. Farms that use large quantities of organic soil amendments (e.g., organic farms, vineyards, and nurseries) often produce compost for farm use.

Some of the factors determining whether farms become composters are directly related to these underlying reasons. For example, close proximity to an urban center favors composting because the urban area hampers traditional farming practices and increases the potential market for compost. Composting is more likely to

be practiced on livestock farms with relatively little cropland. Environmental regulations or policies which restrict manure applications also tend to encourage farms to compost. On the other hand, regulations or permits pertaining to the composting site, the use of off-farm materials, or the sale of compost can discourage composting. Also, composting is not likely to be practiced if a farm (or neighboring farm) has a large land base to safely apply the manure or if other management alternatives are available, such as a local rendering facility for mortalities or livestock farms that use crop residues for feed or bedding.

For manure composting, moisture is an important factor. Composting is practiced primarily by farms which produce manure of a solid or near-solid consistency. Such farms range from small traditionally managed dairy farms which use organic bedding to large outdoor feedlots in arid areas. A lack of locally available dry amendments discourages composting. Composting is rare among farms which handle manure as a liquid, including many dairy farms and most swine farms. Exceptions are those farms that separate manure solids from the liquid. Separation and subsequent composting of manure solids appears to be increasing, largely due to better separation equipment. Abundant precipitation and cold winters contribute to wet manure and site problems. Although these conditions may discourage individual farms from composting, they certainly do not preclude it. Many farm composters are located in the cold humid northeast and north-central sections of the U.S. These farms adapt to cold and wet conditions by scheduling composting activities to minimize weather-related problems or they compost only in the dry season. A number of farms are experimenting with 'fleece' covers which are impermeable to rain water but allow air transfer.

Although the above factors are influential, especially within a state or geographical region, the prevalence of agricultural composting is largely affected by the support of state and federal public institutions and local industry groups. Organizations in several states have made farm composting a priority and established research projects, educational programs, financial incentives, or developed flexible regulations or policies to encourage it. In part, this explains why agricultural composting is more common in particular states. This is not surprising since information on how to compost, compost markets, and the benefits of compost were identified as barriers for on-farm composting.

For instance, widespread use of composting poultry mortalities started in the Delmarva region, stimulated by research and extension educational programs at the Universities of Maryland and Delaware. This led to industry support, adoption of USDA's national standard, changes in regulations, financial incentive programs, and finally widespread use among farms. The trend then spread to other poultry producing states, usually following research and education by state universities. The same pattern is evident in the trend toward composting swine mortalities, with the state of Missouri leading the way.

A number of state representatives considered cost to be an impediment to composting. Several states, including Alabama, Delaware, Maryland, North Carolina, Ohio, Tennessee, and Virginia, have cost-share programs that pay farms for part of

the cost for composting poultry mortalities. The maximum cost covered by these programs ranges from 60 percent to 87.5 percent, and \$3,500 to \$30,000 per year. The state of Ohio also cost shares manure composting up to 50 percent. In the future, the state of Virginia may include composting swine mortalities in their cost-share program once more information is available and the state veterinarian approves the practice. In addition, Alabama and Delaware offer low-interest loans for composting dead poultry, with loan amounts ranging from \$2,500 to \$10,500 at a five percent interest rate in Alabama, and \$1,000 to \$60,000 at a three percent interest rate in Delaware (Kashmanian, 1994).

USDA has a separate cost-share program for composting livestock mortalities and livestock manure, with maximum cost-sharing of 75 percent and \$3,500 per year. However, because states and county offices have local discretion over USDA cost-share programs, farm composters in some states may not be able to take advantage of these funds. In 1994, the cost-share practice for composting was separated from the general category of animal by-product management to emphasize and encourage composting. However, the cost-share funds in the USDA program were cut by approximately \$90 million in fiscal year 1995 to \$100 million, and are expected to be cut by another \$50 million next fiscal year. Another funding source for composting livestock manure and mortalities has been the use of Clean Water Act section 319 nonpoint source pollution management grants from the U.S. Environmental Protection Agency (EPA).

Several vertically integrated poultry companies encourage their farms to compost their mortalities. For example, company contracts with poultry farms, especially new farms, may prohibit incineration and burial pits but allow composting (and/or rendering). Companies, such as Hudson Foods, have their own cost-sharing programs with farms in the Delmarva region. Hudson's program has benefitted 14 percent of its contract farms that compost mortalities. These farms represent 23 percent of Hudson's bird capacity, indicating that the larger farms are more likely to compost their mortalities.

A number of state representatives pointed to cost-share programs and other financial incentives as a key factor in encouraging farms to compost poultry mortalities. For example, almost 60 percent of the farms permitted to compost mortalities in North Carolina have received cost-share funds from the state. One hundred poultry farms have signed up for Alabama's loan program, a program that is two years old and became statewide in May 1994. This represents up to 10 percent of the farms composting poultry mortalities in the state; in addition, nearly 20 percent of the farms composting mortalities have received state or federal cost share funds.

Examples in several states illustrate the positive effect support programs have on composting manure, crop residues, and other organic materials. The relatively large number of dairy farms composting in Michigan, as compared to other states, is largely a result of Michigan State University's dairy manure composting demonstration project. Eighteen of the state's estimated 19 dairy manure composters started composting since the project began. In Pennsylvania, the Rodale Institute

and Pennsylvania State University conduct joint programs to promote farm composting. An emphasis of these programs is to connect farm composters with municipalities and industries which have clean organic by-products. At least 27 of the state's 46 farm composters handle non-agricultural materials (Oshins and Graves, 1993). Similarly, since 1987, Massachusetts has promoted on-farm composting of agricultural, municipal, and industrial by-products by creating incentives through state grants for research and demonstration projects. Massachusetts has also established regulatory procedures which allow farms to compost selected off-farm materials without obtaining an environmental permit. The flexible regulations have been effective in expanding farm composting and in avoiding landfill disposal of organic residuals, such as food and paper processing by-products. Massachusetts has over 100 registered farm composters.

In Maine, cooperative efforts among state environmental and agricultural agencies and the University of Maine have resulted in several successful and novel composting applications involving potato culls, dairy manure, telephone books, and by-products from fish and blueberry processing. Maine farms also can compost off-farm materials without a great regulatory burden. Conversely, comparatively little farm composting takes place in states that do not provide supporting research and educational programs or in states that stringently regulate the practice of composting.

Conclusion

According to information collected from state representatives and previous investigations (e.g., Kashmanian, 1995; Rynk, 1994; Oshins and Graves, 1993), there are over 7,000 farms currently composting in the U.S. However, this number does not include farms that are composting in states that were not contacted. By far, the majority of farm composting takes place on poultry farms for the handling of mortalities, driven by the need to find an alternative handling method. These farms represented approximately 12 percent of all poultry farms in the 25 largest poultry producing states in 1994 (Kashmanian, 1995). In contrast, a very small percentage of farms compost manure or crop residues. Although it is still relatively uncommon, many unique and successful applications of composting exist. The number of farm composters is expected to continue to increase, driven by additional environmental restrictions, losses of available cropland, urban encroachment, the availability of suitable organic, non-agricultural by-products, and a growing appreciation for the qualities and value of compost versus manure. Factors such as shifts toward liquid manure handling and uncertain regulation of farm composting operations may limit its growth, however.

Based on the state-to-state distribution of farm composters, it is evident that support and involvement of industry and public institutions are catalysts for widespread adoption of composting among farms. Aggressive research and/or educational programs initiate interest and provide the necessary information for farmers

to confidently begin composting, though in some cases this stimulus has been provided by a local pioneering composter. Additionally, initial research information may be required by state regulators to gain approval for unique composting applications, as with swine mortalities. The momentum is increased by financial incentives and environmental policies which encourage farms to compost. The history of poultry mortality composting provides a good example of how such support programs can lead to widespread use.

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B2 State of the Art of Composting

Effectiveness of the Rutgers System in Composting Several Different Wastes for Agricultural Uses.

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Abstract

Composting is considered as one of the most suitable ways of disposing unpleasant wastes and of increasing the amount of organic matter that can be used to restore and preserve the environment. The advantage of the Rutgers compsting system is that a stable compost can be obtained in a short period of time.

Eight different composts were prepared by this method, using a wide variaty of wastes. Their evolutions were studied. Two of them were used as organic fertilizer. The results showed that there were not significant differences from the yields obtained with inorganic fertilizer. Other four composts were used as component of substrates for ornamental plants. The results indicated that they could be use sucessfully up to half of the whole volume of substrate. The third application was as substrates for seedling prodution. The preliminary results indicated that the yield depended mainly on the level of salts.

Introduction

The organic matter traditionally added to soils as either fertilizer or soil conditioner was animal manure and straw composted in a mobile pile. However, the increased production of urban, agroindustrial and animal waste in small areas has led to the substitution of manure and straw by other wastes as well as attempts to find quicker and more efficient systems of composting. The open composting system can be classified into two: the traditional turned pile (windrow) and the forced ventilation static pile. The Rutgers system is an example of the latter. This process, devised at Rutgers University in New Jersey, is based on blown air and temperature control. The method maintains a temperature ceiling that provides a high decomposition rate through the on-demand removal of heat by ventilation. The

advantage of the Rutgers system is that a stable compost is obtained in a short period of time (Finstein et al., 1983).

Composting is considered as one of the most suitable ways of disposing of unpleasant wastes and of increasing the amount of organic matter that can be used to restore and preserve the environment (Stentiford et al., 1987). However, to obtain a high quality compost it is necessary to understand the process involved as well as to assess the most suitable performance conditions. The concentration of nitrogen in these materials is one of the most important factors which should be studied in ascertaining their agronomical value. The transformation and loss of nitrogen has been widely studied in manures, slurries and city refuse applied to soils (Witter and López-Real, 1988; Bernal et al. 1995), although there are not many studies of other wastes, especially when the Rutgers composting system is used. Degradation and humification of the organic matter occurs during composting, and the study of both factors will indicate the extent of the stabilizing effect of the organic waste material upon the microbial activity.

When preparing a mixture for composting the following factors should be borne in mind: the wastes to be used and the proportion of these wastes in the starting mixture, the ceiling temperature of the process, the humidity and the ventilation time. The adequate management of all these factors will lead to good quality composts suitable for use as:

- Organic fertilizers
- Substrates for soil-less culture
- Organic amendment
- Gardening and reclamation of degraded soils

The Rutgers composting system (forced ventilation) has the advantage of decomposing four times more waste in half the time of conventional systems. The decomposing rate is negatively affected by temperatures exceeding 60°C owing to inactivation of the microbial community (Finstein and Miller, 1992). However, generally, composting piles self-heat at 80°C, which restrains the decomposition rate. The advantage of the Rutgers system is that the temperature is controlled and kept below 60°C.

Three different experiments will be described in which composts prepared by the Rutgers system have been applied as:

- 1) Organic fertilizer for horticultural plants.
- 2) Substrate for ornamental plant culture.
- 3) Substrate for seedling production.

Organic fertilizer for horticultural plants

Two identical mixtures of sewage sludge and cotton waste were prepared by mixing in a proportion of 32.1 % and 67.9 %, respectively, on a fresh weight basis.

One was watered with water (C_1) and the other with fresh olive-mill wastewater (C_2) (OMW) (943 l/tonne of wet solid mixture). The Rutgers static composting system was used on about 1500 kg of each mixture. The timer was set for 30 sec. ventilation every 15 minutes, and the ceiling temperature for continuous air blowing was kept at 55°C. The piles were turned after 21 and 35 days respectively, in order to improve the homogeneity of the material and the fermentation process. The composting time required for the biooxidative phase was 49 and 84 days, respectively. The piles were sampled weekly during the biooxidative phase and after the maturation period, which lasted two months.

Evolution of the composting mixtures

The addition of OMW led to a longer composting time, nearly five more weeks. This resulted in a greater degree of mineralization of the organic matter (OM) (figure 1). The gradual weight loss of both piles followed the same pattern until the end of the fifth week, when OM degradation almost stopped in the compost without OMW.

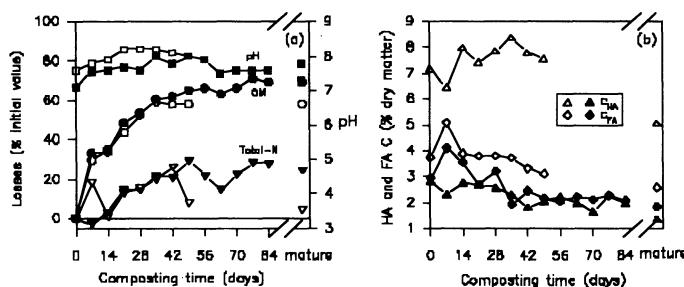


Figure 1 (a) pH values and losses of OM and total-N; (b) humic and fulvic acids during composting (hollow and filled symbols correspond to C_1 and C_2 , respectively).

The N-losses (max. 20 %) were higher in the mixture without OMW, in which the pH was higher. It has been demonstrated that high temperature and raised pH may lead to ammonia losses (Witter, 1986). Furthermore, the strong initial degradation of OM probably facilitated the mineralization of the N to its NH_4^+ form and the consequent losses of this element at the beginning of the process, especially in the mixture receiving no OMW which had a higher pH. After the sixth week, in both mixtures, when the temperature began to fall, the accumulative loss of N fell sharply, suggesting that biological-N fixation occurs through microorganism activity which can easily develop at moderate temperature (De Bertoldi, 1985). The rate of N loss rose again later in C_2 , probably as a result of intensified OM degradation observed after ten weeks.

The evolution of the nitrogen contents during composting was similar in both piles (Table 1), increasing throughout the process. The greatest increases occurred at temperatures above 40°C, until day 28 and 56, respectively, for C_1 and C_2 . This was due to the loss of OM that produced a concentration effect. Any increase pro-

duced from those days on could have been due to N₂ fixation, which seems to be higher for the mixture which received no OMW (C₁).

Electrical conductivity (EC) is a very relevant parameter at the time of deciding the possible uses of compost. When the EC values are high they are not suitable for substrates in soil-less culture. The EC values increased during composting in both piles as a result of OM mineralization (6.74 and 7.66 dS/m), which makes them inadequate as substrates, although they can be used as organic fertilizers.

The cation exchange capacity showed similar increases in both composts with the final values being very close. The parameters which define the humification degree of a compost are shown in Table 2. The level of fulvic acids (C_{FA}) was higher in C₁, indicating a low degree of humification. The C_{ex}/C_T and C_{HA}/C_T did not show relevant differences between both composts, whereas the C_{HA}/C_{ex} and C_{HA}/C_{FA} showed significant differences, compost C₁ having lower values than C₂, which indicates a lower degree of humification. It seems that the addition of OMW favoured the humification of the organic matter during the composting process.

Table 1 Analytical characteristics of compost C₁ and C₂
Compost C₁.

Sampling time	OM %	C _T %	N _T %	C/N	EC dS/m	pH	CEC* me/100 g
0	81.53	43.86	2.08	21.10	3.90	7.6	65.6
7	75.68	40.79	2.24	18.18	3.92	7.8	nd
14	74.10	40.47	2.89	13.99	4.52	7.9	nd
21	71.32	39.82	2.80	14.21	4.31	8.2	133.7
28	67.59	38.20	3.09	12.36	4.50	8.2	nd
35	64.11	37.03	3.24	11.42	4.67	8.2	171.5
42	64.94	36.46	2.91	12.51	5.11	8.1	nd
49	64.89	35.98	3.69	9.86	5.03	8.0	155.2
mature	64.85	35.55	3.79	9.39	6.74	7.3	191.1
Compost C₂.							
Sampling time	OM %	C _T %	N _T %	C/N	EC dS/m	pH	CEC* me/100 g
0	80.74	40.54	1.81	22.45	4.39	7.10	79.58
7	73.78	38.85	2.35	16.50	4.62	7.52	nd
14	73.53	35.10	2.41	14.58	4.87	7.60	nd
21	68.33	33.25	2.53	13.14	5.37	7.69	129.83
28	66.14	32.97	2.72	12.10	5.66	7.58	nd
35	62.52	33.68	2.76	12.20	5.38	8.01	nd
42	61.47	33.31	2.86	11.65	6.01	7.79	167.59
48	59.42	31.67	2.69	11.75	5.66	7.98	nd
56	58.47	32.08	3.05	10.53	6.57	7.95	nd
63	60.67	33.72	3.15	10.69	6.92	7.55	nd
70	58.54	31.43	3.02	10.40	6.96	7.57	nd
77	54.80	30.10	3.03	9.96	7.36	7.58	nd
84	56.33	30.08	2.96	10.16	7.28	7.58	203.12
mature	56.43	29.37	3.08	9.52	7.66	7.84	202.68

*Data refers to total organic matter. nd: not determined

To conclude, C₂ had lower OM and N values than C₁, although the latter seemed to have a better quality of organic matter.

Application as organic fertilizers

Both composts were used in a field experiment with horticultural plants (*Beta vulgaris* and *Lactuca sativa*). The experiment was designed as follows: two composts at two doses and a control of inorganic fertilizer were applied to experimental plots of $2 \times 3 \text{ m}^2$.

2 composts	\times 2 doses
C ₁	30 Tonnes/ha
C ₂	60 Tonnes/ha

The control was run using the standard N, P, K inorganic fertilization (80/50/80). Four replicates per treatment were run.

Table 2 Parameters which define the humification degree of composts

Compost C₁

Sampling time	OM %	C _T %	N _T %	C/N	EC dS/m	pH	CEC* me/100 g
0	6.02	2.27	3.75	13.73	5.16	37.71	0.61
7	7.09	2.02	5.07	17.38	4.95	28.49	0.40
14	6.13	2.25	3.88	15.15	5.56	36.70	0.58
21	5.82	2.02	3.80	14.62	5.07	34.71	0.53
28	5.77	1.98	3.79	15.11	5.18	34.32	0.52
35	5.61	1.88	3.73	15.15	5.08	33.51	0.50
42	5.06	1.74	3.32	13.88	4.77	34.39	0.52
49	4.37	1.26	3.11	12.15	3.50	28.83	0.41
Mature	3.69	1.12	2.57	10.38	3.15	30.35	0.44

Compost C₂

Sampling time	C _{ex} (%)	C _{HA} (%)	C _{AF} (%)	C _{ex} C _T (%)	C _{HA} C _T (%)	C _{HA} C _{ex} (%)	C _{HA} C _{FA} (%)
0	5.78	2.83	2.95	14.27	6.98	48.93	0.96
7	6.42	2.32	4.10	17.57	6.34	36.09	0.57
14	6.32	2.76	3.56	17.99	7.85	43.65	0.78
21	5.36	2.67	2.69	16.30	8.03	49.81	0.99
28	5.77	2.57	3.20	17.50	7.80	44.59	0.80
35	4.21	2.28	1.93	12.52	6.77	54.09	1.18
42	4.25	1.81	2.44	12.69	5.40	42.53	0.74
48	4.20	2.05	2.15	13.35	6.50	48.71	0.95
56	4.25	2.21	2.04	13.23	6.89	52.07	1.08
63	4.22	1.99	2.23	12.44	5.86	47.15	0.89
70	3.74	1.63	2.11	11.92	5.20	43.59	0.77
77	4.54	2.27	2.27	14.99	7.50	50.02	1.00
84	5.01	2.95	2.06	13.33	6.46	48.58	1.43
Mature	3.20	1.36	1.84	10.88	4.62	42.48	0.74

The macronutrients in the matured composts added to the calcareous soil were:

	<i>N %</i>	<i>P%</i>	<i>K%</i>	<i>Na%</i>
C ₁	3.79	0.73	2.52	1.61
C ₂	3.08	0.87	2.67	0.53

The results showed (figure 2) that the yields of both crops with the composts as organic fertilizer did not differ significantly from the yields obtained in the control either as a consequence of the kind of compost or of the dose used. The only significant difference found was in the length of *B. vulgaris* leaves, which were slightly shorter with low doses of both composts.

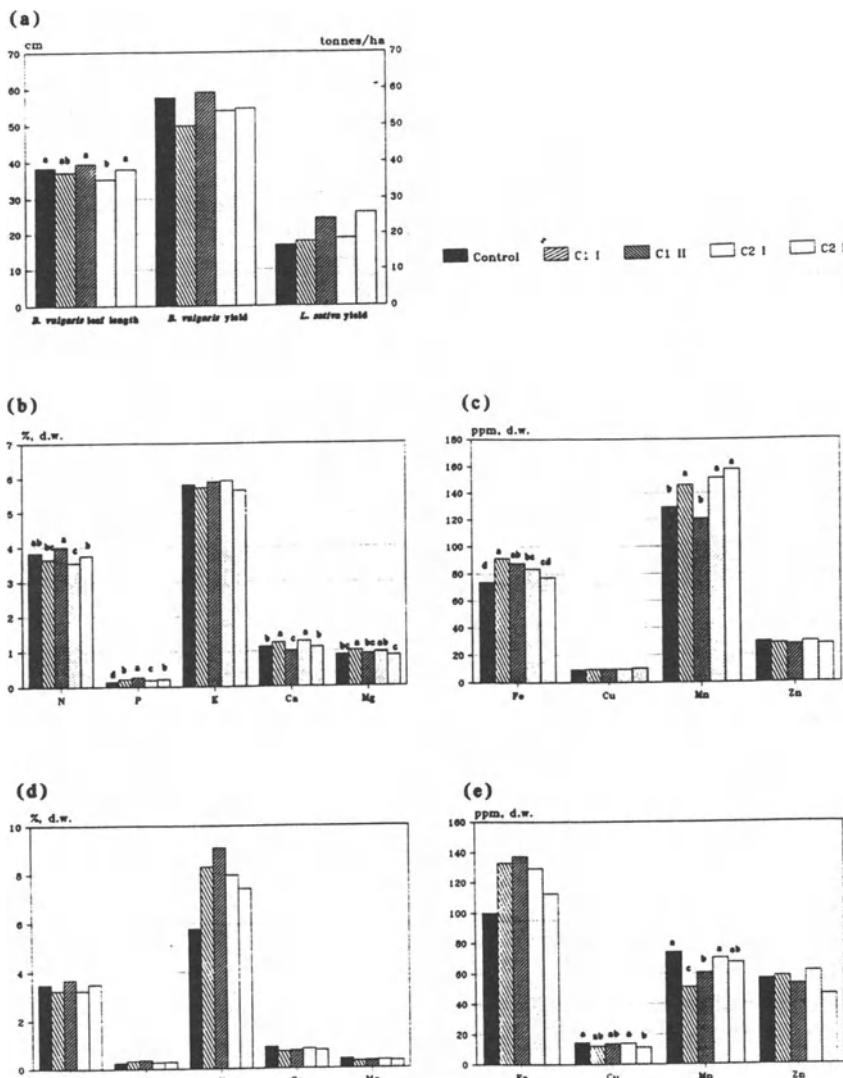


Figure 2 Effect of compost type and dose on leaf length and yield of *B. vulgaris* and *L. sativa* (a), on macronutrients (b), on micronutrients (c) of *B. vulgaris*, on macronutrients (d) and micronutrients (e) of *L. sativa*.

The macronutrient content of *B. vulgaris* was significantly affected by the kind of compost and the application rate, with higher concentrations of all elements except K than the control. The nitrogen content was higher in compost-fertilized plants at a high application rate than in the control, although this increase was less evident when the compost prepared from C₂ was used. A similar behaviour was observed for P, although in this case both application rates resulted in significantly higher concentrations than that obtained with the control. The levels of the others macronutrients (Ca and Mg) were also higher than those observed in the control, but only at high doses, as was the case for N.

As regards the micronutrient content (Fe, Cu Mn and Zn) of the *B. vulgaris* plants, only the concentrations of Fe and Mn were significantly affected by application rate and treatment (figure 2e). The levels of the former were always higher in plants cultivated with compost than the in the control, particularly at high doses and in those plants cultivated with compost C₁. The levels of Mn were greater in organically fertilized plants, except in those cultivated with high doses of C₁ compost, which were similar to those of the control. The macronutrient content of *L. sativa* plants were not significantly affected by either treatment or application rate and the micronutrient content was only slightly affected. In the case of Mn, the concentration in this plant material was almost the same as in the control when C₂ compost was added but clearly less when the soil was fertilized with C₁. Cu concentration behaved in a similar way to Mn, although the differences between both composts and between those and the control were very slight.

Therefore, both composts (C₁ and C₂) were suitable as organic fertilizers and no adverse effect was noticed. This means that soil can be used for disposal of these organic wastes after they have been composted since the addition of large amounts did not produce any negative effect.

Substrate for ornamental plant culture

Four compost were prepared using the following starting material. C₃:70 % municipal solid waste (MSW) + 30 % grape marc, C₄:5 % MSW + 20 % pig slurry + 15 % wood chips, C₅:2 % sewage sludge + 40 % grape marc + 22 % almond shell + 6 % phosphoric rock, C₆:60 % heavy metal contaminated sewage sludge + 40 % MSW. The same Rutgers static pile composting system as in the previous experiment was used.

Tables 3 shows the main analytical characteristics of the end-products of the four composting piles. Compost C₄, C₅ and C₆ showed high levels of organic matter. The N concentration was considerably high in first three. The electric conductivity of compost C₆ was the highest. Compost C₅ has the highest level of humic substances. The content of micronutrients was similar in compost C₃, C₄ and C₅. With regard to the heavy metals, compost C₃, C₄ and C₅ showed moderate levels, whereas compost C₆ exhibit notably high levels mainly for Cr, Ni and Zn, which are clearly above the recommended level for material to be used as substrates (Abad et al., 1993).

Thirty two different substrates were prepared as a result of the factorial combination of the 4 compost + sphagnum peat + pine bark.

4 compost	× 2 ratios	× 2 peat textures	× 2 pine bark textures
C ₃	C ₅	medium	medium
C ₄	C ₆	coarse	coarse

Control: 2/3 sphagnum peat + 1/4 vermiculite. Two horticultural plants were grown in pots, *Pelargonium x hortorum* and *Chrysanthemum fruscence*.

Table 3 Chemical characteristic of the end-products of the four mixtures.

	OM %	C %	N %	C/N	EC* dS/m	pH	CEC me/100 g
C ₃	46.92	23.10	2.22	10.41	2.80	7.30	62.61
C ₄	43.02	21.34	2.27	9.40	2.69	7.55	38.00
C ₅	67.48	34.59	3.33	10.38	2.19	6.70	109.00
C ₆	27.10	16.37	1.13	14.49	2.99	7.65	47.9
ppm	Cu	Mn	Zn	Cd	Ni	Pb	Cr
C ₃	520	411	505	4	155	176	128
C ₄	213	699	353	3	118	115	129
C ₅	359	150	461	6	144	154	200
C ₆	500	689	4896	17	532	358	1049

*EC: 1/10 water extract.

The first three composts showed suitable of density, total pore space and air filled porosity. The pH was slightly acid in all four (data not show). The substrate with C₆ had a low aeration and a high electrical conductivity.

The results of the pot experiment indicated that compost C₃ gave the best yield in the two plants tested (Table 4), whereas the substrate with C₆ gave the worst result. The low yield obtained in compost 4 could be due mainly to: 1) its limited air filled porosity, 2) its high EC, clearly higher than the level recommended for soil-less culture (Abad et al., 1993), 3) its high level of heavy metals, with phytotoxic growing effect.

The two substrates mixtures of different ratios made up with the composts did not show significant difference in plant yield, therefore, compost can be use as substrate component at high rate, such as half of the total volumen. The best yield was achieved with the medium Sphagnum peat texture and with the particle size of pine bark <30 mm. Also the substrate mixtures with compost C₃, C₄ and C₅ had similar or better yields that the control (2/3 peat and 1/3 vermiculite) (Table 5).

It can be concluded that ornamental plants can be grown successfully on substrates made up with composts prepared with organic waste. Thus, the composting of organic wastes help to solve the environmental problem produce by organic wastes by means of obtaining cheap substrates of good quality as an alternative to the Sphagnum peat.

Table 4. Effect of the different substrates prepared using compost on the yield of *Chrysanthemum frutescens* y *Pelargonium x hortorum*.

	Shoot fresh weight (g) <i>Chrysanthemum</i>	Plant height (mm) <i>Chrysanthemum</i>	Plant height (mm) <i>Pelargonium</i>
	<i>Pelargonium</i>		
A) Compost			
C ₃	203.1 a ^y	145.1 a	550.5 a
C ₄	199.6 a	123.7 b	521.9 b
C ₅	196.8 a	129.9 b	523.2 b
C ₆	163.1 b	105.9 c	490.0 c
P ^z	0.001	0.001	0.001
B) Ratio			
1/3 (vol.)	193.0	128.2	523.5
1/2 (vol.)	188.3	124.1	519.3
P	NS	NS	NS
C) Pine bark texture			
< 20 mm.	185.4	122.1	506.5
< 30 mm.	195.9	130.2	536.3
P	0.01	0.01	0.001
D) Peat Texture			
Medium	196.2	129.5	526.2
Coarse	185.1	122.8	516.6
P	0.01	0.05	NS

^zSignificance level. NS = Not significant. Values followed by the same letter are not significantly different at the p = 0.05 (Kruskal test)

Table 5 Influence of the compost culture media upon *Chrysanthemum frutescens* y *Pelargonium x hortorum*.

Growing media*	Shoot fresh weight (g)		Plant height (mm)	
	<i>Chrysanthemum</i>	<i>Pelargonium</i>	<i>Chrysanthemum</i>	<i>Pelargonium</i>
C ₃ + PB + MP	207.0 a ^y	149.1 a	549.0 a	303.1 a
C ₄ + PB + MP	213.6 a	118.0 bc	505.2 b	259.4 b
C ₅ + PB + MP	195.0 a	140.8 ab	548.6 a	267.5 b
C ₆ + PB + MP	144.4 b	107.0 c	521.3 ab	237.5 b
Control mixture	214.5 a	141.2 ab	505.5 b	267.5 b

*Compost mixtures (C) + pine bark < 30 mm (PB) + medium peat (MP) 2/1/1 in volume. Values followed by the same letter are not significantly different at the p = 0.05 probability level.

Substrate for seedling production

Two composts were prepared by using the following starting mixtures; C₇:86 % sweet sorghum bagasse + 13 % pine bark + 1 % urea, C₈:86 % sweet sorghum bagasse + 11 % pine bark + 3 % brewery sludge.

The same Rutgers static pile composting system as in the previous experiment was used. The main analytical characteristics of the end-products were:

Composts			EC		CEC
C %	N%	C/N	dS/m	pH	CEC me/100 g
C ₇	44.31	3.42	12.97	4.50	6.56
C ₈	38.82	2.54	15.65	2.83	6.97

Twelve different substrates were prepared as a result of the combination of C₇ and C₈ composts (C) + peat (P) + commercial substrate (CS).

Composts	Ratio	Controls
C ₇	1/3 C + 2/3 P	100 % Compost (C ₇ and C ₈)
C ₈	2/3 C + 1/3 P.	100 % Peat
	1/3 C + 2/3 CS	100 % Commercial substrate
	2/3 C + 1/3 CS	

Four replicates per treatment were run and three kinds of seeds of different salt tolerance were grown in trays of 264 holes, onion (*Allium cepa L.*) very sensitive, broccoli (*Brassica oleracea*) medium and tomato (*Lycopersicum esculentum*) resistant. Preliminary results indicate that the best germination was obtained in 100 % commercial substrate and the worst in 100 % peat, probably due to its very low pH. Seeds grown on substrates from compost C₇, with high level of salt, had lower yields than those grown in compost C₈. This is true for all the substrate mixtures except the broccoli, which, during the second half of its growing period, grew better in C₇, probably due to a higher level of nutrients in this compost. Onion shows the lowest and tomato the greatest differences between plants grown in the two compost mixtures.

In general terms, it can be concluded that compost C₈ gave better yields in the different mixtures and in the three kinds of seedlings. The mixtures ratio 1/3 C + 2/3 CS was the best and the substrate prepared with 2/3 C₈ + 1/3 P gave results similar to the 100 % commercial substrate, which gave the best yield.

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Composting in Finland: Experiences and Perspectives

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Abstract

Approximately 1 million m³ of compost is produced in Finland annually. Sewage sludges and liquid animal manures are the major waste groups composted in windrows or smaller heaps. Owing to the severe odour and leachate water problems in wintertime, however, in the major cities and towns will probably shift towards closed processing in the near future. At present there are about 100 drum composters in use on Finnish farms. With the new environmental legislation and targets set by the Ministry of the Environment, source separation of biowaste, and centralized composting as the most effective method of treating it, can be expected to expand rapidly. Approximately 3% of detached houses employ small composters and growth is likely to be small. Although many industrial waste fractions could be composted, this is only marginal in Finland.

The composting process is an active area of research in Finland. Of particular interest are the compostability of different waste matrices and management of the process; quality aspects of composts, including the chemistry of biodegradation; the occupational hygiene of the process; and the composting of toxic waste fractions, particularly those containing organo chlorine aromatics.

Introduction

Being mainly rural before the 1960's and relatively sparsely populated Finland used to have few problems with waste management – always there was plenty of space for waste disposal. With the intensive urbanization beginning in the 1960's, and the considerable rise in living standards, the need to develop waste management systems for communities suddenly became pressing (FAMW 1967). Since the 1960's waste management in Finland has undergone rapid change, both in practical arrangements and in the minds of people. In the 1970's the main aim was to destroy waste, in the 1980's treatment became important; and then in the 1990's goals and principles resembling those of the United States and Western Europe were adopted, with emphasis on the reuse and recycling and particularly the reduc-

tion of wastes. The change in direction is clearly seen in the new environmental legislation, in literature (e.g. Kurki-Suonio and Heikkilä 1994) and concretely in the reduction in the number of public landfills: from a maximum of 1,799 to the present 762, of which 548 handle municipal wastes (Lettenmeier 1994).

According to statistics provided by the Ministry of the Environment, the annual generation of wastes in Finland today is 65–70 million tonnes: agricultural wastes 34%, municipal wastes 6% (comprising 1 million tonnes of sewage sludge, and 3.1 million tonnes of solid municipal wastes), industrial wastes 17%, construction and demolition wastes 10%, mining and concentration wastes 32%, and hazardous wastes 1% (Central Statistical Office 1994).

Treatment of organic wastes has been spearheading the development of waste management in Finland during recent decades, with composting the most important method of treatment (Haukioja et al. 1983, Paatero et al. 1984). Composting is a process that can accelerate biodegradation of organic wastes in a controlled manner, and so to avoid environmental and public health risks due to their uncontrolled degradation. Composting in urban areas began in the late 1960's with windrow composting. The reactor composting of mixed municipal wastes was tested too, with Dano composter, located in Helsinki and Turku.

Great amounts of wastes do not necessarily mean great problems for waste management. Political problems may nevertheless arise if the waste handling too closely affects people in their everyday lives, or if the risks associated with the wastes are thought to be great. So municipal wastes have been subject to heavy debate (Hukkinen 1994). Consequently it is natural that composting is currently mainly applied to agricultural manures, and sewage sludges, and large-scale composting of the source separated biowaste fraction of solid municipal wastes took a rapid leap forward in 1994.

The main producers of 'compost peat' are Vapo Oy (60,000 m³/a) and Kekkilä Oy (100,000–150,000 m³/a). Assuming in an average windrow compost to be roughly 40% sludge/liquid manure, 40% bark/wood chips, and 20% peat (by volume), we can estimate that about 300,000–400,000 m³ of sewage sludges and liquid animal manures (with dry matter content of 15–25%) are composted annually in Finland. Vapo also produces 210,000 m³ of peat annually for use as animal litter (Katainen 1995). After use, some of this material presumably is composted. These estimates suggest that about 1 million m³ of compost is produced in Finland annually (Vasara 1995). This amount is equivalent to roughly half the commercial market for soil (Mantsinen 1995).

State of the art of composting

Composting of municipal wastes

Composting of sewage sludges. When the amounts of sewage sludges in cities first began to increase, the digested sludges were applied as such, to public green areas.

In cities, however, the smell and other inevitable accidents in which people came in contact with the sludge have persuaded city officials to compost the sludges before spreading them (Ahmio 1987, Jyränkö 1986).

For its part, digested wastewater sludge, without further treatment, meets Finnish requirements even for agricultural use. Utilization of sludges in agriculture increased rapidly to 50% in the 1980's, while the deposition of sewage sludges on sanitary landfills decreased to 25%. In the 1980's, however, the farmers' union took a negative stance towards the use of all sludges in agriculture. Of the 1 million tonnes of sewage sludge currently generated annually (with a dry matter content of 150,000 – 200,000 tonnes), about 30% is used in agriculture, about 30% is landfilled, about 30% is used in public green areas, and about 10% is kept on storage areas. Since with composting the value of sludges improves to the point where they become acceptable in agriculture, the amount of sludges composted is growing all the time.

The City of Helsinki Sewage Works (CHSW) treats the sewage wastes generated by 750,000 people, and in 1993 produced digested sludge amounting to 79,800 m³ (dry matter content 15–25%). Almost 70% of this is mixed with peat and lime (the final volume being 67,100 m³) and used in agriculture. The rest is composted with chips, mixed with peat and sand (the final volume being 31,400 m³) and used for public green areas. The direct utilization and composting of the digested sewage sludge is actually now a commercial business at CHSW, although the revenues from the product come indirectly, via the savings in landfill costs. CHSW has been able, with active marketing and reliable customers nearby, to maintain 100% utilization of its sludge for the last ten years. (CHSW 1993).

CHSW has been able to do the open air windrow composting in Viikki, just ten kilometres from the Helsinki market place. Now windrow composting of all sludges is carried out at the new modern composting field in Sipoo, 25 km east of Helsinki. Since the composting in windrows of relatively wet sludges during wintertime is difficult, the dry matter content of the sludge coming from the digestor has been increased to 30% with improved centrifugation. So now the sludge can be stored in heaps over hard winters and composted during the milder seasons. There are no plans to switch to reactor composting in the near future (Lundström 1995). *Composting of source separated biowastes (SSSB)*. Voluntarily adopting an environmentally sound way of thinking, in the late 1980's the Helsinki Metropolitan Area Council (HMAC) undertook its first experiments in collecting and composting biowastes. This led in April 1993 to the windrow composting, at the Ämmässuo sanitary landfill, of wastes from North Helsinki, an area of 100,000 people. The collection area is gradually increased to involve by the year 1997 the whole Helsinki Metropolitan Area (HMA) with its 850,000 inhabitants.

The Finnish winter creates serious problems for open air windrow composting of SSSB. Leachate waters in composting fields freeze, rendering the sewer system out of order and causing a terrible mess in the spring when the snow melts. Because of the cold, odorous compounds volatalize less readily than in summer. Moreover, in cold weather, air containing large amounts of odorous gases may

remain intact for many hours, in really cold weather even for days. With a light wind, a layer like this may drift without dispersing, and if it moves into an inhabited area the result will be most unpleasant. The foul smell produced by anaerobicity in the biowaste compost is so unbearable as to drive people crazy. During the first one and a half years, with the exception of a few short periods, the main problem was the offensive odour, and procedures have been expressly directed to dealing with this problem. Recently HMAC adjusted the crushing intensity, reduced the size of windrows, and removed the anaerobic cores by also aerating the windrows mechanically through channels running along the bottom. The odour intensity has been reduced. (Hänninen et al. 1994). The suitability for agriculture of biowaste composted for periods of two to 18 months was investigated through physical and chemical analyses and with pot trials for barley in the summers of 1993 and 1994 (Mäkelä-Kurtto et al 1995).

The experiments carried out suggested that biowaste can be composted in open windrows with adequate hygiene and without unacceptable odour problems and with the production of a qualitatively good compost. However, composting in closed spaces is taken the preferred approach, the main advantages over the open air alternative being better hygiene, odourlessness, and more efficient water management. A closed composting plant for the HMA is currently being planned (Paavilainen 1995).

With the goal of utilizing both composting and incineration, VTT Energy is involved in the development of the Molok deep collection system of recent Finnish design. In the city of Jyväskylä, in Keltimäki suburban area 1,300 inhabitants are using this collection system. Wastes are separated at homes into four fractions: biowaste, paper & cardboard, glass & metal and the rest, called 'mixed waste'. Wastes are collected into 1,000 – 4,000 litre plastic bags placed in holes dug in the ground, with only one metre of the bag above ground. In one block of flats, after three months of collection, the amounts of wastes were as follows: mixed waste 45.8% (57 kg/m^3 ; $65 \text{ m}^3 = 3.7 \text{ t}$), paper & cardboard 25.7% (116 kg/m^3 ; $19 \text{ m}^3 = 2.2 \text{ t}$); biowaste 25.4% (530 kg/m^3 ; $4 \text{ m}^3 = 2.1 \text{ t}$) and glass & metal 3.1% (180 kg/m^3 ; $1.4 \text{ m}^3 = 0.25 \text{ t}$). All wastes are utilized: biowaste is composted in a drum composter, 'mixed waste' is burned in a pulp and paper mill furnace, paper is used for recycling, and glass & metal are separated and used as raw material. This Molok deep collection system is already used in several communities in Finland, Norway and Sweden as well as in some Western European countries.

Now the new environmental legislation and more detailed regulations published by the Ministry of the Environment call for 50% of wastes to be reused or recycled and only 50% landfilled by the year 2000. In response to this the source separation, collection and composting of biowaste will be introduced in all Finnish cities and major towns. Already this has begun in Helsinki, Tampere, Lahti, Oulu and Mikkeli. The presently preferred treatment method is centralized composting in open air windrows, and the amount of biowastes to be collected in 1995 is about 15,000 tonnes. It is currently estimated that only 3% of the detached houses (20,000) within the organized waste management system will choose composting

in their own small composters, but waste collection fees can be expected to influence this number.

The biowaste accumulation in the Helsinki Metropolitan Area (HMA) into 250-litre surface bins, is measured to be 41 kg of SSSB/inhabitant/a, with an efficiency of separation of 47% (Salo 1995). In the Keltinmäki project the accumulation is 49 kg of SSSB/inhabitant/a. The efficiency of the collection is not yet determined. If it can be assumed that the amount of wastes generated per inhabitant is the same all over the country than in Helsinki and Jyväskylä, we can estimate that the whole of Finland, with its 5 million inhabitants, would produce with 50–55% efficiency 200,000 – 250,000 tonnes of SSSB (with a dry matter content of 50–60%).

Composting of agricultural and forestry wastes

About 14 million tonnes of animal manure and 4 million tonnes of straw is generated annually in Finland (Mäkelä-Kurtto 1995). Traditionally these have been composted in early spring in windrows or heaps – although the process was not necessarily intended or thought to be composting. Now the manure is mostly processed as sludges, and the amount that is actually composted is difficult to estimate. Wood harvesting residues are generated annually 15 million tonnes, their utilization degree is poor, only 2% according to the estimates of Ministry of the Environment.

Reactor composting. The experiences with the two Dano reactor composters in the 1960's were failures. Too much was expected of the equipment, and one individual in Helsinki kept complaining about the foul smell, which evidently came from the drum (Lundström 1993). The upshot, however, was that a cylindrical reactor composter that refines animal waste into fertilizer was developed in Finland in 1970's, and this now provides an economically profitable means of production. Various companies, Biofacta the most prominent, have built 100 drum composters for Finnish cattle farms for the treatment of manure, and quite recently also for municipalities for the treatment of sludges (Kangas 1995). Drum composting would seem to be especially appropriate for very wet materials, sludges with moisture content of 75% can be composted in a reactor with peat as the major bulking agent. The homogeneous mixture produced in drum will compost in windrows better than mixtures made only with a front end loader.

Compost fertilizers are currently based primarily on chicken faeces and residues. Biolan, which is the major manufacturer of such organic fertilizers in Finland, runs four production lines: drying and granulation of chicken faeces 25,000 m³/a; composting of chicken faeces, loosely packed or press baled in plastic bags for fertilizers 10,000 m³/a, production of mull by composting of ground bark, clay and sand and mixing this with composted chicken faeces 30,000 m³/a; production of fertilized peat (peat + composted chicken faeces) 70,000 tonnes/a (Haukioja 1995).

Production of carbon dioxide for greenhouses. A commercial application of composting in horticulture is in the experiments of trying to utilize in warm seasons of carbon dioxide produced by the composting of straw bales in greenhouses. Carbon dioxide is of key importance in greenhouses and the cost of the gas is high (about 10 mk/m²). Difficulties have occurred in the collection and regulation of the carbon dioxide stream.

Composting of industrial wastes

From industrial wastes 5.4 million tonnes or 50% of this is organic fractions (see Table 1). Composting of these wastes in Finland is currently marginal, only bark and wood wastes are utilized to some extent as bulking agents. For many industrial waste fractions, composting would be a suitable alternative.

Slaughter wastes of reindeers. The foodstuff and beverage production wastes in Table 1 include the wastes (3,000 tonnes) of 120,000 reindeers slaughtered annually. Although the amount is rather small, this is a significant waste fraction considering that it is generated in Lapland – a very sparsely populated part of the country. Previously slaughtering was carried out on a small scale in many places, and the wastes were often simply buried in the snow and left for nature to take care of. When, as a lead up to joining the EU the slaughtering was concentrated into a few large slaughterhouses (10,000 – 20,000 animals/a), the waste had mainly to be transported to landfills. There are few fur farms near the slaughterhouses, which could take care of the wastes in a natural way. Composting of the waste is the logical alternative, the humus soil produced finds a welcome use in agriculture.

Table 1 Groups of industrial organic wastes and their amounts in Finland.

Waste group	Amount (1000 t)	Recycled (%)	Landfill (%)	Other (%)
Plant and animal waste	249	60.5	15.5	24.0
Foodstuff and beverage prod.	58	62.0	26.2	12.1
Vegetable and animal fat proc.	56	80.7	9.6	10.7
Carbohydrate refining wastes	6	2.8	6.5	90.7
Animal feed wastes	3	17.8	78.7	3.5
Textile and leather prod.	41	5.6	93.2	2.4
Wood wastes	2,493	92.8	6.8	0.4
Bark	1,362	92.2	7.4	0.5
Cellulose, paper & paperboard	788	50.4	45.0	4.7
Waste paper	192	56.8	29.0	14.1
Paper & paperboard	138	47.8	51.7	0.0
Total	5,386			

Pulp and paper mill biosludges (PPMB) from wastewater treatment are generated in the amount of 360,000 tonnes of dry matter annually. This is the most abundant material in Finland available for composting (more than twice the dry matter content of sewage sludges). Nearly half of the collected sludge is transported to landfills run by the mills, while the other half is burned in the mills as low grade fuel.

Only a few composting studies have been carried out on PPMB. In tests on the use of sludge in agriculture, the composted product was found to be more suitable than the untreated sludge (Campbell et al. 1995, Mäkelä-Kurtto et al. 1992, Ruhanen 1992). There are nevertheless major factors arguing against composting: the huge amounts of material to be processed, the large storage and handling areas required, and the need for large quantities of bulking agents. The marketing of the compost might also prove difficult. Spreading of composted material in forests to increase the humus content of forest soils is not seen as a viable solution. The good effects of such an operation are not appreciated and the costs would be high. Spreading of untreated biosludge, in turn in forests could be considered to violate the traditional Nordic right of public access to forests and the right freely to collect berries.

Composting of toxic wastes and toxicity of composts.

The composting of toxic wastes in Finland has been concentrated on destroying of polycyclic aromatic hydrocarbons (PAH) contaminated soils (Lilja & Uotila 1995), oil residues of service stations (Puustinen et al. 1995) and the phenolics in contaminated sawmill wastes and soils. In conjunction with this, research has been going on in the universities of Helsinki and Turku to develop microbes able to metabolize phenolics effectively.

We found higher concentrations of pentachlorophenol (PCP), polychlorodibenzodioxins (PCDDs) and polychlorodibenzofurans (PCDFs) in SSSB compost than in PPMB compost, although all the concentrations were 'acceptable' (Hänninen et al. 1995). The reason for this might have been that the wood chips used as bulking agent in the biowaste compost contained waste wood impregnated with pentachlorophenol. According to the literature, lumber impregnated with PCP is one of the most probable sources of PCDDs and PCDFs in biowaste composts. It is calculated that 1.8 kg of lumber impregnated with a 10% PCP solution could contaminate 1,000 kg of compost with 0.02 mg/kg of octachlorodibenzodioxin (Harrad 1991). Evidently organochlorine phenolics, which are harmful to the environment when they got into watercourses, are not present in PPMB composts to such an extent as to limit the use of composted sludges.

Toxic heavy metals. The toxicity of composts is usually determined by its total heavy metal content. Based on the literature survey and on our own results it seems, however, that the availability to plants of harmful heavy metals, especially cadmium and mercury, decreases when the composted material is used as growth media (de Haan 1981, de Haan and Lubbers 1983). More studies are needed to determine whether, through the increased use of compost humus, we could decrease the amount of cadmium in our food (Stölzer et al. 1994, Hänninen and Mäkelä-Kurtto 1995).

According to the National Food Administration (NFA) Phosphorus fertilizers are considered to be the major source of cadmium in Finnish agricultural soils

(1995). NFA further estimates the average accumulation of cadmium in Finnish food to be 9.5 (g/daily portion of food, which is 16% of the recommended maximum limit. Varo (1984) estimates it be 13 (g, assuming an average meal having an energy content of 12 MJ. About 57% of the cadmium is obtained from cereal products. One third of the cadmium in food is thought to come from air and the rest from the soil.

The amount of cadmium in the PPMB of the Äänekoski mills near Jyväskylä is slightly more than 3 ppm, and in the ash it is about 15 ppm. The trees the mills process comes were growing in a relatively unpolluted area in Europe. Where does the cadmium come from? In general, the trapping of cadmium from flue gases is rather poor. Is perhaps cadmium being kicked into the atmosphere, when burning is done at high temperatures in order to avoid dioxin emissions? Are we cycling cadmium through high temperature burning?

Perspectives of composting

For the incineration of wastes there is only one plant in Finland, in Turku. In the late 1980's and early 1990's HMAC had plans to build a plant for the Helsinki area, but environmentalists and environmental organizations were afraid that incineration would effectively stop waste recycling (Pohjanpelto 1991). This fear is shared internationally (Young 1991). HMAC did not in the end build an incineration plant, but instead started composting.

One plant in Vaasa is treating municipal wastes anaerobically. The plant is advanced and incorporates modern technology, but the wastes it is processing are poorly fractionated. The quality of these wastes can be described as equal to the mixed municipal waste that was used in composting plants in Europe in the 1960's and 1970's.

The compostable biowaste potential of Finland (as well as all other paper producing countries) lay on the wastes of pulp and paper production. If the black liquor of pulp and paper processing is taken into consideration the biowaste potential is increased to a global dimensions. However, at the present fiber production technology this waste group is burned in order to recycle the cooking chemicals, and its energy potential is utilized, too. The Ministry of Environment is planning to levy costs on the landfilling of PPMB (which fraction do not any more contain cooking chemicals), even in the case the landfills are owned by the plants. If such measures are realized the interest on the treatment of PPMB waste e.g. by composting will in the near future increase.

The role of composting in Finland in waste management is expected to increase, and it is not expected to be threatened by either incineration or anaerobic treatment. All are important waste treatment methods, for which symbiotic development is desirable. A danger may lurk, however, in the too eager effort to turn waste management from a cost incurring problem into a profitable business. Profits can accrue only if collection fees are levied on individual households. In Sweden high

fees have already led to a reduction in amounts of waste collected, and communities are concerned about making their investments profitable (Erikson 1995). In Finland the right to dispose of one's waste without or with a minimal charge has long been taken for granted, and levying a too high fee might cause amounts of collected wastes to diminish. Right at the outset this may create an important obstacle to the entrepreneur running a business: can there be guarantees of a continuous supply of the raw material, and of achieving a profitable return on investments within a narrow space of time?

Peoples' attitudes towards waste recycling are relatively favourable in Finland now. All measures should be directed to encouraging these attitudes, because the collection of SSSB fractions for recycling and reuse largely depends on attitude. An obvious danger that needs to be avoided is that householders diligently sorting their biowaste should come to see their efforts as futile if the biowaste (or other waste fractions) ends up on the dump anyhow.

The quality and image of the SSSB compost are important. It should be acceptable for high quality use in home gardens. Means and methods to identify and to standardize the 'good quality' needs to be developed. Chemical identification of the compounds in the organic matter of the compost, and following the changes in composition as the process proceeds, are of key importance in determining the quality of the compost. Chemical analysis of the humus has shown the importance of aliphatic, especially carbohydrate derived-structures, to be underestimated and the importance of aromatic structures to be overestimated. For this, methods for further fractionation and determination of the humus compounds need to be developed. Good quality would guarantee good demand of SSSB compost.

Cradle-to-grave concept. Now, it is no longer sufficient to produce materials with functionality, production efficiency, and economics as the only design criteria. The 'cradle-to-grave' concept of material design requires planning for ultimate disposal of the material in an ecologically sound manner. There is a need to design and engineer materials with consideration for their method of disposal. The attributes of recyclability and biodegradability should be built into the materials, but without loss of the performance characteristics. Separate infrastructures must then be developed for materials in order they then end up in the appropriate processing. Recyclable materials will need to be collected and transported to a recycling facility, to be processed into the same or new products. Similarly, biodegradable materials will need to be collected and sent to a facility where, along with other wastes they undergo biodegradation into compost. (Narayan and Snook, 1994).

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Perspectives and State of the Art of Composting in France

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Summary

The present French situation of waste management is the result of traditional treatment plants, sorting-composting MSW composting plants for instance, which are still running, and new perspectives coming from the achievement of the national policy (law n° 92-646 published in 1992). This transition period can be an opportunity for composting development if the three levels of analyze are correctly assessed as well as waste management alternative and as agricultural and ecological pertinence. For this assessment, better knowledge on impacts and new tools of management (including monitoring and control) are required. Up to now, we can consider that, in France all the conditions of composting development are present depending on a common will to do it. The Ademe will propose an adequate working scheme for the next 5 years, hoping that its partners will agree and correctly consider the effort that must be done.

Introduction

In France, composting has been traditionnally used for municipal solid wastes. In 1989, about 1.1 millions tons of MSW (7.5% of the French MSW production) were treated to produce 650,000 tons of compost. The 75 ‘sorting-composting’ plants used to run either slow composting (open air windrow turning – 42 plants) or accelerated composting (33 plants). The evolution between 1985 and 1989 shows a slow decline of composting (Table 1), partly because of compost marketing problems. During the same period, sludge composting has remained marginal with only 5 to 7 sludge composting plants of the first generation. Since 1985, the ANRED (now Ademe) has tried to develop composting either by improving ‘sorting-composting’ plants and the quality of urban compost or with new applications, to yard waste or animal manure for instance, or new strategies for sludge composting. But, the competition with landfilling didn’t play in favour of more investments, new technologies ...

Table 1 Evolution of Treatment of MSW from households in France (1985 vs 1989)

	number of plants	raccorded population total	%
Thermal Treatments	+5.8 %	+16.4%	+10.5%
Biological Treatments	-16.5%	-1.6%	-6.3%
Landfilling	+41.9%	+29.0%	+0.7%

In 1989, the ANRED has published a technical document on sorting-composting of domestic wastes which analyzed the main problems of these kind of plants: the efficiency of sorting devices applied to such an heterogeneous product: garbage. The development of Quality Certificate for Urban Compost has also been promoted but failed in improving the marketing situation of these products.

Finally, in 1992, the national policy for waste management has been precised with the publication of the law n° 92-646:

- landfilling is no longer a treatment process but a storage stage dedicated to the ‘ultimate waste’
- ‘ultimate waste’ is a waste resulting or not from waste treatment and which cannot be any more treated for recycling or to decrease their pollutant potential, considering the actual technical and economical conditions
- wastes management plans must be realized (deadline 1996) on a department level for municipal (and similar) wastes (excluding toxic and hazardous waste – regional plans).

Considering these events, what can be the place of composting in the future in France? To answer this question, three levels must be analyzed:

- i) the management of wastes through composting
- ii) the conception and running of composting plants
- iii) the process of composting

Composting: from waste management to treatment plants

The French policy for waste management considers:

- reuse and recycling of wastes: waste derived products
- energy recovery through incineration: waste derived energy

as acceptable options. As far as compost is a waste derived organic fertilizer, composting is an acceptable option. But, there is also a specific regulation on waste from packaging, with a specific financial mechanism: Ecoemballage, which aims to help recovery and recycling of this part of the waste flow.

For domestic wastes, the main problem is on source separation and mainly on the number of bins in households. The last evaluation of departmental plans has shown that municipalities prefer the two bins following scheme:

- source separation of clean materials vs the rest,

- developpement of materials sorting centers (150 in 2002) ...
- combined with incineration and energy recovery (twicefold treatment capacity). Only few experiments consider source separation of organic matter. But, composting is chosen for yardwaste treatment from private and public gardens and green spaces.

Sludge management will depend on the access of sludge to agriculture, mainly through spreadings of stabilized products, i.e. after lime, or thermal, or biological treatments, including composting. In some cases, more sophisticated schemes are studied, mainly co-treatment (co-composting) of organic wastes from different origins (municipalities, agro-industries, agriculture ...).

For animal manure, composting is studied as a way to improve their management either on a farmscale level or for marketing. The aim is clearly to answer to the new constraints on nitrogen load limitations coming from nitrate regulations.

In 1993, a national survey of composting plants has given the following results:

- 73 MSW composting plants (no source separation)
- 13 sludge composting plants (+1 project), co-composted with different bulking agents (sawdust, bark, straw...)
- 30 yardwaste composting plants (+21 projects)
- 16 farmyard manure composting plants
- 10 other kind of wastes or mixed composting plants

Future development for composting will depend on two trends:

- a) the emergence of departmental schemes for organic wastes management, whatever the waste origins and including the fate of composts
- b) the attraction of domestic organics source separation, compared with other alternatives and depending on the number of bins in households

Thus, the Ademe is working on:

- a) the concept of biological management of waste, including but not exclusively composting and compost impacts. The aim is to define an acceptable alternative strategy, based on sound scientific knowledge and easy to present and justify.
- b) the role of farmers within this concept, as partners and the possibility of a specific mechanism to guarantee the final use of waste derived fertilizers. It is not only a problem of compost quality, but also a problem of agricultural practices.
- c) Standards for different types of compost and Quality Insurance applied to this kind of waste management

Composting: from treatment plants to technologies

The fate of the existing 'sorting-composting' plants will depend on the strategic choices of each departmental waste management plan. All these plans must be achieved for the end of January 1996. But, it will also depend on their efficiency and of the state of their compost market. The other point is the flexibility of the composting technologies and their ability to compost either source-separated organic waste or other kind of waste. Most of these plants are owned by municipalities, which limits the possibility of new uses. Their treatment capacities range from less than 4,500 MSW tons/year to more than 60,000 MSW tons /year.

Table 2 presents the different technical diagrams of these plants. Different technologies are used for each stage. For instance, shredding can be done with 'rotating shears' or 'shredding trommels'. Sorting devices are numerous and reflects the difficulties of this stage. 7 types of technologies (magnetic, densimetric, air-classification, sieving ...) has been analyzed and evaluated. Slow composting differs mainly by the windrow-turning machineries and by the management of turnings. The technologies for accelerated composting include towers or cells or rotating drums with different kinds of forced-aeration control.

Table 2 Technical diagrams of 'sorting-composting' plants of MSW

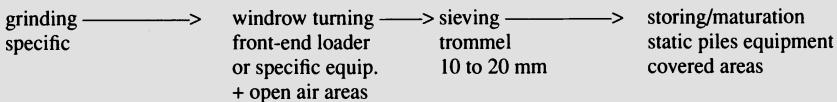
	DIAGRAM 1 (15 plants)	DIAGRAM 2 (10 plants)	DIAGRAM 3 (9 plants)	DIAGRAM 4 (7 plants)
1°	GRINDING	GRINDING	GRINDING	SHREDDING
2°	SORTING	COMPOSTING	COMPOSTING	COMPOSTING
3°	COMPOSTING	SORTING	MATURATION	MATURATION
4°	MATURATION	MATURATION	SORTING	SORTING

The efficencies of these technical chains has been assessed with two types of parameters: the part of organics in compost and the part of non-organics in rejects. The results show that to have a relatively good quality of composts, a significant part of organic matter must stay in rejects. A final assesment of sorting-composting plants is carrying out on the efficiency of sortings on the different trace-elements flows.

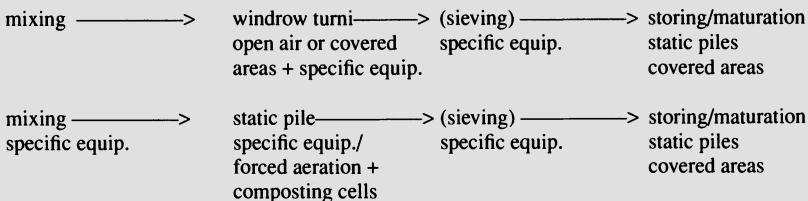
Other composting plants are rather small plants. Treatment capacities range mainly from 5000 to 10,000 tons of waste per year, and investment costs from 2 to 7 millions Francs. The ratio between Investment and Treatment capacity goes from 500 to 800 F/ton. These plants are running at 30 to 60 % of their treatment capacity, with treatment costs between 150 to 300 F/ton. As far as the production of compost is 35 to 65 % of the treated waste, it is difficult to compare the different plants on their production characteristics.

The different technical chains are as follows:

a) for yardwaste composting



b) for sludge composting



For this new composting plants, the problem of composting management is crucial: odour control, leachates, mixing monitoring, retention time ... and is the present field of improvement.

Composting: from technologies to the process

The process of composting is too much considered as a natural process, which works by itself. The management of the microbial ecosystem, related to nutrients inputs, to energy control and to environmental conditions (moisture, oxygen, temperature ...) must be much more strict than it is up to now.

The Ademe tries to develop Research and Development on composting: simulation equipments, process modelling and composting trials.

A first work on composting simulation has been done by the INSA of Lyon. After a first period dedicated to the conception of the equipment, tests of organic mixtures have been carried out. Some improvements are required mainly on the thermodynamic aspects as well as new tests of organic wastes. The aim is to predict the behaviour of products during composting. Composting trials applied to pig slurries mixed with different kinds of carbon bulking agents are realized in Brittany by the C A T of Quatre Vaulx. The aim is to compare forced aeration vs windrow turning and the ability of the bulking agents to compost with a maximum load of pig slurries. This work must be achieved for next June.

The part of R and D on composting is too much low and the Ademe intends to develop it whith Research programmes during the next 2 or 3 years. The problems of nitrogen behaviour and fate, of odour controls, of pathogens control and of air emissions need more scientific works.

The other point is technologies development. The future development of composting will come from yard waste composting. But, the required technologies for YW composting are based on grinding /windrow turning/sieving. It works pretty well because of the 'ideal'composting kinetic of YW. But, mixed with sludge or

with source-separated organic wastes, troubles arise because of a deficiency of process control due to windrow turning limitation. There is a technological breakpoint from windrow turning to forced aeration. So, the Ademe will develop R and D on forced aeration in the next two years: air production and distribution, monitoring equipments and strategies ...

At longer term, a microbial management may be needed for some specific uses of composting or for specific compost qualities (relation with soil ecosystem).

Composting and composts

The application of composting to different types of waste shows that the characteristics of compost are mainly inherited from the waste inputs (graph 1 and 2), even if composting influences numerous parameters as the content and quality of the organic compounds, the moisture, particles size, nitrogen flow, pH, the pathogenic potential, conductivity...

Referring to the French waste management policy, the problem of treatment processes comes after the problem of waste fate. Compost utilization is much more important than compost production. The need of quality parameters related to uses is obvious and supposes to have numerous references from field trials. A major point is to define a soil quality policy in order to control trace-elements flows.

One question for the future is how far must go the transformation process in order to fit agricultural uses, and thus, what will be the limits of composting, facing this production goals.

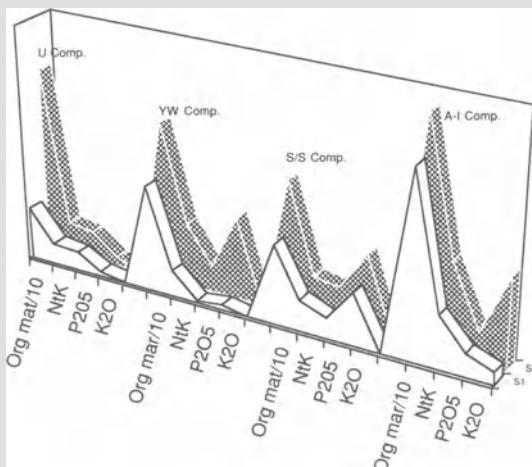


Figure 1 Profiles of different composts according to the Quality of the initial wastes

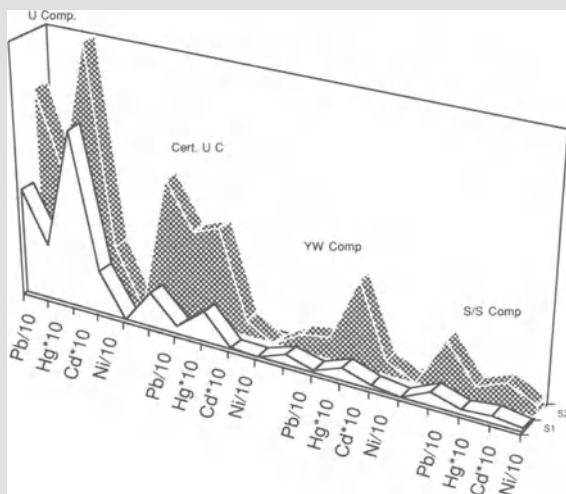


Figure 2 profiles of different composts according to the Quality of the initial wastes

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Composting of Agricultural Waste in Denmark – in Respect of Potential, Industrial Process Technology and Environmental Considerations.

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Abstract

An amount of at least 1.000 mio.tons of slurry from animal husbandry in Europe should, based upon environmental considerations, be subject to centralised treatment in order to recycle nitrogen and utilise the energy potential.

The process technologies until now are lacking behind in order to fulfill ecological requirements to nitrogen recycling and utilisation for fertilising purposes, whereas the energetic utilisation by means of biological processes has been highly developed .

The existing paradox, where costs of BOD reduction in urban areas are accepted to be over 100 times higher than what is allowed in the animal husbandry sector, even under very negative ecological impacts by denitrification and high consumption of fossil energy, can only be overcome through sector integrated waste treatment allowing energy neutral operations etc..

The NRS–SEABORNE technology should be a modern innovative mean to go for in urban/agricultural integration within waste treatment, ensuring ecological sustainability as well as clear advantages expressed in pure financial terms at the moment.

European potential for centralised treatment of agricultural waste.

The major potential emerges as residues from animal husbandry.

As long as milk, meat and eggs etc. are in demand huge amounts of slurry will occur e.g. for 1 ltr. of milk app. 3 ltr. of slurry and for 1 kg of meat app. 13 ltr. of slurry. More industrialised systems in animal husbandry are provoked out of a common public desire to obtain steady relatively lower prices of animal products for food.

Thousands of productive animals gathered together in industrialised farming

systems on the other hand causes troubles to an environmental cross compliance between production, fertilising and substitution of inevitable losses of plant nutrients.

Composting has in the history of farming been the traditional way of ensuring soil fertility by recycling, even that nitrogen has been a limiting factor to production just until the availability of fossil energy in abundance came up in this century. It is thus in an *extremely short period* within the history of mankind that recycling not has been a must, solely as a reason for survival of human beings.

In a work for the European Commission, DGXVII (Lit.ref. 1.) we have examined the european potential which could become a subject to centralised digestion of animal wastes.

The total amounts of animal wastes in the European Union, prior to the enlargement in 1995, were found to be – calculated as slurry with 6% VS and listed in order of magnitude:

France:	425 mio. tons / year
Germany:	300 mio. tons / year (except the new 'Länder')
England:	215 mio. tons / year
Italy:	200 mio. tons / year
Ireland:	125 mio. tons / year
Spain:	120 mio. tons / year
Holland:	110 mio. tons / year
Belgium:	65 mio. tons / year
Denmark:	50 mio. tons / year
Portugal:	30 mio. tons / year
Greece:	15 mio. tons / year
Luxembourg:	3 mio. tons / year
Total:	1.658 mio. tons slurry / year, (6% volatile solids)

The slurry from animal husbandry represents in many regions of the Union an energy potential excessing 250 kg oil equivalents/ha.

Our survey for DGXVII has proved that app. 60 % of the above amounts should be subject to centralised digestion and recycling measures for plant nutrients. This finding has been based upon combining environmental and energetic points of view with the allocation in regard of density per ha for the slurry potential.

Centralised treatment measures for around 1.000 mio. tons / year presents an enormous task of engineering, but seems inevitable if the environmental concerns about recycling and emissions shall be met, ensuring supply and price level for animal products to the consumers.

A great paradox exists among what we are willing to pay for cleaning up waste water of human origin and what is demanded of the farming system as allowable costs for its animal waste, although it basically is about the same stuff.

1.000 kg BOD emerges yearly from around 50 adult human beings equivalent to what comes from 30 pigs or 1 milking cow.

Sewage plants for human beings have costs of establishment around 10 ECU

per kg BOD treated yearly and the yearly costs of operation can come to 15 ECU / kg BOD. It seems somewhat unrealistic to expect that the agriculture can solve its slurry handling problems in an environmental sustainable way for costs *less than 1 %* of what is accepted costs of cleaning up after human beings, but that is as a matter of fact what the european farming industry is up against recently, where recycling and the environment have been put into a political focus. If the previous mentioned costs of waste water treatment from human beings should apply to animal husbandry prices for 1 ltr. milk and 1 kg meat should be added respectively 2 ECU and 8 ECU !

The paradox related to the accepted high costs in cleaning up waste water from human beings also includes the 4 – 5 doubled consumption of fossil energy when removal of N & P is required. Can it be an environmental target to pollute the air, even without substantial recycling of N, in order to have more clean water ? It should hardly be the case and the conclusion remain that more sustainable methods of recycling and low emission for all wastes, including the agriculture, should be in high demand.

Applied industrial process technology and development of new innovative processes e.g. the NRS–SEABORNE technology.

The amounts in question calls for drastic reductions in volumen besides the concerns of preserving nitrogen on plant available forms. Both the aerobic and the anaerobic way can reduce BOD, but hardly cope with the desired reduction in volumen. In DK as in most other european countries a number of physical and biological methods have been put into operation e.g. distillation, reverse osmosis, nitrification and denitrification. They are all costly in terms of energy with e.g. reference to the high costs of purifying human residues in sewage plants mainly based upon the biological processes.

Under parallel session B 5 tomorrow at noon, some innovative processes under patent pending will be presented of the inventor dr. N.O.Vesterager from Germany. It is not up to me to make anticipations about this presentation on its technical aspects, but it shall be stated that the processes of dr. Vesterager's are fulfilling major requirements to ecology and economy as regards treatment of agricultural waste and even can facilitate the gateway to co-digestion and energy-neutral cleaning up after human beings. The point is, in particular for the process to treatment of slurry from animal husbandry – the NRS process (N=nitrogen, R=recycling, S=system), that the innovations of dr.Vesterager's are complementary to usual physical and biological processing, but solely is based upon the chemical premises of the nitrogen itself. We have followed the work of dr. Vesterager for 6 years on an advisory basis as regards the practical aspects to an agricultural implementation. At the moment it is close to a first demonstration plant and the financial competitiveness is seen in the following way:

NRS-40 economy in upgrading slurry from animal husbandry.

Background: 6 years of research and technical development, partly with EU subsidies. The NRS process can be applied without any pretreatment or downstreams an usual aerobic or anaerobic processing. Posttreatment in the aerobic way can come in question.

Preassumptions: 30.000 m³ slurry/year NRS treated. 2/3 of that with NH₄MxPO₄ precipitation and 1/3 with recirkulation of MxHPO₄ and precipitation of C₆H₁₂N₄.

Costs of construction, 1'st demo.plant: 0,8 mio. ECU

Costs of construction, following plants: 0,7 mio. ECU

Depreciation: 15 years, rate of interest: 6 % p.a., maintenance: 2 % p.a..

The NRS-40 plant is with buildings and independent

installations, but connected to exstern heat- and electricity supply.

By integration with a sewage plant and co-digestion of sewage sludge, solid organic household waste and slurry from animal husbandry, including CPH generation, the costs of construction per m³ treated for the NRS part can be very low, cut down to less than relatively half of the above.

	Costs ECU/m ³ slurry NRS upgraded		
	NRS-40	NRS-40	NRS-40
1'st demo.		Following	Integrated
30.000 m ³ /år		30.000 m ³ /år	120-150.000 m ³ /år
Variable	2,0	2,0	1,6
Capacity	0,5	0,5	0,2
Capital	2,8	2,3	1,4
Total	5,3	4,8	3,2

Comparative european slurry costs under 'good' application.

(9 months storage, trailing hose system, 50 % N utilisation)

	ECU/m ³
Storage	3,5
Field application*	1,8
N loss **	0,5
Total	5,8

* Differential costs, equal amount of plant nutrients applied in solid fertiliser incalculated.

** By NRS-40 the N utilisation increases from 50%—> 80 %.

NRS-40 ecological advantages, beyond the above pure financial terms, can in common be quantified to app. 3 ECU/m³ slurry and would be financial relevant, if the farming industry equal to other industries to full extend was underlaid the 'polluter pay' principle.

The NRS costs represents less than 1% of what remains social acceptable costs by cleaning up the very same stuff after human beings and in the case of normal sewage plant operations there will occur negative ecological impacts due to denitrification and hudge consumption of fossil energy.

The NRS-SEABORNE technology of dr. Vesterager's represent a missing link to implement sector integrated waste treatment in a sustainable ecological way under financial competitiveness far beyond what to-day is accepted in urban waste water treatment.

Environmental impacts of the NRS-SEABORNE technology within treatment of agricultural wastes.

Some disadvantages incurred by storage of slurry in environmental and agricultural terms can be listed without any attempt to financial quantification:

- surface emission of NH₄ during time of storage
- CH₄ emission during time of storage
- problems of bad odours from mainly emissions of volatile S compounds
- increases in amount caused by rainfall
- potential danger of uncontrolled slurry outlets to the environment,(concentrated pollution, expensive to clean up)
- high peak in agricultural work pressure by the application within only 3 months.
- problems of social acceptance by the agricultural slurry application in a time of the year, where the farmland is at a peak of its natural beauty.

Environmental benefits as regards a better social acceptance of the agriculture by avoiding bad odours from slurry handling can hardly be quantified in financial terms. Reduced emissions and effluence of nitrogen can better be dealt with.

As indicative figures it should be stated that 1 kg nitrogen more recycled pr m³ slurry saves 17 kWh in fossil energy in reproducing the equivalent amount in commercial fertilisers. In the same way removal of 1 kg nitrogen in waste water, in order to lower the polluting impact by discharging excessive nitrogen to the water environment, demands app. 7 kWh fossil energy equivalents. Altogether it seems realistic to claim savings of more than 20 kWh in fossil energy equivalents pr kg nitrogen recycled from slurry, which also can be expressed in terms of reduced CO₂ emission, possibly subject to a coming environmental levy within the European Union. Reproduction of 1 kg N causes emission of app. 4 kg carbon-dioxide under input of the required fossil energy equal to app. 60 MJ/kg N.

As regards environmental benefits emerging from reduced CH₄ emissions it shall only be stated that methan as a greenhouse-gas has to be considered as several times worse than carbondioxide – a natural consequence of differences in chemical/physical properties.

Denitrification in the soil can, especially by overloaded slurry fertilising, be remarkable causing emission of N₂O, which as an greenhouse gas is considered to be over 20 times so bad as CH₄, which again is considered to be 10–20 times worse than CO₂.

Based upon the above it does not seem unrealistic to assume the more common

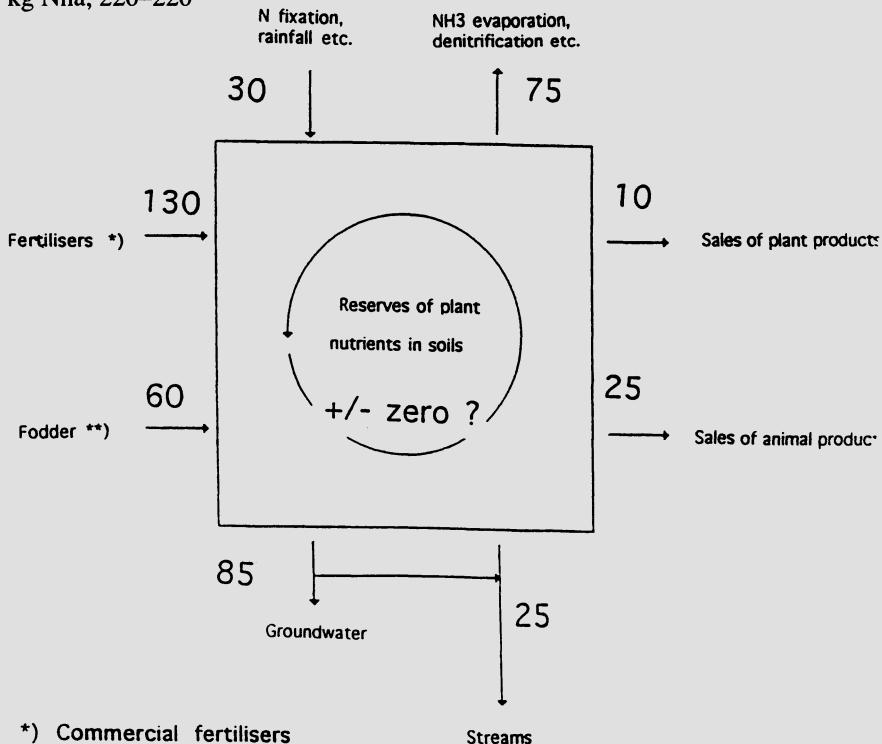
and quantifiable environmental benefits to amount to at least 3 ECU pr m³ slurry treated by the NRS technology.

A number of probable advantages by the new technology related to chemical/physical circumstances around citrate/water solubility and plant up-take of nutrients, all as connected to preservation of groundwater resources, have not been taken into account but these could even be the most striking impact of the NRS technology in the future as the polluting effects of water soluble commercial fertilisers appears more and more.

An attached appendix shows an attempted N mass balance for the agricultural system for emphasising the relations. The approximative figures applies to situations in the northern part of the European Union and is put up after a cross examination and evaluation of datas of environmental investigations from the last 10 years.

Appendix:

N-mass balance, agriculture app..
kg Nha, 220-220



*) Commercial fertilisers

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Composting in Italy: Current State and Future Outlook

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Abstract

In this paper the existing composting plants in Italy, either in operation or that are about to come into operation in a short-to-medium time, are localized and the problems associated with two different approaches to composting are discussed: either from household waste that is not source separated or following the recovery and processing of sorted biomasses.

A general overview shows a large number of ‘conventional’ plants (n° 42), most of which were designed in the late ‘70–80s’. These must undergo deep, albeit gradual, changes in their productive process or, alternately, the organic component is to be biologically stabilized before dumping. The existing processes will be maintained only if there is evidence of actual opportunities to profitably use the compost.

Selected waste processing plants are rising fast (today they are at least 33) and some of them (at least the most efficient ones) have gained large market shares, due to their striking agronomic and environmental features.

These advances, however, may be in vain, if the existing legislation, not encouraging the production of high-quality compost, remains in force. Although, however, this seems to be about to be amended, unacceptable restrictions are likely to be introduced by the Ministry for the Environment in terms of environmental criteria related to the building of plants and compost quality standards (with special regard to the levels of some heavy metals, such as copper, zinc and lead).

Generalities

The processing of municipal solid waste for the purpose of compost production restricts the opportunities to put the resulting products to an efficient agricultural use, these often being of poor quality.

The large number of plants that are currently in operation nationwide (at least 42) must urgently come to grips with the problem of compost underuse in agriculture, either through the identification of other possible applications, such as the daily and final covering of controlled landfills, the reclamation of degraded areas and the sanitation of polluted sites, or through a process of biological stabilization of the waste organic matter, so that this can be then safely dumped, or finally retrofitting these plants to cater for the latest production requirements, as with other plants that already exist or are in the design stage (n° 6).

The possibility of using municipal waste compost as a farmland fertilizer has proven to be virtually non-existent or not feasible, due to a number of factors, mainly resulting from the current complex and conflicting regulations, requiring, among other things, that technical and administrative prescriptions are strictly followed and, thus, discouraging farmers from using compost (prior control of soil conditions, limitations in the usable compost amounts, etc.), as well as to the prevailing conditions in some national areas, where the naturally existing or induced content of heavy metals is higher than is laid down by law, and finally to the likelihood that further legislative constraints are introduced.

In this regard it should be emphasized that at present very few plants turn out municipal solid waste compost that comply with the existing regulations, and are therefore to be considered exceptions (Zorzi and Urbini, 1994).

It should also be noted that the actual composition of waste make it less suitable for the recovery of organic matter from unprocessed waste, due to the fact that this is increasingly mixed with larger and larger amounts of foreign fractions. Indeed, even though the organic matter proportion has remained nearly unchanged in absolute terms in recent years (a decade ago organic matter accounted for 35–40% of a daily waste production, estimated to be equal to 800 g/inhabitant; today the organic matter component is of the order of 25–30%, while the unit waste production has gone up to 1000–1200 g/per unit), the increase in unwanted fractions, such as glass and plastics, may considerably deteriorate the quality of compost from municipal waste (AA.VV., 1994).

It is beyond doubt that any attempt not to landfill the organic component of waste failed not only because of the motley nature of waste, but also of the inefficient sorting and final enhancement technologies, the poor understanding of plant processes and the poor management.

This led to the general consensus that only through the source separation of waste with a high organic component, compost can be obtained that is beneficial for plant crops and environmentally safe. This goal can be achieved through separate collection programmes, that should best be implemented first in large producers of waste, or at least not solely in households.

Any such programme is to be devised while keeping in mind the individuals to be involved in the different steps, finding out whether they are willing to reorganise their waste collection services and identifying in advance the compost center that can handle the selectively collected waste, in the amounts and at the times as are convenient for the collection service.

The separate collection of wet waste, as was provided for in the Ministerial Decree 29.5.91, was never put into practice by the Italian Regional Authorities and just very few of them have taken some measures, failing coordination and planning. If, on the one hand, several municipalities in Piedmont, Lombardy and Veneto, and to a lesser extent even in Emilia-Romagna and Tuscany, have steered the pathway of organic component separation even in household waste, not always exist authorized facilities to accommodate these materials, which are often meant for landfills.

Based on its new concept, composting plays the role of a production technology, whereby products largely fulfilling the market requirements can be won from a large variety of selected waste. This could, therefore, at the same time cover the farmers' needs for organic conditioners and help solve waste disposal problems. The failure of many municipal waste programmes brought a negative feeling about composting to farmers. Hence the proposal that high-quality compost products should be renamed, and be referred to in the fertilizer legislation (Act L 748/84) as green or mixed composted conditioners.

In other European countries the conventional plants underwent dramatic retrofitting changes, so as to process only or nearly only source separated waste.

On account of the high investments made to build the over 40 conventional plants that will shortly become operational in this country (so far a total of between 900 and 1000 billion Lit was spent), a wide-ranging analysis and a global proposal are needed according to guidelines fixed at national level, thus avoiding to fix local situations only, as was actually the case in a few instances. The wealth of technologies deployed in the existing plants, as is required by the complex nature of untreated waste, should not be wasted, indeed retrieved and enhanced, through low-cost investments, in order to process selected waste.

Should the present operational approaches not be revised and things remain as they are, one should find out whether, among the possible alternative uses of compost (intermediate filling of landfills), it is best to perform short biostabilization and sanitation processes of the waste organic matter (25–30 days) rather than a long term composting. The former approach is known to afford advantages not only in relation to quantities and volumes, but also in terms of reduced production of leachate and biogas, materials sanitation, and low emissions of foul smells. In addition the plant capacity would be greatly increased as a result of the shorter leadtime.

If other possible applications of municipal waste compost are to be considered, such as reclamation of degraded sites, a thorough knowledge of all critical cases is needed, as well as a survey of any local short or medium term plans developed or implemented in the fields of landscape architecture and environmental protection. At the same time all those concerned with waste recovery should be bound to use the resulting compost.

Few (n° 6), although particularly significant, plants elected to compromise, and set up, either in a temporary or final way, two different waste processing lines: one intended for the production of compost from unsorted municipal waste or for the biostabilization of organic matter, the other for the biological transformation of

selected waste into top-quality compost.

Separate collection of organic matter from catering operations or commercial businesses, and possible from households, as well as the recovery of waste from fruit and vegetable, flower, fish and neighbourhood markets, of prunings or grass mowings, of selected agroindustrial sludge and sewage sludge, of waste from food, textile, paper and wood manufacturing plants, and of crop and livestock residues are a must if we are to obtain raw materials to produce a high-quality compost that sells easily on the market.

Hence the need or opportunity to develop storage and treatment platforms, which can accommodate waste of different nature and origin, thereby providing a comprehensive approach, not limited to municipal waste, to the disposal requirements of a given catchment area. Such waste, particularly if from large urban areas and production units, are frequently source separated, or can be easily separated, and therefore can be recovered following just a few minor adjustments to the collection and delivery systems.

Of the utmost importance, prior to any biological process, is the identification of guiding principles, whereby the suitability of any waste for processing into quality compost can be evaluated.

For these programmes to be successful and profitable, enterprises should develop a deeper understanding of composting techniques through an ongoing management of plants, i.e. not limited to the design and implementation phases. In this way they could submit more advanced technical tenders than they do now.

After completion of the biological process, users must be assured as to the high quality of compost. To this end a voluntary compost producers' association has been established (Consorzio Italiano Compostatori), who process only strictly selected waste and have adopted a seal of quality, to be granted solely to productions that fulfill the agronomic and environmental standards set by its technical-scientific committee.

Compost plants processing source unseparated municipalwaste

A total of 42 plants for the production of compost from unsorted municipal waste, and in some cases added with sewage sludge from waste water treatment plants, were built or are about to come into operation throughout the country (table 1). Most of these were designed in the past decade (and some even before), but a number of them have not been completed or tested yet. What amazes, and even concerns us, is that several plants, for different reasons, have been for some years now in an advanced state of development, with no estimate whatsoever of when they are going to be completed or start operation (Sulmona and Vallo di Diano 95%, S. Maria Capua Vetere, Tempio Pausania, Col San Felice 90%, Reggio Calabria 75%, Pescara 30%, Ostellato 55% etc.). Consequently chances are that the current technologies become quickly obsolete and inefficient and get into a state of disrepair.

Table 1 Composting plants treating MSW or MSW and Sewage Sludge (still working or to be set up in the short-medium time)

Plants	Technology	N°	Capacity ton/year	ton/d	Products	Compost ton/year
Piemonte						
Cuneo	Peabody		45000	150	compost;RDF	9000
Novara	Emit		75000	255	compost;RDF	15000
SUBTOT.		2	120000	405		24000
Lombardia						
Ceresara (MN)	Daneco		48000	160	compost;RDF	10000
Pieve Coriano-MN	Daneco		63000	210	compost;RDF	12500
SUBTOT.			111000	370		22500
Friuli						
S.Giorgio di Nogaro (UD)	Ferrero		70000	250	compost;RDF	25000
Udine	Daneco		80000	280	compost	16000
Villa Santina (UD)	Daneco		25000	90	compost;RDF	8500
SUBTOT.		3	175000	620		49500
Alto – Adige						
Bolzano	Weiss-Kneer		135000	450	compost	35000
Bressanone	Bühler		22000	75	compost	5000
Pontives	Vöst Alpina		18000	60	compost	4000
SUBTOT.		3	175000	585		44000
Veneto						
Feltre (BL)	db		36000	120	compost	8500
Schio (VI)	Slia – Snam		40000	160	compost;energy	8000
SUBTOT.		2	76000	220		16500
Emilia Romagna						
Ozzano (BO)	Weiss-Kneer		33000	110	compost;RDF	8000
Ostellato (FE)	db		39000	130	compost	9500
SUBTOT.		2	72000	240		17000
Toscana						
Massa Carrara	db		70000	250	compost;RDF	15000
Pistoia	Slia		60000	210	compost	12000
SUBTOT.		2	130000	460		27000
Marche						
Ascoli Piceno	Secit		78000	260	compost	19000
Fermo (AP)	Secit		63000	210	compost	15000
Pollenza (MC)	Secit		55000	180	compost;energy	12500
SUBTOT.		3	196000	650		46500
Umbria						
Perugia	Sorain - Cecchini		115000	380	compost;RDF	15000
Foligno (PG)	Cecchini		38000	110	compost;RDF	6000
SUBTOT.		2	153000	490		21000

db: De Bartolomeis

Table 1 Continued

Plants	Technology	N°	Capacity ton/year	ton/d	Products	Compost ton/year
Lazio						
Col S.Felice (FR)	Sorain C.		160000	600	compost;RDF	28000
Terracina (LT)	Slia		45000	150	compost;RDF	9000
SUBTOT.		2	205000	750		37000
Abruzzi						
Giulianova (TE)	Cons.coop		28000	95	compost	7000
Pescara	Emit -'		60000	200	compost;RDF	15000
Sulmona (AQ)	Emit		24000	80	compost;RDF	5000
Vasto – Cupello (CH)	Daneco		42000	140	compost;RDF	9000
SUBTOT.		4	130000	515		36000
Campania						
Caserta	db		103500	345	compost;RDF	13500
S.Maria Capua						
Vetere (CE)	db		49000	160	compost;RDF	9500
Vallo di Diano (SA)	db		18000	60	compost;RDF	4000
SUBTOT.		3	163500	545		27000
Basilicata						
Matera	Secit		19000	62	compost	5500
Tursi (MT)	Secit		24000	80	compost	5500
SUBTOT.		2	43000	142		11000
Calabria						
Cosenza – Rende	db		60000	215	compost;energy	14000
Lamezia Terme (CZ)	Italimp.		45000	130	compost;RDF	11000
Reggio Calabria	db		75000	260	compost;RDF	18000
Rossano Calabro (CS)	Snam		45000	130	compost	11000
SUBTOT.		4	232000	755		54000
Sicilia						
Regalbuto (EN)	db		36000	120	compost	8500
Trapani	db		30000	120	compost;RDF	8000
SUBTOT.		2	66000	220		16500
Sardegna						
Cagliari	db		150000	600	compost;energy	30000
Macomer (NU)	Ferrero		45000	160	compost;energy	10000
Tempio Pausania–SS	db		30000	120	compost	6500
Villacidro (CA)	db		40000	140	compost from anaer. digestion	8500
SUBTOT.		4	265000	1020		55000
TOTAL		42	2336000	7907		505000

Note: some values are the average of the capacity in relation to the seasonal incomings; the compost production of several plants has been estimated.

The first comment is that there are no certainties as to the future development of these plants, and, as a result, to the strategies to increase their effectiveness and ability to fulfil the desired goals. It should also be emphasized that some of them have been abandoned for years and will require much effort to be brought into operation again (such as Novara and Ozzano).

The processing capacity of all these plants is 2,336,000 tons waste/year, equivalent to 7,907 tons/day; their average unit size is 56,975 tons/year, equal to 192 tons/day. The estimated compost output exceeds half a million tons a year. It therefore appears absolutely critical to find adequate applications for these materials, as was pointed out earlier on.

Composting plants from selected waste

In harmony with the current trends in composting, 33 composting plants have been or are about to be built in Italy. These are mainly located in the northern and central areas of the country (just in a few regions, however, in the centre), whereas there is virtually none in the south of Italy and in the islands (table 2). 22 of them process sludges from sewage and/or agrofood water treatment plants, which proves not only the want of alternative waste disposal methods, but also the possibility to win compost with remarkable agricultural properties from this waste, especially when mixed with other organic matters and, in particular, lignocellulosic waste (table 5).

The environmental quality of products is most often ensured through a strict sorting procedure of inputs (sludges and other biomasses). Mention is made here not only to the plants situated in Piedmont and Veneto, which are compelled to abide by Act 4558 of 23.6.86 and Act 4978 of 6.9.91, but also to the processing plants that have adopted an even more stringent self-discipline than the ones mentioned above, such as Trento and Eco-pol of Bagnolo Mella (table 4).

The year-long experience of the Trento plant in the production of compost from selected sewage sludge (Zorzi et al., 1992) was treasured up by many with the aim of optimizing the way this particular kind of waste is processed. Striking examples are provided by Agrinord in the Verona district, Eco-pol in the Brescia area, Ecopì of Alessandria and possibly the Consorzio del Bacino dello Scrivia (that has just been tested). The Trento plant receives sludges from 12 waste water treatment plants serving small and medium urban communities (out of a total of 65 in operation the provincial area). The average weights of heavy metal concentrations in the sludges are the following: Cd 0,23, Cr 22, Ni 15, Pb 40, Cu 157, Zn 533 mg/kg dry matter. The whole process is constantly fine-tuned and monitored by Istituto Agrario di San Michele all'Adige, that is responsible for the performance of repeated physical, chemical and biological analyses of products as well as for their testing on different crops.

Table 2 Composting plants treating selected wastes in Northern and Central Italy (still working or to be set up in the short time)

PLANTS	CAPACITY ton/year	TREATED WASTES	COMPOST ton/year
Piemonte			
Casalcermelli (AL)	12500	sludge, pruning, barks	6000
Tortona (AL)	33000	sludge, wood chips, barks, pruning	6000
Alba - Brà (CN)	26975	sludge, industrial waste, pruning	7350
Roccavione (CN)	1500	sludge, pulp waste, poultry litter	700
Saluzzo (CN)*	7300	sludge, FPW and yard waste	4000
Verzuolo (CN)	10000	barks and manures	8000
Ghemme (NO)	10000	sludge, manures, agricultural waste	2000
Verbania (NO)	5000	yard waste, source separated MSW *	1220
Ghislarengo (VC)	28000	sludge and industrial waste, pruning	8000
Torino - Italconcimi	10000	yard waste from public green areas	8000
Torino - AMIAT*	54000	FVMW, pruning, source separ. MSW	20000
SUBTOT.	198275		71270
Lombardia			
Bagnolo Mella (BS)	25000	sludge, FPW and pruning waste, FVMW, source separated MSW	8000
Castiglione Stiv. (MN)	4000	sludge, FPW and pruning waste	1300
Milano - AMSA*	43000	FVMW, pruning, source separ. MSW	16500
SUBTOT.	72000		25800
Veneto			
Isola Scala (VR) -	35000	sludge, pruning, FVMW, poultry litter	20000
Agrinord		source separ. MSW, mushroom litter	
Isola Scala (VR) -	35000	sludge, yard waste	15000
Agrofertil			
S. Bonifacio (VR)	16000	sludge, poultry litter and manures	6000
Sorgà (VR)	6000	sludge and yard waste	2500
Vigonza (PD)	9000	sludge, pruning, grape stalks, agric.w.	2500
Trecenta (RO)	12000	sludge, animal residues, agric.waste	3700
Castelfranco (TV)	9000	pruning and grass mowing	3100
Spresiano (TV)*	5000	pruning, grass mowing, FVMW	1700
Mira (VE)	21000	sludge, source sep. MSW, agricultural waste, manures, industrial residues	7800
SUBTOT.	148000		62300
Province of Trento			
	20000	sludge, barks, pruning, grape stalks, FPW, cotton, source separated MSW (experim.)	6000
SUBTOT.	20000		6000
Emilia-Romagna			
Rimini - AMIA	18000	source separated MSW, pruning, sludge, PVW, SHW	4500
Piacenza	29000	sugar beet residues and pruning	10000
Vignola (MO)	5500	pruning, source sep. MSW, sludge	1800
Soliera (MO)	experimental	sludge, pruning, source separated MSW, manures, grape stalks	-
Faenza (RA)			
Cesena (FO)*	5000	pruning, source sep. MSW, FVMW	1750
Imola (BO)*	3600	sludge, pruning, source sep. MSW	1000
SUBTOT.	61100		19050
Marche			
Senigallia (AN)	7500	sludge and sawdust	1100
SUBTOT.	7500		1100

Table 2 Continued

PLANTS	CAPACITY ton/year	TREATED WASTES	COMPOST ton/year
Toscana			
Campi Bisenzio (FI)	9300	pruning, grass mowing, source separ.	MSW 3500
SUBTOT.	9300		3500
TOTAL	516175		189020

FVMW= Fruit and Vegetable Market Waste

FPW=Food Processing Waste

PVW=Processing Vegetables Waste

SHW=SlaughterHouse Waste

* plants to be realized

Note: some data related to the compost production have been estimated

Table 3 Italian composting plants having double trend

Plant	Technology	Capacity ton/year		Capacity ton/day		Compost ton/year	
		MSW	SW	MSW	SW	MSW	SW
Alessandria	Ecologia	30000	12000	100	40	6000	4000
Cedrasco (SO)	Ecologia	30000	15000	100	50	6000	4500
Spresiano (TV)	not realized	70000	20000	230	65	*	7000
Carpi (MO)	Snam	72000	6500	300	25	15000	2000
S.Agata Bolognese (BO)	Castalia – Unieco	45000	22000	170	70	10000	10000
Sesto Fiorentino (FI)	Degremont	110000	8000	358	27	30000	2500
TOTAL		357000	93500	1258	277	61000	26000

SW=Selected Wastes

* Biostabilization of the organic fraction for 30 days

Likewise the Rimini plant has become a reference point for the operators producing compost from organic waste separately collected from hundreds of catering businesses.

A brilliant example of good management is provided by the firm Maserati in Piacenza, which, using oversimplified facilities and technologies, composts waste from sugarbeets mixed with vegetable materials.

The development of two large plants designed to handle waste from marketplaces and other large producers is raising great expectations (AMIAT in Turin and AMSA in Milan).

It should, however, be noted that not all of the surveyed plants accurately screen their inputs and the biological process, in particular, is carried out rather carelessly.

A composting plant must be responsible for all recovery steps: from collection and previous checks of materials to the final destination of output, including testing the impact of compost on crops.

The regions where composting from selective waste is most widespread are Piedmont (11 plants, including the AMIAT plant in Turin that was recently subcontracted) and Veneto (9 plants for now, but more to come).

Table 4 Acceptability limits adopted for the incoming wastes

Parameters	Regione Piemonte	Regione Veneto	Province of Trento	Eco-pol
pH	5.5 ° 8			
Moisture (fresh matter)	_ 80%			
Organic substance (dm)	_ 40%		_ 40%	
Salinity (meq/100g)	_ 200	200		
S.A.R. (with salinity >50)	_ 20			
Volatile Phenols (mg/kg dm)	_ 10			
Surface actives (mg/kg dm)	_ 100			
Chlorides (with salinity>50) (mg/kg dm)	_ 5000			
SO ₄ -S (mg/kg dm)	_ 10000			
Cd tot. (mg/kg dm)	20	10	0.6	< 5
Cr III (mg/kg dm)	1000	750	50	< 250
Cr VI (mg/kg dm)		10		< 1
Hg (mg/kg dm)	5	10		
Ni (mg/kg dm)	250	300	25	< 100
Pb (mg/kg dm)	600	750	55	< 200
Cu (mg/kg dm)	1000	1000	200	< 300
Zn (mg/kg dm)	3000	3000	750	< 1200
As (mg/kg dm)	10	10		
B (mg/kg dm)	60	60		
Se tot. (mg/kg dm)	5	5		

fm=fresh matter

dm=dry matter

S.A.R.= Sodium Adsorption Ratio

The total operating capacity of all plants considered is over half a million tons/year, with a compost output approaching 200,000 tons/year, equal to about 400,000 m³/year (table 2). The market for the highest quality composts is doing well, and indeed is looming large in terms of increased capacity and market demand. The current sales price for top-quality products is about 20,000 Lit/m³ free plant, even though quotations of up to 25–28,000 Lit/m³ are quite common for bulk products. These are remarkable figures, if one considers that unenriched young peats are currently commercially available at 45–50,000 m³ and that no agreement yet exists between plants to harmonize supplies.

The most common applications for products with outstanding agronomic properties (high total and free air space, water volume, little shrinkage) and low or comparatively low salinity and pH values are in the horticultural-flower and forestry nursery sectors and mushroom cultivation. For the preparation of adequate media for cultivation in containers or benches compost is usually mixed with peats in a proportion of 25–25% in volume. In the case of recreational use of compost,

mushroom growing and seedling nurseries the ratio of compost and peats goes up to 1:1. Compost is widely used as it is in grasslands and for open ground organic fertilization, especially in the case of fruit and vine-growing, where the product is not only spread throughout the area but is also filled into plant-holes and used for mulching.

Compost plants based on different approaches

Table 3 shows 6 plants where compost is produced according to two different approaches. The first one concerns the processing of the municipal solid waste organic fraction retrieved by mechanical separation on the spot; the resulting compost is of lower quality (standard compost). In the case of the Spresiano plant the production line is designed to biologically stabilize the organic component before dumping materials into a landfill. The second approach, which usually features smaller capacities than the first until separate collection becomes more widespread, has to do with composting of source separated waste and is meant to produce a high-quality compost.

Following the introduction of information and education programmes, a more accurate identification of waste sources with a high natural organic component, including non municipal ones, and the development of collection services, the first stream of waste will gradually shrink and the second will expand. This newest approach can be applied also to conventional plants and marks a big step forward in the production of higher quality compost.

The potential capacity of these plants is 357,000 tons/year of aggregate waste and 93,000 tons/year of selected biomasses. Compost output is 61,000 tons/year and 26,000 tons/year respectively, that add up to the figures shown in the previous chapter.

Legal considerations

In Italy, in spite of the commendable, albeit lengthy process of revision of the current regulations on compost production and use, the provisions of the Interministerial Commission responsible for the enforcement of Art. 4 of the Decree of the President of the Republic 915/82 are still in force (table 6).

At the same time Act 748/84, issued by the Ministry of Agricultural, Food and Forestal Resources, set new standards on fertilizers and outlines different agronomic properties of conditioners from municipal solid waste (or mature compost) than are set forth in the Decree of the President of the Republic 915/82, in that it requires that just a few agronomic prerequisites be met, and makes no mention of environmental requirements.

If on the one hand DPR 915/82 pursues the aim to prevent an easier use of soil as disposal site for every kind of waste, on the other hand the foreseen procedures block whatever possibility to use the best quality compost (AA.VV., 1994).

Table 5 Analytical characteristics of compost from different plants (values are expressed on a dry matter basis with exception of moisture, pH and EC)

PLANTS PARAMETERS	TRENTO		AGRINORD		SCRIVIA		ECOPOL		AMIA RIMINI		AMIAU (MO)-CRPA S+barks
	A	B	A	B	mixed	green	1	2	1	2	
Moisture %	38.7	34.5	—	—	49.5	46.6	42.0	29.2	37.8	38.4	56.0
pH	7.73	7.66	7.7	8.2	6.4	7.6	6.8	7.6	7.2	7.2	6.9
BC (25°C)µS/cm	1530	2242	2200.0	3600.0	1447	939.0	950.0	—	—	—	—
Ashes %	32.00	37.59	27.1	21.7	33.5	—	—	38.2	40.2	49.6	54.1
Org. C %	37.22	33.51	38.8	45.0	30.9	24.1	22.9	28.3	27.5	34.5	34.1
Org. Substance %	64.18	57.78	66.9	77.6	66.5	41.3	40.0	48.8	47.4	57.7	60.0
Humif. Rate %	18.03	20.15	*	24.1	37.4	34.7	23.7	29.8	15.9	13.2	—
Humif. Index %	12.11	12.72	**	**	—	—	—	—	—	—	—
C Humic/Fulvic Ac	2.26	2.17	—	—	2.5	—	—	—	—	—	—
C/N2.26	16.36	16.8	12.2	8.0	25.3	14.0	15.3	21.7	18.3	23.0	21.3
N %	2.29	2.29	1.6	2.9	1.2	1.7	1.5	1.3	1.5	1.5	1.6
P (P2O5) %	2.49	2.84	—	—	0.3	2.0	0.3	1.1	0.8	1.7	3.0
K (K2O) %	0.97	0.81	—	—	0.2	1.5	0.4	0.8	0.3	0.9	2.1
As mg/kg	—	—	1.0	1.5	1.4	1.8	1.7	nv	nv	—	—
Cd mg/kg	1.28	0.75	4.7	5.0	1.2	<3.0	<1.0	nv	nv	1.6	2.0
Cr mg/kg	36.1	51.8	53.7	63.8	59.0	131.0	64.0	62.0	112.0	133.0	127.0
Hg mg/kg	—	—	0.1	0.3	1.2	0.8	—	nv	2.0	—	—
Ni mg/kg	15.1	16.8	43.2	37.0	37.0	30.0	23.0	32.0	90.0	46.0	48.0
Pb mg/kg	44.5	52.9	66.0	79.5	108.0	130.0	95.0	114.0	38.0	136.0	160.0
Cu mg/kg	124	157	143.0	208.0	118.0	217.0	147.0	318.0	200.0	247.0	222.0
Zn mg/kg	380	480	587.0	993.0	610.0	556.0	260.0	200.0	462.0	1056.0	1279.0
Germinat. Index %	87.47	66.25	—	—	95.0	180.0	366.0	366.0	97.3	—	—
Growth Index %	—	—	284.00	290.57	—	—	—	—	—	—	—
Bulk density g/l	—	—	10.36	8.8	—	—	—	—	—	—	—
S.D. %	—	—	84.27	84.14	—	—	—	—	—	—	—
T.P.S. %	—	—	24.29	31.11	—	—	—	—	—	—	—
Air Volume %	—	—	59.98	53.02	—	—	—	—	—	—	—
Water Volume %	—	—	—	—	—	—	—	—	—	—	—

AGRINORD A= soil improver; B= soil improver with chicken manure

S= sludge

AMIA 1= food waste compost; 2= vegetable compost with low % of sewage sludge

* Humic carbon A= 21% dm; B= 23.9% dm; ** 1th humic fraction A= 16% dm; B= 14.5% dm; nv= not valuable

B.D.= Bulk Density; S.D.= Shrinkage Degree; T.P.S.= Total Porosity Space

Thus new high-quality composting procedures were advocated. For quite some time now a national legislation has been demanded, which systematically brings together all tentative and temporary provisions adopted by some regional authorities, with a view to promoting the free trade and use of quality products, that are to be regarded to all intents and purposes farming aids capable of increasing the physical, chemical and biological fertility of soils (table 6).

Table 6 Quality limits of compost – National and regional regulations

	DPR 915/82	L 748/84	Regione Lombardia	Regione Piemonte	Regione Veneto
Moisture %	< 45	–	–	≤ 40	< 50
pH	6 ÷ 8.5	–	< 8.5	6 ÷ 8	5.5 ÷ 8.0
EC (25°C) µS/cm	–	–	–	–	–
Salinity meq/100g dm	–	–	–	≤ 50	< 50
Soluble Clorures mg/kg dm	–	–	–	≤ 2000	–
Soluble Sulphate mg/kg dm	–	–	–	≤ 5000	–
Volatile Phenols mg/kg dm	–	–	–	≤ 10	–
Ashes % dm	–	–	–	–	< 40
Organic Carbon % dm	–	–	–	–	> 25
Organic Substance % dm	> 40 (%dm)	> 20 (%fm)	–	≥ 40 (% dm)	–
Humic Carbon % on total C	> 20 *	–	–	> 20 *	> 20 **
1 ^h humic fraction % on total Carbon	–	–	–	–	> 25 **
Humic ac./fulvic ac. Carbon	–	–	–	> 1.5 *	–
C/N	< 30	< 30	< 30	< 20	< 25
N % dm	> 1	< 2	–	> 1.7	> 1.5
NH ₄ -N % dm	–	–	–	< 0.06	–
NO ₃ -N % dm	–	–	–	> 0.04	–
P (P2O5) % dm	> 0.5	–	–	> 1	–
K (K2O) % dm	> 0.4	–	–	> 0.7	–
Zn mg/kg dm	< 2500	–	< 400	≤ 1500	< 1250
Cu mg/kg dm	< 600	–	< 200	≤ 500	< 300
Ni mg/kg dm	< 200	–	< 50	≤ 150	< 150
Pb mg/kg dm	< 500	–	< 200	≤ 350	< 200
Cr tot. mg/kg dm	< 510	–	< 150	≤ 500	< 151
Cr VI mg/kg dm	< 500	–	–	–	< 150
Cr III mg/kg dm	< 10	–	–	–	< 1
Cd mg/kg dm	< 10	–	< 3	≤ 5	< 5
Hg mg/kg dm	< 10	–	< 2	≤ 2.5	< 3
As mg/kg dm	< 10	–	< 5	≤ 2.5	< 5
Se mg/kg dm	–	–	–	–	< 5
B mg/kg dm	–	–	–	≤ 40	< 100

* extractable with Na₄P₂O₇ 0.1 M and NaOH 0.1 M

** extractable with NaOH 0.1 M

Legislative inconsistencies curb the expansion of the industry, in that entrepreneurs, willing as they are to make large investments in composting plants, take a 'wait and see' attitude, pending adequate legislative measures.

To set appropriate standards for the production of high-quality compost amounts to giving fair and full consideration to an universally renowned industrial biotechnology designed to process natural-occurring organic matters under aerobic conditions.

Composting is a fully fledged industrial procedure using different raw materials, in well-defined weight ratios, in order to ensure the best possible development of biological processes through suitable technologies and to attain the desired qualitative standards.

An extensive research conducted by Istituto Agrario di San Michele all'Adige on a wide number of compost samples from several kinds of accurately selected organic wastes, including sewage sludge (288 samples from 124 plants), from households as well as from industrial, commercial, business, agricultural and live-stock breeding operations, revealed excellent agronomic and environmental qualities of the resulting products, that are comparable or even superior to conventional commercial organic fertilizers (peat, cattle manure, chicken manure). In these products, despite some differences due to the starting materials, considerably lower levels of heavy metals were found than in municipal solid waste compost (i.e. 1/3 lower for zinc and down to 1/9 for lead). If these concentrations are referred to the latest trends in the Eec legislation, a good accordance can be found between required standards and actual values, with the exception of the very stringent limits set, or should we rather say pursued, by some countries in relation to some potential pollutants. Such limits, moreover, can hardly be assessed, these pollutants being largely spread in the environment. Comforting is the fact that limits are exceeded only in the case of the least hazardous, or even beneficial metals, such as copper and zinc, for which a higher tolerance should be envisaged (Gasperi and Zorzi, 1994).

What strategic role could composting play, if used only in a minority of compost lots? It would not relieve the final disposal site of large masses of waste, it would not promote the dissemination of the method and would not acquire any market shares for compost products.

It should be remembered that the commonly used organic fertilizers are indeed obtained from other residues. This proves that an improper usage of the term 'waste' is usually made, unless its use is associated with a contamination hazard.

From this standpoint quality composts should be viewed as resources that not only restore soil fertility, but, even more importantly, allow to close the nutrient cycle, whereby whatever comes from the soil is finally returned to it (Sequi et al., 1992).

If the Ministry of Environment is to consider quality composting an important link in an integrated waste disposal system (and enough convincing evidence that it is so comes from the above-mentioned processing capacity of plants and from the high, never fully satisfied demand for composting products), it should issue new technical standards and, at the same time, refrain from criticism and remove the constraints provided for in its draft regulations, as well as adjusting the limits to such values as are actually achievable in Italy, with special regard to zinc, copper and lead (the proposed values are 400 and 100 mg/kg dry matter for the first and the following elements, respectively). This adjustment is certainly feasible, considering that copper and zinc play a very minor role in air pollution and lead is contained in many vegetable materials. It is believed that concentration of about

180–200 mg/kg dry matter for copper, 500–600 for zinc and 150 for lead are very far from the present legal standards (copper 600, zinc 2500, lead 500 mg/kg dry matter).

Conclusions

Composting is a fast growing industry. There is increasing awareness that the only chance for compost products to become firmly established on the market is associated with the controlled biological treatment of source separated waste and, consequently, the need arises to find outlets for the outputs of approx. 40 conventional plants processing unsorted waste.

Possible applications in the landscape architecture and environmental protection sectors are dependent on well thought out plans, in which particularly degraded areas are identified and the short and medium term compost requirements are calculated. In addition the contractors executing the land reclamation project must commit to the use of compost.

If that is not the case, plants should be completely revised, so that incoming streams are separated and discrete production lines can be operated (standard compost from source unseparated waste and quality compost from accurately selected biomasses), with a view to giving more and more priority to the most advanced line.

Another feasible and indeed noteworthy alternative to standard compost production is provided by the biostabilization of the organic fraction of the site-separated waste prior to landfilling.

Conversely, the present scenario in the quality composting sectors is extremely reassuring as to the latest approaches taken by over 30 plants.

Adequate regulations and quality certification systems play a pivotal role at a time when increasing attention is given to composting, as, through an accurate and strict process management, they can ensure highest user and environment full protection.

The use of low metal waste allows to minimize the environmental hazards of a procedure that was –and still is– perceived a convenient shortcut to get rid of huge amounts of materials.

Highly-professional and serious plants are not an occasional occurrence, but are becoming increasingly numerous. The existing installation, technological and management solutions are reliable and long-established. New impetus may stem from the removal of the contradictions, uncertainties and inadequacies of the present legislation.

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State of the Art and Perspectives for Composting in the United States of America

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Abstract

During the period from 1985 to 1995, the increased number of composting facilities in the United States of America was primarily motivated by high landfill tipping fees and bans that prevented the landfilling of vegetative organic residuals such as leaves and grass clippings. In the case of waste water biosolids, composting was part of a beneficial reuse strategy that kept sludge from being dumped in oceans and rivers as part of clean water programs. In the 1990s, increasing attention is being given to the utilization of a high quality compost in sustainable agriculture and horticulture. Specifically, compost products are gaining recognition as an economical and environmental substitute for chemical inputs including toxic pesticides. More researchers are proving the relevance of compost applications in sustainable agriculture programs. While much progress has been made in the production and application of quality compost, there still remains great challenges if the potential widespread application of compost is to be realized.

Introduction

Significant changes are taking place in the utilization of organic by-products. Twenty-five years ago, there were only small numbers of composting projects to divert such materials as leaves and grass clippings from landfills; waste water biosolids from being dumped in oceans and rivers; and livestock manures from creating nitrate and odour problems. Today in the United States, as the statistics below indicate, there are broad-based public and private initiatives in the composting of source separated organics.

According to the *BioCycle* 1995 State Of Garbage In America Survey, the number of yard trimmings composting facilities had reached 3,202. When the first survey was conducted in 1988, the figure was 700 facilities. Thus in the last seven years, the number of yard trimmings composting facilities has risen 391 percent. The 1994 *BioCycle* annual survey of biosolids composting facilities in the United

States reported that there were 318 projects. Of the approximate 200 facilities that are operational, 92 utilize aerated static pile methods; 44 have an in-vessel system; 43 use windrows; 11 use aerated windrow; and seven compost in static piles. The balance of the projects remaining are in construction, permitting, design or planning stages. A 1994 *BioCycle* survey of centralized facilities that compost mixed or source separated municipal solid waste specified 17 operational and 34 in various stages of development. A significant finding of the survey was the impact of the Supreme Court's flow control decision in May, 1994 (Carbone vs. Clarkstown). That decision essentially eliminated designated measures implemented by solid waste management facilities specifying where solid waste should be taken for processing.

As pointed out by Richard Kashmanian of the U.S.E.P.A., composting has steadily been increasing as a waste management practice in agriculture. On-farm residuals that are being composted in increasing quantities include manure and crop residues as well as poultry and other livestock carcasses.

Emphasis on end product use

For many farmers, making compost and applying it to soils is an integral part of the transition to more sustainable and profitable crop production. Farmers are changing methods because of steadily growing concerns over high cost of chemical inputs, declining soil fertility, increasing problems with ground water contamination and side effects on their personal health from pesticide applications.

Correspondingly, as solid waste managers in cities and states have come to recognize the role of composting as a way to divert organic residuals from landfills, the importance of producing a quality compost with high value in agriculture has become more widely recognized. Many research findings explain how the nutrient cycle that links urban residuals with agricultural needs can be fulfilled.

Research centers are spending more time and effort to help agriculture and society achieve the ambitious goals of environmental quality, social responsibility and economic success. Increasingly research is being directed towards biological control, soil improvement and organic waste management. When it comes to 'best management practices' for organic residuals, composting is cited as an effective method.

Recognition of the role of composting in the utilization of organic residuals

State agencies — specifically agricultural and environmental departments — are increasingly compiling data on the amount of organic wastes generated in food production and processing industries. Following are some examples of data being published to indicate the potential of compost that could be made available:

Florida: According to the University of Florida's Institute of Food and

Agriculture Sciences, animal manures generated annually total 533,500 tons; yard trimmings represent 3.1 millions tons of compostable material. To illustrate the potential uses for compost in Florida, agricultural specialists provide these estimates of various categories: pasture – two million acres; citrus – 791,290 acres; vegetables – 418,000 acres; field crops – 581,000 acres; annual forest plantings – 170,000 acres; sod farms – 47,500 acres; greenhouse crops – 7,200 acres; lawns – 1,000,000 acres; mine lands – 248,000 acres.

Louisiana: Solid waste specialists at the Agricultural Center of the Louisiana State University System supply these figures on agricultural residuals generated annually in Louisiana. Cotton gin trash – four million tons; sugar cane bagasse – 2.5 million tons; sugar cane filter press mud – 360,000 tons; rice hulls – 1.2 million tons; poultry carcasses – 5,500 tons and poultry litter – 1,000 tons.

Kansas: A survey of 171 Kansas agribusinesses to calculate the types and volumes of waste generated at their facilities turned up 96 different types of discards totalling over 46,000 tons per year. As defined by the Kansas Industrial Extension Service and the Agricultural Engineering Department at Kansas State University, Kansas agribusinesses are those enterprises whose primary process products are associated with the food, grain and/or livestock industry.

Arkansas: More than one billion broilers were produced in Arkansas in 1992, making the state number one in poultry production in the United States. It also meant that too much poultry litter was produced in the western two-thirds of the state. An option to reduce threats to surface and ground water quality is to transport some of the two billion pounds of litter generated annually to the Delta region of the state. A program creating a Poultry Litter Marketing and Utilization Project led to the transport of more than 100,000 tons of litter from western to eastern Arkansas in 1993.

Maryland: On the Eastern Shore of Maryland, as well as in other parts of the Delmarva Peninsula, the poultry industry is highly concentrated. About 517 million chickens are raised annually; broiler houses average 50,000 head. Approximately five tons of manure for 1,000 chickens are produced per year. According to Lew Carr and Herb Brodie of the University of Maryland, annual by-products include 646,250 tons of poultry litter; 24,800 tons of mortality; 12,480 tons of hatchery waste; and 15,510,000 gallons of dissolved air flotation skimmings.

Alabama: The average poultry farm in Alabama produces 180,000 birds per year in six to eight week cycles. As it leaves the broiler house, each bird leaves behind about five pounds of litter composed of its droppings and the bedding spread out to absorb it. In Alabama this is equivalent to about two million tons.

Coordinated approaches to improve knowledge of the composting process

A significant approach to documenting and communicating critical information about composting was taken by a consortium of United States government agen-

cies and nonprofits on the subject of bioaerosols and their impact on public health. The organizers of a special workshop in January, 1993 included the U.S. Department of Agriculture, the U.S. Environmental Protection Agency, the Composting Council, and the National Institute for Occupational Safety and Health. The workshop was held at the Soil Microbial Systems Laboratory of the U.S. Department of Agriculture in Beltsville, Maryland. The specific question addressed by participants was: 'Do bioaerosols associated with the operation of biosolids or solid waste composting facilities endanger the health and welfare of the general public and the environment?'

Dr. Patricia Millner of the Laboratory edited the final report and prepared the following summary:

'The 25 scientists and engineers drawn largely from regulatory and research agencies attempted to examine the full spectrum of potential bioaerosol agents and impacts, including actinomycetes, bacteria, fungi, arthropods, protozoa, and organic constituents of microbial and plant origin and not just those that might arise from the fungus *Aspergillus fumigatus*.

"To the best of our knowledge, this was one of the first attempts at viewing the comparative health impacts of such a broad spectrum of bioaerosols from different sources of decomposing organic materials (e.g. grass clippings, wood chips, food and household wastes, agricultural wastes, and biosolids) in the environment. As such, the report on this effort helps establish a scientifically reasoned basis for evaluation of health impacts from bioaerosols associated with the processing and handling of biologically degraded materials at composting facilities compared with other sources, and helps set the stage for future advances in knowledge about this important subject.

'Several conclusions reached by the working group included:

- 1) The general population is not at risk to systemic (i.e., whole body, generalized, as in circulatory, lymph, etc.) or tissue infections from compost associated bioaerosol emissions.
- 2) Immunocompromised individuals are at increased risk to infections by various opportunistic pathogens, such as *A. fumigatus*, which occurs not only in compost but also in other self-heated, organic materials present in the natural environment.
- 3) Asthmatic and 'allergic' individuals are at increased risk to responses from bioaerosols from a variety of environmental and organic dust sources, including compost. *A. fumigatus* is not the only or even the most important bioaerosol of concern in assessment of risk for ODTs, MMI and HP (extrinsic allergic alveolitis) associated with exposure to dust from organic materials. The amounts of airborne allergens that sensitize and subsequently incite asthmatic or allergic episodes cannot be defined with current information available, especially given the wide variation in host sensitivity, the numerous sources of natural environmental exposure, and the diversity of constituents and bioaerosols. Prospects for such precise definition are limited in the short-term because of these factors.

- 4) In spite of the fact that some types of bioaerosols can cause occupational allergies and diseases, and that some of the same types of bioaerosols are present in the air at facilities that compost organic materials, available epidemiological evidence does not support the suggestions of allergic, asthmatic, or acute or chronic respiratory diseases in the general public at or around the several open air and one enclosed composting sites evaluated.

Hence, the answer that emerged to the question posed at the beginning of the workshop is: "*Composting facilities do not pose any unique endangerment to the health and welfare of the general public.*"

This approach of establishing an objective consensus of well-founded research views that relate to composting will be used frequently in the future. It is predicted that the results of such efforts will increase the acceptance of composting as a major waste management practice throughout the world.

Bioremediation projects using compost

Bioremediation of soils contaminated with pesticides, hydrocarbons, explosives and other pollutants by application of the composting process is rapidly advancing in the United States. While much data being accumulated emanate from anecdotal reports of private companies, research at university centers is verifying the effectiveness of compost methods. The USDA Soil Microbial Systems Laboratory has reported, for example, its research for appropriate disposal/detoxification of pesticide containing waste at remote border sites. Reports the USDA research team:

'Biodegradation studies were conducted using soils from cattle dipping waste pits that were contaminated with high levels of coumaphos. Results showed that the coumaphos in all of the soils could be rapidly biodegraded in soil slurries using indigenous soil microorganisms.'

At two U.S. military installations in the Northwest, large-scale tests are continuing to use compost to remediate soils contaminated with explosives. Windrows are made with dairy manure, wood chips, potato waste, alfalfa and 30 percent contaminated soils. Water is added and each pile composts for about 30 days. The demonstrations are being conducted at the Umatilla Army Depot in Hermiston, Oregon and the U.S. Naval Submarine Base site in Bangor, Washington. At Umatilla, treatment reduced initial average contaminant concentrations of 1,574 ppm TNT to 4 ppm; 944 ppm RDX to 2 ppm; and 159 ppm HMX to 5 ppm in around 40 days. In Bangor, bench scale studies demonstrated that composting reduced concentration of TNT in one kilogram of soil from 822 ppm to 8 ppm after 60 days of treatment. According to Harry Craig, EPA Region 10 in Oregon, a study estimates treatment costs at 40 to 50 percent less than on-site incineration for quantities from 1,200 to 30,000 tons.

At the Seymour Johnson Air Force Base in North Carolina, a method was developed for on-site bioremediation of soils contaminated with petroleum products.

The method uses windrowed layers of 75 percent contaminated soil with 20 percent yard trimmings compost and five percent turkey manure. The base uses a compost turner for thorough mixing; windrows are covered with a vinyl-coated nylon tarp for approximately 30 days.

In 1985, scientists at Utah State University, led by Dr. Steven Aust, began successfully using white rot fungi (WRF) *Phanerochaete chrysosporium* to degrade hazardous materials such as pesticides and PCBs. White rot, a naturally occurring degrader of lignin, commonly is found in compost piles. Aust intensively studied the fungi, determining that the easily grown organism could mineralize complex organic chemical compounds into carbon dioxide. The research led to formation of Intech One-Eighty Corporation which has an exclusive licensing arrangement with Utah State to set up commercial applications of WRF. Currently, Intech is considering combining its white rot fungi technology with the type of tunnel composting originally used in the mushroom industry.

Other companies in the U.S. are involved with using the compost process to clean up soils. In Rouge River, Oregon, J.A. Pinckard – professor emeritus in microbiology from Louisiana State University – writes that his firm, Bioremediation Technology Services, has been working with such companies as Vicksburg Chemical (Vicksburg, Mississippi) and National Helium (Liberal, Kansas). According to Pinckard, his research in the 1940s at LSU demonstrated that rain spoiled legume hay buried under cotton rows suppressed soilborne diseases of cotton. His early work led to use of agricultural wastes for cleansing soils in Florida, California, and elsewhere.

‘A number of agricultural wastes may be composted to build consortia of microorganisms which may then be applied to a contaminated soil for cleansing it,’ writes Dr. Pinckard. ‘We chose to use cotton gin trash because of its consistent suitability for our purposes.’ For the past six years, his company has been marketing a product known as BTS Soil Amendment.

Current research projects focused on use of varied feedstocks

Reflecting the increased awareness of the need for reliable data on combining different organic feedstocks, researchers throughout the United States are focusing on specialized projects. Following is a brief description of some of this research:

University of Maryland – Leslie Cooperband at the Wye Research and Education Center directs a project that combines municipal solid waste compost and poultry litter to create a slow-release organic fertilizer. The project will analyze the compost characteristics of varying combinations of these materials and the nutrient release characteristics when applied to farm fields.

Tennessee Valley Authority – Improving fertilizer quality of broiler manure is the goal of research which is specifically designed to demonstrate ways to use litter for fertilizer, feed and potting mixes.

Agricultural use of municipal wastes

The increased emphasis on agricultural utilization of organic residuals from municipal, industrial and animal sources is accelerating the flow of composted products to the marketplace. These trends are clarifying specific research needs to obtain well-documented data on volumes and characteristics of feedstocks, and their impacts on crop production and soil conservation.

Recently, the United States Agricultural Research Service (ARS) drafted a list of research needs to be addressed in order to 'ensure efficient and environmentally safe utilization of readily available waste materials.' Following is a summary of the ARS list:

A national data base listing the amounts produced and the agronomic characteristics of major wastes generated; Analytical methods to estimate the levels of nutrients and toxic components in wastes and amended soils; and Assessment of the fate and effects of trace elements, synthetic organics and pathogens in wastes on soils, plants, animals and humans. (A risk assessment pathway approach similar to the one used to develop regulations for land application of biosolids will be needed, note the ARS scientists.) Approximately 75 percent of the nitrogen in animal wastes is lost before it is available for crop use. Appropriate research would improve the understanding of basic chemical and biological processes in wastes and waste mixtures, resulting in designs for storage and surface application to minimize losses of objectionable gases and bioaerosols. A clearer understanding is needed of such factors as aeration, temperature, water content, inoculation and mixing on levels of pathogens, beneficial organisms and viable weed seeds in composts.

Research is needed to blend, mix or cocompost different wastes to yield final products with desirable characteristics for agricultural or horticultural uses. According to ARS staff, information on the concentrations, chemical reactions and bioavailability of beneficial and potentially hazardous components of wastes will be needed to develop mixing and composting procedures which can eliminate pathogens and toxins, reduce availability of toxic trace elements and enhance nutrient availability in 'designer waste' end products.

Anecdotal evidence on the multifaceted beneficial results of compost applications on crops and soils has traditionally been a significant factor. The personal experiences of farmers, commercial plant growers and backyard gardeners have played a key role in sustaining interest in compost use for many decades.

An example 'case study' is illustrated by Jack Pandol, Jr. of Pandol & Sons, Inc., who last year became Undersecretary of California's Environmental Protection Agency. Pandol and Sons farms 6,000 acres of vegetables, tree fruits and grapes in California's San Joaquin Valley. They began applying a compost made from manure and cotton gin trash four years ago, seeking to reduce pesticide use by 50 percent over a five year period, and actually achieved an 80 percent reduction in three years.

Flynn Rainbow Nurseries of Fallbrook, California grows 250 acres of container

plants – six to 10 million annually – which are marketed throughout the United States. According to nursery owner Mick Welti, compost has been the significant factor in decreased use of commercial fertilizer and prevention of nitrate runoff into nearby streams. Yard trimmings compost at up to 50 percent of the container mix has allowed the nursery to stop using a sterile growing medium ‘that needs to be fed fertilizers and protected with fungicides,’ notes Welti. ‘Using compost reduces the fungicide bill quite a bit. And while I can’t quantify it, our water usage has been reduced as well. There is less nitrogen runoff – which is a major benefit.’

As this paper indicates, there has been a steady increase in the number of research projects in the United States – as well as throughout the world – that are documenting the practical experiences of growers concerning the methods needed to produce a consistently high quality compost and the beneficial effects of using such materials.

The Present Situation and a New Trend on Composting in Japan

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Abstract

Recycling of municipal wastes has been attracting attention and some practical recycling system has been established in Japan. The trend in disposal methods of municipal wastes in Japan will be explained. The garbage is an appropriate material for composting and thus, many composting plants have been constructed for the past ten years. The fever of the compost production by using garbage, however, is cooling down, mainly because of high construction and operation costs, quality change of municipal waste, contamination of plastics, ill-treatment of malodorous exhaust gas, etc. Characteristics and problems of a large-scale composting plant at Tokyo Metropolitan Government will be a typical example of the big city composting facility.

At present, a small-scale home composter is getting popular especially in local areas. Some local governments prepare a subsidy system to promote the usage of such a composter at each house. The aim of this promotion by local governments is to reduce the amount of garbage disposed from each house.

There are two types of composter. One is a simple plastic bin-type container which is placed in the outdoors. Another one is a new electric type equipped with mixing, heating, and amended with bulking agent to accelerate composting reaction rate. This electric one is also operated outdoors. Although there is a need of a lot of modification of the composters for further proliferation, this trend will be one possibility to loose burden of the waste treatment expenses in local governments.

Introduction

The treatment of municipal wastes is a serious problem in many big cities in Japan. The main purpose of controlling waste discharge in local governments is

focused on discharge suppression and reutilization of renewable wastes. For recycling of the wastes like cans, glasses and papers, many practical achievements are materialized. On the other hand, the garbage or organic wastes produced is considered to be an appropriate material for composting and composting facilities have been built in several cities to reduce waste load to incineration facilities. However, the expectation for composting is fading away recently, because concrete step to solve the waste disposal problem is not established yet. Recently, an electric or bin type home composting equipments are attracting attention and some local governments are promoting such home-base composting as alternative to the large scale composting operated in local government.

The demand for compost

The total demand for organic matter in Japanese farmland is estimated to be about 2.5 million tons on dry basis. The organic matters produced from cattle farming in Japan reach about 2.8 million dry tons. This data indicate that if these organic wastes are properly treated to composts and recycled, enough amount of composts can be produced by using the cattle excreta alone. However, the number of cattle farmers are decreasing due to low price products imported from U.S.A. and Australia and their farming areas are isolated from ordinary farmland and housing areas due to environmental problems. This eventually cut off the recycling system of organic matters which was established previously between them. Thus, as an alternative of organic matters from cattle farming, municipal wastes and organic wastes from food industry are of attention for compost production.

On the other hand, intensive supply of inorganic fertilizers into land reduced the fertility of land and this caused the frequent occurrence of plant diseases in farmland. This introduced the excessive utilization of chemical pesticides or fungicides, which caused the breakdown of ecological system. In this sense, the introduction of organic fertilizer or composts to the land is being promoted.

Hence, the demand for composting is getting popular.

Municipal waste composting

Large-scale composting facilities

In 1991, the total amount of municipal waste produced was about 46 million tons and the waste output per person per day was about 1.1 kg. The municipal wastes are disposed of by incineration, direct reclamation, recycling as resources, composting and others. The chronological change of these treatment methods is shown in Fig. 1. About 73 of the municipal wastes are treated in the incineration, 23 are reclaimed and others including composting are only 4%. Iron, aluminium, glass etc. recovered as resources from collected municipal waste are recycled and the

recycled amount is about 3.4 in 1990 of total amount of disposed waste. This means that the actual percentage of composting is only 0.2% of total amount of disposed waste. This trend is almost constant in these recent years.

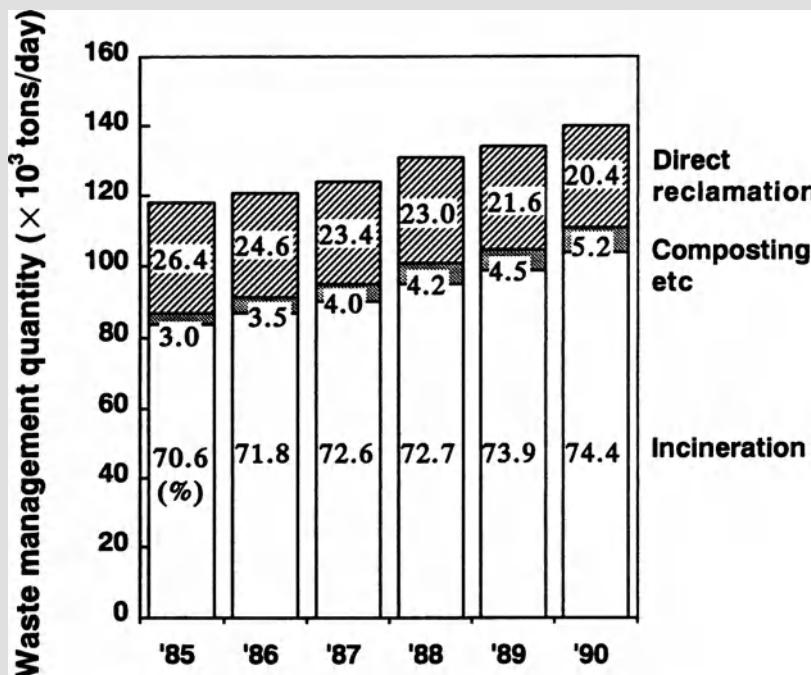


Figure 1 Changes in waste management methods

The percentage of municipal garbage in total amount of municipal wastes is about 24 % in average and the water content is 70%. Thus, 3 million tons of organic matter is produced on dry basis and can be used for composting. In 1976, a big boom occurred in construction of composting facilities of municipal wastes. However, this boom faded down due to ill-separation of waste materials and thus strong refusal of use of such contaminated compost in agricultural areas. In 1986, the second boom occurred and 39 facilities were constructed and at present only 29 facilities are in operation as shown in Fig. 2. There is a big difference between the actual numbers of composting facilities and the number in operation. Only 70% of the facilities are in operation.

The Tokyo Metropolitan Government constructed the composting plant in 1985 with construction cost of 0.73 billion U.S.\$.

The initial specification of the composting plant was as follows:

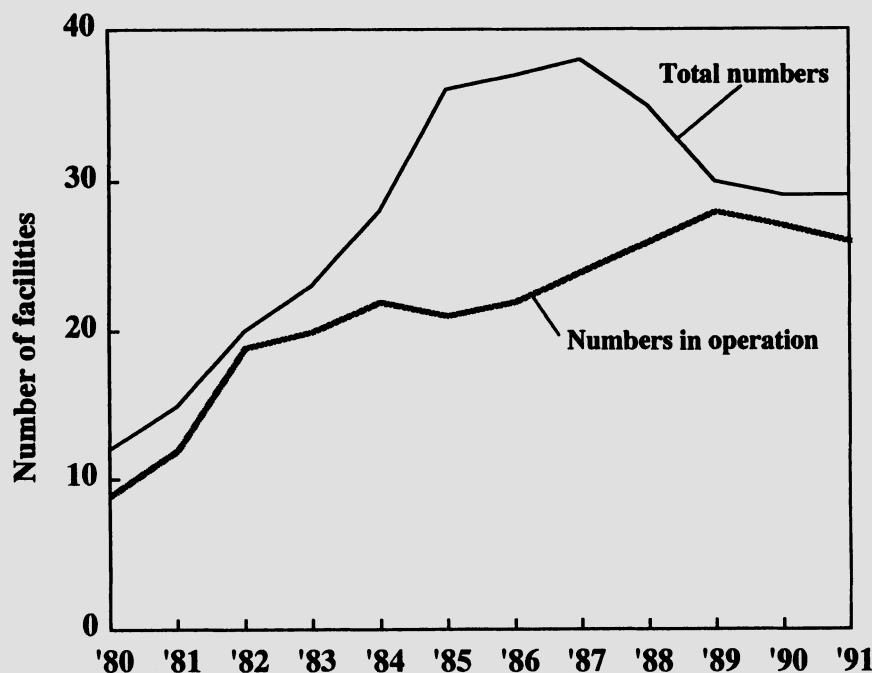


Figure 2 Number of municipal waste composting facilities in Japan (Kimura, 1991)

Capacity of treatment of municipal wastes: 50,000ton/day, Production capacity of compost: 5 ton/day, Composting time: 30 days, Supplementary equipments: mechanical sorting machine, compost pelletizer, chemical deodorizing plant etc. As shown in Table 1, the productivity of compost was fairly lower from the initial operation and maintained at lower level. The following problems were considered to be the main reasons for this low productivity.

Table 1 Composting Operation at Tokyo Metropolitan Composting Plant

	1985	1987	1989	1991
Municipal wastes delivered (ton)	14,620	11,953	13,801	14,282
Municipal waste composted (ton)	3,317	1,589	3,060	4,087
Compost produced (ton)	560	340	288	442
Compost productivity (%)	3.8	2.8	2.1	3.1

(1) Change of quality of wastes.

The municipal waste consists of 88 % of combustible refuse and 12 % of incom-bustible refuse. The former includes garbage 5.7%, papers 33.4%, plastics 21 .4%,

wood and bamboo 8.4%, fibers 5.0%, and others 14%. The latter contains stones 4.6%, shell and eggshell 3.6%, soil and sand 2.7%, and metals 1.2%.

The wastes delivered into the composting plant are the mixture of all municipal wastes mentioned above and the relative ratio of plastic bags, cardboard, plastics, woods etc., became higher compared with garbage and the separation or sorting of these are incomplete. This insufficient separation caused frequent clogging in the machines and thus mechanical trouble and breakdown. This is one of the main reasons in low operation efficiency.

(2) Quality of compost.

The increased content of papers, and plastics like foaming polystyrene in municipal wastes led to the deterioration of quality of the compost.

(3) Corrosion of the plant.

The evolution of high concentration of malodorous gases like H_2S , ammonia and other gases and moisture accelerated corrosion of machines and conveyers. Thus repair expenses increased and operation was suspended frequently.

(4) Inefficient removal of malodorous gases evolved during composting.

The chemical method(acid-alkaline treatment of gases) which was constructed for the treatment of exhaust gas from the plant was inefficiently operated mainly due to higher gas concentrations evolved. Charcoal adsorption treatment column was installed, but the moisture in the exhaust gas reduced the removal efficiency of gases, and another supplementary charcoal column was installed. The operation cost of the treatment hindered the efficient operation.

(5) Cost for operation.

The production cost of compost which excludes depreciation cost of machines was as high as 460 \$/ton.

(6) Demand for compost.

The compost was planned to be used for agricultural areas, but the high cost of the land and urbanization in Tokyo area made farming in Tokyo area impossible. Thus, the main users of the compost were citizens in Tokyo and the demand for the compost was unstable. The final decision to stop the operation due to the problems mentioned above was made in 1993.

However, the quality of the compost was fairly good. The content of ingredients like glasses, plastics, etc. was less than 1 % of unit dry weight of the product. The growth of the vegetables in the farmland where the compost was introduced was 25 % higher than those treated with chemical fertilizer or cow-dung compost. The contamination levels of heavy metals like mercury, arsenate, and cadmium were below the regulated values. The C/N ratio of the compost product was less than 12, which was the recommended value for the municipal compost.

The most effective point in this composting plant is that this plant played an

important role as an educational campaign to demonstrate the importance of recycling in this affluent society to Tokyoites.

Small-scale home composting equipment

As mentioned above, a large-scale composting plant especially in big cities have a low efficiency of production of compost. As an alternative to the large scale composting, small home composters are being popularized recently. There are two types of small composting equipments. One is a bin-type plastic composter and the other is an electric composter equipped with mixing and heating. In some local governments, the subsidy system is introduced for the local residents to promote the use of these home composters.

More than 2 million units of simple bin type composters(100-300 liters in volume) which cost in the range of 50 to 150 U.S.\$ have been reported to be sold in Japan. This number is almost equivalent to 20 % of houses where this composter is available. However, the statistical data which showed the reduction of disposed garbage in proportion to the sold number of composters are not fully collected. However, local governments hope that the proliferation of these composters will eventually loose burden of the waste treatment expenses in the local governmental budget.

Commercial appearance in market of electrical composters is a new trend in Japan. More than 30 kinds of such composters are in markets or in planning to make a debut on market. As the variety of these instruments are so large and the new trend has just started, it will take time to evaluate the effect of the machines. One standard characteristics of the composter is as follows:

The machine generally is equipped with mixing,aeration and heating and this will accelerate the composting reaction and reduce the time of composting.

The size is 30cm in width × 44 cm in depth x 80cm in height and composting rate is about 1 k~ay.

Separation of shells, eggshells or plastics is essential and supposed to be conducted before introducing the garbage into the reactor. The base bulking materials consisting of sawdust, or woodchips or other solid materials with a large surface area are prepared and about 30 kg of them are placed in the composter beforehand. Some machines supply a kind of seed containing mixture of microorganisms prepared by each manufacturer. When the garbage is put into the composter, mixing and aeration automatically promote the degradation of garbage. The exhaust gas is expelled into outdoors through a deodorizing treatment unit. When the outdoor temperature is below 10 C, the heater installed inside the reactor operates to keep the optimal temperature for microbial degradation of organic matter. As most of the inside materials are the bulking agent prepared beforehand, almost complete degradation of organic matter is proceeded. The bulking agent is replaced with a new one every 4-6 months.

These composters cost in the range of 500 \$ to 1 800\$.

By the survey conducted by a local government on the usage of these machines

by local residents reported the following problems.

- 1) The treatment capacity for one family is about 500 g to 1 kg per day. When the amount is too small or too large, the composting is of low efficiency.
- 2) The evolution of malodorous compounds is inevitable in composting. The electric composter has a deodorizing unit, but still the odor problems cannot be solved completely.
- 3) In summer, the operation is fairly well but in winter, the degradation rate is lowered due to low atmospheric temperature.
- 4) The newly designed composter is not like a rice cooker or microwave ovens because care or personalized attention is essential in order to maintain efficient microbial reactions. This is a burden for city people who are busy and have a job.
- 5) The buyers for these composter are at present restricted to the people who own an individual house with yards or gardens where the composter can be set and the composted product can be treated in their own yards. This means that the machine is still insufficient for indoor usage which is essential for people who live in apartment houses.

Future's aspect

There will be several future's aspects to be solved if composting is properly conducted.

- i) In a large-scale composting in big cities, the rational design and economical operation are needed based on source separation, and the materials used for composting should be restricted in quality.
- ii) A medium-scale composting reactor should be developed for a complex of apartment areas.
- iii) Compact and inexpensive home-composter, especially indoor-types should be manufactured. (iv) Development of efficient deodorizing methods are urgent not only for a large-scale but also a small-scale composting.
- v) For recycling of organic matter, as well as technical development, system analysis and system synthesis are essential by the cooperation among local government, private companies, residents who produce municipal wastes and the users of composts and optimal treatment system should be established.

Composting: Experiences and Perspectives in Brazil

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Abstract

The present reports on many aspects of composting in Brazil with particular emphasis on the main problems which contributed to the discredit of this important process in many areas of the country.

Consideration, is made of the constant increase in the use of selective collection which can persuade facilities to increase the use of composting in waste management.

Finally, aspects of solid waste composting in Brazil, related to its perspectives, the low cost techniques and recycling are considered.

Introduction – The Main Constraints and Contradictions

Brazil produces an average of 90,000 tonnes of re-se per day, of which approximately, 80% is disposed of in open dumps. Generally only the major cities have a regular system of collection followed by uncontrolled landtilling or badly managed composting plants.

Open dump disposal, as well as the use of landfills, has led to several problems for the environment and public health with considerable impact on the poor communities surrounding the major cities.

The interest in composting arises from the fact that the refuse produced in the country typically contains an average of 60% putrescible organics (deteriorated food, vegetables and other organics). This amount of putrescible material when disposed of in open dumps or uncontrolled landfill, forms a natural 'habitat' for disease vectors such as, flies, cockroaches, rats, 'vultures, dogs, etc. The effect of these is enhanced with a population which suffers from malnutrition (25% of the population in Brazil). Another problem associated with the organic putrefaction on these sites is the great amount of leachate generated, often flowing out to streams used for domestic services, water for animals, irrigation, etc.

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An additional facet to this complex problem is the decrease in agricultural performance as a result of the decrease in soil fertility due to lack of organic content. To compensate for this loss of fundamental fertility there is an increasing demand for expensive inorganic fertilizers. The high rate of loss of organic matter from soils in tropical areas is a particular feature of the hot climate. The effect of reducing soil productivity is further magnified due to the growth of population which means more people to feed and more pressure on the exhausted soil.

These many factors related to the uncontrolled disposal of waste and the need to improve soil productivity gives rise to a situation where low cost composting come into its own.

The Problem (A Composting Rush)

As soon as it was seen that composting could be an answer to the domestic solid waste problems in Brazil a big rush occurred and composting was seen as the solution for all sanitary and environmental problems related to it. However, unfortunately, it was also seen as a technique worthy of exploitation by greedy speculators and suppliers. This fact brought to Brazil several technologies, mostly emphasising only the equipment side (enormous industrial electromechanical plants) and neglecting the biological side of the process.

Some systems claim to be able to solve the whole problem associated with the solid waste using only composting plants. Others promised to compost the organic fraction of the MSW in only (4) days. Both of these claims were of course untrue. Other plants, locally built (using adapted technology), also neglected the biological side of the process. As a result there spread in the country, a strong 'business' based on composting using inappropriate technologies which formed the basis of large scale projects, and several systems were built based on the wrong concepts about composting. This fact lead to several poor quality products on the market, reducing the credibility of the process in the country. A fact that aggravated this problem was the lack of regulations and legislation for composting, which meant that any inert and dark organic material could be called 'compost'.

The Main Composting Systems in Use in Brazil

At present Brazil has 74 composting plants spread throughout the country, 19% of these are large fully mechanised systems (150 to 1,200 tonnes/day), of which 8 are Dano, 3 Triga, 1 Bartolomeis, 1 Danbraz and 1 Viçosa. The others (81%) are technologies adapted locally called 'simplified systems' and basically consist of ditches (for waste reception), conveyor belts (for hand sorting), a crusher (for particle size reduction) and a screen for the final product (to take off the rejects). A new system which seems to have been well accepted in the country, for mainly small communities (5–20 thousand inhabitants) has been developed by Viçosa

University, which has already built two plants. It is a low-cost composting plant which can be built in three months, using a range of available construction materials such as: bricks, concrete, blocks, soil cement etc. These plants only use man power (typically 6–10 operators) and consist of a refuse reception area (small sloping concreted area), a concrete 'table' for sorting and a composting pad. A small shed is used to store tools and recyclables, and each site has toilets and an office (1).

The Plant Operation

In the case of the 74 composting plants previously mentioned, a current problem is the plant operation. In general all these plants are associated with strong odours, vector (flies) attraction and lechate production. On the compost pad the material is found under anaerobic putrefaction and the composting time is no longer than 30 days. Maturation has never been considered as part of the process.

In the plants using the D'Anio drum systems at the front end with a few exceptions, it is believed by the operators that after an average time of 3 days in the drum the organic is composted and, in many plants, the material is sold named as 'compost' or 'raw compost' (2). The Triga systems has been really the worst in terms of sales promotion and process claims one. In the advertising of it's Brazilian associate they affirm that the 'Triga process makes compost from MSW in only four (4) days.'

This aspect shows how developing countries are suffocated with imported and inappropriate technologies, some of which are not used in their countries of origin. The plants built under the simplified system using an adapted technology, which are the most used plant in the country, although presenting an interesting concept also lack an understanding of the biological needs of the process, and the great majority have not been properly operated. As a result of this, approximately, 40% of the compost plants in Brazil, are closed.

A Good System to be Used in Brazil

A considerable amount of research work carried out by the Universidade de Viçosa-UFV, on several composting plants running in Brazil using different systems has shown that these plants do not produce a stabilised and pathogen free end product.

A comprehensive study was made by UFV on a Dano plant located in Belo Horizonte city (2). The findings were that the material (out of the drum), sold as compost, even though it was well homogenised by the drum action, was far from a stabilized and sanitized material. The pH remained acid (5.8), the final volatile solids was 71% (the same as the initial value) and the bacteriological contamination was considered high (*E. coli* 10^7 c.f.u/g).

Another study was made (with the support of the Universidade de Brasilia and its

bacteriological laboratory) of the Brasilia composting plant which uses Triga technology. The results showed that the material obtained, out of the 'hygienizer silo', supposed to provide a pathogen free product, also had high levels of contamination (e.g. E coli levels between $10\sim$ and 10^6 cf u./g). In both cases the material presented clear evidence of anaerobiosis (3).

This work carried out by Universidade de Viçosa has as its sole objective to contribute to the science of composting, and the work was not funded by any rival composting company. This work represented part of a research programme on recycling and composting, which began in 1987, under an agreement with Leeds University in the UK. The topics studied, included the following:

1. methodologies for refuse and organic waste characterization;
2. sampling and monitoring process methodology;
3. low cost composting technologies for domestic waste;
4. low cost composting technologies for agricultural organic wastes;
5. forced aeration composting using blowing, sucking and a hybrid mode of aeration
6. vector and leachate control;
7. pathogen survival studies;
8. maturation and humification of organic wastes
9. use and application of organic compost;
10. operational procedures in small and large scale operations;
11. extension courses for technicians and plant operators;
12. planning, design, construction and building of recycling and composting plants, and
13. technical assistance to farms and city councils.

From the LFV experience of composting it was evident that the best system for composting the organic fraction of MSW in Brazil is the windrow. It is a very suitable system for Brazil because of the average city's population (60,000 inhabitants) and the fact that land and labour requirements are not a problem. The treatment of the organic matter can be done by a simple system mentioned earlier, which is able to provide a good material to be composted with particle size around 20-50 mm. Once on the composting pad, the pile can be constructed and turned, mechanically by an ordinary front-end loader.

In order to avoid the usual problems associated with this process (such as odour, flies and operational control) a complete investigation was made, where the turning was planned such that the piles remained aerobic and did not reach excessively high temperatures. Working from this data the most appropriate cycle (compared with other cycles turning every 5 and every 8 days) was found to consist of turning every 3 days in the early stages, after which the turning was extended to every 6 days until the maximum core temperature achieved was less than 40°C (a condition achieved on average at around 75 days). The material was then taken and stored for the period of maturation or curing (30 to 50 days). The geometrical configuration of the pile constitutes one of the most important factors in relation to the cross

sectional temperature distribution. It was found that this configuration had to be modified, depending on the stage of degradation, to achieve a thermal balance between the heat produced in the mass and the heat lost to environment. This made it possible to achieve a balance point with a maximum temperature of around 60°C. This temperature was found to be good both to enhance biodegradation and maximise pathogen inactivation.

From the extensive research work on this particular system, a methodology was developed (2), which was shown to be more effective than the conventional windrow process. However, the effectiveness will only be achieved by the following procedures:

- (i) the pile should be covered with 'nature compost at each turning until flies and odour are no longer a problem (generally after the first week);
- (ii) turning should be carried out every 3 days for the first 30 days;
- (iii) the water content should be in the range 45-55% and adjusted if necessary during turning;
- (iv) the operating temperature should be kept in the range of 55-65°C in order to speed up breakdown by making appropriate changes in the pile cross section during the turning process; and
- (v) the composting must be carried out in two phases, the end of the first phase being achieved when the pile core temperature does not rise about 400C, following this the maturation phase which should take place in static piles (unturned for 30-50 days or more).

Using these procedures the following observations were typical:

- (i) the average reduction in volatile solids during composting (90-130 days) was around 45%, considered to be high for this type of turning process. The C/N ratio starting between 38 and 45 showed a final value around 12 reflecting a high degree of degradation and humification; and
- (ii) with respect to pathogen inactivation the previous results were confirmed about the difficulty of elimination organisms during the first phase of the process (4,5,6) however, in the subsequent phase of maturation a satisfactory sanitisation was achieved (*E. coli* <102 c.fu./g from a starting value of more than 10^6 cfu/g).

Conclusions

Composting is recognised as one of the oldest method for biological waste treatment. It is also one of the most effective process for recycling organic waste intended for use in agriculture. Brazil seems to be an ideal country for the use of this system due to its waste disposal problems and the soils need for organic material. However it must be recognised that more effort must be made in order to achieve better dissemination of experience in research and indicate information on successful projects.

Table 1 Characteristics of the MSW from Belo Horizonte and Vicoso Brazil.

Component	Units	Belo Horizonte*	Vicoso**
Organic Material	% total wt	54.06	81.10
Paper	% total wt	12.50	5.28
Cardboard	% total wt	6.00	3.02
Plastic	% total wt	5.90	4.28
Metal Cans	% total wt	2.70	2.13
Glass	% total wt	3.15	1.91
Fabric	% total wt	6.20	0.85
Rubber	% total wt	1.07	0.12
Metal	% total wt	0.60	0.03
Wood	% total wt	1.30	0.58
Leather	% total wt	1.09	0.08
Ceramic and Stones	% total wt	1.60	0.20
Soil	% total wt	2.50	
Other	% total wt	1.33	0.42
pH	—	5.30	5.10
Volatile Solids	% d.w.	72.00	79.20
Carbon	% d.w.	38.00	43.50
Nitrogen	% d.w.	1.03	1.31
P2O-	% d.w.	1.30	1.50
C~ ratio	—	37.00	33.00
Faecal Streptococci	c.fu/g	7 x 10-	3 x 100
Total Coliforms	c.fu/g	2 x 108	5 x 10-
E.Coli	c.fu/g	—	3 x 10~
Density	kg.ml	254	310

* Industrial city (1.5×10^6 inhabitants)** Rural city (5×10^4 inhabitants)

The M SW characteristics, shown in Table 1, indicate the great potential for recycling and composting. The agricultural potential for compost, the climatic favourable conditions, the availability of land and labour makes composting an important process for use in developing countries. In these countries the use of composting will not only recycle organic wastes, but provide treatment for a great amount of contaminated materials which brings enormous benefits for poor communities such as:

1. a product which is stabilised and bacteriologically safe and can be used as organic fertiliser;
2. it breaks the disease cycle related to the MSW, improving public health;
3. it eliminates pollution associated with MSW and rural wastes which enhances the environmental quality of the community;
4. it helps soil fertility and hence agriculture productivity which helps to improve nutrition, and
5. it improves different social aspects in terms of opportunities to obtain a better standard of living.

The potential for the use of composting in Brazil can be promising if a great effort is made, mainly by the government, with policy and legislation to cover the control of the system, its operation and its final products.

In Brazil, more than 30 Municipalities are using a source separation system (Table 2) and valuable components have been reused through industrial processing. This fact will certainly contribute to the improvement of the use of composting in the country.

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Structural Changes to a MSW Composting Plant in Accordance with Modern Waste Management Concepts in Italy

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Summary

Since mid-1993 an already existing conventional MSW (municipal solid waste) composting plant (serving 80.000 population) is being redesigned as a center for recycling and treatment. This comprises not only the construction of a biowaste composting plant according to the latest state the art in engineering for the recovery of reusable, separately collected organic components of domestic waste, but also the stabilization of residual waste according to the concept of ‘cold pretreatment’. The technical conception of the plant allows capacities for a texture-adapted treatment of sewage sludge, too.

The domestic waste composting facility Sciaves/Alto Adige has been in use for more than 10 years and is processing approx. 20,000 tpa of MSW. The essential components of the plant are the mechanical treatment (communition, homogenization, sieving), conditioning and landfilling of screen rejects (facultative production of RDF), and the controlled decomposition of the organic-rich fine fraction which will be deposited or used for remediation measures.

The objective of the new conception and the technical adaption being carried out at present is to treat residual wastes to enable environmentally sound disposal and to treat and subsequently utilize source separated waste streams (compost, ‘dry recyclables’). The result will be a modern, integrated waste management center with several lines of processing.

Most of the already existing equipment can be further used for the processing line ‘cold pretreatment’ and only few modifications of the process have to be carried out. Since the technical optimization of the process is mainly based on a simplification of the procedure it can also be regarded as a ‘low-cost-treatment’. It is envisaged to reduce degradable components of non-utilizable wastes (no incineration plant is projected medium term) by biologic treatment before landfilling and thus establish an inactive state of the material.

On the basis of a preliminary study on the large-scale separation of organic wastes from industrial and domestic sources, an integrated composting facility was planned within the existing plant, which is destined for the sole production of well marketable quality compost. During the determination of the optimal treatment procedure two crucial settings were considered by the use of semimobile and modular enlargeable plant components: firstly the slowly raising amount of biowastes in the next years and secondly the need for a flexible adaptation on varying input materials. Thus it is also possible to selectively treat less contaminated sewage sludge as well as the organic fraction of domestic waste. The central part of the facility is an intensive rotting phase in an enclosed environment which guarantees an optimal process control and a minimization of emissions (especially odour).

The presented project can be regarded as a model for the adaptation of existing, but technically not up-to-date biological waste treatment systems to facilities which are suitable to modern waste management strategies. It shows that realistic approaches for development are applicable to many disposal regions in Italy which are comparable to the described situation.

In Alto Adige esiste l'ordine politico di riutilizzare i rifiuti urbani biogeni dopo averli adeguatamente preselezionati presso il produttore iniziale. L'idea fondamentale di questo modo di procedere viene seguito già da tempo dalle Comunità di Val d'Isarco e Alta Val d' Isarco che gestiscono dal 1985 presso Sciaves un impianto di compostaggio. Le autorità competenti hanno dato ora l'autorizzazione per adattare questo impianto alle esigenze attuali. Sono oggetto della progettazione sia alcune modifiche nello schema d'impianto per facilitare la gestione (tra l'altro la sostituzione necessaria di alcuni blocchi logori) che la realizzazione di un centro di raccolta differenziata primario. Quest' ultimo comprende una zona di trasbordo per materiale riciclabile ed una semplice unità per la selezione dei rifiuti ingombranti ed industriali.

Ambito d' azione relativo alla gestione dei rifiuti

Come future destinazioni per un impianto come quello di Sciaves esistono le seguenti alternative:

1. Riorganizzazione per trattare poi i rifiuti biogeni e stoccare i rifiuti residui non pretrattati in discarica
2. *Riorganizzazione per pretrattare ed inertizzare i rifiuti residui e i fanghi di depurazione prima dello stoccaggio in discarica. Trattamento dei rifiuti biogeni in un impianto a parte.*

La seconda variante assume maggior importanza, in quanto l'obiettivo delle richieste legislative è la riduzione delle emissioni come percolato, biogas, ecc. che sono fenomeni tipici legati allo smaltimento dei rifiuti non pretrattati in discarica. Là

dove l'incenerimento dei rifiuti (il quale soddisfa ampiamente queste esigenze) non è impiegabile, i trattamenti biologici come quello di Sciaves sono di grande importanza nell'ambito della gestione dei rifiuti se vengono utilizzati per il pre-trattamento dei rifiuti residui o, con una parola di moda, per il 'pretrattamento freddo'. Il vantaggio di un tale 'pretrattamento freddo' consiste nella riduzione per via biologica della parte biodegradabile dei diversi rifiuti residui prima del loro smaltimento in discarica, in questo modo si ottiene un materiale da scaricare con un comportamento non attivo, come nel caso dell' ossidazione termica dei rifiuti. Rispetto lo stoccaggio di rifiuti residui non pretrattati è possibile ottenere con tale tecnica un aumento del peso volume e del tempo utile della discarica ca. del 40%.

Trattamento dei rifiuti residui

Coll' adattamento tecnico di un impianto di compostaggio per rifiuti urbani come quello di Sciaves è possibile soddisfare in larga misura le esigenze suddette. Si tratta di apportare leggere modifiche nelle procedure tecniche, preferibilmente da realizzare tramite appalto concorso. Le modifiche significative, che sono riportate nelle due seguenti figure, riguardano la sostituzione del mulino a martelli logoro con uno a bassa velocità di rotazione (con questo è possibile tritare anche tra l'altro anche frazioni di rifiuti ingombranti) e la vagliatura preliminare dei rifiuti residui per tener lontano dal mulino le componenti fini responsabili del logoramento. Per ottenere la riduzione delle attuali emissioni di odori sgradevoli sono previsti diversi interventi tecnici (p.es. incapsulamento della zona di consegna dei fanghi di depurazione, mescolatore rifiuti residui – fanghi). Per l'adattamento della tecnica di fermentazione alle nuove esigenze si offre l'appalto concorso; da prevedere è in ogni caso un processo ampiamente automatizzato. La tabella sottostante riporta le quantità del materiale d'ingresso relativo al trattamento dei rifiuti residui. Tali quantità, considerando di ca. 12 settimane il tempo utile per la maturazione in cumulo, necessitano di un'area pari a più di 3000 m²; un valore che entra nel valor massimo della superficie utile (3.600 m²) dell' attuale capannone.

Table 1 Pretrattamento freddo Sciaves – sommario quantità rifiuti e volumi

Frazioni di rifiuti		tonn/a m ³ /a
Rifiuti residui (pretrattati)	ca. 10.000	ca. 22.000
Fanghi di depurazione (1.500 tonn di materia secca/a, min. 80 % contenuto d'acqua)	≈	
Spazzatura stradale, Materiale sgrigliato e residui da dissabbiatore da impianti di depurazione, terreni contaminati, ecc.	ca. 4.000	ca. 6.000
<i>Totale</i>		
<i>*) volume sommato reale</i>	<i>ca. 23.000</i>	<i>ca. 33.000 *)</i>

Il ciclo operativo riportato di seguito lo si può inserire nel caso dell' utilizzazione di una frazione come RDF; componenti residui non biodegradabili ed ad alto potere calorifico sono RDF ai sensi del modello provinciale di gestione dei rifiuti.

Compostaggio dei rifiuti biogeni

Riguardo questa parte è necessario apporre due condizioni marginali:

1. Le quantità di rifiuti biogeni senza impurità non aumenteranno nei prossimi anni bruscamente ma successivamente.
2. Specialmente per gli impianti di trattamento dei rifiuti biogeni si può notare un rapido sviluppo tecnico.

Ambe due le condizioni marginali suggeriscono di progettare questa parte nel modo più flessibile possibile per ottenere così un adattamento ottimale (riguardo le spese) alle quantità d'input continuamente crescenti e non fissarsi ora su un sistema che forse tra due anni potrebbe risultare superato.

È necessario dunque adattare dal punto di vista edile l'esistente capannone destinato attualmente al raffinamento del compost e al centro di raccolta differenziata ed acquistare inoltre i necessari macchinari (trituratore, vaglio) indipendentemente dal futuro sistema di compostaggio. Nel progetto è previsto inoltre l'aggiunta di fanghi di depurazione a basso carico inquinante con tutte le dovute misure di prevenzione riguardo l'emissione di odori sgradevoli (unità di fermentazione chiuse con depurazione aria in filtro biologico).

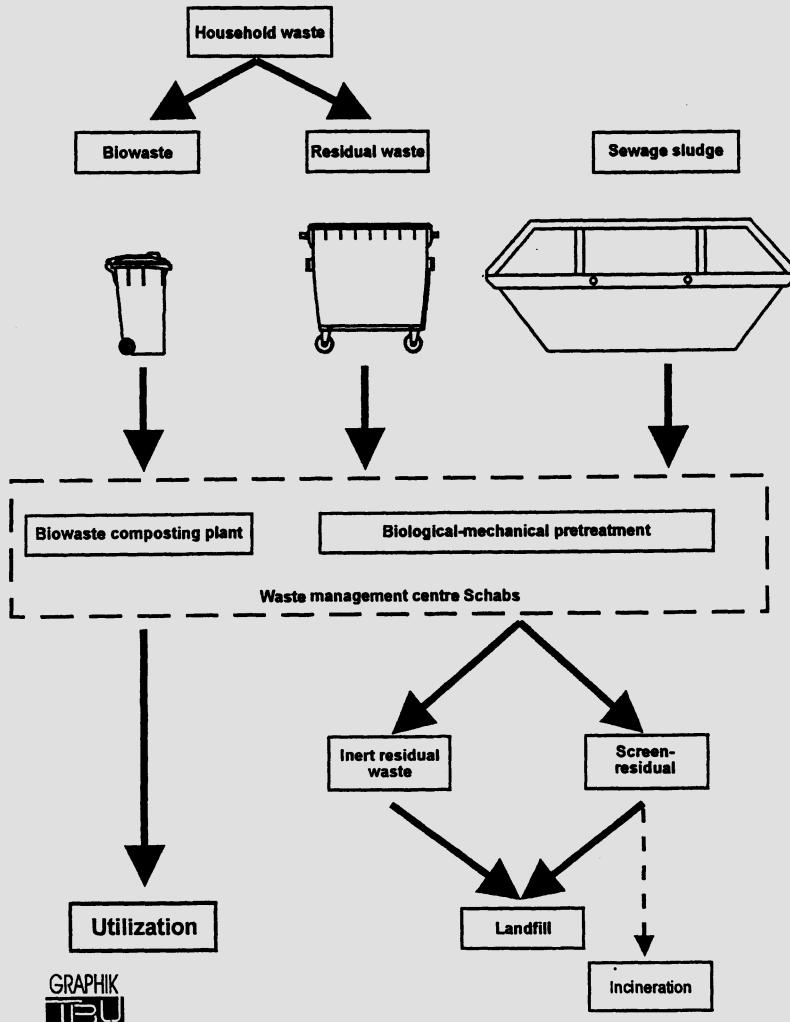


figure 1 Illustrazione schematica del riordinamento del trattamento dei rifiuti nel bacino d'utenza dell'impianto di compostaggio

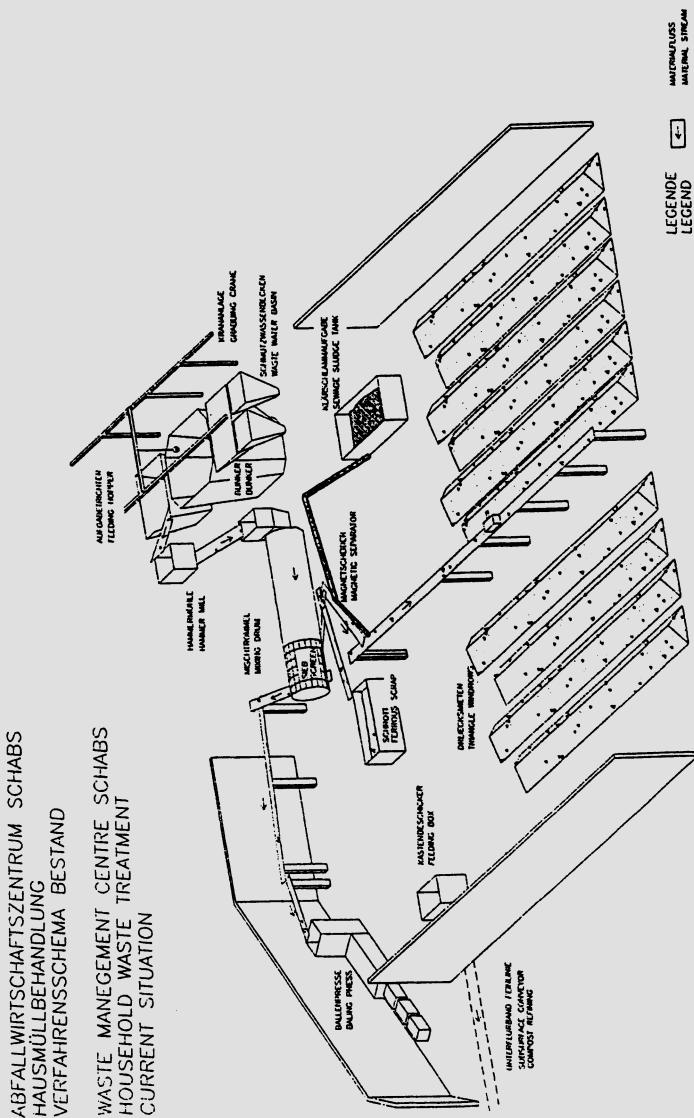


figure 2 Impianto di compostaggio per rifiuti urbani – schema esistente

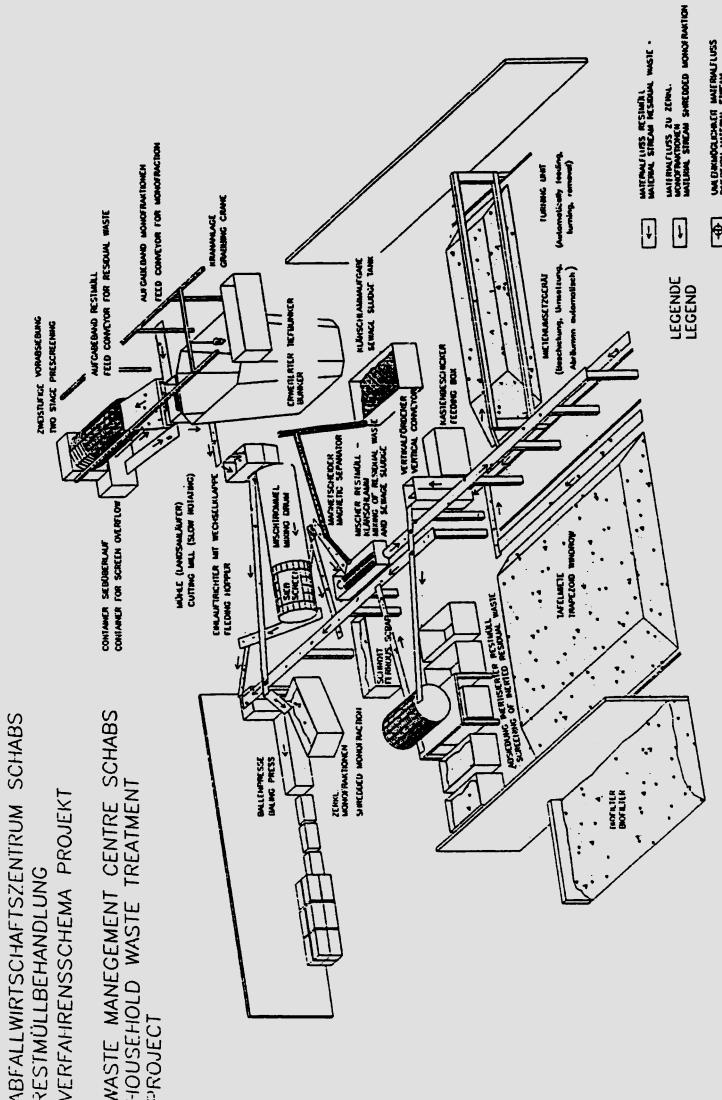


figure 3 Impianto di trattamento meccanico–biologico di rifiuti residui – schema progetto

The Power of Composting; The Power of Partnership.

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Partnerships with environmental groups, industry, and the public sector have proven to be a very effective way to advance source-separated composting of residential and commercial organic waste. The partnership concept has provided an opportunity to gather meaningful data and understanding needed to address key environmental, economic, and institutional questions that hinder broader acceptance and implementation of composting. In the United States, two innovative partnerships have shown that collaboration can achieve these goals. One partnership, ‘Compost for Earth’s Sake,’ involves the Grocery Industry and the environmental group, the National Audubon Society, working with local governments on pilot projects investigating source-separated composting. In addition to gathering data on collection performance, economics, and public acceptance, the team is investigating compost contamination from a multi-stakeholder perspective, both by measuring compost quality directly and by projecting long-term soil concentration levels that might result from sustained use. The second partnership, ‘Food for the Earth,’ is a partnership with representatives from the food service industry, the US Composting Council, and the National Audubon Society. In addition to testing the feasibility of behind-the-counter separation of organics, the food-service team is investigating the options for composting grease, which is an important disposal issue for the industry.

Yard and leaf composting programs are very popular in the United States. The composting of home and commercial organics, however, is in its infancy. The advancement of composting in the United States, beyond yard and leaf composting, requires broad public acceptance. In order to gain that acceptance, it will be helpful if both business and environmentalists support it. This will insure that the same positive message is heard wherever the public turns, helping to forge a social consensus on the value of organics recovery.

In the United States, partnerships with environmental groups, industry, and the public sector have proven to be a very effective way to produce consensus and advance source-separated composting of residential and commercial organic

*The National Audubon Society is a U.S., non-governmental environmental organization with a membership in excess of 600,000. Our interest in composting arises out of a desire to get clean, humic-like materials, which would otherwise be buried or burned, back to the land. This, we believe, will help maintain and restore soils, for the benefit of birds and other wildlife.)

waste. The partnership concept has provided an opportunity to gather meaningful data and understanding needed to address key environmental, economic, and institutional questions that hinder broader acceptance and implementation of composting.

No matter how charismatic and persuasive, no individual from one sector can produce broad-based consensus alone. That means individual groups supporting composting should be willing to go to great effort to get consensus from the key actors in composting. Development of consensus requires listening carefully to the needs of the key constituencies and adopting a position that is as inclusive as possible. This can be a difficult path to follow for those leaders who have gotten to where they are by being stubborn and going their own way, swimming against the tide that keeps down new ideas.

Fortunately, there are techniques to build consensus, even in a litigious society like the United States. One of the best conflict resolution techniques, in fact, is the formation of partnerships which include traditional opponents.

How do you get disparate constituencies to form partnerships? Obviously, there have to be some common interests. And there must also be a safety valve, which protects the core beliefs of the constituencies. This safety valve can be an 'agreement to disagree' on issues that unalterably divide the partnership.

I have been involved in forming two such partnerships in composting, and they are working.

The first is Compost...for Earth's Sake (CFES), a partnership of the National Audubon Society with the U.S. grocery industry (which is made up of groups like the Grocery Manufacturers of America and the Food Marketing Institute and individual companies like Procter & Gamble, Quaker Oats, Nestle's, Kraft, Scott Paper, Hannaford Brothers, Krogers, Pricechoppers, Lucky Stores, Shoprite and others). The goal of CFES is to promote compost collection in homes and grocery stores. CFES has undertaken a number of collection and composting pilots as well as joint publications, including a 'how-to' guide for establishing pilot programs. We have prepared a 'thought' piece on the importance of composting and a paper on the soil contaminant issue, both of which are now circulating for review.

The second partnership is Food for the Earth (FFE), a partnership of the Composting Council, the National Audubon Society and the food service industry (with groups like McDonald's, Cargill, Sweetheart cups, James River, and International Paper). All of this is in association with the National Restaurant Association. The goal of this partnership is to promote composting in the food service industry. This group is also working on pilot programs.

We believe that pilot programs are needed in each part of the country, despite the fact that successful pilots have been done elsewhere and that successful programs are already operating in other countries. In addition to having completed successful pilots in Connecticut and California, the partnerships are in the midst of a commercial pilot in Minnesota, as well as a residential drop-off program in New York State. We have been working with a Florida Solid Waste Authority to assist them in exploring composting operations in their community. We are also working

with yard waste composters in Ohio and Vermont who are in the process of adding commercial organics to their mix.

What common interests led to the formation of the CFES and FFE partnerships? A major commonality was an eagerness to find a waste diversion technique that would extend traditional recycling. A second was to get compost used for land restoration. A third commonality was support for source-separated composting even though some of the involved parties might support mixed waste composting in other forums.

(To Audubon and other environmental groups, 'doing composting right' means source separating at home or store, with actual composting taking place at home or at a central facility. U.S. environmental groups cannot at this time support mixed waste composting because of concern about contamination with household hazardous waste.)

A fourth commonality was that composting of some sorts of paper was appropriate and desirable (for example, soiled paper and paper that would not be recyclable for many years). There was agreement on this point, although the parties have differing views about exactly which types of paper are acceptable for composting. Everything has worked because of a willingness to work on common elements, while agreeing to disagree on divisive issues.

The goal of both of these programs is to make source-separated composting a reality in the United States without interfering with recycling and even helping the economics of recycling while at the same time keeping environmentalists, industry and government happy. Sound like an impossible dream? Well there's a vision out there that can make it work in the United States; a vision of people separating their compostable organics at home, restaurants and supermarkets into smoothly integrated collection systems; a vision where traditional recycling of paper would be given the top priority; a vision of composting providing a very high diversion rate when coupled with traditional recycling. Compost would be produced in filtered facilities when the operation is situated anywhere near homes.

With this joint vision, we have found in our partnerships that it is pretty easy to gain ideological acceptance in the communities where we have worked. This was true in our Connecticut pilot, where editorial writers and participants all wanted the efforts to continue beyond our experiments. When we had to get an emergency permit from the state of Connecticut, we got tremendous and quick support. In our California pilot, we also saw great community acceptance.

We are also finding that state solid waste and environmental agencies are quite receptive to this vision, especially in the crowded Northeast.

Examples of the vision can be found all over the country: at supermarkets in Washington and New Jersey, where separation takes place in the store and composting goes on in large wind rows. Cracker Barrel restaurants has shown that behind-the-counter separation of compostables is easy at its family-style restaurants. McDonald's has shown the same to be true for its quick-service restaurants.

These activities around the country are the kinds of examples that show everyone moving in the same direction. These activities show that there's something in

composting for everyone. When you add pictures of backyard composting and community yard and leaf composting as well as the idea of compost going to restore degraded lands and help community gardens, you have a powerful and exciting vision of getting organics back to the land to serve a useful social purpose. Now we need to be able to show a lot more examples from around the country so we can extend ideological acceptance nationwide. The question becomes: How do we do that?

A major strategy for reaching the goals of both CFES and FFE is to find champions in the community, government agencies and businesses. A champion in someone who believes in the potential of organics recovery, who can see beyond the obstacles and who is willing to speak out in favor of composting and take supportive actions. We need to find them and provide them with both psychological and technical support.

There are also potential champions who with a little education and acquaintance with the vision will become champions. There are hundreds and thousands of such people out there in government agencies, environmental groups and the recycling community. These are the people who are going to be there at the crucial moments, which occur all too often in the U.S., when public acceptance hangs in the balance in a community.. These are the people who will speak in defense of composting at a critical public meeting or in a critical planning meeting in a public agency or at a crucial business meeting. The recycling community has lots of potential champions, although they may not know it at this point. The recycling community is a natural ally for economic and preservation reasons.

As we have learned in our California collection pilot, wet/dry bag combinations can reduce the system costs in a community doing curbside recycling. When solid waste is collected in an organics container that has all of the messy stuff like food, soiled paper, cat litter and diapers (all of which can be composted in closed vessel facilities), it is very easy to handle the rest of the waste stream in one or more dry containers and easy to pull out the recyclables. The only residual is household hazardous wastes and large material that need not be collected very often. This means you can reduce the number of truck passes, dramatically reducing the system costs of a typical trash/recycling system, which today tends to have lots of redundancy. As pressure builds to cut costs in materials recycling programs (which seems to be happening more and more around the U.S.), the recycling community will be more and more receptive to composting beyond leaf and yard waste. If the traditional recycling community becomes supportive, it will really help with acceptance of centralized composting.

To maintain long-term ideological acceptance of composting, there are going to have to be markets for the final product. Thus, markets are more than an economic issue – markets are also an acceptance issue. An example of how to address markets in a consensus fashion is offered by the Coalition of Northeastern Governors (CONEG), which has established a Compost Committee. The committee has decided to focus its first efforts on developing model product specifications for compost. I serve as the group's co-chairman.

Right now, state and local governments have a difficult time in purchasing compost because of the absence of consensus language on product specifications. By bringing together the major actors in the composting field, CONEG hopes to fill the gap, as well as insure that specifications are uniform across the Northeast so finished compost can freely travel across borders. Adoption of model language by CONEG would not only help local government in the Northeast, but also provide guidance for commercial customers as well as government bodies outside the region.

As I said in the beginning, the first step in gaining public acceptance is getting ideological acceptance. This has been proven easy to do when one goes into a community with industry and environmental partners to help with source-separated composting, and when we all agree to put paper recycling above composting in the hierarchy.

Gaining local acceptance of communities for the siting of compost facilities is more difficult, but we have learned that it, too, is helped by the partnership approach.

I am optimistic for the long run because we have a great vision. However, it is a hard task that we've all taken on, namely to promote composting as a major handler of waste. It cannot be done alone. Environmentalist and industry must get down in the trenches together.

Composting Plant in the City of Forli' The Public Administration Experience

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Summary

After illustrating the reasons behind the decision to support the development of composting plants and after enumerating the facilities already present in the Province of Forli', the authors of this paper proceed to describe the main problems encountered in the operational phase of the plants and the solutions and legislature proposed, with a view to guaranteeing, in the future, an activity that conforms to the environment requirements of the population that resides close to the plants.

Introduction

The Province of Forli' has a high density of animal-farms, in particular, battery and ground poultry-farms. The fact that little land was available and suitable for spreading, plus the fact that the population is scattered, together with the fact that greater attention is being paid to environment issues and, in particular, to those resulting from the zootechny industry, has determined a general awareness of the problems arising from environment disharmony due to the presence of refuse deriving from animal-farms and, consequently, the need to identify possible solutions to these problems.

In particular, while on the one hand the Municipal Authorities sought to limit the creation of new plants by increasing restrictions and controls, on the other, the technicians of the Administrative Board of the Province of Forli' and the Local Health Units, by detecting the more serious problems on hand, worked towards identifying, amongst a series of technological proposals available, those that were the most qualified to restore balance to the production activity already present in the area.

After many attempts, some of which were not satisfactory (for example, the case of plants for the drying and combustion of chicken dung), the conclusion was reached that *composting* was the direction to take to solve various problems; thus, on the one hand, various proposals for plant organization were favoured, whilst on the other, a collaboration project with the research institutes was activated for the monitoring and testing of the concrete possibilities available to solve the problem.

Composting

The first approaches at studying this technology took place towards the middle of the '80s. The technology certainly presented itself as a system having different positive characteristics such as low consumption of electricity and the possibility of transforming the bio-mass into a mature conditioner that could be utilized in agriculture without causing all the health-hygiene problems arising from the utilization of animal dung.

As transportation even at great distances was possible, both from an economic and sanitary point of view, the problem of local excess of fermentable elements and bearers of fertility, with consequent negative effects on the environment, was solved.

However, a certain number of negative circumstances took place which were basically, but not solely, ascribable to the strong bad-smelling emissions which had a determining importance in numerically limiting the diffusion of this solution. At that time, in fact, it was necessary to risk utilization of technologies that were not the result of national research programs, but which derived from tests and uses carried out in areas that had characteristics quite different from the territory under examination, and, therefore, which were not always suitable for the operational conditions of the site to be utilized.

In fact, the first plants that were constructed also created problems of bad-smelling emissions deriving both from the technologies adopted as well as from management shortcomings; notwithstanding this, the actions that were undertaken led to the belief that the real solution to the environment problems already present was contained in the utilization and diffusion of such technology - after appropriate re-examination and updating in order to respect the health and environment requirements of a territory that was highly populated, also bearing in mind the economic-management compatibility of the technology with the existing breeding facilities.

Difficulties encountered in identifying suitable sites

Once it became apparent, also with the help of scientific literature, that the production of compost to be used for agronomic purposes furthers, at the same time,

both the safeguard of the environment and the improvement of soil fertility, the Administrative Board of the Province of Forli', together with the Public Health Departments and the world of the manufacturers, carried out research, tests, and promoted the creation of plants for the production of compost.

The public offices were responsible for defining the criteria to be adopted in identifying suitable sites for the plants, whilst the private bodies were responsible for the construction and the management of the same plants.

The problems that arised from the running of the first plants caused alarm in the public offices that in the meantime were ready to authorize the construction of new plants, and in the inhabitants of the areas that had been selected to locate the plant, so much so that in certain cases, anti-project committees were created. Even in the presence of extremely degraded situations, in which the creation of a plant would have in any event brought an advantage with regard to the existing situation, and in which the incertitude of the Public Board was more accentuated and this interacted with the strong opposition of the inhabitants, even in this case it became impossible to construct new plants, even in the presence of new improvement proposals with respect to the exisitng ones which had proved to be defective and difficult to implement.

To this we must add the fact that not always did the builders of the plants behave correctly (the plants at times proved to be unreliable and had the wrong dimensions), and likewise behaved the persons managing the plant, who did so both for the financial problems encountered in utilizing mixing material having a high cost, as well as for their real technological incapacity in correctly managing the plant. In the meantime, however, technologies evolved, knowledge of the most correct management techniques increased, and this led to the construction of other plants; at the present time, different composting plants are present on the territory, and this circumstance has also increased the experience of the authors regarding the identification of the most important factors for the management of processes devoid of negative effects.

If, on a theoretical basis, it has been possible for quite some time to define the conditions for an optimal project and functioning mode, operationally-speaking, a large number of possible conditioning factors capable of varying the emission situation and therefore the environment acceptability of the plants, must be taken into account.

Initially, these essentially provided a solution to poultry breeding problems, and only subsequently were other types of organic refuse, both mixed or not, taken into consideration.

Existing plant typologies, even if they vary from each other, take into account the original interest for poultry residues, because plants equipped with troughs and turning-over machine are the more frequent, even if other types of technologies exist, with a wide variety of organic products that can be treated, compost that can be obtained, and finally disposed of.

Current experiences

The plant for the composting of poultry dung and, in lower quantities, of special assimilable refuse, of the AGROFERTIL company, in S. Sofia, was created in the '80s and originally provided answers to the problems linked to the treatment of poultry dung; subsequently its license was extended to encompass the treatment of other types of assimilable refuse such as: urban biological sludge, food industry refuse, refuse from abattoirs, wastes from paper mills, wood shavings, vegetable refuse and food residues.

The technology that was adopted, which derived initially from Japanese proposals and which was subsequently modified on account of mechanical insufficiencies, proposes mainly to treat animal dung through an exothermic process that allows dehydration through evaporation and stabilization of organic material, carried out inside greenhouses. The plant comprises 4 troughs measuring 105m x 12m in which aeration is obtained by turning-over and advancing of the material through the use of special machinery.

Frequent moving of the material (twice daily) would favour dispersion of thermal energy if the process were not contained within greenhouses having controlled replacement of air and humidity. For the start-up of the process, there is a requirement for a maximum humidity rate of 70%, therefore the dung and other refuse are mixed with each other before starting the fermentation phase.

The plant is able to treat 25,000 metric tons/year of refuse that is composed of poultry litter (14,000 metric tons/year) and poultry (egg-laying chickens) dung (9,000 metric tons/year); the remaining quota originates from diverse organic refuse. The compost produced is available for use in agriculture, both loosely or in sacks, or in pelletized form.

Other companies have acquired their own composting plant for the disposal of poultry dung; the first of these companies to do this was ARRIGONI whose facility dates back to 1987, and which can treat 40 metric tons/day of poultry dung mixed with a substratum to reduce its humidity, thereby allowing fermentation.

Composting takes place in troughs and the material under fermentation undergoes turning-over in order to aerate it, and the troughs are enclosed within a structure similar to a greenhouse. The end of the process is obtained once a level of 15%–18% residual humidity is reached, to allow for pelletization of the compost.

The plant is comprised of 3 troughs having a length of 45m each, surmounted by tracks on which the turning-over machine runs; fermentation time is 35 days. Other similar plants can be found at the AVIZOO company, in Savignano, at BERARDI, in Borghi, at CAICONTI, in Bagno di Romagna, and at GUIDI, in Selvapiana.

A different type of treatment is that applied to the litter piggeries having an external composting reactor at the AGRICOLA CANALI farm in Piano di Spino di Meldola. In this plant, pig litters are treated. Before the entry of the pigs in the piggery, the litters, composed of a stratum 80cm deep of wood shavings and sawdust, are mixed with liquids plus special enzymes so as to allow the enzymes to act

and destroy the manure when the pigs settle on them.

In this case, it is the litter that acts as a composting plant, the top stratum blocks thermal dispersion, whilst in the lower stratum, metabolic processes are started that increase the temperature. Oxygenation of the material is supplied both by the animals and by the personnel who periodically overturns the material, thereby burying the fresh dung (once weekly) and inoculating new enzymes and bacteria. After approximately 15–18 months, the top stratum (25cm–35cm) is removed and is renewed with other fresh wood-cellulosic material; the removed litter represents the residue of the breeding activity.

The part of this farm that has not been able up until today to house this type of deep litter, produces at the current time diluted sewage that undergoes composting in an external litter contained in a waterproof trough surmounted by a machine that distributes the sewage and the enzymes. Everything is enclosed to avoid direct contact with atmospheric agents.

The AMIA plant, in Rimini, for composting of pre-selected and special assimilable organic refuse, which was created in 1989, and is located near the dump of Ca' Baldacci, gathers within differentiated storage troughs, urban wastes, sludge, cellulosic material (originating from certain urban areas), from which are singularly extractable the quantities required in order to obtain diversified dosage of the components within the proportioning devices that control the C/N ratio and humidity level. The resulting mixture which is distributed in heaps in the trough so as to allow for a double aeration action leads to a composting cycle of 35–45 days.

To date, the plant has operated from June until September, a period which coincides with the tourist season during which time there is the greatest production of organic refuse. The quantities of waste being treated has increased from year to year and has now reached the level of 905 metric tons (in 1991); when the plant reaches full planning configuration, a volume of at least 4,750 metric tons of urban organic waste will be treated. Compost produced in 1991 was 181 metric tons with a residual humidity rate of 32%–33%, and a production/refuse treated ratio of 20%; the loss of water is estimated at 60%–65% of the initial quantity treated.

All this was made possible through daily differentiated collection of organic refuse with special containers having a capacity of 240 l. Always with regard to the urban area where this collection takes place, 50 l containers for the collection of glass are distributed and the remaining quota of urban refuse is made through 360 l containers. The compost produced is utilized for public parks and large-scale farming.

The processing plant of food industry refuse of the FRUTTADOLORO company of Cesena will be able to treat a total of 240 metric tons by end-May 1995; refuse utilized results from the processing of food, vegetables and sludge deriving from the biological treatment of industrial waters. Its technology is the classic technology in which heaps are aerated through the overturning technique; the experimental part of this plant accelerates and controls the different phases of the composting process by utilizing enzymatic and bacterial mixtures in the heaps.

In this part of the plant, the dimension of the composting trough is 22,5 sq.m

and can house tests carried out on a heap having a dimension of 6m x 3m and a height of 3m–3.5m, which is subjected to fermentation cycles and to 3–4 turnings-over, one every 15 days, thus the composting period is of 45–60 days.

Operational considerations

As stated beforehand, operation of the above-described plants, especially those associated with poultry breeding and which are generally based on the technique of trough-composting with turning-over machine, has brought out numerous problems resulting from plant deficiencies and bad management. Without entering into an individual analysis of the functioning of each plant, the negative aspects that were encountered can be grouped in the following categories:

1. Breakdowns in the machinery.
2. Production capacity which is inferior to the one stated.
3. Fermentation problems.
4. Ammonia emissions and other bad-smelling products.

The analysis of these events has allowed the authors, in the majority of cases, to identify the effects and causes, and therefore to foresee a series of cautionary measures to be applied when realizing new plants.

Breakdowns in the machinery.

Breakdowns in the machinery have proved to be more frequent in the latest and more mechanically– sophisticated machinery compared with the simpler machinery of the past.

The nature of the breakdowns (breaking of rotational parts, breaking of movement arms, problems with electric cables, electrical problems in the command panels, etc.) points out how often the mechanical systems are underdeveloped for the required exertions or else are scarcely protected with respect to highly corrosive environment conditions.

Furthermore, many breakdowns are ascribable to lack of maintenance and, above all, to lack of lubrication, both due to oversight of the person running the plant, as well as to a real lack of evident lubrication points on the machinery itself.

Also, if the initial breakdown is of a minor entity, the same can trigger a series of effects and, above all, can cause halting of the process and could require human intervention in conditions which are often hygienically unacceptable.

Halting of the process in fact quickly sets off anaerobic phenomena in the bio-material, with consequent bad-smelling emissions, while often it is necessary to see to repairs directly in the fermentation troughs and, at times, having to manually remove the fermenting material to allow access to the turning-over machine.

These conditions must therefore be avoided, or at least must be drastically

reduced, both for hygiene reasons in the workplace, as well as for the negative effects that often arise in the surrounding area following blockage of the fermentation process.

It is therefore necessary to create systems that are capable of guaranteeing, for the majority of the breakdowns possible, and in any circumstance, transportation of the turning-over machine to the extremities of the trough, in an area which permits greater access.

Furthermore, a maintenance plan must be prepared and rigidly observed, whilst, in the plant testing phase, conformity to safety norms, which are not always observed, must be verified.

Production capacity inferior to the one stated.

This has proved to be a nearly constant characteristic in the various plants examined, mainly due to the fact that, at time of planning, the volume of mixing products to be added for the correct balance of the reactions was often not taken into consideration.

As will be explained further on, it appears evident that, for a correct management of the plant, it is necessary to guarantee certain conditions on the initial material, which can be summarized in an apparent density not above 700 g/dmc, humidity not above 70%, and C/N ratio not below 15–20.

These conditions are not generally found in the raw material being treated, therefore it is necessary to add other products (straw, sawdust, or other wood-cellulosic residues) to allow for correct initial balance.

This entails an obvious increase in the volume of the total composted mass which, depending on varying conditions, can reach an increase of over 50% with respect to the basic product, and from this derives, in general, an incapacity to treat the total product available, with consequent management problems.

Another deficiency aspect has often resided in the movement capacity of the turning-over machines. If we exclude the case, which was encountered, of machinery having completely insufficient dimensions, we often find that there is an inadequate moving capacity of the material to be treated which is due to an insufficient couple in the turning-over machine.

Though these situations usually occur on account of excessive compactness and density of the material employed (therefore, material that does not meet the above-stated standard conditions – a requirement which cannot be excluded on an operational level), these situations lead to blockage of the movement and require direct human intervention. The same, furthermore, are stimulated by mechanical coupling between the electric engine and rotor, thus, in the event of a sudden increase in the torque, a slowing of the rotation takes place with exit from peak r.p.m.

Utilization of hydraulic transmissions and automatic control systems of the movements according to the torque would allow reduction, if not elimination, of this problem. Even automatic controls on the loading and on the mixing of the

incoming materials, which would guarantee a mixture which is closer to standard values, would contribute to the solution of such problems which, we repeat, often require manual 'demolition' of the mass that has been formed.

Fermentation problems.

The fermentation process takes place spontaneously, but requires the observance of certain conditions if it is to be correctly carried out.

We have already mentioned composition of the material, above all for what concerns permeability to the air (correlated with the apparent density) and humidity. Experimental situations have occurred with densities above 1,2 kg/dmc and humidity above 80%.

In these conditions, in addition to the problem of compacting of the material, which results in the operational incapacity of the turning-over machines, anaerobic phenomena are favoured which, due to the hydrolysis processes that accompany them, further accentuate the negative situation. Fermentation is blocked, the material is 'disactivated' and the only possibility of activating it anew is to drastically mix it with dry material, an operation that often requires human intervention.

Similar conditions are favoured by prolonged breakdowns which lead to halts of over 48 hours, which give rise to processes of excessive cooling of the mass caused by insufficient protection from adverse atmospheric conditions and from recondensation of the evaporated water onto the material itself.

These phenomena have been observed in the case of light coverings, as in a greenhouse, which were once utilized because it was erroneously thought that light panels would be effective insofar as they would capture and utilize solar energy.

Obviously, fermentation problems can occur because of disinfectants or sterilizing agents present in the material that is subjected to fermentation; in this case, however, it has been observed that it is useful to recycle part of the fermented product and use it as 'triggering' material, even if this at times requires manual intervention.

Ammonia emissions and other bad-smelling products.

Maintaining a correct C/N ratio (between 20 and 30) is a guarantee from possible ammonia emissions. In operational terms, at least in the presence of residues that are rich in nitrogen, such as fecal or animal-farm residues in general, this ratio is not easily reached because in the originating material the ratio is usually around 8–10.

Consequently, the mass of wood-cellulosic additive to be used should exceed 100% of the main mass, thus bearing negative consequences on plant productivity and on costs (insofar as the additive in general can be found only upon payment). Furthermore, even the quality of the composted product, having levels of nitro-

gen below 3%, would qualify it as a conditioner and not as a fertilizer, thereby considerably lowering its market value.

Consequently, in practical terms, the operational C/N ratio does not exceed 15, as this would cause emission of ammonia into the atmosphere. Inside the reaction sheds, the value of concentration of ammonia is around 40–50 ppm, which is not very high but superior to those allowed for the presence of human operators, as during the mixing phase peaks of over 250 ppm can be reached.

These emissions, which do not permit the presence of humans inside the sheds and which therefore lead to the requirement for global automation of the processes (an event that has nearly never occurred), do not generally create problems for the surrounding environment. In fact, due to the high diffusivity of the gas, in general, an immediate remixing with the surrounding air takes place, with consequent lowering of the levels within the norms in the immediate surroundings of the facilities.

On the contrary, many problems have been caused by bad-smelling emissions which were due to long-chain composts deriving from decomposition of nitrogenous and sulphurized organic products. These are materials having a high molecular weight, with low diffusing capacity, which can suffer from atmospheric phenomena such as thermal changes or draughts, and which can cause, even at a distance, concentrations of bad-smelling gases which are even superior to those found in the vicinity of the facilities.

To this category of products can be ascribed the series of phenomena, currently existing, which have led to problems of acceptance on the part of the inhabitants who are seriously subjected to smells which are often extremely nauseating. Unfortunately, existing legislature is not easily applicable, while the same monitoring of smells is costly and extremely criticizable.

Experience has shown that these situations are the result of bad plant management (aeration blockage, anaerobic pockets, insufficient C/N ratio), or derive from the moving of originating material which is already in an advanced anaerobic state when it reaches the composting plant. Several attempts were made to find a solution by using enzymatic products, pre-mixings, etc., but they all proved useless, and at times even adverse.

On the basis of the tests carried out, we have come to the conclusion that possible solutions consist in placing particular attention on the initial fermentation phase, by opportunely mixing the incoming material with important quotas of recycled material and facilitating air-material contact, thereby ensuring, in any circumstance, the possibility of treating the expelled air, through suitable biofilters.

This obviously implies a covering that is designed expressly, and therefore it is not always possible to adapt existing facilities. Because the cost of utilizing biofilters has proved to be high, it is opportune that a methodology limiting the use of such structures be created, to be used only when it is indeed necessary.

Conclusions

From this brief summary, all the tests that have been carried out by the various public boards are not entirely evincible to allow for a correct indication as to the most suitable methodology for the recycling of solid organic wastes. The economic importance of animal farms and related transformation and food industry activity is evident as it guarantees a high standard of living and is labour-intensive for many municipalities of the Province of Forli'.

On the other hand, the need to guarantee a high quality of life and respect for an enjoyable environment has convinced us that it is worthwhile to verify the possibilities offered by technology, and to intervene on them in order to suggest, if not impose, a whole series of adjustments capable of guaranteeing correct plant management, convinced as we are that industrial and operational projects can be created from such an activity. These would no longer be borrowed from other countries, such as Japan, as was the case in the majority of the plants described above, but would be the result of tests and applications of conditions found both on a national as well as on a European level.

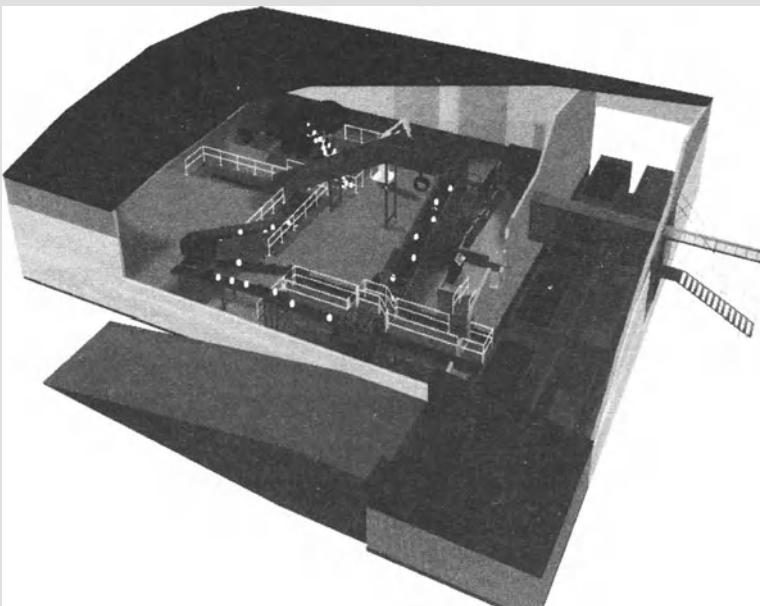
Digestion by WAASA Process of Optically Separated Waste

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Introduction

Household waste has been treated by digestion in city of Vaasa, Finland since 1990. The plant capacity is 25.000 t/a, which is corresponding to biowaste from 200.000 inhabitants.

Part of the waste treated at the plant is source separated by a new method. The system is based on using plastic bags of different colours, starting in the kitchen. The bags are detected by optical sensors and automatically separated from each other. The biowaste from households is digested in thermophilic condition. Special components are necessary for successful digestion of household waste and such components have been developed and patented by AVECON Ltd in cooperation with the waste treatment company in Vaasa.



General

Ab Ekorosk is a waste management company owned by five communes in Finland. Source separation was introduced in the area with 50.000 inhabitants at June 1st 1993. The waste treatment system practised at Ab Ekorosk is based on an unique separation concept of household waste. The waste is separated into two different coloured bags in the kitchen. Wet waste, consisting of food, wet paper and other organic waste, is placed in black bags, and dry waste, like packages, plastic and paper is placed in non-black bags. In the optical sorting plant the two different waste types can be automatically separated. The wet fraction is suitable for digestion and the dry fraction as a fuel in energy plants.

In the digestion plant in Vasa this source separated waste is treated by the Waasa Process. The RDF, consisting mainly of non-recyclable paper, plastics and textiles is used as fuel in a plant using coal and peat as main fuel. Up to 30% RDF mixed with other fuels is allowed in Finland without classifying the process as waste incineration.

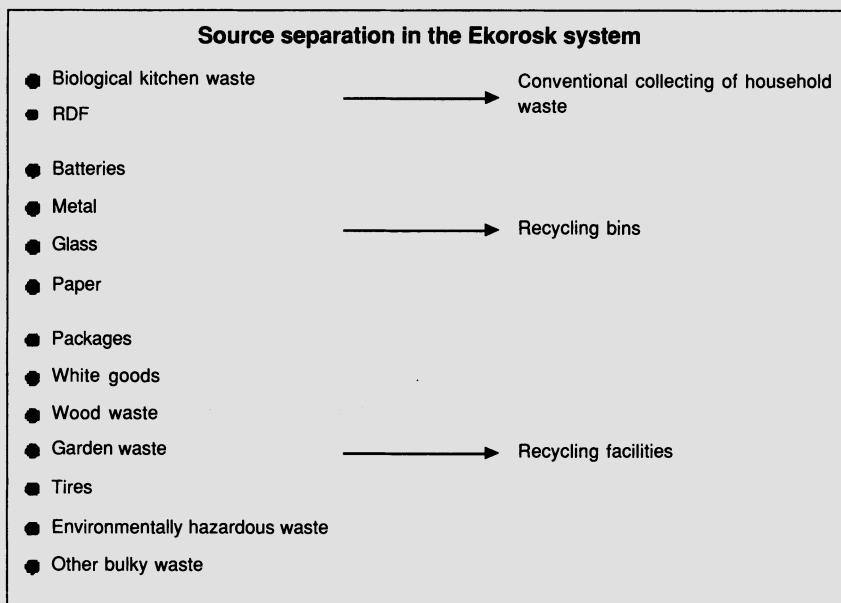


Figure 1. Source separation in the Ekorosk system.

Choise of source separation model

The concept named OptiBag is based on source separation of household waste, with households placing the various types of waste in different coloured bags. Ab Ekorosk Oy has built up a model (see Figure 1) in which the waste is divided into

a digestable fraction and other waste, which is collected on the premises. In addition, there is separate collection of paper, glass and batteries at local recovery stations. Bulky waste and environmentally hazardous waste are collected at larger recovery stations.

Before, during and after the introduction of the system, the inhabitants of Jakobstad were given systematic information in source separation of household waste. Effective information is necessary for achieving a satisfactory result.

The optical sorting plant (OptiBag) permits a continued utilization of conventional, compressed single compartment trucks for collection, as well as one bin per household. Thanks to these advantages the collection costs can be kept low and the hygienic level high. Studies show a significant cost reduction using the OptiBag method in comparison to alternative methods.

Experience of the OptiBag system since 1990 in Sweden

The separation results are excellent, with over 90% being sorted correctly by households. The automatic separating system has also produced very good results, with 99% of the bags being separated correctly.

The advantages of the OptiBag system compared with other solutions are:

- conventional collection trucks and bins can be used
- lower investment costs
- high flexibility to meet future requirements
- superior hygiene and working environment.

The system's flexibility allows source separation to be easily extended with several fractions which can be placed in bags of different colours.

The Vaasa-plant for anaerobic digestion of MSW

The waste treatment company ASJ Ltd, owned by the commune of Korsholm and the city of Vaasa has operated an anaerobic digestion plant for treatment of mechanically separated Municipal Solid Waste and sewage sludge since the spring of 1990. After a few years experience the ASJ-company decided to extend the biological treatment capacity and a second line, using the further developed Waasa-process was built during 1993.

The yearly energy-balance at the Vaasa plant is the following (design figures):

- The plant has a total design capacity of treating the waste from 200.000 inhabitants. The waste is divided into three streams in a conventional pre-treatment plant; RDF (55%), organic material (40%) and ferrometals including bulky waste (5%).

- RDF (Refuse Derived Fuel), heat value of 14,5 MJ/kg, a total energy content of 133.000 MWh/a
- Bio waste, 150 m³ biogas/ton_{input of waste}, heat content of 6,5 kWh/m³, gives a total energy output of 25.000 MWh/a
- The internal energy consumption of the digestionplant is about 7.000 MWh/a including the heat needed during wintertime with an ambient temperature of -25 (C for several months. Calculations show that if operated in a Central European climate the plant would consume less than 10% of the energy provided by the biogas.

The total energy surplus for the ASJ-plant when including the energycontent of the RDF is 150.000 MWh/a.

The digestion plant is processing about 40% of the total household waste and also sludge from the sludge treatment plant in Vaasa, some industrial organic waste and some manure from the agriculture.

The end-products from the biological treatment are digestate (compost), biogas and water. The compost is used as a fertilizer, cover material on old disposal places and for green areas. The biogas is utilized in a gas-engine for electricity and heat production. A part of the electricity is used in the plant and the remaining part is sold to the local electric network. The excess water from the process is pumped into the municipal network and is treated at the sewage treatment plant in Vaasa.

Experience

The availability of the mechanical and electrical systems in the ASJ digestion plant has been over 95 % since mid 1990 . The biological process has worked without disturbances.

The biogas quality has been stabile and the analyzes made during 1992–1993 gives a mean gas quality as follows:

CH ₄	65%
CO ₂	34%
N ₂	<0,5%
H ₂ S	<, 5–12mg/m ³
Cl ⁻	<0,5mg/m ³
F	<0,5mg/m ³
NH ₃	<0,05mg/m ³
Humidity	1%

The heavy metal content in the compost has been measured since the start and the results have improved by time. A serie of analyzis (n=6) made in 1993 gave the following content of heavy metals.

Zn	1250 mg/kg	TS	Stdev	258
Cu	200 mg/kg	TS	Stdev	22
Pb	190 mg/kg	TS	Stdev	83

Cr	67 mg/kg	TS	Stdev	4
Ni	32 mg/kg	TS	Stdev	5
Cd	3,1 mg/kg	TS	Stdev	1,0
Hg	1,4 mg/kg	TS	Stdev	0,2

The heavy metal content in the compost depends directly on the quality of the incoming waste. The excess water from the process is pumped directly, without cleaning, to the municipal waste water treatment plant.

Digestion plant in finland extended by the waasa process

Choise of process

The treatment company ASJ decided on the Waasa Process developed by Avecon International Ltd Oy. In 1989 Avecon started to change and develop the process in Vaasa together with the plant owner ASJ.

More than doubled treatment capacity per reactor volume is expected compared to the first line. With the experience from the first line a strong technical development has taken place in Vaasa. Avecon has developed technical solutions for increased efficiency. One example is the Twin reactor solution, which means that the reactor consists of a pre-chamber and a bacteria injection system. In a conventional reactor there is always a risk of emptying untreated organic material, but the Twin reactor eliminates the risk of short circuit. The new solutions shorten the retention time and create a digestate of better quality. The second line is a thermophilic Waasa Process, which is the most influential factor in achieving a shorter retention time.

Avecon has developed a special component named a Mixseparator for handling the temperature and water content variation problems; it also has many other functions. The household waste consists of many different materials and, even when course-separated, the waste must be thoroughly separated further before digestion. The fine separation is most effective in the wet stage and this is carried out in the Mixseparator.

European interest

The Waasa Process has aroused interest in many European countries. Avecon has signed licence and co-operation agreements with Ingg. De Bartolomeis for Italian market and Thyssen Still Otto Anlagentechnik for the German market and with Holland Construction Group (HCG) for the Benelux countries. Co-operation partners for other markets are being sought in 1994 and 1995. Interest in the Waasa Process is based on the reference plant and the level of development (its theoretical biochemical research is a cooperation venture between Avecon and the University of Tampere). As in most technical fields product development in anaerobic digestion technology is a continuous process necessary for future success.

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Sources:

Optical sorting of source separated household waste: The OptiBag concept by Anders Wahlquist.

B3 Composting as an Integrated System of Waste Management

The Co-Treatment of Municipal and Industrial Wastes

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Abstract

Regulatory pressures are forcing major changes on the waste disposal industry. The proposed EU Directive on Landfilling of Waste, if implemented in its current form, will ban the co-disposal of industrial and municipal wastes in landfill. These developments indicate a likelihood that co-disposal will no longer be available as a disposal option for industrial wastes in the long term.

Above-ground co-treatment of industrial wastes with sewage sludge and/or municipal solid waste *prior* to landfill is an approach to enhancing the efficiency of waste disposal to landfill and reducing reliance on incineration. It also provides an alternative to disposal to land where the wastes are considered too toxic. Degrading municipal waste and sewage sludge have been shown to promote the degradation of many toxic organic compounds and fix other organic and inorganic substances, for example as sulphides or into humic matter. These processes are used to justify the practice of co-disposal to landfill. Unfortunately, these processes are not optimised and cannot be controlled in landfill and hence co-disposal has come to be viewed unfavourably in many countries. Optimisation of these processes in an above-ground treatment system would have many advantages, including:

- 1 Stabilisation of environmentally damaging substances,
- 2 Reduction of waste volumes prior to landfill,
- 3 Generation of recoverable biogas,
- 4 Detoxification of hazardous substances in a low temperature biological process,

- without the input of additional fossil fuel or the likelihood of generating dioxins and furans,
- 5 Generation of a benign stabilised residue,
 - 6 Biological sanitisation of the treated waste stream,
 - 7 Disposal of a waste with a reduced capacity to generate landfill gas and possibly improved geotechnical performance.

Introduction

The co-treatment of waste is the use of one waste in the treatment of others, or the combination of a variety of waste types within one process to achieve some treatment advantage. Historically, incineration and landfill processes have commonly had co-treatment applications. Co-treatment applications for biological processes, anaerobic digestion and composting, have been less well investigated, although aerobic processes are applied to the treatment of contaminated soil. However, they may offer significant advantages in some cases over co-incineration and codisposal.

It is not the purpose of this paper to describe a proprietary system or specific research approach, but rather to demonstrate the potential use of biotic and abiotic processes that occur in composting and anaerobic digestion in the combined treatment of municipal and industrial wastes and so stimulate research in the field. As well as being a valid treatment approach in its own right, we suggest that co-treatment offers an opportunity to alleviate the process limitations of codisposal landfill in an above ground treatment system.

Background

For all waste management practises, the ideal is the achievement of sustainable wastes management, within the framework of sustainable development. The acceptance of sustainable development for waste treatment is a pre-requisite to the acceptance of co-treatment as a waste management practice, and is therefore discussed in some detail in Text Box 1. Parts of the co-treatment approach are already enshrined in the waste management policy of several countries which still find themselves disagreeing on waste management practice at the most fundamental levels. Co-treatment may be a viable compromise position for these various waste management philosophies, and should therefore be of direct interest to the European Commission and European proponents of biological waste treatment processes, such as ORCA.

Industrial and municipal waste management strategies appear to fall into four broad areas:

- 1 Pre-treatment of all wastes before landfill to render them as inert as possible

- and limit as far as possible biological activity in the landfilled waste [5,8]; (For example, in Germany the maximum allowable organic content in any landfilled waste will be 5% by the year 2005, which, with the present state of the art, leaves thermal treatments as the only practical pre-treatment [39]);
- 2 Operating landfills to achieve complete and permanent containment (the so called 'dry tomb') reducing ingress of water and eliminating as far as possible emissions from the site [39], and where possible segregating wastes into different types, in particular using *monofill* sites for hazardous industrial wastes, or wastes which might conceivably be recyclable at some time in the future [5,8];
 - 3 Using landfill cells as active bioreactors to accelerate decomposition rates and landfill gas production, and minimise the time the landfilled wastes are a potential pollution source, and hence reduce the lifetime of landfill containment [5,8,24,35,58,59];
 - 4 Codisposal of municipal and compatible industrial wastes is widely practised in the UK and USA, and to a lesser extent in other European countries [24,35,58,79], some of which used the approach more widely in the past [60]. It is salient to note municipal solid wastes (msw) also contains hazardous substances. For example, msw in the USA is thought to contain 0.2 to 5% by mass of hazardous substances [76]. Codisposal of msw and sewage sludge is practised in many countries, and appears to accelerate landfill gas generation [18,93].

Codisposal sites accept municipal wastes (eg refuse and/or sewage sludge) and permitted liquid and solid industrial wastes [32]. Such codisposal has been common practice in Europe and North America for many years. Recent data [35] indicate that leachate from efficiently managed codisposal landfills is similar to that from those accepting only municipal waste, lending further support for the argument that the biological attenuation processes of codisposal can effectively treat a wide range of industrial wastes. Indeed the view of the UK Department of the Environment [35] is that for certain waste streams, codisposal may represent the Best Practicable Environmental Option (BPEO) [74]. Effective codisposal landfills are regarded as stationary fixed film reactors [24,59], in which mixing of substrate and bacteria is the rate limiting step in the degradation of the industrial wastes. The effectiveness of codisposal landfill sites as a treatment is limited by waste heterogeneity, moisture availability, temperature and pH [21,40,45,58,75,92], which can result in wastes remaining undegraded for significant periods [73], or otherwise degradable contaminants such as phenol being persistent problems in landfill leachate [92].

Within Europe there is significant political pressure to phase out codisposal. Although moves to achieve this in the proposed European Directive on Landfill [26] are being strongly resisted by the UK, the long term future for codisposal in Europe is uncertain [5–8]. The proposed Directive on Landfill will, if introduced, ban the codisposal of wastes to landfill, except at those sites with existing codisposal licenses, who will be allowed to continue until those sites are complete (sub-

ject to meeting set criteria for landfill control). Within the UK, approximately 2,070 landfill sites receive some combination of domestic, commercial or industrial waste, and of these, approximately 360 landfill sites are licensed for codisposal [35]. In Germany, most hazardous industrial wastes that are disposed to land are monodisposed in various containment facilities, including disposal to underground salt mines, which are exempted from the provisions of the Directive [5,8].

Concerns about codisposal, and indeed biologically active landfills in general, include the following:

- Generation of landfill gas (which may be a major source of atmospheric methane and also contains trace levels of carcinogens), recovery of landfill gas from sites is incomplete and landfill gas may be generated for many decades [4,5,8,39];
- Poor control of degradation processes in landfill sites, some operators may be unable to achieve methanogenic conditions in their landfill sites [79];
- The impact of landfill emissions, such as landfill leachate [38,58,60] but also arising from the volatilisation of industrial chemicals such as cyanides [59]
- The possibility of corrosion of clay liners by leachates from active sites [22].

Whilst critical attention has been focused on biologically active and codisposal landfill sites, the disadvantages of other approaches have been ignored.

- The extreme pretreatment requirement in Germany presupposes the general acceptance of thermal treatment processes by the public [39];
- Landfilling of ‘inert’ wastes, may also generate methane [3];
- The leachates from monofill sites, or sites largely composed of incinerator residues are likely to have a greater pollution potential than those from bio-reactor landfills [35];
- The sorption capacity of wastes landfilled after thermal pretreatment for inorganic and undegradable pollutants will be significantly less than that of landfilled waste containing organic matter¹ [59,76], and the hazardous substances themselves will be more concentrated. Not only does this increase the pollution potential of the site, it may take many hundreds of years for such a site to become reusable or for containment to be relaxed [38]. It also makes stringent demands on containment design because of the enhanced risks of damage if containment fails.

These considerations do not include wider issues of environmental cost and benefit. For example waste management based exclusively on intensive pre-treatment and monofills, there is likely result in greater use of waste transportation to centralised high cost (thermal) pre-treatment facilities or monofills. Furthermore, such landfills commit our descendants to their care for many hundreds of years, which is not compatible with any notion of ‘sustainability’.

In broad terms, at present countries appear to be choosing one of two options: pre-treatment and long term containment of landfills, or using landfills as bioreactors and taking advantage of this for codisposal. The two approaches are seen as mutu-

ally antagonistic [5,8]. Unless extreme positions are taken by both sides this antagonism is unnecessary. Co-treatment offers a means of combining the advantages of both approaches, whilst also reducing their disadvantages.

Co-treatment Processes

A co-treatment system could include a variety of process steps. For example, co-treatment could employ an anaerobic first stage, including biogas recovery, with an aerobic second stage to maximise nitrification. Co-treatment facilities could be part of an overall waste management strategy where recyclable materials were recovered as far as feasible from msw, trade and industrial wastes, and the residues were treated together to maximise the flexibility and capacity of scarce landfill resource. Residual activities from co-treatment processes would be likely to persist through the early stages of treated waste disposal, and this activity could be regarded as the closing phase of the co-treatment. It is conceivable that with good landfill design and careful optimisation of the end point of the above ground process, the residual activity of the infilled wastes would create a stable long term environment within the landfill site maintaining pH and redox conditions at optimal levels for the retention of immobilised substances and the continuation of long term degradation processes. The aim of this would be to achieve as rapid a stabilisation of the pre-treated and infilled waste as possible.

Technologies which might be applied to co-treatment are already well established. The application of composting to treating municipal wastes is well established [43]. The use of anaerobic digestion is well established for wastewater and various industrial wastes [80] but has yet to be widely used for the treatment of msw, although there have been pilot and full scale initiatives in Europe and North America [27,68,71,80]. Combinations of anaerobic digestion with composting [51,57] or combinations of biologically active landfilling with anaerobic digestion (ie using a landfill cell as an acetogenic bio-reactor followed by an invessel methanogenic reactor [44,96]) have been less well studied.

A variety of biotic and abiotic processes taking place in these biological treatment systems have the potential to destroy, immobilise or transform hazardous organic and inorganic substances, for example:

Biological processes: Biodegradation of organic substances to simple mineral compounds and biological transformation of organic substances into less toxic or less mobile forms;

Abiotic processes: Immobilisation of organic and inorganic substances in humic materials; Immobilisation of inorganic substances by biologically generated or mobilised ions such as phosphate ions, sulphide ions under anaerobic conditions, or bicarbonate under aerobic conditions; and neutralisation of pH and consequent reductions in heavy metal mobility.

Box 1 Sustainable Development in Waste Management

'Sustainable development' has been defined in 1987, in the report of the World Commission on Environment and Development (The Brundtland Report) as 'development which meets the needs of the present without compromising the ability of future generations to meet their own needs'. This report identified the characteristics of sustainable development as:

- The maintenance of the overall quality of life
- The maintenance of continuing access to natural resources and
- the avoidance of lasting environmental damage

These concepts are also iterated in the 5th EC Action Programme [26] which states that "sustainable development implies putting in place a policy and strategy for continued economic and social development without detriment to the environment and the natural resources on which human activity depends". The concept of sustainable development recognises that both economic and environmental factors affect 'quality of life', and that any new development must account for the environmental cost as well as the *economic cost*.

Among other things, sustainable development implies that:

- the environment and its natural resources must be recognised as the basic foundation of all human activity, and their satisfactory guardianship is a precondition for sustainable development [26].

The concept of sustainable development was addressed at the United Nations' Conference on Environment and Development in Rio de Janeiro in 1992. Chapter 21 of the conference's Agenda 21 specifically addresses 'Environmentally sound management of solid waste and sewage-related issues' and was written in response to the conference assembly's decision that environmentally sound management of wastes was among the environmental issues of major concern in maintaining the quality of the Earth's environment, and especially in achieving environmentally sound and sustainable development in all countries. Agenda 21 states that environmentally sound waste management must go beyond the mere safe disposal or recovery of wastes that are generated and seek to address the root cause of the problem by attempting to change unsustainable patterns of production and consumption. Four major waste-related programme areas were identified. These were:

- Minimising wastes
- Maximising environmentally sound waste re-use and recycling
- Promoting environmentally sound waste disposal and treatment and
- Extending waste coverage service

In keeping with the theme of sustainable wastes management, the European Commission, in its 5th action Plan [26] has identified a waste management hierarchy as follows:

- Prevention of waste
- Recycling and re-use
- Safe disposal of remaining waste in the following ranking order
 - combustion as fuel
 - incineration
 - Landfill

The overall aim of the above is to achieve more appropriate waste management techniques that minimise the impact upon the environment, and account for the environmental cost (short-term AND long-term), and not just the economic cost.

Biological Processes

Biodegradation describes the decomposition of an organic compound into smaller chemical subunits through the action of organisms, and both aerobic (oxygen requiring) and anaerobic degradation pathways exist, although there are some differences in which types of compound will degrade under aerobic compared with anaerobic conditions [2,63]. Principally micro-organisms (bacteria, fungi and actinomycetes) are responsible for practically useful bio-remediation processes. Completely degraded compounds are said to be mineralised, and the end products might be carbon dioxide, water and chloride ions for a chlorinated hydrocarbon degraded under aerobic conditions. Guthrie [47] describes this as 'ultimate biodegradation'. He defines 'acceptable biodegradation' as implying breakdown to below toxic levels, and 'primary biodegradation' as a structural change in the parent molecule, which is more commonly referred to as 'biotransformation'.

Biodegradation may proceed via enzymic activity on compounds adsorbed into cells or through the activity of extracellular enzymes active outside the confines of the cell. Cells may also use enzymes to generate free radicals or peroxide ions that attack organic compounds, particularly insoluble compounds. In many cases organic compounds do not enter microbial cells since the compounds are either sorbed to soil surfaces, are too large or are physically incapable of being sorbed into cells. More complex compounds may not be completely degradable by single organisms, and are degraded by *consortia* of organisms, and in some cases may not be completely degradable in any circumstance. Some organic compounds may be coincidentally degraded as a result of microbial activity against other substrates, *cometabolism*. For example lignin degradation processes may also degrade complex organic compounds such as polynuclear aromatic hydrocarbons (PAHs) [1,10,12,33,82].

The use of biological processes for treating toxic substances is perhaps best advanced in the bio-remediation of contaminated soils. At present practical soil bio-remediation processes are limited to the degradation of fairly readily degradable contaminants: mononuclear aromatic (eg benzene toluene, ethylbenzene, xylenes); simple aliphatic hydrocarbons (eg mineral oils, diesel fuel) and lower PAHs (2,3 and 4-rings) [14]. However, full scale applications of bio-remediation to treat more complex contaminants (such as pentachlorophenol) are taking place, and some success is reported by the process operators [53]. Biodegradation of a variety of recalcitrant compounds, including polychlorinated compounds has been demonstrated under laboratory conditions [17,29,70]. Examples of composting or similar processes applied to the treatment of contaminated soils are reviewed in Text Box 2.

Aerobic decomposition processes appear to be more thoroughly investigated than anaerobic processes [19]. There is some dispute about both the general effectiveness of anaerobic decay processes, which are perceived by some as being slower and/or less complete than aerobic processes in soil or landfill [11,32,58]. Other researchers argue that the potential destruction of organic substances under

optimal anaerobic conditions is or must be the same as for aerobic processes [19], and the anaerobic decomposition of a variety of organic pollutants such as chlorinated solvents and aromatics PAHs and PCBs has been demonstrated [46,48,90].

Concerns about the use of biological processes in waste treatment include:

- Their susceptibility to inhibition by toxic contaminants, for example heavy metals. However, aerobic biodegradation processes appear quite robust to inhibition by toxic substances [53,54], and methanogenic activity in landfills appears to resist heavy metal toxicity [59].
- The mobilisation and release of potentially toxic partially degraded contaminants and the mobilisation of inorganic pollutants, for example by methylation under anaerobic conditions, the production of ligands, or indeed the microbial oxidation of sulphides under aerobic conditions [12,15]. Immobilised contaminants, may only remain sorbed if suitable stable conditions of redox and pH can be maintained in the landfill site where residues are disposed of. Notwithstanding this limitation, the possibility of immobilisation in landfilled co-treatment residues seems to be a clear advantage over the potential mobility of contaminants in thermally pretreated wastes.

Abiotic Processes

These processes include physico-chemical processes such as adsorption to surfaces and also immobilisation by biologically produced materials. Organic matter sorbs heavy metals and organic substances [37,59]. There is experimental evidence to suggest that the extractability of heavy metals from msw decreases over the course of composting, even although absolute concentrations increases as organic matter is degraded [88].

There is some evidence that PAHs may be irreversibly adsorbed into humic matter [65,66,85,87], through a variety of biological and non-biological processes. Indeed, the possibility exists that humus naturally contains subunits similar to PAHs although this observation may be an artifact of the digestion processes used in the analyses. [65,66]. Soil organic matter also appears to be important in promoting abiotic processes of contaminant degradation for some organic compounds and in co-metabolic degradations of organic compounds [37,94].

Some industrial waste materials may themselves sorb dissolved species such as heavy metals [9]. In addition some inorganic contaminants, such as lead, may gradually become immobilised as insoluble phosphates by precipitation with phosphate ions and this has been proposed as a means of dealing with contaminated sites [78].

Box 2 Composting and similar processes used in land remediation

Full scale treatments where excavated soil is placed in windrows or piles and subjected to forward (blowing) or reverse (suction) aeration akin to aerated static pile composting are in use in North America and European countries [31,67,69] and simple windrow turning processes have been applied in Germany. Alternatively, contaminated soil may be contained in some form of lined receptacle [91]. The aerated contaminated soil windrows may also contain amendments, either added through mixing before the pile is constructed or through irrigation, which is also used to adjust moisture content.

Amendments that may be mixed into the soil include organic matter (such as bark, straw, sewage sludge) [13,50,53]; microbial inocula; proprietary agents to enhance contaminant availability and protect micro-organisms from contaminant toxicity such as 'Daran.end' or 'Biocrac' [28,30,81] and structural materials such as pulverised debris [13,20,50].

Organic matter may be added for one or more of the following reasons: to supply an active microbial population; to add structural material (see below); to add microbial nutrients; and to add water [41,50,52,95]. Organic matter may also have the benefit of sorbing and rendering contaminants less toxic [85]. This sorption may also inhibit biodegradation according to some studies [49]. However, sorption of contaminants to surfaces may also promote their degradation by both biological and non-biological processes [37]. There is uncertainty over whether the addition of readily biodegradable organic matter assists contaminant degradation through co-metabolism or interferes with contaminant degradation through the diversion of microbial activity to easier substrates [10].

A good structure in the windrowed soil is important to process performance by ensuring adequate aeration and irrigation of the pile. Structural materials tend to be non-biodegradable (pulverised debris) or slowly biodegradable (eg bark, straw or wood chips). The incorporation of structural materials may also have the benefit of allowing a greater recycling rate of on site materials (eg debris), or the inclusion of an additional waste stream in the treatment process (eg straw or sewage sludge).

Mixing is important for all *et situ* approaches to allow them to exploit their major advantage over *in situ* approaches which is improved accessibility of the contamination to the treatment. In some *et situ* venting approaches mixing only takes place when the pile is established [62]. In some cases biodegradation in windows is not assisted at all by venting; regular mixing is used to ensure aeration and the exposure of fresh surfaces to microbial decay [50,6 I].

In some cases process temperatures may reach the thermophilic range [95] although full scale designed use of thermophilic composting in contaminated soil treatment is rare. Most experience is related to the treatment of TNT contamination [55] which, incidentally also appears to be degradable under anaerobic conditions [72]. Pilot scale studies of the co-composting of sewage sludge and gasworks soils have also taken place, along with observations of the degradation of recalcitrant organics such as PCBs through composting [41,52,56]. For municipal waste composting a major thermophilic process control difficulty is the control of moisture content, since the amount of heat generated is usually sufficient to cause excessive drying of the windrowed materials [86] particularly at the core of the pile where aeration is employed. One interesting possibility is the use of mushroom composting reactors, where air is recirculated through the compost pile, after controlled cooling via a heat exchanger. Fresh air is then drawn in only to support microbial processes and not for cooling. This not only eases the management of water balance (since cooling of the exhaust air need not be to fresh air ambient levels), but also helps ensure a more even process temperature since edges can be kept warm [42].

Determining mass balances for contaminants is important in process evaluation [83]. In some cases it may be that dilution of the soil mass with pulverised debris and/or losses through volatilisation/leaching may be responsible for a significant part of observed contaminant losses.

Codisposal Studies

Decomposition and attenuation of organic compounds has been demonstrated under simulated landfill conditions in mixtures of msw. Tests fall into three general types [59], column tests, lysimeter and microcosm studies, and observations and measurements made on landfill sites.

A variety of column and lysimeter tests, in which the migration of substances through columns packed with msw, have been carried out internationally [35,59,76]. Degradation of a proportion of added organic compounds and sorption of both inorganic and organic substances has been demonstrated. Sorption processes can be reversible, although the extent of any such reversal under landfill conditions is not clear.

Microcosm studies, to simulate microbial activity in landfills, have demonstrated the possibility of degradation of a variety of organic compounds such as aliphatic compounds, some plastics and PAHs [22,58,59,75]. Measurements using landfilled wastes have demonstrated evidence of microbial assays using assays of enzyme activity [45], although there is some evidence that such activity, for example degradation of cellulose in newsprint, is suboptimal [16,34].

Although proponents of codisposal would argue that these observations support the view that effective codisposal is possible [53,59,79], there is little doubt that codisposal at some landfill sites has caused significant contamination of leachates by organics arising from industrial wastes, and/or adversely affected methanogenic processes, for example by changing the pH of the saturated zone, in some landfill sites [22,92,93]. Whilst it is possible that poor performance of codisposal may be due to poor site management [79], it is perhaps more realistic to recognise that control of such a vast and heterogeneous, static *in situ* system as an entire landfill site or cell is difficult to achieve and its performance hard to predict. Use of an above ground system would allow true process control and the mixing of substrates. It would also allow monitoring of both the treatment and the composition of treatment residues prior to their disposal.

Processes on the Landfill Periphery

Landfill disposal is the final stage of a co-treatment system, in which biologically stabilised wastes are landfilled within a containment system designed to permit the continuation of residual biological and abiotic activity. Emissions (ie landfill gas and leachate) might be expected to be reduced compared with untreated msw. For instance, leachates from aged composts have lower chemical oxygen demand and total dissolved solids than landfill leachates [36]. Ideally such emissions could be dealt with by passive means, in principal enhancement of naturally occurring processes of decay and attenuation that occur in the vicinity of landfill sites. These processes are poorly understood [32] but include biological processes (ie anaerobic processes in areas where biological oxygen demand exceeds supply, and aero-

bic processes in groundwater where dissolved oxygen is present) and physical and chemical processes: these include precipitation of inorganic hydroxides along with co-precipitation and sorption of other substances; adsorption and ion exchange; mechanical filtering and buffering.

Enhancement of naturally occurring decay and attenuation processes are widely used in other environmental applications such as: the use of wetlands for the treatment of acid mine drainage [89] and the use of reed beds for the treatment of industrial and municipal waste-waters [23] and the use of low level fertiliser additions to stimulate biodegradation of oil spills on beaches [64]. Attempts have been made to passively enhance these processes beneath landfills by careful design of drainage and bottom layers [77]. Enhancement of natural or intrinsic decontamination processes is likely to be a longer term and lower input approach, but requires much greater knowledge of fundamental soil processes, how these are affected by site specific conditions and what factors are likely to be rate limiting for a particular site.

Environmental Costs and Benefits of Co-Treatment

Table 1 is an illustration of the environmental benefits (advantages) and costs (disadvantages) in comparison with the four major waste management approaches discussed earlier in the paper. These are: codisposal as currently practised, landfill after *stringent* pretreatment aimed at eliminating biological activity (ie thermal pretreatment), long term 'dry' landfills including monofills, and bioreactor landfills (excluding codisposal sites). Each of the five approaches has been ranked in terms of its likely environmental impact under a variety of categories, with a ranking of 1 representing 'good', and a score of 5 'bad'. For example, with regard to waste transportation: codisposal and bioreactor landfills score 1 as their sites are the most flexible, co-treatment 2 as co-treatment plants are less flexible so conceivably more waste will have to be transported between plants, and stringent pretreatment and long term landfill / monofills 3.

The following attributes are considered: the likely generation of methane rich landfill gas and the likely generation of high COD leachate over time; the potential for hazardous leachate generation if containment is breached; the duration that isolation monitoring and control of the site will be required until stabilisation; the energy and resource requirements for facility construction and operation and maintenance; the likely impact of disposal strategy on the prospects for re-use of the site once the waste is stabilised or if it is stabilised; and the likely environmental impact of waste transportation and preliminary treatment for example at transfer stations that each approach would require.

Table 1 Illustrative Environmental Cost Benefit Analysis for Co-treatment

Attribute	Co-treatment and Landfill	Stringent Pretreatment	Bioreactor Landfill and Landfill	Dry Landfill	Codisposal
Landfill gas generation	2 ¹	1	3	1	3
Leachate generation	2	5	3	1	4
Impact of containment breach (ie potential generation and impact of leachate)	1	3	2	3	3
Duration of containment requirement (rate of site stabilisation)	1	3	2	3	3
Use of resources and energy in facility construction	3	4	2	3	1
Use of resources and energy in facility maintenance	4	5	2	3	1
Possibilities for site re-use	1	2	1	2	2
Requirement for waste transportation and transfer stations	2	3	1	3	1
Total	16	26	16	19	18
Ease of environmental verification and process validation	1	1	3	2	4
Total including verification score	17	27	19	21	22

Note Landfill gas emissions may be sufficiently slight to allow oxidation of most methane to carbon dioxide using passive control measures, which would make this score 1, and hence the total 15.

Although this table is only illustrative, the apparent cost (ie high score) of using stringent (ie thermal) pretreatment as a matter of course before landfill is striking. At first glance the other four approaches are broadly similar in their environmental cost. The lowest scoring approaches are bioreactor landfills and co-treatment. However, bioreactor landfills have yet to be demonstrated for an operating lifetime in practice, whereas co-treatment offers the real advantage of verifiable process performance in short timescales.

Conclusions and Recommendations

The potential of established biological waste treatments for municipal and industrial wastes to the combined treatment of these wastes has yet to be fully explored. Studies of the behaviour of wastes in codisposal sites and observations of their use in other environmental applications, such as contaminated soil treatment, indicate their potential to not only reduce waste volumes and reduce potential leachate

and landfill gas volumes per unit of input waste, but also their capacity to ameliorate industrial wastes.

The potential of the co-treatment approach should be more fully investigated, both in terms of its likely environmental benefits and costs, but also to determine the requirements for optimal process performance.

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NOTES:

1) To obtain Warren Spring Laboratory reports, contact Caroline Wood, AEA Technology, National Environmental Technology Centre, Glasgow Office, Kelvin Road, East Kilbride, Glasgow, G75 0RZ. Tel 03552 42626, Fax 03552 33355.

2) NATO/CCMS conference papers are abstracted in a forthcoming publication of the United States Environmental Protection Agency: Interim Status Report: NATO/CCMS Pilot Study on Research, Development and Evaluation of Remedial Action Technologies for Contaminated Soil and Groundwater (Phase II). February 1995, Draft. Available from: Technology Innovation Office, OSWER, US EPA (OS11OW), 401 M Street, SW, Washington DC 20460, USA.

1Whilst such sorption is reversible, eg by EDTA #33#, it does enhance the contaminant buffering capacity of the waste – containment system.

The Importance of Waste Characteristics and Processing in the Production of Quality Compost

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Abstract

The quality of compost produced from municipal solid waste or selected waste components therefrom is determined primarily by the characteristics of the waste components and by the processing methods. Consequently, a knowledge of the characteristics of the waste components and of the fundamentals of preprocessing and composting technologies is required in order to design a system to produce a compost to a desired set of specifications. The specifications can be a result of regulations, or market conditions, or both. The characteristics of the waste to be composted can be manipulated at the point of collection (e.g., by separate collection of the predominantly biodegradable waste components) and during subsequent processing. This paper focuses on the characteristics of various waste components and of mixtures thereof, the key fundamentals of processing relevant to composting, and the influence of waste characteristics on compost quality. Besides the discussion of applicable fundamentals, the characteristics of compost produced from mixed solid waste organics and from mixtures of source separated components are compared both on a theoretical basis and related to some actual data. The discussion provides information relevant to the determination of the advantages and disadvantages of using mixed solid waste organics or source separated wastes as compost feedstocks.

Introduction

The production of compost of high quality from mixed municipal solid and fractions derived therefrom can be an important factor in the acceptability of this form of processing as a means of recycling post-consumer wastes. Compost of high quality means a material that satisfies regulatory conditions, market specifications, or both.

Two predominant factors govern the quality of compost produced from solid wastes, namely the characteristics of the parent material and the methods of pro-

cessing. The manipulation of the characteristics of solid wastes to produce a high-quality product can start as early as the point of generation, e.g., separation at the source (i.e., source separation), of only the biodegradable organic materials from other wastes set out for collection, and separate collection and processing of them. Alternatively, processing of mixed solid wastes can be used to produce a compost product, wherein all of the manipulation of characteristics occurs subsequent to collection. Manipulation of the biodegradability ('compostability') of materials can occur as early as the design of the products that contain the materials. In fact, product formulations are currently being designed to enhance their ability to be composted or recycled. The focus of this discussion, however, is the manipulation of material properties after the useful life of the materials.

Waste Characteristics

Many of the characteristics of the compost product have their genesis in the characteristics of the parent waste. For example, the concentration of glass and of heavy metals in a compost produced from waste materials is related to the concentration of these materials in the solid waste feedstock. Processing can be and is used to change the properties of the solid waste feedstock to those that are needed for a high-quality compost product. Processing is used here in the broad sense, i.e., any form of manual or mechanical methods of processing, including manual segregation of waste materials by the generator prior to collection.

The characteristics of solid waste also impact the performance of manual and mechanical processing systems, the design of composting operations, and act as a determinant of the operating conditions of the systems. Characteristics that impact system performance, operating conditions, and design include the particle size distribution and the ratio of carbon to nitrogen of the solid waste feedstock. The ratio of carbon to nitrogen in the feedstock, to a large extent, determines the magnitude of the need for a nitrogen source. If sufficient nitrogen is not inherently available in the solid wastes, the length of time required for the composting process will be unduly long.

The particle size distribution influences the type of equipment selected for handling (e.g., the infeed conveyors must be of adequate dimension to contain and transport the materials), the degree of segregation of oversize (i.e., non-processible) waste prior to processing, and the selection of the appropriate size reduction equipment.

A typical composition of mixed solid waste is given in Table 1. The carbon and nitrogen content and metal concentrations found in some waste components are shown in Tables 2 and 3, respectively. The average metals concentrations shown in Table 3 are the results of component analyses conducted on waste components collected from one eastern and from one western U.S. location. The maximum and minimum concentration of one metal (lead) are also shown in the table to illustrate the range of concentrations. As opposed to the other components listed in

Table 1, the Other Organic category requires some additional explanation since it will be shown later to significantly impact compost quality. This category includes textiles, wood, and fine organic materials that cannot be visually classified because of their small particle size.

Table 1 Typical Composition of MSW

Component	Wet Wt. %
Corrugated	7
Newspaper	9
Mixed Paper	22
Yard Waste	15
Food Waste	8
Other Organic	9
Plastic	9
Ferrous	4
Aluminum	1
Glass	8
Other Inorganic	<u>8</u>
	100

Table 2 Carbon and Nitrogen Contents of Some Solid Waste Components (% Dry Wt.)

Element	Corru-gated	News-paper	Mixed Paper	Yard Waste	Food Waste	Other Organic
Carbon, C	45.5	48.8	44.0	49.3	41.7	48.8
Nitrogen, N	0.16	0.10	0.43	3.00	2.80	1.75
C:N	284	488	102	16	15	28

Table 3 Metal Concentrations in Some Solid Waste Components (Mg/kg, Dry Wt.)

Metal	Number of Samples	Corru-gated	News-paper	Mixed Paper	Yard Waste	Food Waste	Other Organic
Avg. Cadmium	18	0.88	0.91	0.76	0.69	0.30	6.19
Avg. Chromium	18	39.2	36.9	42.2	124.6	27.0	821.5
Avg. Copper	18	30.9	44.1	62.4	73.4	18.2	54.3
Avg. Mercury	18	0.042	0.021	0.024	0.027	0.007	1.835
Avg. Nickel	18	16.6	25.9	20.8	38.5	14.2	41.6
Avg. Zinc	18	51.5	46.8	175.7	205.6	25.9	2167.6
Avg. Lead	18	21.9	28.9	31.4	36.1	201.5	91.7
Max. Lead	18	101.0	106.0	131.0	106.0	3050.0	436.0
Min. Lead	18	0.1	1.2	4.1	0.1	0.2	3.1

Relevant Fundamentals

Several factors, such as particle size distribution, heavy metal content, and carbon/nitrogen ratio of the feedstock have been mentioned previously to illustrate the relevancy of waste characteristics to process design and to the quality of the compost end product. Practically speaking, two general areas within the waste management system envelope are conducive to manipulation of the characteris-

tics of the end product – the generator and the processing operation. Of these two, the generator can usually exercise the greater degree of quality control if properly educated and motivated.

Some mention must also be made of the role of collection as it pertains to composting of wastes. The role is primarily one of transport in the case of collection of source separated biodegradable materials. In the case of collection of mixed solid waste, while the role again is primarily one of transport of waste, an important consequence is the fostering of contaminating events, such as the breaking of glass containers and scattering of glass throughout the load, and the rupturing of metal containers holding fluids during compaction and unloading activities. The broken glass is difficult to remove by processing. Similarly, the contents of the ruptured metal containers can include toxic organics and heavy metals which have been dispersed among the materials in the load of waste and which, once dispersed, are difficult or impossible to remove from the other materials or to render innocuous through microbial activity.

The initial carbon/nitrogen ratio (C:N) plays an important role in determining the length of the composting process. A stable compost has a C:N of about 20: to 25:1 for a solid waste-derived compostable mixture; the achievement of a value in this range requires different lengths of time, depending on the initial C:N – a higher initial C:N requires more time for the organic material to stabilize than a mixture having a lower ratio, all other conditions being equal.

The composting process for the organic fraction of solid waste requires proper conditions. The proper conditions include a mixture with a moisture content of about 55%, with sufficient structural integrity to support porosity and maintenance of aerobic conditions, and containing an adequate population of microorganisms and nutrients. Also, a high percentage of biodegradable materials is advantageous in order to minimize contamination of the compost product and production of process residues. These aforementioned conditions can be met through judicious selection of wastes to be processed, through supplements (e.g., addition of water or nutrients), or a combination of these means.

The composting process converts biodegradable materials into predominantly intermediate solid products, CO_2 , and H_2O . The process of conversion also applies to some toxic organics, but excludes a number of chlorinated organics (e.g., PCBs) that are recalcitrant to aerobic processes of conversion. The compost process does not alter the molecules of heavy metals that are in the waste. In fact, a concentrating effect occurs since the mass of the solids is reduced (through the conversion of a portion of the biodegradable material to gaseous CO_2 and water), and the mass of metals remains constant.

Important Process Related Factors

Three of the more important considerations for determining feasible solid waste-derived organic feedstocks are moisture content, carbon/nitrogen, and concentra-

tions of metals. Of the three, moisture content is the least significant, as explained subsequently. Except in the case of the food waste component which usually has a moisture content above 60%, most organic components typically have moisture contents below 40%. To conduct aerobic composting, a moisture content of about 55% is optimum. Consequently, moisture typically must be added if non-food waste organic components or mixtures of them are to be composted in an efficient manner. Thus, consideration of moisture content normally is not a driving consideration in defining which components should be selected for collection, processing, or both.

On the other hand, the carbon/nitrogen and metal concentrations have substantial significance in the selection of feasible components and mixtures of them. In the simplest of terms, carbon/nitrogen is important because, to a large degree, it governs the duration of the composting process to stabilize the organic materials. An initial C:N of about 40 is optimum for solid waste-derived organics (i.e., containing cellulosic materials) from the standpoint of efficient use of time and equipment.

Compost Characteristics

The component characteristics given in Tables 2 and 3 can be used to estimate the characteristics of various mixtures of components as compost feedstocks and of the resultant compost product. It should be borne in mind that the estimates are only as accurate and reliable as are the data concerning the component characteristics.

Seven alternative feedstock mixtures have been constructed as examples and analyzed in terms of appropriateness for composting and of the quality of the composted product. The mass loss of organics is assumed to be 40%, as a result of microbial activity. The quality parameter studied is metals concentration. The composition of the seven feedstocks are shown in Table 4. The mixtures range from all of the organic components (Alternative Feedstock No. 1) to individual components (i.e., Alternative Feedstocks 5, 6, and 7). The component compositions of the feedstocks listed in Table 4 are derived from those in Table 1.

Table 4 Composition (%) of Feedstock Alternatives

Component	1	2	3	4	5	6	7
Corrugated	7	7					7
Newspaper	9	9					
Mixed Paper	22	22	22				
Yard Waste	15	15	15	15	15		
Food Waste	8	8	8	8		8	
Other Organics	9						
TOTAL	70	61	45	23	15	8	7

The carbon/nitrogen ratios of the feedstock alternatives are shown in Table 5. The impracticality of composting corrugated in the absence of a source of nitrogen

(e.g., food, materials, yard waste, or sludge) is reflected in its carbon/nitrogen ratio of 284. The relatively low carbon/nitrogen ratios of Alternative Feedstocks 4, 5, and 6 identify them as potential sources of nitrogen in those instances where nitrogen is required to reduce a high initial carbon/nitrogen ratio of a feedstock to an acceptable one.

Table 5 Estimated Carbon and Nitrogen Content (% Dry Wt.) of Feedstock Alternatives

Chemical Element	1	2	3	4	5	6	7
Carbon	46.3	45.9	45.4	46.7	49.3	41.7	45.5
Nitrogen	1.35	1.29	1.71	2.93	3.00	2.80	0.16
C:N	34.2	35.5	26.6	15.9	16.4	14.9	284.4

Table 6 Estimated Concentration of Chemical Elements in Composts for Various Feedstock Alternatives (Mg/kg Dry Wt.)

Chemical Element	1	2	3	4	5	6	7
Cadmium	2.37	1.20	1.09	0.92	1.15	0.50	1.47
Chromium	262.2	98.9	111.6	151.1	207.7	45.0	65.3
Copper	88.3	97.0	90.3	122.3	30.3	51.5	
Mercury	0.428	0.040	0.037	0.033	0.045	0.012	0.070
Nickel	44.6	40.9	42.5	50.1	64.2	23.7	27.7
Lead	97.2	89.0	105.3	156.1	60.2	335.8	36.5
Zinc	653.5	216.9	265.1	238.5	342.7	43.2	85.8

The estimated metals concentrations of the feedstock alternatives are given in Table 6. The results in the table indicate that Feedstock Alternative No. 1 in general would have the higher concentration of metals, particularly chromium, mercury, and zinc. These metals are disproportionately contributed to Feedstock Alternative No. 1 by the Other Organics category. The composition of this category was described earlier. Materials included within the Other Organics category as defined herein could be expected to be set out with the more conventional organic materials (i.e., paper, food, yard waste, etc.) as one component of a wet/dry collection system. This analysis shows the potential magnitude of the quality difference that might be expected between a collection and/or processing system that targets all organic categories of the waste stream versus the targeting of 2, 3, or 4 component categories.

The estimated metal concentrations of compost, as determined by this analysis, are generally similar to and generally support the trends of metal concentrations found in composts produced in Germany from source separated MSW and from yard waste and agricultural wastes [Golueke and Diaz 1991]. As one example, defining Alternative Feedstock No. 1 is a source separated MSW compostable feedstock, this analysis reports nickel and zinc concentrations of 653.5 mg/kg and 44.6 mg/kg, respectively, for the compost product versus 408 mg/kg and 29 mg/kg, respectively, reported for a comparable feedstock in Golueke and Diaz 1991. Complete comparisons with the compost metal concentrations and feedstocks

reported are not possible since the feedstocks (both the theoretical feedstocks defined herein and the German feedstocks) obviously are not identical. In fact, in the case of chromium, this analysis predicts concentrations in source separated MSW organics and yard waste that are 8 to 16 times those reported in Golueke and Diaz 1991. However, for the same metal (chromium), this analysis and the German data indicate that the concentration in the compost produced from source separated MSW organics is about 1.3 times that in compost produced from yard wastes.

Bearing in mind the range of lead concentration given in Table 3 for various organic components, the concentration of lead among samples of composts produced from the feedstock alternatives could be expected to differ by a factor of 3 to 15. This large potential for variation can have substantial repercussions in terms of meeting regulatory standards on a sample-by-sample basis.

Comparing the strictest metal standards (i.e., the Minimum Value) shown in Table 7 with the estimates given in Table 6 indicate that compost produced from any of the seven alternative feedstocks will have trouble meeting on average one or more of the limits, in particular cadmium, copper, and zinc. In some locations, even the purest of individual organic categories may not be able to meet the strictest metals limits, especially if the maximum concentration measured among samples is the governing metal criteria.

Table 7 Compost Standards (Mg/kg Dry Wt.)¹

Chemical Element	U.S. EPA	Holland	France	Austria	Germany	Blue Angel	Minimum Value
Cadmium	39	1.5	8	4	2	1	1
Chromium	1200	100		150	400	1000	100
Copper	1500		400	100	75	50	
Mercury	17	1.5	8	4	1.5	1	1
Nickel	41	50	200	100	50	41	
Lead	300	150	800	500	150	100	
Zinc	2800	250		1000	400	300	250

Conclusions

Composts produced from materials derived from the solid waste stream will have different characteristics depending on the characteristics of the parent materials, market specifications, regulatory limitations, and type of processing. Manipulation of compost characteristics can commence at a number of points after the wastes are generated. Thus, source separation is a possible initial manipulation. Manual and mechanical processing also can be used after collection of materials for the purpose of producing compost with the desired or required characteristics. The characteristics of several solid waste-derived composts have been shown to have substantial and important differences based on the types of feedstocks and the methods of processing.

The results presented herein indicate the magnitude of metals concentrations of compost produced from a variety of mixtures of organic components of the waste, including single component feedstocks (e.g., yard waste). The analysis indicates that the inclusion of the Other Organics material category in a compost feedstock (such as might occur in a wet/dry collection system) could result in substantially greater metal concentrations in some cases than for other combinations of components.

However, depending upon the regulatory criteria and methods of sampling and analysis, even the purest of material categories and combinations of them may not meet some of the allowable limits for metal concentrations.

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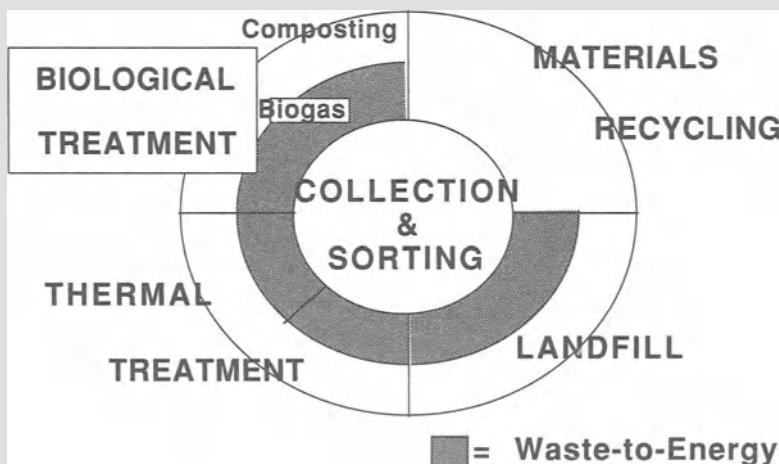
¹ Holland through Blue Angel standards—World Wastes, Aug./Sept., 1993.

The Role of Biological Treatment in Integrated Solid Waste Management

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Abstract

Biological treatment plays an important role in solid waste management since it can effectively treat a significant proportion of municipal solid waste, as well as certain industrial wastes. However, no one treatment method can manage all waste materials in an environmentally effective and affordable way. Biological treatment therefore needs to be part of an overall integrated waste management (IWM) system. Making such IWM systems both environmentally and economically sustainable requires that both their overall environmental burdens and economic costs can be predicted, and then optimised. This paper shows how a Lifecycle Inventory (LCI) tool can be used to assess overall sustainability and optimise the role of biological treatment within integrated solid waste management. It suggests that further integration of both solid and water-borne CTwaste treatment can lead to additional environmental and economic improvements.



Introduction

Biological treatment, whether the aerobic process of composting, or the anaerobic process of biogasification, represents a valuable opportunity for solid waste management. Organic materials suitable for biological treatment arise from many industrial processes, such as food production and processing, brewing, and paper, leather, wool and textile production (BfE, 1991). A large proportion of municipal solid waste (MSW) also consists of biodegradable material which can also be treated biologically. In Europe, for example, food and garden waste can contribute up to 52% of MSW in some countries, whilst food, garden and paper waste together can account for up to 80% (see data given in White et al., 1995). Biological methods present an opportunity, therefore, to treat a significant proportion of both municipal and other solid wastes.

The benefits of biological treatment

The benefits of biological treatment are two-fold:— where markets for energy and products exist, biological treatment represents a method for valorising part of the waste stream; it also acts as a pre-treatment of solid waste prior to final disposal.

Valorisation

Both composting and biogasification produce a stabilised organic material that may be used as a compost, soil improver, fertiliser, filler, filter material or for decontaminating polluted soils (Ernst, 1990). The key point that distinguishes the compost-like product, from a residue that needs to be disposed of, is the presence of a market for the material.

In addition to a compost-like product, biogasification also recovers value from waste as biogas, which can be sold as gas, or burned on-site in gas engine generators to produce electricity. Around 90–150 Nm³ of gas, with a calorific value of 21–29 MJ per Nm³, can be produced per tonne of organic waste treated (White et al., 1995). There is normally a market for this product, at least for the electricity. Since the gas can be stored between production and use for electricity generation, export of power into the national grids can be timed to take advantage of high energy prices during peak consumption periods.

Pre-treatment for disposal

Volume reduction

Breakdown into methane and/or carbon dioxide and water can result in the decomposition of up to 75% of the organic material on a dry weight basis (BfE, 1991). On a wet-weight basis, the weight loss is of the order of 50%. As paper, food and garden waste together can contribute up to 80% of MSW, the potential for reducing the volume of landfill required for final disposal is considerable.

Stabilisation

Since much of the decomposition has occurred during the biological treatment, the resulting material is considerably more stable than the original waste. If subsequently landfilled, this material will produce less landfill gas and leachate than the original waste, so alleviating potential problems elsewhere in the waste management system.

Sanitisation

Both composting and biogasification are effective in destroying the majority of pathogens that are typically present in the feedstock. Aerobic composting is a strongly exothermic process, generating elevated temperatures of 60–65°C over an extended period of time, which is sufficient to ensure the destruction of most pathogens and seeds. Biogasification processes are only mildly exothermic, but may be run at an elevated temperature of 55°C (thermophilic process) by the addition of heat. This temperature, plus the anaerobic conditions, is usually sufficient to ensure that the residue is pathogen-free.

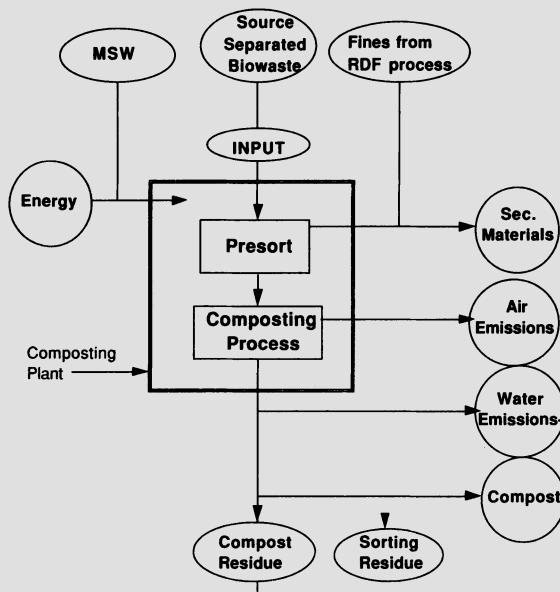
Optimising the biological treatment process

There are many routes to optimise the biological treatment of solid waste, whether by composting or biogasification. Selecting the appropriate process type and feedstock material are two basic choices. Taking the feedstock material, for example, it has been shown that using a broader feedstock definition for source-separated material that includes paper (non-recyclable paper and paper products) can offer processing advantages over treatment of a more narrowly defined vegetable, food and garden waste (VFG) feedstock.

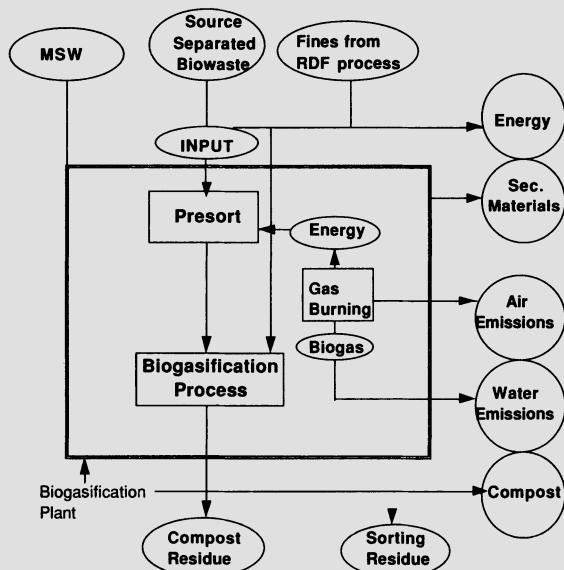
The advantages can include:

- Reduced production of leachate during the process (Verstraete et al., 1993)
- Reduced requirement for bulking agents (Haskoning, 1991)
- Improved carbon:nitrogen ratio for the composting process (Jespersen, 1991)
- Increased organic content of the final compost (ORCA, 1991)
- Reduced salt level of the final compost produced (Fricke, 1990)

To consider the effect of any proposed improvement, however, it is necessary to look at the overall biological treatment process (Figure 1) to consider the inputs and outputs of the process. Optimisation consists of increasing the production of useful products (gas/energy and marketable compost), whilst reducing emissions (to water, air and land) and the consumption of energy. There are always two sides to the optimisation process: minimising the environmental burdens of biological treatment, and keeping the overall cost to an acceptable level relative to other available waste treatment options.



(a) COMPOSTING PROCESS



(b) BIOGASIFICATION PROCESS

Figure 1 Flow Diagrams for Typical Composting and Biogasification Plants

Biological treatment as part of an integrated solid waste management system

Whilst the composting or biogasification process can itself be optimised, biological treatment does not operate in isolation. It relies on the existence of an appropriate collection and, in some cases, sorting system to provide the input materials in a suitable form. Collection and treatment are inter-dependent. For example, if the biological treatment process is designed to accept a narrowly-defined feedstock, the collection system and public education programmes must ensure that only the desired materials are collected. Conversely, if only commingled materials are collected, then the biological treatment plant must be designed to deal with this feedstock. Biological treatment must therefore be considered within the overall waste management system.

Despite its value, it is clear that biological treatment alone cannot effectively manage all materials in the waste stream, since a significant proportion of materials will not be decomposed by such processes. Similarly, there will be residues from biological treatment that need to be treated further by other technologies, such as incineration or landfilling. Overall, therefore, it is becoming accepted that no one single treatment method can deal with all materials in the solid waste stream in an environmentally sensitive way. What is needed is an integrated waste management (IWM) system that uses a range of treatment methods, including biological treatment, materials recycling, thermal treatment (burning of refuse-derived fuel (RDF), packaging-derived fuel (PDF) and/or mass burn incineration) and landfilling. The elements of an integrated waste management system are shown in Figure 3. Following an appropriate collection and sorting system, a combination of such treatment methods should be able to deal effectively with all materials in the solid waste stream.

Biological treatment can, therefore, play an important role within integrated solid waste management.

Optimising the overall iwm system

As it is part of the larger solid waste management system, any changes in the biological treatment process will have effects elsewhere. Taking the earlier example of including paper in the feedstock for composting, this will have effects on the collection and sorting operation, and also on the overall performance of the waste management system.

Reported advantages of collecting a broader 'biowaste' fraction that contains paper include:

Reduction of malodours during collection (White et al., 1995)

Reduction of seepage water during transport and storage

Reduction in seasonal variability in the amounts of biowaste collected

Increased acceptance by participating households (Boelens, 1995).

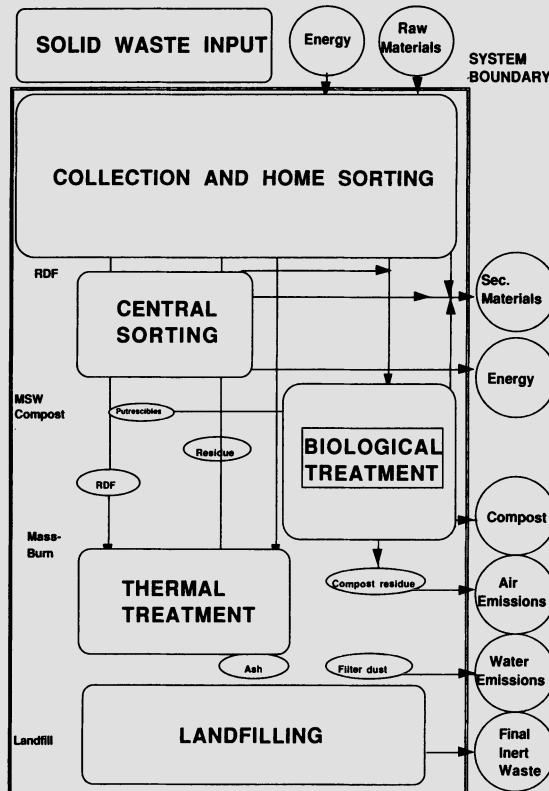


Figure 2 The role of biological treatment in an integrated solid waste management system.

Including paper in the biowaste fraction is also likely to have the overall effect of increasing the total amount of municipal solid waste that is valorised (ORCA, 1991).

Because of the interactions between the different elements of a solid waste management system, the best approach is to optimise the overall system. The objective should be sustainable waste management, which can be broken down into both environmental and economic aspects.

Environmental sustainability involves reducing the overall environmental burdens associated with managing society's solid waste, both in terms of resource usage (energy and materials) and the release of emissions to air, water and land.

Economic sustainability requires that the overall waste management cost is acceptable to all sectors of the community which is served.

If we want to optimise the overall system against these objectives, we need to be able to predict both the overall environmental burdens and economic costs of

waste management systems. The developing tool of Lifecycle Inventory (LCI) can be used for this purpose. We have applied the lifecycle concept to solid waste management to produce a Lifecycle Inventory for the management of municipal solid waste (White et al., 1995). The details of the solid waste system modelled in this LCI are shown in Figure 3.

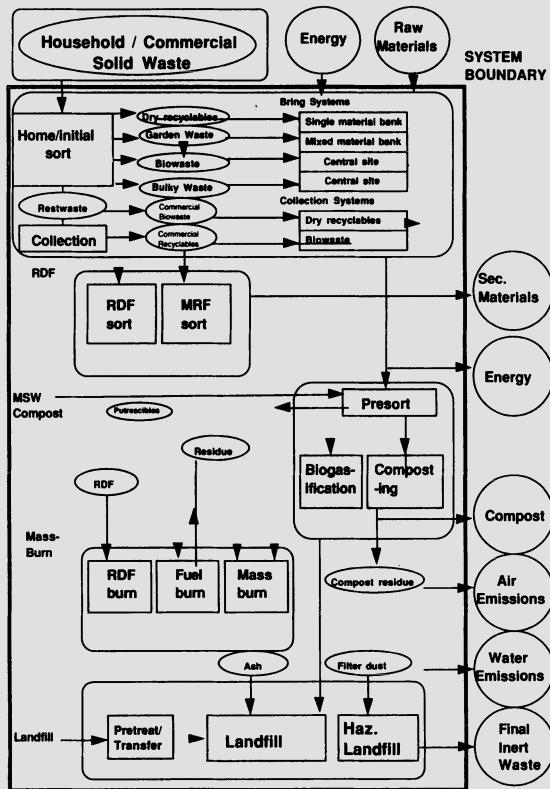


Figure 3 Detailed Materials and Energy Flows in the Lifecycle of Solid Waste.

Whilst individual processes, such as composting or biogasification, need to be optimised, optimising the overall IWM system involves choosing which waste management options should be included, and how they best fit together. Focusing on biological treatment, for example, how do the overall environmental burdens and economic costs for a solid waste system that relies on landfill only compare with those for a system using mixed waste composting? How does this compare with a system that uses incineration rather than composting? How would the overall performance alter if biogasification were used instead of composting, or if a source-separated feedstock were used instead of mixed waste? What would be the overall effect if there was a market for the compost so produced, versus if there were no market and the compost residues needed to be landfilled?

To be able to carry out such 'What if ...?' calculations a flexible, yet easy to use, LCI tool is required. We have created such an LCI tool as a spreadsheet. The user defines the amount and composition of the waste to be managed (this can be on the scale of a town, city, region or country) and selects the waste management options desired. The options available are shown in Figure 3. The spreadsheet will then calculate the overall environmental burdens in terms of energy consumption and production of emissions to air, water and land, and the overall economic cost.

A hypothetical case of how this can be applied is shown in Figures 4–6. This example takes an area containing one million households, with the waste generation and waste composition characteristics of France. It then considers five different ways of managing this waste, using a combination of biological treatment, incineration with energy recovery, materials recycling and landfilling. Biological treatment options include composting of commingled MSW (both with and without the presence of a market for the composted material) and composting of a source-separated biowaste fraction (with both narrow and broad definitions). For each scenario, results for just three parameters are given here: overall energy consumption, final landfill volume and global warming potential of resulting air emissions. The LCI tool itself will give the full range of emissions as well as energy consumption. Full details of these analyses are given in the book *Integrated Solid Waste Management: A Lifecycle Inventory* (White et al., 1995), though not included here due to lack of space.

Using an LCI tool of this kind, it is therefore possible to optimise an overall Integrated Waste Management system, in terms of both environmental and economic sustainability. Thus it is possible to consider the effects of including any form of biological treatment on the overall performance of a solid waste management system.

Details of Waste Management Systems compared in Figures 4–6.

1. Basic System: commingled collection of household waste followed by landfilling.
2. Commingled collection and mass-burn incineration of household waste.
3. Commingled collection and composting of household waste, with market for the compost.
 - a. As in case 3, but with no market for the compost.
4. Separate collection and composting of biowaste, landfilling of restwaste.
 - a. As in case 4, with an integrated collection system.
 - b. As in case 4, including washing of the biobin.
 - c. As in case 4, but including paper in the biowaste collection.
5. Separate kerbside collection of dry recyclables and incineration of the restwaste.
 - a. As in case 5, with an integrated collection system.
 - b. As in case 5, with a close-to-home bring system for dry recyclables.
 - c. As in case 5, with a central bring system for dry recyclables.

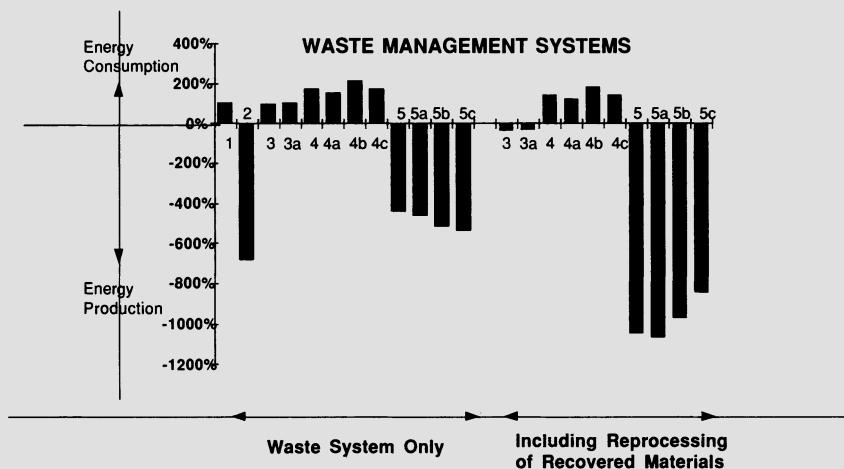


Figure 4 Overall energy consumption of different solid waste management systems.

Note: Energy consumption (thermal energy equivalent) indexed relative to basic waste management system (Case 1).

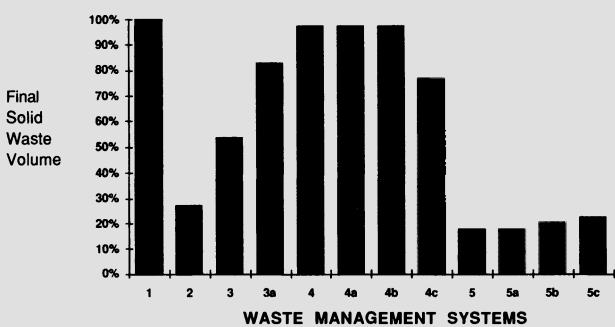


Figure 5 Overall final solid waste produced by different solid waste management systems.

Note: Final Solid Waste Volume indexed relative to basic system (Case 1)



Figure 6 Relative global warming potential (GWP) due to air emissions from different solid waste management systems.

Notes: 1. Global Warming Potential (GWP) is shown relative to the basic waste management system (Case 1)

2. GWP values used are CO₂ = 1, CH₄ = 35, N₂O = 260. (Values for 20yr timescale, IPCC, 1992)

Further integration of waste management

This paper has dealt with the role of biological treatment within integrated waste management systems that manage solid waste, and in particular, municipal solid waste. It has shown that by taking an holistic approach, it is possible to optimise the overall system both environmentally and economically. Such integrated systems, however, are also capable of managing other types of wastes. In particular, IWM systems employing biological treatment are capable of handling sewage sludges that arise from the treatment of water-borne wastes. Sewage sludges can also be treated thermally, by incineration with municipal solid waste. There are other connections between the two waste systems:— solid waste and water-borne waste can represent alternative disposal routes for some waste items such as paper products (tissues/hygiene products). Since there is this overlap between the solid waste and water-borne waste systems, it makes sense to plan their treatment together in an overall integrated strategy for all wastes. Benefits of this further level of integration include the prevention of problem-shifting (i.e. so that improvements in water-borne waste management do not give rise to greater problems in the management of solid waste or *vice-versa*), plus the greater efficiencies, economies and flexibilities of scale.

Conclusions

Composting and biogasification both present good opportunities to manage significant amounts of municipal and other forms of solid waste.

Biological treatment cannot effectively treat all materials in a municipal solid waste stream, so needs to be part of an integrated solid waste management system.

Whilst it remains important to optimise individual biological treatment processes, real, overall environmental improvements will be achieved by optimising the overall IWM system against the goals of environmental and economic sustainability. Lifecycle Inventory, and in particular a user-friendly LCI tool, can be used to optimise IWM systems and predict the effects of wider use of biological treatment within integrated waste management systems.

Further integration of waste management systems, to include both solid and water-borne wastes, offers potential for further overall environmental and economic improvements.

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Acknowledgement.

The figures in this paper are taken from *Integrated Solid Waste Management: A Lifecycle Inventory.* by White, P.R, Franke, M. and P. Hindle. Published by Blackie Academic and Professional. 1995.

Results of Laboratory and Field Studies on Wastepaper Inclusion in Biowaste in View of Composting

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Abstract

A comparative study was run during 13 months on two biowaste definitions involving both lab tests and field surveys. A narrow biowaste definition, allowing only biogenic wastes was compared to a broad biowaste definition, including compostable man-made products, such as non-recyclable wastepaper and diapers. Two similar real-life test areas with each about 425 inhabitants were defined in a semi-urban area North of Antwerp. During the whole test period the amount of curbside waste, this is biowaste and restwaste (the 'non-biowaste'), was continuously and precisely measured and also analysed regularly (twice per season) for composition. At the start, middle and end of the test, surveys were held with a questionnaire for the population of each test area. In each season of the year, bench-scale aerobic composting experiments were run to evaluate the influence of both biowaste definitions on the composting process and the compost end product.

The introduction of source-separated waste collection resulted in an overall landfill diversion of 43% for the narrow biowaste definition and 46% for the broad biowaste definition. The contamination of biowaste (about 3%) was low for both definitions, the restwaste (or so-called grey waste) still contained a lot of organics (34 to 66%). Supposing that the collection and the appropriate disposal of organics could be improved to 95% efficiency (compared to about 60% currently), the landfill diversion could be increased to 59% for the narrow and 74% for the broad definition. Whereas the average efficiency of separate collection of organics is about 61%, it is 49% for non-recyclable paper and even about 20% only for certain categories of compostable, non-recyclable paper. Apparently some more education or a better system of recognition and identification is needed to improve the collection efficiency of man-made compostables.

The acceptance and goodwill of the population was significantly higher for the broad biowaste definition, especially in the summer months. The yearly, overall composition of the total curbside waste (biowaste and restwaste combined) is 17% kitchen organics, 47% yard waste, 4% recyclable paper, 13% non-recyclable paper

and 19% non-compostables. It must be mentioned that glass, paper and large yard waste are collected separately by a voluntary bring-system. The broad biowaste typically contained 16.0% paper (of which 2.9% was recyclable) versus 2% for the narrow (0.3% recyclable).

The aerobic composting process was improved by expanding the biowaste definition through easier moisture control, better aeration and a more tempered pH evolution. A significant difference was seen for NH₃ and corresponding odour emission, being much lower in the broad definition. The quality of the compost produced was similar and acceptable for both biowaste definitions.

Introduction

In recent years a strong trend has developed in several European countries towards source separated household waste collection and subsequent composting or biogasification of the organic biowaste fraction. In several cases the biowaste fraction is limited to natural, biogenic organic material only although several other man-made or manufactured products could be considered to be compostable and given access to the biobin (or biowaste).

At the same time, a parallel move arose to recuperate and recycle as many waste products as possible. Well-known examples are the Töpfer-law resulting in the Green Dot and DSD system in Germany, the similar Eco-emballages in France and Fost+ in Belgium, and the packaging directive on a European level (Club de Bruxelles, 1994). The Flemish Masterplan on Solid Waste 1991–1995 stipulates that waste products which can be ‘recuperated’ may not be landfilled or incinerated (OVAM, 1994). In all these regulations composting of waste products is considered a form of material recycling.

Materials and methods

In order to evaluate the effect of source separated household waste collection and more specifically of biowaste definition on the diversion of household waste from landfill, a comparative field study on biowaste definition was carried out in the area of the ‘intercommunale’ IGEAN, northeast of Antwerp, Belgium. The study lasted 13 months, from the beginning of September 1993 to the end of September 1994.

The main objectives were to investigate the effect of biowaste definition on:

- Appreciation, participation rate and sorting behaviour of households
- Quantity and composition of Biowaste/Biowaste Plus and restwaste (impact of seasonal variations)
- Landfill diversion of household waste
- Sorting behaviour and performance

- Composting processing
- Compost quality

To achieve the objectives, 2 test areas in a semi-urban region were selected, each with a population of + 140 households, identical demographics and maximum similarity. In one area, Wuustwezel, a narrow biowaste definition (kitchen + garden waste) was applied and in the other area, Essen, an expanded biowaste definition (kitchen, garden and non-recyclable paper waste). Further on the narrow biowaste definition will be referred to as 'Biowaste' and the expanded biowaste definition as 'Biowaste Plus'.

During the first month of the study mixed household waste was collected and analysed to establish baseline data. After that the source separated household waste system was applied in which every week one waste collection was run, alternating between Biowaste/Biowaste Plus (in 120 L rigid biobins) and restwaste (in plastic bags). The amounts of waste collected were recorded as well as the participation rate of the households. Per season 2 detailed sorting tests on both Biowaste or Biowaste Plus and restwaste were done. Once per season a representative sample of the respective biowaste fraction was composted at pilot plant-scale (200 L) and the quality of the produced compost was determined according to the German RAL GZ 251 analytical methods (BGK, 1994).

At start of the study the households were well informed through teasers and newsletters. To evaluate the reaction of the population throughout the project 3 polls were carried out at start, middle and end of the project.

Results

Participation rate and reaction of the population

The introduction of the source separated household waste collection system in substitution for a mixed household waste collection system was very well accepted and supported by the population, irrespective of the biowaste definition. At mid term, the population connected to the Biowaste scheme, requested change over to Biowaste Plus.

Expanding the biowaste definition with the non-recyclable paper fraction resulted in a higher and more consistent participation rate (= number of households using biobin divided by total number of households), + 22% on the average, and fuller biobins in comparison to Biowaste collection (Figure 1). As a result, the households with the Biowaste Plus definition asked for larger biobins.

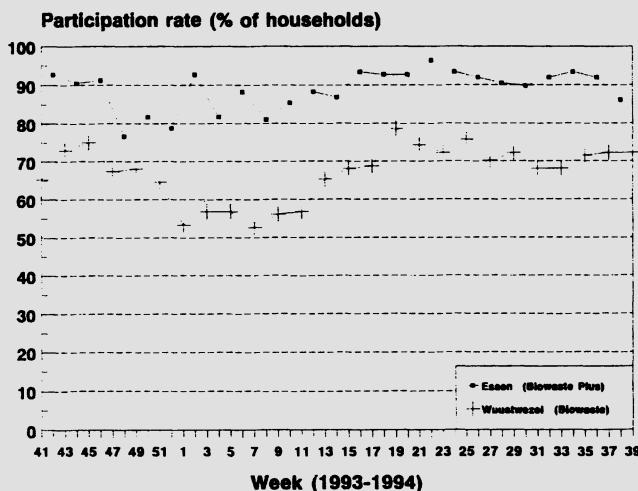


Figure 1 Measured Participation Rate of Households in Wuustwezel (Biowaste) and Essen (Biowaste Plus).

The level of comfort was much higher for the Biowaste Plus definition than for the Biowaste definition. Most complaints of households with the Biowaste collection were about odor, vermin and cleanliness. As a result about 6% of the household stopped separated biowaste collection during summer (versus < 1% for Biowaste Plus collection). Finally, households in both areas urged for a more frequent collection.

Household waste production

The amount of household waste to be collected at curbside was 60% of the total household waste stream. About 40% was already collected through container parks (paper, glass, recyclable paper, construction debris, oversize garden waste, metals, plastics,...).

The introduction of the source separated collection system resulted in both test areas in more household waste being collected (+ 15–30% versus baseline). The results of the weekly weighings showed that a major part of the Biowaste or Biowaste Plus could be diverted from landfill by composting/anaerobic digestion. The measured yearly landfill diversion percentage was 44% in case of Biowaste collection and 51% in case of Biowaste Plus collection (increase of 16%) (Figure 2). These results are comparable to those obtained in other studies (Spencer, 1993). Finally, biowaste production was subject to strong seasonal effects. In winter 20 to 40% less biowaste was produced. The amounts of restwaste produced remained fairly constant throughout the year.

Composition of waste, sorting behaviour and performance

Expanding the biowaste definition with the non-recyclable paper fraction did not lead to a higher amount of non-compostable products (contaminants, nuisance) in Biowaste. For both Biowaste definitions the sorting behaviour in the biobin was very good (3% impurities in Biowaste and 3.6% in Biowaste Plus). However, the purity of the restwaste was poor in both areas. In the 'Biowaste area' 34% of the restwaste consisted of Biowaste. In the 'Biowaste Plus area' 47% and 66% of the restwaste consisted of Biowaste and Biowaste Plus respectively. These results were striking, moreover because of the fact that even in winter about 40% of the restwaste consisted of Biowaste, although less Biowaste was produced then and the biobins were on the average not completely full (impact of bi-weekly collection) (Table 1).

Table 1 Sorting Behaviour of Households (% of Incorrect Disposal).

Season	BIOWASTE			BIOWASTE PLUS	
	Biobin	Restbag	Biobin	Restbag (Biowaste Plus)	Restbag (Biowaste)
AUTUMN	1.7%	36.5%	2.5%	69.3%	49.0%
WINTER	4.1%	39.9%	4.3%	61.9%	40.4%
SPRING	3.4%	28.9%	3.5%	70.4%	55.0%
SUMMER	3.1%	29.5%	3.9%	60.2%	40.2%
TOTAL	3.0%	33.6%	3.6%	65.6%	46.5%

Assuming that the incorrect disposal of Biowaste/Biowaste Plus in the restwaste fraction could be reduced to 5%, the potential landfill diversion in Wuustwezel (Biowaste) would be 61.1% and in Essen (Biowaste Plus) 82.3% (increase of 35%).

The compostable fraction amounted to 84.2% of the total curbside waste stream in Wuustwezel (Biowaste) and 81.5% in Essen (Biowaste Plus). Of this the paper/board fraction amounted to 15.8% in Wuustwezel (Biowaste) and 16.9% in Essen (Biowaste Plus). This paper fraction consisted of 22.2% of so called recyclable paper in Wuustwezel (Biowaste) and 23.1% in Essen (Biowaste Plus). These figures show that expanding the biowaste definition is not disadvantageous to recyclable paper collection efforts (Table 2).

Table 2 Composition of Biowaste, Restwaste and Total Curbside Household Waste (Yearly averages in %).

Component	BIOWASTE			BIOWASTE PLUS		
	Biowaste	Restwaste	Total	Biowaste Plus	Restwaste	Total
Compostables	99.1	66.7	84.2	96.4	65.6	81.5
Kitchen waste	38.1	31.8	35.2	16.0	18.3	17.1
Yard waste	58.9	1.8	32.7	64.2	28.1	46.8
Compostable paper/board	2.0	32.1	15.8	16.0	17.8	16.9
Recyclable	0.3	7.3	3.5	2.9	4.9	3.9
Non-recyclable	1.7	24.8	12.3	13.1	12.9	13.0
Other compostables	0.1	1.0	0.5	0.2	1.3	0.7
Non-Compostables	0.9	33.3	15.8	3.6	34.4	18.5

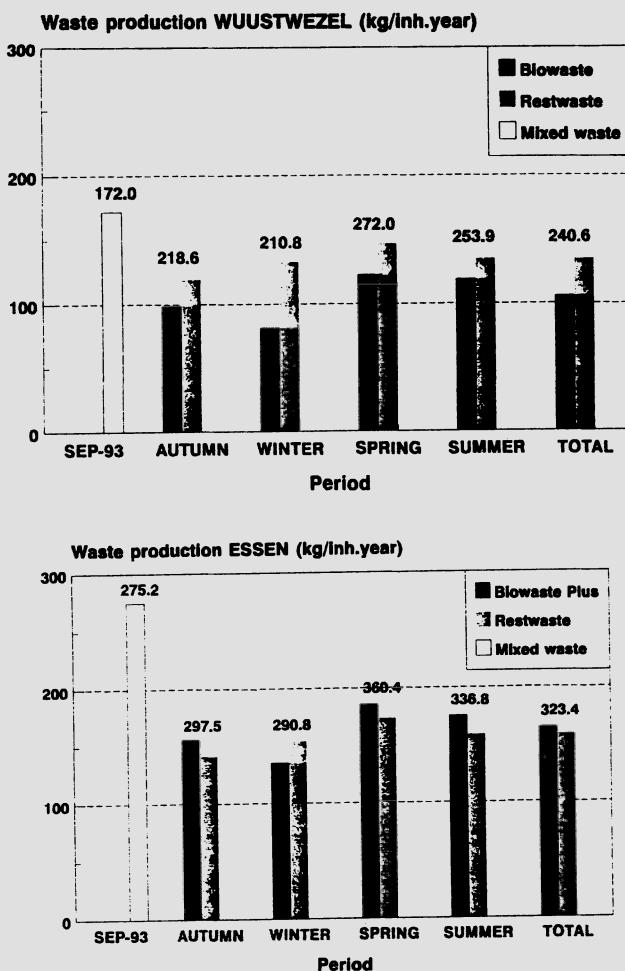


Figure 2 Amounts of Household Waste Produced per Inhabitant and Extrapolated to a Period of a Full Year. (The Figures on Top of the Bars are the Sum of Restwaste and Biowaste in the Respective Season).

The sorting performance was good to very good for garden waste and non-compostables with more than 70 to 90% of correct disposal. For kitchen waste the sorting performance was only 50 to 60%. This is a strong indication that kitchen waste was disposed of into the waste fraction to be collected first, be it biobin or restbag without any conscious sorting.

For the biodegradable/compostable products, other than garden or kitchen waste, the sorting performance varied a lot. For easily recognizable products (e.g. diapers) it was rather good (+70%). However, for products that are more difficult to recognize as 'compostable' e.g. cardboard packages, the sorting performance was less good (22 to 52%). These results show that an even better information

system is needed so that compostable products are better defined and sorting rules easier to apply for the households.

Composting process

In general it was easier to compost Biowaste Plus than Biowaste. Temperature could be better controlled and pH remained more stable. Especially in winter it was very difficult to compost Biowaste, with a large amount of leachate, heavily loaded with organic material, coming out of vessels. For Biowaste Plus, on the contrary, water had to be added to ensure a good composting.

During composting the NH_3 emission was 2 to 3 times higher for Biowaste than for Biowaste Plus. This is important because NH_3 contributes to the phenomenon of acid rain. At the same time a better nitrification occurred during Biowaste Plus composting which is an indication of a better composting process (Figures 3 and 4).

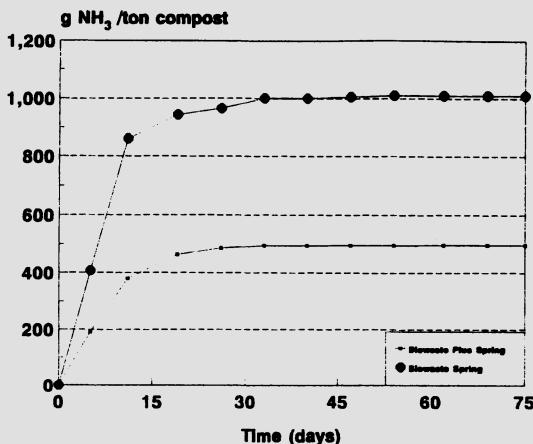


Figure 3 Cumulative NH_3 Emission During Composting of Biowaste Collected in Spring.

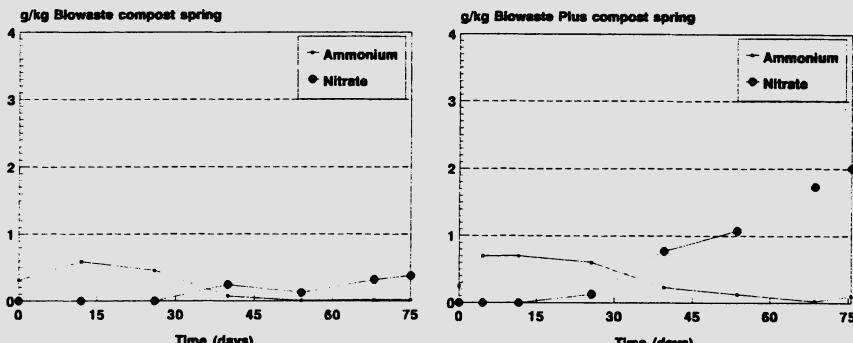


Figure 4 Evolution of NO and NH During Composting of Biowaste Collected in Spring.

Expanding the biowaste definition did not prolong the duration of the composting process. For both Biowaste and Biowaste Plus composting CO₂ production and organic matter degradation slowed down after 30 days. At the end of the test (75 days) there was no difference in CO₂ production and the % degradation of organic matter.

Refining of the compost resulted in a much bigger > 25 mm fraction of Biowaste Plus compost. However, this fraction consisted for a great deal of top and back sheets from disposable diapers. Based on the screening results the final landfill diversion could be calculated. In Wuustwezel (Biowaste) a landfill diversion of 42.6% was obtained, in Essen (Biowaste Plus) 45.6%. Assuming a 95% purity in the restwaste fraction a theoretical landfill diversion of 59.0% and 73.5% respectively could be obtained (Figure 5). Figure 6 shows the distribution of the household waste stream including the recycling efforts through container parks.

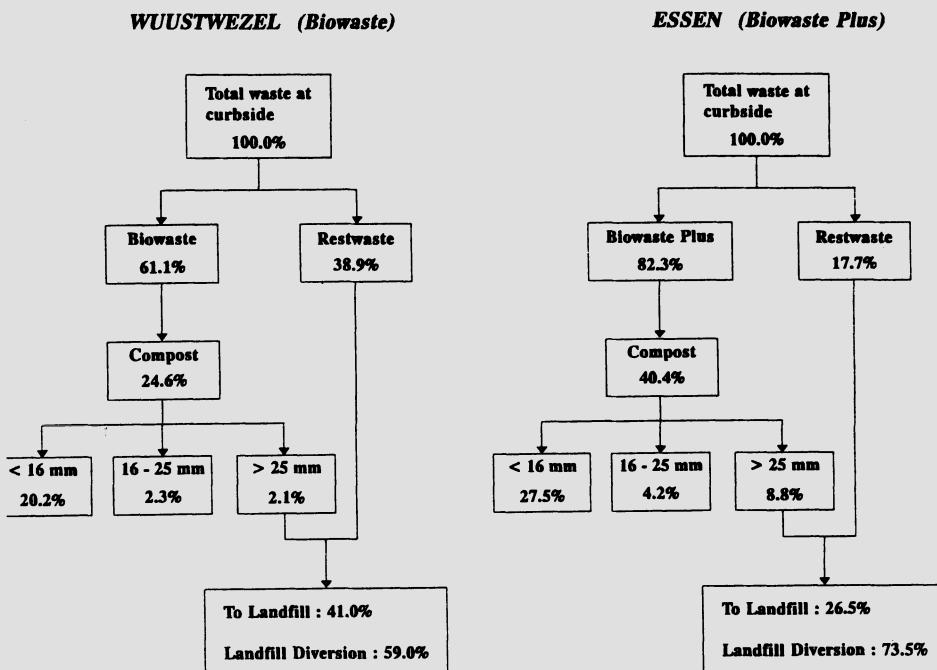


Figure 5 Total Potential Landfill Diversion.

Compost quality

Expanding the biowaste definition has no effect on the level of impurities in the marketable (< 16 mm) compost fraction. Large impurities such as the remainder of plastics or disposable diapers are almost entirely screened off over 25 mm and therefore do not end up in the marketable compost fraction.

Expanding the biowaste definition has no effect on the chemical quality of the marketable compost. On the contrary, Biowaste Plus compost had a higher organic

matter content, a better nitrification and a slightly lower salt content. The heavy metal content of both Biowaste and Biowaste Plus compost was well below the limits. The Biowaste Plus compost had a lower zinc and copper content than Biowaste compost (Table 3).

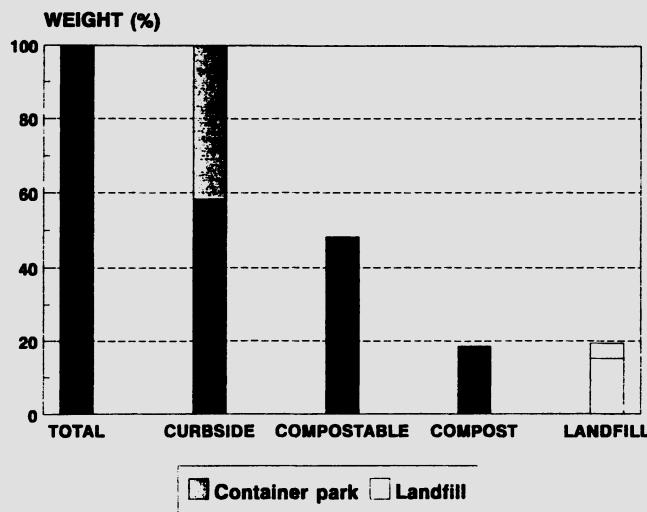


Figure 6 Distribution of the Household Waste Stream.

At the end of 75 days of composting the Biowaste Plus compost was in general more stable than Biowaste compost, in spite of the addition of a non-recyclable paper fraction. This shows that expanding the biowaste definition does not lead to longer composting. With regard to phytotoxicity there was no difference between Biowaste and Biowaste Plus compost.

Table 3 Chemical Analyses of the Marketable Compost Fraction.

Parameter	YEARLY AVERAGE	
	Biowaste	Biowaste Plus
TS (%)	64.6	61.2
VS (% on TS)	23.6	28.1
Kj-N (g/kg TS)	12.4	12.7
NO-N (g/kg)	0.25	0.41
NH-N (g/kg)	0.00	0.03
C/N	9.5	11.1
pH	7.4	7.4
Ec (mS/cm)	3.04	2.95
Heavy metals (ppm on TS)	Zn Cu Pb Ni Cd Cr Hg	172 24 47 7 1.0 16 0.08
		143 19 48 8 1.1 19 0.09

Conclusions

From the comparative lab- and field study, it could be seen that the inclusion of wastepaper in biowaste resulted in a higher acceptance and participation of the population while the purity of the biowaste fraction was not significantly affected. In both cases with or without wastepaper, large amounts of biowaste were still disposed of through the grey, restwaste fraction. The introduction of separate biowaste collection resulted in a landfill diversion of 43% in case no wastepaper was included and of 46% with wastepaper inclusion. The potential landfill diversion after better performance could however be estimated at respectively 59 and 74%.

With regard to composting, the inclusion of wastepaper in biowaste leads to an easier and more stable process with much smaller NH_3 emission whereas the quality of the compost produced is comparable or even slightly better (higher content of organics, lower level of heavy metals).

Acknowledgements

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Fuel Recovery: Valorization of RDF and PDF

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Abstract

Energy recovery of used materials can be performed as mixed municipal solid waste (MSW) incineration or as fuel recovery for co-combustion with conventional fuels. Recovered fuels are refuse derived fuel (RDF) which is mechanically separated and processed from MSW, as well as packaging derived fuel (PDF) which is the source separated, processed, dry combustible part of MSW.

A one year long co-combustion test of RDF with peat and coal has been carried out in a 65 MW CFB power plant in Kauttua, Finland. The efficiency of the combustion process and corrosion behaviour of the boiler were of particular interest in this study. Five different PDFs were also tested. A wide analytical programme was carried out including solid and gaseous emission measurements.

The results are encouraging, showing that RDF and PDFs are technically and economically feasible and environmentally friendly fuels for co-combustion. Low CO emissions showed clean and efficient combustion. SO₂ emissions decreased, because part of the coal was replaced by RDF and PDFs. HCl emissions increased when the chlorine content of the fuel mixture increased. Heavy metals were concentrated to the fly ash in unleachable form. PCDD/F (dioxin) emissions were at the normal power plant level and far below the strictest incineration limit.

Long-term co-combustion of 10 % RDF did not cause any high temperature chlorine corrosion of the superheater (500°C) of the boiler. Soot blowing sequences did not change and no fouling was detected.

The results show that it is useful, technically possible and environmentally friendly to combine resource and waste management in the form of fuel recovery for energy production in solid fuel fired power plants.

Introduction

A packaging system is designed for efficient distribution, protection of the packed product and for saving energy and other resources in the distribution chain. Light

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weight one-way packaging is often the best solution for long distance deliveries of consumer goods. 'Source reduction' of packaging waste is a continuous process, because packaging materials are being constantly developed for strength and weight reduction. Short range distribution can utilize re-usable packaging, and industrial raw materials are increasingly transported in bulk without packaging. Modern lightweight packaging materials are often difficult to recycle. The packaging itself has a high surface-to-weight ratio and used packaging is often contaminated with product residues. This makes separate collection and recycling costly and environmentally burdening. Energy recovery is therefore often the preferable recovery option for post consumer packaging waste.

In the combustion process, organic carbon (C) is oxidized to carbon dioxide (CO_2). The release of CO_2 from combustion for energy conversion is a much discussed issue. It is important to realise that a high energy conversion efficiency in any combustion process gives a low fuel consumption and consequently low CO_2 release per unit energy produced. One should also remember that organic carbon under anaerobic landfill conditions is converted to landfill gas, mainly methane (CH_4), which is considered a much more severe greenhouse gas compared to CO_2 . The nature of the released CO_2 is also debated. Carbon in wood based combustible materials is of recent origin and the use of these materials as fuel is therefore generally considered CO_2 neutral. This means that the released CO_2 will be assimilated by growing biomass within a reasonable time. The use of fossil fuels increases the content of CO_2 in the atmosphere.

Plastics are today mostly made of oil fractions which are less suitable for liquid fuel products. The production of plastics requires roughly the same amount of energy as contained in the oil fraction transformed to polymer. Plastics in packaging, automotive, construction, insulation, etc., however, during its lifespan saves a many times greater amount of energy in the form of oil-based fuels, gasoline, diesel fuel and heating oil. The avoided fuel consumption due to use of plastics leads to a decreased extraction of crude oil and consequently to a decreased overall CO_2 release.

The use of modern lightweight packaging materials, paper, board, plastics and composites of these, is sustainable. Energy recovery of used combustible packaging is part of the larger system and it could be shown that net CO_2 release may even be negative when total system fuel consumption is taken into calculation, compared to a system using non-combustible packaging. This is, in most cases, also true when compared to open loop recycling of small post consumer packaging.

Source Separation for Fuel Recovery

Energy recovery from used products and packaging can be performed in two principally different ways. It is, however, common to consider only incineration of mixed municipal solid waste, when addressing the subject. This is often called Waste-To-Energy.

Energy recovery can also be realized as fuel recovery for co-combustion with conventional fuels. In this case, the recovered fuel is refuse derived fuel, or packaging derived fuel, (ref. CEN-CR 1460). RDF is mechanically separated from MSW. PDF is the source-separated, processed, dry combustible fraction, otherwise ending up in MSW. This solution is natural when the wet organic part of MSW is diverted to composting or anaerobic digestion for biogas production. The system is cost efficient compared to separate collection aimed at material recycling, because the yield per bin and collection trip is high. Fuel recovery has a low environmental impact because of the high collection efficiency and because of the high energy efficiency of conventional industrial boilers and utility plants.

Fuel recovery will contribute to resource conservation by substituting fossil fuels. Acceptable environmental standards for co-combustion can be based on proper sorting instructions, permitted fuel processing and maintaining or even improving the clean front end combustion of the boiler plant, meeting emission regulations set for the primary fuel of the plant. The scheme can be fulfilled under the concept of shared responsibility as suggested in the 'Packaging Directive'.

Full Scale Co-Combustion Test Power Plant and Fuels

Combustion tests were carried out in a 65 MW Pyroflow CFB boiler in the Kauttua power plant in Finland in order to verify the technical and environmental aspects of fuel recycling. The unit consisted of a furnace, two hot cyclones, a 500°C, 84 bar steam boiler and electrostatic precipitators (ESP) for dust control. Fuels normally used in the plant include peat, wood waste, coal and mixed scrap from a paper mill and a packaging production plant. The boiler load consisted of steam provided to the two plants, heat supplied to the district heating network of the municipality of Kauttua and electricity for the grid.

Polish coal and milled peat are the primary fuels of the power plant. The following recovered fuels were tested.

- PDF/LPB (liquid packaging board) – Separately collected post-consumer milk and juice cartons from Helsinki. The cartons were shredded to about half of their original size.
- PDF/PE Separately collected post-consumer polyethylene bottles. The material contained mainly bottles and canisters from gasoline stations and households, but also some film material was included. The material was shredded to a 40 mm mean particle size.
- PDF/PET One-way polyethylene terephthalate bottles from the soft drink industry. The material also contained polypropylene caps and it was shredded to a 10 mm mean particle size.
- PDF/YTV The Helsinki Metropolitan Area Council operates a separate collection scheme for wet organic waste. Metals and glass were separated from the remaining dry fraction of MSW by hand. The fuel contained

a large amount of organic components in spite of the separate collection scheme. The material was shredded to a 50 mm mean particle size.

- PDF/
Ekorosk** Collected by the Ekorosk-company in Pietarsaari. The wet and dry fractions of MSW were source separated into black and white bags. Both bags were collected in a normal one-bin system by a compacting lorry. The bags were mechanically separated by colour in the Ekorosk plant. The dry fraction was baled, transported to Stormossen (see below) and shredded to a 50 mm mean particle size.
- RDF/ASJ** Mixed MSW was collected and processed in the Stormossen, Vaasa mechanical waste sorting plant, where metals, glass and organic components were separated out. RDF was shredded to a 50 mm mean particle size.

Test programme

The research project was divided into two parts: a one-year long-term study and two short-term emission measurement periods. The long-term study was carried out from September 1993 to July 1994. Primary fuels were peat, coal and wood and the secondary recovered fuel was RDF. Availability of the boiler, efficiency of the combustion process, and corrosion susceptibility of the super heater were of particular interest in this long-term study.

Table 1 Test Matrix.

RUN	TIME	Secondary fuel	Amount %—thermal	Duration hours	Remarks
1	Nov/93	—	—	26	Peat+coal/ reference
2	Nov/93	PDF/LPB	13	24	
3	Nov/93	PDF/YTV	12	21	
4	Nov/93	RDF/ASJ	13	24	
5	April/94	PDF/PE	19	24	
6	April/94	PDF/PET	19	16	
7	April/94	PDF/Ekorosk	26	28	
8	April/94	RDF/ASJ	26	17	

- PDF = Packaging Derived Fuel
 RDF = Refuse Derived Fuel
 LPB = Liquid Packaging Board
 YTV = Helsinki Metropolitan Area Council
 ASJ = Ab Avfallsservice Stormossen Jätehuolto Oy
 PE = Polyethylene
 PET = Polyethylene terephthalate

One-day combustion test runs for RDF and PDFs from different sources were carried out during the emission measurement campaigns. Gaseous and solid emissions were extensively analyzed. Continuous flue gas analyses and other samplings

were performed by the Combustion and Thermal Engineering Laboratory of the Technical Research Centre of Finland (VTT Energy). The samples were analyzed by the Department of Environmental Sciences of the University of Kuopio (organic components), University of Jyväskylä, Outokumpu Oy, Hans Ahlström Laboratory and Neste Scientific Services. The first measurement period took place in November 1993 and the second one in April 1994. The test matrix is presented in Table 1.

Peat and coal only were combusted for two days before the emission measurement campaigns. Test runs for each recycled fuel lasted 16–28 hours. The change-over to the new fuel mixture was made in the evening, the process was stabilized over night and the emissions sampling and on-line measurements started the next morning. The first run was a reference test employing peat, coal and wood waste as fuels.

Results

Long Term

Feeding and combustion of coarse, fluff RDF did not cause any drawbacks to the effective operation of the plant during the whole year of co-combustion. Visual inspections and wall thickness measurements of the boiler before and after the one-year co-combustion of 10 % RDF did not show any signs of abnormal corrosion of superheater (500°C) or boiler tubes. Corrosion probe tests (600 h) at 500°C and 550°C did not show corrosion or chlorine containing deposits.

Emissions

Heat value, moisture and ash contents of the tested PDFs and RDF were between the values of peat and coal. Sulphur and nitrogen contents of RDF and PDFs were lower and chlorine and certain heavy metal contents, especially chromium, copper, lead and zinc, were higher than the respective values of peat and coal. The basic analysis of the fuel mixtures are given in Table 2.

The feeding line limited the amount of secondary fuel to 25 % because of an increased number of CO peaks at higher rates, so the original goal of 30 % could not be reached. Operation at the upper limit caused uneven feeding and consequently somewhat unstable combustion conditions.

The basic level of carbon monoxide (CO) in flue gas (Table 3) was low (15–40 mg/m³n) in all tests proving clean and efficient combustion. Operation near to the maximum capacity of PDF and RDF feeding line caused CO peaks increasing the mean CO level near to 200 mg/m³n. Sulphur dioxide (SO₂) emissions were lower in co-combustions than in the reference test (560 mg/m³n). Nitrogen oxide (NO_x) emissions were at the same level in all tests (below 200 mg/m³n).

Hydrogen chloride (HCl) emissions increased from 20 mg/m³n to about 150

mg/m³n when the chlorine content of the fuel mixture increased. HCl emission results are mean values of three samples. The scatter was rather high, indicating the heterogeneous chlorine content of RDF/PDFs and somewhat unstable feeding. According to Cl-balance calculations, the HCl content in the flue gas should have been higher in tests with high contents of recycled fuel which, on the other hand, contained larger amounts of Ca which binds chlorine. HCl should not be a problem in a plant using desulphurization technology. HBr was not detected and HF values were very low.

Table 2 Basic analyses of the fuel mixtures.

Run	1	2	5	6	3	7	4	8
Secondary fuel % -thermal	Ref	PDF LPB	PDF PE	PDF PET	PDF YTV	PDF Ekor	RDF ASJ	RDF ASJ
		13	19	19	12	26	13	26
Moisture, wt-%	43.5	40.3	39.0	36.7	41.5	37.2	41.9	38.9
Volatile, wt-%	67.7	61.1	64.2	68.4	57.7	61.4	59.6	61.6
Ash, wt-%	5.8	6.1	5.8	4.7	8.2	8.5	7.8	9.1
HHV, MJ/kg	23.0	22.7	24.0	22.0	22.8	21.6	22.5	21.9
LHV, MJ/kg	21.8	21.5	22.6	20.7	21.6	20.3	21.3	20.6
C, wt-%	60.1	59.3	57.7	55.1	59.5	53.4	58.9	53.7
H, wt-%	5.5	5.6	6.7	6.1	5.4	6.0	5.5	6.0
N, wt-%	1.0	1.1	1.6	1.6	1.3	1.6	1.2	1.6
S, wt-%	0.37	0.36	0.35	0.27	0.40	0.36	0.37	0.37
O, wt-% (as difference)	27.2	27.5	27.7	32.1	25.1	29.9	26.1	29.0
Cl, wt-%	0.06	0.07	0.10	0.11	0.20	0.33	0.18	0.29
Cr, ppm	24	26	22	20	43	58	36	55
Cu, ppm	<10	<10	<10	<10	10	38	12	61
Ni, ppm	11	12	11	10	15	16	15	18
Pb, ppm	31	33	36	32	66	236	50	157
Zn, ppm	17	18	35	38	110	124	121	105
S/Cl ₂ , mol/mol	14	12	8	6	4	2	4	3

All results in dry solids

Table 3 Flue gas analyses of the test runs.

Run	1	2	5	6	3	7	4	8
Secondary fuel % -thermal	Ref	PDF LPB	PDF PE	PDF PET	PDF YTV	PDF Ekor	RDF ASJ	RDF ASJ
		13	18	21	12	26	13	26
H ₂ O, %	15.8	15.4	15.4	16.1	15.5	16.4	15.5	16.3
CO ₂ , %	12.2	12.8	12.2	13.7	12.6	12.8	12.2	12.3
CO, mg/m ³ n, mean value ¹	49	73	58	155	44	185	44	160
CO, mg/m ³ n, basic level ²	40	35	15	30	25	35	30	30
CH ₄ , mg/m ³ n	2	4	6	16	2	20	2	19
SO ₂ , mg/m ³ n	560	520	450	460	550	480	520	480
NO ₂ , mg/m ³ n	170	180	180	180	200	150	190	160
N ₂ O, mg/m ³ n	ND	ND	ND	ND	ND	ND	ND	ND
Particles, mg/m ³ n	2	3	5	2	2	5	3	4
HCl, mg/m ³ n	17	40	34	30	154	140	60	120
HBr, mg/m ³ n	<3.5	<3.5	<3.5	<3.5	<3.5	<3.5	<3.5	<3.5
HF, mg/m ³ n	0.5	0.8	0.3	0.4	1.2	0.4	0.5	0.3

Results corrected to 11 % O₂ dry gas 1) including peaks 2) basic level without peaks

Heavy metals did not volatilize into the gas phase, and due to the efficient dust separation by the ESP and consequently low outgoing dust load ($5 \text{ mg/m}^3\text{n}$), the total concentrations in the flue gas were well below present EC incineration limits.

Table 4 Heavy metals in flue gas

Run	1	2	5	6	3	7	4	8
	Ref	PDF LPB	PDF PE	PDF PET	PDF YTV	PDF Ekor	RDF ASJ	RDF ASJ
Secondary fuel %-thermal		13	18	21	12	26	13	26
Hg, $\mu\text{g/m}^3\text{n}$	<1	<1	<1	<1	<1	<1	<1	<1
Cd, $\mu\text{g/m}^3\text{n}$	1	<1	<1	<1	<1	<1	<1	<1
Ni+As, $\text{mg/m}^3\text{n}$	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Cr+Cu+Mn+Pb $\text{mg/m}^3\text{n}$	1.61	0.74	0.20	0.08	0.06	0.12	0.17	0.13

Fly ash (Table 5) showed enriched amounts of heavy metals. The EPA-TCLP tests showed no adverse leaching of these elements, and the ashes can be disposed of in normal landfills.

Table 5 Fly ash analyses.

Run	1	2	5	6	3	7	4	8
	Ref	PDF LPB	PDF PE	PDF PET	PDF YTV	PDF Ekor	RDF ASJ	RDF ASJ
Secondary fuel %-thermal		13	19	19	12	26	13	26
Main components	%	%	%	%	%	%	%	%
C ¹⁾	15.0	12.2	7.2	7.7	12.2	5.9	6.1	4.8
H ¹⁾	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
N ¹⁾	0.4	0.3	0.3	0.3	0.3	0.3	0.5	0.2
S ¹⁾	1.0	0.8	0.7	0.7	1.0	1.1	1.0	1.2
Cl ²⁾	0.02	0.01	0.07	0.05	0.03	0.38	0.12	0.22
Al	9.75	11.1	9.47	9.48	10.6	11.2	11.3	11.0
Ca ²⁾	4.42	4.52	6.49	6.19	4.85	8.53	6.40	7.91
Fe	6.50	6.30	10.2	10.9	6.15	8.22	6.20	8.57
K	2.05	2.06	1.49	1.42	1.97	1.80	2.07	1.81
Mg	1.63	1.68	1.89	1.76	1.62	1.94	1.76	1.79
Na	0.64	0.70	0.51	0.47	0.76	1.12	1.12	1.21
P	0.29	0.30	1.01	1.07	0.34	0.94	0.58	0.93
Si	17.8	18.5	16.6	16.4	18.5	14.9	18.8	16.4
Ti	0.45	0.48	0.61	0.57	0.50	0.85	0.64	0.70
S/Cl ₂ , mol/mol	141	151	22	31	85	7	18	12

¹⁾ by Leco analyzer ²⁾ by chemical methods All other by XRF

The emissions of PCDD/Fs, 'dioxins' (Table 6), were far below the strictest incineration regulation limit $0.1 \text{ mg/m}^3\text{n}$ I-TEQ in all tests. The dioxin values were close to the detection limit in most cases, but increased slightly at higher contents (26 %) of PDF and RDF. Increased frequency of CO peaks because of mechanical problems, increased chlorine content of the fuel mixture, decreased sulphur to chlorine ratio and most significantly increased content of heavy metals like copper and lead in the fly ash are the probable reasons for the increase.

Table 6 Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs)

Run	1	2	5	6	3	7	4	8
	Ref	PDF LPB 13	PDF PE 19	PDF PET 19	PDF YTV 12	PDF Ekor 26	RDF ASJ 13	RDF ASJ 26
PCDD/Fs								
Actual concentrations								
Flue gas, ng/m ³ n	<0,01	<0,01	0,19	0,06	0,09	31,7	0,16	1,87
Fly ash, ng/g	0,85	0,31	1,94	1,11	1,17	38,3	0,96	18,4
I-TE								
Flue gas, ng/m ³ n	<0,01	<0,01	0,02	<0,01	<0,01	0,02	<0,01	0,04
Fly ash, ng/g	0,01	0,01	0,06	0,06	0,01	0,77	0,01	0,37

Conclusions

The test programme was the third full scale co-combustion test co-financed by the Finnish Ministry of Trade and Industry through its LIEKKI combustion research programme and by the industry. All tests with scrap and real waste, RDF and PDF, at a co-combustion rate of around 20 % together with coal containing primary fuel have shown good combustion efficiency, sufficient heavy metals capture in fly ash and PCDD/F emissions clearly below the strictest suggested incineration regulation. This test has also shown the long term technical feasibility of co-combustion in a CFB system. It is important that the recovered fuel is processed to a physical form compatible with the primary fuel and fuel feeding system of the plant in order to accomplish a steady combustion without CO-peaking. The results indicate that fuel recovery is a valuable alternative for resource management complementing biological treatment of the wet organic fraction of MSW and separate collection for recycling materials to products with a real market value.

The results show that used packaging contain higher amounts of certain heavy metals than conventional fuels. These metals mostly do not play a functional role in the packaging material itself but come from colouring pigments and printing inks. Although it is shown that these metals are efficiently concentrated to ash and filter residues it can be concluded that a consumer driven reduction of excessive ‘cosmetics’ could even further decrease the environmental impact of all resource and waste management routes.

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A Database for I.W.M. Covering Recycling and Composting

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ERRA mission

ERRA was established in 1989 by industries involved in the manufacture and sale of packaging. ERRAs mission is to 'help organise economically efficient and environmentally effective packaging waste recovery and recycling'.

ERRA Network of Reference Programmes

ERRA initially helped to establish 10 pilot projects in Europe. It has recently begun expanding its data analysis and currently it has 17 programmes in its network of reference programmes.

The programmes reflect diversity in location, housing type and technology, but are representative both at national and European level. They can be put into three broad categories:

Kerbside box e.g. Adur (UK), Dublin (Eire), Sheffield (UK), N.district of Messine (F) Kerbside bin/bag e.g. Dunkirk (F), Lemsterland (NL), Louviers (F), Saarland (D) Bring *close-to-home* e.g. Prato (I), Queijas (P), Barcelona (E), Pamplona (E), Athens (GR)

The range of materials collected in each scheme is dependant on local conditions, but they all collect dry recyclables including packaging (plastic, glass, paper, metal) and news print. A number also include organic (kitchen and garden) material as well.

ERRA collects data from these programmes and analyses it in order to understand the factors that influence the success of a scheme in the recovery of materials for recycling or other forms of recovery.

The Critical Factors ERRA has identified are:

1. The composition and quantity of the waste being handled.
2. The amount of material that can and is be diverted for recycling.
3. The operational factors (convenience, efficiency, etc.)

4. The overall cost of the recycling operation within the total waste management scheme.

Steps to prepare useful analysis – standardising diversity

Collecting data in a database alone is not enough to understand the effectiveness of different approaches. It is a key step that provides the raw information. The real challenge facing ERRA was how to analyse data from such a wide range of systems, each reflecting local conditions, in a way that could give meaningful answers and lead to a better understanding of household waste recycling.

The steps that must be systematically taken to achieve the understanding are:

1. *Define the objective of the analysis.* The objective clearly must be to be able to understand how and why a programme is operating the way it does, thereby identifying strengths and weaknesses allowing for the introduction of changes to achieve better results.
2. *Clearly identify the boundaries for the analysis.* Locally, the starting and the end point might be obvious. However, if data is to be collected From a wide range of different programmes ERRA had to define clear boundaries.
3. *Identify' and define what measurements or results are needed.* The next step is to identify what the key impacts are that will influence the operation of programme. Once these have been identified, data relevant to them must be identified, defined and then collected in a standard way. Obviously, local conditions will have a role in what will influence the good operation of a programme, but it is possible to identify broad categories, within which the local influences can be placed.
4. *Standardise the data to eliminate local variation.* Having collected data even according to standard definition it is necessary to standardise it by calculating relationships that eliminate the different baselines that exist locally. Calculating percentages gives the best type of result for comparative purposes as it removes all the variations. The system of Key Ratio Analysis that ERRA has developed is based on this principle.
5. *Recognise the limitations of the quantitative analysis.* Finally, it is important to recognise the limitations that a purely quantitative analysis provides. Qualitative assessment is always needed to assess the validity of the results and to explain them.

Key Ratios

ERRA believes that the only way to compare programmes across Europe in a meaningful way is to use ratios that cancel out local factors that influence the results. For example, a major factor influencing the quantity of recyclable material

collected is the quantity generated by the householders i.e. thrown into the waste.

Through the experience of analysing programmes, ERRA has defined a limited number Key Ratios that measure the factors that influence the results. The Key ratios can be considered individually, but for a proper understanding of each programme they should be analysed together. These ratios are described in detail in the ERRA reference publication 'Programme ratios'.

Ratio analysis provides a method of comparing not only schemes that collect dry recyclables from households. The boundaries can be broadened to include, for example, commercial and industrial waste, and/or kitchen and garden waste. The boundaries must be clearly defined before attempting to compare schemes, but once the boundaries are set, ratios will put the different data sets on a common baseline removing the impact of local factors. The local factors will be used to explain differences in results between programmes, and must therefore be known to be used in the qualitative analysis of programmes.

For this reason ERRA collects description and background data on the demographics of the programme area, and descriptions of all the waste management activities that impact on the waste streams that ERRA is analysing (Primarily household). The database allows this data to be used directly in the analysis of the results.

The other data that ERRA collects is ongoing mass flow data, for example, the quantities collected, sorted and sold. This data can be collected and included in the database for any streams that are collected, for example dry recyclables, refuse or a separate organic or compostable fraction. Indeed, in a number of the programmes compostables are collected as a separate stream and the data collected and entered in the database in exactly the same way as for the other streams.

Table 1 Waste stream Quantity and Composition

Total waste stream (kg/inhab/yr.))	Composition (in % of total)					
	paper	glass	metal	plastic	organic	rest
Dublin (Eire)	226	25	5	3	9	46
Adur (UK)	244	42	9	8	9	19
Sheffield (UK)	300	33	7	11	8	26
Dunkirk (F)	344	24	17	3	6	26
Barcelona (E)	370	32	6	3	13	37
Lemstertand (NL)	380	29	6	3	5	46
Prato (I)	386	19	4	3	6	33
Saartand (D)	366	21	11	4	7	29
Pamplona (E)	387	25	7	2	6	46
						14

Why Integrated Waste Management

The baseline used in the Key Ratios is always the total waste that is being managed. It is therefore clear to see why it is important to consider not only the dry packaging components. Indeed it is difficult to segregate these items both in the

collection and the analysis. ERRA believes that the waste stream needs to be considered as a whole, and that the most effective and efficient solutions to handling the packaging fraction will be found when an integrated waste management approach is taken.

Though the data can all be collected together it is important to understand that the boundaries are different for programmes that collect different materials, and cannot be directly compared except to illustrate the impact including or excluding particular materials has on the overall results.

The table above details the quantity and composition of the waste streams in a number of the ERRA programmes across Europe. It illustrates the need to consider more than just the dry recyclables for maximum diversion.

Before putting together an integrated waste management strategy it is essential to understand both the quantity and the composition of the waste that is being generated in the area concerned. The quantity of waste generated can be established from the quantities of waste collected regularly. The composition can be established by waste stream analysis. These results are only sample results, though, so great care and attention must be taken to ensure that representative samples are analysed. Verification of the representatives of the samples should be carried out by comparing the sample results with actual collection quantities.

Once the composition and quantity of waste are known these data can be recorded in the database. They provide the baseline for the Key ratio analysis and are therefore critical information. As the baseline is the whole waste stream and not just the specific materials the ERRA programmes collect the whole composition analysis must be entered.

Table 2 The Effectiveness of Different Types of Programme

		Potential diversion rate	Actual diversion rate	Recovery rate
Dry recyclables				
bring	Barcelona (E)	36%	8%	21%
bring	Prato (I)	25%	9%	36%
teraalde	Sheffield (U~)	38%	15%	39%
kerbside	Dublin (F)	39%	16%	40%
keri'ald~ bring	Saarland (D)	40%	17%	43%
kerbside	Dublin (Eire)	30%	17%	50%
keri'aide	Adur (UK)	34%	20%	50%
kerbside	Lemstertand (NL)	38%	30%	83%
Dry recyclable and Organics				
bring	Bnsda high-rise (NL)	60%	37%	62%
kerbslde	Breda low-rise (NL)	76%	55%	72%
kerbside	Lemstertand (NL)	86%	69%	80%

The Effectiveness of different types of programme

Applying the Key Ratios to the raw data from the programmes, trends start to become visible between the different programmes. There are groupings between specific types of operation, bring/kerbside, and in the materials covered by the programme, dry recyclables only or organics as well. The data above illustrate the need both for mass flow and context data, as well as a clear definition of boundaries, with the schemes that collect organics as well as dry recyclables clearly forming a distinct group.

The results suggest that bring systems, where most of the materials are collected mixed together and are sorted at a MRF, generally can be expected to achieve lower diversion rates, and be slightly less effective (recovery rate). However, the results from Prato suggest that bring systems can be almost as effective as kerbside systems. As none of the schemes are optimised it is too early to draw definitive conclusions.

The results from Sheffield seem to be out of the general trend if the programmes are considered with respect to recovery rate. The probable explanation for this is that the scheme is small and has only had very low investment. Problems have occurred in the past where the collections have had to be suspended due to the collection vehicle breaking down. This has affected the morale of the householders, some of who stopped participating.

The most effective programmes appear to be the kerbside 'box' schemes. This is probably due to the high visibility of the box, and householder pride in putting out a box of clean recyclables. In the other kerbside schemes, and indeed in the bring schemes, much larger, closed containers are used so the contents are not clearly visible. The critical neighbourly eye, nor the householder pride play roles in these schemes. The costs are reviewed later.

The data illustrate trends only, and more programmes are now needed to establish baseline reference points for the different types of operation.

It must be stressed that the purpose is NOT to find the 'winner' and then apply this type of programme every where. There is no single solution. Baseline references should be used to identify where improvements in existing schemes are possible, and to forecast results from programmes that are being planned.

Table 3 Cost of the ERA Pilot Programmes 1993 (Locs/currency)

	Total Local currency	Collection Total	Processing Total
Adur	380787	278801	100886
Prato	1057 mil.	354 mil.	673 mil.
Barcelona'	426 mil.	320 mil.	106 mil.
Sheffield	63883	63993	
Dublin	746954	386147	380707
Lemsterland	702495	804687	87808
Dunkirk	25.8 mil.	16.1 mil.	8.7 mil.

*contractor cost onft + calculated from incremental cost

Programme cost

The cost data illustrates very clearly the problems in trying to compare different programmes, but again ratios can be used to reduce the impact of local influences.

As well as all the issues with respect to the size of the programme, quantity of the waste stream etc. there is the problem of currency. The simplest solution, to convert all the individual currencies into a single currency, for example the ECU., while standardising the units does not actually help understanding the real costs as even within Europe there are sometimes major fluctuations in exchange rates. Recent fluctuations, for example, resulted in the Barcelona project becoming suddenly 20% cheaper on conversion into ECU.

In addition, the total cost of a programme includes capital items, labour costs and other operating expenses. Just comparing the cost does not take account of differences in local or national taxes nor in the cost of living in different countries. It is common knowledge that gross salaries cannot be compared across national borders, and you would be considered foolish, or at best naive, to expect the costs of any operation in the Netherlands to be the same as a similar operation in, for example, Greece.

Finally, published costs generally reflect an accounted cost rather than an actual cost. The cost therefore is more a reflection of accounting practice, for example asset depreciation and profit and loss statement, than cash required for payment. Hence, comparisons of cost without standardisation are at best meaningless and at worst very misleading.

The first step towards a meaningful comparison is the collection of 'actual cost' data as opposed to 'accounting cost' data. To achieve this ERRA developed, with Coopers Lybrand, a system of standard data recording. ERRA has implemented this in most of its pilot projects, and has used the results to develop a cost analysis that standardises the data from different programmes and allows direct comparisons to be made.

This standardised cost data is collected and entered into the database for the total waste operation in the ERRA schemes, in other words, for the dry recyclables and the refuse streams..

Ratio Analysis of Costs

On closer evaluation of the question 'how much does it cost to recycle?' it becomes clear that this is not the real issue. The immediate evaluation that the enquirer does is to compare the answer with the cost of recycling elsewhere and the existing refuse disposal costs. Only after this comparison will the conclusion be drawn that 'that is an expensive scheme' or 'this is a good value scheme'.

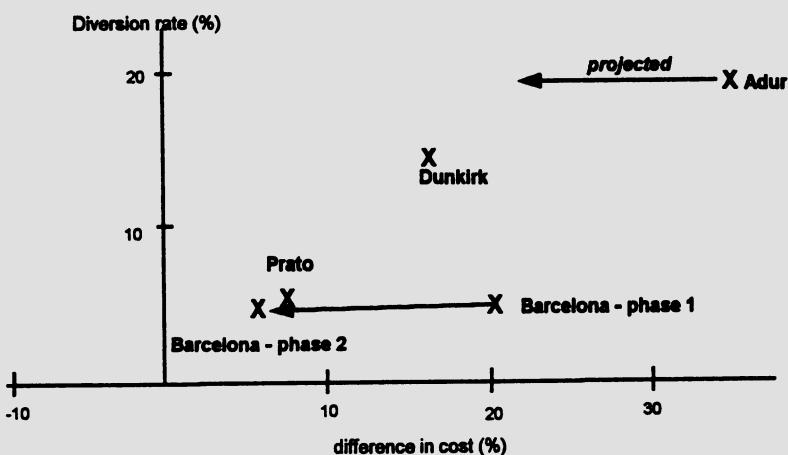


Figure 1 Trends in Programme Cost

The real question is therefore not the actual cost, but information demonstrating if the scheme is *affordable*. How affordable anything is will depend on the difference between doing it or doing something different instead. So in waste management terms can be defined as the difference in cost between having a scheme that collects recyclable separately, and just collecting and disposing of the waste. Hence the ratio '*% difference the cost*'.

The calculation of % difference in cost also achieves the elimination of local variables through the calculation of a percentage. It also has the same boundaries as the Key Ratios that measure the mass flow results (diversion rate, recovery rate, etc.).

Initial Trends in Programme Cost

It is possible to plot the results of this ratio with the diversion rate to evaluate the results that are being achieved against the cost. In this way the different programmes and their results can eventually be compared. Unfortunately, today it is difficult to make definitive comparisons as programmes are generally not optimised, but eventually it will be possible to establish benchmark values for the different types of programmes.

The data above illustrates the improvements that programmes are currently making and the general trend in cost reduction. The cost reduction can be due to both internal and external factors, for example higher sales revenues. The explanation is essential if valid conclusions are going to be drawn.

From the analysis of the data ERRA has been able to develop a theoretical relationship between the cost and the results.

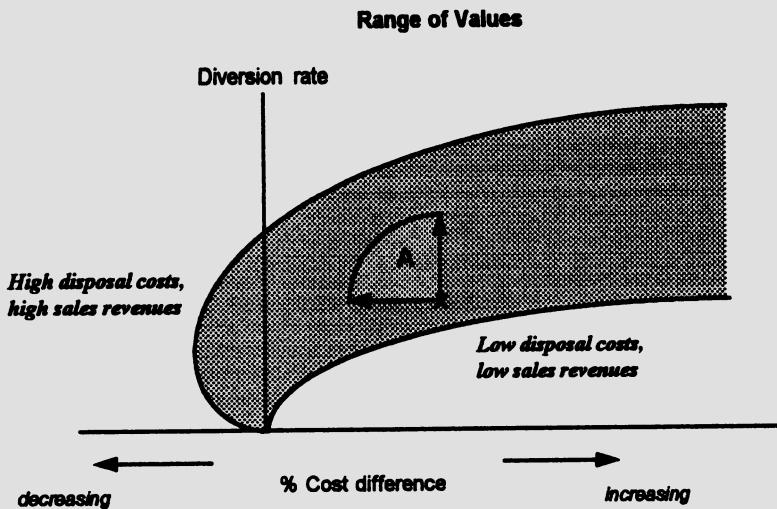


Figure 2 % Cost Difference vs Diversion Rate

How much Diversion is Cost Effective depends on the Cost of Disposal

For each programme area it should be possible to plot the range in which the programme should be with respect to cost and diversion. The range will depend on the cost and availability of different recycling, recovery and disposal options.

The programme results should fall into the shaded area on the graph. The exact position will depend on the actual conditions and waste management options selected as well as the efficiency of the specific programme.

Optimisation

Having established the position of a programme within this range it is then possible to track the programme to monitor it, over time, it is becoming more efficient. It is also possible to project the impact of changes that could make the system more effective.

In general terms, as a programme becomes more effective i.e. optimised, the effect should be indicated by a movement towards the left i.e. cost reduction, and/or a move up, i.e. an increase in diversion without additional cost. This field is indicated by the shaded area A.

This model can be used in the planning of the whole waste management system towards an optimum diversion to cost impact.

It is also possible to convert targets set in waste legislation into diversion targets, and thereby work towards cost effective methods of meeting the targets.

Data Management for I.W.M.

- Data Collected needs to cover background description, mass flow and cost
- Precise definition of the data is required
- Clear definition of the boundaries for the analysis is essential
- Ratios should be used to standardise data for valid comparisons to be possible
- The whole waste management system should be managed and hence analysed complete
- Data from all the streams should be stored in a single database to facilitate the analysis of the total system

Conclusions

ERRA has helped to establish a number of recycling programmes in Europe from which it has gathered data. Data describing the programmes, as well as mass flow and cost data relating to the waste management system defined by the boundaries of the analysis have been, and continue to be entered into a specifically defined database. ERRA analyses the data using ratios in order to minimise the impact of local influences on the results.

Experience has allowed ERRA to identify a limited number of Key Ratios that can be used to provide an understanding of the efficiency of a programme, as well as allow comparison with other programmes across Europe. The Key Ratios only required a small number of carefully defined data to be collected.

ERRA uses the Key Ratios to analyse primarily the collection and sorting of dry recyclable packaging materials, but where other materials, for example kitchen compostable waste are collected in the programme areas, ERRA has shown that the ratios can be used to analyse these programmes in the same way.

Having the data from all the waste streams in a single database permits the analysis of integrated waste management systems in a simple and coherent way.

Alternative Utilization of MSW Compost in Landfills

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Abstract

In this paper the Authors discuss the possible utilization of compost in landfills as cover material and biofilter. Compost can act as control layer of water inflow and perform a precious buffering function; contact with compost can remove some heavy metals from leachate under basic conditions. Well cured, unrefined composts can be suitable due to favourable size distribution, low compactability and high permeability.

Introduction

To date, many of the composts produced in Italy from MSW rather than from organic matter deriving from separate collection do not meet legislative limits with respect to inerts, glass, paper, plastics and heavy metal content. Thus, the final destination of these composts is not use in agriculture, but disposal in landfills. Heavy refining of these composts in order to meet legislative limits would require very high costs and extensive modification of existing plants.

In the near future the new technical directives will probably foresee two types of compost:

- type A deriving from composting of organic matter from separate collection;
- type B deriving from composting of unsorted MSW.

Type A will be used in agriculture, while for type B it will be necessary to find alternative uses.

Some characteristics of compost should allow its utilization in MSW landfill construction and management (Figure 1) as:

- daily covering material;
- temporary cover material;
- final capping material;

- biofilter for leachate drainage system.

Several tests on utilization of MSW compost in sanitary landfills were performed at the Department of Environmental Technologies of the University of Cagliari. Six types of MSW composts are under experimentation in order to verify their possible utilization as daily, temporary and final covering material. Tests have been made and are in progress in order to define physical parameters of compost (such as granulometry, permeability, void index, compaction rate, composition), bio-chemical parameters and characteristics (stabilization level, heavy metal content, possible interactions with MSW landfill leachate and biogas).

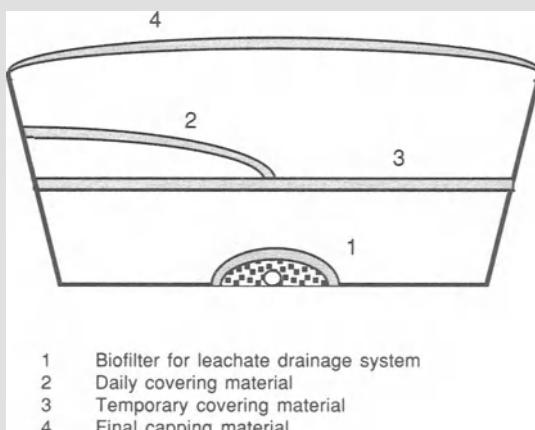


Figure 1 Possible utilizations of compost in MSW landfills

Use of compost as covering material

Daily covering of waste is recommended by the current management procedures of sanitary landfilling in order to avoid dispersion of light fractions (paper, plastics) and feeding of animals (rats, birds). Daily covering leads to several disadvantages such as loss of volume for waste disposal and high costs if the material is not available near the facility. Moreover, field experience has shown that the main problems derive from the utilization of low permeability soil as covering material: in this case the landfill is divided into many hydraulically insulated 'pockets' where leachate and biogas accumulate. Consequences are: difficulties in draining leachate and biogas, side and surface escape of leachate and biogas, stability problems, limitation of water circulation inside the landfill and therefore inhibition of waste stabilization. For these reasons finding new materials for daily covering is becoming a pressing need.

The new materials should have the following main characteristics:

- to be easy to manage;
- high permeability;

- low costs;
- their use in landfill must not cause an increase of pollution, but, possibly, the opposite effect.

Well stabilized compost seems to have these characteristics, in fact:

- if the compost is well stabilized there is not a considerable increase of waste organic load; moreover compost does not attract animals and the mass losses for biodegradation are negligible;
- well stabilized composts have usually a low moisture content, thus they can not be compacted very well and maintain high void index and permeability; moreover the low permeability allows compost to absorb infiltration water and control water flow inside the landfill;
- compost could act as biofilter improving leachate and biogas quality by means of hazardous compounds removal.

The above mentioned characteristics could also allow compost utilization as:

- material for temporary covering before the final capping.
- material for final capping;

Final capping usually is not carried out until the waste mass is not yet settled in order to avoid damages to the components of the barrier system (membranes, geotextiles, geocomposites etc.). During this period it is necessary to cover waste with a temporary layer. Temporary covering could be necessary also when an intermediate sector of the landfill is completed. The material used for build up the temporary covering layer has to perform the following main functions:

- to insulate waste from outside environment (and it itself has not to be feeding material for animals);
- to control water inflow, avoiding high rate of infiltration, but allowing the permeation in order to provide the water amounts necessary for biostabilization of waste;
- to limit biogas dispersion.

The outside component of the final cover system usually is a vegetative layer which has to perform the following functions:

- to protect the underlying layers;
- to allow the growth of plants and grass;
- to limit erosion phenomena.

Use of compost as biofilter for leachate drainage system

Keeping the efficiency of drainage systems is the main problem in managing sanitary landfills; failures of leachate collection systems are mainly caused by bio-fouling (formation of insoluble, consolidated deposits and incrustations).

Incrustations are made of calcium carbonate and iron sulphide; the metabolic activity of anaerobic bacteria proved to be the direct cause of these phenomena and formation of incrustations is prevalent during the early stages when the landfill is 'young' and the leachate is acid and characterized by high organic load. The problem can not be avoided completely, but it can be limited by means of internal reduction of organic load of leachate (Brune et al., 1991; McBean et al., 1993). This result can be achieved setting over drainages layers of unrefined compost which can perform a partial degradation of the organic compounds in leachate; moreover compost can act as buffering material limiting the acid phase and enhancing waste biostabilization. Another possible advantage of using compost as biofilter could be the removal of heavy metals from leachate due to adsorption or complexation phenomena. Laboratory experiments were conducted by Brune (Brune et al., 1991) by means of plastic columns filled with 30 cm of drainage material on top of which a further layer of 15 cm of compost was placed; highly and lightly loaded leachate were supplied during a period of 18 months; samples of leachate inflow and outflow were taken and analyzed for COD, Ca, Fe and Mg content. A general positive effect due to the presence of compost was observed: columns where compost was not placed showed quick bio-fouling of gravel. Compost layers were able to remove organic load, Ca and Fe ions from leachate, as reported in Figure 2.

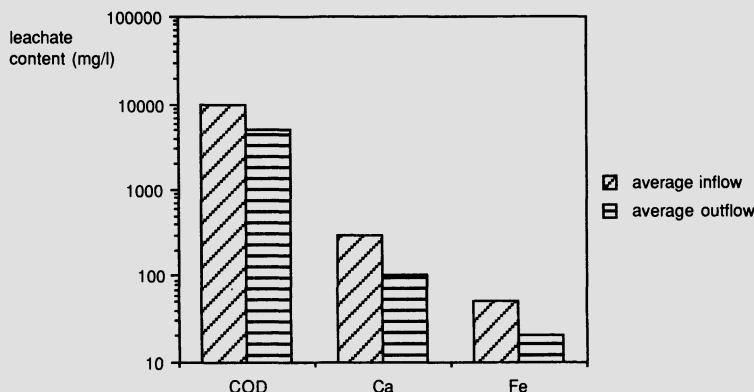


Figure 2 Average effects of compost on leachate quality (from Brune et al., 1991).

Brune reports of some problems occurred with high loaded leachate: removal efficiency was lower due to the acid pH which inhibited bacteria activity and compost layers showed phenomena of consolidation and fouling with decrease of permeability. For these reasons, use of unrefined composts should be recommended, especially when contact with young leachate is expected.

Table 1 summarizes the characteristics of compost and consequent possible utilizations in sanitary landfills.

Table 1 Compost properties related to possible utilizations in MSW landfills

	Compost properties					
	A	B	C	D	E	F
Compost utilizations (see Figure 1)	1		■		■	■
	2	■	■	■	■	■
	3	■	■	■	■	■
	4	■		■		■

- A Removal of hazardous compounds from biogas
- B Removal of organic load and heavy metals from leachate
- C Control of water inflow
- D Buffering
- E High permeability
- F Enhancement of plant and grass growth

Materials and methods

Six types of compost produced in two different plants were tested:

- 6 months cured, unrefined compost (NR6);
- 2 months cured, unrefined compost (NR2);
- 6 months cured, refined compost (R6);
- 2 months cured, refined compost (R2);
- cured, unrefined MSW compost (NR);
- ‘green’ compost, produced by means of stabilization of waste deriving from cleaning of parks and gardens and from agricultural and zootechnical activities (CV).

Composts NR6, NR2, R6 and R2 were produced at the same facility. Compost NR6 and NR2 were pretreated by means of shredding, screening (rotary screen, 70 mm) and aerogravitational classification; the curing phase was carried out at an uncovered area provided with insufflation-aspiration device. Compost R6 and R2 were refined by means of aeraulic zig-zag classification and vibrating screening (15 mm).

Compost NR was pretreated by means of shredding (rotor mill), screening (rotary screen), glass and iron separation; the accelerated biooxidation phase was carried out by means of aired windrows (25 days) and followed by a curing phase of 50 days.

The following parameters were determined for each type of compost:

- pH;
- moisture content;
- volatile substances;
- total humic substances, humic and fulvic acids;
- total organic carbon and organic substances;
- total N, total P (P_2O_5) and total K (K_2O);
- glass, inerts, plastics and iron content;
- heavy metal content.

Particle size distribution was determined taking into account the following size classes (mm):

-	+25	-	-3 +1
-	-25 +10	-	-1 +0,5
-	-10 +5	-	-0,5
-	-5 +3		

In order to define the stabilization rate, respirometric tests were carried out using a common BOD device; 40 g of compost were diluted in 400 ml of standard solution. Oxygen consumption due to aerobic degradation was measured for a period of 5 days.

Anaerobic digestion tests were performed to estimate the biogas production deriving from compost utilization in a sanitary landfill; 300 g of compost diluted according to a liquid-solid ratio of 2 were set inside airtight glass bottles connected to a hydraulic gager in order to measure biogas production. The devices were placed in a thermostatic room regulated at a temperature of 30 °C. Gas flow was recorded daily.

Several leaching tests were carried out in order to define heavy metal mobilization and interactions between compost and MSW leachate; four types of leaching tests were performed using as extraction liquid: water acidified by means of CO₂ or acetic acid (recommended by Italian legislation), a acid phase and a basic phase MSW leachate. Leaching tests with MSW leachates were carried out following the same methods recommended for the test with acetic acid.

Eluates of the leaching tests were analysed and the following parameters were defined:

- heavy metal content;
- pH;
- COD and BOD₅;
- chloride and volatile acids (from C₂ to C₇).

In order to measure the permeability, compost samples were compacted into steel cells using a Proctor device. Compaction was performed according to ASTM prescriptions.

Compacted composts were saturated with water and permeability was measured by means of a variable head permeameter.

Results and discussion

Characterization

The values of VS, organic carbon and organic substances showed that unrefined composts have, as expected, an organic content lower than refined compost. This characteristic is positive for use of compost in landfill: infact the organic load of waste mass does not increase much. CV compost showed a high organic content.

N and P content showed that composts can introduce nutrients into the landfill, thus improving waste stabilization in view of the fact that these elements are scarce in waste.

NR6, R6 and CV composts have low moisture contents (10 – 20%), rendering them suitable for utilization in a landfill: in fact they are not an additional source of leachate and, on the contrary, can act as a control factor of water flow into the waste mass: considering a compost field capacity equal to 40% by weight and a moisture content equal to 14%, a layer of 1 m², 0,3 m thick and specific weight equal to 0,8 t/m³, could keep 70 l of water.

Composts have an alkaline pH (7,5–8,6); for this reason they could be considered as buffering material capable of avoiding excessive decrease of pH due to the high production of volatile acids typical of the first phase of waste anaerobic degradation (low pH values inhibit waste stabilization) and limiting heavy metal mobilization and drainage incrustation.

Unrefined composts are characterized by high content of plastics, inert and glass. The presence of inert and glass and the absence of refining treatment in NR6, NR2 and NR allows a fairly well-balanced size distribution (Figure 3) which should allow good void index and permeability. For other reasons also CV compost is characterized by the prevalence of large particles.

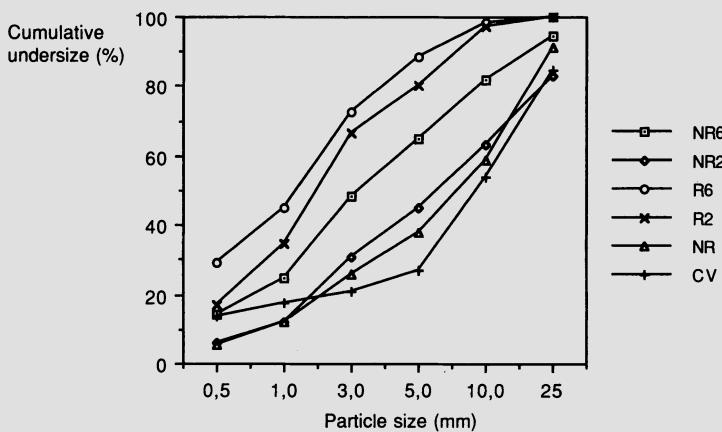


Figure 3 Compost size distributions.

Respirometric tests

In Figures 4 O₂ consumption measured during the respirometric tests is reported; results are referred to unit of compost mass. These data evidenitiate how organic substance of composts from MSW is readily biodegradable, while slowly biodegradable matter (cellulose) is prevalent in CV compost. For composts from MSW, O₂ consumption is high during the first days but subsequently decreases, while the opposite occurs for CV compost. NR6 compost would appear to have a low organic content and therefore to be the more suitable for utilization in landfill.

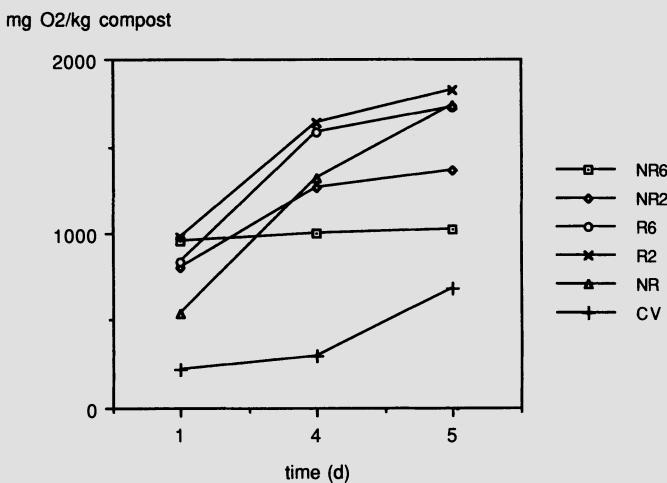


Figure 4 Oxygen consumption for unit of compost mass.

Biogas production tests

In Figure 5 daily biogas production curves referred to unit of compost mass are reported.

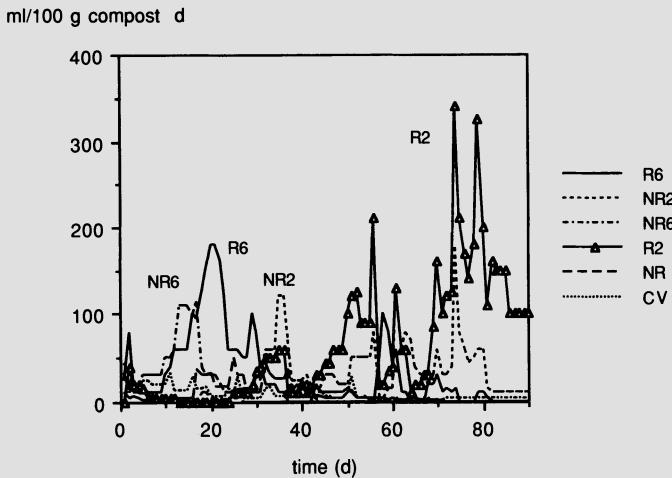


Figure 5 Daily biogas production referred to unit of compost mass.

R2 compost was characterized by the highest daily production ($350 \text{ ml}/100 \text{ g compost d} \approx 3,5 \text{ Nm}^3/\text{t compost d}$) reached during the last days of experimentation; this delay in reaching the peak of production could be attributed to the high content of biodegradable matter which probably led to a consistent production of fatty acids and thus to inhibition of methanogenic bacteria due to acid pH values. The lowest daily production was given by CV, NR and NR6; the utilization of unref-

fined, well cured compost in a landfill will not lead to a consistent increase of biogas production from the waste mass.

Figure 6 shows cumulative biogas production curves referred to unit of compost mass.

Curves obtained confirm findings reported by daily production curves. NR2, R2 and R6 composts were characterized by negligible production during the first part of experimentation; subsequently the curves presented a flex point and production increased rapidly; gas production had not been exhausted following the 90 days of experimentation. The highest cumulative production was by compost R2 (5.500 ml/100 g compost). Gas production from compost NR6 started quickly but finished after 20 days; the gas production from compost CV (rich of slowly biodegradable organic matter) was low but not end up after the 90 days of experimentation.

The low gas production renders NR6 compost the more suitable for utilization in a landfill.

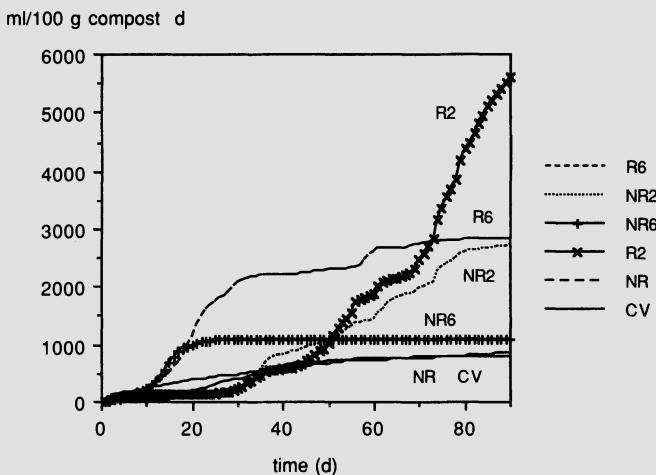


Figure 6 Cumulative biogas production referred to unit of mass of compost.

Heavy metal content in composts

Zn, Pb and Cu are metals found in the highest quantities, as verified also for MSW (Cannas et al., 1990; Muntoni A., 1994), due probably to the presence of dust from road and domestic cleaning, but legal limits for waste classification are respected. Compost CV has a considerably lower heavy metal content. Refining has not a remarkable effect on heavy metal content.

Leaching tests

Table 2 reports concentrations of metals found in eluates of leaching tests carried out using water acidified by means of CO₂ and acetic acid. A general low mobi-

Table 2 Metal concentrations in eluates of leachng tests.

lization of metals can be stressed. The negligible mobilization of metals from compost to eluates is probably due to the buffer characteristics of composts: eluates presented a final pH of 7–8. Cu, Pb and Zn, the main metals present in composts, were leached in small quantities, probably due to their anphoterism which allows release only at very low or very high pH values, conditions which are not common in a MSW landfill. Concentrations of heavy metals are well below the common concentrations for MSW leachate.

Table 3 shows the values of several parameters measured for eluates of leaching tests compared to average values of MSW leachates. The buffering effect of composts is evident; this is surely a positive aspects in order to evaluate the utilization in MSW landfills; buffering capacity should limit the inhibition phenomena of methanogenic bacteria due to excessive decrease of pH, thus enhancing biostabilization of waste and limiting clogging of draining systems; moreover under-basic conditions mobilization of heavy metals from solid matrix is reduced and removal of metals from leachate enhanced. The values of organic parameters (BOD, COD etc.) are well below values commonly found in acid MSW leachates and near to values typical of basic leachates produced from stabilized waste.

Eluates from tests using acid leachate and MSW compost show higher metal concentrations or similar than those of acid leachate itself: this means that the contact between compost and leachate facilitates mobilization of heavy metals from solid matrix to eluate; only compost CV seems to be able to slightly remove some metals (Cu, Ni and Zn) from acid leachate.

Tests with basic leachate show a remarkable removal of Cr III, Cu, Ni and Zn, in particular by compost CV: this means that contact between compost and leachates under basic conditions could improve inorganic load of basic leachates (see also Figures 7 and 8). This effect could be explained by adsorption or complexation phenomena which may prevail over mobilization effects probably because pH is not low enough.

Table 3 Main parameters measured for the leaching test eluates and average ranges in MSW leachates.

Parameters and tests	NR	CV	NR6	NR2	R6	R2	Average range in MSW leachate
pH							
- CO ₂	7,43	7,40	6,89	7,31	7,43	7,45	5,3 – 8,5
- acetic acid	5	5	5	5	5	5	
COD (mg O ₂ /l)							
- CO ₂	1.389	1.155	1.394	1.524	1.848	1.889	1.000 – 70.000
- acetic acid	-	-	-	-	-	-	
BOD ₅ (mg O ₂ /l)							
- CO ₂	189	155	230	274	428	419	500 – 30.000
- acetic acid	-	-	-	-	-	-	
volatile acids (mg C/l)							
- CO ₂	10	7	13	15	29	31	50 – 5.000
- acetic acid	-	-	-	-	-	-	

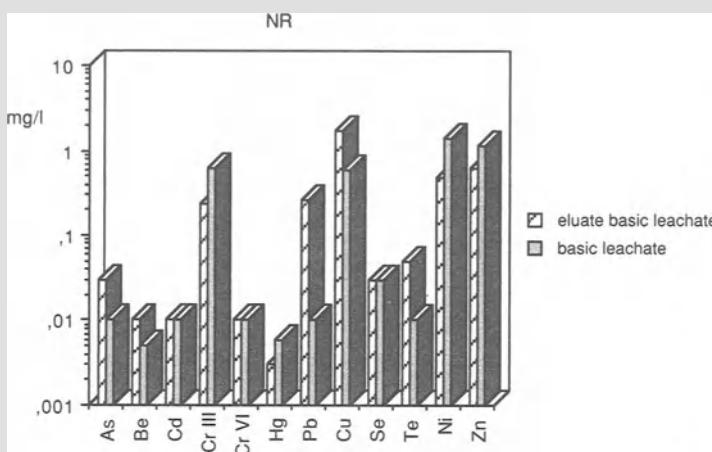


Figure 7 Concentrations of metals in basic leachate and in the eluate of leaching test carried out on compost NR using basic leachate as lixiviant.

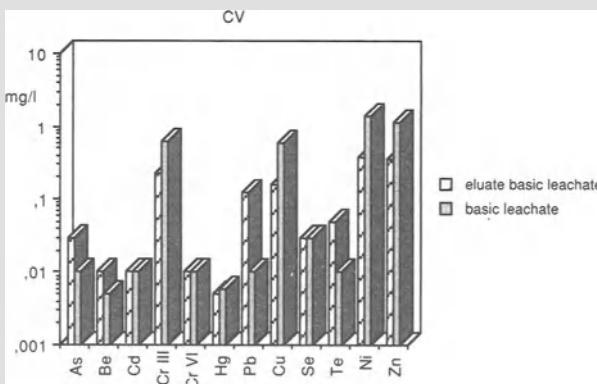


Figure 8 Concentrations of metals in basic leachate and in the eluate of leaching test carried out on compost CV using basic leachate as lixiviant.

Permeability tests

Figures 9 and 10 show compaction rate and permeability measured for the composts tested .

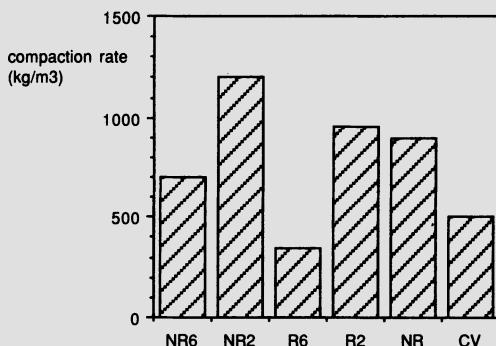


Figure 9 Compaction rates of composts tested.

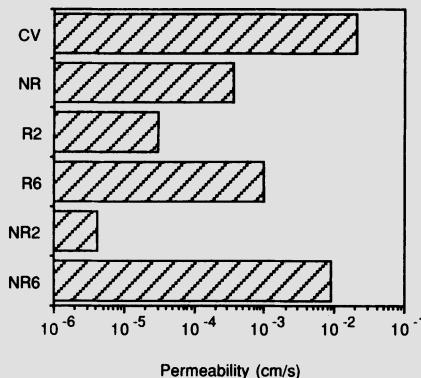


Figure 10 Permeability of composts tested.

It is evident that compost CV and R6 are the less compactable; this is probably due to the lower moisture content and to the particular physical structure of CV (similar to a fluff). The low compaction rate and the favourable size distribution allow compost CV to keep a high permeability and render it suitable to be used as cover material in MSW landfills. Also compost NR6 and R6 posses a sufficient permeability for use in landfills: the low compaction rate and, for compost NR6, the favourable size distribution, allow cured composts to keep high permeability.

Tests in progress

Currently, other tests are in progress in order to verify whether dangerous trace components of biogas (mercaptans, chlorinated components etc.) can be removed by means of flowing through compost layers. Several experiences (Figueroa and Stegmann, 1991; Figueroa, 1993 (a), Figueroa, 1993 (b)) have shown that methane can be oxidized to CO_2 and H_2O by a bacteria population growing in compost layers used as final capping of MSW landfills. The research programme aims to

assess also whether trace components can be chemically or physically removed. An experimental device has been set up at a sanitary MSW landfill: biogas flows in columns filled with compost; samples are taken before and after the passage through the compost and analysis of gas composition are made by means of gas-mass-cromatography.

Conclusions

The experiment allows the Authors to assess that:

- a) use of MSW composts in landfills brings the following advantages:
 - compost can act as buffering material enhancing waste stabilization and limiting clogging of leachate draining system;
 - compost can decrease the content of some heavy metals in leachate under basic conditions, while under acid conditions there is a negligible mobilization of metals from the solid matrix;
- b) tests have to be carried out in order to evaluate the compost influence on the organic load of leachate;
- c) green (CV) compost keeps a high permeability due to its favourable size distribution and particular physical structure; concerning MSW composts, in order to keep sufficient permeability values it is necessary to avoid refining treatments and improve curing phase;
- d) well cured composts are more suitable to be used as cover material because:
 - they do not increase too much the organic load of the waste amount;
 - they have a lower moisture content which allow them to work as a control layer of water inflows;
 - they produce less biogas in anaerobic conditions;
 - they are less compactable and thus keep a high permeability.

Acknowledgement

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B4 Bioremediation

Stabilization of Hazardous Wastes Through Biotreatment

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Abstract

Biological treatment of hazardous wastes is the application of microorganisms to break down the toxic compounds in the wastes into innocuous intermediates or end products. This paper discusses the basic requirements in order to use biological treatment to stabilize toxic compounds. In addition, the paper presents an overview of available types of treatment, including: *in-situ* remediation, treatment of liquid wastes, treatment of solid wastes, and the application of compost technology. Finally, a discussion is made of a case study in which oil refinery sludges were stabilized using a composting technology. In the case study, laboratory-scale experiments were first carried out to determine the viability of the composting process. The laboratory-scale experiments were followed by a series of pilot-scale tests, as well as extensive analyses of the gaseous and solid byproducts.

Introduction

Contamination due to industrial activity now is widely recognized as a potential threat to public health and the environment. Both industrialized and developing countries are facing serious problems associated with contamination due to toxic and hazardous wastes. Several countries have developed and implemented regulations to either limit or completely eliminate the production and release toxic chemicals to the environment. Unfortunately, significant environmental contamination already has taken place which will require various technologies and substantial resources to successfully remediate.

The need to clean up the contaminated sites, combined with the financial requirements associated with the cleanup, have encouraged the development of new technologies which emphasize detoxification and destruction of the contaminants. One of these technologies is bioremediation. Bioremediation is the application of microorganisms to detoxify and degrade toxic or hazardous compounds. Microbiological processes have been used for the stabilization of organic residues

for a number of years. For instance, conventional municipal wastewater treatment relies heavily on the application of microbiological processes. These processes are engineered and controlled to accomplish specific goals and specifications.

In the context of this presentation, biotreatment is applied to the stabilization of toxic and hazardous compounds found in primarily soils, as well as in surface and groundwater. Thus, in general, the new application of microbiological processes differs from previous applications in terms of the types and concentrations of chemicals undergoing treatment and the medium in which the treatment may take place. Typically, a site is contaminated with complex mixtures of organic compounds. The concentrations of contaminants may vary substantially within the site. Frequently, inorganic residues such as metals also are present. The contaminated media adds another degree of complexity to the mixture in the waste. Consequently, bioremediation generally involves the handling of multiphasic, heterogeneous materials such as soils in which the contaminant may be present in association with the soil particles or dissolved in liquids.

Bioremediation technologies can be classified in two general categories: *in-situ* and *ex-situ*. *In-situ* techniques involve the treatment and stabilization of the contaminated material in place. *Ex-situ* are those processes which involve the collection, removal, and transportation of the contaminated material to another location for treatment.

The success of a bioremediation technique is dependent upon the following conditions: the presence of large enough populations of the correct type of microorganisms, and the proper conditions for the organisms to grow. The correct type of microorganisms are those which have the physiological and metabolic capabilities to break down the contaminants into harmless products. In many situations, the required organisms already are present at the site. In other cases, it may be necessary to introduce a particular culture to the material. The microorganisms must be in close proximity to the contaminants for degradation to take place. It is fairly common that the presence of a biodegradable contaminant leads to the establishment and enrichment of a culture capable of degrading it in the contaminated area. In situations in which the required populations are not present, a mechanism must be developed to bring the microorganisms into contact with the contaminants. Once the proper type of microorganisms are present, the environmental conditions must be adjusted to promote the growth and metabolic activity of the microorganisms. Environmental factors such as temperature, inorganic nutrients (primarily nitrogen and phosphorous), electron acceptors (oxygen, nitrate, and sulfate), moisture, and pH can be adjusted to optimize the environment for bioremediation.

Bioremediation offers several advantages over conventional treatment techniques. In most cases, bioremediation can be carried out on site, thereby eliminating liabilities and transportation costs. Similarly, industrial use of the site can continue while bioremediation is taking place. Biotreatment can result in the breakdown of the waste materials into carbon dioxide and water, thus permanently eliminating the waste and the liability associated with non-destructive treatment

methods. Bioremediation can also be combined with other technologies allowing for the treatment of mixed, complex wastes.

Just like any treatment technology, bioremediation also has its disadvantages. For instance, some chemicals, such as highly chlorinated compounds and metals, are not readily amenable to biological degradation. In some situations, biodegradation may lead to the production of substances that are more toxic than the parent compound. Bioremediation is a scientific procedure which must be specifically designed to conditions prevalent at the site. Therefore, the capital investments required for site characterization and feasibility analysis for bioremediation may be higher than the capital costs associated with conventional technologies.

Degradation of Xenobiotics

Organic compounds are broken down through a series of reactions known as catabolism. In the process, a complex carbon compound is converted into carbon dioxide and water. Microbial breakdown of a complex organic compound does not always result in complete breakdown. Microbial degradation can transform a compound into one that is more toxic to the environment than the original compound. Thus, biodegradation studies which only measure concentrations of the compound of interest may not be totally accurate.

Petroleum Hydrocarbons (PHCs)

Petroleum and its products, such as diesel fuels and gasoline, are complex mixtures of organic compounds. The majority of the compounds found in petroleum products are hydrocarbons.

Aliphatic hydrocarbons are straight or branched chains of carbon atoms which have enough hydrogen to satisfy the valence requirements of the carbons. Depending upon the number of carbon-carbon bonds, aliphatic hydrocarbons can be classified into: alkanes, alkenes, and alkynes. Other important types of hydrocarbons are those known as aromatic compounds. In general, aliphatic hydrocarbons are easier to break down than aromatic compounds.

Straight-chain alkanes are primarily degraded through oxidation of the terminal methyl group. This is followed by cleavage of the molecule between the second and third carbon in the chain. The first reaction in the process consists of the addition of oxygen to the terminal carbon. Oxygen addition to the terminal carbon results in the formation of primary alcohol. Eventually, the primary alcohol is oxidized to a fatty acid. Anaerobic degradation of aliphatic hydrocarbons does not play a significant role in the degradation of petroleum hydrocarbons in the natural environment [Atlas 1988; Atlas 1991].

Aromatic hydrocarbons such as benzene, toluene, ethylbenzene, and xylene (BTEX) are found predominantly in light petroleum fractions such as gasoline,

although they may be present in trace amounts in any type of petroleum product. These compounds also are widely used as industrial solvents and intermediates in chemical production. Benzene, toluene, ethylbenzene, and xylene are relatively soluble in water. The solubility of BTEX allows them to be transported away from spills, resulting in extensive soil and groundwater contamination. Because of their small molecular size and low boiling point, BTEX volatilize at ambient temperatures and as such may be substantial sources of air pollution. Aromatic hydrocarbons are highly toxic and are classified as carcinogens.

Biological degradation of aromatic hydrocarbons under aerobic conditions was first demonstrated in the early 1900s [Gibson 1984]. Since then, several studies have been carried out to investigate the biochemistry and genetics of the degradation of aromatic hydrocarbons. The results of these studies have demonstrated that bacteria and fungi are capable of degrading aromatic compounds under aerobic conditions. Biological degradation of these compounds can follow either one of several pathways.

Until recently, microbial breakdown of aromatic compounds was considered to be possible only under aerobic conditions. However, during the last ten years, a number of investigations have demonstrated that these compounds can also be degraded under anaerobic conditions. Many of these investigations have used enrichment cultures of mixed microbial populations.

Anaerobic degradation of aromatic compounds has been demonstrated to take place under methanogenic, denitrifying, and sulfate-reducing conditions [Sufliita 1991]. Ferric iron and manganese oxide have also been shown to serve as alternate electron acceptors for the anaerobic degradation of aromatic compounds. The initial steps of aromatic degradation under anaerobic conditions are considerably different from those found under aerobic degradation.

Preliminary steps for system design

One of the most important steps in the design of a biotreatment system is the performance of biotreatability laboratory studies. These studies are important in determining whether or not the contaminants are biodegradable and if a large-scale biological process can be applied to the project.

One of the most difficult tasks in a site remediation project is the selection of the most appropriate treatment technology. This is due to the lack of reliable data on the treatability of different compounds. In addition, another complicating factor is the variability that may take place from site to site. Laboratory- and pilot-scale studies can play a critical role in determining whether or not biotreatment technologies can be applied in full-scale projects.

Treatment of specific compounds

Since pesticides and oily sludges have been demonstrated to be biologically degradable, the greater part of the sections that follow deal with those two groups of wastes.

Laboratory Experience

An extensive literature survey covering about sixty studies of microorganisms able to assimilate recalcitrant organic materials is presented in a report edited by De Renzo [Noyes Data Corporation 1980]. In the survey, it is pointed out that: 1) relatively little information is available in terms of descriptions of microorganisms capable of metabolizing recalcitrant materials; and 2) most of the studies dealt with monocultures and idealized carbonaceous substrates applied under carefully controlled laboratory conditions. Therefore, although information gained in those studies may perhaps not be directly applicable to the complex conditions characteristic of the compost process, it can serve as a foundation for studies of complex interactions among microbial populations, and for selecting a suitable microbial 'seed' either for starting or accelerating the composting of degradable organic wastes.

Petroleum hydrocarbons can be assimilated by more than 200 species of microbes. Indeed, fungi have been observed growing in jet fuels [Prince 1961] and in toluene [Nyns 1968]. Examples selected from this assortment are listed in Table 1.

Table 1 Microbial Groups Capable of Metabolizing a Hydrocarbon Substrate

Bacteria		Actinomycetes	Fungi
Achromobacter	Flavobacterium	Actinomyces	Aspergillus
Aerobacillus	Gaffkya	Debaryomyces	Aureobasidium
Alcaligenes	Hansenia	Endomyces	
Arthrobacter	Methanomonas	Nocardia	Cephalosporium
Bacillus	Methanobacterium	Proactinomyces	Cunninghamella
Bacterium	Micrococcus	Saccharomyces	Mycelia (Fungi imperfecti)
Beyerinckia	Micromonospora		Monilia (yeast)
Botrytis	Mycobacterium		Torula (yeast)
Candida	Mycoplana		Torulopsis (yeast)
Citrobacter	Pseudomonas		Trichoderma (yeast)
Cellustomonas	Sarcina		
Colostridium	Serratia		
Corynebacterium	Apicaria		
Desulfvibrio	Spirillium		
Enterobacter	Thiobacillus		
Escherichia	Vibrio		

Compost Experience

The literature on the composting of hazardous wastes is relatively small. Probably the first such report is that by Rose and Mercer [Rose 1968], who investigated the composting of insecticides in agricultural wastes. They found that the concentrations of diazinon and parathion rapidly decreased by continuous thermophilic composting. Thus, the concentration of diazinon was reduced from about 3.3 ppm to less than 0.002 ppm within 42 days. The degradation of parathion amounted to 50% of its original concentration in 12 days. In an investigation of the compostability of a 5% to 10% TNT mixture, it was found that the TNT could be reduced to zero, or an acceptable level, within a relatively short time. Since then, other studies have been conducted to evaluate the feasibility of biodegrading soils contaminated with explosives [Argonne National Laboratory]. In a project involving the composting of sewage sludge [Epstein 1980], it was found that many of the aromatic compounds in the sludge were reduced to negligible levels. Results of research done by CalRecovery, Inc. indicate that concentrations of the oil in oil sludge were reduced to less than 75% of their original concentrations in less than a month. The breakdown of the oil occurred only when the environment was aerobic [Diaz 1994].

'Seeding,' Substrates, and Mechanisms of Breakdown

Composting hazardous wastes differs from routine composting in that 'seeding' of the raw wastes is an important feature. The seeding is done by recycling a portion of the compost product into the raw waste to be composted. A suitable ratio would be on the order of one part seed to nine parts raw waste. The seeding ensures the presence of a population of organisms capable of attacking the hazardous contaminant without incurring the need for a lag period during which the necessary population could develop.

Given the right conditions, hydrocarbons are broken down relatively readily. Aromatics are degraded more slowly than aliphatics and alicyclic nonaromatics. Microbes have enzymes (oxygenases) that convert polynuclear aromatics into unstable cyclic peroxide, which in turn is reduced to cisglycol. The cisglycol is further oxidized. The researchers who determined this pathway contend that in landtreatment, a period of 1 to 2 years might resemble the potential of soil to decompose these compounds [Overcash 1979].

Not all of the breakdown in a compost pile is biological in nature. Chemical and physical conditions established by the process can exert an important influence on the breakdown of certain organic compounds. Ultraviolet light, temperature, and pH level are three such conditions. Many biodegradable pesticides are so vulnerable to these factors that isolating and determining the role of microorganisms in the breakdown of the pesticide is very difficult [Paris 1975; Mount 1981]. Temperature and pH levels reached during the composting process are those at which such pesticides decompose most rapidly [Mount 1981]. Hence in compost-

ing, physical, chemical, and biological destructive agents combine to degrade the pesticides, thus magnifying the effectiveness of composting.

Research studies

A series of studies were carried to ascertain the degradability of API separator oily waste. The studies were conducted at the laboratory- and at the pilot-scales. The primary objectives of the studies were to: 1) determine the effectiveness of composting in the destruction of hazardous sludges generated in the process of refining petroleum; 2) isolate and classify the predominant microbial populations in the compost and test the microorganisms' effectiveness in treating the wastes; and 3) determine the potential of composting the material at the pilot-scale.

Laboratory-Scale Degradation Experiments

In the research program, four 12-liter glass jars were used as the reactors. The medium used was a mixture of composted sewage sludge, dewatered digested sludge, and woodchips. The sludges were obtained from a wastewater treatment plant, and were intended to serve both as a mass inoculum and as sources of nutrients. The woodchips served as a bulking agent.

The medium was thoroughly mixed with the oily wastes. The mixture of refinery sludge and medium was divided into two portions. A 10-liter aliquot of each of the two portions was placed in glass reactors. The reactors had been previously sterilized. One of the portions of the mixture of oily waste and medium served as 'control.' Medium used in the control was sterilized in an autoclave prior to being mixed with the respective test materials.

The reactors were placed in a water bath. The water bath was operated such that the temperatures of the reactor contents could be maintained within plus or minus 1°C of a desired temperature. The reactors were loosely covered to prevent airborne dust from contaminating their contents.

The parameters used for monitoring the process included: 1) extent of destruction of the test substances, and 2) odor and appearance of the reactor contents. The temperature of the reactors' contents was varied by changing the temperature of the water bath. The temperature was changed to simulate the temperature fluctuations found in conventional composting. The experiment was conducted for a 33-day period. The reactors were aerated manually by stirring the composting masses. The pH level was monitored and recorded periodically. No attempt was made to control the pH.

Sampling and Analyses

Samples for use in the second phase of the experiment were removed from all of the reactors. The appearance and odor of the individual cultures, as well as their

loss in mass and volume, were observed and recorded on the days on which they were stirred. The concentration of oil and grease was determined according to Method 503D, 'Extraction Method for Sludge Samples' [American Public Health Association 1971].

Results of degradation experiments

During the first 13 days, the rate of destruction was more rapid in the active reactor. However, the downward trend for destruction paralleled that for the rise in temperature.

Odor and pH Level

Initially, the odor in the control reactor remained strongly oily in nature. After Day 5, the material began to take on the odor associated with anaerobiosis. Beginning about Day 11, the odor of ammonia became noticeable, and thereafter increased in intensity. However, by Day 24, it began to lose its intensity, such that by the 32nd day, the odor of ammonia was barely noticeable.

In the active reactor, during the first 6 days of the run, the predominant odor was the oily one. Thereafter, the odor became that of a faintly earthy odor that slowly increased in intensity until around Day 14. At Day 14, ammonia began to be noticeable and the odors of anaerobiosis became detectable on the 19th day. The 19th day coincides with the highest temperatures in the reactors. As the temperature was lowered beginning on Day 24, the anaerobic odors decreased. Finally, by the 31st day, the predominant odor was earthy.

During the course of the experiments, the pH level was on the order of 7 to 7.5 in all reactors. The only exception was the active oily waste reactor in which the pH level reached about 9 for only a short time, and then decreased to about 5.5.

Discussion – degradation experiments

The results demonstrated the importance of biological activities in the destruction of oily wastes. This was shown by the greater reduction by Day 13 in the concentration of oily waste in the active culture. However, the major difference was limited to the first 13 days in that after that time, the concentrations in both reactors were very similar.

The degradation that began on the first day and continued until the end of the experiment in the control was a function of the microbial population in the oily wastes. Since the oily wastes could not be sterilized, the contents of the control reactor were inoculated with the microbes in the oily waste. The rather high initial breakdown in the active reactor was due to the bacterial populations introduced with the composted and digested sewage sludges combined with those in the oily waste.

Laboratory-Scale Microbiological Experiments

The microbial program was conducted in two phases. The first phase involved the isolation of predominant microorganisms in samples taken from the active oily waste reactor. The second phase involved the challenge of the isolated microorganisms under aseptic conditions with the refinery wastes in order to determine the ability of the microorganisms to decompose the wastes.

In the isolation phase, microbial counts and isolation were conducted by using agar slants. The slants were incubated at 22°C to 37°C for 2 to 5 days.

The medium used in the challenge run was made up by adding sterile oily waste to sterile distilled water such that the concentration of oily waste in the mixture approximated that of the waste in the reactors. The oily waste was sterilized through gamma irradiation.

The oily waste medium was divided into seven 500-ml aliquots. Each of the aliquots was placed in a liter flask. Two of the flasks were inoculated with a single isolate, and three were inoculated with two isolates per flask. The seventh flask served as a control. In order to be able to account for the loss of oily wastes due to volatilization, two additional controls were established; one of the controls contained distilled water, and the second, oily waste. All flasks were aerated by bubbling air through the cultures. The cultures were incubated at 35°C over a 13-day period. Initial and final concentrations of oil and grease were determined by chemical analysis.

Results and observations – microbiological experiments

The level of destruction of oil and grease is presented in Table 2. As the data in the table show, the 'net' percentage destruction over the 13-day challenge period was the highest in the flask containing isolate number 5, i.e., the degree of degradation attributable solely to microbial activity was 25.6%. Net destruction in the other flasks ranged from 0% to 5.5%.

Table 2 Results of Challenge Rounds – Oily Waste

Isolate	Net Oil and Grease Degradation ¹ Cumulative Percent
5	25.6
1,2	0
3,4	0
6,7	2.4
8	5.5
E	0.5

¹ Net degradation = (gross)–(control over the 13-day period).

Discussion – microbiological experiments

The destruction of oily waste obtained with isolate 5 confirms the results obtained in the compost experiments. In this particular case, the degree of destruction of oily waste obtained in this run was similar to that obtained during the composting experiments.

The results obtained in this study can be compared with those experienced in conventional landfarming. Monthly rates of degradation of oily waste were calculated using data available in the literature on landfarming [Environmental Research and Technology 1983; Meyers 1980]. The results of the analysis indicated that landfarming achieved degradation rates between 4% and 11.9% per month. On the other hand, the compost reactors achieved rates between 30% and 66% per month. The data show the substantially higher rates of degradation that are obtained with composting [Environmental Research and Technology 1983; Meyers 1980].

In this study, the loading rate applied in the compost reactors was on the order of 1 to 3 lb oil and grease/ft³ per month. Landfarming typically uses loading rates in the range of 0.2 to 1.1 lb oil and grease/ft³ per month.

Pilot-Scale Experiments

The medium used for the experiment was obtained from an active composting pile used for treating non-hazardous residues. The toxic waste used in the experiment was API separator oily waste collected from a refinery. In the experiment, organic waste in the process of stabilization was loaded into a reactor. The material was thoroughly mixed three times per week. Water was added as needed in order to maintain appropriate moisture content. No other nutrients were introduced into the material. Oily waste was slowly introduced to the material in order to allow for acclimation of the culture. The total amount of oily waste added to the composting mass was 36 liters.

Samples of the gases released during the biotreatment process were collected for analysis. Representative samples of the mixture in the process of stabilization were taken before and during the addition of oil.

Results

The results presented in this paper are limited to the analysis of the oil and grease fraction before and after treatment. The analyses were conducted by means of gas chromatography. The main reason for the analyses was to characterize the oily waste in terms of the chain length of the hydrocarbons comprising the oil and grease fraction.

The results of the analyses are presented in Figure 1. The curves in the figure show that the hydrocarbons present in the oily waste had carbon lengths within

the range of 8 to 29. The non-aromatic hydrocarbon species present in the waste had a high concentration of chain lengths in the neighborhood of 14 to 20 carbon atoms. The predominant aromatic species had chain lengths greater than 12.

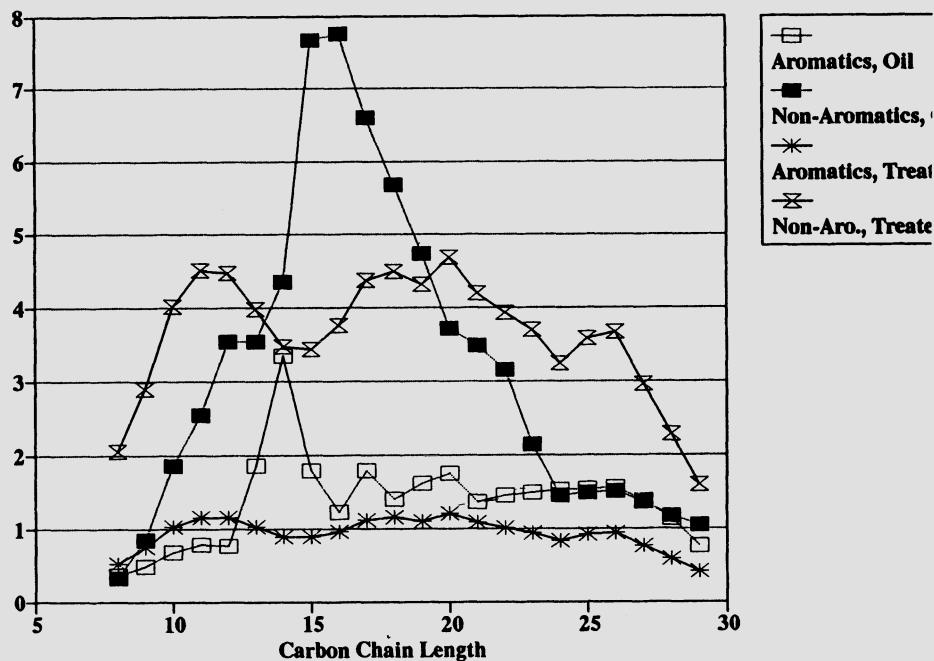


Figure 1 Comparison of Hydrocarbon Distribution (Oily Wastes vs. Finished Product)

The chromatographic scans of the final oily waste compost are also shown in Figure 1. The curves in the figure show relative uniformity between C10 and C26. Thus, the process resulted in the breakdown of the larger hydrocarbons into shorter chains.

Conclusions

The research demonstrated the technical feasibility of composting refinery sludges. Rates of degradation achieved and the size of the loadings applied in the research are substantially greater than those typical of landfarm treatment of oily waste. These factors contribute to a reduction of the land requirement for an oily waste compost operation in comparison with that for landfarming. Containment and biological treatment of oily wastes in totally enclosed reactors also substantially reduce the environmental monitoring required of land application sites and the problem of containment and treatment of the volatile constituents of the oily wastes.

Existing technology can be applied to the composting of hazardous biodegrad-

able wastes through suitable modifications. The need to control the gaseous emissions from composting hazardous wastes demands the use of a system especially designed to meet it. Therefore, one of the modifications would be to install a mechanism for treating the gaseous emissions. The type of mechanism for the task would depend upon the nature of the gaseous substances.

An important constraint is the necessity of confining objectionable gaseous emissions within the reactor or enclosure until they are processed. This constraint rules out arrangements in which the only provision for gaseous emission control is by way of a ventilation system. Most of the current enclosed compost systems probably could be suitably to fit these requirements. Practically all available compost systems are readily adaptable to managing liquid and solid emissions.

Unless halogenated organic compounds are to be destroyed, an aerobic system would be the one of choice. If the halogenated compounds are to be composted, then an anaerobic phase would have to be included. If an oily sludge is to be composted, a bulking agent would be required.

The future of composting refinery sludges

In general, some of the alternatives available for the disposal of refinery sludges include: landfilling, landspreading, landfarming, and thermal destruction. Both landfilling and landspreading require that a specific amount of land be dedicated for the purpose. A certain amount of breakdown may take place during storage of the waste material due to natural decomposition. Oily wastes may also be tilled into the soil to promote additional decomposition. In most cases, the breakdown of toxic organic compounds may take on the order of months or even years [Ann Arbor Science Publishers 1981; Butterworth Publishers 1983; Norris 1980]. Since landfarming generally is not controlled, the process typically requires relatively large amounts of land.

Some organic residues can be used as substrates for the microbial activities that take place in composting [Epstein 1980; Pitter 1976]. Consequently, composting can be used for treating biodegradable hazardous wastes [Rose 1968; Goldstein 1983]. In addition, composting has become increasingly popular for the treatment of sludges from municipal wastewater treatment facilities [Golueke 1980].

Composting offers a major advantage over other available alternatives. The process, in essence, reduces the length of time necessary to detoxify the toxic compounds and stabilize the biodegradable components. Typically, simple storage or landspreading requires several months [Ann Arbor Science Publishers 1981; Butterworth Publishers 1983; SCS Engineers 1979]. Furthermore, if the containment site is not covered, the time required for stabilization becomes longer. On the other hand, a well-designed and managed composting operation does not have to be negatively impacted by the climate.

Aerobic composting can be a relatively simple operation in terms of equipment and manpower requirements, especially when compared with incineration.

Incineration of hazardous wastes usually requires the use of sophisticated air pollution control equipment and involves appropriate treatment and disposal of the ash. On the other hand, a composting operation normally affects a well-defined area. Consequently, the potential for adverse environmental impact by a composting facility is less than that by an incinerator.

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Starch Based Biodegradable Materials in the Separate Collection and Composting of Organic Waste

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Abstract

Biodegradable plastics are a new generation of materials, still at an early stage of development. Their development is tied to the growth of composting infrastructures, to the definition of severe standards for biodegradability and compostability, and to the marketing of effective and truly compostable products. The data reported in this paper, show that Mater-Bi Z grades comply with the compostability requirements. The biodegradation studies at laboratory scale, the full scale trials, and the toxicity and compost quality tests prove the compostability of Mater-Bi Z grades according to the scheme followed by the different International Committees (ISR/ASTM, CEN, DIN, ORCA). Moreover, experiments of separate collection of organic waste organized in several European Countries with Mater-Bi bags were fully satisfactory. These data indicate that biodegradable materials are mature for a real industrial development starting from specific applications such as composting bags.

Introduction

Biodegradable plastics are a new generation of materials, still at an early stage of development, which retain their shape and properties while in use, but completely biodegrade when properly discharged.

While the plastics marketed ten years ago as ‘biodegradable’, constituted by synthetic polyolefin resins and small amounts of corn starch, were just disintegrable, today’s degradable plastics meet stringent requirements for biodegradability. Many of the new plastics are actually made from natural sources. Exposed to the microbes and moisture in a compost pile, they break down, like paper, in carbon dioxide, water and humus; no toxic residues are left behind.

Degradable polymers alone are not going to solve the world’s waste problems,

but they can offer to waste producers additional options in situations where recycling is difficult or too expensive.

Expanded foams in place of polystyrene, composting bags, paper coatings, cutlery, diapers and other hygiene products are some of the possible applications of biodegradable polymers; many others can be foreseen if price targets, new commercial potentialities, and development of new or improved degradable resins are met.

At the moment, the main producers of biodegradable materials are: Novamont with starch based materials, Cargill with poly-lactides, Rohm and Haas with poly-aspartic acid, Union

Carbide with poly-epsilon-caprolactone, Zeneca with poly-hydroxy butyrate-valerate, Showa Denko with poly-butylene succinate, Eastman Chemical with cellulose acetate.

The growth of these materials in Europe is strictly linked to the development of source separation and composting of the organic fraction of municipal solid waste. In Germany, for example, the capacity for biowaste treatment has increased from 183750 tons/year at the end of 1992 to 425300 tons/year at the end of 1993. This evolution offers great possibilities to biopolymers on condition that they are truly compostable and do not jeopardize the quality of the compost.

International organizations such as the American Society for Testing and Materials in connection with the Institute for Standards Research (ASTM/ISR), the European Standardisation Committee (CEN), the International Standardisation Organisation (ISO), the German Institute for Standardisation (DIN), the Organic Reclamation and Composting Association (ORCA), are all actively involved in developing definitions and tests for biodegradability and compostability (ORCA, 1994; ASTM, 1993). They have already defined, at draft level, the basic requirements for a product to be declared compostable based on:

- Complete biodegradability of the product, measured through respirometric tests like ASTM D5338-92 and the CEN proposal (Degli Innocenti et al.) or Sturm test (OECD, 1981), in a time period compatible with the selected disposal technology (some months) (ASTM, 1993);
- No negative effects on compost quality and in particular no toxic effects of the compost and leachates to the terrestrial and aquatic organisms;
- Control of laboratory scale results on full scale composting plants (ORCA, 1994).

An important driving force for the development of biodegradable materials is the recently adopted European Directive on packaging waste (European Union, 1994). Composting of packaging waste is considered a form of material recycling whereas incineration with energy recovery is considered a form of recovery with lower priority. CEN (European Standardisation Committee) has been appointed to define the compostability criteria for packaging waste.

Moreover, in Germany, Entwurf LAGA-Merkblatt M10, has recently defined the list of products suitable for composting. This list includes fully biodegradable

and compostable materials, according to the criteria of DIN FNK 103.2.3 on 'Biodegradable Plastics', based on test methods simulating watery and composting environments.

Aim of this work is to present an example of industrial development of biodegradable plastics, i.e. the starch based Mater-Bi Z grades, produced by Novamont, and an example of a specific application, the composting bags.

Composition and main features of Mater-BI Z grades

The main components of Mater-Bi grades belonging to the class 'Z' are starch and poly-epsilon-caprolactone. Minor components are natural plasticizers and compatibilizers.

Grade	Molding Technology	Use
ZI01U	Extrusion/casting/ film blowing/ injection molding	General purposes
ZF02U	Film blowing paper lamination	Diapers back-sheet,
ZF03U	Film blowing lamination	Bags, nets, paper

Under the trade mark 'Mater-Bi', Novamont produces other three classes of biodegradable materials (A, Y and V), all containing thermoplastic starch, characterized by different synthetic components (Bastioli in press; Bastioli et al. 1993a; Bastioli et al. 1993b; Bastioli et al. 1992; Mater-Bi Technical Bulletins 1991, 1992a, 1992b, 1993).

The properties of the products, in comparison with LDPE are reported below, together with the standard methods.

Compostability of Mater-bi z grades

The compostability of these materials has been demonstrated according to the common approach followed by the different International Committees.

1. Intrinsic biodegradability of the material. This is shown by standard respirometric tests simulating composting conditions (ASTM D5338-92) and watery environments such as the urban depurator (OECD, 1981; Molinari 1993; Molinari and Freschi, 1994; Freschi et al., 1994).

These tests are intended to measure the degree of mineralization, namely the transformation of the test material organic carbon into carbon dioxide. The controlled composting test simulates a composting environment and compares the biodegradation behaviour of the test material with that of microcrystalline cellulose, both at concentrations of 10% w/w. After 45 days the biodegrada-

tion of ZF02U, ZF03U, ZI01U, and cellulose was respectively of 74, 78, 100, and 85% (J.Boelens 1992a; J.Boelens, 1992b).

The OECD modified Sturm procedure is similar to ASTM D5209-91 and to the test of the Italian Decree DM 7/12/90. All Mater-Bi grades 'Z' showed after 56 days a biodegradation level quite similar to that of paper for food contact, according to what required by the Italian Decree to define an insoluble material as biodegradable. The biodegradation index was of 93% for ZI01U, 77% for ZF03U, and of about 73% for the reference paper.

2. Absence of negative effects of the test material on compost quality. This is demonstrated with terrestrial toxicity tests (Seed Germination as described by Zucconi et al. (1981), Terrestrial Plant Growth tests by OECD 207, Worm Acute Toxicity tests by OECD 208) and physical and chemical characterization of the compost obtained by controlled composting test and prepared according to the ASTM procedure 'for preparing residual solids obtained after biodegradability standard methods for plastics in solid waste for toxicity and compost quality testing'. All these tests, performed by the Belgian Company Organic Waste Systems (De Wilde and Boelens 1992) on the compost obtained by ASTM test D5338-92, demonstrated that Mater-Bi Z grades did not affect the compost quality and were not toxic. The compost obtained in presence of 10% of Mater-Bi ZFO3U, when added to agricultural soil, gave, in fact, results comparable with those for the reference compost, coming from the degradation of cellulose, and for the control compost.
3. Final cross-verification through full scale composting trials. The compostability of Mater-Bi Z grades was evaluated in composting plants located in different countries (Germany, Italy, Japan) using different technologies (static windrows, turned windrows, rotary fermenting reactors).

At the Scuola Agraria-Parco di Monza in Italy the degradation of ZI01U was tested in a yard static windrows (Favoino and Centemero, 1993). Pen caps in ZI01U were threaded with a plastic line and entangled in a plastic tubular net. Before every turning, the samples, located by sticks, were carefully removed by digging the surrounding composting mass, examined, and re-introduced in the compost. Examinations of the ZI01U pen caps were made at 20 days, 54 days and at the end of the standard cycle after 8 months. After 20 days the caps presented a strong degradation. At 54 days the phenomenon was more pronounced and the residue was constituted by fragments of 1 mm, soft and dank. At the end of the cycle, the nets were empty and only residual lumps were recoverable, stuck on the net with the typical appearance of compost. Other solid natural products in the heap, such as small pieces of wood, were yet not degraded, only the surface being slightly attacked. At the plant located in Limidi di Soliera, Modena Italy, belonging to the AMIU (Municipal Waste Treatment Department) of Modena, in a trench reactor a complete degradation of ZI01U was observed without any effect of the final quality of compost (Piccinini et al.).

At the Istituto Agrario San Michele all'Adige, Italy an experiment of source

separated collection and composting of organic fraction using 100 liters bags of Mater-Bi ZF03U, was performed (Silvestri et al.). The compost quality parameters were within the specifications of the 'green' composts.

At the Nogi-Cho Recycling Center/Japan (Yoshida and Tomori, 1993) the composting behaviour of Mater-Bi bags containing organic wastes was followed during the process. No film-like material was found in the primary compost coming out of the rotary fermenting reactor. Only some knots of Mater-Bi bags were observed at 40 days. After 84 days there was no residue of Mater-Bi bags on the 5 mm opening sieves. The results of the experiment proved the compostability of Mater-Bi films under the standard 90 days treatment of the facility.

Production and use of composting bags made with mater-bi zf03u

An example of a successful application of Mater-Bi Z grades is represented by the compostable bags. ZF03U tubular film is produced by means of a traditional film blowing equipment for LDPE. The extruder is a 60 mm one, with a spiral head of 130 mm of diameter. The blow up ratio used is of 5 and the draw ratio of 3.8. The film thickness is between 25 µm and 40 µm. The plant throughput is of 80 kg/hour (Mater-Bi Technical Bulletin, 1992b). ZF03U bags are produced with traditional bag-making machines, increasing the hot knife temperature for the longitudinal sealing and adopting semicircular sealing profiles for the impulse sealing on the bottom.

Bags of different dimensions were used by thousands of citizens in different municipalities for tests of separate collection of organic wastes to be composted. In these experimental projects paper bags were compared with Mater-Bi bags to estimate, in addition to their compostability, the in use behaviour.

Here below the results obtained in the two municipalities of Furstenfeldbruck Bavaria and Korneuburgh/Austria are shortly summarized.

Furstenfeldbruck/Bavaria (Landratsamt Fürstenfeldbruck, 1993): an experiment of separate collection of organic waste performed by 2000 inhabitants with Mater-Bi and paper bags was followed for one year. In terms of in use performances (mechanical properties in wet environment, manageability, smell barrier, transparency etc.), 55.6% of the citizens preferred Mater-Bi bags, and 28.6% preferred paper-bags. The compost quality was found in line with the German specifications for compost.

Korneuburgh/Austria (Hauer W., 1993): This experiment was similar to the trial of Furstenfeldbruck. The citizens preferred Mater-Bi bags (87%) rather than the paper bags. The compost quality was estimated good.

Today more than 20 municipalities in Europe are using Mater-Bi Z bags with positive results.

Conclusions

The future of biodegradable plastics, a new generation of materials, is closely linked to the growth of composting infrastructures which can be considered, in agreement with the European Directive of packaging waste, as effective systems of recycling. The availability of a significant amount of biodegradable packaging waste to be composted can even strengthen the value of this technology. The acceptance of biodegradable plastics in composting, however, requires specific points to be met. First of all, the definition of standards for biodegradability and compostability, to provide clear decisional tools to the Authorities and to the other parties involved in production, disposal, and composting of biodegradable goods. Then, the industrial research & development must satisfy the market requirements by offering effective and truly compostable products. The data reported in this paper, show that Mater-Bi bags for composting comply with the requirements outlined by the International Organisms working on compostability criteria definition. Furthermore, experiments of separate collection of organic wastes organized in several European Countries with Mater-Bi bags, were fully satisfactory. In conclusion these data prove that biodegradable materials are mature for a real industrial development starting from specific applications such as composting bags.

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Degradation of Naphthalene by Microorganisms Isolated from Compost

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Microbial strain capable of degraded complex polycyclic aromatic hydrocarbons are enough difficult to isolate because their scarcity in nature. With increasing PAHs contamination is possible to find sites where microorganisms had developed the mechanisms of adaptation in confront of these compounds. This is especially true for the community present in soils or sediments that have been chronically exposed to PAHs.

Our past experiences (1) showed also the possibility to increase the population with PAHs catabolic activity by composting. It could be done looking for to optimized the most important parameters to improve biological activity and using an preadapted inoculum in the starting material.

Isolation of strains

We believed that organic matter from Municipal Solid Waste could be a good starting material due its high number of microbial population and ecological nick. For these reason we chosen to use this material to prime adaptation mechanisms in microorganisms respect at naphthalene and byphenil.

For several months about ten kilograms of this material with right moisture content was feed by air in let with naphthalene and byphenil due their volatilization propriety.

Enrichment cultures were set up involving minimal salt basal medium (2) and supplemented with naphthalene and byphenil as the sole source of carbon. The enrichments were seeded with the PAH contaminated samples mentioned above. The enrichment cultures were monitored for the presence of microorganisms and subcultured into fresh medium when significant quantities of microorganisms were obtained. After four such subcultures the cells were plated onto solid medium and the PAH was applied as an ethereal solution to the surface of the agar. Colonies appearing were purified on the same medium and then stored at -80°C.

Characteristics of strains

Representative strains resulting from these isolation experiments are listed in Table 1.

The strains 2NR, 10N1 and C4B was chosen for further study because of the strong growth and due their different phenotypes.

The strains were identified to the genus level using the Oxi/Ferm Tube II (Roche) system. The presumptive species name were obtained by further analysis as indicated on the system and from Bergey's manual of systematic bacteriology (vol.1). The strain 2NR was identified as *Pseudomonas aeruginosa*, 10N1 as *Pseudomonas putida* and C4B as *Pseudomonas putrefaciens*; their characteristics are reported in Table 2.

In order to confirm that the strains could completely degrade Naphthalene, several experiments were performed with non-radiolabeled substrates following carbon dioxide evolution (3).

Respiration tests

Microbial inoculum for Biometer flasks (Figure 1) was a suspension of cells in mineral salt basal medium. The optical density at 600 nm was adjusted around the value of 0.4.

The cells of strain test were growth on suitable broth in order to produce the same definite sequential-induction pattern.

2NR and 10N1 were growth on mineral salt basal medium plus Succinate (20 mM) and Naphthalene (2.5 mM). C4B had Biphenyl instead Naphthalene as induction conmpounds. The two water-insoluble PAH was added trough a N,N Dimethylformamide stock solution (100 mg/ml).

The cells growth at 30 °C for 36 hours were harvested by centrifugation, washed three times with Na-K buffer 50 mM, pH 7. The cells were resuspended in 300 ml of mineral salt basal medium and adjusted at the value of 0.4 of optical density (600 nm).

50 ml of this sospension was share in each of the four biometer flask; two were used as a control and the other as a repetition for degradation test. The biometer flasks were incubated in rotary shaker at 30°C. Carbon dioxide was evaluated, by titolation of the KOH with HCl normex, at different time using some attention for external CO₂ contaminations.

Table 1 Screening of the activity of the isolated strains

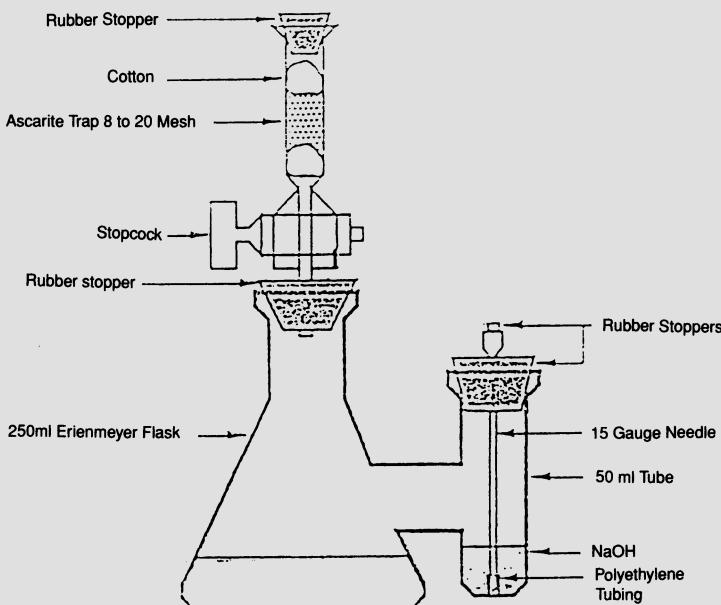


Figure 1 Biometer flask

GC mass analysis

To identified intermediates of naphthalene catabolism, 250 ml of a suspension of cells of the strain 2NR in mineral salt basal medium (O.D.600 nm: 0.4) was added with naphthalene (1 mg/ml) and incubated for 290 hours at 30°C with agitation. At different interval time, 1.5 ml of the culture was take out for samples. After centrifugation 1 ml of supernatant was acidified with HCl 1 N to pH 2 and then extracted with ethyl acetate. The extracts were evaporated to dryness. The residues were analyzed with GC-ITDMS either directly or derivatized with diazomethan to produce methylated compounds. The GC instrument was a Varian 3400 gas chromatograph associated with an ion trap mass spectrometer Varian Saturn (Ion Trap Detector ITD). Compounds separation was achieved by using a fused silica capillary column DB-1701 (J & W, Folsom, CA, USA) (30 m x 0.25 mm I.D., 0.25 µm film thickness) using the following condiction: Helium as carrier gas (1 ml/min), the injection was in split mode (1:20, v/v, ratio); the column temperature was 70 °C increased to 270°C at 10 °C/min and maintained at 270 °C for 10 min. The temperature of injector, transfer line and manifold were 270°C, 270 °C and 170 °C respectively. The filament emission current was 10 mA and an electron beam of 70 eV was used for electron impact ionization (EI).

The same method was used looking for intermedie of 2NR catabolism starting from catechol, salicylic acid and gentisic acid which important intermedies of the naphthalene degradation pathway by microrganisms (Scheme 1).

HPLC analysis

The target compounds reduction and metabolites production was follow by HPLC analysis during 2NR growth as explain for GC-ITD-MS method.. Samples were extracted with ethyl acetate after acidification to pH 2–3 with phosphoric acid. The ethyl acetate was evaporated and the residues were dissolved in methanol (4). The instrument was a liquid chromatograph Varian 5040 (CA, USA) with UV–VIS detector Varian 50 (λ of analysis was 290 nm). The column was 5 μ m a Spherisorb C18 (15 cm x 4.6 I.D., Phase Sep, Deeside, UK). The solvent system was of methanol (A) and a mix of water-methanol-acetic acid 80:20:3 respectively (B). Starting from 100% B to 20 % B a gradient of 1 ml/min was applied.

Results and discussion

The characteristics of the strains showed in Table 1 induce us to look for different aspects of three strain mentioned above. In particular, the strain 2NR was positive at the naphthalene dioxygenase tests (4) and at the antibiotic test. These two results associated at the lower growth of the strain with higer concentration of Streptomycin and Tetracycline could indicate the presence of plasmid coding for naphthalene degradation as reported in bibliography for other strains (6, 7, 8 and 9). Strain 10N1 and C4B were negative for presumptive presence of plasmids coding for naphthalene degradation.

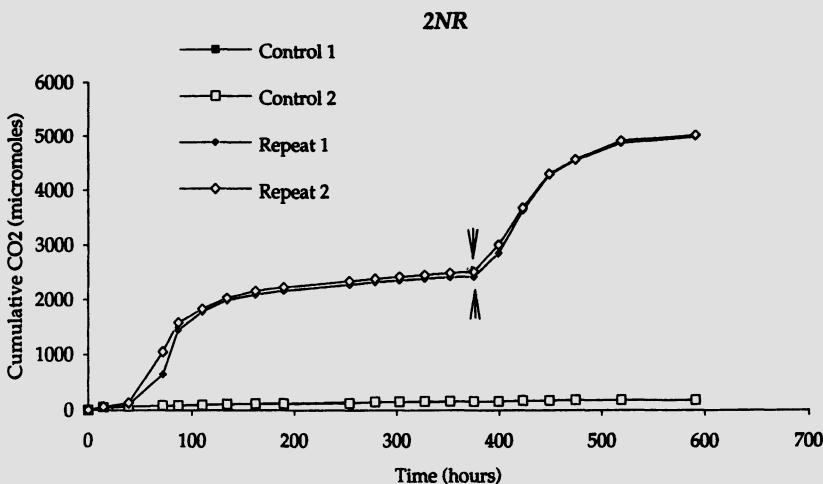


Figure 2 CO₂ behaviour from 2NR growth on naphtahalene; Control: suspension of cells Control 2: suspension of cells + 500ml Dimethyl formamide Repeat 1: suspension of cells + 500 ml naphtahalene/Dimethyl formamide Repeat 2: suspension of cells + 500 ml Naphthalene/Dimethyl formamide

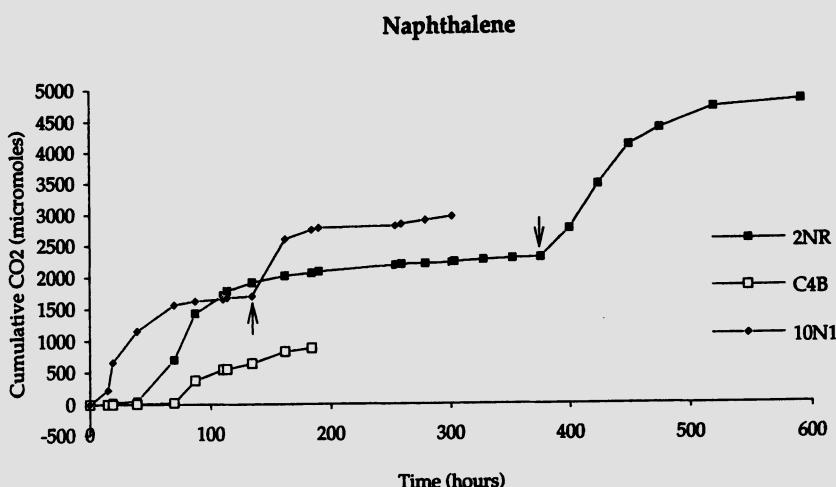
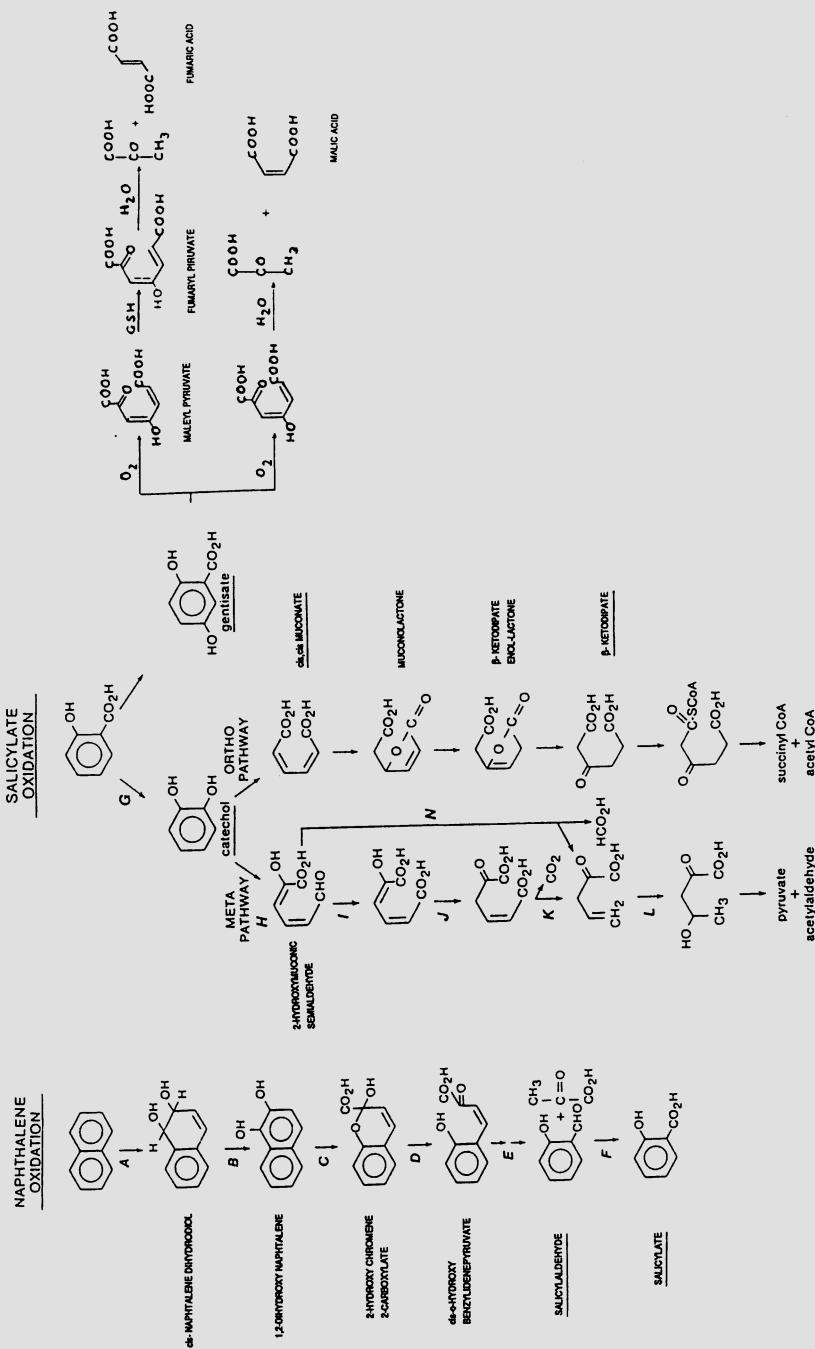


Figure 3 Comparison among CO₂ behaviour of the different strains (arrows show the time where new naphthalene was added)

The respiration results give further information on the difference among the strains; the method was applied to follow the strain's growth on naphthalene: Fig. 2 show the good reproducibility of the no-quantitative method either for the controls that for the repetition flask. A confront among the different strains behaviour on naphthalene was reported in Fig. 3, where, for strain 2NR and 10N1 at time 350 (h) and 137 (h) respectively, was added new substrate to confirm its degradation. The naphthalene degradation pathway find in bibliography (Scheme 1) give us idea to use some metabolite as substrate for biometer flask method in order to know more information of degradation route of our strain. In particular 2NR (Fig. 4) and 10N1 (Fig. 5) could be compared due the same naphthalene induction (C4B inductor was byphenil). The growth of the two strains on salicylic acid, gentisic acid and catechol was different: 2NR used all three compounds instead strain 10N1 growth only on salicylic acid. Seeing the 2NR behaviour may be hypothesize that gentisic acid pathway is different from catechol and salicylic acid pathway. Infact the initial exponential growth (quickly gentisic acid and later the other two) changed when further addition of substrates was added (quickly for catechol and salicylic acid, later for gentisic acid). This mean that gentisic acid pathway could be constitutive (chromosomal coded) whereas salicylic acid and catechol could be inductive pathway (plasmid coded).

To verify this hypothesis and to know the 2NR naphthalene pathway, studies to isolate and identify possible intermedies were performed by HPLC and GC-ITD-MS.

The disappearance of starting compounds and the production of methabolites during the growth of the microorganism was follow by HPLC analysis confirming naphthalene (non-quantitative), gentisic acid, salicylic acid and catechol degradation.



Scheme 1: Bacterial metabolism of naphthalene (underlined compounds were identified in 2NR naphthalene degradation pathway)

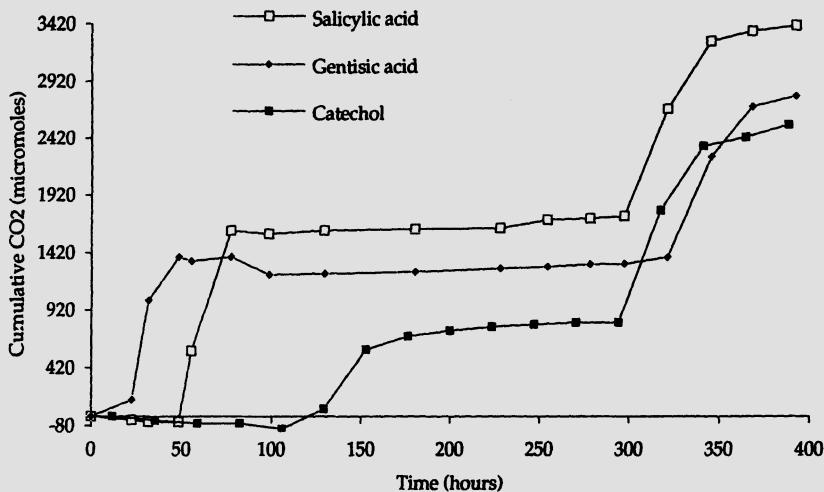


Figure 4 Comparison among CO₂ behaviour of 2NR strain growth on catechol, salicylic and gentisic acid.

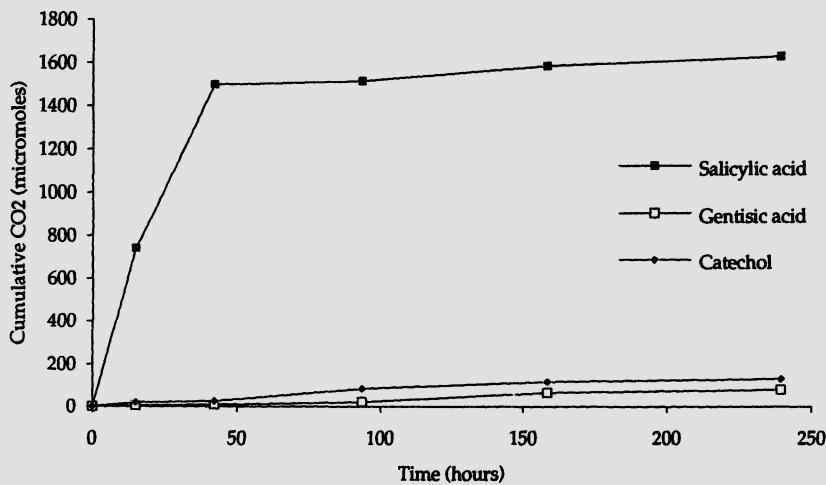


Figure 5 Comparison among CO₂ behaviour of 10N1 strain growth on catechol, salicylic and gentisic acid.

The qualitative identification of intermediates was done by GC-ITD-MS analysis looking for retention time and mass spectre of standard or only computer library mass spectre when standard of the compound was not available. Starting from naphthalene as substrate, after 2 hours (Fig. 6) could be identified two compounds, salicylaldehyde (Fig. 7) and catechol (Fig. 8 and 9); after 6 hours (Fig. 10) other three compounds were found: salicylic acid (Fig. 11) and gentisic acid (Fig. 12). The presence of gentisic acid mean that at least two pathway for naphthalene

degradation are involving in the same time: the ortho cleavage pathway and the gentisate route.

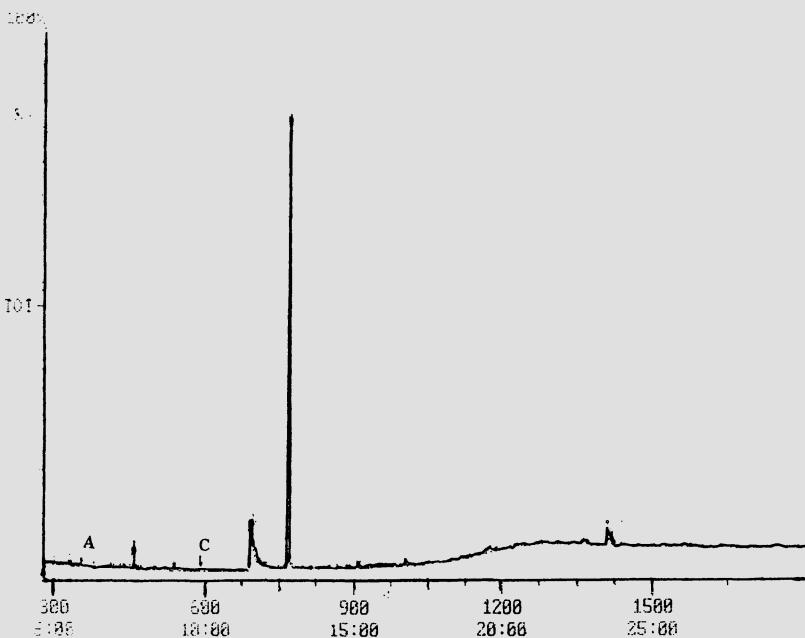
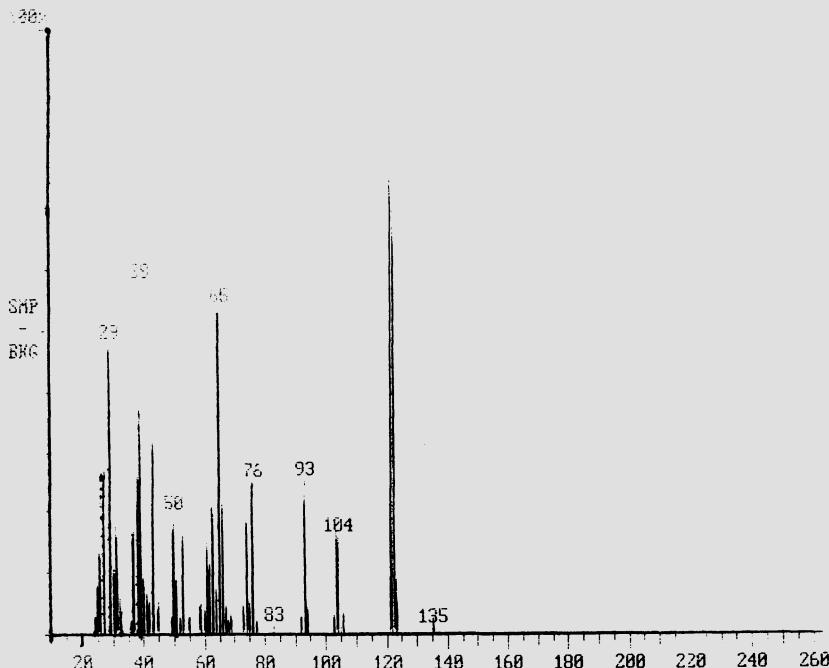


Figure 6 GC-ITDMS chromatogram obtained after two hours of 2NR growth starting from naphtahalene; A: salicylaldehyde C: catechol



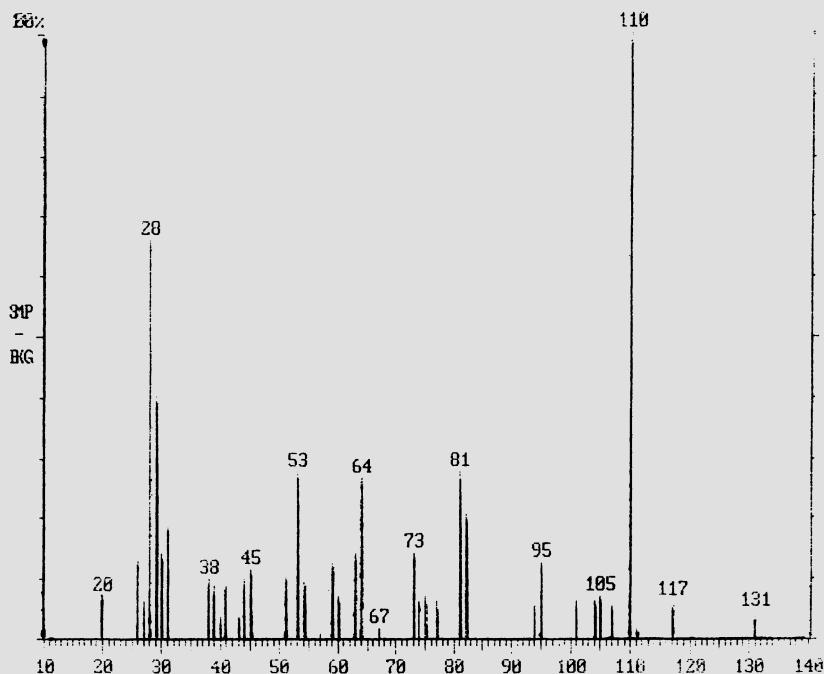


Figure 8 Mass spectra of catechol (C)

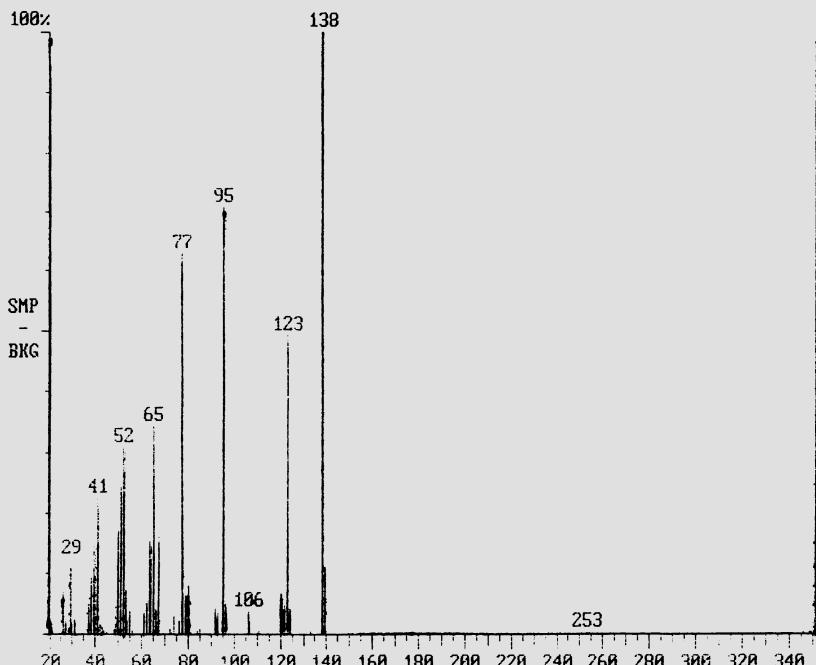


Figure 9 Mass spectra of catechol dimethyl ester (E)

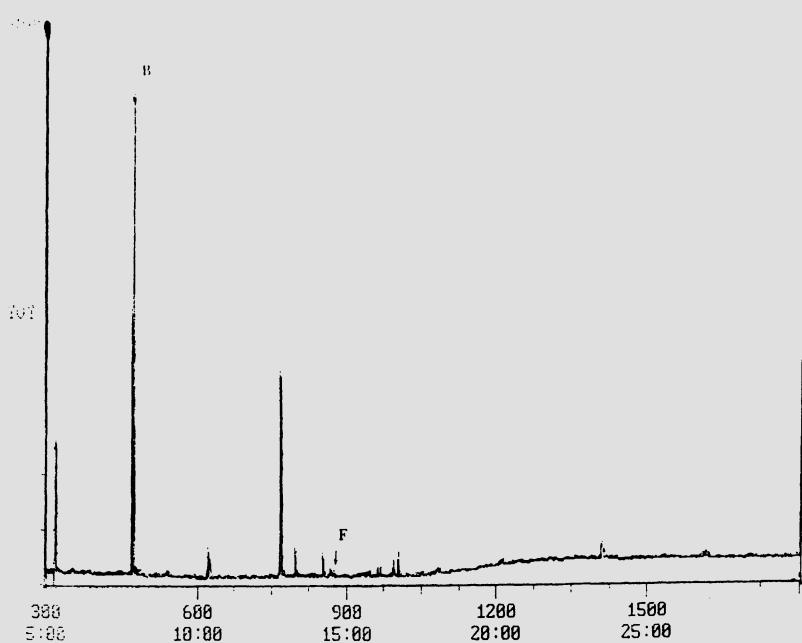


Figure 10 GC-ITDMS chromatogram obtained after six hours of 2NR growth starting from naphthalene B: salicylic acid methyl ester F: gentisic acid methyl ester

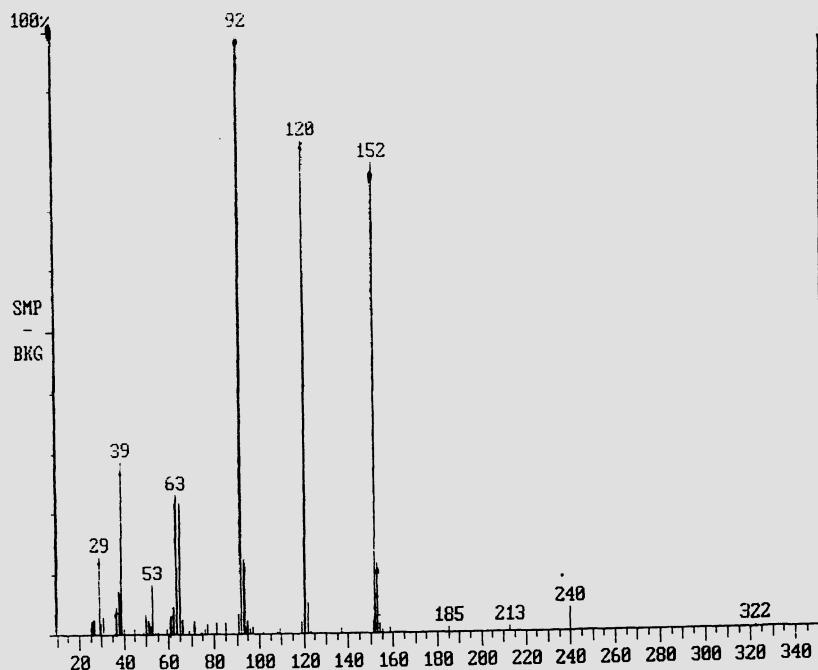


Figure 11 Mass spectra of salicylic acid methyl ester (B)

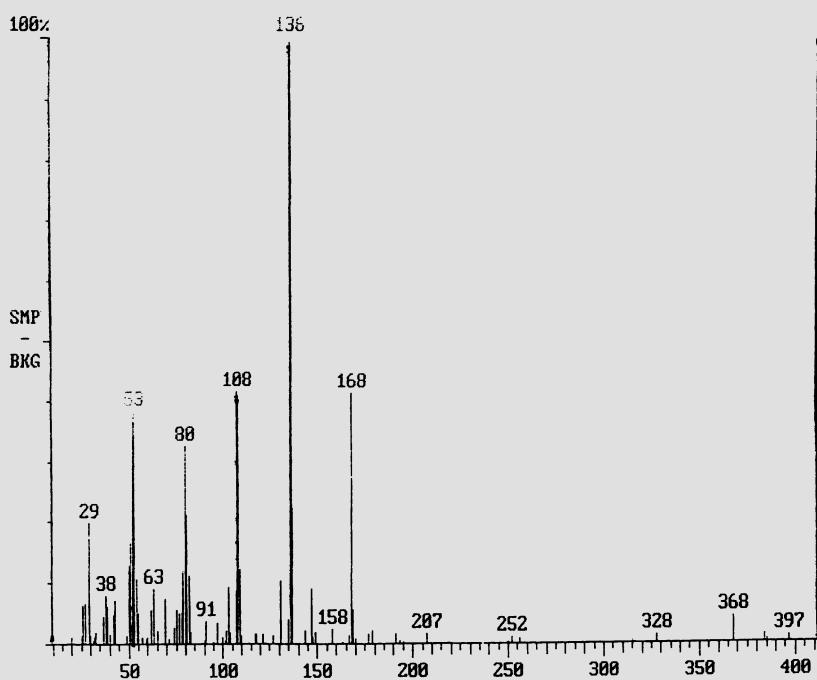


Figure 12 Mass spectra of gentisic acid methyl ester (F)

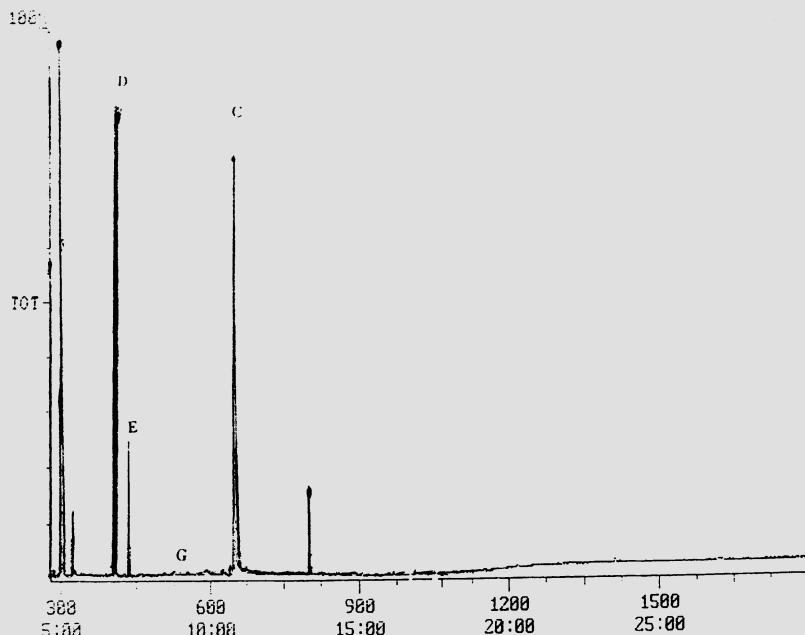
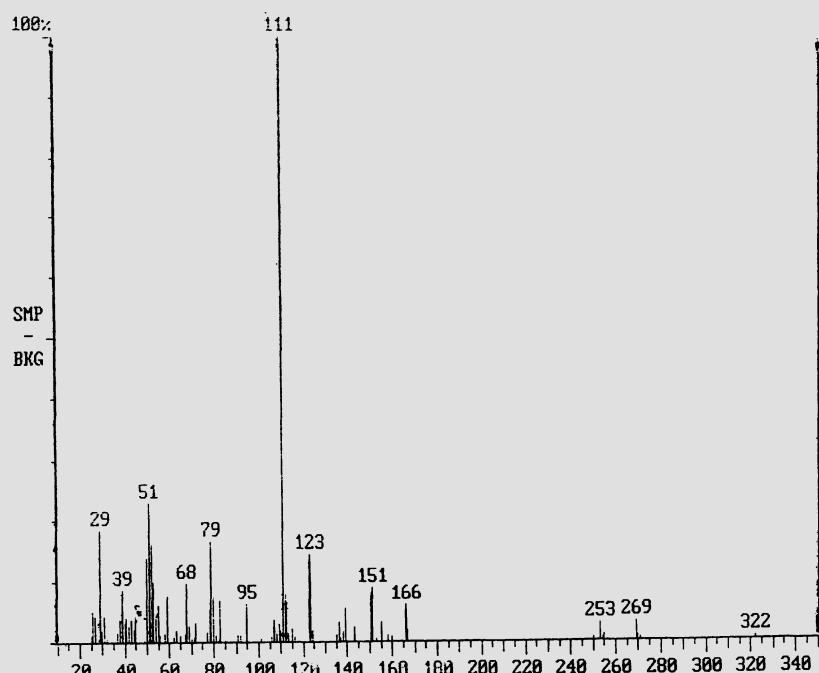


Figure 13 GC-ITDMS chromatogram obtained after eighteen hours of 2NR growth starting from catechol; D: catechol methyl ester G: cis, cis muconic acid dimethyl ester

Table 2 Morphological and biochemical characteristics of some strains

	2NR	10N	C4B
Morphology	Coccorods	Coccorods	Rods
Gram	-	-	-
Oxidase test	+	+	+
Oxi/Ferm tube			
Ana-Glucose	-	-	-
Arginine	+	-	-
Lysine	+	+	+
Lactose	-	-	-
N2	-	-	-
Sucrose	-	-	-
Indole	-	-	-
Xylose	+	+	+
Aer-Glucose	+	+	-
Maltose	-	-	-
Mannitol	+	-	-
Phenyl-Alanine	-	+	+
Urea	+	+	+
Citrate	+	+	+
Growth at 42°C	+	n.d.	n.d.
	<i>Pseudomonas aeruginosa</i>	<i>Pseudomonas putida</i>	<i>Pseudomonas putrefaciens</i>

**Figure 14** Mass spectra of cis, cis muconic acid dimethyl ester

Always with cultures of strain 2NR but starting with catechol was possible after 18 hours (Fig.13) point out an other compound cis,cis muconic acid (Fig. 14) to confirm the ortho cleavage pathway.

Culture of 2NR starting with salicylic acid confirmed some of the above identified compounds, instead for cultures with gentisic acid was not possible identified intermedies due their standards were not avaialble.

Conclusion

From this work is possible say that:

- the organic matter from municipal solid waste is a good source of heterogeneus microrganism which are sensible at the adptation method applied to select PAH degrading microrganisms;
- the biometer flask method has a good reproducibility when applied in pure culture and its high performance permit to have important indication on the possible metabolic pathway of the target compounds;
- the isolated strains show catabolic proprieties not only on the inductor compounds but also on other PAH;
- the strain 2NR show at least two pathway for naphthalene degradation: the ortho pathway of catechol and gentisate pathway.

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Composting and Selected Microorganisms for Bioremediation of Contaminated Materials

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Environmental contaminants such as the monocyclic aromatic group and polycyclic aromatic hydrocarbon (PAH) group can be found in practically all industrial areas. Pollution by these compounds are primarily associated with the processing, combustion, and disposal of fossil fuels. Industrial effluents from coal gasification and liquification processes, waste incineration, coke, carbon black, coal tar, and other petroleum-derived products are all major sources of contamination.

Bio-remediation is emerging as a proven technology to remove xenobiotic compounds from the environment. Advantage in using microorganisms for environmental clean-up include their ability to degrade a wide range of compounds, their ability to degrade those compounds to below detectable limits, the ease with which microorganisms can be handled and applied to a contaminated sites, and their cost effectiveness.

Among the different technologies applied for bio-remediation (1), composting may be described as a system with double potentiality: treatment system in bioreactor and treatment system in-situ. The first need to move the higher quantity of contaminated materials from polluted area to a bioreactor for composting. The replacement of its original site with cleaned material, enriched with higher number of microorganisms with catabolic properties, can express their activity at the remained contaminated soils in the polluted area.

As regards composting as a treatment system to convert a waste to a processed residue acceptable for disposal and/or productive purposes, a project was carried out to evaluate the bio-remediation of ‘creosote’-contaminated materials.

The fate of 13 most abundant toxic compounds of creosote contaminated soils mixed with organic matter from municipal solid waste was followed during fifteen days of composting (2). The laboratory apparatus consisted of three incubators within three independent reactors having a working volume of 14 liters. The temperature set point (45°C) was regulated automatically by air flow through the mass, while samples for the chemical and microbiological analyses and the correction of moisture content during the 15 days of composting were taken at days 0, 5, 10 and 15. The values of mass balance parameters (3) permit calculation of the thirteen most-important creosote compounds, herein expressed in terms of the per-

centage reduction compared with the initial concentration (Table 1). To understand the ratio between the toxic compounds elimination by biological activity, chemical-physical trasformation and volatilization during composting the recovery comparison among different points of the composting apparatus are showed in Table 2. Both tables show as composting is an efficient technology for soil clean up because it removes large quantities of toxic compounds in a short time and high efficiency was also achieved for higher molecular weight compounds. From this experience to verify the microrganism activities on creosote compounds, different microrganism groups present in organic matter (eterotrophic bacteria, gram positive non-sporing rods, aerobic and/or facultatively anaerobic endospore-forming rods, anaerobic endospore-forming rods, gram positive cocci 'Strepto', gram negative rods and coccooids: oxidase positive, oxidase negative lactose positive and negative) were grown on selective and/or non-selective media. After incubation, some plates were scraped with water solution of tween 80 (2%). The microrganisms were harvested by centrifugation at 8000g for 15 minutes and three time washed with 2.5 mM phosphate buffer, pH 7. A suspension of the cells of each groups were inoculated in 500 ml of mineral-salt- (KH_2PO_4 , 200 mg/L; K_2HPO_4 , 800 mg/L; NH_4NO_3 , 100 mg/L; $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, 100mg/L; $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$, 100 mg/L; FeCl_3 , 10 mg/L) –water emulsion of aromatic compounds (33, 34, 35) and incubated in a rotary shaker (New Brunswick) at 30°C and 250 rpm. The biodegradative activities were performed by GC analysis. Target compounds were estimated after ten days respect to the control at the same time incubated of a no-inoculated mineral-salt-water emulsion of aromatic compounds. The microbiological results showed in Figure 1 point out the presence of high number of different groups during composting. Their values confirm the possibility of a large biodegrading potentiality of the microbial community respect at the other elimination characteristics of the toxic compounds by composting. The activity of some of these groups, evaluated by the above PAH-water-emulsion flask method, are rapresented in Table 3. The disappearance of the most compounds respect at the control, may depend from high production of enzymes as oxygenase to attach the aromatic compounds (Scheme 1), bio-surfactant, as molecules of Scheme 2, to make more avaialible the organic compounds for microrganisms and/or synergic activity of heterogenic microbial population. To verify the presence in the inoculated flask of single strains able to PAHs degradation, enriched cultures were set up involving a minimal salt basal medium (4) and supplemented with different polycyclic aromatic hydrocarbon as the sole source of carbon. Isolation and characterization of the strains was performed as described in reference (5). Among the numerously strains same were tested for CO_2 evolution derived from aromatic hydrocarbons measured by a non-radioactive method (6). The results show as single strain can use same different PAH as source of carbon and energy. Their different efficiently, valuable with the quantity of CO_2 produced, may be relatively important because same time is more important produce the first attach at the aromatic molecule than to arrive to CO_2 with a single strain. A particular organism may possess the correct catabolic ability to catalyze the trasformation of one compound but then may not

possess the enzymatic system for further degradation. In composting populations these may be supplied by a second organism and so on, so that communities of organisms possessing complementary catalitic capabilities are established and the compound degraded.

OXYGENASES



Scheme 1 Oxigenase mechanisms on generic substrate (R)

Growth behaviour on PAH of three out of twenty different isolated strains are represented in figure 2, 3 and 4 (for strain 2NR see also reference 5). Naphthalene was the induction compound for 2NR and 10N1 while biphenyl for C4B. The importance of induction compound is the activation of all enzymatic pathway coded in plasmid or chromosomal genes. About naphthalene microbial degradation different pathways were establish. Organization and physical map of naphthalene genes encoding the enzymes for the 11 steps of naphthalene oxidation have been mapped on plasmid NAH 7. Looking for this plasmid in our strains, positive results were obtained for 2NR while was negative for 10N1 and C4B: indolo test (7) point out the presence of naphthalene oxigenase encoding in genes *nah ABC*. Presuntive presence of catechol 2,3 doxygenase genes (*xyl E*) was supposed be present on the three strain due the yellow color from 2 hydroxy muconic acid 6 semialdehyde production (8). About plasmid presence, only microorganism group '2' (5) confirmed the presence of R factor as antibiotic resistence plasmid encoded, but extraction procedure analysis (9 and 10) didn't show them yet.

Studies in progression on biodegradation of higher molecular weight compouds give idea that composting may be an interesting technology because it is a versatile process at both physical and microbial levels. Degradation of hydrophilic and hydrophobic contaminants may occur due the physical attributes of the starting materials depending from the composition of the community and its adaptative response to the presence of hydrocarbons. During composting the mechanisms of adaptetion and genetic changes resulting in a net increase in the number of hydrocarbon utilizing microorganisms and in the pool of hydrocarbon catabolizing genes within the community.

STRUCTURES OF SOME BIOSURFACTANTS	
POLYSACCHARIDE	
GLYCOLIPID	
FATTY ACID	$\text{CH}_3(\text{CH}_2)_N\overset{\text{O}}{\underset{\text{H}}{\text{C}}}-\text{OH}$
PHOSPHOLIPID	<p style="text-align: center;">$\text{R} = \text{alkyl groups}$</p>
LIPopeptide	

Scheme 2 Structure of some biosurfactants

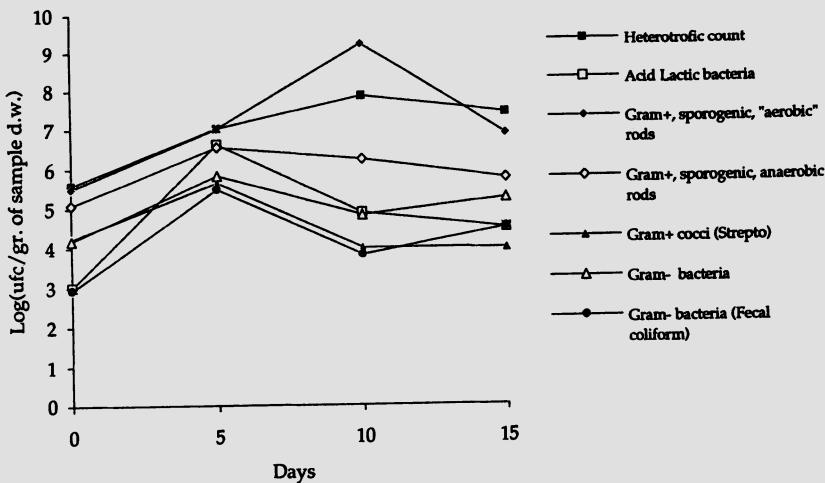


Figure 1 Microorganisms behaviour during composting

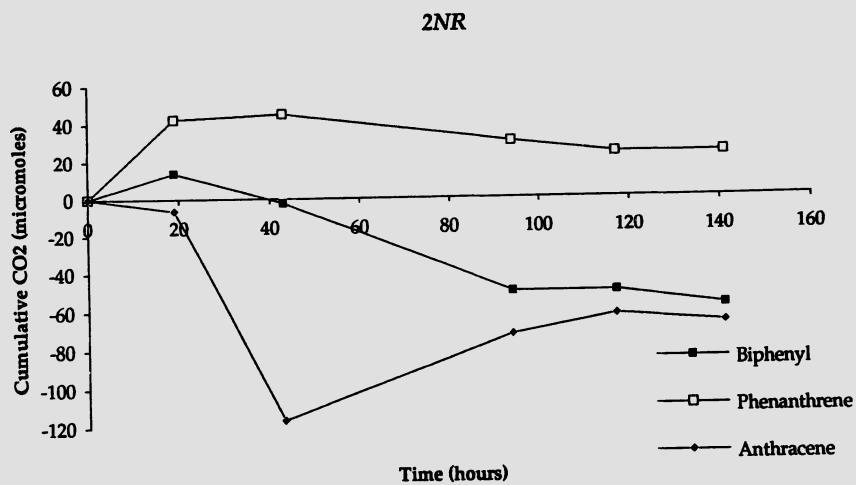


Figure 2 CO₂ evolution from strain 2NR measured with biometer flask on different substrates

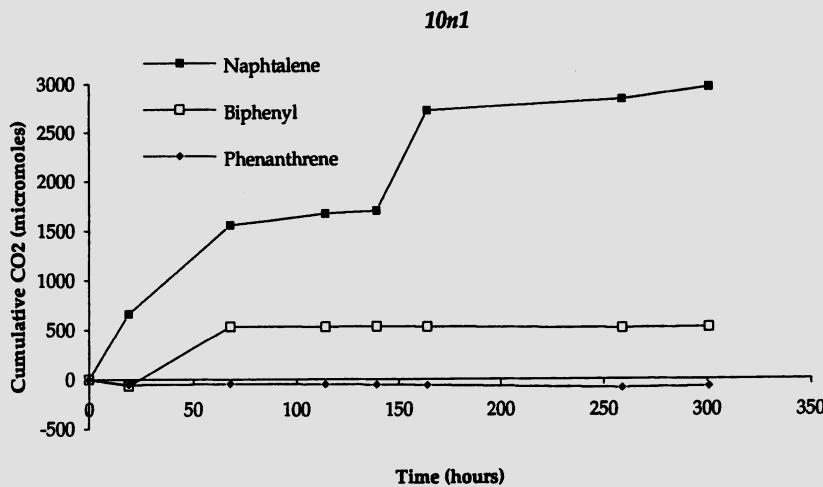


Figure 3 CO₂ evolution from strain 10N1 measured with biometer flask on different substrates

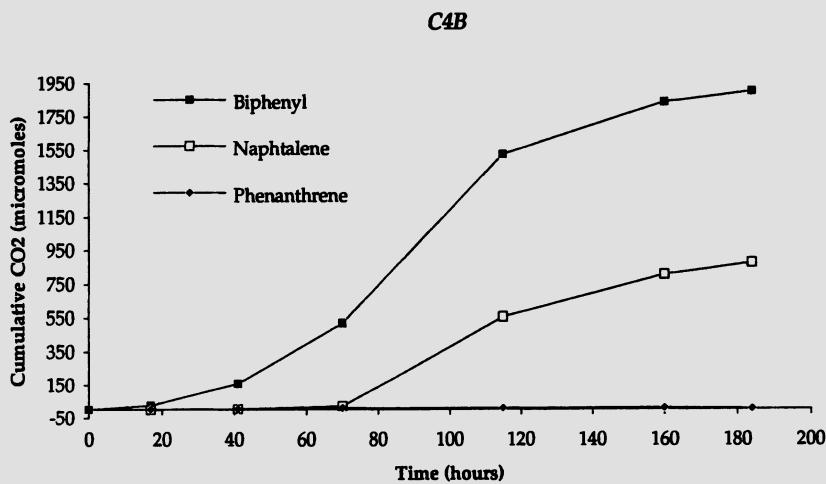


Figure 4 CO₂ evolution from strain C4B measured with biometer flask on different substrates

Table 1 Percentage reduction of each target creosote compound according to removal route (average of the three chambers)

	Recovery from Condensate plus Carbon trap	Recovery from samples	Reduction due to chemical, physical and biological biological activities	Total reduction
Naphthalene	7.990	0.142	90.40	98.53
2-Methyl Naphthalene	3.545	0.317	96.10	99.96
1-Methyl Naphthalene	5.330	0.609	94.01	99.95
Biphenyl	31.502	0.381	68.12	100
Acenaphthene	53.653	4.007	39.90	97.56
DibenzoFuran	9.012	2.502	87.86	99.38
Fluorene	6.539	2.909	89.18	98.63
Phenanthrene	0.601	2.734	94.64	97.98
Anthracene	1.525	5.184	90.98	97.69
Fluoranthene	0.114	6.797	85.76	92.67
Pyrene	0.069	5.454	90.06	95.58
Benzo(a)Anthracene	0	10.711	70.92	81.63
Chrysene	0.015	12.428	74.90	87.35

Table 2 Percentage reduction of each target creosote compound during the three composting phases (average of the three chambers)

Composting	A-B Period (day)	C-D 0-5	E-F 5-10	10-15
Naphthalene		93.33	5.23	-0.03
2-Methyl Naphthalene		94.19	4.71	1.06
1-Methyl Naphthalene		90.08	7.89	1.97
Biphenyl		65.48	33.34	1.17
Acenaphthene		17.40	69.93	10.23
DibenzoFuran		67.57	29.31	2.48
Fluorene		67.44	28.01	3.18
Phenanthrene		75.90	18.87	3.21
Anthracene		57.14	30.32	10.23
Fluoranthene		45.47	37.94	9.25
Pyrene		55.14	32.64	7.80
Benzo(a)Anthracene		34.18	22.15	25.30
Chrysene		27.39	18.80	41.16

Table 3 Percentage recovery of each target compound after 10 days of incubation (average of two tests) in Elmeyer fask at 30 °C and 150 rpm

Recovery	Recovery from control	Recovery from control	Recovery from control	Recovery from control
Naphthalene	126	n.d.	n.d.	0.5
2-Methyl Naphthalene	116	1.7	1	1.5
1-Methyl Naphthalene	119.9	n.d.	8	n.d.
Biphenyl	127	56.36	24.8	n.d.
Acenaphthene	116.9	n.d.	n.d.	n.d.
DibenzoFuran	106.7	n.d.	n.d.	n.d.
Fluorene	138.1	n.d.	n.d.	n.d.
Phenanthrene	81.3	n.d.	n.d.	n.d.
Anthracene	96.7	4.3	n.d.	n.d.
Fluoranthene	100.67	n.d.	n.d.	n.d.
Pyrene	175.8	n.d.	n.d.	n.d.

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Bioremediation of PAH-Contaminated Soil

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Abstract

Biodegradation of PAH-contaminated soil was studied by a slurry reactor test and a soil column test. The initial total concentration 1000 ppm PAH soil was decreased to 50...100 ppm in the slurry reactor in 6 weeks. In the soil columns the concentration was decreased to 120...770 ppm in 4 weeks. Addition of coniferous tree bark enhanced degradation significantly in the soil column tests, but not in slurry reactor tests. Use of inoculants had only a slight positive effect in slurry tests; the effect was even negative in the degradation of 5–6 ring compounds in some soil column tests.

The experiences were applied to practical scale by using a composting method where bark is used as a bulking agent. High moisture content is maintained in the heap and the leaching water is circulated until the target concentration is reached. The different functions of the bark addition is discussed.

Introduction

Contaminated soil remediation is a growing environmental sector also in Finland. In a recent study by the Ministry of the Environment a total of 10,000 contaminated sites was estimated to exist in Finland. Of these 1200 are assessed to need remediation. Biotechnical treatment is considered to be suitable for 20...25% of the volume of the contaminated masses. (Ministry of the Environment, 1994).

A consortium of Finnish companies has established a method of biotechnical treatment of soil contaminated by creosote-oil or other wastes containing high concentrations of polycyclic aromatic hydrocarbons (PAHs). The method is based on laboratory scale studies (Silvennoinen H. et.al. 1994) and it is now applied to four practical cases in Finland.

Laboratory-scale biodegradation tests

The bioremediation technique was studied by two main methods in laboratory scale.

A *slurry reactor* test was used to study enhanced degradation of indicator PAH components in tests lasting 4–6 weeks. The method was inspired by reports by Linz D.G. et.al. (1991), Müller et. al. (1991) and others. Four 1000 ml glass reactors were equipped with aeration (1 liter/min) and mechanical agitators. The reactors were used in room temperature and protected from daylight with a aluminium foil. Neutral pH was maintained. NPK-, S-, Mg- and Ca-nutrients were added. A sample of 100 g of the contaminated soil was agitated in each reactor for 4–6 weeks. After the end of the test the residual concentrations in the slurry solids and the water phase were analyzed. Also the adsorption losses were assessed by rinsing the reactor with chloroform and analyzing the eluate.

The effect of carbon source addition was studied (10 % ground bark). Also the effect of a surface-active detergent was studied.

Another serie of tests was accomplished by using glass columns filled with the test material. The *soil column* was washed with a nutrient/buffer solution which was circulated through the soil in room temperature for 4–6 weeks.

The effect of using 20 vol-% grounded bark or acetate (3 g / 400 g soil) as carbon source was studied. Also the effect of microbial inoculation of the soil was studied. A mixture of a pure culture growing on phenanthrene and an enriched mixed-culture from creosote contaminated soil was used as inoculum.

Solid phase samples were Soxhlet-extracted by toluene and the water samples with chloroform. 21 indicator PAH-compounds were analysed using ISO-standard draft 13877 with 1,3,5-triphenylbenzene as an internal standard. Concentrations were detected by GC with a detection limit of 1 $\mu\text{g}/\text{kg}$. The absence of other PAH-compounds was verified by scanning the mass-spectrum 20–550 with a detection limit of 500 $\mu\text{g}/\text{kg}$.

Results

Slurry reactor tests

The changes in concentrations of the 21 monitored PAH compounds in one of the samples are shown in table 1.

The initial PAH concentration of the soil sample (sandy soil with 1,3% organic matter) was about 1000 mg/kg.

Of the sum concentration:

- 20% consisted of 2-ring compounds,
- 70% of 3–4 ring compounds,
- 5,4% 5–6 ring compounds and
- 4% of heterocyclic compounds.

Table 1 PAH concentrations in slurry reactor test

PAH compound	Initial conc.	Concentration after 4 weeks		Column no2	Column no3	Column no4	Column no5
		Column no 1	ppb		ppb	ppb	ppb
2-ring PAHs							
acenaphthene	21100	137215	65	109772	52	2381	1
benz(a)anthracene-7,12-dione	2108	2318	110	1580	75	750	36
naphthalene	1994	5085	255	4247	213	906	45
Sum 2-ring PAHs	215202	144618	67	115599	54	4037	2
% of Total PAHs	21.8	19	20	3	3	6	8
3-4 ring PAHs							
anthanthrene	<1	<1	<1	<1	<1	<1	<1
anthracene	103229	87745	85	67099	65	5208	5
1,1,2,2-benzanthracene	50019	39014	78	33012	66	1119	2
chrysene	61148	58885	96	37912	62	14967	24
4H-cyclopenta(def)phenanthrene	32087	39145	122	28236	88	22659	71
4,5-methylenephenanthrene	<1	<1	<1	<1	<1	<1	<1
fluoranthene	146763	80719	55	46964	32	15202	10
phenanthrene	191206	86043	45	66922	35	1418	0
pyrene	93197	105313	113	71762	77	26346	28
truxene	<1	<1	<1	<1	<1	<1	<1
Sum 3-4 ring PAHs	677649	496865	73	351908	52	96920	14
% of Total PAHs	68.5	65	61	80	80	61	60

In the slurry reactor tests a 90–95% reduction in the total PAH concentration from 1000 ppm to 50...100 ppm was achieved in 6 weeks in all the vessels.

Addition of ground tree bark (reactors 3 and 4) had a positive effect on the degradation rate of total PAH's, but the effect on the 5–6 ring PAH degradation was negative compared to the control (reactor 1).

The use of a detergent (reactor 2) increased degradation by about 30%. The effect was most notable on the 3–4 ring components. The best impact on the total PAH decrease was achieved in the vessel with both carbon addition and detergent (reactor 4).

The degradation rate of the 5–6 ring compounds was only moderate with 40...70% of the initial concentration remaining. Addition of carbon and detergent favored the degradation of 2–4 ring compounds.

Adsorption losses were 88...1122 µg/vessel, which corresponds to 0,3...4,8% of the end content of the soil sample. Evaporation losses were not studied. They were presumed to be low on the basis of former research data (Müller 1993).

Soil column tests

The results of the soil column tests after recycling the nutrient solution for 4 weeks are shown in table 2.

With no addition of extra carbon source only a 20% reduction of the initial total PAH-concentration was achieved. Microbial inoculation had a small positive effect on the degradation of 2–4 ring PAH's.

Addition of bark had a strong positive effect with only 12% of the initial concentration left after 4 weeks. Addition of bark resulted also in degradation of the resistant 5–6 ring PAH's in contrary to the findings in slurry reactor tests. However, when adding both bark and inoculum the positive effect was modest. Addition of an easily available carbon source (acetate) was not as effective as when using bark. Specially the microbial attack on the 5–6 ring compounds was hindered.

The residual PAH concentration in the recycled nutrient solution correlated with the concentration in the corresponding soil sample. The total amount of PAHs in the water phase was 9...28% of the remaining content in soil. This result differs notably from the finding in the slurry reactor tests, where the PAH concentration in the water phase was below detection limit.

Discussion

According to the results, PAH compounds can be degraded in a slurry reactor or by composting, which has been proved also in various other studies (Freeman, H.M., Sferra, P.R. 1991, Sayler, G.S. et.al. 1991, Pollard, S.J.R. et.al, Seman, P-O., Svedberg, R. 1990, Civilini, M. 1994 etc).

Interesting findings in our studies were that:

- coniferous tree bark enhanced the degradation in the soil leaching method, but not in the slurry tests.
- use of inoculants had only a slight positive effect in slurry tests; the effect was even negative in the degradation of 5–6 ring compounds in some soil column tests
- in the slurry reactor the remaining PAH concentration in the water phase is very small, but it can be quite significant in soil leaching procedures.

Some contradictory results were achieved in the soil column tests with negative reductions for some PAH-compounds. For 2-ring compounds the explanation is probably metabolic reactions. For the high increase in the concentration of several 5–6 ring compounds one explanation could be a change in their adsorption to the soil matrix and thus an increase in their extractability during composting.

The conclusion of the studies was that creosote can be degraded by composting with the following conditions:

- the soil must be effectively mixed with a suitable bulking agent
- a high moisture content must be maintained; this means that the leaching water must be collected and recycled or treated
- the degradability of the 5–6 ring PAHs might be enhanced by adding a detergent, but the detergent must be selected so that it does not compete as a substrate with the PAH compounds.

Bark addition seems to be very beneficial. It can have the following effects:

- it increases porosity in the mixture enhancing aerobic degradation
- it increases the moisture retention capacity of the soil
- it provides a large area for microbes to attach themselves on
- it provides a matrix for efficient PAH adsorption
- it provides the microbes with a co-substrate; not a too easily available carbon source (see eg. Keck et.al 1989).
- bark contains a high percentage of aromatic compounds some of which could act as co-substrates for PAH metabolism (eg. Fengel D., Wegener G. 1984).

Practical applications

Remediation project in Helsinki

The experiences from the laboratory studies were first applied to a full scale remediation of a contaminated site in Helsinki, Finland. The site was contaminated by a former enterprise handling tar products. A total of 1500 m³ soil was contaminated with concentrations of 100...1200 ppm of PAHs in spot samples. Of the individual PAH-substances phenanthrene, fluoranthene, anthracene, pyrene and

carbazole were most abundant. The soil type was loam.

After laboratory scale pre-tests were performed successfully, the full scale project was accomplished in the following way:

1) The contaminated soil was excavated and stones were screened away. The masses were mixed during excavation so that the medium starting concentration was diluted to about 200 ppm PAH.

A composting place was prepared near the site on a plot with low permeable soil plus a HDPE liner. The area was equipped with a drainage layer and drainage pipes to collect the trickling water from the compost into a water tank. On top of the drainage layer a 20 cm layer of gravel was spread to improve aeration.

The soil mass was mixed with crushed bark and a long compost pile with a 6–8 m breadth and a 2 m height was formed. pH was adjusted to neutral by adding lime. Nutrients were added as a solution of potassium phosphate and ammonium nitrate. The soil mass was wetted to optimal moisture. Preparations were made to cover the piles with plastic covers and to suck the evaporating hydrocarbons from the pile and through a compost filter. However the odor emissions were so low that the authorities gave up with these requirements.

The mass was aerated and mixed 3 times in 2 months with a heavy duty crushing device (ALLU SM) mounted on an excavator. Water and nutrients were added as needed. Samples were taken with an auger drill through the pile. Oxygen was measured with a probe from the pile.

After a 2 month composting period the PAH concentration dropped to 50 ppm. 200 ppm is usually regarded as the limit concentration for dumping contaminated soil at a sanitary landfill in Finland. The project is now continuing until autumn 1995. The objective is to bring the PAH concentration down to 20 ppm, which could allow the masses to be used in landscaping.

Remediation in Petäjävesi

A wood preservation facility using creosote in Central Finland had caused contamination of the soil in the 1970's. The top 5 cm layer of soil was removed and transported for incineration at the hazardous waste treatment plant. The deeper layer of sandy soil was moderately contaminated up to 50 cm.

The soil mass of 2800 m³ was excavated and transported to the municipal landfill. There the composting/heap leaching process is to be started in summer 1995. The PAH concentration ranges from 800 to 1000 ppm. The concentration limit for landfill dumping is in this case 50 ppm. The target is expected to be reached in one or two years.

A major environmental problem is however still unsolved. Creosote oil has leaked through drainage pipes into the nearby lake. A 10–20 cm thick layer of creosote sludge was detected in the lake sediment. The contaminated sediment covers an area of about 10.000 m² of the lake bottom. PAH concentrations are high: 2.000 – 20.000 ppm.

Laboratory tests in a slurry reactor revealed that the PAH concentration could be decreased from 12.000 ppm to 500...1100 ppm (4...9% of original) in 4 weeks.

Luckily the concentrations of 5–6 ring PAHs were low (0,5% of total PAHs) compared to the corresponding concentration in soil (5,4%).

Pumping of the contaminated sediment would cause a major risk of contaminating the lake. The PAH compounds are very toxic to water organisms. It would also produce huge volumes of thin slurry, which should be concentrated and dewatered before treatment. The waste water should be treated before discharge back to the lake. An alternative response could be to cover the contaminated sediment with a filter cloth and a layer of sand. The problem has been disputed between the owner and the authorities for several years now.

Remediation plans at Ilmajoki

An abandoned wood preservation plant in Ilmajoki, Western Finland is ranked as potentially one of the most expensive remediation projects in Finland. The site is highly contaminated with both creosote oil and CCA-salts (chromium, copper, arsenic). The soil type is loam and clay.

7000 m³ of highly contaminated masses with PAH concentrations from 2000...20.000 ppm have been assessed. Additionally we calculated 50.000 m³ of masses with 200...2000 ppm PAH. A part of the mass contains both PAH- and CCA-contamination. Leaching from the site causes emissions into a nearby river. The river's water is used to produce drinking water.

Our laboratory tests have shown that a concentration of 600 ppm As does not prevent biodegradation of PAH.

Thus our suggestion for remediation is:

- 1) sorting of the contaminated masses into different hazard classes based on concentration and soil type.
- 2) degradation by heap leaching of the moderately contaminated masses until the limit for landfill treatment is achieved
- 3) degradation by composting of the heavily contaminated masses until a residual concentration 2000 ppm or lower is reached. Special methods for attacking the 5–6 ring PAHs may be necessary.
- 4) stabilization of the toxic metals and As by precipitation with salts and lime to decrease solubility
- 5) placing the masses on site isolated with an impermeable bottom and top cover and cut-off walls.

The tendering process for contractors for this remediation project is going on in March 1995. As an alternative to composting solidification into concrete has been suggested as a solution.

Table 2 PAH concentrations in slurry reactor test

PAH compound	Concentration after 6 weeks					
	Initial		Reactor no1		Reactor no2	
	ppb	conc.	ppb	% of init	ppb	% of init
2-ring PAHs						
acenaphthene	211100	567	0.27	949	0.45	692
benz(a)anthracene-7,12-dione	2108	674	31.97	1466	69.54	1004
naphthalene	1994	450	22.57	107	5.37	62
Sum 2-ring PAHs	215202	1700	0.79	2522	1.17	1758
% of Total PAHs		21.8	1.53	2.66	2.42	3.11
3-4 ring PAHs						
anthanthrene	<1	<1		<1		<1
anthracene	103229	845	0.82	895	0.87	1034
1,2-benzanthracene	50019	17047	34.08	15872	31.73	2947
chrysene	61148	20862	34.12	22552	36.88	20836
4H-cyclopenta(def)phenanthrene	32087	2028	6.32	803	2.50	437
4,5-methylcyclopentaanthracene	<1	<1		<1		<1
fluoranthene	146763	34283	23.36	7509	5.12	4321
phenanthrene	191206	1090	0.57	914	0.48	904
pyrene	93197	10863	11.66	4264	4.58	2544
truxene	<1			<1		<1
Sum 3-4 ring PAHs	677649	87019	12.84	52810	7.79	33024
% of Total PAHs	68.5	78.34		55.69	45.41	32.83

5-6 ring PAHs									
coronene	1164	<1	0.00	<1	0.00	<1	0.00	<1	0.00
benzo(ghi)perylene	7501	1571	20.94	2935	39.13	2845	37.93	2868	38.23
benzo(a)pyrene	23240	10258	44.14	20732	89.21	19872	85.51	19444	83.67
benzo(c)pyrene	15581	6435	41.30	10205	65.50	10020	64.31	9898	63.53
perylene	6182	3489	56.44	4975	80.48	4891	79.12	4724	76.42
Sum 5-6 ring PAHs	53668	21754	40.53	38848	72.39	37629	70.11	36935	68.82
% of Total PAHs	5.4	19.58		40.97		51.74		63.31	
Heterocyclic PAHs									
5,6-benzoquinoline	6097	270	4.43	335	5.49	45	0.74	94	1.54
carbazole	16003	223	1.39	201	1.26	188	1.17	269	1.68
dibenzothiophene	20709	110	0.53	115	0.56	78	0.38	77	0.37
Sum heterocyclic PAHs	42809	603	1.41	651	1.52	311	0.73	440	1.03
% of Total PAHs	4.3	0.54		0.69		0.43		0.75	
TOTAL PAHs	989331	111076	11.23	94831	9.59	72722	7.35	58341	5.90
Legend:									
Reactor 1	yes	bark	no	deterg.	no				
Reactor 2	yes		yes		no				
Reactor 3	yes		no		yes				
Reactor 4	yes		yes		yes				

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Minimum Effective Compost Addition for Remediation of Pesticide-Contaminated Soil

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Abstract

Mature yard waste compost was mixed with pesticide-contaminated soil obtained from an agrichemical retail dealership to determine how much compost was needed to significantly stimulate plant growth, microbial activity, and pesticide degradation. The soil initially contained 1.6 mg kg⁻¹ trifluralin, 1.7 mg kg⁻¹ metolachlor, and 2.0 mg kg⁻¹ pendimethalin. Proportions of the mixes were 0, 1, 5, 10, 20 and 40% compost (w/w). Mixtures were planted with sweet corn (*Zea mays*) and placed in a greenhouse for 4 weeks. Plant dry matter production, microbial activity (dehydrogenase), and pesticide content were determined. Maximal stimulation of plant growth was found at 20% compost, at which amount, plant growth was 154% of growth in only contaminated soil. Significant increases in soil dehydrogenase were seen at 20% and 40% compost with the activity being 18.8 times higher than it was in only contaminated soil. The soil was inhibitory to microbial activity at all rates of compost addition, with no stimulation in microbial activity at <20% compost. Degradation of trifluralin and pendamethalin was increased at compost rates of 20% or more. Only 40% compost significantly stimulated metolachlor degradation. Percentage degradation of the pesticides after 4 weeks of greenhouse incubation and 16 weeks of laboratory degradation was 85% (trifluralin), 100% (metolachlor), and 79% (pendimethalin). The results indicate that addition of relatively large amounts of compost to soils with phytotoxic and antimicrobial properties can significantly improve prospects for successful remediation, but smaller amounts have no significant benefit.

Introduction

A survey of 49 agrichemical facilities in Illinois (Krapac, *et al.*, 1993) showed that soil contamination with herbicides was very common, while contamination with insecticides was much less common. Herbicide concentrations ranged from a few $\mu\text{g kg}^{-1}$ soil to several g kg^{-1} soil. Since most herbicides are effective in the mg kg^{-1} range, there were secondary problems at the sites, including off-site erosional transport of contaminated soil by wind and water, which resulted in plant death

on adjacent property or pollution of surface water. Similar results were found in a survey of Wisconsin agrichemical dealerships (Habacker, 1989). Taylor (1993) found detectable pesticides in groundwater samples from wells at agrichemical retail sites, including several compounds for which drinking water standards exist. He suggested that agrichemical facilities are primary sources of groundwater contamination in Illinois. The combination of adverse environmental impacts on the earth's surface and subsurface indicates that remedial activities at these sites would be appropriate. In most cases, the pesticides detected at the agrichemical facilities were not there as the result of recent spills, but rather were the result of years of accrued contamination.

Felsot and coworkers (1988, 1990) attempted bioremediation of pesticide-contaminated soil from an inactive agrichemical facility and found that pesticide degradation occurred quite slowly, with detectable concentrations of alachlor, atrazine, metolachlor, and trifluralin still present at 380 days after land application of excavated soil. Since these authors demonstrated that freshly-added herbicides were degraded rapidly in comparison to aged materials when applied to agricultural fields, it is likely that the bioavailability of the herbicides from the agrichemical facilities was low, thereby decreasing the degradation rate. Felsot and Dzantor (1990) found that dehydrogenase activity increased only slightly in herbicide-contaminated soils amended with corn or soybean stubble, so lack of sufficient stimulation of microbial activity may also have been a contributory factor to the slow degradation they observed.

Biodegradation is the principal mechanism for destruction of trifluralin and metolachlor (Weed Science Society of America, 1989). Based on work by Nelson (1979), pendimethalin is apparently degraded by both chemical and biotic reactions, since soil sterilization reduced degradation to about 50% of the values obtained with non-sterile soil.

Because microbial degradation was the major route for environmental destruction of trifluralin and metolachlor and also contributed to pendimethalin degradation, one objective of this work was to stimulate microbial activity in the contaminated soils with the expectation that such stimulation might accelerate degradation of these pesticides. Two approaches and a combination of both approaches were tried (Cole, *et al.*, 1994; Cole, *et al.*, in press). First, an attempt was made to grow plants in the contaminated mixes, since plant growth increases microbial populations in soil, especially root-associated (rhizosphere) bacterial populations. Second, compost was added as a source of microorganisms and organic matter because addition of compost or other organic materials can stimulate soil microbial activity. Compost often has a stimulatory effect on plant growth, and therefore, a combination of planting and compost addition was tried.

Materials and Methods

Soil and Compost Samples. Contaminated matrix was obtained from a loading area at an agrichemical retail facility located in Illinois that was designated Site 20 in survey sponsored by Illinois Department of Agriculture (Krapac, *et al.*, 1993). The sampled area was used as a work area for loading and mixing of pesticides. Cores of 8.1 cm diameter were collected to a depth of 457 cm and a composite sample of all contaminated cores was used for the present work. The matrix consisted of 27% sand, 32% silt, 19% clay, and 22% gravel, had a pH of 8.4 and the electrical conductivity was 2.08 ds m^{-2} . The organic content was very low and inorganic-N ($\text{NO}_3^- + \text{NH}_4^+$) was $< 3 \text{ mg kg}^{-1}$. Prior to conducting the experiments described below, the material was screened and material passing a 4 mm mesh was used.

Mature yard waste compost was obtained from DK Recycling Systems, Inc., Lake Bluff, IL. The compost was produced by a thermophilic process with average high temperatures of 60°C . Material that passed a 6 mm mesh was used.

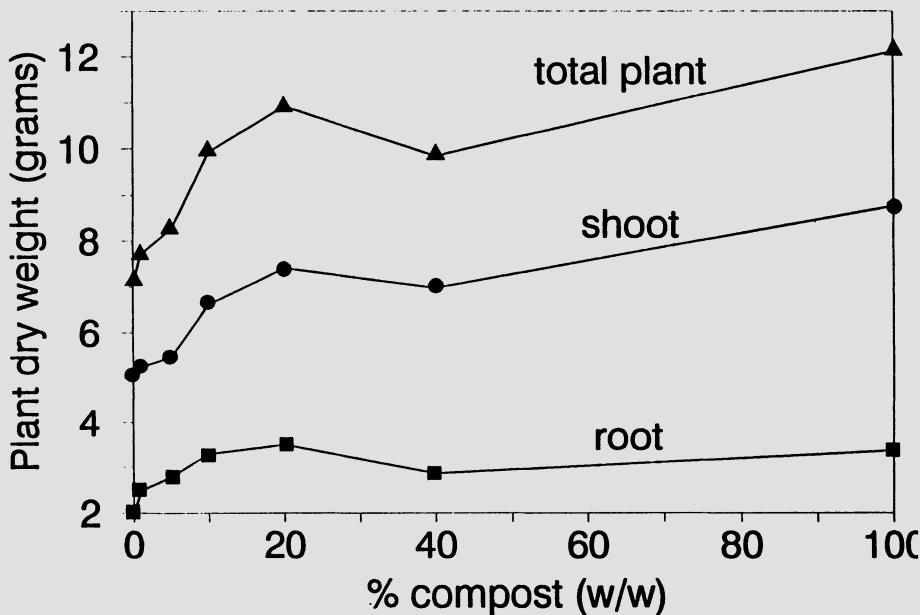


Figure 1. Effect of compost addition rate on plant dry matter production. Values are the means of three replicates of each treatment.

Physical and Chemical Analysis of Samples. Bulk density, % sand, silt, clay, and gravel, inorganic-N, pH, and electrical conductivity were determined by standard methods (Klute, 1986; Page, *et al.*, 1982).

Plant Growth and Analysis Procedures. Blends of compost and contaminated matrix which contained 0, 1.5, 10, 20, and 40% compost (w/w) were prepared and

transferred into 15 cm diameter pots for greenhouse studies. Three pots of each mixture were planted with 6 seeds of sweet corn (*Zea mays*, cv. 'Golden Beauty') and placed in a greenhouse. Plants were watered weekly with NPK fertilizer.

Plants were harvested at 30 d after planting and separated from soil. Roots and shoots were separated, and the roots were washed in tap water to remove adherent soil. Dry weights of roots and shoots were determined by drying at 90° C to a constant mass.

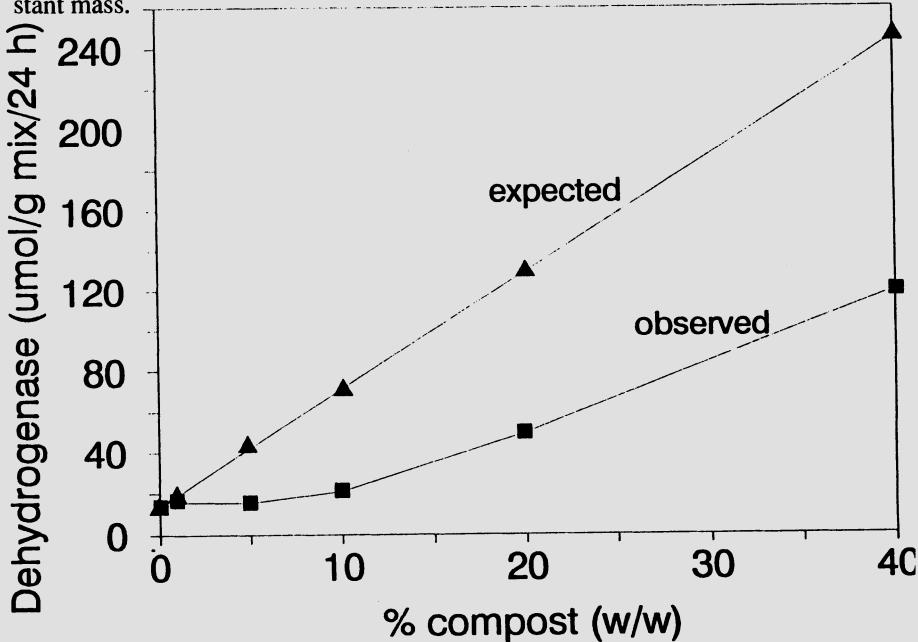


Figure 2. Effect of compost addition rate on dehydrogenase activity. Values are the means of duplicate analyses of three replicates of each treatment.

Soil Dehydrogenase Activity. Dehydrogenase activity was determined as previously described (Cole, *et al.*, 1994).

Pesticide Extraction and Analysis. Procedures were described in detail elsewhere (Cole, *et al.*, submitted for publication). Briefly, a 25 g sample was ground in a Waring blender and transferred into a rectangular 160 mL glass bottle with a PTFE cap liner. Ten milliliters of 1M sodium chloride solution was added along with sufficient water to make a soil slurry, followed by 50 mL ethyl acetate and 2 mL acetone. The bottle was shaken horizontally on a rotary shaker at 150 rpm for 24 h at 20° C. The ethyl acetate (upper) layer was removed, dehydrated by passage through a column of anhydrous sodium sulfate, and reduced to 1.0 mL final volume in a Kuderna-Danish concentrator. Samples were injected without further purification into a Chrompack CP9000 gas chromatograph equipped with a nitrogen-phosphorus detector. A 50 m X 0.25 mm (i.d.) column of WCOT fused silica with CP-Sil-8 CB stationary phase (Chrompack, Inc.) was used for all analyses.

Recovery of freshly-added pesticides ranged from 70 to 100% of addition with no significant effect of compost on % recovery when compared to recovery from soil alone. Identity of the pesticides was established by GC/MS analysis of ethyl acetate extracts. Compounds with the retention times of the pesticides listed in Figures 4, 5, and 6 were not detected in pure compost, nor in uncontaminated soil. The principal contaminants found in the samples used for this investigation were trifluralin (2,6-dinitro-N,N-dipropyl-4-(trifluoromethyl)benzenamine; marketed under the US tradename, TREFLAN), metolachlor (2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)acetamide; marketed under the tradenames DUAL or PENNANT), and pendimethalin (N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine; marketed under the tradename, PROWL).

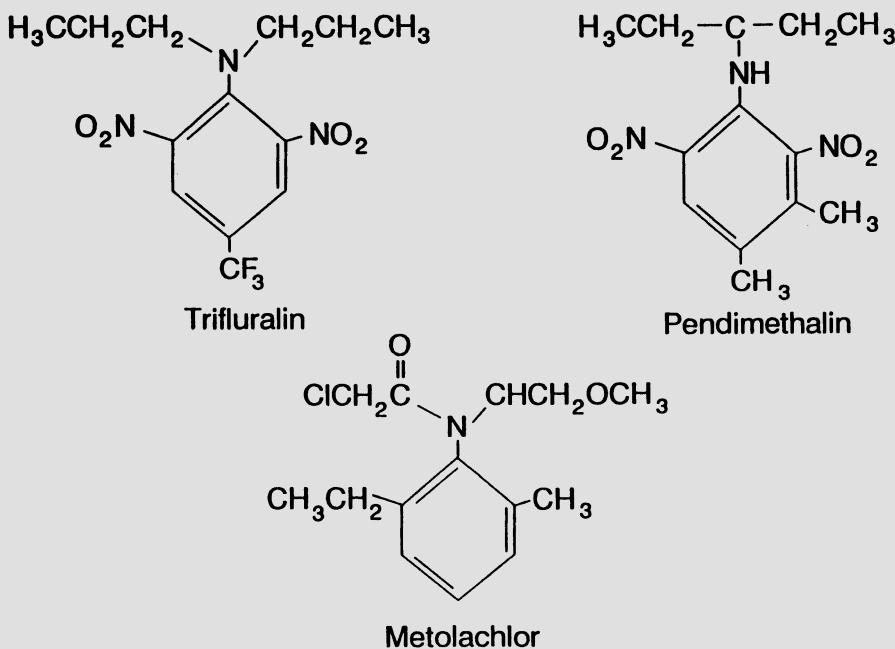


Figure 3. Structures of pesticides whose degradation was studied.

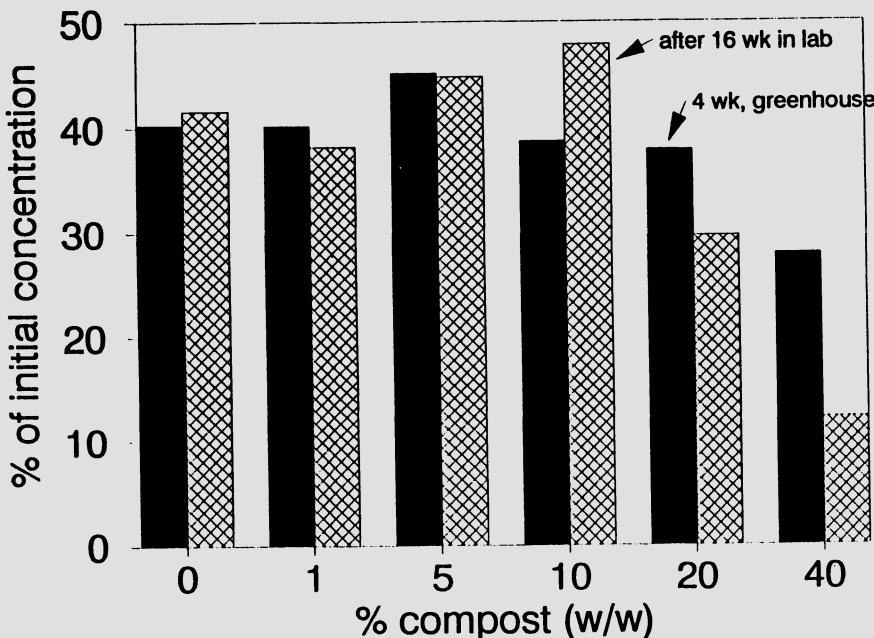


Figure 4 Trifluralin degradation as affected by % compost in mixtures. Values are the means of duplicate analyses of three replicates of each treatment.

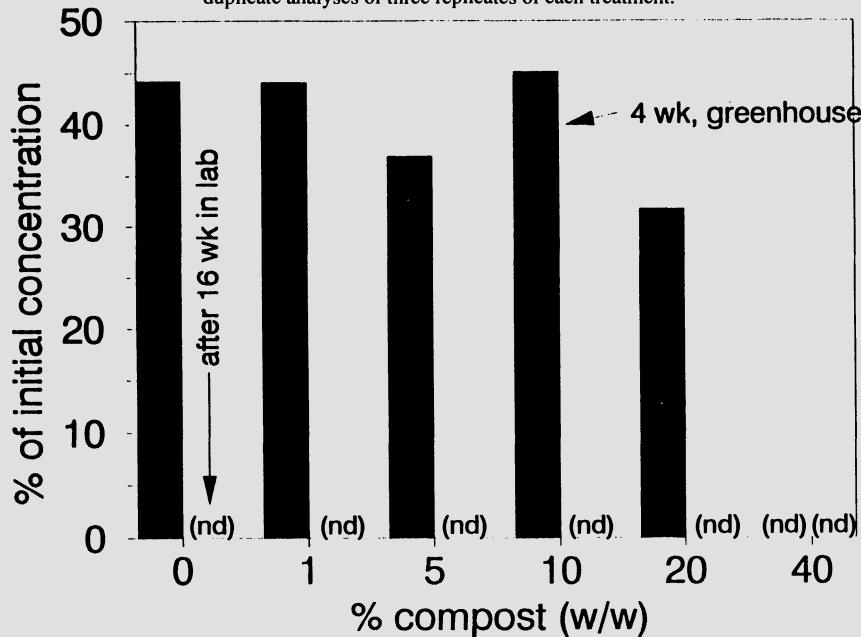


Figure 5 Metolachlor degradation as affected by % compost in mixtures. Values are the means of duplicate analyses of three replicates of each treatment.

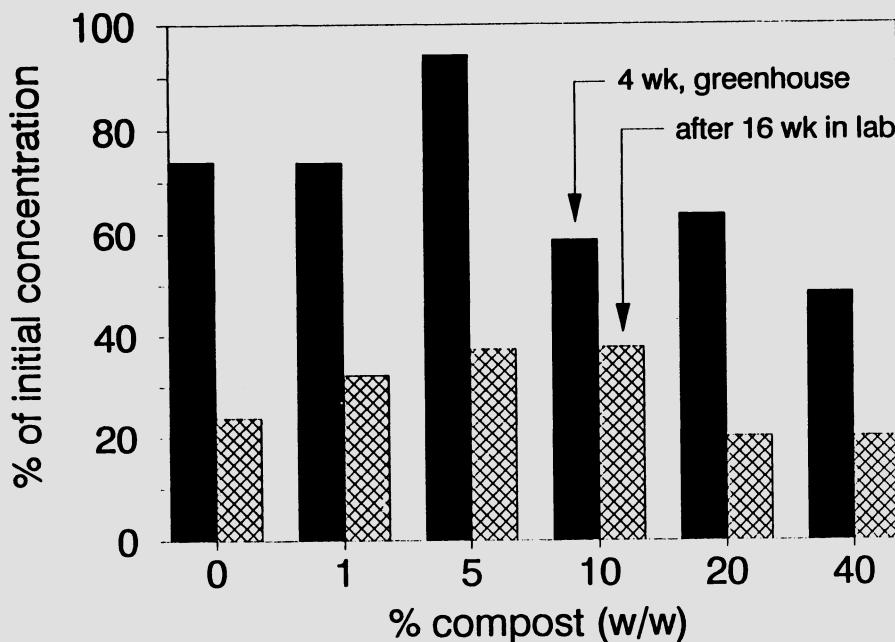


Figure 6 Pendimethalin degradation as affected by % compost in mixtures. Values are the means of duplicate analyses of three replicates of each treatment.

Results and Discussion

Plant Growth. Plants were harvested when the root systems had completely filled the pots. Maximal benefit to dry weight of roots, shoots, and total weight was obtained at 20% compost (Figure 1). The results indicate that compost has a significant protective effect against phytotoxic compounds in the contaminated matrix. The phytotoxic contaminants included herbicides (as described below) as well as other organic compounds such as phthalate esters (data not shown), which are phytotoxic (Herring and Bering, 1988). There is considerable interest in the ability of plants to stimulate xenobiotic degradation and the data in Figure 1 indicate that compost can be a significant aid in establishing plants in contaminated soils.

Microbial Activity. We used dehydrogenase activity as a broad-spectrum indicator of microbial activity in the mixes. This enzyme has been used by several investigators as an indication of overall heterotrophic activity in soil (Schaffer, 1993). There was no significant increase in dehydrogenase activity until the compost content reached 20% (Figure 2). Dehydrogenase activity was significantly lower than expected from the additive values of activity in the compost + contaminated matrix, a result that indicates that the matrix contained antimicrobial compounds as well as phytotoxins. We had reported previously that microbial activity was

reduced in samples obtained from a different location at the same facility used for this work (Cole, *et al.*, in press), but there was no inhibition by samples obtained from a different facility (Cole, *et al.*, submitted for publication). Inhibition of microbial activity would be expected to increase the time required for successful remediation and the results indicate that addition of at least 20% compost is needed to overcome the inhibitory effects of the contaminated matrix.

Herbicide Degradation. The major herbicides found in contaminated matrix were trifluralin, metolachlor, and pendimethalin, whose structures are given in Figure 3. Initial concentrations in the contaminated matrix were 1.6, 1.7, and 2.0 mg kg⁻¹ for trifluralin, metolachlor, and pendimethalin, respectively.

Trifluralin degradation after greenhouse incubation was significantly increased only at the 40% compost addition (Figure 4), but was significantly increased at 20% and 40% compost addition after a 16 week laboratory incubation. Compost had no effect on trifluralin degradation at 10% compost or less. Comparison of residual trifluralin in the 4 week greenhouse samples with residual trifluralin after 16 weeks of laboratory incubation indicates that 40% compost greatly increased the degradation rate of trifluralin during the 16 week period when compared to lower percentages of compost.

Metolachlor degradation was increased at the 20% and 40% compost rates after greenhouse incubation, with no detectable residues (< 0.1 mg kg⁻¹) in the 40% compost samples (Figure 5). Since metolachlor had degraded completely in all samples after laboratory incubation, the effects of compost could not be determined.

Mixtures containing 40% compost had less residual pendimethalin than samples with lower percentages of compost after greenhouse incubation (Figure 6). High addition rates of compost did not increase pendimethalin degradation during laboratory incubation, and the results suggest that lower rates of compost retarded degradation somewhat.

Conclusions

Plant growth has been shown to facilitate degradation of several environmental contaminants in addition to pesticides (Anderson and Coats, 1994). As described by Shann and Boyle (1994), pesticide degradation in the rhizosphere can be rapid, which may decrease the time required for remediation. An established plant cover will decrease erosional transport of contaminated soil to adjacent surface water or property. Since many pesticides are toxic to fish, decreased transport of contaminated soil to surface water would substantially diminish adverse impacts of contaminated sites. Plant growth will improve soil structure and provide organic materials which may stimulate microbial cometabolism of pesticides. The ability of compost to decrease phytotoxicity toward sensitive weed species was demonstrated previously with mixtures contained 50% w/w compost + contaminated soil

(Cole *et al.*, submitted for publication). The data presented in Figure 1 indicate that only 20% compost is needed to maximize plant growth. Regardless of any beneficial effect on soil microbial activity, the ability of compost to increase plant growth in contaminated soils is a good reason for its use. One would expect the optimal amount of compost to vary depending on site and matrix conditions, and therefore, preliminary greenhouse studies should be conducted with a specific sample to determine the best mixture of compost + contaminated soil.

The failure of compost to stimulate microbial activity in mixes containing 10% compost or less is different than usually reported. Numerous studies have demonstrated that addition of 1% to 10% (w/w) organic materials such as compost, manures, sludges, or other organic wastes will increase microbial activity in ordinary field soils and will stimulate degradation of some pesticides (Pettygrove and Naylor, 1985; Winterlin, et al., 1989). The low activity found in our samples containing 10% or less compost is probably due to the presence of antimicrobial compounds in the contaminated matrix. This inhibition may explain why Felsot and coworkers (1988) found little stimulation of degradation of herbicide wastes when applied to agricultural soils along with supplemental crop residues.

Compost, when added at less than 20% w/w, was not effective in stimulating degradation of any of the herbicides studied in this work, either when plants were growing in the soil or not. In previous studies, we had found much faster degradation of the same herbicides that were present in this study when the mixtures contained 50% compost. The difference in rate may have been the result of differences among batches of compost or differences in the contaminated matrix among different samples. We are currently investigating the impact of compost production methods and source materials on the effectiveness of compost for remediation of xenobiotic-contaminated soil.

Acknowledgments

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Enhancement of the Biological Degradation of Contaminated Soils by Compost Addition

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Abstract

Within the programme of the Research Centre SFB 188 – entitled 'Treatment of Contaminated Soils' and funded by the DFG (German Research Foundation) since 1989 – one project has been investigating the fundamental principles of the biological treatment of contaminated soils in bioreactors. The aim is to optimize the processes of biological soil treatment so that the highest possible degree of degradation is reached within the shortest possible period of time. Pre-investigations using test systems on different scales will provide information on the potential for enhancement in decomposition processes. This is dependent upon various influencing factors such as milieu conditions, additives, etc., which must be known before remedial action can be taken.

The investigations carried out so far have shown that it is beneficial to add compost during the biological treatment of oil-contaminated soils. The degradation of contaminants was enhanced by the addition of compost. This positive effect is attributed to various mechanisms. This paper presents the results from a variety of test systems on different scales.

Introduction

To apply biological soil treatment under optimum conditions and to discover the treatment limits, the specific factors of influence must be determined in advance by using a series of bench scale experiments. Since each case is different, this step is mandatory. Using these tests the following influencing factors can be optimized: oxygen supply, temperature, water content, addition of structural material (e.g. compost), microbes, nutrients, and other additives.

Within the framework of these investigations it was shown that the biological

degradation of contaminated soils can be enhanced by the addition of compost. The degree of biological degradation in relation to the maturity of the compost added, and the influencing factors of the compost were investigated.

Methods Applied

For systematic investigations a model soil from an A_h-horizon, which had been contaminated artificially with diesel fuel in a defined way, was used (description of the material: Goetz et al., 1990; Miehlich & Wagner, 1990). To obtain a material as homogeneous as possible for the test series the soil was sieved to 2000 μm . The soil that was treated had a high content of solid ('dry process'). The optimum water content lay at 60–70% of the maximum water capacity (WC_{max}). The diesel fuel, which was analyzed in detail had the following composition: n-alkane, 31.9%; rest aliphatics, 39.8%; monoaromatics, 16.4%; diaromatics, 8.0%; and poliaromatics, 3.9% (Steinhart et al., 1990).

The compost added was biocompost derived from kitchen and garden waste separately collected in households; it showed very low contamination. The compost was composted at a small windrow plant in Hamburg-Harburg.

Test Units

In order to be able to draw up mass balances only closed systems were used to evaluate and optimize biological soil treatment processes. Special glass vessels and respirometers were used in the experiments to optimize the milieu conditions (temperature, water content, additives). These systems have been described in numerous publications (e.g. Stegmann et al., 1991; Hupe et al., 1993; Hupe et al., 1994).

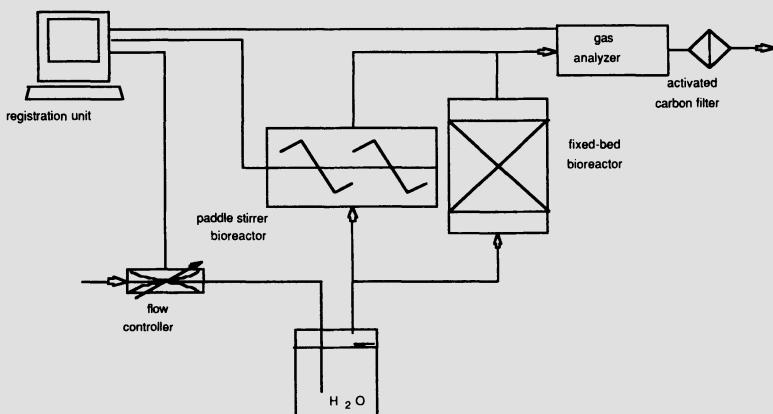


Figure 1 Principle of the bioreactor test system (schematic of a static bioreactor and a paddle-stirrer reactor)

Reactor systems were applied at different scales (volume: 3 litre, 6 litre or 90 litre) to simulate the conditions in an aerated windrow or in large-scale reactors. Aeration was conducted by compressed air and the volatiles can be easily measured in these systems. Figure 1 shows the schematic of a static and a dynamic bioreactor¹ (here: a paddle-stirrer reactor) including continuous recording and control of the measured values.

The bioreactors developed by the authors were continuously improved on the basis of the data and experience gained during the test series. In the lower part of the static bioreactor there is a sieve on which soil material is placed. Sampling pipes are located at different heights in the reactor. Controlled aeration is conducted from the bottom to the top, where the feed air is led through a wash bottle filled with water in order to avoid the soil drying out. The CO₂-content of the exhaust gas is quasicontinuously measured by infrared (IR) spectrometry and the volatile organic carbon (VOC) content by flame ionization detector (FID). Additional gas samples are taken from the reactors with a syringe through a septum and directly injected into a gas chromatograph (GC).

The paddle-stirrer reactor consists of a horizontal glass cylinder. The driving shaft is driven by an infinitely variable motor. For optimal mixing various mixing tools can be affixed to the shaft. In the middle of the glass cylinder there is a sampling pipe. The air is supplied into the reactor over the face areas. For the continuous monitoring of CO₂ and VOC in the exhaust air stream of the reactor an infrared device and a FID are used.

Investigations and Results

Carbon Balance of the Oil Degradation

Based on the results of extensive test series carried out in static bioreactors, an approach was developed to determine the carbon balance of oil degradation. During the investigations the parameters listed in Table 1 were measured.

Table 1 Investigated parameters and analytical methods for the balancing approach (Lotter et al., 1992)

parameter	analyzing method
hydrocarbon content in the soil	H18 after ultrasonic extraction
biomass	SIR-method in the respirometer
CO ₂ in the exhaust air stream	gas chromatography with TCD
VOC in the exhaust air stream	gas chromatography with FID

H18: DIN 38 409 H18 (Anonymous; 1981); SIR-method: substrate-induced-respiration method (Anderson & Domsch, 1978; modified after Beck, 1984); TCD: thermal conductivity detector; VOC: volatile organic carbon; FID: flame ionization detector

Using the data of the contaminated samples and the uncontaminated control for each parameter (Table 1), an oil carbon balance can be calculated. This approach

only partly describes the changing conditions in the soil after the addition of oil; however, it provides an approximation and a good overview of the decomposition of the contaminants. The C-content of the measured hydrocarbon concentrations is calculated on the basis of the carbon content of the initial oil. The analysis of the oil showed a carbon content of 86.1% for diesel fuel and 83.8% for lubricating oil (Francke, 1990).

Figure 2 shows the C-balance of the carbon content of the oil during treatment in the static bioreactor. These data are based on the results of the test series. It was observed that there was always a gap in the balance sum. The analytically measured reduction of hydrocarbon cannot be quantitatively explained by decomposition into CO_2 , by volatilization or the production of biomass. In relation to this the weak and/or strong interactions of the contaminants or the metabolites with the humus matrix of the compost are of particular importance (Lotter et al., 1990; 1992). The potential interactions were investigated and described by various research groups (Gerth et al., 1990; Kästner et al., 1994). For biological remediation it is important to know whether the adsorption to the soil particles and/or to the humus matrix is reversible or irreversible.

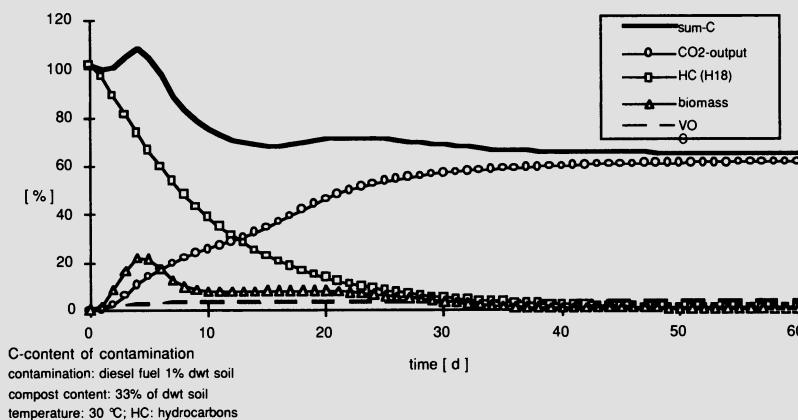


Figure 2 Model of a carbon balance of the C-content of the oil during treatment of an artificially oil-contaminated soil material with compost addition in a static bioreactor at 30 °C (Lotter et al., 1992)

In the case of a permanent gap in the C-balance it may be assumed that bound residues have formed. The analytics to determine the incorporation of the contaminant into the humus matrix are still in the process of being developed (Michaelis et al., 1991). If the balance is restored even after a period of time, it can be concluded that the adsorbed/incorporated substances were possibly set free during humus degradation and have been subsequently biologically degraded. If a C-balance is made for soil contaminated with oil without compost addition, the balance works out within the scale of measuring accuracy (100 – 10%) (Stegmann et al., 1991). Since the humus content of the soil is clearly lower than that of the compost this is a further indication of the importance of the interactions between compost and contaminants.

Effect of Compost Addition

Several investigations have shown that the degradation of organic contaminants may be enhanced by means of the addition of biocompost. This effect was further investigated in several respirometer test series using compost at different stages of maturity. The following influencing factors may be of importance:

- compost as bulking agent to improve aeration particularly in cohesive soil materials
- compost as supplier of a great variety of microorganisms (Kästner et al., 1994)
- improvement of the pH buffer capacity (Dalyan et al., 1990) and water storage capacity due to the addition of compost
- compost as structural material to reduce pellet formation when cohesive soil materials are treated in mixing reactors (dynamic treatment)
- compost as source of nutrients and trace components (particularly nitrogen and phosphorus); compost as depot fertilizer
- compost as co-substrate
- interaction of the organic matrix of compost with the contaminant (incorporation of the contaminants in the soil/humus matrix)

In Germany, the degree of compost maturity is measured on a scale of I to V (measured as self-heating or respiration; Anonymous, 1985). The composting process itself can be divided into three stages: high-rate decomposition, stabilization and curing. During the high-rate decomposition stage, fresh organic matter is transformed into 'fresh compost'; this compost is hygienically acceptable and the most significant odour-causing organics have degraded (about 2 – 4 weeks, degree of maturity: II). In the stabilization stage the material is further decomposed and stabilized (2 – 4 weeks, degree of maturity: III–IV). The final curing formation takes place over a period of several weeks to as long as 18 to 20 weeks (degree of maturity: V; Krogmann, 1992).

In order to discover the most effective biocompost additive the following factors were investigated: compost age in relation to degradation efficiency, the relation of compost quantity to degradation and the effect of the addition of nitrogen.

Quantity of Compost Added

It could be shown that the addition of compost in a soil/compost ratio of 2:1 enhanced the degradation of oil significantly. For remedial action in practice, however, this compost ratio is too high. In Germany, when windrow techniques are applied, a volume rate of about 9:1 (soil/additive) is frequently used. For this reason soil/compost-mixtures of 2:1, 4:1, and 8:1 (referring to dry matter) were investigated. In all cases the diesel oil addition was 1% by weight of soil dry matter. The temperature was adjusted at 22° C.

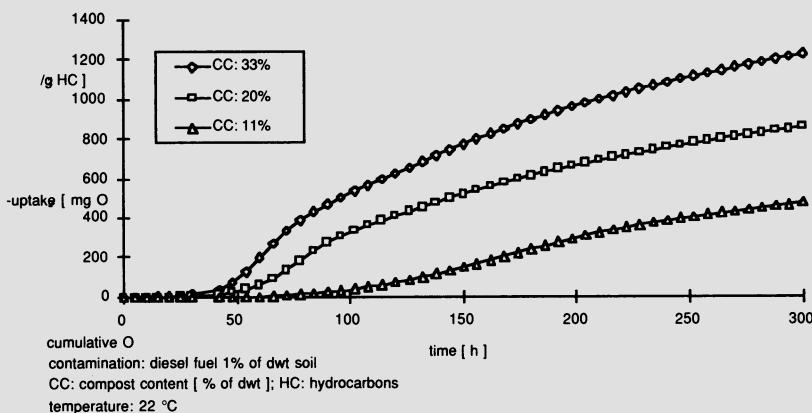


Figure 3 Cumulative O₂-consumption from the degradation of the oil contaminant in the soil materials using various soil/compost-mixtures (Stegmann et al., 1991).

Figure 3 presents the cumulative oxygen consumption for the test series described above. For all set-ups the lag-phase was approximately 2 days. It was found that with decreasing compost content the cumulative O₂-consumption caused by the oil degradation decreased. Moreover, the maximum oxygen consumption in relation to the oil degradation per hour was reached when the compost addition was increased at an early stage.

Abiotic Influence of Compost

As mentioned above, a balance gap was detected when compost was added to the soil during balancing investigations with artificially contaminated soil material. No carbon balance gap was observed where compost was not added to the soil (accuracy of measurement: 100 _ 10%). The interaction between compost and the contaminants in the soil was of fundamental significance with regard to the carbon balance gap (Lotter et al., 1992). In order to find out more about the phenomenon, matured compost artificially contaminated with diesel fuel was used in tests for balancing contaminant degradation in bioreactors (Wolff, 1993). In Table 2 the different test conditions are presented.

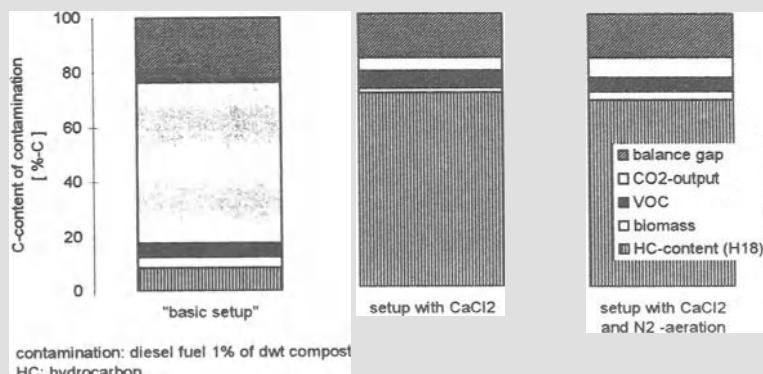
Table 2 Test conditions for determination of the interactions between compost and the diesel fuel contamination

test	concentration of diesel fuel [% of dwt]	addition of CaCl ₂ [% of dwt]	aeration	comment
A	1	-	air	'basic setup'
B	1	10	air	inhibition of microbial activity by CaCl ₂ addition
C	1	10	N ₂	inhibition of microbial activity by CaCl ₂ addition and oppression of oxidation process by N ₂ aeration
D	-	-	air	'control'; endogenous respiration

dwt: dry weight of compost

For test series A, B and C the compost was contaminated with diesel fuel (1% of dwt compost). The compost in test series D was left uncontaminated in order to measure the endogenous respiration ('control'). In test series A activated biomass was used to investigate the degradation of oil in the compost; in test series B and C the microbial activity was inhibited to a high degree by the addition of CaCl₂ (10% of dwt compost) in order to determine the abiotic interactions between compost and contaminants. The influence of oxidation processes by aeration was investigated indirectly by using nitrogen instead of air in test series C.

As is shown in Figure 4, after 21 days in test series A (basic set-up) only 8% of the carbon content of the original contamination was extractable, 59% was mineralized, 5% was stripped and about 4% of original contamination had been transformed into biomass. Thus a gap of 24% in the carbon balance was established. In comparison, only 14% of contamination was mineralized, stripped or transformed into biomass in the 'inhibited' series; a balance gap of 16% was observed and about 70% of the original contamination was extractable after a test period of 21 days.

**Figure 4** Abiotic influence of compost on the carbon balance of diesel fuel; here: carbon balance after 21 days at 30°C

This experiment demonstrated that the incorporation of the contaminants in the compost also could be due to abiotic interactions between these compounds such as sorption and/or diffusion effects. Apparently the incorporation of contaminants in the compost matrix was not dependent upon an oxidative milieu since the incorporating effect in an oxygen atmosphere (Test A: 'basic set-up') was almost identical to that taking place in an atmosphere lacking in oxygen (test C: set-up with CaCl_2 and N_2 -aeration).

Influence of compost maturity on the carbon balance

In order to examine the influence of the maturity of the compost on the biological degradation of hydrocarbons, soil material of an A_h -horizon was contaminated with 1% (of dwt soil) diesel fuel. 20% (of dwt soil) compost of varying ages (2 weeks, 2.5 months, 6 months, 13 months) was added in the different set-ups. In Table 3 the compost materials used are described.

Table 3 Description of the characteristics of the used compost materials employed

parameter	0.5 months	2.5 month	6 months	13 months
biomass [g C/kg dwt]	17.6	14.1	1.4	0.4
TC [% dwt]	26.8	19.4	12.7	10.6
nitrogen (TKN) [% dwt]	1.2	2.4	1.4	1.0
ignition loss [% dwt]	44.8	41	24.4	20.8
degree of maturity	I	III	IV	V
reduction of hydrocarbon content after 60 days [%]	95	95	94	93

The results (Figure 5) show that the reduction in the hydrocarbon content of the diesel fuel after 60 days was more or less independent of the age of the compost; it amounted to approximately 94% of the original contamination. The established carbon balances indicate different balance gaps. The size of the balance gap decreased with increasing compost age.

In the case of fresh compost (degree of maturity < IV) it was very difficult to determine the influence of the contamination on the CO_2 - and biomass-production. This was due to the high endogenous respiration of the fresh compost material. The differences of these parameters in contaminated and uncontaminated set-ups were marginal. It was possible to reduce the size of the balance gap for the set-ups with fresh compost by increasing the concentration of the diesel fuel added (to 2.5% of dwt soil). The higher quantity of oil made it easier to observe the degradation of oil into CO_2 and biomass. The results indicate that the balance system established here is not useful when fresh compost/organic matter is used as an additive.

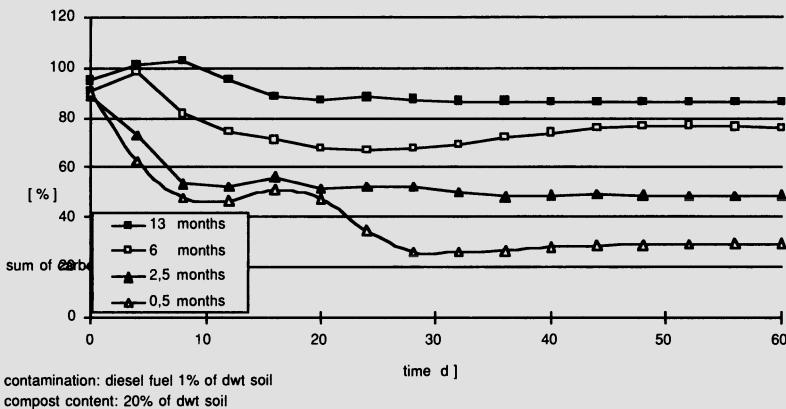


Figure 5 Influence of varying compost age on the carbon balance

Dynamic Treatment

In investigations carried out with paddle-stirrer reactors it appeared that the dynamic treatment had a positive effect on the contaminant turnover. But these tests also showed that during turning and mixing in the reactor the soil had a tendency to form pellets. It was discovered that pellet formation could be reduced if the water content was relatively low (<55% WC_{max} (maximum water capacity)), the proportion of organic structural material was high, the structural material contained only a low proportion of fines ($d_p < 630\text{-m}$; <10%) and the rotational speed of the mixer was low (8 rpm).

The addition of biocompost as structural material proved to be useful for the reduction of pellet formation. The addition of compost leads to a reduction of the water content and to a disintegration of the soil materials. However, it will be necessary to carry out further investigations to optimize this process.

Summary

A series of investigations has shown that the degradation of organic contaminants may be enhanced by means of the addition of biocompost. It was shown that a number of the characteristics of biocompost were important factors:

- compost as bulking agent to improve aeration particularly in cohesive soil materials
- compost as supplier of a great variety of microorganisms
- improvement of the pH buffer capacity and water storage capacity due to compost addition
- compost as structural material to reduce pellet formation when cohesive soil

- materials are treated in mixing reactors (dynamic treatment)
- compost as source of nutrients and trace components; compost as depot fertilizer
- compost as co-substrate
- interaction of the organic matrix of compost with the contaminant

Moreover, it was established that the addition of compost led to a decrease in the ecotoxicology of soils contaminated with oil. This was measured by bacterial activity as well as in the results from algae and plant toxicity tests (Ahlf et al., 1993).

In addition, it was discovered that the degree of maturity of the biocompost used seems to have no influence on the degradation rate of the contaminant. The formation of non- bioavailable (non-extractable) residual contaminants remains to be investigated (interaction of the contaminants with humus / compost). Here the processes of carbon turnover in the soil have to be thoroughly examined.

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¹dynamic bioreactors: systems in which the contaminated soil is mixed gently
static bioreactors: no mixing

Heavy Metals Removal by Clinoptilolite in Pepper Cultivation using Compost

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Abstract

The compost used, was produced in a pilot plant in which household refuse from Attica Region was treated. The composting took place in piles using forced aeration with air blow and suction. In compost, soil, and manure, that were used for the cultivation of pepper plants in pots and under greenhouse experimental conditions, the following metals were determined : Cd, Cr, Ni, Pb, Cu, Zn, Mn . There were also determined the metals fraction concentrations in compost. In part of the experimental cultivation, natural zeolite was used in various compositions with compost and soil. The natural zeolite used was the clinoptilolite. The removal of metals in compost and the compost-soil system were studied, and the metal contents in the leaves, body, crops, and roots of the plants were determined .The results showed that the plants contained lower quantities of metals when cultivated with zeolite and even lower when more zeolite was used .

Introduction

The presence of heavy metals in composts derived from household refuse is a significant problem which can make prohibitive their application in agriculture when these heavy metals are found in high concentrations in the composts (Kapetanios et al 1988, Kapetanios et al 1993) . The heavy metals when contained in small quantities are valuable trace elements necessary for the growth of plants, while when contained in high quantities they become phytotoxic and toxic for the man factors (Zucconi and De Bertoldi 1986, Petruzzelli and Lubrano 1986, Petruzzelli et al, 1992).

Zeolites, synthetic or natural, have the ability to remove heavy metals by ion exchange (Loizidou and Townsend, 1987), and this characteristic ability they possess can be used to remove the heavy metals contained in composts so that they do not pass to the plants (Kapetanios, 1990) . From previous studies (Kapetanios and

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Loizidou, 1992, Kapetanios and Loizidou, 1995) on tomato plant cultivation in compost with zeolite added compared to tomato plants cultivated in compost without zeolite added, a significant percentage of the heavy metals contained in the compost was removed by zeolite. In this work are reported the experimental observations when a natural zeolite, namely clinoptilolite, was used for pepper plant cultivation in compost.

Materials and methods

For the experimental work, the soil (S) used was from the Attica region. Compost (C) and stabilized natural sheep manure (K) were used as soil conditioning materials. The compost used which originated from the biodegradable fraction of household refuse from Attica region, was recovered from a pilot plant with a capacity of 2 Mt / h, and the composting was completed in piles ventilated through forced aeration with air blow and suction. The zeolite (Allison F.E., 1973) used, was clinoptilolite (CLI) and as an experimental plant, pepper was used in a 12 l pot. The proportions of compost, manure, and zeolite used, were as shown :

$$\begin{aligned}C_1 &= 200 \text{ cm}^3 \text{ compost} \\C_2 &= 400 \text{ cm}^3 \text{ compost} \\C_3 &= 800 \text{ cm}^3 \text{ compost}\end{aligned}$$

$$\begin{aligned}Z_1 &= 15 \text{ gr CLI} \\Z_2 &= 30 \text{ gr CLI} \\Z_3 &= 60 \text{ gr CLI}\end{aligned}$$

$$\begin{aligned}K_1 &= 200 \text{ cm}^3 \text{ manure} \\K_2 &= 400 \text{ cm}^3 \text{ manure} \\K_3 &= 800 \text{ cm}^3 \text{ manure}\end{aligned}$$

$$\begin{aligned}2Z_1 &= 30 \text{ gr CLI} \\2Z_2 &= 60 \text{ gr CLI} \\2Z_3 &= 120 \text{ gr CLI}\end{aligned}$$

The various combinations resulted were :

$$\begin{aligned}C_1 &= 200 \text{ cm}^3 \text{ compost} \\C_2 &= 400 \text{ cm}^3 \text{ compost} \\C_3 &= 800 \text{ cm}^3 \text{ compost}\end{aligned}$$

$$\begin{aligned}Z_1 &= 15 \text{ gr CLI} \\Z_2 &= 30 \text{ gr CLI}\end{aligned}$$

$$\begin{aligned}K_1 &= 200 \text{ cm}^3 \text{ manure} \\K_2 &= 400 \text{ cm}^3 \text{ manure} \\K_3 &= 800 \text{ cm}^3 \text{ manure}\end{aligned}$$

$$\begin{aligned}2Z_1 &= 30 \text{ gr CLI} \\2Z_2 &= 60 \text{ gr CLI}\end{aligned}$$

As references, plain compost, manure and soil were used and the respective processes are denoted as OCO, OKO, SOO .

A total of nineteen combinations were performed and each one was repeated four times. Pesticides used, were selected on a basis that no metal under consideration was present in any of them. The experiments were carried out in an open experimental cage. For the determination of the total heavy metals in the compost and the various parts of the plants, the $\text{HNO}_3 / \text{HClO}_4$ method was applied and measurements were taken by atomic absorption. The metal fractions, which can be solubilized, after consecutive extraction with distilled water, KNO_3 (1M) and

EDTA, were determined again by atomic absorption. The chemical exchange capacity (CEC) was determined using the sodium acetate method At a pH of 8.2 . The organic substance was evaluated from the organic carbon (C_{org}) which was determined by oxidation with K_2CrO_4 , using the formula:

$$\text{Organic substance} = K \times C_{org} \quad K = 2$$

Experimental Results – Discussion

The most significant parameters which influence the cation exchange (Cooke G.W., 1967, Gerritse et al, 1985) of zeolites are :

- Type, size and valence of the anhydrous and hydrated cations, pH, temperature, and characteristics of the zeolite structure and ion exchange capacity .

In this work, the theoretical ion exchange capacity of the zeolite was 2.358 meq / gr obtained by chemical analysis of the mineral. From kinetic experiments it was observed that the selectivity series of clinoptilolite for the various metals is $Pb > Cd > Zn > Cu > Ni > Mn > Cr$.

It was also concluded that the selectivity series remains the same even when the solution concentration changes and also high quantities of metals are removed within the first minutes. There is an unstable equilibrium between the soluble and insoluble forms of heavy metals in compost and the major parameters which influence it are pH, organic substance, the presence of various anions and the redox potential. The chemical form of metals in compost depends significantly on their chemical form in refuse as well as on the composting process followed.

Table 1 Metal and metal fraction contents in compost

Metals (mg./kg. d.w)	1	2	3	4	Deduced % from 2, 3, 4
Cd	2.80	0.05	0.04	0.03	4.28
Cr	80.00	0.78	0.22	0.13	1.41
Ni	35.00	0.96	0.35	0.82	6.09
Pb	236.00	0.32	0.41	6.73	3.16
Cu	204.00	3.37	1.11	4.89	4.59
Mn	196.00	3.65	1.14	8.50	6.78
Zn	759.00	4.64	0.78	26.88	4.26

1 : Total metals in compost using the $HNO_3/HCIO_4$ method

2, 3, 4: Metal fraction soluble in H_2O , KNO_3 and E.D.T.A. respectively.

Heavy metals are found in the soil in one of the following chemical forms :

- Simple or complex ionic forms.
- Exchangeable ionic forms.
- Complex organometallic or chemical forms.

- Coprecipitated (with various cations as carbonates, sulphates, etc.) forms, as well as participation of the various minerals contained in the soil.

The root system of plants takes from the soil solution not only the free ionic forms but the exchangeable ones as well as the organometallic forms. In Tables 1 and 2 are given the contents corresponding to compost and soil in Cd, Cr, Ni, Pb, Cu, Zn, and Mn. In those tables, for every metal, is given the total content in column 1, the simple and complex ionic forms in column 2, and the exchangeable forms in column 3. The main parameters that regulate the passage of heavy metals from the soil into the plant are, pH, organic substance, humidity, temperature, and ventilation (Allison F.E., 1973, Cooke G.W., 1967, Gerritse R.G et al, 1985, Smilde K.W., 1981). In Table 3 the pH, CEC, and the organic substance of the soil used, compost and manure are given. In Table 4 the concentration of total heavy metals in the soil, manure, and compost are given. In Tables 5 – 11 are presented the metal contents of the pepper plants in the roots, bodies, leaves, and crops.

Table 2 Metal and metal fraction contents in soil

Metals (mg./kg. d.w.)	1	2	3	4	Deduced % from 2, 2, 4
Cd	1.70	0.01	0.02	0.03	3.53
Cr	67.00	0.23	0.14	0.39	1.13
Ni	31.00	0.65	0.27	0.61	4.91
Pb	58.00	0.46	0.51	0.63	2.76
Cu	93.00	1.15	0.72	1.31	3.42
Mn	187.00	4.75	2.25	3.78	5.76
Zn	256.00	2.08	2.18	5.48	3.80

1 : Total metals in soil using the $\text{HNO}_3/\text{HClO}_4$ method

2, 3, 4: Metal fraction soluble in H_2O , KNO_3 and E.D.T.A. respectively.

Table 3 pH, C.E.C. and organic substance for compost, manure, and soil

Material	pH	C.E.C. (meq./200g. d.w.)	Organic substance %
Compost	7.62	54.20	45.00
Manure	9.55	64.70	51.60
Soil	7.30	16.30	1.43

Examining Table 1, it is shown that the compost has a low content in available ionic forms for all the metals. It is also shown that it has a low content in organometallic compounds. From the same Table it is shown that the percentage of the metals Cd, Cr, Ni, Pb, Cu, Zn, Mn that is available to the plants, corresponds to 4.1, 1.41, 6.09, 3.16, 4.59, 6.78, 4.26 of the respective total content in the compost. Observing Table 2 it can be seen that Cd, Cr, Ni, Pb, Cu, Zn, and Mn in soil are found in a lower content compared to their content in compost. Also, it can be seen that the available ionic and organometallic forms of the above mentioned met-

als are very low. The percent proportion of Cd, Cr, Ni, Pb, Cu, Zn, and Mn which is directly available to the plants corresponds to 12.73, 1.42, 1.95, 10.16, 6.56, 5.76, and 5.33 of the respective total percent proportion in the soil. In Table 3 a high CEC of compost and manure is shown in relation to what other researchers report (Guidi G., 1981, Manios V.I., 1986), a fact which resulted in a low mobility of the heavy metals. It is also observed that compost and manure have high organic matter while the soil has a very low one. The pH of the compost and soil are about neutral but that of manure is quite alkaline. Observing Table 4, it is apparent that Cd, Cr, Ni, Pb, Cu, Zn, and Mn are in a quite lower content in manure in relation to compost and soil. The metal contents in the roots, bodies, leaves, and crops of plants are shown in Tables 5–11 and the following comments can be reported for each one. Finally, in Table 12 are shown the contents in Cd, Cr, Ni, Pb, Cu, Zn, and Mn in pepper plant crops from the market of Athens. In fact, 15 samples were taken from vegetable markets and the results obtained from their mixture are shown in this Table.

Table 4 Cd, Cr, Ni, Pb, Cu, Mn, and Zn contents in compost, manure, and soil

Metals (mg./kg. d.w.)	Compost	Manure	Soil
Cd	2.80	0.76	1.65
Cr	80.00	0.94	67.42
Ni	35.00	2.30	31.76
Pb	236.00	2.46	58.25
Cu	204.00	2.10	93.23
Mn	196.00	2.71	187.20
Zn	759.00	4.73	256.32

Table 5 Cd content (mg./kg. d.w.) in pepper plants

Numb.	Process	Roots	Bodies	Leaves	Crops
1	OCO	0.143	0.111	0.130	0.112
2	OKO	0.060	0.092	0.970	—
3	SOO	0.101	0.094	0.107	0.082
4	SC ₁ O	0.102	0.080	0.106	0.091
5	SC ₂ O	0.113	0.091	0.240	0.106
6	SC ₃ O	0.130	0.138	0.105	0.101
7	SK ₁ O	0.093	0.061	0.091	0.072
8	SK ₂ O	0.087	0.073	0.086	0.063
9	SK ₃ O	0.097	0.067	0.093	0.087
10	OCZ ₁	0.157	0.103	0.123	0.118
11	OCZ ₂	0.130	0.110	0.127	0.125
12	OCZ ₃	0.098	0.086	0.101	0.108
13	OC2Z ₃	0.072	0.078	0.090	0.071
14	SC ₁ Z ₁	0.113	0.092	0.139	0.103
15	SC ₂ Z ₂	0.100	0.117	0.103	0.090
16	SC ₃ Z ₃	0.106	0.103	0.117	0.108
17	SC ₁ 2Z ₁	0.121	0.105	0.105	0.103
18	SC ₂ 2Z ₂	0.095	0.109	0.095	0.097
19	SC ₃ 2Z ₃	0.087	0.093	0.102	0.080

Table 6 Cr content (mg./kg. d.w.) in pepper plants

Numb.	Process	Roots	Bodies	Leaves	Crops
1	OCO	1.137	1.098	1.195	0.532
2	OKO	0.309	0.280	0.428	—
3	SOO	0.933	0.656	0.893	0.470
4	SC ₁ O	1.012	0.863	0.977	0.200
5	SC ₂ O	0.918	0.978	0.893	0.312
6	SC ₃ O	1.103	0.907	1.004	0.305
7	SK ₁ O	0.470	0.597	0.921	0.462
8	SK ₂ O	0.386	0.610	0.720	0.378
9	SK ₃ O	0.412	0.508	0.811	0.360
10	OCZ ₁	1.156	0.922	1.225	0.581
11	OCZ ₂	1.110	0.970	1.207	0.595
12	OCZ ₃	1.126	1.056	1.111	0.463
13	OC2Z ₃	0.900	0.712	0.904	0.428
14	SC ₁ Z ₁	1.128	0.930	0.908	0.229
15	SC ₂ Z ₂	1.109	0.971	0.913	0.287
16	SC ₃ Z ₃	0.830	0.860	0.925	0.328
17	SC ₁ 2Z ₁	0.941	0.875	0.890	0.320
18	SC ₂ 2Z ₂	0.957	0.788	0.723	0.297
19	SC ₃ 2Z ₃	0.768	0.536	0.670	0.213

Table 7 Ni content (mg./kg. d.w.) in pepper plants

Numb.	Process	Roots	Bodies	Leaves	Crops
1	OCO	1.722	1.830	1.930	0.812
2	OKO	0.315	0.400	0.411	—
3	SOO	1.605	1.513	1.722	0.690
4	SC ₁ O	1.780	1.722	1.768	0.650
5	SC ₂ O	1.590	1.791	1.813	0.687
6	SC ₃ O	1.613	1.710	1.700	0.592
7	SK ₁ O	1.628	1.431	1.840	0.813
8	SK ₂ O	1.645	1.370	1.892	0.708
9	SK ₃ O	1.830	1.455	1.714	0.740
10	OCZ ₁	1.830	1.647	2.070	0.730
11	OCZ ₂	1.671	1.720	1.820	0.747
12	OCZ ₃	1.414	1.563	1.714	0.634
13	OC2Z ₃	1.219	1.510	1.580	0.602
14	SC ₁ Z ₁	1.687	1.739	1.829	0.612
15	SC ₂ Z ₂	1.693	1.615	1.690	0.671
16	SC ₃ Z ₃	1.580	1.417	1.735	0.593
17	SC ₁ 2Z ₁	1.652	1.680	1.510	0.627
18	SC ₂ 2Z ₂	1.112	1.675	1.221	0.530
19	SC ₃ 2Z ₃	0.087	1.044	0.937	0.485

Table 8 Pb content (mg./kg. d.w.) in pepper plants

Numb.	Process	Roots	Bodies	Leaves	Crops
1	OCO	0.747	0.593	0.614	0.305
2	OKO	0.272	0.387	0.498	—
3	SOO	0.580	0.572	0.598	0.243
4	SC ₁ O	0.618	0.627	0.580	0.222
5	SC ₂ O	0.586	0.641	0.608	0.208
6	SC ₃ O	0.645	0.610	0.540	0.231
7	SK ₁ O	0.471	0.495	0.327	0.225
8	SK ₂ O	0.493	0.454	0.404	0.210
9	SK ₃ O	0.422	0.408	0.326	0.237
10	OCZ ₁	1.695	0.611	1.602	0.281
11	OCZ ₂	0.687	0.582	0.672	0.298
12	OCZ ₃	0.635	0.570	0.585	0.227
13	OC2Z ₃	0.578	0.591	0.563	0.240
14	SC ₁ Z ₁	0.689	0.600	0.645	0.267
15	SC ₂ Z ₂	0.622	0.623	0.570	0.245
16	SC ₃ Z ₃	0.638	0.570	0.593	0.271
17	SC ₁ 2Z ₁	0.580	0.582	0.562	0.208
18	SC ₂ 2Z ₂	0.565	0.545	0.567	0.214
19	SC ₃ 2Z ₃	0.476	0.507	0.522	0.202

Table 9 Cu content (mg./kg. d.w.) in pepper plants

Numb.	Process	Roots	Bodies	Leaves	Crops
1	OCO	15.950	12.410	16.740	11.970
2	OKO	5.130	4.170	7.110	—
3	SOO	8.620	9.720	10.270	7.290
4	SC ₁ O	13.270	12.480	15.730	12.080
5	SC ₂ O	12.110	11.140	16.020	11.620
6	SC ₃ O	14.820	11.390	15.090	11.970
7	SK ₁ O	7.620	9.140	10.460	11.060
8	SK ₂ O	7.150	8.630	9.400	11.480
9	SK ₃ O	7.030	8.560	8.750	10.100
10	OCZ ₁	15.880	11.600	16.400	11.260
11	OCZ ₂	15.240	12.130	16.720	10.950
12	OCZ ₃	14.330	11.080	16.140	9.120
13	OC2Z ₃	14.080	11.110	15.200	8.730
14	SC ₁ Z ₁	14.360	13.270	15.830	12.180
15	SC ₂ Z ₂	13.280	11.150	14.760	11.740
16	SC ₃ Z ₃	13.400	12.860	14.200	11.400
17	SC ₁ 2Z ₁	12.960	12.340	12.970	10.760
18	SC ₂ 2Z ₂	13.070	12.570	12.700	10.240
19	SC ₃ 2Z ₃	12.180	11.900	12.060	8.200

Table 10 Zn content (mg./kg. d.w.) in pepper plants

Numb.	Process	Roots	Bodies	Leaves	Crops
1	OCO	39.310	51.270	40.750	22.200
2	OKO	24.070	32.910	29.500	—
3	SOO	35.120	40.060	27.260	17.150
4	SC ₁ O	36.180	43.900	28.350	19.140
5	SC ₂ O	36.700	42.710	28.900	19.010
6	SC ₃ O	39.310	42.830	27.630	20.230
7	SK ₁ O	34.650	37.220	23.150	18.880
8	SK ₂ O	33.180	36.120	29.170	15.610
9	SK ₃ O	34.900	31.330	27.520	17.950
10	OCZ ₁	40.370	30.220	26.400	23.270
11	OCZ ₂	41.080	27.310	27.200	22.000
12	OCZ ₃	39.700	28.290	25.760	21.630
13	OC2Z ₃	36.170	25.120	23.600	21.720
14	SC ₁ Z ₁	36.380	33.700	28.300	19.100
15	SC ₂ Z ₂	35.130	35.620	29.150	19.170
16	SC ₃ Z ₃	36.150	35.380	25.100	18.630
17	SC ₁ 2Z ₁	36.720	39.270	25.960	18.070
18	SC ₂ 2Z ₂	35.060	34.100	23.120	18.350
19	SC ₃ 2Z ₃	33.120	33.700	23.710	17.700

Table 11 Mn content (mg./kg. d.w.) in pepper plants

Numb.	Process	Roots	Bodies	Leaves	Crops
1	OCO	20.230	22.400	27.370	11.840
2	OKO	6.700	9.820	17.120	—
3	SOO	10.280	15.430	20.100	6.120
4	SC ₁ O	12.720	14.180	20.550	7.100
5	SC ₂ O	12.940	13.920	19.700	7.560
6	SC ₃ O	13.800	13.670	21.070	7.920
7	SK ₁ O	8.470	16.710	19.400	7.600
8	SK ₂ O	8.650	16.020	19.100	7.710
9	SK ₃ O	7.260	15.130	18.770	6.600
10	OCZ ₁	19.200	21.220	26.130	12.270
11	OCZ ₂	19.780	20.100	24.200	10.250
12	OCZ ₃	16.100	18.350	20.810	7.130
13	OC2Z ₃	13.120	15.920	17.400	5.750
14	SC ₁ Z ₁	13.300	14.710	19.120	10.110
15	SC ₂ Z ₂	12.900	14.870	18.730	9.630
16	SC ₃ Z ₃	13.370	13.250	18.810	8.900
17	SC ₁ 2Z ₁	11.820	13.060	17.100	7.820
18	SC ₂ 2Z ₂	12.070	11.930	16.170	7.190
19	SC ₃ 2Z ₃	10.100	11.700	15.540	6.180

Cadmium

The potential properties of cadmium in their entireness show a similarity with those of zinc, but cadmium is more kinetic and found in less in soil. The use of zeolite in single proportion gave a reduction of the cadmium content, but an even higher reduction was observed using a double proportion of zeolite which in the

case of a higher proportion gave significantly lower cadmium contents compared to plants cultivated in plain soil. Also, the cadmium content in pepper plant crops cultivated in a mixture of compost-soil-double proportion of zeolite was significantly lower compared to the cadmium content in pepper plant crops from the market of Athens.

Chromium

Chromium according to Leeper is considered less toxic than the other heavy metals because the hexavalent chromium which is probably found in the biodegradable fraction of refuse, with the aerobic conditions that prevail during composting, is oxidized to trivalent chromium which is much less toxic. In pH 6–8 chromium gives compounds of very low solubility which has as a result a low mobility. The addition of zeolite, mainly in double proportion, gives a chromium content for the plants much lower than the one for plants that were cultivated in plain soil. Also, the chromium content in pepper plant crops cultivated in a mixture of compost-soil-double proportion of zeolite was significantly lower compared to the content in chromium of pepper plant crops from the market of Athens.

Table 12 Metal content (mg./kg. d.w.) in pepper plant crops from the market of Athens

Cd	Cr	Ni	Pb	Cu	Zn	Mn
0.063	0.356	0.747	0.220	9.140	22.760	8.170

Nickel

Humus, according to Leeper, has the ability to remove nickel with which it forms chelates. The highest percentage of it is adsorbed from the negatively charged surfaces of humus, and the adsorption increases when the pH values get close to 7. The addition of zeolite, mainly in double proportion, gave nickel contents for the plants much lower than the ones that were cultivated in plain soil. Also, the nickel content in pepper plant crops cultivated in compost-soil-double proportion of zeolite was significantly lower compared to the content in nickel of pepper plant crops from the market of Athens.

Led

Led has been studied by many researchers (Petrizzeli, 1982, Wolnik, 1985) due to its significant mobility in the chain soil-plant-man. According to Leeper bivalent led is hydrolyzed and polymerized easily in the soil and with the increase of pH becomes inert.

From Table 1 can be seen that only 3.16 % of the total led, found in compost, is available to the plants. From Table 8 can be seen that the lower content in led is found in the crops.

The best results were obtained by a double proportion of zeolite. Indeed, the led contents in plants cultivated in soil-compost-double proportion of zeolite were lower compared to the ones in plants cultivated in plain soil.

Led content in pepper plants cultivated in a compost-zeolite mixture was lower compared to the one in plants cultivated in plain compost.

The led content in pepper plant crops cultivated in soil-compost-double proportion of zeolite was significantly lower compared to the one in crops from the market of Athens.

Copper

A significant part of the Cu^{2+} ions found in compost is combine with the organic substance in compost to form complex organic salts. In the soil-compost mixture a part of Cu^{2+} ions combine with clay, but this combination is less strong than the one with the organic substance. Also, a significant part of the Cu^{2+} ions, in the compost-soil mixture, form insoluble CuSO_4 .

Only 4.59 % of the total Cu contained in compost is found in extractable form with H_2O , KNO_3 , and E.D.T.A, and consequently can pass into the plants.

The best results in soil-compost mixtures were obtained with plants cultivated with addition of a double proportion of zeolite. But it was observed that plants cultivated in plain soil had a lower content in copper compared to every soil-compost mixture even in the cases when a double proportion of zeolite was used.

It was also observed, that the addition of zeolite in compost significantly reduced the content in copper compared to that of plants cultivated in plain compost.

The copper content in the pepper plant crops which were cultivated in a soil-compost-double proportion of zeolite mixture was significantly lower compared to the one in crops from the market of Athens.

Zinc

The Zn^{2+} ion has the tendency to combine strongly with the organic substance and form organic complex salts. In the soil-compost mixture the Zn^{2+} ions combine with the organic substance and the clay.

Only 4.26 % of the total zinc contained in compost is in extractable forms with H_2O , KNO_3 , and E.D.T.A, and consequently can pass in the plants.

The best results in soil-compost mixtures were obtained with plants cultivated with addition of a double proportion of zeolite. But it was observed that plants cultivated in plain soil had a lower content in zinc compared to every soil-compost mixture even in the cases when a double proportion of zeolite was used.

It was also observed that the addition of zeolite in compost significantly reduced the content in zinc compared to that of plants cultivated in plain compost.

The content in zinc in the pepper plant crops which were cultivated in a soil-compost-double proportion of zeolite mixture was significantly lower compared to the one in crops from the market of Athens.

Manganese

The chemistry of manganese in the soil is complicated and Lindsay reports that this is due to the fact that manganese forms mixed oxides with different valences, and these oxides have different crystal forms or are amorphous, and it is possible for them to combine with iron or other metals oxides.

In Table 1 can be seen that 6.78 % of the total manganese contained in compost is found in extractable forms with H_2O , KNO_3 , and E.D.T.A, and consequently can pass in the plants.

The best results were obtained by a double proportion of zeolite. In fact, the lead contents in plants cultivated in soil-compost-double proportion of zeolite were lower compared to plants cultivated in plain soil. Manganese content in pepper plants cultivated in a compost-zeolite mixture was lower compared to plants cultivated in plain compost.

The Manganese content in pepper plant crops cultivated in soil-compost-double proportion of zeolite was significantly lower compared to crops from the market of Athens.

Conclusions

- Plants cultivated in plain compost gave the highest heavy metals content in the crops, roots, bodies, and leaves. The addition of zeolite in plain compost significantly lowered the metal content in the plants.
- Plants cultivated in plain manure gave the lowest metal content found in the, roots, bodies, and leaves.
- Plants cultivated in plain soil gave a metal content lower than that with plain compost and higher than that with plain manure.
- Plants cultivated in various compost-soil mixtures gave a metal content lower than those cultivated with plain compost, and higher or even equal to those cultivated in plain soil
- A significant reduction in metal content was observed in plants cultivated in compost-soil mixtures with zeolite added in a single proportion.
- The addition of a double proportion of zeolite contributes to the further reduction of metal content for almost all parts of the plant, and in the most of the cases, especially with the higher proportion in zeolite, it was observed a metal content even lower than that of cultivation with plain soil.
- The results concerning the metal content in the pepper plant crops, cultivated in a compost-soil mixture with a double proportion of zeolite added, and especially for the higher proportion of zeolite, compared to pepper plant crops from Athens markets the metal content was lower for all metals, except Cd, when zeolite was used.
- The observed reduction in metal contents of plants cultivated with the addition of a single and even more with the addition of a double proportion of zeolite,

showed that zeolite removes significant quantities of the metals available to the plants and prevents their intake from the plants.

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B5 Composting Design

Composting Technology in the United States: Research and Practice

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Introduction

Composting is a time-honored, worldwide practice as an inexpensive, effective means of enriching soil for crops and gardens. Over the past two decades, composting has become an increasingly common method for reducing the volume of organic materials – particularly yard waste – sent to landfills. In Europe, the entire organic portion of municipal solid waste (MSW) is often composted. Up until recently, that approach had been less common in the United States; however, as more states enact tougher landfill laws, diverting a higher percentage of organics found in MSW is attracting more interest.

Although composting has been around for centuries, we are continuing to learn more about ways to make composting a more cost-effective alternative to source reduction, methods of controlling odors, and new technologies enabling acceptance of a greater variety of organic materials.

In the United States, this knowledge is pursued through the efforts of developers, academia, environmental entities, and municipal governments.

Composting technologies

Basics of the Composting Process

In its most basic form, composting needs no technology – it is simply the natural result of microbial breakdown of organic materials in the presence of oxygen; this same process has been producing humus (organic topsoil) in forests for millennia. Technology was introduced into the composting process to regulate the methods used in order to produce certain qualities of compost, and to increase the speed of the process to enable the processing of larger volumes of materials.

Types of Technologies

In the United States, composting technologies are typically classified into three basic methods: windrow systems, aerated static pile systems, and in-vessel systems. The first two methods are relatively simple and inexpensive to develop. In-vessel systems are more costly to build and operate; however, they can be built in a smaller area and offer better process control.

Windrow Systems

In the windrow approach, the feedstock is arranged in long piles (windrows) on a gently sloping site that may be open to the air or covered. Windrows are aerated through natural convection, assisted by periodic turning with front-end loaders or special turning equipment. The turning frequency depends on the material's moisture, texture, and stability, aeration methods, and operational goals such as odor control, composting speed, or pest control. Blowers may be used to force air through the windrows for more efficient aeration and heat removal. Both windrow and aerated windrow facilities typically rely on process controls to minimize odors.

Static Pile Systems

In a static pile system, the feedstock is placed in a large pile that is not disturbed during composting. Air is introduced into the pile through duct systems installed beneath the pile. Aerated static pile operations avoid anaerobic conditions by introducing a controlled volume of air into each pile. This air can be positive, blowing up through the pile, or negative, drawing air down through the pile.

Several operators of static pile systems use negative aeration during active composting and no aeration during curing. Some operators use positive aeration during both stages, while other operators use positive aeration during active composting and no aeration during curing. One operator uses negative aeration during both phases.

Most aerated static pile facilities use process controls for managing odors (i.e., optimizing aeration, moisture control, porosity, etc.), as opposed to using more costly systems for capturing and processing odorous process air.

In general, aerated static pile systems have higher capital costs but lower operating costs than windrow systems.

In-Vessel Systems

In-vessel systems are designed to promote rapid digestion rates by careful monitoring and control of the composting process. Although these systems can produce an end-product more quickly, they are more complex and costly to build, operate, and maintain. Designs for in-vessel systems vary widely; however, they

commonly use a system of fixed augers or agitated beds to promote mixing. Moisture and temperature levels must be closely monitored. Most systems feature forced aeration, as well as vessels or bays that allow new material to be introduced at one end as more mature material exits from the other.

The more technologically advanced in-vessel systems are more costly to build and operate and require more operator attention. Those systems are typically applied to more complex mixtures such as sludge MMSW; they are almost never used to compost yard waste alone.

Actual operations

General

The interest in composting continues to grow throughout the United States, despite the difficulties encountered by some facilities who are no longer operating, or are continuing to operate, but providing only a marginal financial return. Although these early projects have been unsuccessful for some, they have provided insight for others who have an interest in developing composting facilities in the future. However, mistakes continue to be made by communities who either ignore, or are not aware of basic composting principles.

Following are case histories of actual operating facilities. Each facility experienced significant operating problems. One facility, located in Sevierville, Tennessee, has overcome some of their difficulties. The other three facilities (Riedel, Oregon Compost Facility; Fembroke Pines, Florida facility; and the Agripost facility) are no longer operating due to their inability to provide the basic operating parameters needed to ensure an efficient operation.

Case Studies

Sevierville, Tennessee Co-Composting Facility. The Sevier County Solid Waste Composting Facility was designed and built, and is operated by Bedminster Bioconversion Corporation. The facility began operations in September 1992.

The facility processes a 2 to 1 ratio of unseparated MSW (150 tons per day (TPD)) and dewatered, aerated biosolids (75 TPD), along with grease trap waste. The quantity of MSW received at the facility varies with the influx of tourists, at times exceeding design capacity by 30 percent. The operators accommodate the excess tonnage by maximizing the material in each stage of the composting process.

Ram pits feed material into one of three rotating drum digesters. The drums are separated into three chambers where each chamber is separated by a bulkhead with a square door. The digesters are slightly inclined, and material is transferred from one drum to the other by gravity. The continuous tumbling of material inside the drums reduces particle size and helps provide mixing of oxygen, moisture, and

nutrients required for microbial growth.

Material exiting the drums drops onto a conveyor, which feeds the material into the primary trommel screen. The screen separates the non-organics from the organics. Ferrous metal is extracted for recycling from the non-organic fraction and the residue is landfilled. The organics are composted in aerated bays, where the demand for air is governed by cooling requirements. Large, plastic hoods collect air over each bay, which is scrubbed through biofilters. The material in the bays is moved by bucket loaders about twice a week.

Processed material is typically cured for an additional 25 to 30 days.

Three biofilter areas scrub odorous compounds from process air leaving the digester, holding tank and curing building. In 1992, the facility began accepting material before it was fully enclosed, and the present biofilter system had not been installed. As a result, the facility received numerous odor complaints. The last biofilter installation was completed in August 1993, and few odor complaints were received until the peak tourist season the following spring.

Finished compost from the Sevier Solid Waste Composting Facility is utilized in a number of beneficial uses. Much of the material is given away in an effort to develop markets for the material. A small quantity of the material is taken by SSWI for use as final landfill cover. Other uses include agricultural research, landscaping, athletic fields, and parks. The price for the finished compost is at approximately \$10 per ton.

Riedel Oregon Compost Facility. This facility was owned by Riedel Oregon Compost Company, Inc. (the Company). The Company offered a residential mixed waste processing and disposal contract to the Portland Metro Service District for 600 TPD, six days per week. Major elements of the facility included a tipping floor with twin apron feed conveyors, picking stations for manual recovery of recyclables and undesirables, twin DANO drums for maceration and mixing, twin covered aeration slabs, a final screen to separate contaminants and produce finished compost, and scales, conveyors, laboratory, truck wash, offices, and other support facilities.

The facility experienced problems from the time it started operating in April 1991. Limited front-end processing equipment was a key problem at the facility. The conveyor from the tip floor to the picking lines transported the waste in trickles and surges. This meant that a large portion of the waste passed by the picking stations in clumps, hampering recovery of recyclables and hazardous materials. High employee turnover and bag-breaking problems also contributed to material recovery rates that were well below the guaranteed material recovery rate of 5 percent.

The facility also experienced significant biological process control problems. Moisture content was often too low for composting to progress at a reasonable pace, clumping of material on the aeration slabs led to channeled air flow, and conditions became too hot and anaerobic in maturation piles. Together these conditions resulted in an immature compost product and additional screening problems. Odor was also a significant problem. Major odor sources were: the tipping

floor, aeration bays, maturing material, and the screening operation. Other conditions that may have contributed to the facility's failure were inadequate house-keeping, resulting in pest problems, and liquids collecting in sumps and floor drains, which became septic.

Another contributing factor to the shut-down of this facility was the fact that this was Riedel's first composting project. Riedel facility staff seemed to believe that composting was a 'simple' and 'natural' process. Furthermore, Riedel was apparently not concerned over the lack of certain contingencies built into the final design of the facility. One result of this attitude was that the people running the plant had little or no compost experience; no compost 'brewmaster' was permanently on-site to draw on past experience for day-to-day operations and to develop operation practices for the new facility. The operators had no apparent appreciation for the plant as a 'manufacturing process' instead of a waste disposal operation.

The facility ceased operations in January 1992 and was purchased by the Credit Suisse bank in February 1992.

Pembroke Pines, Florida Facility. The Pembroke Pines facility, a MMSW materials recovery and composting facility, started operations in September 1991. This facility incorporated extensive front-end material recovery technology as well as process control measures such as aeration, moisture control, agitation, odor scrubbers, size reduction/screening and density separators, and oxygen monitoring equipment. The Pembroke Pines facility was operated by Reuter of Florida (Reuter) and utilized Buhler equipment. The facility processed 600 TPD of MSW and produced 200 TPD of compost.

The total cost of the project including financing was nearly \$50 million. Tipping fees were between \$50 to \$60 per ton. The facility used a front-end processing system that removed non-processibles from the tipping floor and then fed the material through a trommel to separate three different sized fractions (smaller than 2 inches, between 2 inches to 6 inches, greater than 6 inches). The two larger fractions were hand picked to recover recyclable material and the unders were routed to mixing drums. Material not recycled at the hand picking station was shredded and then mixed with the unders from the primary trommel. The organic material was composted using aerated windrows for six weeks. Although the composting was accomplished under a roof, no side walls were used on the composting building.

The final compost refining system used a hammermill as the first step followed by screens and density separators. All final processing equipment was located within a building to control dust and blowing material separated from the finished compost. The final compost product produced at the Pembroke Pines facility was guaranteed by Buhler to meet Florida requirements for use by commercial, agricultural, institutional or governmental operations.

Operation of the Pembroke Pines facility continued for 14 months. During this time, approximately 55,000 tons of finished compost was produced, most of which was land applied for agricultural use.

Due to the vicinity of residential homes to the facility, fugitive air emissions led to numerous odor complaints. In addition to the siting problem, the following critical problems were also experienced at the facility: undersized biofilters; an inadequate aeration system; inappropriately sized final compost screening and processing equipment; and an undersized compost hangar.

The compost building hangar was undersized by 15 percent causing overstacking of the compost rows and/or reducing the time for the compost material to decompose. Thus as the compost proceeded to final screening and processing, the material was not fully mature and could not be processed properly. The facility is currently not operating.

Agripost Facility. The Agripost facility was located in Dade County, Florida. The 800 TPD facility began operations in September 1989. The process included a tipping floor where large articles were removed for recycling or landfilling, a shredder, a covered windrow composting area using composting turning machines for aeration, and final screening equipment. The basic operational design concept for the facility was 'shred and compost.'

Problems encountered at the Agripost facility included several episodes of odors detected off-site, a severe bottleneck in its product finishing equipment, poor siting, difficulty with financing, and poor public relations. Odor problems at the Agripost facility were compounded by weather conditions including wind shifts and thermal inversions. There was also controversy over a new cell being prepared at the county's landfill next to the Agripost plant.

The plant's material processing problems were related to a bottleneck in the fine shredding and screening machinery. This bottleneck meant that while Agripost was able to receive, process and compost the incoming waste, it could finish less than a quarter of the incoming waste.

Although the facility was located adjacent to a landfill, it was also across the street from an elementary school and surrounded by a middle- to low-income, community. During the public hearings regarding the siting, concerns were raised by the neighbors about odors, noise, truck traffic, and property values. However, the site was approved for the facility.

The project's financing was based on the assumption that the process required minimal equipment and would produce virtually no residues. Unexpected cost for operations, regulations, public relations, and product marketing quickly depleted contingency funds, and refinancing became impossible due to the uncertainties associated with the project. With no ability to finance needed improvements, the facility was forced to cease operations.

Composting research

As was mentioned in the aforementioned case studies, there remains a lot to be learned about how certain mechanical devices help promote the decomposition

process and how they affect certain environmental factors, such as odor levels, during the composting process. Much of the research currently being conducted is by developers trying to perfect their specific mechanical devices or systems, which will allow them to offer systems economically, while still providing the necessary environmental controls. Typically, the information these groups acquire is not available to the public unless it will help promote their products.

In an attempt to provide communities, regulators, and developers with specific guidance to help ensure successful composting projects, several initiatives have been developed through cooperative efforts with the United States Environmental Protection Agency, the Compost Council, and the National Audubon Society. Although many of these initiatives would not be considered hard research by most scientists, significant effort has been expended to determine the critical aspects of composting that will help ensure successful composting operations.

The Composting Council contracted R. W. Beck to produce the *Compost Facility Operating Guide* (the CFOG) to assist compost facility operators with:

- Developing standard operating procedures for facilities producing compost;
- Controlling the composting process in order to protect public health, safety, and the environment;
- Producing marketable compost; and
- Training and education.

The CFOG focuses on the biological needs of the microorganisms and the practical steps that facility operators can take to satisfy those biological needs. It also defines steps to prevent chemical, biological, and physical pollution of the finished product.

The CFOG is intended to have universal application to all technologies commonly used in treating organic feedstocks derived from any residential, commercial, and institutional source. It presents discussions of principles as they apply to the various steps involved in the recovery and preparation of feedstocks, composting through the high rate and stabilization, screening and refining compost, and finally, curing, storing, and packaging. It also presents principles for operating associated systems, such as odor and dust management.

The CFOG is intended for use primarily by:

- *Facility Operators and Technicians* – The operating principles are designed to assist operators and technicians as they conduct day-to-day operations at their facilities.
- *Public Planners and Decision-Makers* – As public planners and decision-makers gain a better understanding of what is required for successful composting, they will be better equipped to plan and implement compost facility projects.
- *Consultants and Designers* – The operating principles found in the CFOG should be considered when designing a facility, and it can be used to form the basis for facility-specific operating manuals.
- *Regulators and Enforcement Agencies* – The CFOG is an excellent source for

regulators and enforcement agencies who are interested in understanding basic principles of compost facility operations.

Widespread use of the CFIG within the industry is intended to promote a common understanding of composting and lend credibility and appropriate consistency to operating facilities. The CFIG is designed to be updated as innovative technologies are developed.

To date, all 200 copies of the first edition have been sold, and a second edition of the CFIG is under way.

Additionally, the Composting Council's Standards Committee has been developing product standard guidelines, which can be used throughout the industry as a basis for product quality. They are currently working with experts from academia, regulatory agencies, and the composting industry to develop stability and maturity standards.

The Water Environment Federation has also recognized the need for more operating guidance for biosolids composting. A member group is currently finalizing a publication focusing on technical issues associated with composting municipal wastewater biosolids, which also includes co-composting with MSW.

Composting Promotion Alliances

Work in the public acceptance and educational arena is being championed by a few alliances. The first, Compost...for Earth's Sake (CFES), a partnership made up of the National Audubon Society and the grocery industry (made up of groups like the Grocery Manufacturers of America, the Food Marketing Institute, and individual companies like Procter & Gamble, Quaker Oats, Nestle's, Kraft, Scott Paper, Krogers, and others) is promoting the collection of compostable organics in homes and grocery stores.

Another alliance is Food for the Earth (FFE). This partnership of the Composting Council, the National Audubon Society, and the food service industry (groups like McDonalds, Cargill, James River, and International Paper) is working with the National Restaurant Association to promote composting in the food service industry.

Both partnerships have or will implement a number of pilot programs throughout the United States. The long-term vision for both partnerships is to make source-separated composting a reality without interfering with recycling, and even improving the economics of recycling. For example, a Santa Barbara, California collection pilot program demonstrated that wet/dry bag combinations can reduce the system costs in a community doing curbside recycling. The partnerships intend to work with environmentalists, industries, and the government to accomplish this vision.

In addition, a third partnership, the Compost Action Alliance, was recently formed. It comprises the some governing bodies as the other two partnerships,

plus representatives from compost businesses and the U.S. Conference of Mayors, among others. The Compost Action Alliance intends to fill in the gaps that are hindering composting growth.

A composting demonstration project is planned in Gloucester City, New Jersey to research the collection and composting of source-separated organic waste from residential and commercial sources. The types of waste that will be composted include source-separated yard waste, food wastes, wet and soiled paper, diapers and sanitary products, pet waste, and dry paper packages that are not being recycled because of weak or nonexistent markets. The organic waste will be composted by Compost America, using an enclosed system, which will demonstrate a unique technology and construction methods. The developers hope to demonstrate how their system can provide lower cost systems that will gain wide acceptance in the composting industry.

Conclusion

Operators of composting facilities, regulators, and others in the composting arena have created a base of knowledge that has dramatically improved the odds for project success. Facility managers are responding more quickly and effectively when challenges arise, and customer satisfaction with the finished compost is strong.

Composting continues to grow as a technology for processing the organic fraction of a solid waste stream, a trend driven by disposal bans at landfills and a scarcity in virgin organic materials like peat, forest products, and to a certain extent, topsoil. Cities and counties continue to see higher diversion rates, as they strive to attain their waste reduction goals, produce a beneficial end-product, and minimize environmental pollution from organic solid waste. Emerging statistics are very promising, showing an increase in biosolids composting facilities and in farms using yard trimmings. Other strong indicators of composting growth can be seen in the educational area – such as hundreds of school programs placing compost bins in classrooms, adjoining the recycling containers. Further, composting continues to be a useful application for private industry seeking to manage selected organic waste streams in a more cost-effective and environmentally beneficial manner.

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Reconversion of Traditional Composting Plants for a Policy of Quality

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Abstract

In Austria the separate collection and treatment of municipal biowaste was introduced about 1989, and is now ordered by law since January 1995. From a population of about 7,8 Million, living in 3,1 million households, the expected total quantity of biowaste, coming from municipalities, parks and gardens, and the commercial sector is about 2 million tons per year. This quantity should be collected by the year 2000. At this time about 42 % of the organic waste will be managed decentralised and composted by private people and farmers. About 58 % of the biowaste is treated in composting plants with a capacity of more than 50t/a up to 100.000t/a. On the one hand in Austria a lot of new biowaste treatment plants have to be built, on the other hand existing co-composting plants have to be reconstructed and enlarged to convert biowaste with aerobic or anaerobic technologies into high a quality compost product.

Introduction

Composting and the methods of biological waste treatment have a tradition over more than 20 years in Austria. In the eighties about 25 % of municipal solid waste (MSW) and sewage sludge was treated in co-composting plants. At least there have been 19 plants with an overall capacity of approximately 600.000 t/a.. Depending on a poor endproduct quality, containing impurities, ballast matters and heavy metals, it was the next step to force, the separate collection of the biogenic fraction out of the commercial and municipal garbage.

To date the implementation of the collection policy has progressed well. Almost 78 % of the households being connected to the separate collection system, or practising composting at their compound themselves. In the meantime recycling of biowaste and its conversion into a useful product, which can be applied without

ecological risks to the soil, is an essential component of integrated waste management concepts, not only in Austria. Also in other European countries like Germany, Switzerland, Sweden and the Netherlands composting of GFT is usual, to prevent biowaste being landfilled or incinerated.

The separate collection and treatment of biowaste in Austria is regulated by the 68. amendment to the waste management law, the so called „Biological Waste Decree“ which came into effect on 1.1.1995. This decree orders to utilise waste with an high contend of biodegradable matter, such as natural organic waste from gardens and parks (yard waste), solid vegetable refuse from households, commercial and industrial processing and distribution of agricultural products, as well as uncoated paper which was in contact with food stuff or used for the collection of biowaste. All this wastes have to be particularly suitable for an aerob (composting) and/or an anaerob (fermentation) treatment. Commercial kitchen and food waste is only then to be collected, as far as a suitable aerobic or anaerobic plant is available. Another field to operate the methods of biological waste treatment is the pre-treatment of remaining waste after separation of the recyclable fractions, before incineration and landfilling. Using modern process controlled indoor composting systems, it will be possible to prevent biodegradable organic substances from waste disposal. Furthermore it's to minimise the capacity of methane gas production out of landfills, to reduce organic harmful substances and the quantity of leachate emissions, to ensure the hygienisation and to produce a plant tolerant humus product which can be used as a landfill construction material specially for the final cover and recultivation. If incineration of the remaining waste, which contains a high quantity of not collected biogenic waste is taken in consideration, the biological processing will be changed to grant the reduction of the water content to less than 18 % and the decrease of the total quantity before.

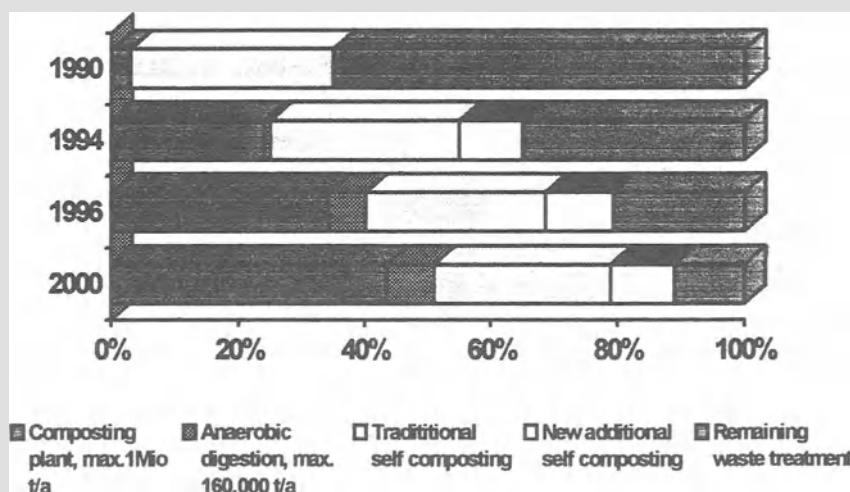


Figure 1 Types and development of biowaste treatment in Austria (2,2 million t/a), from 1990 to the year 2000

Reconversion of Co-composting plants

In Austria 12 of former 19 co-composting plants have been reconversed or supplemented to pure biowaste composting plants for a policy of quality. Different types of composting systems are implemented depending on the local conditions, like:

- the climatic situation (rainfalls, wind)
- distance to the neighbourhood (odour, noise and spores emissions control)
- requirements on the hygienisation (removal of human- and phytopathogens)
- constants of compost quality (maturity degree, plant tolerance)
- space availability
- type of biowaste (water content, density, structure stability, availability of structure material)
- quantity of biowaste
- possibilities of energy recovery (electricity, biogas, heat)

The following types of composting and digestion systems are implemented (Table 1)

Table 1 Types of composting and digestion systems used at reconverted co-composting plants in Austria

Type of treatment	Number of plants	Tot. Biowaste-capacity (t/a).
Open pile composting	3	13.500
Hangar composting (not closed, without automatically turned piles, ROTTEFILTER)	2	14.000
Hangar composting (automatically turned table piles AE&E-KOCH, WENDELIN, DYNACOMP)	2	13.000
Tunnelcomposting (BAS)	5	58.000
Anaerobic fermentation (DRANCO)	(1*)	18.000

* in connection with a Tunnelcomposting plant

Finally there will be in Austria about 50 biowaste composting plants with an specific annual capacity between 2.000 tons and 100.000 tons and an total processing capacity of 380.000 t/a. In all the expected number of composting plants (> 50 t/a) will be more than 350 with an over all capacity of 680.000 t/a.

Selected examples of reconverted composting plants in Austria

Allerheiligen

At the Allerheiligen co-composting plant a daily amount of 80 t of solid waste and 25 t of sewage sludge was treated from 1978 to 1992 by a VA – compost technology, running a forced aerated table pile at a maturation platform and a post-maturation, turned by a ENGELER windrow machine. The treatment of separate

collected biowaste was started 1992 with a „THÖNI – Silo composting plant“. This processing was not working successfully because of an insufficient oxygen supply of the rotting material. The neighbourhood was complaining about massive odour emissions, threatening the company to block the driveway. Finally this type of plant operation has been stopped after a two years test run period in 1994.

After this the plant design has been changed. In consideration of the extreme sensitive situation at Allerheiligen site a tunnelcomposting was recommended by the consultant, but not only to treat 4.000 t/a of biowaste, also the remaining waste and the sewage sludge with a total quantity of 20.000 t/a will be automatically processed in 9 compost tunnels after an appropriate pre-treatment, in the future. The special requirements at this site are the minimisation of odour emissions caused by the process or by the endproducts, which are on one hand recycled (high quality compost according to the ÖNORM quality standard I A) and which are on the other hand going to be dumped at the same site after the biological stabilisation has happened. The operation times are 2 to 3 weeks in the tunnelcomposting, 5 weeks at the forced aerated maturation platform and about 12 to 16 weeks storage and stabilisation in the compost hangar.

Liezen

The co-composting plant from 1979 of *Abfallwirtschaftsverband Liezen* was expanded 1992 by a biowaste composting plant with an annual capacity of 3.000 t/a. After all, checking different available biowaste composting technologies by the consultants, the a BAS tunnelcomposting plant was selected to be built.

Before implementation of the tunnelcomposting system, a test run with Austrian biowaste in the Netherlands was done at the BAS pilotplant for biowaste treatment in Tholen. In cooperation with the Technical University of Vienna, Prof. P. Lechner, the benefits of an overall closed and process monitored composting system have been demonstrated.

After two years operation experience in Liezen the tunnelcomposting system has been completely adapted to the biowaste substrate. The major benefits of the tunnel composting are

- a batchwise operation of the waste materials with a high flexibility to the different types of waste (seasonal differences, yard waste, sewage sludge, commercial biowaste, . . .)
- an optimal process control ensures a fast microbiological degradation of biodegradable organic matter under regulated and optimised ecological conditions
- the essential process parameters are controlled and monitored by computer, like the oxygen supply ($> 12\% O_2$), the water content (45 – 60 %), the energy output and the process temperature, depending on the stage of process like heating up, hygienisation (65 °C), maturation (56 °C), drying, cooling e.t.a.
- minimal odour emissions, the off air contains a relative low level of smelling units

Table 2 Co-Composting Plants in Austria (Capacity > 2000 t/a) which have been reconverted or supplemented to Biowaste-Composting plants

Location	Operator	Co-Composting		Biowaste-composting	
		1990	Technology	1995/96	Technology
		tons/a	tons/a		
AICH-ASSACH	municipality	6.000	windrow, forced aeration (Rottefilter) of preseparated MSW	6.000	windrow, forced aeration (Rottefilter) of preseparated MSW (on trial same type of collection)
ALLERHEILIGEN	municipality	20.000	mixing drum, forced aerated tablepile, aerated platform and postmaturation (VA) system for Co-composting	4.000 + 16.000 MSW	mixing unit, <i>tunnelcomposting</i> (BAS) and forced aerated postmaturation (same
BREITENAU / NEUNKIRCHEN	private	8.000	windrow, forced aeration (Rottefilter) of wet-waste fraction (Grüne Tonne)	8.000	windrow, forced aeration (Rottefilter) of wet-waste (Grüne Tonne)
GRAZ / LANNACH	private	4.000	municipal biowaste windrow forced aeration (Rottefilter)	15.000	<i>tunnelcomposting</i> , postmaturation and aerated storage in the final stage of maturation (planned)
LIEZEN	municipality	15.000	mixing drum, windrowmachine for aeration of triangle piles at postmaturation (VA)	3.000	<i>tunnelcomposting</i> (BAS), forced aerated postmaturation and trianglipes
LUSTENAU	private	10.000	forced aerated indoor windrow (WENDELIN), triangle pile postmaturation, turning by frontendloader	10.000	planned anaerobic digestion (<i>COPROGAS</i>) and aerobic stabilisation by indoor <i>tunnelcomposting</i>
OBERPULLEND / ORF / GROßHÖFLEIN	municipality	50.000	dynamic pre fermentation (DANO) forced aerated indoor table pile, windrow system (WENDELIN), postmaturation turned by frontendloader	6.000	triangle pilecomposting, operated by farmers there is no biowaste composted at the existing co-composting plant
PÖchlARN	municipality	12.000	dynamic fermentation (DANO) outdoor piles	4.500	outdoor triangle windrows
ROPPEN	municipality	22.000	Fermentation drum, forced aerated indoor pile (DYNACOMP)	7.000	forced aerated indoor windrow (DYNACOMP)
SIGGERWIESEN	municipality	160.000	Fermentation drum, forced aerated table pile, outdoor postmaturation or degassed landfill	18.000 +8.000	anaerobic digestion (<i>DRANCO</i>), yard t waste tunnel-composting (BAS), roofed postmaturation, outdoor windrows for yard waste with tablepile turning machine
TRAISKIRCHEN	municipality	17.000	dynamic fermentation (DANO), outdoor piles	3.000	windrows outdoor triangle piles for yard waste
ZELL AM SEE	municipality	20.000	Fermentation drum (DANO), forced aerated table pile (VA), outdoor pile maturation	6.000	forced aerated indoor windrow, turned stack composting (AE&E KOCH) for co-compost and biowaste compost

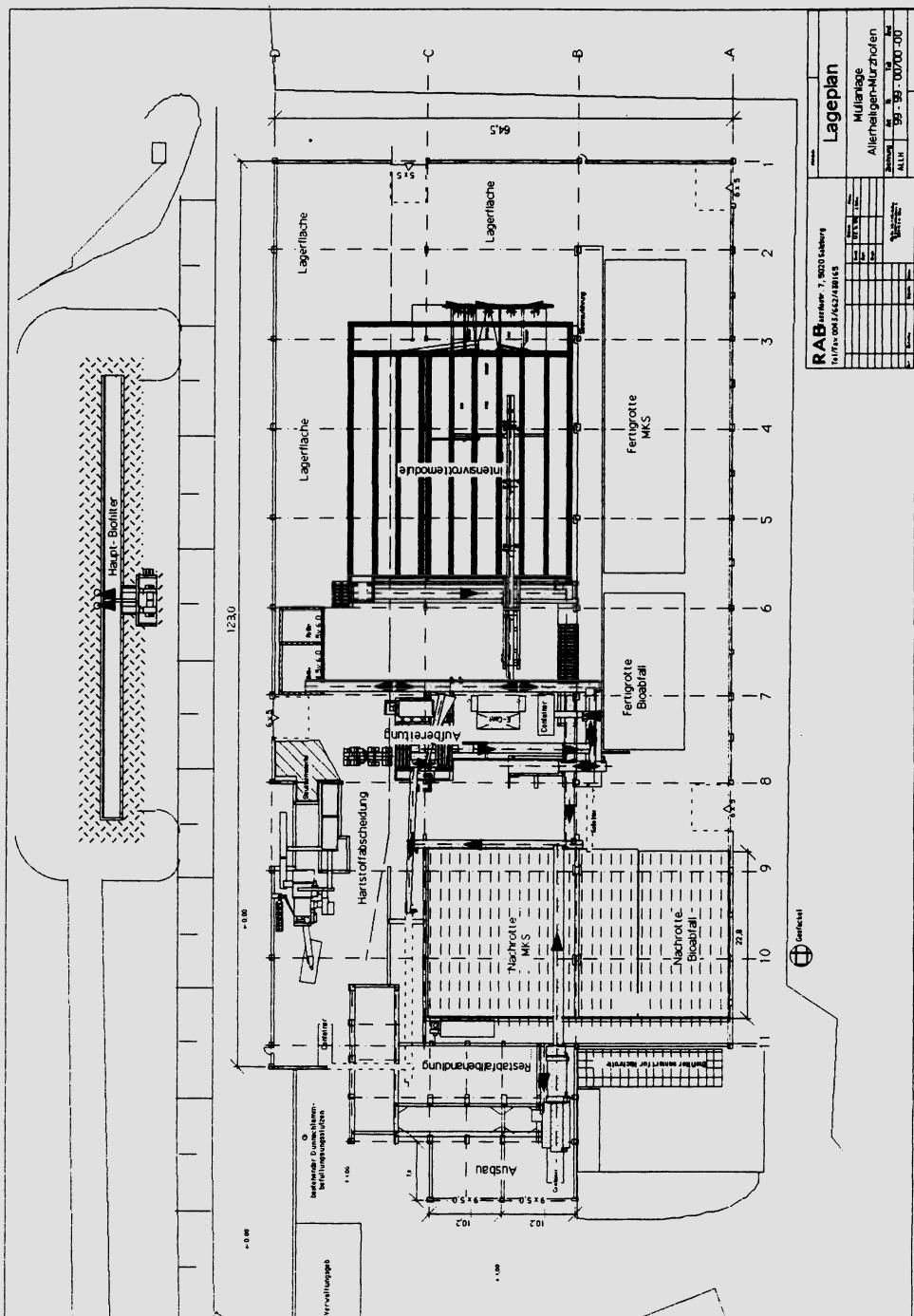


Figure 2 Layout of Allerheiligen Plant (20,000 t/a) after improvement of biological waste treatment via tunnelcomposting

- no waste water emissions, depending on the consumption on percolate water to add process water to the compost during the exothermic processphase. The process water is evaporated and discharged via the biofilter.
- short residence time to reduce the biodegradable organic matter to 50 % or 60 % DS in mass.
- low land requirement of about 0,1 to 0,2 m²/t input, concerning a residence time of 14 days
- acceptable working condition, as far as the process is automatically operated, especially during the filling and emptying procedure.
- modular design, easy to extend the capacity.
- even the central process monitoring stops, each unit is selfmanaged by a satellite processor
- a warranted hygienisation including the reused process water
- small demand of structure material or other additives
- no mechanical parts of the equipment are exposed to the corrosive atmosphere inside the operating tunnel
- an intensive air and oxygen supply ensured by an intensive air circulation in combination with the required fresh air supply, while a relatively small air volume is exhausted to the air cleaning system, which is normally a biofilter, transporting carbondioxid, water steam and energy.

Oberpullendorf

In Oberpullendorf the second largest co-composting plant of Austria is operating. permanent problems, concerning odour emissions with the DANO – WENDELIN technology have been one of the main reasons not to enlarge this plant building a biowasteline. Therefore an alternative concept was created for this mostly rural area. The biowaste of the Burgenland is treated at different decentralised composting plants, which are operated by farmers via traditional pile composting.

Roppen

Originally the THYSSEN DYNACOMP composting system was implemented for the processing of MSW. The biowaste composting is managed by the same technology. The raw compost tablepile is aerated by underpressure and the off air cleaned via biofilter. The homogenisation of the compost material is done by a mixing screw, moving through the table pile, fitted on the pile set up system.

The dynamic prefermentation in the DANO drum is not used for the biowaste processing because of the deficit of structure and pours volume of the raw compost.

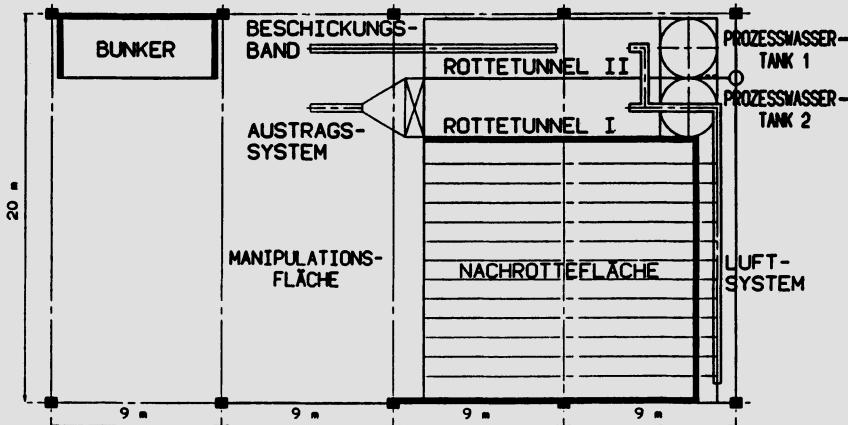


Figure 3 Basic layout of biowaste composting plant LIEZEN

Siggerwiesen

For Salzburg, a region of about 280.000 inhabitants, a biowaste plant capacity of about 15.000 to 20.000 t/a is needed. In this area two separate collection systems, one for biowaste (Biотonne) and another one to collect yard waste are existing. The mainly 120 l biowaste bins are to dispose the biowaste from households, containing mainly kitchen waste with a high water contend. Depending on former odour emissions, caused by the old co-composting plant and the Siggerwiesen landfill, before a degassing system was installed, a biowaste technology without the hazard of any production of smell has to be chosen. Depending on an anaerobic systems, which has sufficient references, available on the marked, the DRANCO fermentation system in connection with a controlled aerobic postcomposting, the BAS tunnel system, was favoured.

The DRANCO process is a one step, thermophilic anaerobic digestion process. After a mechanical pre-treatment the fraction < 50 mm is directly pumped into the fermentor. Depending on the type of biowaste (high moisture contend, minimal lignin contend) the total solids in the system are adjusted between 35 to 15 %. Below about 18 % DS a liquid anaerobic system should be chosen. In Salzburg the specific biogas production is about 130 – 140 Nm³ /t input material. The gas is used to run a 1,5 MW gasgenerator.

The postmaturation and hygienisation of the output of the anaerobic digester, is done after dewatering and after adding 10 – 20 % of yard waste screen overflow

(>12 mm < 50 mm) as a bulky agent in the BAS tunnelplant. The thermophilic phase is easily reached during the last period of aerobic stabilisation after the 10 th day of processing. After this time an additional maturation and material storage for the nitrification of ammonia is needed.

In a separate line the yard waste composting is done via a outdoor tablepile, regularly turned by a WILLIBALD tablepile windrow machine.

Zell am See

In Zell am See the old co-composting system from 1978 (DANO drum and forced aerated table pile) is totally be renewed to a forced aerated AE&E-KOCH System with automatic stack turning and moistening in a closed composting hangar. The pile is turned and moved by an automatic turning unit that travels across the trapezoid or table pile as well in line with the movement of the compost through the composting hall. At the end of the hall the compost is reclaimed with the turning unit itself. Depending on the process requirements, that are based on the composition of the compost, the required degree of maturity of the final compost is reached after approximately 12 weeks of biodegradation. The fields of compost, each pile formed as the turner moves across the trapezoid, are generally moved on a weekly basis corresponding to the rates of compost degradation and new material introduced to the hall as finished material is extracted. The exhaust air is treated in a biofilter.

The major advantages of the free programmable stack turning method are

- The composting hall is covered with compost and this provides the maximum amount of compost production from the smallest possible building footprint
- the turning frequency is freely selectable, for homogenisation and aeration of compost
- the air required for the composting hall is recirculated and finally washed, cooled and exhausted through the biofilter
- a heat exchanger provides the ability to regulate the temperature of the incoming or the exhaust air

Compost quality

The goal of all this collection and treatment strategies are, besides of the avoidance of landfill capacity, to improve the compost quality and to ensure a compost market on a long-term basis. Ballast matters, heavy metals, organic pollutants and a lack in plant tolerance have been the reasons that co-compost and sometimes also sludge – compost could not be successfully applied for example in the plant production, gardening , landscaping and agriculture. A clean inputmaterial and a high developed compost technology will provide that the objectives of organic waste recycling can be reached. In Table 3 the actual heavy metal restrictions are shown for co-compost and biowaste compost in Austria and other European countries.

Table 3 Limiting values for heavy metal in different types of Compost of Austria, Germany and Netherlands

	Limiting value SOIL	Limiting value COMPOST ÖNORM S 2200 and S 2202			Limiting value COMPOST NL & Germany	
		Class I Biowaste ecompo- st	Class II Biowaste ecompo- st	Class III Co- compost	Nether- lands	GERM RAL/ LAGA Kl. I
ÖN L1075						
Cr	100	70	70	150	50	100
Ni	60	42	60	100	20	50
Cu	100	70	100	400	60	100
Zn	300	210	400	1000	200	400
Cd	1	0,7	1	4	1	1,5
Hg	1	0,7	1	4	0,3	1
Pb	100	70	150	500	100	150
						250

Conclusion

Most of the former co-composting plants in Austria have improved their facilities with an equipment appropriate for biowastematerials. Composting and especially biowaste composting is a very complex microbial oxidation process, influenced by a few parameters like moisture contend, process temperatures, oxygen supply and CO₂ removal, the concentrations and compositions of nutrients, operated by a huge number of different types of mikroorganism in a very sensitive ecological environment. The selection of an optimal biowaste treatment technology is a very important decision. Whilst for biowaste composting dynamic systems more and more loose their importance, static, frequently turning over and homogenising indoor systems, batchwise operated and process controlled are most successful. Specially for wet-biowaste mainly one step liquid anaerobic fermentation technologies are recommended for implementation. Furthermore energy recovery from biogas is a positive effect on the world wide carbondioxid economy.

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Basic Processing Technologies and Composting Plant Design in Italy.

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Summary

This study offers an up-to-date picture of the basic processing technologies and composting plant design undertaken in Italy for the treatment of unselected MSW. Present trends in the field of the high quality compost production from pre-selected organic refuse are here analyzed in order to highlight the different components and sections of the composting plants. A special care was used in analyzing technologies proposed by the different firms for the management of the first phase of the biological process. This work integrates and concludes the state of the art and perspectives about the composting theme developed in a specific report presented in this symposium.

Introduction

Composting in Italy follows two different procedures:

- compost production from unselected wastes, developed in 42 plants located all over the nation;
- recovery and utilizing of source pre-selected organic substances, a procedure used in 33 plants located in northern and central regions.

The mixed composition of unselected refuse makes it necessary to provide a series of devices capable to ensure high efficiency and effectiveness in the operation of selection and refining upstream and downstream the biological process. The biological transformation of organic substances is effected by means of different technological systems, but process may not be satisfactory and, on the other hand, recent projects cannot fill this gap. The composting of source pre-selected waste allows for a simplified technology. This last system has been widely used, recently, but sometimes it is not well managed. The analysis of the solutions applied in both composting procedures, is not complete yet, being only a first contribution to a critical knowledge of technological situation of Italian plants.

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Analysis methodology

The scheduled plants were analyzed according a logical path of all the operations performed in sequence to treat refuse for composting. All operations that are not significant in the process or that are common to all solutions (storage, magnetic separation, rejected material treatment) were not taken into account. Following this path, the plants were divided into three fundamental operational blocks [Vastola and Pizzo, 1987]; inside each block the sections and the related electro-mechanical devices are highlighted.

The first block, defined as pretreatment, encompasses unit operations designed for the preparation of the organic substances for an efficient and controlled development of biological reactions.

The second block specifies the process solutions proposed for accelerated biostabilization and curing.

The third block includes a unit operation for the final refining of raw compost.

Composting plants for raw municipal solid wastes

In Table 1 technical characteristics of the scheduled plants are summarized. The planning and technological options of the different systems used in each block or section are defined below.

The Pretreatment block.

Receiving and feeding section.

In nearly all the scheduled plants the receiving and feeding sections are uniform made of three days capacity storage pits, by overhead cranes with grapple bucket and feeders. In three plants wastes are discharged on a tipping floor and daily removed.

Shredding section.

It is well known that this section is fundamental in composting plants, in view of both reliability and management, and of final product quality.

In 15 out of the total scheduled plants the shredding equipment are mills, but of different types:

- in 6 plants they are high speed rotating horizontal hammermills which pulverize the inert material (glass and ceramic) whose separation downstream becomes very difficult;
- in 3 plants they are impact breaker mills, with comb and counter comb or with tough steel bars;
- in 2 plants they are mills with two horizontal cutting shaft with blades and counter blades;

- in 4 plants they are low speed roller shredders, which simplify subsequent operation of separation.

In 9 plants the operation of size reduction is substituted or preceded by bag breaking. The operation is done by a rotary drum with sharp elements inserted inside. In 8 plants bag breaking is done on the upper part of the plate feeder.

The DANO type rotary drum operates also as bag breaker and size reducer of the organics by means of friction with hard materials in the refuse and by impacts with steel pikes inside the drum. This type of drums is proposed as biostabilizer of the organic fraction (see part 3.2.1), but since its detention time is too short (10 hours instead of 3–4 days), it can only be used to reduce the size of wastes.

The preselection with this rotary drum is more effective than the one realized with only mechanical systems, because the first biological transformations contribute to optimize efficiency in subsequent separation. On the other hand the costs of this kind of devices are considerable.

Organic fraction separation

Pre-treated organic waste have presumable a smaller size than raw refuse. The first and coarser separation of the organic fraction that feed the biological process, is mainly effected by means of rotary screens with hole diameters of 60–100 mm; only 3 of the scheduled cases use vibrating screens.

The organics separation in 9 plants is completed with density separation following the screening; the devices used are either ballistic or density separators. The former process is based on the different paths the particles follow after bouncing on a rotating surface; the latter process is based on the different deviations undergone by particles carried in an air stream.

In presence of fresh organic substances we must take into account that the process of density separation has a low efficiency, because the difference in specific weight between the undesirable materials and the organic fraction of the refuse is very small.

Biological process block

The section and the related technologies directly involved in the biological transformation of the organic substances are considered in the second block.

The whole process is usually divided into two distinct phases:

- the accelerated bio-oxidation at the beginning of the process, carried out in reactors;
- the curing at the end of the treatment, carried out in windrows.

The two steps are in general physically separated as above, but in some cases they can both take place either in reactor (4 plants) or in windrows (4 plants).

Accelerated bio-stabilization

The first phase of biological transformation is characterized by high-rate reaction; it is exothermic, it have a high oxygen uptake rate and it generate a potentially high environmental impact which can be lowered in a vessel system. Here the organic mass is mixed and aerated by means of forced ventilation systems. The accelerated bio-stabilization section characterizes the 'composting system'. The solutions used in Italy are presented below.

a) Horizontal rotating drums.

This system is widely used in Italy (in 8 plants) to start the biological processes (with the exception of what stated in capt. 3.1.2), it allows a first hygienisation of the material and facilitates the separation of the organic fraction from the inert components. The rotating drum is manufactured with welded steel section installed at regular intervals. Its length and diameter range between 25 and 3 m, and 42 and 6 m respectively. At the end of the drum, installed at 120 degrees, there are 3 fans. These fans insufflate the air against the flow of the refuse; an exhaust air fan is installed on the front of the drum.

This system was proposed by SLIA, Daneco and Snamprogetti.

b) Vertical reactor with multiple decks.

The structure is cylindrical and enclosed; material is fed at the top of the structure and the product is outfed at the bottom. In the Cuneo plant there is a group of 4 reactors, 24 m total height, 8 m diameter, 3 m height for each module. Each one of the 6 decks has rabbler arms for material movement and forced ventilation. The organic refuse drops from an upper deck to a lower one.

This system was proposed by Peabody.

c) Vertical cylindrical packed bed reactor.

This system is used in 2 plants. The material is fed at the top of the structure by means of a screw conveyor. The refuse passes into a system composed of 3 horizontal rotating disks that distribute the material uniformly on the pile below. The reactor is not mixed. The aeration system is composed of radial manifolds installed at the basis of the reactor, grouped into 8 sectors (angle of 45°) and fed in sequence. The air flows upward, counter-current to the flow of refuse, by means of an exhaust air fan installed at the top of the reactor. The outfed system is a screw conveyor installed on an adjustable cylinder inside the reactor; the discharge of the product is done at the center of the reactor.

This system was proposed by Weiss-Kneer.

d) Fixed basins with automatic turners.

The organic material, in these reactors, is moved and put forward inside rectangular or circular basins; these reactors are horizontal, nearly horizontal or with inclined bed; the organic fraction is moved by means of screws installed on traveling bridges. Continuous aeration is guaranteed by forced ventilation systems. The plans are different in number, volume and geometry of the reactors and in number of the screws, as summarized below:

- single rectangular reactor, horizontal or nearly horizontal, with traveling bridge on which screws are mounted coupled up to a number of 14; the material is loaded along one side of the reactor and is discharged at the opposite side.

The system is present in 4 plants and was proposed by Sorain Cecchini and De Bartolomeis.

- single rectangular reactor with inclined bed (13°) agitated by means of 4 screws attached on a traveling bridge; the mass is transferred perpendicularly to the upper loading side, of the reactor;

The system is used in 2 plants, proposed by Emit.

- single rectangular reactor with automatic turning of the material. This system is realized in one plant, with one basin crossed by a traveling bridge carrying a movable arm with screws and belts that collect and distribute the material; the organic fraction is deposited in one pile 3.5–4 m height, and moved from the cross-front to the back toward the extraction zone.

The system was proposed by Ferrero-Savona.

- multiple reactors side by side; the organic fraction is loaded along the short side and is moved forward by means of 4 screws installed on a traveling bridge. The extraction is done from the opposite side.

The system is used in 4 plants, proposed by Secit and Emit.

- circular shape reactor, with screws installed on a traveling bridge (Fairfield); the material is fed along the external circumference by means of a screw moving with the traveling bridge; the product is extracted from a central pit; the organic fraction is moved forward by means of 13 screws; the diameter of the bin varies from 10 to 17 m, with volumes from 200 to 450 cubic meters; the aeration system is on the bottom of the reactor, the manifold is divided into concentric rings (3 for each sector).

The system was proposed by De Bartolomeis.

e) Aerated dynamic troughs with automatic turning.

This system has two variants depending on the turning device employed:

- in the first case the material is discharged at the back of the device, along the advancing axis,
- in the second case the material is discharged sidewise in an adjacent trough.

accelerated bio-stabilisation area, in both systems, is divided into multiple trough; the length of these troughs depends on the detention time and on the number of the week turnings. The volume of the material to be treated each day determines the number of the troughs. The troughs in the system proposed by Saceccav and used in 5 plants (3 of which treat source-selected refuse) are 3 m wide and 2.13 m high. These troughs have a loading zone (each one loading 19 m^3 of material daily), different aerated zones and a discharge zone. Rails are set on top of the walls where the compost turner moves the material along all the length of the trough.

The device is made of a rotor (1 m diameter) with agitators mounted on the surface; of a conveyor at 45° that moves the material backward for 3.66 m at each passage and makes room for the next day; of a hoist for lowering and raising the rotor and the belt conveyor; and of a transferring dolly for moving automatically the turner from one trough to the other. The aeration system is composed of different fans, each one serving a part of a trough.

In 2 plants the turner is of the Siloda type, and is made of a paddle drum (3.5 m diameter and 4 m width), that while moving loads the material into a screw mounted on its shaft. The screw transfers the material to the adjacent trough. At the end of the cycle the turner returns to the initial position by means of a transfer dolly that moves it to the next trough; the system is aerated by forced ventilation. This technologies was proposed by OTV and Daneco.

f) Aerated cells.

The process develops inside primary cells with forced aeration.

This system is used in only one plant and was proposed by Voest Alpine.

g) Aerated and turned windrows.

This system is used in 2 plants. The turning of the windrows is carried with a turner provided with a thread-guide system that allows its automatic advancing; in both plants, since the material is side-discharged, a side free windrows needed, as well as the movement of all the windrows.

The system was proposed by Buehler and De Bartolomeis.

h) Aerated static windrows.

This system is used in 2 plants; the material is aerated by forced aeration and turned by means of a loading shovel.

The system was proposed by Daneco.

Curing

The biological process is completed in a suitable curing area. In this phase the oxygen demand is reduced, but the need to ensure favorable conditions for a regular transformation of the material and in particular for the organic substances humification is constant. The proposed solutions, in most cases, are very approximate and look more like a storage than like a biological process phase that must be controlled. The proposed solutions are usually limited only to unplanned movements the material with a loading shovel, and are managed with too extended windrows.

The final treatment block

The polluting elements still present in the compost are removed in the main section of this third block; the same equipment seen in the organic fraction separation is employed in this section. The final screening is made by means of a rotary screen with circular (or, in some cases, elliptical) mesh, with a diameter between 4

and 20 mm. In 6 plants this selection is made by means of an elastic vibrating screen (flip-flow type). The gravimetric selection is made in most plants by means of a vibrating inclined table with a fluidizing up flow forced ventilation. The ballistic separation is used in 5 plants (in one case it is used as a pretreatment). A zig-zag separator is used in 2 plants. The secondary shredding of raw compost is used in few cases; this practice is due to the need to have a thin final product.

Composting plants for source selected materials

The recovery of organic refuse by means of separate collection allows for the construction of plants with simplified electro-mechanical devices. However it must be taken into account that some types of refuse, as the catering food residues and the refuse derived from greengrocery markets, can be contaminated with 10–20 % of inerts (glass, plastics and ceramics). This requires the use of more complex structures, particularly when the inflow of refuse is important, as with the plants of Turin and Milan.

The fundamental blocks described in capt. 3 are present also in the simplest plants; for the analysis of technological systems these must be referred to (see table 2).

Conclusions

The examination of technological systems used in the composting plants described in this paper is not complete and can certainly be improved, but however it can give a better knowledge of the solutions employed in Italy both in the recent past and at the present; the aim of this work is to improve the planning philosophy for the future.

In most cases collecting data and information about the treatments is difficult because the planning solutions vary during execution. The number increases if we consider the great delay in plant commissioning.

The general view of the situation highlights a wide availability of systems and equipment, which, however, are not always reliable and efficient.

The modifications that can be proposed for plants treating raw MSW are the following:

- to provide the plant with receiving section for storage of source pre-selected organic fraction and the conditioning with specific equipment before composting;
- to manage the biological process of this pre-selected materials, with the aim of producing a first quality compost by means of existing devices or of up-to-date equipment;
- to remove hammermills shredding; .

- to remove the thin fraction of the material very often full of heavy metals;
- to manage the bio-oxidation phase in a more controlled way;
- to equip and manage the curing phase in a suitable manner.

Modern trends, employed by plants treating source pre-selected materials, warrant the highest technological simplification and, at the same time, the production of a highly agronomic valuable compost, environmentally safe.

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Table 1 The technological solution in raw MSW composting plants.

PLANTS AND PRETREATMENT		BIOLOGICAL PROCESS		FINAL TREATMENT	
TREATMENT CAPACITY	Devices			Devices	
Cuneo 150 t/d	Hammermill (330 kW, 1,490 rpm) Rotary screens, mesh 50x80 mm and 8 mm	Accelerated bio-oxidation	Curing	Windrows in covered area	12 days + 20 days densimetric table, final shredding. Detention time
Novara 255 t/d	Primary rotary screen with bag breaker, secondary screen, air classification, sludge mixer	Rectangular covered reactor, inclined bed (13°), length 72 m, width 21 m, useful deep 2.5 m, bridge crane with 8 screws	In covered area	30 d+ 40 d	Air separation, cylinders-mill.
Cedrasco (SO) 100 + 50 t/d	Refuse receiving pit, bag breaker, rotary screen, mesh 250 mm.	Two Dano horizontal rotating reactors, length 42 m, diameter 4 m; the first phase is completed in a 1,500 m ² area, turning windrows.	In area, not yet realized	4–5 d + 20–25 d	Screening before the curing phase, vibrating table.
Alessandria 100 + 40 t/d	Rotary screen with bag shredding.	Dano horizontal rotating reactor, length 42 m, diameter 4 m; raw screening (100 mm) in the final side.	In 2 sections with 7 windrows in each one; CNTM turning device; forced ventilation with 14 fans	72 hours + 60–70 d Screens 50 mm and 16 mm before curing phase, final rotary screen with elliptical 6x12 mm holes, vibrating table.	
Ceresara (MN) 160 t/d	Hammermill with combs and counter -combs (160 kW), rotary screens 40 and 80 mm mesh, air classification	Static aerated windrows in covered area, 1,200 m ² divided in 10 spans; forced ventilation realized with 4 manifold/ windrow served by 9 + 9 fans	Covered area, 1,200 m ²	30 d + 90 d	Zig-zag separator, vibrating screen, 15 mm mesh.
Pieve di Coriano (MN) 210 t/d	Like above	Like above	Like above	Like above	Hammermill with 12 little hoes, Flip-flow screen, 5–12 mm mesh, vibrating table.
S.Giorgio di Nogaro (UD) 280 t/d	Hammermill with vertical axis (250 HP), rotating screen with 4 sectors with holes from 10 to 35 mm, bridge; one pile up to 4 m height, forced aeration by means of 27 fans.	Horizontal bioreactor, 3,000 m ² , mobile arm with screws installed on a traveling table (flip-flow) with mesh 10 mm.	Covered area	28 d	Densimetric table, vibrating elastic screen (flip-flow) with mesh 10 mm.

Udine 280 t/d	Rotating/shredding screens with mesh 10 and 70 mm, vibrating screens with mesh 40–70 mm, hammermill	Two cylindrical bio-stabilizers then, in Static aerated windrows in an area of 1,200 , 5 turned and aerated troughs with a wheel turning device installed on rails.	14 d + 30 d	Flip-flow screen, densimetric separation, compost dryer.
Villa Santina (UD), 90 t/d	Shredding cylinder with blades	Horizontal rotating reactor, DANO-type, 25 m length	Eight static aerated windrows 30 d	Rotating octagonal screen (mesh 30 mm) before curing, Zig-zag classification, vibrating screen (18 mm mesh).
Bolzano	Rotating screen, mesh 70x70 mm, with bag breaker, manual selection on a tape conveyor, roller shredder (160 kW), secondary screen, sludge mixer	Three primary vertical cylindrical reactors (Weiss-Kneer), 18.3 m diameter, 1.3 m total height, 9 m useful height, 2,400 m ³ volume, bottom aeration	Three secondary reactors, as before. 21 d	Flip-flow screen, 8 mm mesh, densimetric table.
Bressanone (BZ), 75 t/d	Hammermill with 2 horizontal rotors, 130 kW, mixer/rotating screen 35 mm mesh.	Six turned aerated windrows in a covered area of 6,000 m ² , automatic turning equipment Buehler Compo-Star 4000, 52 kW, 150 m ³ /h.	Four windrows in covered area of 3,600 m ² 40 d	Rotating screen 10 mm mesh, densimetric table.
Pontives (BZ)	Impact breaker, rotating sludge mixer drum.	Primary aerated cells, each one with a capacity of 150 t	Secondary cells in covered area 60 d	Vibrating combs screen, Flip-flow screen, 10 mm mesh, air separation.
Feltre (BL) 120 t/d	Aerated area, turning with a specific turning machine			
Schio (VI) 160 t/d	Refuse receiving pit with a capacity of 1,500 m ³	Horizontal rotating reactor, DANO-type, One windrow in a covered area, the others uncovered, turned by a loading shovel.	48 hr + 90 d	Rotating screen, 12 mm mesh, and ballistic separator before the curing. Screen, 8 mm mesh, and rolling mill.
Carpì (MO) 300 + 25 t/d	Bag breaker, knifes-mill for pre-selected organic refuse, primary selection.	Two horizontal rotating reactors DANO-type.	Turned windrows, aerated in a half of the area 60 d	Rotating screen, air classification.
Ozzano (BO) 110 t/d	Shredding screen with 60 mm holes, air separation, knifes-mill.	Two vertical cylindrical reactors (Weiss-Kneer), 11.4 m total height, 8.2 m useful height, 1,500 m ³ each one.	Uncovered aerated windrows 30 d	Screen, 10 mm mesh, rolling-mill.

Table 1 Continued

PLANTS AND PRETREATMENT TREATMENT Devices CAPACITY		BIOLOGICAL PROCESS	FINAL TREATMENT Devices	
		Accelerated bio-oxidation	Curing	Detention time
S Agata bolognese (BO)	Knives shredding screen with 60 mm holes, slow knifes -mill (45 kW), mixer (22 kW), rotating screen. 170 + 70 t/d	Eighteen windrows, in an area of 2,800 , turned by a device installed on a traveling bridge; forced aeration with 2 insuffating and 2 extracting fans.	Covered area, 2,800 m ² , turned by CRAI device, 137 kW, 1,200–2,000 m ³ /hr.	21 d + Rotating screen, ballistic separator; for the high quality line: fine screen and rolling mill
Massa Carrara	Hammermill, rotating screen with 20 mm mesh, sludge mixer with 6 coupled screws 250 t/d	Circular aerated reactor Fairfield-type, 17 m diameter, 2 m useful height, 400 m ³ volume, Traveling bridge with 13 screws, 250 kW.	Static windrows, 3 m height, forced aeration in a covered area	Air separation, rotating screen 8 mm mesh. 40–50 d
Sesto Fiorentino (FI)	Three dimensional screen, densimetric table, air separation, ballistic separation, sludge mixer. 385 t/d 45 d	Turned and aerated troughs (19+5), 3,920+1,200 m ³ total volume, 2 Royer-type devices installed on rails. Rotating screen, air separation, final shredding.	Static windrows, turned with loading shovel.	18-30 d +
Pistoia	Bag breaker with sharps. 210 t/d 60 d	Two horizontal rotating cylinders Dano-type, 42 m length, 6 m diameter.	Turned windrows in uncovered area.	36–48 hr + Rotating screens, 30 and 10 mm mesh, and ballistic separation before the curing.
Ascoli Piceno	Bag shredding on belt conveyor, rotating screen for three outflows (organic fraction from 20 to 80 mm). 260 t/d	Five horizontal rectangular covered reactors, 30 m length, 10 m width, 2.5 m deep, 3,750 m ³ volume, with 4 turning screws installed on a traveling bridge, forced aeration by each one 5 fans.	Uncovered windrows 30 d + (8), turned with a loading shovel, on 2 areas of 1,600 m ²	Screen, 20 mm mesh, vibrating . 30 d
Fermof(AP)	Like above, no sludge mixer 210 t/d	Four reactor, like above.	Uncovered windrows 30 d+30 d	Rotating screen, densimetric table.
Pollenza (MC)	Hammermill, rotating screen, 40 mm mesh, sludge mixer. 180 t/d	Two horizontal cylinders Dano-type, 27 m length, 3.5 m diameter; the first phase is done in 20 turned and aerated troughs, 2,300 m ³ volume, with a Royer turning device.	The second phase is done in 27 turned and aerated troughs with another Royer device	2–3 d 15 d + 24 d

Perugia 380 t/d	Bag breaker, rotating screen with square 80 mm holes.	Horizontal aerated reactor 70 x 21 m, turned by screws installed coupled on a traveling bridge.	Uncovered storage of large windrows.	28 d	Rotating screens, 12 and 4 mm mesh, air separation.
Foligno 110 t/d	The refuse is selected by mechanical and by air systems	Like above		28 d	
Col S.Felice (FR) 60 t/d	Bag breaker, knife-mill, rotating screens with 35 and 20 mm mesh, sludge mixer.	Rectangular aerated reactor turned by screws.		28 d	Rotating screens, air separation.
Terracina (LT) 150 t/d	Sharps bag breaker.	Horizontal rotating reactor Dano-type	Windrows turned by a specific device	48-72 hr + 20 d	Rotating screen and vibrating before curing, then air separation.
Pescara 200 t/d	Bag breaker on belt conveyor, polygonal screen with 3 flows of material, sludge mixer.	Two side-by-side inclined closed reactors, 3,000 m ³ each volume, screws installed on a traveling bridge.	Windrows turned by a loading shovel	30 d + 30 d	Flip-flow screen, densimetric table.
Sulmona (AQ) 80 t/d	Rotating screen with 110 mm holes and bag breaking shafts, sludge mixer.	Two side-by-side uncovered reactors, 700 m ³ each volume, 4 turning screws installed on a traveling bridge, aerated by 1 fan/reactor.	Uncovered windrows, on a 2,400 m ² area, aerated by 4 fans	15 d + 20 d	Ballistic separation, hammermill, rotating screen and densimetric table.
S.Maria Capua Vetere (CE)	Two knife-mills (37 kW each one), rotating screen with 20-60 mm mesh.	Two turned aerated closed rectangular reactors, 50 m length, 8 m width, 14 coupled turning screws installed on a traveling bridge, forced aeration by means of 7 manifolds.	3+1 covered windrows, aerated and turned by a specific device.	28 d + 32 d	Rotating screen, air separation.
Vallo di Diano (SA) 60 t/d	Bag breaker, hammermill, rotating three-dimensional screen (little fraction out at 20 mm)	Circular closed reactor (Fairfield), 10 m diameter, 13 turning screws installed on a rotating bridge.	8 covered windrows, turned by a CNTM specific device (55 HP)	4 d + 60 d	Rotating screen, 12 mm mesh, densimetric table.
Matera 62 t/d	Bag breaker on a belt conveyor, knife mill (75 kW), rotating screen, sludge mixer.	Aerated reactors (4 basins), 700 m ³ each volume (30 m length, 10 m width, 2.5 m deep), turned by 4 screws installed on a bridge crane, forced ventilation by 1 fan.	One windrow, height, on an uncovered floor, 1,000 + 1,000 m ² .	28 d + 60 d	Two rotating screens, 40 and 12 mm mesh, respectively, densimetric table.
Macomer (NU) 160 t/d	Rotating screen, 350 mm mesh, with shafts, secondary screen, 30 mm mesh, sludge mixer.	Aerated troughs (6 + 6), 50 m length, turned by a Siolad-type paddle wheel.	Uncovered area	28 d + 60 d	Flip-flow screen, 10 mm mesh, and ballistic separation.

Table 2 Present trends for processing technologies and composting plant design in Italy.

PLANTS AND PRETREATMENT		BIOLOGICAL PROCESS	FINAL TREATMENT	
TREATMENT CAPACITY	Devices	Accelerated bio-oxidation	Curing	Detention time
Trento District 55 t/d	Sludge and vegetables received in 3 uncovered tanks, hammermill (124 kW) and knife-mill (290 kW), mixing with loading shovel.	The process is now managed in one phase, in a covered 10,000 m ² area, 10 windrows turned by a Scat 4883 specific device (103 kW, 1,200–2,000 m ³ /hr). In a short time it will be realized a new 3,600 m ² area with 4 windrows, aerated by 10 fans.	now 90 d, then 33 + 57 d	Hammermill (60 kW), rotating screen, 10–25 mm mesh (Favorit max, 42 kW)
'Consorzio Bonifica Valle Scrivia' Tortona (AL) 90 t/d	Sludge receiving in 9 pits with dosing screws, vegetables storage in uncovered area (7,320 m ²) and in covered area (1,800 m ²), 3 mixers.	Closed aerated troughs (15), forced ventilation by 4 fans/rough, 3 turning device Royer-type moving on rails (62 kW each one).	Uncovered area, 3,650 m ² , the windrows are turned by a loading shovel.	21 d + ballistic separation, rotating screen with 3 outflows (compost at 10 mm), packaging device.
Agrinord Isola della Scala (VR) 96 t/d	Sludge receiving in 2 covered tanks, vegetables storage in uncovered area; the mill is rented; turning with loading shovel.	Five closed glasshouses, 2,800 m ² , turning by a straw-distributing device (in a short time it will be a CRAI specific device, 137 kW 1,200–2,000 m ³ /hr).	Twenty unclosed glasshouses, 11,200 m ² , turned windrows.	30 d + Rotating screen, 8 and 12 mm mesh, packaging device.
CE.LO.Mira (VE) 57 t/d	Sludge and wet fractions receiving in a covered box 1,500 m ² , vegetables storage in uncovered area, hammermill (184 kW), mixing by loading shovel.	Closed area, 4,500 m ² , the windrows are turned by a specific device (178 kW, 1,00–2,000 m ³ /hr), forced aeration.	Uncovered turned windrows.	30 d + Hammermill (135 kW), rotating screen (10–20–40 mm mesh), packaging devices.
Eco-pol Bagnolo Mella (BS) 68 t/d	Sludge receiving in 2 concrete uncovered tanks, vegetable storage in a covered area, hammermill (200 kW), mixing by loading shovel.	Closed tunnel, 90 × 10 m, turning and forwarding by belt conveyors installed on a bridge crane (45 kW, 400–500 m ³ /hr).	Windrows turned by a Backhus specific device (136 kW, 1,00–1,500 m ³ /hr).	28 d + Rotating screen, 8–15 mm mesh (41 kW).
Ecopi Ghislarengo (AL) 77 t/d	Organic refuse storage in closed sectors, vegetables storage on uncovered floor, shredding, mixing.	Aerated windrows in a closed area, turned by a specific device	Curing on uncovered floor	20 d + Dryer, refining and packaging.

Ecopì Casalcimelli (AL) 34 t/d	Sludge receiving in 2 tanks, vegetables storage in uncovered area, hammermill, mixing by loading shovel.	Windrows (12) turned by a specific device (Morawetz, 96 kW, 400–500 m ³ /hr).	Windrows covered by a sheet (synthetic non woven material)	28d+ 60 d	Screen with 50 mm mesh, Hammermill, dryer, screen 2–5 mm mesh.
Maserati Piacenza 79 t/d	Vegetable storage in uncovered 60 m ² area, hammermill (135 kW), mixing by loading shovel.	One phase process, 26 windrows, coupled, in 10,350 m ² area, covered by a sheet (synthetic non woven material), the specific turning device (Kompatech 300, 500–700 m ³ /hr), is moved by a tractor (90 HP).	Horizontal reactor, 60 m length, 3 m width, 1 m deep, specific turning device Okada-type, forced aeration in the first 2/3 of the trough by 2 fans.	80 d Uncovered windrows 30 d + turned by a loading shovel.	Hammermill and vibrating screen (50x50 and 14x14 mm mesh, 67 kW)
AMIU (IMO)- CRPA (RE) Test-plant	Storage, shredding, mixing by loading shovel.				Rotating screen
AMIA Rimini 41 t/d	Four covered pits, vegetable storage in uncovered area, hammermill (300 HP), pre-mixer, rotating cylindrical mixer.			45–60 d	Rotating screen 20 mm mesh.
Bioter 25 t/d	Vegetables storage in uncovered area, One phase process in uncovered area, table-windrows hammermill (243 kW)	10 x 20 m up to 10 x 40 m, 2.7 m height, turned with loading shovel]	120 – 180 d	Rotating screen (54 kW)	
Castelfranco (TV) 25 t/d	Vegetables storage in uncovered area, Process in one phase in 13,000 m ² area, windrows turned by a specific device.	10 x 20 m up to 10 x 40 m, 2.7 m height, turned with loading shovel	150 – 180 d	Rotating screen 10 mm mesh.	
Castiglione delle Stiviere (MN) 11 t/d	Receiving floor, hammermill, mixing by loading shovel.	Covered 2,800 m ² area, 6 aerated windrows, 3 aeration manifold for each one, 3 fans.	80 d	To be defined.	
Vignola (MO) 15 t/d	Three receiving boxes, mixer- shredder with 5 horizontal and 1 vertical screws.	A 1,028 m ² area, 7 windrows aerated by A 1,828 m ² area, 4 manifolds each one and 7 fans. with 7 windrows.	21 d + 40 d	Rotating screen.	
Alba-Brià (CN) 74 t/d	Closed 520 m ² area, shredding for vegetables, screen-bag breaker, mixer with 2 dosing screws.	Closed 4,770 m ² area, 9 aerated windrows, 18 fans, turning with Morawetz specific device.	Nine windrows turned a second time with Morawetz device.	21 d + 40 d.	Rotating screen with 10–15 mm mesh.
Vigonza (PD) 25 t/d	Three receiving tanks (160 m ²), hammermill to be defined, mixing § by loading shovel.	One phase process, covered 3,178 m ² area, 8 windrows turned 90 d by CRAI specific device with elevator belt (137 kW, 1,200–2,000 m ³ /hr, belt width 3.15 m).			Screen with 10–15 mm mesh.
Spresiano (TV) 14 t/d	Vegetables storage in 160 m ² tanks, market refuse receiving in 80 m ² tank, shredding, mixing by loading shovel.	Covered 1,000 m ² area, 4 windrows, the specific turning device (Kompatech 300, 500–700 m ³ /hr), is moved by a tractor (90 HP).	Uncovered area, 5 windrows 77 m length, 4 windrows 22 m length.	28 d + 120 d	To be defined.

Table 2 Continued

PLANTS AND PRETREATMENT TREATMENT Devices CAPACITY		BIOLOGICAL PROCESS		FINAL TREATMENT Devices	
		Accelerated bio-oxidation	Curing	Detention time	
Turin AMIAT	Two receiving pits, bag breaker on the belt conveyor, hammermill, rotating screen with 100 mm mesh, rotating mixer.	Thirty windrows turned by a specific Royer device with rotor and reller, installed on rails, forced aeration by 2 fans for each trough.	Covered area, windrows turned by 2 screws installed on a traveling bridge.	32 d + 38 d	Rotating screen with 20 mm mesh, densimetric table.
Milan AMSA 118 t/d	Receiving pits, bag breaker on the belt conveyor, hammermill, rotating screen with 100 mm mesh, rotating mixer with 2 screws.	Twenty windrows turned by a specific Royer device with rotor and reller, installed on rails (72.6 kW), forced aeration by 2 fans for each trough.	Windrows (28) turned by 2 screws installed on a traveling bridge.	28 d + 60 d.	Rotating screen with 20 mm mesh, densimetric table.
Verbania (NO) 14 t/d	Three receiving tanks, shredder-mixer with 2 screws.	Closed 720 m ² area, 3 turned windrows, forced aeration by 6 fans.	Closed 1,440 m ² area, 6 windrows.	28 d + 90 d.	Rotating screen with 10x25 mm holes
Saluzzo (CN) 20 t/d	Sludge receiving in 2 closed sectors, vegetables storage in uncovered area, shredded-mixer.	Closed 1,580 m ² area, 4 windrows aerated and turned by a specific device.	Five windrows in a closed 1,580 m ² area, 60 d. turned by a loading shovel.	24 d + To be defined.	To be defined.
Pirinoli Paper-mill Roccavione (CN) 14 t/d		Turned and aerated windrows in covered area		20 d +60 d	
Agriseta (NO) 27 t/d		Windrows inside a tunnel, turned by a specific device (Tritter, 44-59 kW, 300-350 m ³ /hr) moved by a tractor	Uncovered area.	120-150 d.	Shredding and screening with 15 mm mesh.
Italconcimi (TO) 27 t/d		Uncovered 15,000 m ² area, windrows turned by a loading shovel.			
S. Carlo fertilizers (TO) 27 t/d		Uncovered 25,000 m ² area, windrows turned by a loading shovel			
Faenza (RA) 55 t/d		Nine turned and aerated troughs, 1,800 m ² area.			The plant is described in a specific relation presented in this Congress.
Senigallia (AN) 151 t/d	Sludge and saw dust storage in closed tanks, 2,000 m ³ volume, with screw extraction, mixer.	BAV vertical closed reactor, 300 m ³ volume, fed on the top, outlet in the bottom, forced aeration in the bottom	Windrows 1.5-2 m height	14 d + 42-56 d	

Design of Passively Aerated Compost Piles: Vertical Air Velocities between the Pipes

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Abstract

Our goal is to develop design procedures for passively aerated compost piles. In this system, piles are built on a base of porous material such as straw or peat moss. Perforated pipes are placed on this base, and the compost pile built over the base and pipes. The pipes are open to the atmosphere on the ends. As the warm moist air in the compost piles rises, the pipes increase the amount of fresh air drawn into the pile by free convection. The piles are not turned, nor is forced aeration equipment used, which significantly reduces the operating and capital expenses associated with these piles. The specific geometry considered here is that of a long windrow with pipes embedded in the porous base perpendicular to the length of the windrow. Currently, mathematical models are not available that describe these piles to aid in design, and optimum pile configurations and materials are worked out by trial and error.

Models are difficult to develop for passively aerated piles because the air flow rate is not explicitly known, but coupled with pile temperature. In this paper, we develop a mathematical model to calculate the upward air flow velocity over a

$$\frac{v_y}{}$$

pipe, v_{yo} , and the fraction of that velocity $\frac{v_{yo}}{}$, that is present as one moves away from the pipe. The temperature difference between ambient air and the pile is used to calculate the driving pressure drop. This model can be solved analytically, and

$$\zeta = \frac{Kd^2 \rho}{K_b H H_b \rho_b}$$

contains one dimensionless number, $\frac{v_y}{}$, which characterizes

$$\frac{v_y}{}$$

v_{yo} , where K is the permeability of the composting material, d is the distance

between the pipes, K_b is the permeability of the porous base, H is the height of the pile, and H_b is the height of the porous base. The results of these air flow calculations will serve as starting point to design passively aerated piles.

Introduction

In a compost windrow, air is heated due to microbial metabolism and rises, pulling in fresh air via a chimney effect. This passive aeration can be enhanced by strategically placing perforated pipes in the pile to increase airflow through the pile. Such an approach is attractive when the capital and operating costs associated with frequent turnings or forced aeration equipment cannot be justified. These piles would also be attractive in bioremediation technologies to minimize handling and potential spreading of contaminated wastes. Although several workers (Mathur, Daigle et al. 1988; Mathur, Patni et al. 1990; Mathur 1991; Patni, Fernandes et al. 1992) have illustrated the feasibility of these systems, design procedures are not readily available to extend these results to different pile configurations or feed materials. This is because, unlike in forced aeration systems, air flow, substrate degradation and heat removal are coupled. Consequently, it is difficult to accurately predict how pile dimensions, the number and placement of perforated pipes, and the feed composition will affect pile performance.

The air flow rate is a key parameter in any compost model because it determines whether the pile will be aerobic or anaerobic, and the rate of heat removal by water evaporation. Current models for static pile forced aeration processes are possible because the air flow rate can be controlled by the operator and is therefore known. In a passively aerated pile, the air flow rate intrinsically is coupled with temperature. This coupling prevents direct analytical solutions, and requires rigorous numerical solutions involving finite element or finite difference methods. This problem is even beyond the scope of current computational fluid dynamics models because the problem includes several difficult aspects, such as free convection in porous medium, reaction on the media surface, a phase change (vaporization of water), and the need to track various species, especially oxygen.

We seek to develop a simpler, mathematically tractable model that still embodies the important aspects of a composting process. A simpler model should emphasize the relationships between design variables and process variables that may be lost in all of the detail provided by a numerical model. This paper represents a first attempt at developing correlations for the air flow rate in a passively aerated pile.

Problem Definition

Figure 1 illustrates the windrow geometry considered in this paper. The windrow is built upon a base of porous material, such as straw or wood chips, having a

height H_b and a permeability K_b . The permeability is a measure of how freely air can flow through the material. Pipes are embedded in the porous base across the pile's width, with a distance d separating them. The air here has a temperature T_b and density ρ_b , which are at ambient conditions (T_o and ρ_o) since no composting reaction occurs in the base. The compostable material (permeability K) is piled to a height H on this porous material. We neglect temperature gradients, and assume that the temperature T and air density ρ in the pile are constant. Typically, the pile is covered with a material like peat moss, straw or finished compost to provide insulation and act as a deodorizer. We assume that this material had the same physical characteristics as the compostable material, and this layer was included in the pile height H . However, the model can easily be modified to include a covering layer. In the chosen coordinate system, x is in the horizontal direction perpendicular to the pipe length, y is the vertical direction, and z is the horizontal direction parallel to the pipes.

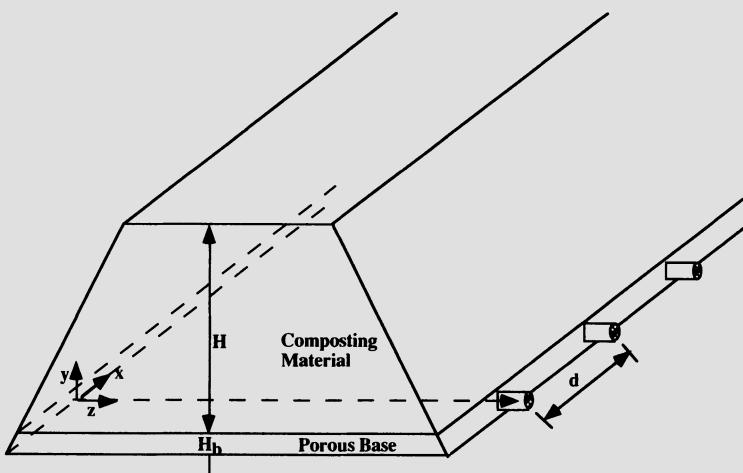


Figure 1 Compost Pile Geometry

Air flows through this pile via free convection, as the warm air in the pile rises and pulls in fresh air. In the considered problem, air enters the pipes and travels down the pipe length. At some point, the air will exit the pipe, and travel upward and outward through the compost pile, eventually exiting through the pile surface. It is this part of the journey, after the air exits the pipe and begins to travel through the pile itself until the air exits the pile, that we will concern ourselves with in this paper. Pressure losses and air flow rates in the pipe will be addressed in a later paper.

Several simplifying assumptions were made in the following calculations:

1. Air can exit the pipe at any point along the pipe. This effectively neglects the effects of hole spacing, and allows the following assumption.
2. Once air exits the pipe at a particular value of z , it no longer can move in the z direction; but is limited to the $x-y$ plane at that particular z , until the air exits

the pile. This implicitly assumes that pressure drop along the length of pipe and across the exit holes, ΔP_{pipe} , is small, and confines us to regions where the pile height is constant. This assumption allows us to reduce air flow through the pile to a two dimensional problem.

3. Air can only travel horizontally through the porous base in the x direction, and only vertically (y direction) through the compostable material. While we might realistically expect the air to follow a curved streamline, identifying these streamlines requires a rigorous numerical finite difference or finite element model. This assumption allows the problem to be solved analytically by reducing the two dimensional problem even further to two one-dimensional problems.
4. The fluid, air, can be treated as an incompressible fluid in the composting and base material since the pressure drops encountered in this process are small. We assume a uniform temperature in the composting material, and allow a density change between the porous bed and the composting material.
5. The base material has a higher permeability than the composting material ($K_b > K$).
6. The mass of air entering the pile through the porous base and exiting the pile surface are the same. This neglects the change in mass caused by oxygen consumption, CO_2 and NH_3 generation, and water vaporization.

The specific goals of this part of the model are:

1. Determine v_{yo} , the upward air velocity at $x = 0$.
2. Determine $\Phi = \frac{v_y}{v_{yo}}$ from $x = 0$ to $x = d/2$.

Darcy's Law

Flow through porous media is governed by Darcy's Law (Nield and Bejan 1992), which is written as

$$v = -\frac{K}{\mu} \left(\frac{\Delta P}{L} \right) \quad (1)$$

where v is the fluid (in this case, air) velocity; μ is the fluid viscosity, K is the permeability of the porous medium, and ΔP is the pressure drop across a length L of the medium. The permeability K , has units of area; as K increases, air can flow more easily through the medium. Darcy's Law applies only for low flow rates, and requires that

$$Re_K = \frac{\rho v K^{1/2}}{\mu} < 1 \quad (2)$$

where Re_K is the Reynolds number.

The pressure difference driving passive aeration can be calculated as

$$\Delta P = \int_0^H (\rho_b - \rho(z)) g dz$$

where g is the gravitational constant. This becomes

$$\Delta P = (\rho_b - \rho) g H \quad (3)$$

with the assumption that T and consequently ρ are constant throughout the pile. When calculating ρ , the effect of the water vapor must be included as this can contribute significantly to the density difference between ambient air and air within the pile (Haug 1980). ΔP represents the pressure difference driving force from the point where air first enters one of the pipes until it exits from the surface of the pile.

As stated in assumption 3 and illustrated in figure 2, in this model the air is constrained to flow only in the z direction through the pipe, then to flow only in the x direction through the porous base beneath the pile, and finally flow vertically upward in the y direction only through the pile. The entire pressure drop of equation (3) can be thought of as the sum of three components, namely, the pressure drop in the pipe and its exit holes, the base, and through the pile,

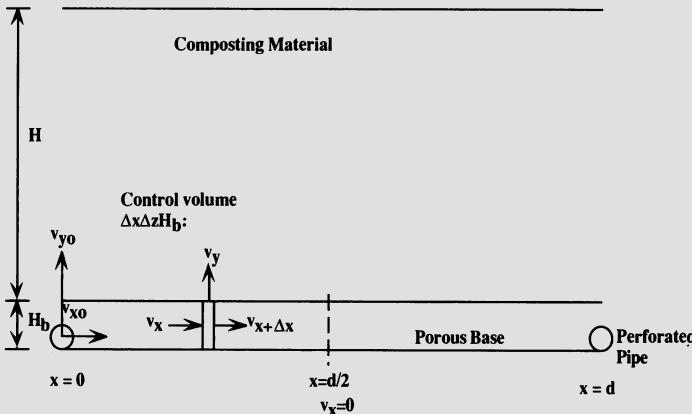


Figure 2 An interior slab of the compost pile. Air exiting the pipe can either travel straight up, or travel horizontally through the pile base before traveling straight up, and exiting the pile surface.

$$\Delta P = \Delta P_{\text{pipe}} + \Delta P_{\text{base}} + \Delta P_{\text{pile}} \quad (4)$$

At the present time, calculating the pressure drop as the air moves through the pipe, ΔP_{pipe} , will be neglected here. Thus, let us approximate equation (4) as

$$\Delta P \approx \Delta P_{\text{base}} + \Delta P_{\text{pile}} \quad (5)$$

Both ΔP_{base} and ΔP_{pile} will change as a function of x , but the sum of these pressure drops, ΔP , will remain constant. At $x = 0$, $\Delta P = \Delta P_{\text{pile}}$, since air traveling upward at that point does not have to travel (much) through the porous base. For

simplicity in the equations which follow, let us define

$$Y = \Delta P_{\text{pile}} \quad (6)$$

and

$$Y_o = \Delta P \quad (7)$$

where Y is a function of x and Y_o is a constant.

At any point x , the vertical velocity of air traveling through the pile in the y -direction is

$$v_y = \frac{KY}{\mu H}, \quad (8)$$

and let us define

$$\Phi = \frac{v_y}{v_{yo}} = \frac{Y}{Y_o} \quad (9)$$

Our challenge, then, is to determine Y as a function of x . To do this, consider the control element $\Delta x \Delta z H_b$ shown in the porous base in Figure 2. Applying a mass balance and using the constant density assumption, we find

$$v_x H_b \rho \Delta z = v_{yb} \rho \Delta z \Delta x + v_{x+\Delta x} H_b \rho \Delta z \quad (10)$$

which simplifies to

$$\frac{v_x - v_{x+\Delta x}}{\Delta x} = \frac{v_{yb}}{H_b}. \quad (11)$$

The quantity v_{yb} in (10) and (11) is the velocity the air has when exiting the porous base, where it has a density ρ_b . Considering an arbitrary area $\Delta x \Delta z$ and assumptions 6 (constant mass), 2 and 3 (fluid flows only vertically in pile), we can write

$$\rho_b v_{yb} \Delta x \Delta z = \rho v_y \Delta x \Delta z \quad (12)$$

which leads to

$$v_{yb} = \frac{\rho}{\rho_b} v_y \quad (13)$$

Taking the limit as $\Delta x \rightarrow 0$ in equation (11), and combining with equations (8) and (13), we find

$$\frac{dv_x}{dx} = - \frac{K\rho Y}{\mu \rho_b H H_b}. \quad (14)$$

Applying Darcy's Law to this control volume yields

$$\frac{dY}{dx} = - \frac{v_x \mu}{K_b}. \quad (15)$$

Equations (14) and (15) will be subject to the following boundary conditions:

$$\text{At } x = 0, Y = Y_o; \quad (16)$$

$$\text{At } x = d/2, v_x = 0. \quad (17)$$

By applying the chain rule, x can be eliminated from (14) and (15) to obtain

$$\frac{dY}{dv_x} = \frac{Av_x}{Y} \quad (18)$$

where

$$A = \frac{\mu^2 H H_b \rho_b}{K_b K \rho} \quad (19)$$

The boundary condition will be

$$\text{At } Y = Y_o, v_x = v_{xo} \quad (20)$$

where v_{xo} denotes the velocity at $x = 0$, which is an unknown that must be determined.

Integrating with boundary condition (20), we recover

$$Y^2 - Y_o^2 = A(v_x^2 - v_{xo}^2). \quad (21)$$

To determine v_{xo} , equation (21) is solved for Y , and the result inserted into equation (14). Integrating yields

$$v_x \sqrt{A} + \sqrt{Y_o^2 - A(v_{xo}^2 - v_x^2)} = (v_{xo} \sqrt{A} + Y_o) e^{-\sqrt{\zeta} \left(\frac{x}{d} \right)} \quad (22)$$

where

$$\zeta = \frac{K \rho d^2}{K_b H H_b \rho_b} \quad (23)$$

Now we can apply the boundary condition in equation (17) and solve for v_{xo} :

$$v_{xo} = \frac{Y_o}{\sqrt{A}} \left(\frac{1 - e^{-\sqrt{\zeta}}} {1 + e^{-\sqrt{\zeta}}} \right) \quad (24)$$

and using equation (21), can also determine Y at $x = d/2$.

Next, equation (21) is solved for v_x , and the result inserted into equation (15). Integrating again with boundary condition (16), we recover

$$Y + \sqrt{Y^2 - Y_o^2 + Av_{xo}^2} = (v_{xo} \sqrt{A} + Y_o) e^{-\sqrt{\zeta} \left(\frac{x}{d} \right)} \quad (25)$$

This equation can be simplified considerably by using the following substitution

$$a = e^{-\sqrt{\zeta}}, \quad (26)$$

and combining equation (25) with equations (24) and (9) to recover

$$\Phi = \frac{a^{(x/d)} + a^{(1-x/d)}}{1+a} \quad (27)$$

We have plotted Φ as a function of (x/d) for various values of a in Figure 3. The parameter a must be between 0 and 1, and can be increased by decreasing the distance between pipes, d , decreasing K , or by increasing H , H_b , or K_b .

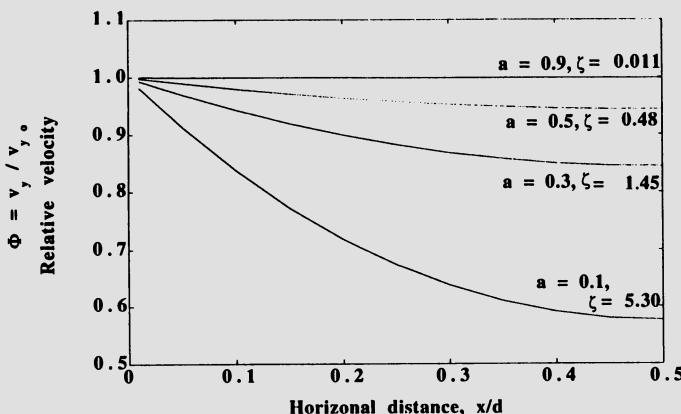


Figure 3 F/F_0 as a function of x/d for several values of $a = \exp(-\sqrt{\zeta})$.

Results and Discussion

There are several interesting things to note about this model. As we might intuitively expect, the highest air flow rate will be v_{yo} , which is directly over the perforated pipes. That velocity is given by

$$v_{yo} = \frac{KY_o}{\mu H} \quad (28)$$

Note that changing the properties of the porous base or the pipe spacing, d , does

$$\frac{v_y}{v_{yo}}$$

not affect v_{yo} , but only $\frac{v_{yo}}{v_y}$. This result will only be valid if ΔP_{pipe} is negligible; otherwise, the distance down the length of the pipe must be included. Also, if the assumption of constant T and ρ applies, incorporating equation (3) yields

$$v_{yo} = \frac{K(\rho_b - \rho)g}{\mu} \quad (29)$$

This result implies that v_{yo} can only be manipulated by changing K , for instance by adding a bulking agent.

The dimensionless number ζ occurs throughout the model and can be written as

$$\zeta = \frac{K\rho d^2}{K_b H H_b \rho_b} = \frac{\frac{Qd}{K_b \rho_b (H_b \Delta z)}}{\frac{QH}{K \rho (d \Delta z)}} \quad (30)$$

Q represents the volumetric flow rate, which is the same order of magnitude in the porous base and the pile. Darcy's Law, equation (1), can be rearranged to

$$\Delta P = \frac{\mu v L}{K} = \frac{\mu Q L}{\rho A K} \quad (31)$$

and the two equations combined to find

$$\zeta = \frac{\Delta P_{\text{base}}}{\Delta P_{\text{pile}}} \quad (32)$$

For small values of ζ , the air flows relatively freely through the porous base, and

$$\underline{v_y}$$

the profile of v_{yo} versus x/d is fairly flat (Figure 3). As ζ increases, the air finds it easier to move upward through the pile than to travel through the porous base,

$$\underline{v_y}$$

and v_{yo} drops off quickly as x/d increases to 0.5. This effect becomes significant when ΔP_{base} is comparable or larger than ΔP_{pile} , and ζ approaches or exceeds one.

Permeabilities for compost materials have not been commonly reported in the literature. We have measured the permeabilities of several compost mixtures, and report the values in Table 1 only to help determine reasonable values for ζ . The materials were tightly packed into a 30.5 cm inner diameter reactor to a nominal height of 30 cm. The reactor ends were sealed except for air inlet and outlet lines and pressure taps. The pressure drop across the bed was measured using an inclined manometer (Cole-Parmer) with a range of 0– Pa. Flow rates were measured using a bubble flow meter (Cole-Parmer) of the appropriate size. The permeability was determined from equation (1).

Consider a 1 meter tall pile constructed on a 15 cm bed of wood chips with perforated pipe every 1 m, where the inside temperature is 60°C and the ambient air is dry at 20°C. Here, $\rho_b = 1.21 \text{ kg m}^{-3}$, and $\rho = 0.94 \text{ kg m}^{-3}$ at 760 mmHg, and $\mu = 2.04 \times 10^{-5} \text{ kg m}^{-1} \text{ sec}^{-1}$ at 60°C.. If the pile is composed of the most porous compost feed tested ($K = 2.4 \times 10^{-5} \text{ cm}^2$), we find $\zeta = 2.26$, $a = 0.22$, and $v_{yo} = 0.031 \text{ cm sec}^{-1}$. If the pile permeability K were instead $1.0 \times 10^{-6} \text{ cm}^2$, $\zeta = 0.094$, $a = 0.73$ and $v_{yo} = 0.0013 \text{ cm sec}^{-1}$. In the second case, the lower K leads to a flatter

v_y

v_{yo} profile, but v_{yo} is also considerably lower. These numbers can also be used to check that Darcy's law applies, as stipulated by equation (2). Using the largest compost permeability, $2.4 \times 10^{-5} \text{ cm}^2$, and the corresponding velocity, $Re_K=0.00090$ in the compost bed, so Darcy's Law applies. In the porous bed, v_{xo} will have its largest value as ζ tends to ∞ . For this system, $v_{xo} = 0.107 \text{ cm sec}^{-1}$, and the corresponding $Re_K = 0.0047$.

The next steps in this analysis will include accounting for ΔP_{pipe} , removing the assumption that p and T are constant in the pile, and experimentally verifying the results presented here.

Table 1 Permeabilities for several compost materials.

Description of Compost Material	Permeability, cm^2
Wood chips	5.5×10^{-5}
Sheep Manure / Straw Mixture (predominantly straw)	1.0×10^{-5}
Equal volumes of cow manure, straw, horse manure and wood chips	8.1×10^{-6}
One volume straw, one volume cow manure, two volumes horse manure, two volumes wood chips	2.4×10^{-5}
Finished cow manure and straw compost (small particle size, no bulking agents)	$\approx 2.1 \times 10^{-6}$

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A Review of Features, Benefits and Costs of Tunnel Composting Systems in Europe and in the USA

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Abstract:

Odour control is identified as the critical technical issue for the success of composting projects. Tunnel composting has the advantages that the compost can be kept aerobic, all the excess air is collected for treatment and that building corrosion, that leads to fugitive emissions, is prevented. Data is given for the number of installations in Holland and USA. Rough costs indicate that tunnel composting has comparable costs to other s mechanised systems. Two types of tunnel system are described: batch and plug flow and their features compared.

All compost projects are subject to the same pressures to a lesser or greater degree depending on the difficulty of composting the source material and local sensitivities. Compost projects fail for 3 major reasons: lack of proper project finance; poor community acceptance normally due to poor odour control and third, lack of product market. The first and the last come down to good management, but some systems are more prone to odour problems than others. Table 1 is a summary of technical factors to consider when choosing a composting system.

There has been a gradual evolution and a wider range of wastes composted. In the US there was a large increase in composting following the USDA work at Beltsville in the late 70s. There was a dramatic increase in aerated static pile systems. Many of these early systems have had to be retrofitted with expensive leachate collection and odour control systems. The researchers did not take into account community acceptance as a key issue. This then led to upsurge so called in vessel systems in the mid 80s. Some being true in vessel built around a silo configuration and others being based on shed or hangar systems where aerated static pile, windrows or a combination has been carried out in a building. Many of the early silo systems had problems, primarily due to poor porosity and mechanical failure. The longitudinal or agitated bin system has proved to be the most robust system of the shed systems and has been widely adopted. There are still some inherent weaknesses due to the possibility of fugitive emissions and building cor-

rosion for the more putrescible wastes which is coming to light for some of the earlier systems.

Table 1

	heap	windrow	aerated static pile	shed hangar systems *	vertical enclosed vessel	tunnel systems
Odour control	low	low	low/med	med	variable	high
Temp control	low	med	med	med/high	variable	high
Pathogen kill	low	low	med	med/high	variable	high
Weather tolerance	low	low	med	high	high	high
Ease of operation	med	med	med	med	med/low	med/high
O & M staffing	med	med	med	med/low	med/low	low
Refits	low	med	high	med	high	low
O & M costs	med	med	med	med	med/low	med/low
Operator environment	low	low	med/low	med/high	high	high
Capital costs	low	low	med/high	high	high	high
Appearance	low	low	low	med/high	med	med/high
Noise	high	high	med/high	low	low	low
Process reliability	low	med	low	med/high	low	high
Feedstock versatility	low	low	low	med/high	low/high	high
Process tolerance	low	med	med	med/high	low	high
Product reliability	low	med	med	med/high	low/high	high

In Europe the development of composting has varied from country to country. The most rapid rise in composting has been in Holland where the problem of ground-water contamination has driven a movement to take organic waste out of landfills. The development of Biowaste composting systems is more recent than the USA developments and there has been a more rapid move to tunnel systems. Statistics are given in Table 2 for the USA and Holland

Table 2

Holland 1993 1		USA 1993 2
Biwaste		Biosolids + MSW
Shed systems	12	In vessel and Shed
Tunnel systems	15	Agitated Bed
Other Aerobic	5	Tunnel
Anaerobic	3	7

Whilst the use of open systems is generally appropriate for garden waste, more in-vessel systems are being used for sludge and for MSW their use is virtually universal.

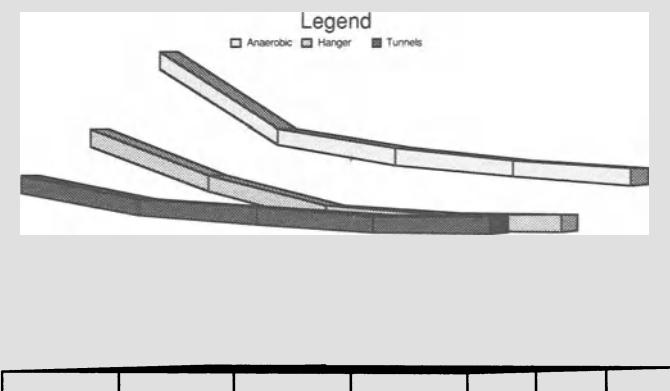
Composting tunnels are large rectangular boxes which tightly control the composting environment of the organic material by means of a computer controlled supply of forced air through a perforated floor structure. Two main forms of tunnel are available :batch tunnels and plug flow tunnels.

Batch tunnels have been used in the mushroom industry for 30 years to produce high quality compost which acts as the growing medium for the white mushroom, *Agaricus bisporus*. A great number of these tunnels are in use around the world to produce many hundreds of thousands of tonnes of compost each year. They work on the principle of composting one batch of waste at a time under highly controlled conditions. The control of the composting environment is brought about by means of recirculated forced air supply system under computer control. This allows temperatures throughout the composting mass, often up to 400 tonnes, to be kept within 2–3°C. of that required for the different stages of the composting process. This in turn allows a fine manipulation of the microbiology of the composting process to bring about a near optimum composting regime and to produce a tightly specified compost product. Composting is normally complete within 14 days.

The plug-flow tunnel system has been designed with similar principles in mind but operates in a continuous rather than in a batch mode. This system allows the continuous feeding of a wide range of organic wastes into the composting tunnel by means of a supply conveyor and a hydraulically driven ram plate at one end of the tunnel. This has the advantage that the material can be kept fully enclosed during feeding the conveyor and that there is no chance of fugitive emissions. The composting material within the tunnel is compressed enabling considerable quantities of waste to be composted in a small area. As the composting mass passes along the tunnel it is taken through the various composting stages by means of differential temperature control brought about by the supply of air in the various zones in the tunnel. The completed compost leaves the tunnel at the other end of the tunnel and is removed by a second conveyor. Once again the residence time in the tunnel is about 14 days. The process can be totally automated from the beginning to the end.

The computerised regulation of temperature within both systems by the supply of forced air allows an unrivalled control over the composting process. Further control is enabled by the strict regulation of the nature and consistency of the organic feedstock. Many of the problems that have been encountered in the composting of organic wastes, such as the generation of offensive odours, are caused by the lack of sufficient control leading to anaerobic conditions.

Other papers describe the virtues of tunnel systems most notably that of Loikin and Oorthuys¹. They summarised the benefits as follows: substrate flexibility; optimum process control; acceptable working conditions; low maintenance; short retention time; small footprint; no leachate. The same authors reviewed operating costs which are illustrated in Table 3.

Table 3

Batch tunnel systems have had a rapid growth in Europe. In Holland there are now more tunnel systems than other system for composting Biowaste(source separated MSW). In the US the development of tunnel systems has been led by the Tunnel Reactor^R system which is a plug flow system.

The main advantage of this configuration is that odour is completely contained not just during the composting phase but during the materials handling prior to loading. The other benefits are that it has lower capital cost for small systems due to low number of tunnels to be constructed (sometimes only one) and thus also a very small footprint. There are several reference facilities in the US – the longest running one is near Cincinnati at Hamilton OHIO.

Tunnel systems are the next generation composting system. Their use is growing rapidly in Europe and USA. The preference is for the tunnel reactor^R in the USA because of the very high community reaction to odour and a preference for systems that do not expose employees to composting atmospheres. Costs are similar for both systems and comparable to other mechanical systems.

Waste generators need the right technology coupled to effective management. For instance in MSW composting over half the cost and skill is in the operation of MRFs to be able to produce a reliable feedstock. There is now a growing trend for technology vendors to develop other skills: financing, operations and product marketing so that customers can be offered the certainty of a gate fee with guaranteed compliance and recycling, product marketing and odour control. Waste management companies are in the USA and Europe are exploiting the benefits of Tunnel composting to reduce landfill and promote beneficial use, to the extent that some proprietary systems are now owned or operated by waste companies.

1. P Loikin and T Oorthuys, Major Benefits from Tunnel Composting for Production of Biowaste and Dried Sewage Sludge. European Conference on Sludge and Organic Waste, University of Leeds 1994.
2. Biecycle November & December 1993

B6 Marketing and Economy

Compost Marketing Trends in the United States

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Abstract

As programs are being implemented throughout the United States to divert wastes from landfill disposal, composting is continuing to increase in popularity as a means of treating organic wastes. As the number of composting facilities increases, the competition for markets and the importance of producing a high quality compost also increase. This paper provides an overview of composting in the United States, a discussion of compost markets and marketing efforts, and a presentation of factors that affect compost marketing. Trends in composting and compost marketing are discussed, including the use of source separated feedstocks, composting of segregated wastes, and governmental policies that affect composting.

Introduction

As communities in the United States implement new programs and expand existing ones in order to divert larger quantities of materials from landfill disposal, composting is playing an increasingly important role as a waste management tool. However, as the number of composting facilities grows, the quantity of compost product available on the market increases. As a result, more attention is being given to product quality and market development. Composting projects that produce inferior quality material or that do not take the steps necessary to develop markets will find it difficult to compete.

As background to the subject of compost marketing, this paper begins with a brief review of the current role of composting as a waste management tool and of the types of wastes being composted in the United States. Compost uses and markets, marketing practices, and factors affecting compost marketing are then discussed.

Composting as a Waste Management Tool

In 1993, 207 million tons of municipal solid waste (MSW) were generated in the United States, or 4.4 lb per capita-day (U.S. EPA, 1995). As shown in Table 1, paper and paperboard make up the largest component of MSW, at 77.8 million tons annually or 37.6% of the waste stream. At 15.9% of the MSW generated in the nation, yard trimmings also represent a substantial fraction of the waste stream. Nationally, 21.7% of the MSW was recovered (18.6% through recycling and 3.1% through composting), 15.9% was incinerated, and 62.3% was landfilled in 1993 (U.S. EPA, 1995). Although still relatively small, the role of composting as a waste management tool has increased substantially during recent years (i.e., from less than 1% of MSW generated during the mid 1980s, to more than 3% in 1993).

Table 1 Quantity and Composition of MSW Generated in the United States in 1993

Component	Million Tons	% by Weight
Paper and paperboard	77.8	37.6
Yard trimmings	32.8	15.9
Plastics	19.3	9.3
Metals	17.1	8.3
Food	13.8	6.7
Wood	13.7	6.6
Glass	13.7	6.6
Other	18.7	9.0
Totals	206.9	100.0

Types of Wastes Being Composted

Composting facilities that utilize biosolids, mixed municipal solid waste (MSW), or yard trimmings have been operating in the United States for many years. More recently, facilities using source separated MSW or segregated fractions of MSW other than yard trimmings (e.g., grocery waste, cafeteria food waste) as a feedstock have been gaining popularity.

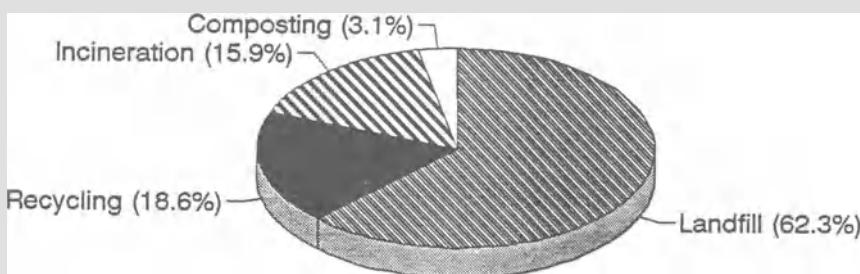


Figure 1 Disposition of MSW Generated in the United States in 1993

Municipal Solid Waste

As early as the 1950s, MSW composting was being considered as a solid waste management process in the United States. However, in the 1960s the prospects for MSW composting decreased, largely due to a lack of a market for compost, the low cost of landfilling, and the high carbon-to-nitrogen ratio of MSW.

In the late 1980s, MSW composting began once again to gain in popularity. As shown in Figure 2, the number of operational facilities increased substantially from 5 in 1988 to 21 in 1992 (Eggerth, 1992; Goldstein, 1994B). The interest in MSW composting was the result of a number of factors including the closure of substandard landfills, strong anti-incineration sentiments, the introduction of high technology systems to process a mixed waste stream, a growing confidence in composting as an option to handle municipal waste, and economics that would allow composting to compete with incinerators and landfills.

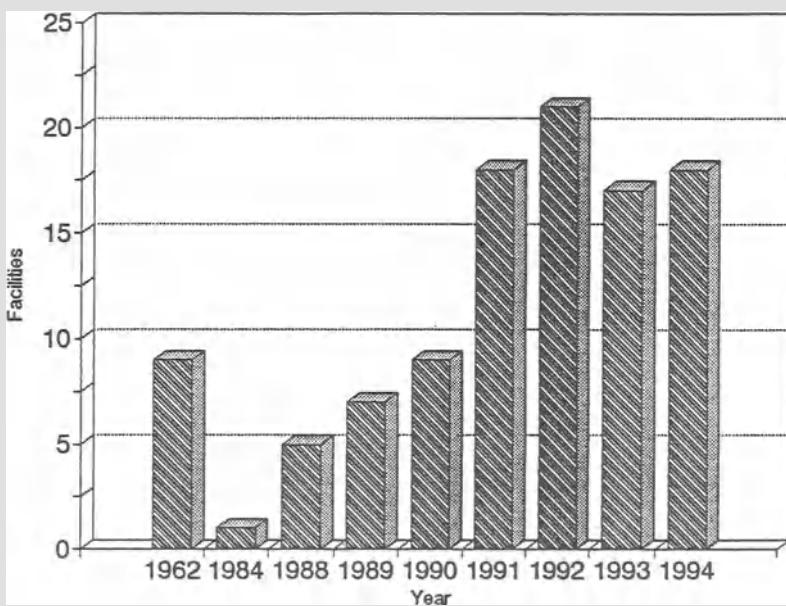


Figure 2 Number of MSW Composting Facilities in the United States

In the early 1990s, trends emerged that had a negative impact on project development. Cutbacks in state and municipal budgets restricted the funds available for projects, the implementation of recycling and yard trimmings composting programs resulted in sufficient levels of diversion to meet short-term mandates, the ability of a project to control the flow of waste to a facility was challenged in the court system, some of the larger mixed MSW composting plants were closed, and large landfills were opened making landfill disposal more cost effective. The num-

ber of MSW composting facilities in 1994 was 18.

In the 1990s, mixed MSW project failures, combined with skepticism about the quality of a mixed waste compost product sparked interest in composting source separated organics. Currently, 4 of the 18 operating MSW composting projects process a source separated stream. In these communities, residential waste is separated into three fractions – compostables, recyclables, and trash.

Segregated Fractions of MSW

Yard Trimmings

Although composting of yard trimmings has been practiced for many years, it was not until the late 1980s that this practice began to attain widespread application in the United States. As shown in Figure 3, the number of yard trimmings composting facilities increased from about 650 in 1988 to about 2200 in 1991, and to 3014 in 1993 (Eggerth, 1992; Steuteville, 1994).

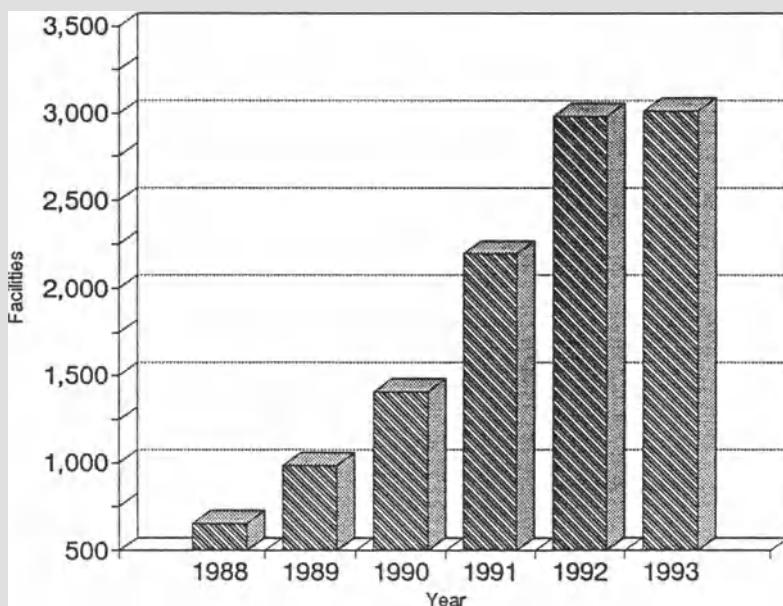


Figure 3 Number of Yard Trimming Facilities in the United States

A number of factors have been responsible for the growing interest in yard trimmings composting: 1) the potential for diversion of substantial quantities of organic materials from landfill; 2) implementation of regulations by some local governments to ban yard trimmings from landfills; 3) the compostability of the material; 4) lower technology process requirements than MSW composting; 5) less stringent regulatory requirements than MSW composting; and 6) the high quality of the end product.

Approximately two-thirds of the yard trimmings composting programs in the United States involve the composting of leaves collected in the autumn. These types of programs are more common in the northeastern portions of the country where greater quantities of leaves are generated. Leaf composting programs generally utilize low-technology composting processes.

The implementation of programs that process a mixture of yard trimmings materials (e.g., leaves, grass clippings, and brush) throughout the year are becoming more common, particularly in the western portion of the United States. These yard trimmings composting programs generally require higher levels of processing technology and more comprehensive marketing programs than do leaf composting programs. Mixed yard trimmings are generated year-round, and consequently the facility must be capable of processing the materials continually. In addition, some portions of the feedstock (e.g., brush) should be size reduced prior to composting.

Other

In 1993, 18 pilot programs were being conducted to evaluate the technical feasibility of composting segregated components (other than yard trimmings) of the solid waste stream. The projects primarily use windrow technology and range in size from 1 ton/week to 100 tons/day (Martin, 1993). Most of these programs process some type of food waste that had been separately collected from residential, commercial, or industrial sectors. Sources for the food waste vary, e.g., commercial food processing, restaurants, grocery stores, residences, and college cafeterias. Other types of segregated waste fractions that are being tested in pilot programs are chicken litter, paper, and combinations of separately collected organic wastes.

The pilot programs have demonstrated the technical feasibility of the composting process itself. As they consider full-scale implementation, communities are dealing with questions regarding collection methodology, economics, and markets.

Biosolids

Although biosolids composting has been practiced for decades in the United States, it wasn't until the 1980s that it became a preferred method for managing the material. The interest in biosolids composting, as demonstrated by the number of operational facilities, has continued to grow during recent years – from 159 operations in 1992, to 186 in 1993, to 201 in 1994 (Goldstein, 1994A).

During the 1990s, a few significant trends have developed related to biosolids composting, including an emphasis on producing an exceptional quality of product (i.e., one that meets federal requirements for unrestricted distribution); an increase in the use of yard trimmings (primarily leaves and woody material) as a bulking material; and private ownership and operation of composting plants.

Compost as a Product – Its Uses and Markets

The benefits of using compost as a soil amendment have been known for many years. When incorporated into the soil, compost increases the organic content of the soil and can improve its texture, its nutrient content, and its water retention and aeration capacities. Because of its beneficial characteristics, the material can be used in a variety of applications. Six major market segments for compost in the United States have been identified (U.S. EPA, 1993):

- Agriculture – food and nonfood crops and sod farms
- Landscaping – industrial and commercial properties; grounds maintenance (golf courses, cemeteries, and athletic fields)
- Nurseries – potted plants, bare root planting, and forest seedling crops
- Public agencies – highway landscaping and maintenance, parks, recreational areas, and other public property
- Residents – home landscaping and gardening
- Other – land reclamation, reforestation projects, landfill cover, hydromulching

The agricultural industry is the largest potential market for compost in the United States, although it is also the most difficult to penetrate. In addition to product quality, cost, ease of application, and availability are extremely important to farmers.

Marketing Practices

Various approaches are used to market finished compost products. These approaches can be generally categorized either as: 1) direct marketing (e.g., to landscapers, nurseries, homeowners, product blenders); or 2) brokering (i.e., marketing through a single distributor or a series of distributors who sell the product on a retail or wholesale basis). Strategies used for developing markets include providing information on the product (data and instructions), demonstration plots, giving samples of the product away, participation in trade shows, and advertising.

The majority of composting operations in the United States market the compost directly, primarily to professional customers, in bulk form, at a relatively low cost. Many facilities are recognizing the need of having a diversified customer base.

A recent survey of 60 composting facilities (Alexander, 1994) indicated that approximately 70% have a marketing or product distribution program. Of those with a program, 70% sell the compost in bulk form only, and 30% sell in both bulk and bags. None of the facilities sell only in bags. Facilities that do not have a marketing program either distribute the material at no cost or use it on municipal projects, as landfill cover, or in land application projects.

Municipal Solid Waste

Due to a lack of a significant track record, generalizations regarding markets and marketing practices for MSW composting facilities are difficult to make. With a few exceptions, the facilities have not established long-term, paying markets for their products, for a variety of reasons. Some facilities have chosen to utilize the compost for municipal projects (e.g., landfill cover, public works projects) or to give the product away. Others have experienced difficulty in meeting state regulations or in producing a quality compost.

Currently, of the 18 MSW composting facilities in operation, only one (Lakeside, Arizona) reports that it sells all of the compost it produces. The compost is sold to a soil blender, for use by nurseries and landscapers.

Several other facilities sell a portion of total production. Other uses for the finished compost are landfill cover, public works projects, or application to farmland owned by the public entity. Some facilities give material to farmers, soil blenders, or landscapers.

Yard Trimmings

During the late 1980s, the majority of the composting facilities that processed yard trimmings (primarily leaves) were low technology, produced a medium-grade compost product, and either used the compost for municipal projects or distributed it at little or no cost to homeowners. More recently, a number of factors have resulted in an increasing emphasis being placed on the production of a high quality compost. These factors include: 1) the implementation of programs for composting a mixture of yard trimming materials (e.g., leaves, grass clippings, and brush); 2) the higher cost associated with these programs (i.e., due to size reduction, aeration, post-processing, etc.); 3) competition from other composting programs; 4) market demand for a higher quality product; and 5) privatization of some of the programs.

Direct bulk sale to the landscape and nursery industry is the primary market for compost produced from yard trimmings. Homeowners also represent a significant market, both for bulk product (either directly from the facility or through topsoil dealers) and bagged product (usually through garden centers). Markets for lower quality compost include land application, land reclamation, and landfill cover or closure. A number of facilities are having some success at marketing to agriculture.

Biosolids

At the present time, the most popular markets for biosolids compost are landscapers, topsoil dealers, and garden centers and nurseries. Biosolids compost is also frequently used for landfill closure and land reclamation, and by public agencies in parks, for highway maintenance, on building grounds, etc. Neither residential use

nor agricultural use represent significant markets for the product.

Biosolids composting facilities typically manage their own marketing programs rather than utilizing the services of a broker for product distribution, and have a combination of public and private sector outlets for the compost. Most of the compost produced by facilities with an aggressive marketing program meets federal (Part 503 Class A) requirements for unrestricted distribution. According to facility operators, customer satisfaction with finished compost is strong.

Factors That Affect Demand

A large number of factors affect the demand for compost. A few of the important factors will be discussed here, including product quality, policies/regulations, competing and complementary products, and transportation.

Product Quality

Marketing studies conducted throughout the United States have identified quality and consistency of the product as key elements in the utility and marketability of the products (CalRecovery, 1988, 1992, 1994; U.S. EPA, 1993). Consequently, an increasing number of facilities are placing emphasis on producing a quality product.

High-quality, mature compost has a dark color, uniform particle size, and a pleasant earthy odor. It should not contain visually identifiable contaminants (such as bits of glass, metal, and plastic). In addition, the compost should contain minimal levels of chemical residues, heavy metals (such as cadmium, lead, and mercury), herbicides, pesticides, and other potential toxic compounds. The compost also should have a high concentration of organic matter, contain nutrients, be free from pathogenic organisms, and contain no viable weed seeds.

Policies/Regulations

A wide range of policies and regulations affect composting, including quality standards, process requirements, and procurement policies. In addition, flow control policies are also having an effect on the implementation of composting projects, particularly MSW composting projects that require a large throughput to be cost effective. The two policies that are most likely to affect compost marketing efforts are product quality standards and procurement policies.

Quality Standards

While product quality is very important to the marketability of compost, with the exception of biosolids, uniform specifications have not been developed nationwide for compost. Product quality standards for solid waste composts have been

implemented in a number of states. These standards vary in terms of terminology, feedstocks regulated, parameters monitored, allowable limits, and allowable uses. The discrepancies among the states, and the evolving nature of the regulations, can negatively affect the implementation of composting programs and marketing efforts for the finished products. Efforts are currently underway by private and public agencies to develop national product quality standards for solid waste composts.

Procurement Policies

Public procurement policies in effect in many parts of the country historically have essentially served to discourage the use of composts produced from waste materials. Most often, this is the result of specifications for soil amendment products that stipulate the source material for the product. A number of state and local agencies have revised or are in the process of revising their specifications to allow or encourage the use of waste-derived compost by public agencies.

Competing and Complementary Products

Another factor that affects demand is the quality, availability, and cost of compost compared to its competing and complementary products in the marketplace. Many of these products (e.g., fill dirt, topsoils, silt, potting soils, custom soil mixes, bark mulch and wood chips, manure, peat moss, mushroom compost) have a long history of consistency, availability, reliability, acceptance, and use in agriculture, horticulture, public and private landscaping projects, and residential gardening. Development of a market niche for compost requires an aggressive and consistent marketing program, including giveaways, demonstrations, advertising, and promotional efforts.

Transportation

Distance also is a factor affecting demand. One reason is that proximity to compost facilities promotes product acceptance and recognition. Thus, a potential user is more likely to know of a product that is produced nearby, and may feel compelled to support the project. Also, if the composting facility is located a long distance (e.g., more than 50 to 100 miles) from compost markets, the cost of transport may be prohibitive, particularly for bulk product which has a relatively low product value. Strategies that can be employed to mitigate high transportation costs include siting the facility near markets, developing local markets for compost, backhauling, and establishing a network of distribution centers.

Conclusion

Composting seems to have a bright future in the United States. As land suitable for landfilling continues to decrease and regulatory mandates require the diversion of wastes from the landfill, composting will play a major role in the treatment of the wastes.

However, as the number of composting facilities increases, competition for markets will also increase. Competition will more than likely lead to stringent requirements for high quality products, which must be able to meet the demands of knowledgeable users, and will be able to command high prices.

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The Natural Markets for Compost*

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'Every man owes a part of his time and money to the business or industry in which he is engaged. No man has a moral right to withhold his support from an organization that is striving to improve conditions within his sphere. – *Lawn & Landscape Maintenance Magazine*, 1993, after President Theodore Roosevelt, 1908.

In every major industry, the learning curve associated with the identification, quantification, and understanding of the markets is possibly the most limiting factor to total industry development. The faster the markets are identified, quantified, and understood, the faster the industry will grow. Where little information on the market is available, equally small market development seems to follow.

Financially oriented companies use profitability, cash flow, return on investment, and ratios of liquidity as rulers of measurement to compare success within their industry. Although all of these standard measurements are important in determining performance of compost producers today, so are identification, quantification and understanding of available compost markets. After all, if markets are not yet identified, how can total profitability be calculated? Moreover, if accurate quantification of markets are not possible, how can reliable, accurate financial forecasts be developed? If salespeople do not understand customer needs, how can they satisfy the customer?

Since no thumb rules have been established for the measuring of markets involved in composting, some limitations in the industry's growth have occurred. This is not entirely unusual. Historically, the compost industry has not considered the production of compost at each 'compost factory' a manufacturing process at all (Tyler, 1993). Compost plants have been built without adequate market assessments. Why else are there so many noted facility failures which point to excess inventory and odor as main problems? When market development does not keep up with products manufactured from the 'compost factory', a market surplus in eminent, making the tidal wave of compost feared by the year 2000 quite feasible (Tyler, 1993).

Thinking of a composting facility as a manufacturing plant identifies critical components of a successful operation. Like any manufacturing operation, there is a need for consistency in product quality, which is dependent on the incoming raw materials and the production process (Tyler, 1993). Without control over the inflow

*This is an excerpt from Chapter One of the book, 'Winning at the Organic Game' – The official Compost Marketers Handbook', by Rodney W. Tyler, available late 1995 from GIE Publishers, (publishers of *Lawn & Landscape Maintenance Magazine*), Cleveland, Ohio.

of materials, the factory cannot promise that high quality products will be produced. However, some compost factories have become quite advanced, timing production with sales and resulting in just in time inventory programs that satisfy market demands.

The Compost Factory Model

The compost factory model is a set of charts, theories and diagrams which help structure the thought processes of decision makers to help them become successful. The model includes a compost factory diagram, natural hierarchy flow chart, charts for uses of compost within each major market, and economic graphs indicating various example results of actions taken. The combination of these items should link the individual compost use within each market to the big picture. This is necessary for compost marketers who want to be sure to maintain the highest return for their products marketed while not creating an inventory problem. The model structures markets so simple measurement of each area can be communicated accurately, to the industry or within a company, about a broad range of issues.

The Compost Factory model is based on two major theories: 1). There are a number of dollar markets close to cities that will currently purchase all of the compost produced and 2). The historical development of compost markets in every major city of the United States has shown a *natural market hierarchy* which identifies *dollar markets* as those developing first and *volume markets* developing last. Dollar markets are described as such because they have the ability to generate revenue for organic materials by either reselling them directly or charging appropriately for their costs within current service businesses. Many dollar markets, like garden centers, actually act as middlemen in the marketing process. The Volume markets have little ability to pay middlemen and these markets are more challenging to develop without some type of built in economic incentive.

The difference between dollar and volume markets is subtle yet enormous. Collectively, the dollar markets represent the majority of the revenue potential of all markets, while massing only a minor amount of total volume. Individually, with all of the markets listed together, it is hard to say exactly where dollar markets and volume markets meet, especially considering local and regional market conditions. Therefore an arbitrary line exists at the point where the natural market development (for profit) ends and subsidized marketing takes over.

There will be over 200 million tons of urban waste generated in the U.S. yearly by the year 2000 (USEPA, 1994). Estimates vary, but most experts agree that about 60% of the waste stream is compostable, which may result in about 120 million tons of compost produced yearly. These figures generally are expected to increase proportionately as population increases. In year 3000, there will be more compost available from recovered organics than in year 2000, assuming we do not destroy the planet before then.

For the general populous reading this book, 120 million tons of compost produced is a good round number to focus on for available compost in the future. Where will all this compost go? The Battelle study (Slivka, et al., 1992) indicates that a market for 518 million tons per year exists, but does not identify time lines for development, nor does it focus on standard use guidelines within each market (Tyler, 1993). It is interesting to note that the majority of the Battelle study indicates that compost will be marketed to the volume markets. This has not yet happened.

Volume markets are the largest markets but compost sold in these markets must be offered at a low cost (USEPA, 1993). Further, the largest barrier to agriculture market development for compost is price (Jones, 1993). Over the last five years, the dollar markets have proven to be large enough to absorb most compost produced in large urban areas (see 'evidence' later in the chapter). The data search performed to validate the theories for this book was exhausting and show that the theories are indeed reality in most large cities where the majority of the organic residuals are generated..

In every city, a natural market structure, or hierarchy, has evolved. Why? Because most companies making and marketing compost products are trying to be profitable. They want to sell products for as much as possible, because that is what a good business does. Compost products of high quality have been reasonably priced compared to alternatives like peat moss and have sold well. Composts of lesser quality have been lower in price, free, or negative in value.

Sales of compost has revolved, at least initially around 'dollar markets' rather than 'volume' markets. The split is identified in the figures below and validated by the amount of evidence supporting this claim. Since a natural split already exists, it seems logical to measure the markets in the same way on a regular basis. Subsequently, yearly sales and marketing reports can be compared to understand increases or decreases in various market sectors.

The Natural Market Hierarchy

Local supply and demand helps determine a natural economic hierarchy for local markets. Major metropolitan areas will fall prey to the Dollar markets because there are enough people creating the demand for high quality compost and willing to buy the product. Volume markets will probably be left vacant for those companies entering the industry later or for lower quality products.

Business economics suggest that compost effectively marketed will find its way to the highest dollar market. In resource management, this is referred to as highest and best use. 'Excess' compost will naturally gravitate to the next highest paying market. Unfortunately, using this method alone for market development may lead to a market surplus due to lack of diversification during initial market development. Ironically, the highest dollar markets also have correspondingly low total volume potential. It appears that these two measurements (volume and revenue

potential) are inversely related. Evidence supporting this theory is plentiful. Another example of the hierarchy is listed in figure 1.

Evidence of natural hierarchy within dollar markets

- 1). A study of 35 compost facilities in New England by Lang and Jager concluded that only 13 of the total had developed more than one market for the final product. This is usually the case for marketing programs which involve low yearly volumes. They further showed that market development followed a somewhat logical pathway of landscape contractors, public agencies, nurseries, groundskeepers, homeowners, and finally agriculture (Lang and Jaeger, 1993). Due to many of the facilities giving the product away, the natural hierarchy was somewhat skewed, but Agriculture was noted to be underdeveloped as a market because of so many other uses in dollar markets were available within acceptable price ranges (Lang and Jaeger, 1993). This study clearly shows dollar markets develop first.
- 2). Malcolm Beck has been building the compost market in Texas for many years and has done it based on returns from some of the higher dollar markets identified in the hierarchy (Goldstein, 1993; Tyler, 1993). In Beck's case, retail and wholesale markets equal 40% and 60% of sales respectively. Although it is always hard to determine if the local retail market is saturated, it is obvious that dependence upon other markets is eminent as production increases. Malcolm Beck's market is entirely focused upon the dollar markets (Goldstein, 1993).
- 3). Collins, Fritsch and Diener (1993) identified three basic market areas at increasing distances from Washington D.C. as high value, medium value and low value markets, respectively. For low value markets at a far distance, product was planned to be given away. Markets closer to the Baltimore-Washington D. C. area commanded \$14.00 per cubic yard in the plan (Collins et. all, 1993). They went one step further to suggest the market development plan be segmented by increasing the program's % of compost sold (vs. given away) from 25% to 75% over three years. This allowed for the give away market to be shifted slowly to the dollar markets over time (Collins et. all, 1993). In this particular case, the free compost actually found a home in dollar markets. This is often done in an effort to introduce new products and establish utilization habits. Danger exists when customers begin to rely on the free compost and price it accordingly in their work. When the cost of compost suddenly increases, they are unable to use it unless they take a loss.
- 4). American Soil inc., in New Jersey has established an extensive network of buyers including Garden Centers, Landscapers, Horticultural and Green Retail outlets, Homeowners, Urban Gardeners and Soil Blenders (Young, 1993). All of these markets represent dollar markets available between the Philadelphia-Newark swath of urbanization that have customers willing to pay top dollar

- for high quality products (Young, 1993).
- 5). Data collected on 290 Biosolids composting projects in development or operation showed the most widely developed markets were: 1) Landscapers, 2) Nurseries, 3) Public works agencies, 4) Topsoil blenders, and 5) Golf courses (Goldstein et. al., 1992). All of the options for high volume markets were listed last. It is interesting to note even in this example that the retail market, although it offers high potential returns, has rarely been targeted exclusively for any compost factory's main marketing strategy. This is because in most cases, the volume associated with the retail sector cannot completely absorb all production from the factory and other markets must therefore be relied upon.
 - 6). In yet another review of 60 marketing programs at various facilities, Landscapers, Garden Centers, and Topsoil dealers were the top three markets identified for Biosolids or yard debris composts (Alexander, 1994). The natural market hierarchy definitely exists, at least for high quality products. In the same study, MSW compost claimed Farmers, Landscapers, Landfills and local Government as the top four markets (Alexander, 1994). This data suggests that MSW historically has not been as suitable or successful penetrating dollar markets and has developed a low value stigma.
 - 7). A recent study conducted by USEPA focused on 30 compost factories which showed the majority of users were from dollar markets (see table 1.1). Ironic as it may be, the majority of the volume potential for all markets lies in the volume market, and economic potential for the majority of all markets lies in the dollar markets. These names do not suggest that money cannot be made *selling* compost to the turnip growers or that lots of compost cannot be *given* to the retail sector. Indeed, special exceptions exist, but when comparing both dollar and volume potential to the total market, the titles adequately describe natural market segmentation that exists today.
 - 8). A recent market assessment in California identified 13 separate potential markets for compost products with the dollar markets indicated as those willing to pay the most money for products (Shiralipour and Zachary, 1994). Additionally, all of these dollar markets identified quality as a key barrier to market development. (See chart below...Dollar markets are in bold).
 - 9). Even in Florida, where composting research is quite diverse, especially in the Agriculture sector, products produced find their way first to Dollar markets. Undoubtedly, Florida is one of the largest potential Agriculture markets due to the sandy nature of soils, amount of high dollar Agriculture, citrus and greenhouse crops. Regardless of this vast market, the primary markets for compost include Landscapers, Nurseries and Soil blenders (Kelly, 1994).
 - 10). A marketing study conducted by E & A Environmental Consultants for Hamilton County, Ohio indicated initial high end markets to be local Topsoil blenders, Brokers, Landscape Contractors, and Nurseries (Shiralapour and Zachary, 1993). This study was conducted in the early 90's and was strictly for composted Biosolids, but indicates that any organic material of high quality will first be sold to the Dollar markets.

Table 1 Compost/Mulch End Products

Community	Compost or Mulch End Product	Compost or Mulch End User	Compost or Mulch	Sale Price (\$)
Austin, TX	Compost Compost, Mulch Compost Mulch	Landscapers, Retailers Wholesalers, Nurseries, Residents Residents Residents, Public Facilities	Marketed as "Dillo Dirt"	\$7 - \$15/cy
Berkeley, CA	Compost Compost, Mulch	Residents		\$0
Berlin Township, NJ	Compost	Residents		\$0
Boulder, CO	Compost Mulch	Residents		\$0
Bowdoinham, ME	Compost Mulch, Wildlife Habitat	Residents, Landscapers		\$0
Columbia, MO	Compost, Mulch	Residents, Landscapers		\$0
Dakota County, MN	Compost, Farm Application	Farmers		\$0 to \$8/cy used in City
Fennimore, WI	Compost, Farm Application Compost, Mulch	Privately marketed		NA
King Co., WA	Compost	Residents		\$0
La Crescent, MN	Compost for Public Facilities	Public Facilities		Not sold
Lafayette, LA	Compost for Landfill, Mulch	Landfill, Landscapers		Mulch \$3-\$8/cy
Lincoln, NE	Compost, Mulch	NA		NA
Lincoln Park, NJ	Compost, Mulch	Residents, Landscapers	Compost \$10/, Mulch \$4- \$6/cy	\$0
Mecklenburg Co., NC	Compost	Residents, Public Facilities		\$0 for Mulch \$0 to \$2/cy
Monroe, WI	Compost, Mulch	NA		\$0
Naperville, IL	Compost, Mulch	Rutgers U.Urban Gardening, Businesses		–
Newark, NJ	Compost, Mulch	Landscapers, Farm		\$0
Perkasie, PA	Farm Application, Mulch	–		–
Peterborough, NH	–	Residents, Landscapers, Community Gardens		NA, Mulch \$0
Philadelphia, PA	Compost, Mulch	Residents, Landscapers, Nurseries	Varies	–
Portland, OR	Compost, Mulch	–		–
Providence, RI	–	Retail and Residents		–
San Francisco, CA	Compost, Mulch	Retail and Wholesale Outlets	\$6/cy, \$3/cubic-foot bag	Sonoma Co., CA
Seattle, WA	Compost	Landscapers, Farmers, Residents	\$1.5-\$25/cy	
Compost	Compost, Mulch	Residents, Garden Shops		\$0
Tacoma Park, MD	Compost, Mulch	Wildlife Habitat, County, Residents Compost	\$7/cy Mulch	
Upper Township, NJ	Compost, Mulch	Residents, Farmers	\$0	
Wapakoneta, OH	Farm Application	Residents, Public Facilities	\$5/cy or \$3/3 ft bag	
West Linn, OR	Compost, Mulch	Residents (Mulch), Landscaping at Landfill	\$0	
West Palm Beach, FL	Mulch			

Key: *cy = cubic yard* *NA = Not Available* *– = Not applicable*

(Source: Adapted from EPA530-R-92-015, 1994)

Table 2 Market Assessment Summary

Compost User Group	Potential Demand for Compost	Willingness Key User Specifications	Potential Barriers to Compost Use	
	Low	Medium	High	to Pay (\$/ton)
<i>Avocados and Lemons Vineyards</i>	3,953	11,293	16,942	1–10
	1,030	3,433	5,149	1–10
<i>Vegetable Crops</i>	8,961	29,871	44,807	1–10
	375	1,250	1,875	1–10
<i>Strawberry Crops</i>	—	—	—	—
<i>Miscellaneous Crops</i>	—	—	—	Odor, salt content, pH, nutrient content
<i>Organic Farms</i>	4,085	16,341	24,512	6–10
	345	862	1,725	Nutrient content, salt content, moisture, pH
<i>Ornamental</i>	2,593	6,483	12,967	6–10
	931	2,327	4,655	Salt content, pH, consistency, odor, & moisture content
<i>Landscape Companies</i>	700	2,100	3,500	20–40
	700	2,100	3,500	Odor, salt content, pH, nutrient content, consistency
<i>Nurseries</i>	46	117	233	20–40
	46	117	233	Salt content, pH, nutrient content, odor, consistency
<i>Mining Industry</i>	—	—	—	Nutrient content, pH, salt content
<i>City and County Parks and Recreation</i>	—	—	—	Salt content, odor, product consistency
<i>Public Works Landfill Cover</i>	1,900	4,750	9,500	Moisture content
<i>Caltrans District 05</i>	0	0	0	—
Total	24,919	78,827	125,365	Uncertainty of potential need Uncertainty of potential need

Notes: 1) — = data not available.

(Source: Shiralipour and Zachary, 1994)

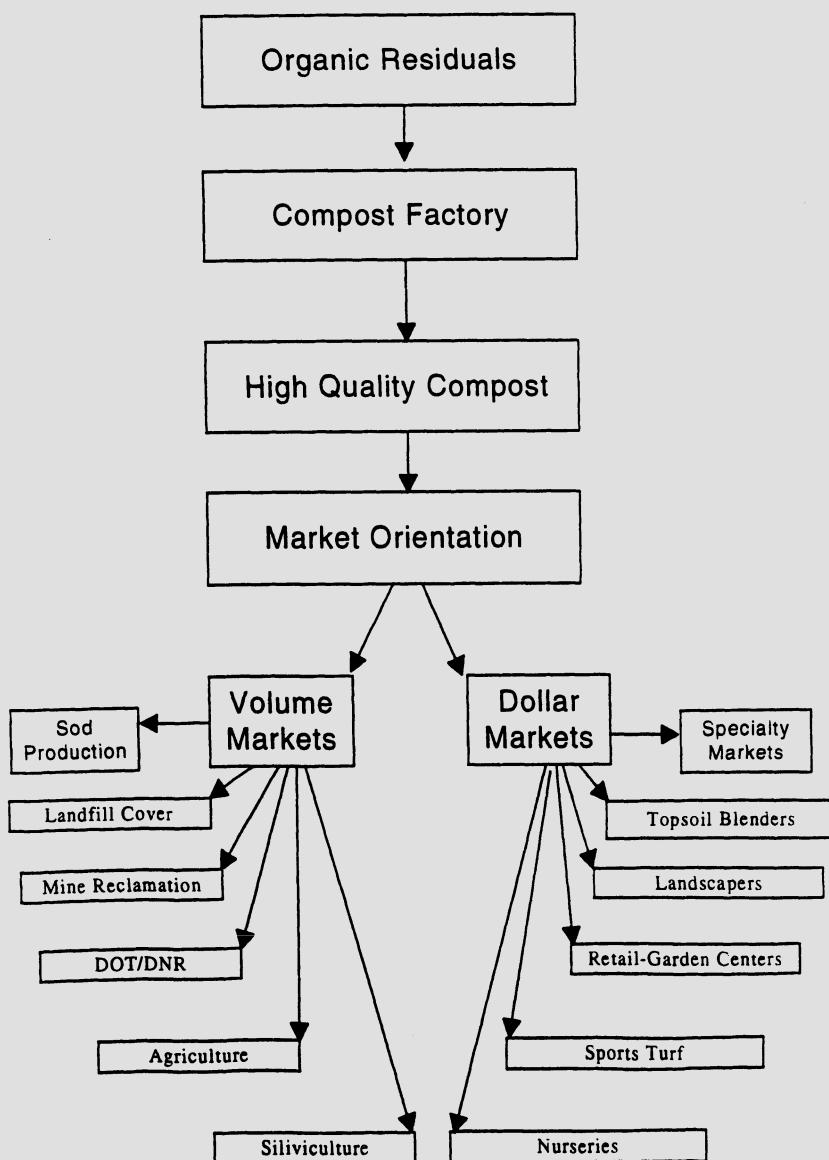


Figure 1 The compost Factory and Natural Market Hierarchy

- 11). In the early 80's, D. D. Southgate from Ohio State University determined that the greatest demand for compost produced in the future would be in markets willing to pay the most money, especially the horticulture and landscape industries (Southgate, 1981). Although compost was not as commonly accepted in the green industry in the early 80's as it is today, this study shows that the dollar markets were proving to be the greatest attraction for quality products.

- 12). A 'Market Status Report' in 1992 was written by the California Integrated Waste Management Board (CIWMB) and indicated the 'most established markets in California for organic soil amendments are Landscaping, Nursery, Gardening and Soil blending sectors'. They also point out that soil blenders are not actual end users but are middlemen, using compost as an ingredient in final products produced from a variety of ingredients (Jones, 1992).
- 13). AgRecycle, a leading composting company in Pittsburgh, Pennsylvania, has a diversified marketing program targeting 100% of all production to landscapers and other high end markets (Goldstein, 1994). DK Recycling Systems in Lake Bluff, Illinois processes large amounts of yard trimmings (125,000 cubic yards per year) and markets about half of the final product to landscape contractors while the rest is sold to nurseries, golf courses, and garden centers (Goldstein, 1994).

This book does not suggest pricing nor guarantee accuracy of figures listed as example prices. However, prices are listed to give examples credibility and to reflect general marketing experience within the industry at this point in time.

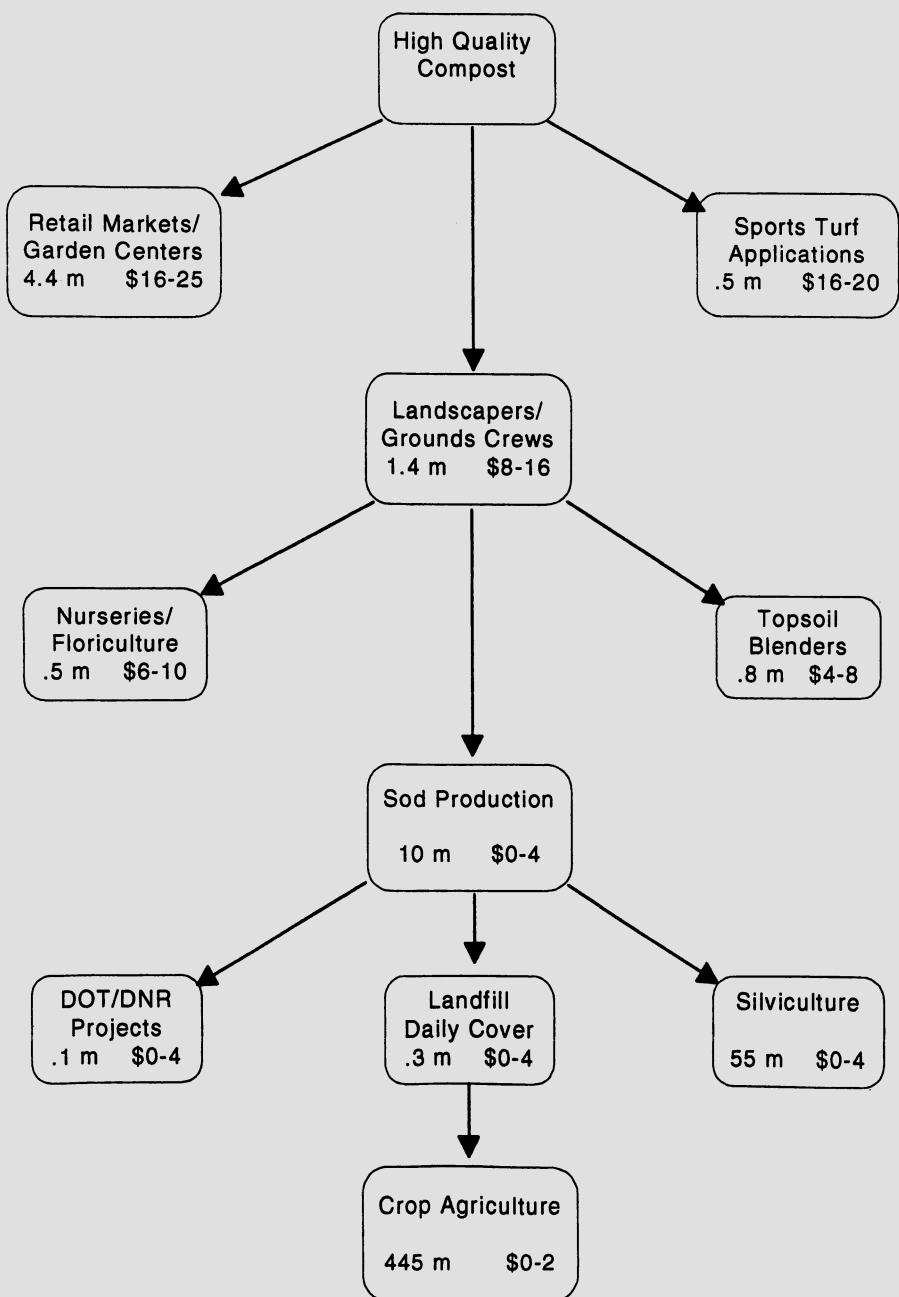
Benefits of the Compost Factory Model

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- 1). Allows the industry to be identified, segmented, quantified, and understood based on natural division in the marketplace.
 - 2). Increases research and development projects which will be based on the needs of the marketplace.
 - 3). Improves communication about markets, uses and the difference between them.
 - 4). Helps educate decision makers so correct compost facilities *are built after* appropriate market assessment.
 - 5). Helps marketers keep profits in mind which should positively affect their bottom line.
 - 6). Provides a mode of interaction between the marketplace and manufacturers of compost products to increase awareness of needs on both ends.
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Applying our history lessons to future challenges

Although the composting process is centuries old, it's full development into a successful organic recovery option in a myriad of waste management choices is underutilized. The model described in the following pages helps all those associated with composting by using a standard: The identification, quantification and understanding of markets based on common use guidelines. Although the industry is far from mature, enough information is available about compost utilization in the major markets to form a measurement system.

The composting business is a relatively new industry struggling to communicate between researchers, market developers, engineers, contractors, and the green industry. They all look for common ground which they can agree upon long enough to at least present their point of view. In order for composting to reach its full potential as a organic recovery option, markets for the final product must be identified and developed. Without adequate market development, other options for waste management may be chosen in place of composting.



Adapted from Tyler, 1993.

Figure 2 Market Development Hierarchy with market size and value

The examples in this book set forth a measurement system of currently identified *uses for compost within each market*. The natural balance of ‘dollar’ and ‘volume’ markets is easily measurable and therefore fulfills the vital objective of quantification of each market *based on use*. As time goes by, measuring the industry using the same template, year after year, will increase the accuracy of the information. The model is therefore justified *from the market for the market* yet provides extremely useful information to the *entire* industry. Some key definitions follow.

Market: Defines the customer base ie., Chicago compost market

Market Sector: Customer bases within markets, ie., Landscape market segment in Chicago

Use: Defines how the product is utilized, independent of customer base ie., Topdressing can be done by homeowners, golf courses, & landscapers (each are market segments).

The method of breaking down the above definitions into organizational and informational forms can be structured using an outline format:

- I. Market (Usually geographical area)
 - A. Market Sector (Usually customer base)
 1. Use (How they use it)
 - a. Thumb rule guidelines

Do not confuse uses with markets when measuring market potential (because we measure what customers buy, not how they use it...yet). Compost sales and marketing programs are *based on popular uses* and within the markets affected most. A topdressing program (the use) is promoted to Golf Courses, athletic fields, and grounds managers (market sectors).

Conclusions

The objective of the Compost Factory model is to help determine potential consequences of decisions before they are actually made. Playing the ‘what if’ game in business is probably one of the oldest management tools around, yet a format to do this in the compost business has not been established until now. With the help of the Compost Factory model, industry personnel can determine the appropriate estimates for each market area and estimate the bottom line with some simple calculations on a computer. Of course, this is assuming that only high quality, source separated composts will be made that will be welcome in any market.

Markets can be determined chiefly by supply and demand, product quality, feedstock materials, technology available, potential volume and product sales price (Tyler, 1993). The degree of both market development and manufacturing diversification at compost factories is crucial to long term success of any marketing program. Obtaining reliable dollar markets are worth the wait, providing profitable

returns to successful marketers (Tyler, 1993). The dollar markets may be adequate in size to satisfy production from urban compost factories in the future if products are of acceptable quality. For many companies, research and development involving compost use in the dollar markets is easier to show an economic return than research relating to volume markets. Therefore, it is expected that dollar markets will naturally develop first around each urban center (Tyler, 1994).

If private or public decision makers are considering building a compost factory, using the 'what if' situation is a powerful tool when used with the compost factory model. Initial planning involving engineers, bankers, plant pathologists, marketers and the markets can be successfully accomplished by using the compost factory model as a central discussion theme. The result should be compost factories manufacturing products to meet specified demands, impacting the industry, markets, and environment only in a positive way (Tyler, 1993).

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Monitoring Strategies and Safeguarding of Quality Standards for Compost

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Summary

The qualified separated collection of organic residues from households, garden- and park areas is the actual technical standard in Germany and obligatory as to the regulations of the waste law. The former composting municipal solid wastes has not been proved to be successful.

The German Federal Compost Quality Assurance Organisation (FCQAO) defined a general quality standard (RAL compost quality sign) and established a nation-wide system for external monitoring of composting plants and compost products. Today approximately 170 compost plants participate in the quality assurances of the FCQAO.

The quality assurance programme contains the definition and continuation of quality requirements, the organisation and enforcement of quality monitoring, the punishment of regulation omissions and violations and the labelling of the quality standard.

The type, extend and frequency of evaluations depends on the capacity of the composting plant. In order to guarantee an identical standard for the monitoring all over Germany, FCQAO established a central office where all results originated from external monitoring are evaluated.

Introduction

Biocomposts are composts originating solely from organic residues. These residues consist mainly of biowaste (source separated organic household waste) and residues from garden and park areas (generally municipal yard waste).

The qualified separated collection of organic residues from households, garden- and park areas is the actual technical standard in Germany and obligatory as to the regulations of the waste law and the TA Siedlungsabfall. The former composting municipal solid wastes has not proved to be successful because of lack of utilization. Today it is no longer permitted in Germany.

The evaluation of organic residues to be utilised in compost production has to take into account value adding contents and properties as well as those which diminish the value of the product.

Depending on the kind of use, properties such as nutrient and organic matter contents, the level of substances showing alkaline reactions or the magnitude of active substances which, for example are able to suppress plant pathogens are seen as positive with respect to compost quality.

With regard to product properties which are value diminishing, the content of undesirable materials and contaminants as well as hygienic aspects have to be considered.

Therefore, compost quality is determined by an array of different contents and properties, rendering the objective evaluation of *the* compost quality to be a difficult task. An additional problem poses the fact that the various quality parameter are evaluated quite differently according to the type of use, the objective of the discussed regulation or to ones individual prejudice.

This was the situation when the Federal Compost Quality Assurance Organisation (FCQAO), in association with affected industries, i.e. mainly compost users, defined a quality standard for compost which ensures that the product meets the highest quality requirements posed by the industry.

This step made not only compost quality objectively determinable and comparable but also created a defined product standard which was then available on the market. To identify products of this standard, FCQAO created a quality sign for compost (RAL-GZ 251) (Figure 1). The German Federal Compost Quality Assurance Organisation is recognised by the RAL-Institute as the organisation to handle monitoring and safeguarding of compost quality in Germany.



Figure 1 RAL compost quality sign

During procedural steps to obtain RAL recognition, relevant industries and compost users as well as involved authorities were consulted on the issue of quality requirements to be contained in the compost quality sign.

The compost quality sign provides evidence for quality assurance. It has been recognised by RAL on 28. 1. 1992 and was subsequently published by the Minister for Trade and Commerce in the Federal Legal Gazette and also

registered in the trade mark register with the Federal Patent Office.

During the last two years the Federal Compost Quality Assurance Organisation (registered society) established a nation-wide system for external monitoring of composting plants.

Today approximately 170 compost plants in Germany with a yearly input of 1,5 Mio. tons participate in the quality assurances of the German Compost Quality Assurance Organisation.

According to RAL principles governing a compost quality sign, a quality assurance programme needs to contain the following:

- *Definition and continuation of quality requirements*
 - regulations concerning quality and its evaluation (e.g. product diversification)
 - definition of analytical methodologies (handbook)
 - criteria and provisions for internal evaluations of a composting plant (e.g. guarantee that the finished product is hygienically quite safe)
- *Organisation and enforcement of quality monitoring*
 - evaluation and designation of authorised laboratories
 - handling of forms, data and statistics
 - independent assessment of examination results
- *Punishment of regulation omissions and violations*
 - complaint about missing examination results
 - definition and fixing of required repeated examinations
 - decision on specific cases
- *Labelling of the quality standard*
 - award and certification of the compost quality sign
 - issuing of the test certificate containing details on
 - product and producer
 - declaration in accordance with the rules
 - appropriate application rates
 - analytical results and potential differences

Organisation of the quality assurance programme

The way to obtain the compost quality sign is described in detail in our brochure of the same title. Further information (application form for the quality assurance programme, model contract with laboratories, list of authorised laboratories, model sampling report, examination report, control of sanitation) is provided by the FCQAO office.

Fundamentally, the quality assurance programme represents a triangular setup comprising the operator of a composting plant, the Federal Compost Quality Assurance Organisation and one of the laboratories which are recognised by FCQAO. Recognition and authorization of laboratories follows established criteria.

The plant operator is a member of a regional association for compost quality. Through the regional association he files an application with FCQAO to use the compost quality sign and at the same time commits himself to obey the regulations governing the quality assurance programme.

The plant operator chooses one of the registered laboratories to carry out external monitoring of the plant, i.e. to take the required annual number of samples and to analyse them. Since the laboratory is recognised by FCQAO it is obliged to obey the regulations governing the quality assurance programme.

The laboratory conveys the examination results to the plant operator and FCQAO at the same time. This way it is guaranteed that all external examinations are used for the assessment and that external monitoring really takes place.

With respect to the award and use of the compost quality sign, the so-called recognition procedure needs to be differentiated from the monitoring procedure. The recognition procedure is carried out in order to obtain the compost quality sign and the monitoring procedure in order to check subsequent obedience with the quality assurance programme regulations. (Figure 2)

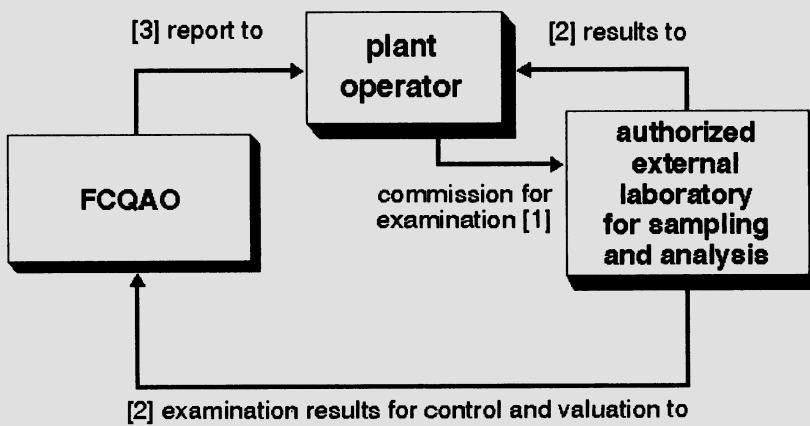


Figure 2 The monitoring procedure of the RAL quality sign compost

If the results of the one year recognition procedure comply with the requirements, FCQAO awards the RAL compost quality sign on the basis of a recommendation made by the FCQAO quality committee. Subsequently, the evaluated composting plant is transferred from the recognition to the monitoring procedure.

Assessment of external monitoring within the monitoring procedure is carried out once a year by the FCQAO quality committee. For the monitoring procedure, it is recommendable for the plant operator to sign a new contract with a recognised laboratory or to prolong the current contract. This guarantees that the sampling frequency and analysis are correct and that the tasks are carried out regularly and timely. Results of the monitoring procedure provide the basis for FCQAO's annual confirmation that a composting plant is entitled to carry the compost quality sign. In order to guarantee an identical standard for quality monitoring all over

Germany, FCQAO established a central office where all results originating from external monitoring of composting plants are evaluated.

The establishment of this office made it possible to issue uniform certificates to composting plants throughout Germany. This certificate is updated annually and contains the following:

- acknowledgement of obeying quality requirements
- summary and assessment of analytical results, including average, median and variation of the specific parameter as well as a comparison with recommended levels
- information concerning declaration, suitability and utilisation
- information concerning the application rates based on proper agricultural and horticultural usage (legal requirements)
- information concerning limited compost application rates due to potential contaminants (LAGA– information sheet M10)

Type, extend, frequency and time of evaluations

The type, extend and frequency of evaluations to be carried out according to FCQAO depends on the capacity of the composting plant, either on the authorised capacity or the actual input (Fig. 3). The type of licensed products is also of importance in this context.

The total number of evaluations has to be spread over the year in such a way that at least one sample is taken every quarter and that sampling dates are at least four weeks apart. However, it is possible to take two samples at one particular sampling date, provided it is ensured that samples are taken from different batches (proof through sampling record).

Figure 3 Frequency of quality testing within the recognition and monitoring procedure required by the RAL compost quality sign

Input	Recognition	Monitoring
< 2.000	4	4
2.000 - 5.999	6	4
6.000 – 11.999	8	6
12.000 – 19.999	12	8
20.000 – 25.000	12	10
> 25.000	12	12

Status of external monitoring

Presently, FCQAO carries out external monitoring in some 170 composting plants throughout Germany.

Total capacity of all composting plants looked after by FCQAO amounts to an input of 1,5 Mio. t. 71 % of this compost material carries the RAL compost quality sign when it is put on the market (Figure 4).

Figure 4 German composting plants participating in the quality assurance programme¹⁾

Characteristic value	Year
Number of plants participating in a quality assurance programme	170
Number of plants carrying the RAL-compost quality sign	130
Number of samples in 1994	900
Total authorised plant capacity (Mio. t)	1,80
Amount of processed organic residues (Mio. t)	1,50
Produced compost (total, Mio. t)	0,75

1) Quality assurance programme according to RAL GZ 251

Quality properties and characteristics of compost

Quality characteristics of compost from separately collected original materials vary in a typical range. (Fig. 5). The definition of the individual quality parameters is determined by different influences.

The inputmaterials which are used for composting have to be appropriate in structure and composition for composting. Furthermore they may only include a slight contents of impurities and harmless contents of harmful substances. These are the basic requirements for the production of usable composts in the sense of the governmental regulation TA Siedlungsabfall and the qualification for the RAL quality recognition. The producer has to guarantee these requirements by means of proper technical and organising measures.

Apart from the influences on the quality which are caused by technical/organising measures, influences on the quality of compost are to be considered which usually cannot be foreseen, such as:

- regional characteristics of geogen origin,
- regional characteristics of antropogen origin.

Considering the individual compost plant, a difference in quality will be caused respectively shown by further influences:

- Variation of produced composts on account of differences caused by seasonal conditions in character and composition of the delivered compost rawmaterial (up to approx. 30 % discrepancy of the plant average value of single quality parameters).
- Tolerances that result from the statistical possible faults of sample-taking, sample treatment, analysing and differences between authorised laboratories (up to approx. 50 % deviation from the statistical 'true value').

Finally german peculiarities are to be named such as e.g. the wide-spread conversion of the content of heavy metals in compost on a unified reference to a defined standardised compost with 30% organic substances. This means that compost having a measured value of e.g. 250 mg Zn/kg dry substance and 65% organic sub-

stances is rated in such a way as if it had 500 mg Zn/kg dry substance; (after a calculated reduction of the organic substances on 30% dry substance). Such a product would not meet the approximate value of the RAL quality sign on account of its high content of organic substances but not on account of a real high content of Zinc.

Figure 5 Valuable characteristics and constituents of biocompost

Parameter	Dimension	Average value	Range
Loss of organic matter			
due to burning	% DS	35	25–45
Water content	%	36	30–50
Net weight or volume	g/l	680	550–850
Soluble salt content	g/l	4	2–8
pH value		7,6	7,0–8,3
Main nutrients:			
Nitrogen (N-total)	% DS	1,1	0,8–1,5
Nitrogen (N-min.)	mg/l FS	150	100–400
Phosphor (P-total)	% DS	0,3	0,2–0,4
Phosphor (P-soluble)	mg/l FS	520	200–900
Potassium (K-total)	% DS	1,0	0,5–1,2
Potassium (K-soluble)	mg/l FS	2000	1200–4000
Magnesium (Mg-total)	% DS	0,4	0,2–0,7

DS = Dry Substances FS = Fresh Substances

Hygienic requirements

Composts have to comply with hygienic requirements. This is achieved if it is assured that patho-gens are inactivated during the composting process. Many research projects investigating hygienic aspects of composting have shown that sanitation achieved during the composting process is sufficient to comply with the requirements, as long as the composting plant is managed properly.

Micro biological methods are used to evaluate elimination of pathogens in various composting systems. This requires that typical and representative micro-organisms are used as test organisms which pass through the entire composting process (evaluation of the composting process). Additionally, chemical and physical parameter of the various composting processes as well as the processes themselves have to be included in the examination.

The level of sanitation depends mainly on the duration of the composting process and the reached temperatures. In order to obtain favourable conditions for progression of the composting process and associated sanitation, input materials need to be mixed and processed with special reference to water content, proportion of pore-volume, nutrient supply etc.

Due to the magnitude of pathogens potentially contained in the input material, it is not possible to meet hygienic requirements through an evaluation of the cured compost (evaluation of the compost). Only an evaluation of the entire operating

composting plant (evaluation of the composting process) is able to provide reliable data. Such an evaluation of sanitary effects of the composting process involves the passage of typical pathogens through the entire composting process, followed by their isolation from the finished compost and a virulence test. It is required that used test organisms are inactivated sufficiently during the composting process. With respect to survival of micro organisms during composting, used test organisms have to be selected in such a way that the following deduction can be assumed: If test organisms are killed, other pathogens will be also sufficiently inactivated. Therefore, it does not make sense to use many different test organisms. It should be adequate to use only one pathogen, provided its hardiness infers that the obtained results apply also to other potential test organisms.

FCQAO regulations determine

- that each composting plant utilising a specific composting system has to record operational composting conditions relevant to the sanitary status of their entire compost production (e.g. temperature level). These records are checked regularly as part of the external plant evaluation and have to be made available to FCQAO, if required.
- that a systems examination of the applied composting system is a prerequisite for the above procedure. Within the framework of this examination, relevant composting conditions (e.g. range of favourable water contents of input materials, temperature regime of the composting process, turning interval) have to be determined and recorded.

If the required records can not be provided, the produced compost can not be labelled as quality controlled.

In case no systems examination has been carried out yet for a comparable type of composting plant, it is required to take such action when a new plant is put into operation. Even if a certain type of composting system has been evaluated already, a new composting plant of the same type has to be examined when it is put into operation, if the input materials or the composting process itself vary from the examined type of plant with respect to sanitary effects.

In response to the fact that many new composting systems have been introduced over the last couple of years, FCQAO is presently preparing a list of available types of composting systems which passed the systems examination successfully, either through a so-called prototype examination or when the first plant of a certain type was put into operation. This list will also contain FCQAO requirements regarding checkable documentation of long-term operational composting conditions which affect compost sanitation.

LAGA information sheet No. 10 stipulates requirements concerning a systems examination for composting plants. In this context the representative test organisms are '*Plasmodiophora brassicae*' and '*Salmonella senftenberg*'.

In certain cases it might be wise to examine the finished compost for pathogens (e.g. check for club root if the compost will be used in potting soils) but generally it is not useful to postulate a product examination as obligatory.

From a quality control and quality assurance point of view documentation of long-term operational composting conditions is a lot more important. However, this approach requires that the specific composting plant either went through a systems examination when the plant was put into operation or that a prototype examination was provided when the composting operation applied for building permission.

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Minimizing the Cost of Compost Production Through Facility Design and Process Control

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Introduction

Abstract

Excessive cost of producing compost at many facilities through out the world continues to burden taxpayers. Observations on failed designs and management strategies in large scale facilities demonstrate operators have not clearly understood the interrelationship of the biological, physical and economic variables on the cost of production. This paper identifies the major variables under management control and their relationship on the cost of producing compost. Governing equations, based on energy and mass balances and the kinetics of composting, are presented and used to quantify the effects on cost and throughput capacity of in-vessel composting systems as operating practices are changed. Factors studied include air recycling, ambient air conditions, remix frequencies and moisture control, bed depths, fan management strategies (on/off, staged levels), temperature set points, and airflow paths. Data used in the analysis are from both pilot and full scale composting studies.

The composting process transforms biodegradables into nonodorous, more stabilized materials. Today it is accomplished using systems identified as windrow with turning, static pile with forced aeration and in-vessel (Anonymous, 1991). For the process to be used commercially, systems must be properly designed and operated (Hoitink et al., 1993).

The process is governed by the basic principles of heat and mass transfer and biological constraints of living organisms (Keener et al., 1993a). Many researchers have studied such systems and determined operational data for the success of their particular configuration (Kuter et al., 1985; Nakasaki et al., 1987). Haug's (1980,

1993) books details governing principles and reports on some of the systems that have been used for composting. Keener et al. (1993a) presented analytic expressions showing the interdependence between biological and physical factors. They used these expressions to derive the governing equations for optimizing the efficiency of the composting process. Later, Keener et al., (1993b, 1994) expanded those equations to aid in the efficient design and operation of the air handling system for compost facilities , to estimate remix times and to evaluate water requirements of a composting system.

This paper presents data on composting parameters, as derived in controlled experiments, and uses that data to analyze the operation of the composting system.. The reader is referred to Keener et al. (1993a, 1993b, 1994, 1995) for specific details on development of the derived equations used in this paper.

Theory

Kinetics of the Process

The active stage of composting is the time where substrate is readily available for microbial decomposition. From a design standpoint, this first stage of composting is most important for proper sizing of equipment. During that time, the rate of disappearance of biomass can be written as a first order reaction (Marugg et al., 1993). As the composting process approaches the curing stage, this assumption may be wrong, but it is then of lesser practical significance. The rate of disappearance of biomass, written as a first order reaction term, is

$$\frac{dm_c(\theta)}{d\theta} = -k(m_c(\theta) - m_e) \quad (1)$$

If k is constant, the solution to the equation is mR, the compost mass ratio.

$$mR = \frac{m_c(\theta) - m_e}{m_o - m_e} = e^{-k(\theta)} \quad (2)$$

The compost mass ratio, a dimensionless number, is a useful way to describe how far the process has advanced (Marugg et al., 1993; Keener et al., 1993a). It always ranges from 1 to zero. For $\theta=0$, $mR=1$ and for $\theta=\infty$, $mR=0$.

Equilibrium Mass (me) – Evaluation

The use of the term m_e in Eq. (1) assumes that decomposition of the organic matter by microorganisms is limited. The expression m_e/m_o (called β) represents that fraction of materials which remains after a long period of composting (6 months to 1 year). It has a value greater than the ash content since some organic fractions will remain in the stabilized end product. β should not be confused with non-volatiles, a proximate analysis measurement evaluated under high temperature¹ conditions. Keener et al. (1993a, 1995) discusses evaluation of β for a large num-

ber of materials. Evaluation of k and β using pilot scale data (Keener et al., 1995) are given in table 1.

Using the results for k and β , airflow, time fan could be off, and time to first remix were evaluated and included in Table 1. See appendix for the equations used. Airflows ranged from $0.5 \text{ m}^3/\text{kg}_{ds}\text{-day}$ for MSW to $3.5 \text{ m}^3/\text{kg}_{ds}\text{-day}$ for high grass yardwaste and separated dairy waste. Allowable fan time off ranged from 4 to 27 minutes. Time to first remix, based on moistures of 65% wb, was from 2–18 days (See Appendix for equations).

The equation for airflow,* is based on the fact that temperature control normally governs the airflow (rate) requirement rather than oxygen levels within a compost system (Finstein et al., 1986). Use of the equation with specific data for yard waste composting shows airflow requirements decreases 50 fold from day 0 to day 21 for this material (Hoitink et al., 1993)). Other materials, such as MSW, have a lower k value and therefore require less airflow.

Fan Power

Keener et al. (1993b) derived fan power per unit area of vessel size as

$$P'(\theta) = \sum_{\ell=1}^2 \left[\frac{-h_C \rho_{\odot} k d e^{-k\theta}}{\rho_a * [HAO - HAI]} \right]^{n_\ell + 1} \frac{a_\ell d^{j_\ell}}{\alpha \varepsilon} \quad (3)$$

where $\ell = \{1 \Rightarrow \text{piping and } 2 \Rightarrow \text{compost}\}$. For the piping system it is assumed $j_1=0$ and $n_1=2$.

The fan power required for unit weight of compostable material can be calculated from

$$P''(\theta) = \sum_{\ell=1}^2 \left[\frac{-h_C k e^{-k\theta}}{\rho_a * [HAO - HAI]} \right]^{n_\ell + 1} \frac{a_\ell \rho_{\odot}^{n_\ell} d^{n_\ell + j_\ell}}{\alpha \varepsilon} \quad (4)$$

This expression can be used to investigate the effects of factors, such as n , ρ_{\odot} , h_C , $[HAO - HAI]$, ..., on fan power requirements. The general relationship is based on air pressure drop through porous media and in piping(Steele and Shove, 1969; Higgins et al., 1982). Equations 3 and 4 do not account for the effect of moisture on air porosity. (See Das and Keener in this proceedings) Table 2 list values for j and n for some specific composts.

*STM calls for 950°C; American Society of Agronomy uses 550°C.

Table 1 Evaluations of k, β, Airflow Requirements, Allowable Fan Off Time, and Time to First Remix Based on Moisture Loss.^a

Compost Mix ^b	k (1/day)	β	temp	H ₂ O	C/N	rho	inert	re-mix ^c days	airflow m ³ /kg da	time off min.	re-mix days
g33/b/133	.201	.009	.751	.011	60	62.0	27.2	286	4	2,002	5.93
g50/b/117	.178	.024	.511	.038	60	63.0	20.4	223	3.4	3,482	4.38
g50/b/c17	.185	.008	.512	.022	60	63.0	21.3	223	3.4	3,611	4.22
yw/kw	.230		.770	.57	62.1	16.7	175	.040	3.7	2,381	1.93
yw/kw	.156		.781	.72	62.1	16.7	172	.040	3.7	.683	4.45
yw/cm	.172	.023	.663	.017	65	43.2	22.0	345	3.4	1,739	4.25
yw/cm/fw	.089		.630	.65	43.5	16.0	386	3.4	.988	6.68	5.46
yw/cm/fw	.176		.664	.65	41.5	25.0	365	3.4	1,774	3.93	3.13
yw/wc/s	.153		.701	.60	63.1	19.4	209	3.4	1,830	8.89	4.41
yw2/wc/s	.132		.694	.60	55.8	12.8	272	3.4	1,616	7.73	4.95
yw/wc/s	.092		.680	.60	58.8	18.3	204	3.4	1,178	14.14	6.67
120/wc/s	.248	.016	.842	.015	60	58.6	13.3	309	7	1,567	7.01
wc/s	.176		.800	.032	60	61.2	14.4	283	7	1,408	8.53
wc/s	.137		.709	.60	65.0	11.4	211	7	1,595	10.09	5.12
wc2/s	.149		.739	.60	57.4	19.4	219	7	1,556	9.97	5.54
p/s	.143		.679	.60	63.6	20.6	220	7	1,836	8.41	4.27
p2/s	.097		.586	.60	64.0	14.8	23	7	1,606	8.89	4.51
b/s	.169		.718	.45	61.0	46.8	224	.197	7	1,387	27.33
msw	.083		.735	.62	61.0	46.8	212	.197	7	.836	18.21
msw	.024	.003	.393	.023	55	56.4	33.2	226	.083	.758	25.79
msw	.032	.007	.594	.045	60	39.7	31.1	386	7	.520	16.93
msw/clm	.033	.004	.349	.126	60	43.5	19.3	376	3.4	.859	10.51
sdw	.215	.031	.541	.021	60	71.4	114	3.4	3,947	7.55	1.79

^a Temperature, moisture, C/N, and compost density, dry basis, are shown for test conditions.^b g—grass, b—brush, l—leaves, c—cardboard, yw—kitchen waste, kw—chicken manure, fw—food waste

s—biologics, yw2—2nd use yardwaste, p—particle board, p2—2nd use particle board, b—barb, wc—woochips

wc2—2nd use woodchips, msw—municipal solid waste, clm—caged layer manure, sdw—separated dairy waste.

^c Remix days were intervals used during experimental studies.

Table 2 Pressure drop parameters^a for two cereal grains, poultry manure mixes, MSW, and sludges.

MATERIAL(s) ^b	Material Ratio	Moisture % w.b.	Pressure Drop Parameters.....		
			a	j	n
WC/sludge ^c	2:1 v		1.02 x 10 ⁻¹	1.05	1.61
WC/sludge ^c	3:2 v		1.59 x 10 ⁻¹	1.30	1.63
WC/sludge ^c	1:1 v		5.03 x 10 ⁻¹	1.47	1.47
WC/sludge ^c	1:2 v		1.43 x 10 ⁰	1.41	1.48
Fresh wood chips ^c			3.13 x 10 ⁻¹	1.08	1.74
Recycled screened wood chips ^c			9.74 x 10 ⁻¹	1.54	1.39
Final compost material ^c			3.61 x 10 ⁻¹	1.66	1.47
CLM/sawdust ^d	1:2 w	60	4.71 x 10 ⁻²	1.0	1.17
CLM/corncobs ^d	1:2 w	60	3.72 x 10 ⁻²	1.0	1.60
WC/RC/Leav/sludge ^d	2:0:2:1 v	50	1.37 x 10 ⁻¹	1.0	1.56
WC/RC/Leav/sludge ^d	3:0.5:1.5:1 v	49	9.49 x 10 ⁻²	1.0	1.73
WC/RC/Leav/sludge ^d	3:0:1:1 v	49	1.00 x 10 ⁻¹	1.0	1.82
WC/RC/Leav/sludge ^d	3:1:0:1 v	52	6.45 x 10 ⁻²	1.0	2.02
MSW ^d			7.82 x 10 ⁻¹	1.0	1.23

^a Pressure drop(cm H₂O); depth(m); velocity (m/min)^b CLM=cage layer manure. WC=wood chips. RC=recycle. Leav=leaves. MSW=municipal solid waste.^c Higgins et al., 1982. ^d Keener et al., 1993

Variable cost of composting

Composting economically requires efficient design and operation of the compost facilities. In particular, since many large compost facilities are designed to operate using forced ventilation, it is important that power requirements be low while still allowing efficient operation of the facility. For example, a facility composting 80 ton_{ds}/day may require as much as 225 kW of fan capacity. [Based on 20.3 cm static pressure, 1.34 m³/kg_{ds}–day, 22 day compost cycle] If these fans have a 50 % duty cycle, total power cost is about \$4/ton_{ds} composted or \$88,000/yr, when electricity cost is \$0.08/kWh. Although not the major cost of producing compost, it is one which the compost system designer and/or operator can control.

Energy for composting

Energy for composting per unit compostable material assuming a variable speed fan and inclusion of piping losses is (with * signifying desired level of compost maturity)

$$E = \sum_{\ell=1}^2 \frac{a_{\ell} \rho_{\odot}^{-n_{\ell}} k^{n_{\ell}} d^{n_{\ell}+j_{\ell}}}{\alpha \varepsilon} \left[\frac{-h_C}{\rho_a * [HAO - HAI]} \right]^{n_{\ell}+1} \left[\frac{1 - mR * n_{\ell} + 1}{n_{\ell} + 1} \right] \quad (5)$$

Variable cost per unit compostable, C_v, is

$$C_v = c_v E \quad (6)$$

The above expression (Keener et al., 1993b) shows the interdependence between biological and physical factors and can be used to optimize the efficiency of the composting process. (See appendix for nomenclature).

Fan Sizing and Variable Cost

Selection of fan size is governed by the airflow requirement and will be determined by (a) maximum airflow which generally occurs within the first 36 hours of the process and (b) the way the total composting operation is managed. For example, consider a compost operation with three windrows. Each windrow has a 3-week ventilation schedule and is turned in place with water addition based on moisture levels (Keener, et al. 1994). The windrows are started 1 week apart. Two fan arrangements are considered for this example.

Case 1: Each fan delivering air to only one windrow or section of a windrow. This scenario requires the largest fan power and shows the least efficient duty cycle. It generally uses some type of two stage fan control (high/low or on/off) using compost temperature for feedback control.

Case 2: One fan delivering air to all three windrows. This arrangement requires the least fan power and maximum duty cycle. It requires air dampers on feedback control regulating airflow to each windrow.

Table 3 shows the fan sizes required for case 1 and case 2 if pressure drop is similar to a 2:1 wood chip/ sludge mixture. To solve this problem, parameters associated with pile size along with the compost material have to be specified. In this example, compost depth is 3 m, compost density is $290 \text{ kg}_{ds}/\text{m}^3$ and pressure drop in the aeration duct is limited to 7 cm H_2O at maximum flow to the windrow. For case 1 power requirements are .0702 watts/ kg_{ds} while for case 2 the requirements are .0345 watts/ kg_{ds} . This example suggest that by sharing fans across windrows, fan power requirement can be cut in half. This leads to lower fixed cost and ventilation cost to ventilate the compost piles.

Some compost systems mechanically move the compost from one section to the next at regular intervals, eventually moving the compost out of the system. For these systems , sizing the fan for each section based on days into the composting will achieve minimal power requirements.

Table 3 Fan power requirements to meet temperature control in sludge composting system. Case 1 unshared fan; Case 2 fan shared across windrows.

Time Days	Airflow ^a $\text{m}^3/\text{min}\cdot\text{Mg}_{\text{ds}}$	Velocity (compost) m/min	Δp^b (compost) $\text{cm H}_2\text{O}$	Fan Power unshared watts/ Mg_{ds}	shared watts/ Mg_{ds}
Case 1					
0	2.54	2.54	1.46	70.2	
Case 2					
0	2.54	2.54	1.46		34.9
7	1.04	1.04	0.34		34.9
14	0.16	0.16	0.02		34.9

^a $\text{Mg}_{\text{ds}} = 1000 \text{ kg dry solids}$

^b $\Delta p_{\text{total}} = \text{pressure drop (duct + damper)} + \text{pressure drop (compost)}$. For case 2 with shared fan, static pressure fan works against is maximum $8.46 \text{ cm H}_2\text{O}$ while airflow is $1.25 \text{ m}^3/\text{min}\cdot\text{Mg}_{\text{ds}}$.

Fan sizing based on an on/off mode (signified by ') leads to higher cost. Keener et al. (1993) found a one fan size system has variable energy cost given by

$$C_v = c_v \sum_{\ell=1}^2 \frac{a_\ell \rho_{\infty}^{n_\ell} k^{n_\ell} d^{n_\ell + j_\ell}}{\alpha \varepsilon} \left[\frac{-h_C}{\rho_a * [\text{HAO} - \text{HAI}]} \right]^{n_\ell + 1} [1 - mR] \quad (7)$$

The cost ratio between an on/off fan and a continuously variable fan speed (Eqs. 6 and 7) when $n_1=n_2$ is given by

$$\frac{C_v'}{C_v} = \frac{(n+1)[1-mR]}{[1-mR^{n+1}]} \quad (8)$$

Fan energy cost ratio for the on/off fan is given in Table 4. A similar analysis can be done for a fan with various levels of control. For a mR value of 50 percent, variable cost of composting is 71 percent higher using an on/off fan system rather than a variable fan approach. Note that the earlier analysis of sharing the fan across a number of windrows approaches the variable fan concept in terms of fan sizing/utilization.

Effect of mR on Variable Cost

Table 5 shows how C_v varies with mR for the case $n_1=n_2=2.0$ and, where $C_{v\infty}$ equals the maximum cost which occurs when $mR \rightarrow 0$ (i.e., time $\rightarrow \infty$). For such compost mixtures the results showed that $C_v \propto (\sim) 0.88 C_{v\infty}$ when $mR=0.5$. These results apply when the fan power changes with ventilation needs of the composting system and the assumption that the coefficient a and depth d are fixed. Although this is an approximation, since $n_2 < 2$ for most compost mixes, the results illustrate the importance of specifying mR when calculating system efficiency. It also indicates the relative savings on power which can be achieved by moving compost from stage one composting to an unventilated operation as soon as possible.

Table 4 Effect of fan operation on the relative cost^a of ventilating a compost pile $n_1=n_2=2$.

mR	$C_{\text{O}}(C_v) / C_v$
1.00	1.00
90	1.11
80	1.23
70	1.37
60	1.53
50	1.71
40	1.92
30	2.16
20	2.42
10	2.70
00	3.00

^a $C_{\text{O}}(C_v)$ is cost of on/off fan;
 C_v is variable speed fan

Table 5 Effect of final maturity ratio on the relative costs^a of ventilating a compost pile for case $n_1=n_2=2$.

mR	$C_v / C_{v\infty}$
1.0	.00
9	.27
8	.49
7	.66
6	.78
5	.88
4	.94
3	.97
2	.99
0.0	1.00

^a C_v = ventilation cost when time goes to ∞ .

Effect of Depth on Variable Cost

Variable cost per unit weight to be composted is proportional to d^{n+j} . For poultry manure plus corncobs doubling of the depth increases C_v four to six times ($n_1+0=2$ and $n_2+1=2.6$; see Table 2). In the case of sewage sludge and wood chips, doubling of depth would increase cost four to eight times since n_2+j_2 is as high as 3.02.

Effect of Air Enthalpies on Variable Cost

The effect of [HAO – HAI] cannot be evaluated independent of k , given current information that rate of composting may increase significantly (Q_{10} effect) as temperature increases up to a value of 60°C (Schulze, 1962; Haug, 1993; Snell, 1991). Table 6 shows how C_v varies with the temperature of the compost pile using $C_v(60)$ as a reference value and $n_1=n_2=2$. Results show that minimum cost occurred at 60°C and would be 2/3 the cost of operating at 50°C. If k should be constant between 50°C and 60°C, the operating cost at 60°C would be only 17%

of the cost at 50°C, i.e. it would cost 5.8 times more to compost at 50°C than at 60°C.

Table 6 Effect of compost temperature on the relative cost of ventilating^a a compost pile for the case $n_1=n_2=2$.

T°C	[HAO-HAI]	k = fct(T) k _T /k ₆₀	C _v (T)/C _v (60)	k = constant k _T /k ₆₀	C _v (T)/C _v (60)
30	50.6	0.125	9.59		
40	113.8	0.25	3.04		
50	215.6	0.5	1.61	1.0	5.8
60	387.7	1.0	1.00	1.0	1.0

^a Based on incoming air, $T_{ai}=20^\circ\text{C}$, $w_{ai}=0.107$.

Effect of Air Recycling on Variable Cost

Use of recycle air increases incoming air temperature and potentially increases decomposition rates during composting if the Q_{10} effect applies to the composting rate. Analysis of the effect of incoming air temperature on variable cost was done using equation 6 for the cases (1)decomposition rate is uniform from inlet to exit and is equal to k at the exit temperature, and (2)decomposition rate is determined by the compost temperature and is linearly increasing from inlet to exit. Evaluation of ρ_c , [HAO-HAI] and average k^2 was required. Table 7 shows the effect of raising inlet temperature from 20°C to 30, 40, or 50°C (using recycled air) and exiting the system at 50 or 60°C. Results showed for a linear k profile and 10°C difference across the bed, variable cost increased 32 to 34 time, compared to the reference conditions. The potential cost savings due to an increase in throughput caused by the uniformly higher temperatures were not evaluated here.

Table 7 Effect of Recycle Air on Variable Cost of Ventillating Compost.

T _{in} °C	T _{out} °C	[HAO-HAI]	Uniform (k) ²	Linear (k) ²	Uniform (C _v /C _{v,ref})	Linear (C _v /C _{v,ref})
20	60	387.7	1.00	0.36	1.00	1.00
30	50	165.0	0.25	0.11	3.79	4.67
40	50	101.8	0.25	0.15	19.6	32.2
30	60	337.1	1.00	0.38	1.78	1.90
40	60	273.9	1.00	0.44	4.03	4.95
50	60	172.1	1.00	0.58	21.2	34.8

(k)² represents $(k/k_{ref})^2$; Uniform represents condition where k is constant over the bed; Linear represents k increasing linearly through the bed; C_{v,ref} represents C_v for the first row in table (i.e. for 20–60°C air temperatures).

Fixed Cost and Optimizing Depth

Fixed cost of a composting facility represents land, buildings and equipment. Minimum operating cost, as a function of depth, must occur between 0 and ∞ . At zero depth, infinite land area is needed while at infinite depth, vessel construction cost and power cost for fans become infinite. This minimum cost can be solved by using

$$\frac{\partial C_A}{\partial d} = 0 \quad (8)$$

where C_A is annual operating cost and d is the depth of the bed. To solve for optimum depth requires evaluating only those cost factors which are a function of compost depth. Keener et al. (1993a, 1993b) has solved this problem for composting systems with fixed area per day (IPS system) and the fixed depth system. Because the cost function for machine size is a discontinuous function it was not included in their analysis. Solutions for optimum depth were as follows.

Case 1 – Analysis of Fixed Area Per Day

For the case of fixed daily land area, A_o (IPS system), daily feed rate, m_o , and total composting time, s , optimum depth is

$$d_{OA}^* = n_1 + j_1 + \sqrt{\frac{\Phi_c s}{(n_1 \Phi_{A1} d_O^{n_1 - n_2 - j_2} + (n_2 + j_2) \Phi_{a2} \Phi_{A2})}} \quad (9)$$

where * signifies optimum. See nomenclature for definitions of Φ_c , Φ_{a1} , Φ_{a2} , Φ_{A1} and Φ_{A2} .

Case 2 – Fixed depth (variable floor area per day)

For the case of fixed depth and daily feed rate, m_o , optimum depth is

$$d_{od}^* = n_1 + j_1 + \sqrt{\frac{\Phi_c \Phi_{vs}}{(n_1 \Phi_{a1} \Phi_{d1} d_o^{n_1 - n_2 - j_2} + (n_2 + j_2) \Phi_{a2} \Phi_{d2})}} \quad (10)$$

Eqs. 9 and 10 can be used to estimate optimum depths for the two types of system analyzed. They also allow one to estimate the effect of changing parameters on composting system efficiency.

Estimates of parameters required in the design analysis of compost systems are given in Table 8.

In this table, cost term c_l , c_f and c_v are assumed. Using these table values, and assuming Φ_c ranges from 2–32, solutions of optimum depth for a reactive compost mix ($k=0.1/\text{day}$) were solved and are given in Table 9. For $n=2.0$ and the parameters selected, optimum depth $dS(*,oA)$ ranged from 1.8 to 3.6 m while $dS(*,od)$ ranged from 1.5 to 3.1m.

Summary

This paper presents analytic expressions which show the relationship between compost properties and maturity. Specifically it analyzed the effect of pressure drop parameters on the variable cost of composting and presents an optimization

analysis for composting in a system with uniform temperature across the bed. The analysis assumed continuous remixing and constant bed density during composting. The analysis of optimum depth for fixed and variable bed depth systems was performed. Although most results presented are restricted (uniform temperature), the procedure outlined (1) does serve as a focal point for optimizing composting systems, (2) has identified groups of parameters which allow results to be applied to many different types of wastes and (3) should allow improved design of in-vessel composting systems.

Table 8 Parameters and range of values for use in calculating optimum depths of compost systems.
(No piping losses, $a_i=0$)

Parameters	Range	Value Used	Calculated Variables		
			n=	1.5	2
n	1.2 to 2.0	(1.5, 2.0)			
a	2.02×10^{-7}	.0000002			
α	8816	8816			
ϵ	.5 to .6	.5	f=	$4.54e-11$	
h_c	20000	-20000	J/kg		
ρ_c	200–600	500	kg/m ³		
ρ_a	1.29 to .85	1.29	kg/m ³		
ΔHA^a	330 to 410	400	kJ/kg _a	D=	19380.
k	.01 to .2	.1	1/day	$\Phi_{a2}=$.007501
β	.25 to .75	.5			.330247
θ	10 to 20	15	day	$\Phi_{vs}=$	10.67
s	$\theta+1$	16		$\Phi_{A2}=$	3.7
r	.20 to .30	.3		$\Phi_{d2}=$	3.91
c_1	10–100	20	\$/m ²		
c_f	150×10^{-3}	.15	\$/watt	$\Phi_c=$	12.4
c_v	$.05 \times 10^{-3}$.00005	\$/watt-hr		

^a $T_{ai}=20^\circ\text{C}$; $T_c=60^\circ\text{C}$

Table 9 Optimum depth for composting^a for the case $n_2=(1.5, 2.0)$, $j_2=1$, and $\Phi_c = (2, 4, 8, 16, 32)$ and no piping losses ($a_i=0$).

Φ_c	1.5	2	1.5	2
	$dS^{(*,oA)}$	m	$dS^{(*,od)}$	m
2.0	5.8	1.8	4.8	1.5
4.0	7.0	2.2	5.9	1.8
8.0	8.6	2.6	7.2	2.2
16.0	10.5	3.0	8.8	2.6
32.0	12.7	3.6	10.7	3.1

^a $T_{ai}=20^\circ\text{C}$; $T_c=60^\circ\text{C}$

Appendix

Airflow Requirements

The fundamental equation for design of the aeration requirements for a compost system (Keener et al., 1993a) is (note: h_c is negative):

$$Q(\theta) = \frac{(m - m_e)}{\rho_a} \frac{-h_C}{[HAO - HAI]} \quad (A1)$$

Values for $\frac{-h_C}{\rho_a [HAO - HAI]}$ are given in Table A1.

Table A1 Effect of Compost Temperature on the Airflow Requirements During Composting.

T °C	[HAO-HAI] kJ/kg _a	$-h_c/\rho_a [HAO-HAI]$ m ³ _a /kg _c	Φ
30	50.6	0.306	0.306
40	113.8	0.136	0.136
50	215.6	0.072	0.072
60	387.7	0.040	0.040
70	678.0	0.023	0.023

Based on incoming air, T_{ai}=20°C, w_{ai}=0.0107, ρ_a = 1.29 kg/m³, h_c = -20 kJ/kg_c

Maximum Time Fan is Off

The maximum time the fan can be off is given by

$$\Delta\theta^* = \frac{\epsilon \rho_a (C_{O_2} - C_{O_2}^*)}{G (1-\beta) k \rho_{co} e^{-k\theta}} \quad (A2)$$

For analysis ε = 0.4, ρ_a = 1.29, (C_{O₂} - C_{O₂}^{*}) = 0.16, G = 1.37, and θ = 0.

Remix Time and Water Addition

Keener et al. (1994) presents the equations on remix times. Remix occurs at time θ* when moisture drops below w_{c,L}.

$$\theta^* = \frac{-\ln(z1/z2)}{k} = e^{-k\theta} \quad (A3)$$

where

$$z1 = w_{c,o} M_{c,o} + \Phi - \beta_o (w_{c,L} + \Phi) \quad (A4)$$

$$z2 = (1 - \beta_o) (w_{c,L} + \Phi) \quad (A5)$$

Values for Φ (Keener, et al., 1994) are given in Table A1.

Nomenclature

Letters

a_f = coefficient-pressure drop airflow relationship

c_f = variable fan cost, \$/W

- c_L = variable land cost, \$/m²
 c_v = variable cost coefficient, \$/W · hr
 C_A = annual operating cost, \$
 C_v = variable cost, \$/ kg
 C_v = variable cost, \$
 C_{O_2} = oxygen concentration of ambient air,
 $C_{O_2}^*$ = lower limit for oxygen concentration of compost
 d = compost depth, m
 $D = \frac{-h_c \rho_c}{\rho_a [HAO - HAI]}$, energy density number
 E = energy, W hr/kg
 f_ℓ = $\nabla F(a_\ell, \alpha \epsilon)$, pipe or fan factor
 G = mass rate of oxygen uptake per unit of dry matter disappearance
 h_c = heat of combustion at T, MJ/kg
 $[HAO-HAI]$ = enthalpy difference air out – air in for compost system, KJ/kg_a
 j = exponent–pressure drop, compost pile height
 k = rate of disappearance of dry matter, day⁻¹. It is a function of substrate compounds, microbial populations, temperature, moisture content, surface exposed, interstitial atmosphere (oxygen, NH₃ ...)
 m or m_c = compost-dry mass, kg
 m_o = initial dry mass in composter, kg
 m_e = equilibrium mass, non-compostable (dry basis), kg; $m_e = \beta_o m_o$
 $mR = \frac{m_o - m_e}{m_o}$
 $M_c = m_c/m_e$
 n_e = exponent-pressure drop, airflow relationship
 P' = power per unit area, watts/m²
 P'' = power per kg_©, watts/kg (kg_© implies kilograms compostable)
 Δp = pressure drop, cm H₂O
 q = airflow per unit dry matter of compost, m³/kg_c day
 Q = airflow, m³/day
 r = annual rate for fixed cost
 s = index number for total number of days of composting
 T = temperature, °C
 v = air velocity, m/min
 V_c = composting vessel volume, m³
 w_c = moisture content-compost, dry basis, kg/kg

Greek Letters

- α = conversion coefficient, $0.612 \frac{m^3 \text{air. cm H}_2\text{O}}{\text{watts . min}}$
 β = compost equilibrium value, kg/kg. (determined by level of sugar, cellulose, hemi-cellulose etc)

- ϵ = efficiency of fan system
 = air porosity of compost
 θ = time, day
 ρ_a = dry air density, kg/m³
 ρ_c = dry matter density of compost, kg/m³
 $\bar{\rho}$ = average density, kg/m³
 ρ_{\circ} = dry matter density of compostable portion; $\rho_{\circ} =$

$$\frac{m - m_e}{V} = \rho_c - \frac{m_e}{V}, \text{kg/m}^3$$
 Φ = moisture loss term, aeration factor
 Φ_{vi} = $\beta + (1-\beta) e^{-k(i-1)}$, daily volume number

$$\Phi_{vs} = \sum_{i=1}^s \Phi_{vi}$$

 Φ_{vs} = cumulative volume number
 Φ_{al} = $f_l(Dk)^{(n/l+1)}$, aeration factor

$$\Phi A_{\ell} = \sum_{i=1}^s (e^{-k(i-1)})^{n_i+1} \Phi_{vi}^{n_i+j_i+2}$$

 ΦA_{ℓ} = fixed floor area number

$$\Phi d_{\ell} = \sum_{i=1}^s (e^{-k(i-1)})^{n_i+1} \Phi_{vi}$$

 Φd_{ℓ} = fixed bed depth number

$$\Phi_c = \frac{r_c L}{(r_c f + 365.24 c_v)}, \text{cost ratio number (fixed to variable cost)}$$

Subscripts

- i = ambient condition
 i = running index associated with compost vessel length
 ℓ = index, 1=pipe, 2=compost
 o = initial value at time zero
 L = lower value

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Final Reports

A1 Composting Process

Prof E I STENTIFORD

In all a total of 12 papers were presented in this session covering the process aspects of composting on both the macro and the micro scale, and addressing some of the more frequently occurring process problems. The core feature which ran through these papers was the important of a relatively few process characteristics during composting itself. Essentially these are:

- the amount of aeration;
- the process operating temperature(s); and
- the moisture content of the composting mass.

The Macro Scale

The three characteristics are very much interactive and the changing of one generally affects the other two. It was pointed out that when considering the process itself it is important to understand something of the many types of mass transfer taking place within the system boundary. For example in most properly run systems:

- the greatest moving mass in many composting plants during the overall process period is air;
- for many waste combinations to maintain the water balance more water is added than substrate processed; and
- the key to understanding these mass transfers is a knowledge of the energy balance with the system boundary.

The papers confirmed the importance of separating heat generation from temperature with one particular example showing that a compost mass operating at 70°C showed the lowest volatile solids loss and heat output.

The Micro Scale

The use of inocula in general waste composting was shown to have no significant effect on the composting process with the organisms present in the waste being more than adequate to ensure effective composting.

Two papers dealt with organisms filling two specific niches, those of nitrogen

fixation and functioning at high temperatures. In the later case some novel groups of bacteria were identified which were operating in the 75 – 80°C range. However the general consensus was that although the organisms were present at these temperatures their general level of activity was very low. There is a general consensus that the maximum rate of degradation takes place in the 45 – 55°C range and conditions outside this range are sub-optimal.

Process Problems

Composting plants around the world are experiencing local residence due to the generation of obnoxious odours to the extent that many of them have been forced to close. It is important to realise that all composting processes produce odour, what we have to ensure is that the odour is either inoffensive or at such a low level in sensitive areas to make it undetectable. The major factors to consider in relation to compost plant odour:

- the different quantities, strengths and flow rates from various parts of the process installation;
- the correct siting of the installation to minimise impact; and
- developing an odour ‘footprint’ for any site to anticipate the potential impact and thus minimise the chance of complaints.

The other major problems covered during the meeting involved the following:

- leachate – difficulties in this area almost totally related to open systems, covered installations only had to cope with relatively ‘clean’ surface run-off;
- airborne microorganisms – the difficulty here was largely related to the high levels of organisms in the immediate vicinity of the composting operation, and this was normally addressed by the use of suitable face masks; and
- compaction of the composting mass – this affects air flow rates, cooling, and thermal properties but with biosolids provided the moisture content was < 55% and the bed depths were , 2.5m compaction was not a process limiting factor.

The overall conclusion was that the majority of process problems arose either as a result of:

- bad design of the composting installation; or
- poor management and operation; or in many cases
- both of these.

B1 Starting Materials

Dr J LOPEZ-REAL and Dr J MERILLOT

A wide range of waste materials used for composting – organic and inorganic – was reported in the fourteen paper presented in this session. From lignin containing materials through agricultural wastes including composting of whole pig and poultry mortalities), grass, sludges and even diapers from the urban sector to the use of bauwte and coal ash. Solid wastes such as these to the more intractable and problematical organic liquid wastes, such as cattie slurry and olive-mill wastewater were discussed. A session that proved once and all that if the substrate/waste is organic it can be composted; if the waste is inorganic it can be incorporated into the process.

Many of the starting material covered, and mentioned above, represent wastes with problem of disposal, storage and treatment, whose previous route have become less attractive or constrained because of environmental concerns, environmental legislation and of course increasing economic cost.

The composting technology applied to these wastes covered the whole range of system available from windrowing to tunnel reactors. In the agricultural sector the simpler more easily adapted windrowing technique, utilising appropriate turning regimes, predominates. The application of composting technology to agricultural wastes – the largest waste producing sector of society – is hampered by ignorance, increased costs and a reluctance to shift from traditional methods of treatment and disposal. Alternative to composting such wastes may be ecologically unsound if this is resulting in increased levels of important greenhouse gases such as methane - an area requiring further urgent investigation.

It is self evident that the starting material determines the greater part of the quality criteria of the final product. Moreover the economical and even the social status of the starting material (urban waste, sewage sludges) may determine the rationale for its treatment by composting. Co-composting can answer these questions as a part of an integrated system. When referring to starting materials it must be clearly stated why it is being composted as well as how.

B2 The State of the Art of Composting and Perspectives

Summary Report Presented by JEROME GOLDSTEIN –
BioCycle

The specific challenges and operational experiences were reported by the presenters who described the status of composting in Austria, Brazil, Denmark, Finland, France, Italy, Japan, Spain, and the United States of America. The specific challenges included the following themes which were cited by most presenters:

- The need to overcome legislative barriers and enhance economic incentives so private companies will assume a greater role in composting;
- The need to integrate waste management solutions into the framework of societal issues – and to explore the links between quality of life and recovery of organic residuals;
- The need to build on the awareness of the relevance of composting through research on critical issues, and to identify those issues and use research centers more effectively to develop solutions;
- The need to form new partnerships among the private sector, government agencies, nonprofits in order to expand the impact of composting projects. To achieve successful partnerships, it is necessary to aggressively show the common interests of environmentalists, industry associations, private corporations and public policy-makers;
- The need to develop the diversity of approaches in managing and recycling organic residuals. These approaches range from decentralized, backyard programs using home compost bins and regional ‘self-composting’ to curbside collection of source-separated residential organics and residuals from commercial generators where they are composted at centralized facilities. The diversity also relates to combinations of aerobic and anaerobic systems to produce energy in the form of biogas as well as soil-improving materials for application to farms and gardens.

Representatives of different nations provided data of relevant conditions which directly affect the role of composting in waste management. Waste audits of organic residuals were cited for each country, indicating the percentage and volume of biosolids, paper and wood products, food waste, etc. which are generated from the commercial and residential sectors. Mention was made, for example, of national laws in Finland that require a 50 percent reduction in solid waste diversion by the year 2000. Many states in the United States of America have passed

laws against the disposal of yard trimmings in landfills and incinerators. These states have also set recycling goals that encourage the greater use of composting. France has set a national policy for waste management in 1992 that requires regional plans and should foster composting of source separated organics.

In Denmark, there is a growing emphasis to reduce the use of commercial nitrogen as part of a program to save energy and protect streams. The economic rationale for new recovery plants for centralized digestion of animal waste slurries is being recognized.

Several speakers – including those from Italy and France – noted the failure of past compost plants to achieve objectives and perform successfully. A specific common problem cited was the poor quality of compost produced for agricultural markets. The presenters reported on the great potential which exists in countries like Italy and France to use existing facilities to process a wide range of source separated organic feedstocks.

For example, future developments in France have been simulated and the potential for different kinds of composts was calculated as follows: six million tons from source-separated household wastes; one million tons of yard waste composts; four to five million of sludge composts (mixed with sawdust, bark, etc.). While yard waste composting is expected to increase in France in the coming years, it is expected that composting of source-separated household organics will remain low, with only five to seven experiments. A 1993 survey of compost plants by Ademe (the French Environment and Energy Management Agency) indicated the following data: 73 municipal solid waste composting plants (no source selection); 13 sludge composting plants; 30 yard waste composting plants (plus 21 projects); 16 farmyard manure composting plants; 10 mixed organics composting plants; and five experiments for source-separated household wastes.

By comparison, data reported for the United States of America indicate that there are 3,202 yard trimmings composting facilities; 318 biosolids composting facilities (including 118 in construction, permitting, design or planning stages as of December, 1994); 17 operational mixed or source separated municipal solid waste composting facilities (and an additional 34 in various stages of development).

Several speakers also stressed how existing laws needed to be changed since they were outdated and prevented progress.

The paper concerning composting experiences and perspectives in Brazil specifically pointed out the special problems facing developing countries, where practices had to reflect the links of the compost method to food production, public health, environment and social aspects. It was noted that 80 percent of the 190,000 tons per day of refuse in Brazil are disposed of in open dumps. A previous 'rush' to use composting led to use of inappropriate technologies, systems based on wrong concepts that neglected biological principles, and poor quality products. Presently, Brazil has 74 composting plants – 20 percent are fully mechanized systems and 80 percent are described as 'simplified systems' using locally adapted technologies. Most plants have problems of strong odors, vectors and leachate production. Concluded Prof. Neto of the University of Vicosia in Brazil: 'The

potential for the use of composting in Brazil can be promising if a great effort is made, mainly by the government, with policy and legislation to cover the control of the systems, in operation and its final products.'

The perspective on the state of composting in the nations represented in this session at the International Symposium is that a great effort is needed now to fulfill the potential of composting. There is a sense that in each nation, there is an emerging infrastructure of dedicated researchers, policy makers, companies, project managers and individuals to achieve the full potential of composting.

B3 Composting as an Integrated System of Waste Management

BERT LEMMES – Managing Director ORCA

The intention behind the session was to avoid the possible overfocussing on the specific composting / biogasification problem, and to avoid the kind of composting euphoria or megalomania that has caused very serious harm to the acceptance of biological treatment in the past.

We only have to think back about the experiments with total MSW-composting ,that produced an end-product that one could never call compost. Some people still advocate this strategy as a pure reduction and stabilisation-process ,with an end-product called ‘STABILAT’ (in German) or stabilised matter.

But apart from that, the general tendency goes in the direction of source-separated collection, and the biological treatment of the separated organic fraction. To oversimplify, it boils down to the question of principle whether we should try to compost as much as possible or *impose* a sufficient level of self-discipline on the sector to treat only that part of the organic resources,that will lead ultimately to the production of a valuable product ‘compost’ and to achieve this result in an *eco-efficient* manner.

We are faced in politics and legislation with the choice between waste and non-waste and a lot will depend on the final decision concerning this issue. But for the sake of this discussion ,we will continue to use the definition of recyclables and organic matter as waste for the time being.Nevertheless I want to stress already now that a basic change should be made in the thinking and therefor in the wording and definitions.

We should start calling ‘waste’ what is definitively ‘wasted’ and should adopt the positive philosophy of ‘RESOURCES-MANAGEMENT’ instead of ‘waste-management’ for all the fractions that can eco-efficiently be recovered.

We are faced with choices in resource-management about how to deal with the organic fraction. Biological processes are one of several means of dealing with this part of the secondary resources , but there are obviously others.

The integration of composting, anaerobic digestion or biogasification and stabilisation into an overall recovery strategy, not only seems the logical way to go but will avail itself the only solution for specific fractions of the waste stream if we want to achieve the recovery targets that will be imposed.

To help the European legislators prepare decisions and mandates to implement biological treatment as a solution, it is necessary to provide a rational framework and a matrix to judge the opportunity of the solution.

This framework will have to take into account:

1. The specific objectives of the waste management (local-regional constraints, etc.)
 2. The broad environmental merit via the LCI's and LCA's
 3. The economic merit:
 - impact on the primary production
 - social acceptability and ease of implementation

This should enable the decisionmakers to determine the eco-efficiency of their strategy.

Eco-efficient would mean in this case: *eco- logically sound
eco-nomically viable*

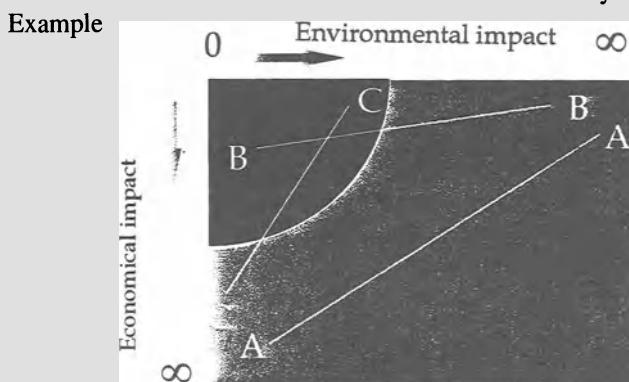


Figure 1 Operating Eco-efficiency

Legend:	Project A	Big ecological impact but very expensive
	Project B	Big Ecological impact and low price
	Project C	Small ecological impact and very expensive

Black section is the operating window that can assure eco-efficient sustainable activity

We acknowledge that in the end the decision will remain political, but we can proactively create an *operating widow* to point out to the authorities that any decision outside this operating widow would be unreasonable and certainly not sustainable.

A lot will depend on the definition of the waste and its separation in different fractions.

Depending on the collection system, the source separation system, the fraction of grey waste could go from 100% (as in some areas using mass burn-technology) (to only 10% after source separation and pre-treatment.

The more efficient the separation, the smaller this grey fraction will become and the more important the diversion from landfill will be. But, whatever we do,

we admit that there will always *be* a grey fraction. But this has to be as small as possible.

Dealing with that issue, Paul Bardos exposed a possibility to implement the *co-treatment of this grey fraction with industrial wastes in order to reduce the volume and stabilise and sanitise the waste to be landfilled*. At the same time the possibility to recover biogas, and the detoxification of hazardous substances.

Two other aspects of well managing the landfill, where it avails itself unavoidable, were addressed by Prof. Cossu and Dr. Muntani. The former addressed the problems with the containment in landfilling and the treatment of the percolate.

This discussion put the finger on every sore spot in the whole waste management strategy.

'How do we estimate the long-term environmental impact of a landfill and the economical implications of its sanitation afterwards.'

'How do we reflect this in the actual landfill-levies and do the existing or revised landfill levies such as in the UK reflect the real cost for providing an acceptable solution.'

Dr. Muntani addressed a different issue of landfilling by advocating the use of compost to avoid some of the engineering problems in well-managed landfills. According to him compost can function as a filter, a buffer, an absorbent in landfills to avoid the problems with leachate (among others) by binding toxic ingredients.

From the landfills we turned our attention to the solutions that are provided respectively by recycling of dry matters and the use of R.D.F. and P.D.F. in co-combustion processes.

Julia Hummel presented the pioneering work done by ERRA in setting up a database to collect data in a dozen pilot cities and to design a number of analyse-tools to interpret those data.

The motivation and participation ratio's for the source separation schemes and the cost for collection and separation are especially interesting for our sector as we are confronted with the same problems.

For this reason ORCA and ERRA will join forces in the very near future and combine their information and the processing of the data with this data-base to achieve a global view on the recovery-issue and to put these data at the disposal of the decision-makers. The collaboration with a university and a number of motivated researchers will guarantee the academic and scientific accuracy of these data and make this a tool of high value to the EU , OECD and other authorities,faced with the elaboration of mandates in this complex sector.

Martin Frankenhaeuser of Borealis advocated the reduction of the grey fraction by extracting the recyclables first, splitting the waste into a dry and a wet fraction. This proves once more that the different technologies can be complementary with a common denominator : good source separation.

The colours of state of the art composting were defended by: George Savage, of California Recovery ,who advocated the use of the C/N ratio as a possible tool to judge the efficiency of process design.

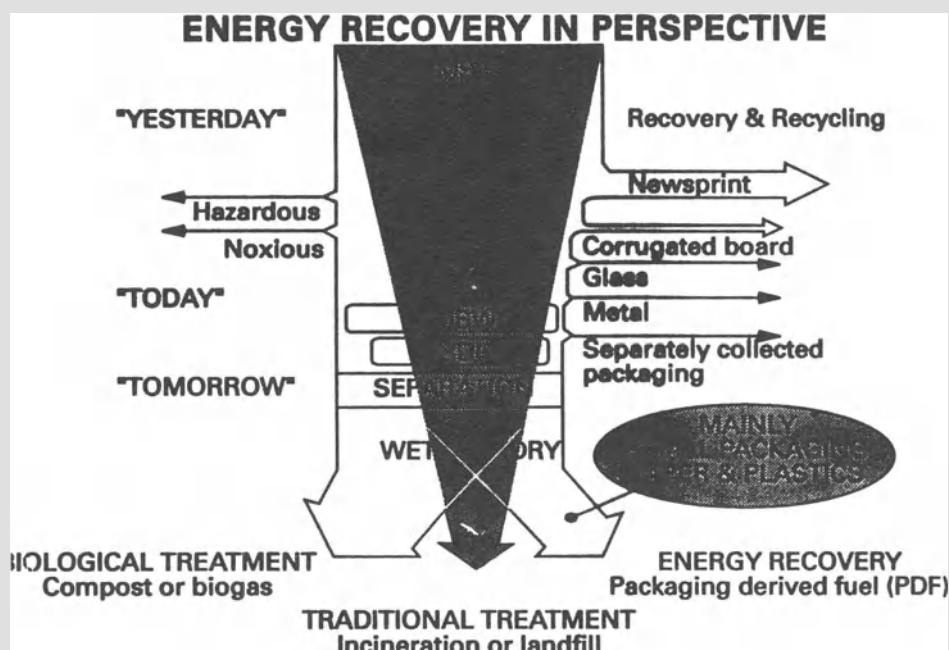


Figure 2 Vision for Municipal Solid Waste Management

At the same time he focused the attention once more on the *importance of the waste characterisation on the quality of the final compost*.

Going deeper into the problem of the definition of biowaste and broadening that definition by adding a paper fraction, Bruno De Wilde of Organic Waste Systems N.V. (OWS), Belgium, provided us with a clear insight in the advantages of paper inclusion in composting. As there are (among many others):

- reduction in salts
- more organic content
- better compost

The complete text of this research-project is available in the ORCA Technical Publications.

To close this compost section, Karel Mesuere commented and analysed the compostability criteria elaborated by ORCA as a framework to define the acceptable feedstock for state-of-the-art composting, and in order to make a quality compost.

These criteria create the link between the biodegradability (as tested in the labs) and the practice of composting, by integrating parameters that are relevant to the operations of composting/biogasification-plants. At the same time these criteria are scientifically correct and take into account the technical, biological and economical factors of the different processes. This very important work has been reviewed by a Peer-Review-Committee consisting of the leading authorities in the

academic world and has therefore also been accepted by different authorities to form the framework for future legislation.

This publication is also available in the ORCA Technical Publications.

Last but not least, Peter White, Procter & Gamble Ltd., UK, author of the book 'Integrated solid waste management' showed us in his exposé, apart from the well-known advantages of biological treatment, the necessity to optimise biological treatment, to optimise source separation and to optimise the whole system, in order to reduce overall environmental impacts and to make integrated waste management economically sustainable.

Through LCI and LCA ,we can create tools to model the options ,even if questions will always remain concerning the validity of socio-political parameters and their evaluation in the overall LCI. At least we will have a more comprehensive view on the problem that will help us design a possible solution ,that will always have to be a custom made ,local or regional solution.

He warned us once more for the danger of isolating systems or technologies that will distort the total picture and shift the problems and advocated *the integrated waste management approach*.

Conclusion

I just want to close this report, by urging all you ladies and gentlemen to do the same. Biological treatment, our technology (including the correct applications of biodegradable materials and products) has so much to offer ,that we should not try to pretend it has no limitations

We most certainly have an *economical, ecological and socio-psychological advantage* over the other waste-treatment options , so why avoid the challenge to situate our technologies in an overall sustainable integrated waste-management system.

- ◆ Taking into consideration a similar environmental impact
- ◆ landfill
- ◆ incineration with energy recovery
- ◆ biological treatment relate as shown here

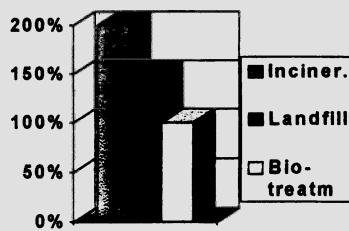


Figure 3 Cost-relation Waste-treatment

Lets sit together with the representatives of the other resource-recovery technologies, and discover where we are complementary, where competitive, to ensure an overall better result and the recovery of valuable resources and energy.

B4 Bioremediation

LF. DIAZ – Moderator CalRecovery, Inc. Hercules, California, USA

In this session, a total of seven presentations were made. Five presentations dealt with bioremediation of contaminated materials, one covered the “removal” of heavy metals by the addition of a natural zeolite, and one discussed the application of starch-based biodegradable materials in the separate collection and composting of organic waste.

The papers dealing with bioremediation reported the results of experiments and tests conducted to break down primarily hydrocarbons and pesticides. One paper described the methodology for conducting biotreatment analyses and presented the results of laboratory-scale and pilot-scale studies. The results of the studies indicated that existing technology can be applied to the composting of hazardous biodegradable wastes through suitable modifications. Another paper reported the results of composting creosote in reactors (under mesophilic temperatures). The results of these tests indicated that composting can be applied for the treatment of soils polluted by creosote. The results of experiments performed on the bioremediation of soils contaminated by PAII indicate that biotreatment of the contaminated soils in slurry form is too expensive under full-scale conditions and that heat treatment and solidification may be more cost-effective. Another presentation dealt with the use of compost in the treatment of soils contaminated with pesticides. The results of this work demonstrated that the addition of 20% to 40% of compost to contaminated soils stimulated the degradation of pesticides. Another presentation described the use of closed systems to evaluate biological degradation of hydrocarbons in soil. The results of the work indicated that the application of compost had a positive effect on the degradation of FAIIs. In general, the results of all of the studies discussed in this portion of the session showed that hydrocarbons and pesticides can be effectively degraded biologically. The results also indicated that degradation increases as the quantity of composts added to the contaminated materials increases. Presenters stressed the importance of conducting laboratory-scale tests to assess the impact of the addition of compost to the hazardous wastes before large-scale projects are perlbrmed.

With regard to using natural zeolites, results of tests conducted cultivating peppers in compost showed that plants contained lower quantities of metals when cultivated with zeolite. Lower concentrations of metals were obtained when higher concentrations of zeolite were used.

Finally, it was reported that starch-based biodegradable materials compatible with composting and having good mechanical properties currently are available. Starch-based materials can be used as a replacement for LDPE in the manufacture of products such as trash bags, packaging materials, and diapers. In addition, the results of experiments of separate collection and composting of organic wastes conducted in Germany, Austria, Italy, Sweden, and Finland using starch-based materials indicated that these materials have acceptable mechanical properties and they are compatible with the process of composting.

B5 Composting Design

ROGER T. HAUG, PhD, PE – Session Moderator

Six papers were presented in Session 5B, each addressing aspects of composting plant design. A brief summary of each paper is presented along with the moderator's closing comments.

Summary of papers

Mr. Robert Tardy, Director of Compost Projects for R.W. Beck, presented an overview of U.S. composting practice and experiences, with particular emphasis on recent experiences with municipal solid waste (MSW). MSW composting in the U.S. has had some successful facilities, but also a number of high profile failures. Significant progress has been made in understanding the design criteria necessary for successful operation. Despite this better understanding and the fact that some MSW facilities are still being planned, Mr. Tardy felt that the industry was moving away from MSW composting toward composting of source separated organics.

Dr. Bernhard Raninger, University of Salzburg, presented an overview of composting practices in Austria. 12 of 19 former co-composting plants (MSW plus biosolids) are being converted to source separated biowaste. Over 78% of households are required to source separate and this is expected to increase to 90% by the year 2000. Dr. Raninger felt that future facilities, particularly those composting substrates with high odor potential, should be 'industrial' types with enclosed processes and odor control. Several examples of 'industrial' conversions were presented, including composting plants at Salzburg and Allerheilegen. The Salzburg facility has added anaerobic composting of biowaste followed by enclosed aerobic curing.

Mr. Fabio Conti, Research Engineer at the University of Pavia, presented an overview of Italian experiences and plants. Photos and descriptions were presented of a number of plants of historic significance. Many of these are being modified to more modern standards. Mr. Conti mentioned that some drum systems did not provide sufficient residence time to start the compost process.

Mr. Mogens Hedegaard, Project Manager for Kruger A/S, presented new ideas on biosolids stabilization and removal of heavy metals. Some laboratory work has been conducted in support of the concept, but there are no commercial installations at present.

Dr. Nancy Lynch, Research Engineer with the Idaho National Engineering

Laboratory, presented the results of simulation modeling to develop design guidelines for passively aerated compost piles. The latter rely on the 'chimney effect' for pile aeration, enhanced by perforated aeration pipes, open at each end, and arranged perpendicular to the pile or windrow length. This work is a good example of basic research designed to improve understanding of the physics of air movement in such piles. It is expected that guidelines will be developed on pile dimensions and the distance between aeration pipes.

Mr. Keith Panter, Product Development Manager for Thames Water International, presented an overview of tunnel systems in the U.S. and Europe. A new tunnel system at Camden, New Jersey, began commissioning in April, 1995. Designed for 50 dtpd of biosolids, it is one of the largest in the U.S.

Moderator's comments

Today's composting market is characterized by a wide variety of commercially available systems being applied to a variety of substrates. Many systems are enjoying commercial success, whereas some formerly popular systems are less prominent. Systems with more advantages and improvements are replacing less successful designs. The composting industry is maturing and design criteria for successful facilities are understood better by today's design professionals than at any time before. Many of the recent improvements focus on the needs for containment and treatment of odors, particularly for substrates with 'high odor potential.'

This is a time of great optimism in the composting industry for a number of reasons, including the following.

- More substrates are being considered for composting than at any previous time. In the U.S. the 1950's and 60's saw composting applied to MSW with only limited success. In the 1970's composting was first applied to biosolids with the 80's devoted to expansion and problem solving. Yard waste started to be a significant composting substrate in the late 80's and has grown explosively since then. The 90's will be the decade in which composting is applied to almost all degradable organics using latest generation technologies.
- There is general acceptance that composting is part of an integrated approach to solid waste management.
- There is a return to source separation of urban organics, begun in Europe and now spreading in the U.S. This will be a tremendous help to composting because once wastes have been mixed together, such as with MSW, it is very difficult to separate the clean compostables. The engineer can design separation equipment, but no separation process is ever 100% efficient. Separation efficiency can be increased, but only at the expense of producing more rejects. It is becoming generally accepted that producing a high quality compost with an acceptable level of rejects is not possible with MSW. Simply stated, the quality

of the compost product depends on the quality of the feedstocks.

- Support has grown to make the difficult political decisions to support reuse of waste materials, such as by composting. In addition, favorable regulations have been adopted by many governments which support composting and attempt to reduce the regulatory burden associated with permitting new facilities.
- Research in support of composting is being conducted in many related fields, such as plant physiology and disease suppression. Such research is advancing to the point where the information may soon influence both process design and operation.

While optimistic about the current state-of-the-industry, I am concerned about certain clouds that we must jointly work to dispell. First, the history of the composting industry is not well documented. Many current mistakes, such as recent MSW composting failures in the U.S., may have been avoided if the lessons of history were better known. Many of our early pioneers are aging and we risk further loss of our history with their eventual passing. Second, significant barriers exist to the transfer of information across different parts of the composting industry. In the U.S. for example, lessons learned from biosolids composting appear to be little applied by those engaged in MSW composting. This is in part caused by the fact that professionals active in the biosolids industry in the U.S. are generally not the same ones active in the solid waste industry. Also, the MSW composting industry in the U.S. seems to be dominated by entrepreneurial ventures. The wealth of talent developed in the biosolids industry is not well used outside that industry. Third, high profile failures of several MSW composting facilities have occurred in recent years, mainly due to odor control issues. This has had a cooling effect toward composting in many circles. While it is true that composting can be applied to a variety of substrates, it is equally true that composting is not a panacea for all wastes and circumstances. Using the wrong substrate or not building odor control adequate to the site and substrates is a disservice to the composting industry. Eagerness to 'do the right thing' must be tempered by the cool eye of engineering analysis, field experience, and historical perspective.

B6 Marketing and Economic

L.L. EGGERTH – Moderator CalRecovery, Inc Bercules, California, USA

In the session on marketing and economy, live presentations were given: two dealing with the importance of marketing efforts and markets for composts; one dealing with the principles of the German quality assurance program; one on the activities of the Italian Composting Council; and one on economic modeling.

The presentations on marketing focused on the status of compost marketing in the United States of America. Important points that were addressed include:

- marketing is often forgotten, but needs to be included early in the project development process
- there is a still mentality in the USA from considering composting strictly as a waste
- disposal process to consider as a product manufacturing process
- production of a quality product is critical to market development
- public education must be an integral part of the composting program

The presentation on the principles of the German quality assurance program stressed the fact that marketing depends on user confidence – in the product, in the producer, and in the compost quality. In Germany approximately 170 composting plants representing 1.5 million tons of organic material participate in the quality assurance program. Of the participants, 130 plants, producing 71% of the product in the country, meet the standards and carry the compost quality standard emblem.

The Italian Composting Council is a technical national scientific organization designed to promote compost use. The objectives of the Council are to:

- disseminate information by organizing meetings to increase awareness
- work with agriculture to develop confidence in compost
- implement a certification process
- create markets

The speaker also stressed the importance of producing a high quality compost to agricultural market development.

The presentation on economics stressed the fact that composting currently is a subsidized industry and that there is a critical need to reduce costs. The author presented a series of mathematical relationships to describe the composting process and thus use the mathematical models to optimize the system through

process control, producing a stabilized product, and actueving the lowest cost.

The pervading theme of the session was on the need to utilize feedstock selection, process control, product quality standards, and public education efforts to ensure the availability of Ngfi quality composts and to develop markets for the products.

Posters

Thermophilic Pilot Scale Composting of Olive Cake

**BACA, M.T.¹; BELLVER, R.¹; DE NOBILI, M.² and
SANCHEZ-RAYA, A.J.¹**

Summary

Olive press cake are solid agroindustrial residues produced during the extraction of olive oil, disposal of wastes produced during this process is a particularly pressing problem in Southern Spain and other mediterranean countries. We developed a pilot-scale windrow composting process for optimal transformation of this kind of substrate, characterized by a high lignocellulose content. We found that the 82% of lignocellulose degradation took place when temperatures were above 50°C. After three months temperature was still relatively high; this notwithstanding the phytotoxicity of the compost was almost nil as demonstrated by biological tests.

Introduction

Decomposition of biodegradable organic wastes is a continuous and natural process developed in the soil by its biological community especially at the soil surface. But the soil has a limited resources to adsorb, absorb and transform this organic matter. Debris inputs and soil biomass are in dinamic equilibria influenced by many environmental factors. The elimination of the orgánic wastes generated by the human activities without breaking the equilibria could request a hight soil surface which makes unviable the process.

With composting, we reproduce in industrial scale these natural degradative processes, obtaining a stable organic product with similar characteristics to soil organic matter in a short time. Olive press cakes are solid agroindustrial residues produced during the extraction of olive oil, disposal of wastes produced during this process is a particularly pressing problem in southern Spain and other mediterranean countries. Residues are produced for 4–5 months in a high rate producing serious problems of storage, transport and disposal. Composting it, we eliminate those problems obtaining paralely an organic matter which can be applied as ammendment on several crops and soils. The aim of this work was to develop in

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pilot scale, a composting process to transform this lignocellulosic byproduct in a substrate rich in nutrient and organic matter suitable as soil amendment.

Material and methods

We developed a windrow composting process to transform pressed olive cake. The characteristics of the product during composting are in Table I. We prepared a windrow of 5000 Kg of dry mater and we controlled its physico-chemical characteristics during 3 months. Initial C/N and C/P ratios were adjusted to 33 and 240 respectively by adding urea and superphosphate. The composting mass was turned periodically to homogenize the compost and to control humidity, temperature and aeration. Humidity was maintained above 40–50% to promote fungal growth. O₂ concentration was measured by gas chromatography at 20 cm of deep where the temperature was higher. Humification was determined according to Sequi et al. (1986), which separate polyphenolic (humic like) and non polyphenolic (labile) substances extracted in alkaline solution by adsorption chromatography on PVP resin. Biological tests were realized to determine the evolution of the phytotoxicity during the process; we determined the shoot dry weight of sunflower plants grown for 21 days on soil:compost (1/1 w:v) mixtures at 0, 15, 30, 60 and 90 days of compost transformation. Nitrate content was determined using the phenol-disulphonic method proposed by Lachica et al. (1972).

Table 1 Physicochemical characteristics of the compost at the beginning, and at the end of the thermophilic phase (60 d) at the end of the experiment (90 d).

		Days	
	1	60	90
pH	6.60	7.70	7.80
E.C. (dS/cm)	3.50	3.50	2.50
WHC	21.50	84.30	92.10
%H	60.00	35.00	44.00
Density (g/l)	0.48	—	0.58
Volatile solids (%)	90.30	86.90	85.80
TOC stractable (mgC/gds)	87.90	54.50	59.00
HS mgC/gds	50.40	36.20	42.90
NHS mgC/gds	40.70	12.00	12.90
HI	0.80	0.30	0.30
C/N	33.00	19.20	17.00
C/P	240.00	180.00	128.00
Lignin	31.20	22.30	19.90
Cell + hemicell.	29.80	16.60	9.60
NO ₃ %	0.04	0.02	0.01

Result and discussion

Temperature reached thermophilic values after several hours and remained elevated throughout the process. The thermophilic phase lasted for 55 days with an average T^a of 55°C and recovered fastly after turning (Fig. 1). After 55 days, the temperature decreased slowly to mesophylic values above 40°C. At the end of the experiment after 90 days of composting, it remained at mesophylic values.

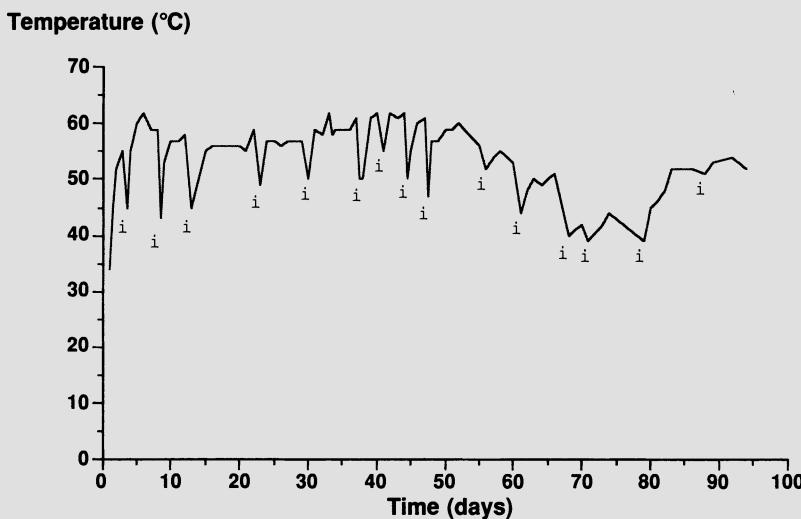


Figure 1 Temperature curve during composting determined at 20cm deep. Arrows indicate turning points.

Aeration was carried out by turning to assure an adequate oxygen level into the compost mass that required over the 5% O₂ to assure the aerobicity. Only during the first days, when the biological activity was highest, the O₂ level decreased to 2% (Fig. 2).

During the thermophilic phase, lignin, cellulose and hemicellulose were hardly mineralized by the microorganisms, which performed above 82% of the total degradation in these phase and the remaining 18% during the last month at temperatures around 40°C (mesophilic phase)

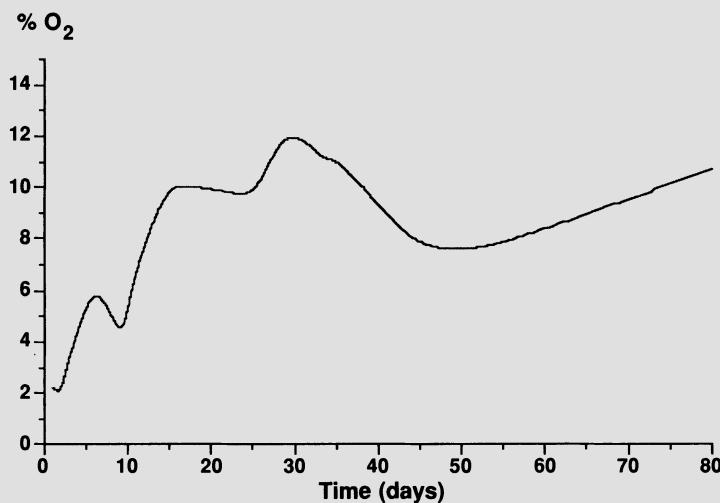


Figure 2 % of O₂ content in the compost mass at 20cm of deep determined by GC.

Structural changes were observed during composting, the density increased from 0.48 to 0.58 g/cm³ with a paralell loss of 2/3 of the initial volume. WHC changed in the same time from 21.6% to 92.1% (Table I).

At the end of the experiment, the temperature was still quite high (above 40°C). Nevertheless, the phytotoxicity of the compost was almost nil as demonstrated by biological tests carried out periodically with sunflower plants grown on soil-composts mixtures. After 90 days of composting, the plant development were similar in the controls and in the mixture (Fig. 3).

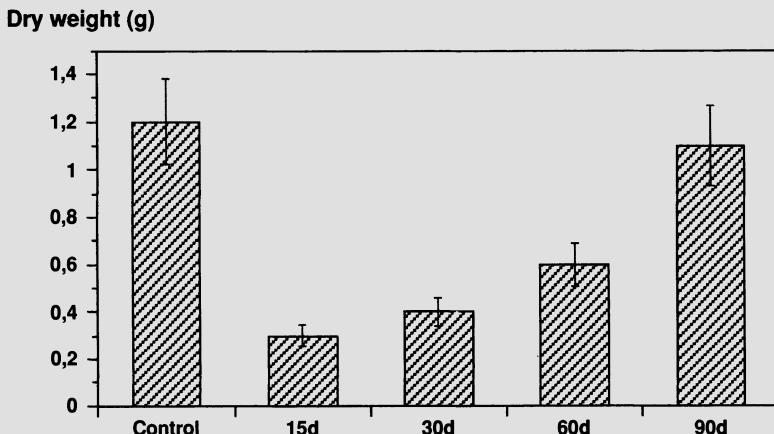


Figure 3 Shoots dry weight of the plants grown on the control and on the soil-compost mixture at 15, 30, 60 and 90 days of transformation (any growth was found at 1 day of transformation

In a previous work, nitrificant activity was found to be as an index of the aerobicity and maturity of these processes (Baca et al. 1995), nevertheless, the presence and activity of the nitrificant bacteria diminished with temperature and it could'n be used in this experiment as an indicator of compost stabilization complementary to the biological test.

Total extractable organic carbon (TOC) decreased during the composting passing from 87.9 to 59.0 mgC/g ds. In the same time, extractable polyphenolic (HS) substances decreased from 50.4 to 42.9 mgC/gds while non polyphenolic (NHS) were strongly consumed by microorganisms as a carbon source, passing from 40.7 to 12.9 during the process (Table I). Humification index, which is the quotient between NHS and HS decreased from 1.1 at the beginning to 0.3 after 60 and 90 days indicating that the chemical stability reached before the disappearance of the phytotoxicity.

Discussion

The composting process proposed in this works suitable for transforming by-products with a very homogeneous composition and high content of polyphenolic (lignin) and polysaccharidic (cellulose and hemicellulose) substances. The phytotoxicity was almost nil even before the maturation phase, probably because the biological activity was very restricted and specialized due to the composition of the by-product with more than 60% of dry weight constituted by polysaccharides and lignin. The later compound, rich in polyphenolic and polycarboxilic acids could be transformed by the biological degradation and posterior synthesis and diagenesis in a stable organic matter rich in humic-like substances. The disappearance of the toxicity was a slow process throughout the experiment, while the chemical stabilization of the orgánic matter seemed to be related to HI values of 0.3 found at the end of the thermophylic phase.

The compost obtained by these method can be used as a soil ammendment and even also as an organic fertilizer in ecological agro-culture (Guía de productos utilizables en agricultura ecológica, 1993).

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Changes in the Amino Acid Composition of Grass Cuttings During Turned Pile Composting

M.T. BACA*, I. FERNANDEZ-FIGARES*, C. MONDINI and M. DE NOBILI*****

Abstract

The amino acid composition of composts derives in part from the original amino-acid pool of the substrate and in part from extracellular enzymes and cells of the dead and living micro-organisms. Because of their high biodegradability, the relative molar distribution (RMD) of amino-acids in compost depends on a balance between re-synthesis and decomposition and should be related to changes in microbial community. The total amino-acid content increased sharply during the first days of composting fairly as a consequence of weight loss and remained fairly constant up to the 75th day of composting, decreasing thereafter during the curing period to about one half of the maximum value obtained (139 mmol/100g). The RMD shows a decrease in acidic amino-acids and particularly in the content of glutamic acid (11.19% at 7 days and 7.75% at 100 days), with a concomitant increase in cystine (6.85% at 7 days and 10.07% at 100 days) and methionine (8.45% at 7 days and 11.95% at 75 days). Comparison with previous work suggests that changes in RMD are related to process strategies.

Introduction

Good quality compost could represent a used alternative to peat as growing substrate and organic ammendant. The quality of compost is related to the quantity and the quality of humified fraction of organic matter, but also to the presence of a biologically active fraction that acts as a readily available source of nutrients. Amino acids (AA) represent an important part of this fraction. Recently, relative molar distribution (RMD) of AA was related with changes in soil organic matter quality (Campbell et al., 1991), but information on the composition of the

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aminoacidic fraction of compost are very scarce. The AA composition, in soils as in compost, depends on a balance between re-synthesis and decomposition: if the former is prevalent, changes in the amino-acids composition should reflect changes in the composition of microbial population.

In this work we studied the variations in AA composition of grass cuttings during composting and its relation with the degree of stabilization of compost.

Material and methods

In the compost process grass cuttings (50 Kg) were piled and manually turned, at regular intervals, for a period of 100 days. Humification index was determined according to Sequi et al. (1986). Samples for amino-acid analysis were hydrolyzed with HCl 6M and 1% phenol for 24 h at 110 × C. Aminoacids were analyzed quantitatively by high performance liquid chromatography (HPLC) using the Waters Pico-Tag method and Nor-leucine as internal standard.

Results and discussion

The regular trend of 111 (table 1) indicates the progress of humification processes with the increasing time of composting. Nevertheless HI already at 7 days shows values which are typical of well humified materials. This could be explained by the presence in the starting substrate of a high content of phenolic (humus-like) substances that are extractable with alkali and contribute to the amount of C in the B fraction (humic). In fact the B fraction decrease during composting up 61% of the initial value. Total extractable C decreased as well during composting.

Table 1 Extractable organic carbon and humification index of grass cuttings during composting

Days	TE	O.C. (mg/g)		H.I.
		A	O	
7	182.70	48.76	131.82	0.37
21	129.05	25.63	99.73	0.26
41	107.34	18.34	86.81	0.21
75	120.49	17.93	103.11	0.17
100	60.63	8.93	50.13	0.18

The total AA content (table 2) increased sharply during the first day of composting, mainly as a consequence of weight loss and remained fairly constant up to 75th day of composting, decreasing afterwards during curing period to about one half of the maximum value obtained (139 mmol/100g). This would indicate that with advancing humification, decomposition overcomes re-synthesis. The prevalence of mineralization processes at the end of composting period could be demonstrate by the increasing content of NH₄ (tab. 1).

Table 2 Total aminoacid acid and NH4 content of grass cuttings during composting

Days of composting (mmol/100g)	Total aa content (mmol/100g)	NH4
7	130	13
21	139	13
75	125	18
100	71	17

Table 3 Amino acid composition of grass cuttings during composting

Amino acid	7 days	21 days	75 days mmol/100g	100 days
<i>Acidic</i>				
Aspartic a	6.235	4.806	4.392	2.022
Glutamic a., a.	14.531	12.507	11.784	5.478
Total	~.788	17.313	18.178	7500
<i>Basic</i>				
Hi-histidine	2.382	2.430	2.301	1.332
Lysine	3.987	4.219	3.723	1.949
Arginine	4.949	5.687	4.504	2.473
Total	11.318	15.338	10.6~	5.754
<i>Neutral</i>				
Threonine	6.529	7.142	5.796	3.685
Serine	8.290	9.792	8.786	5.324
Prone	4.210	5.676	3.730	2.470
Glycine	14.133	15.995	13.731	8.736
Alanine	14.555	15.572	13.242	7.554
Vane	7.990	9.606	6.907	4.020
I-leucine	4.662	5.093	4.076	2.558
Leucine	9.437	10.627	8.319	4.821
Tyrosine	3.809	4.054	3.343	2.044
Phenilalanine	4.305	5.001	3.984	2.333
Total	77.9~	88.55	71.914	43.545
<i>Sulphur c</i>				
Methionine	10.968	10.718	14.988	6.746
Cystine	8.902	9.700	11.765	7.113
Total	19.870	418	~753	13.859

The amino acid composition is shown in table 3. Total acidic AA is the class of AA that shows the higher decrement respect to initial value (63.9%). This trend is confirmed by the RMD of total acidic AA (fig. 1) showing a regular decrease, particularly in the content of glutamic.c acid (11.19% at 7 days and 7.75% at 100 days). This is in agreement with the trend found during humification of spruce and aspen leaf litter (Ladesmaki and Phspanene,1989). RMD of sulphur-containing AA shows a marked increase (28.2%). In particular cystine increased from 6.85% at 7 days to 10.07% at 100 days and methionine from 8.45% at the beginning to 11.95% towards the end of composting. Change in RMD of sulphur-containing AA is particularly evident between 21 and 75 days, suggesting a change in

the composition of microbial population from thermophilic (50-60 °C) to mesophilic (30-40 °C) microorganisms of total basic and neutral AA remained practically constant. of total acidic and sulphur containing is quite different from that of a well stabilized population such as that of an organic matter rich soil (Campbell et al., 1991). Comparison with previous work (Baca et al., 1992), suggests that changes in RMD are related to process strategies. Therefore changes in AA composition can be a useful parameter to characterize the compost, but her works is necessary to use AAccomposition to assess compost maturity.

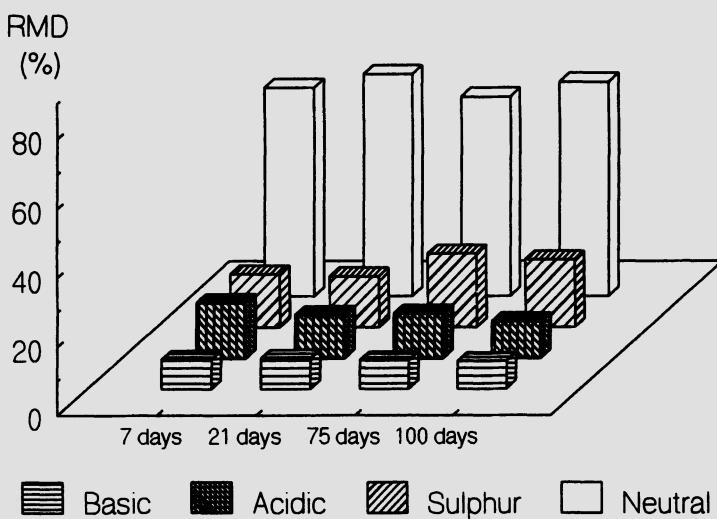


Figure 1 RMD of amino acid of grass cuttings at different composting times

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Composition and Chemical Characteristics of the Main Compostable Organic Wastes

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Introduction

In order to produce high quality composts it is necessary to start from selected organic wastes, non polluted by heavy metals and with limited inerts and unwanted materials. The source separation of municipal solid wastes and especially the separate collection of wastes from specific categories of producers, can help to supply good quality waste materials that can be composted together with yard wastes to advantage. This poster reports the most important results of a wide range of experiments, carried in Piedmont (Northern Italy), on separate collection of organics from specific categories of producers such as restaurants, canteens, and vegetable markets, foodstuff stores, and so on. Chemical characteristics and composition of these wastes were compared with those of mixed municipal wastes selected after collection.

Discussion

Solid wastes contain high percentages of organic compostable materials (food and yard wastes, paper, wood, ...); in particular wastes coming from specific producers are prevalently made of compostable materials. The pictures in annex show the main components of MSW and of wastes from specific producers (restaurants, canteens, foodstuff stores, etc.), the latters contain very high percentages of compostable materials which reach 90% of the waste when separate collection programs are implemented on purpose for the abovesaid categories. The table report the results of chemical analyses carried out on the organic fraction of wastes collected from the above-mentioned producers, the results are then compared with those of chemical analyses of the organic fraction of MSW separated after collection. The organic materials coming from selected producers contain vary low percentages of heavy metals, this is particularly evident when the data are compared

Table 1 Chemical analyses of compostable materials (dry weight except for pH and moisture content)

Parameter	Domestic Wastes (1)	Foodstuff Store Wastes	Restaurant Wastes	Canteen Wastes	Yard Wastes	MSW (2)
Moisture (%)	66,5	40,5	61,5	78,2	33,0	42
pH	5,3	5,2	4,9	4,6	5,8	7,1
Conductivity (mS/cm)	3,0	3,6	2,7	2,9	2,0	2,4
Salinity (meq/100g)	80,1	98,7	71,2	77,3	58,6	64
Ash (%)	23,6	33,8	9,6	5,8	17,7	50,9
Organic carbon (%)	35,1	31,8	41,40	40,83	41,6	22,7
Total Nitrogen (%)	2,1	1,6	4,1	2,8	1,3	1,3
C/N Ratio	16,9	19,5	10,0	14,8	40,4	17,4
Phosphorus (%)	0,42	0,27	0,25	0,196	0,17	0,37
Potassium (%)	1,30	1,15	0,60	1,26	1,15	1,03
Calcium (%)	4,10	2,32	2,69	1,45	2,41	1,28
Magnesium (%)	0,07	0,05	0,01	0,01	0,61	0,76
Sodium (%)	0,35	0,58	0,53	0,68	0,57	0,60
Lead (mg/kg)	50	41	9	10	183	891
Nickel (mg/kg)	23	97	6	19	62	48
Manganese (mg/kg)	53	213	11	24	124	568
Zinc (mg/kg)	284	197	80	187	111	822
Copper (mg/kg)	31	41	8	18	13	302
Chromium (mg/kg)	41	58	6	27	41	71
Cadmium (mg/kg)	1,2	0,5	0,4	1	0,3	5

(1) Source separated organic wastes from the homes

(2) Organic fraction selected from Municipal Solid Wastes after collection

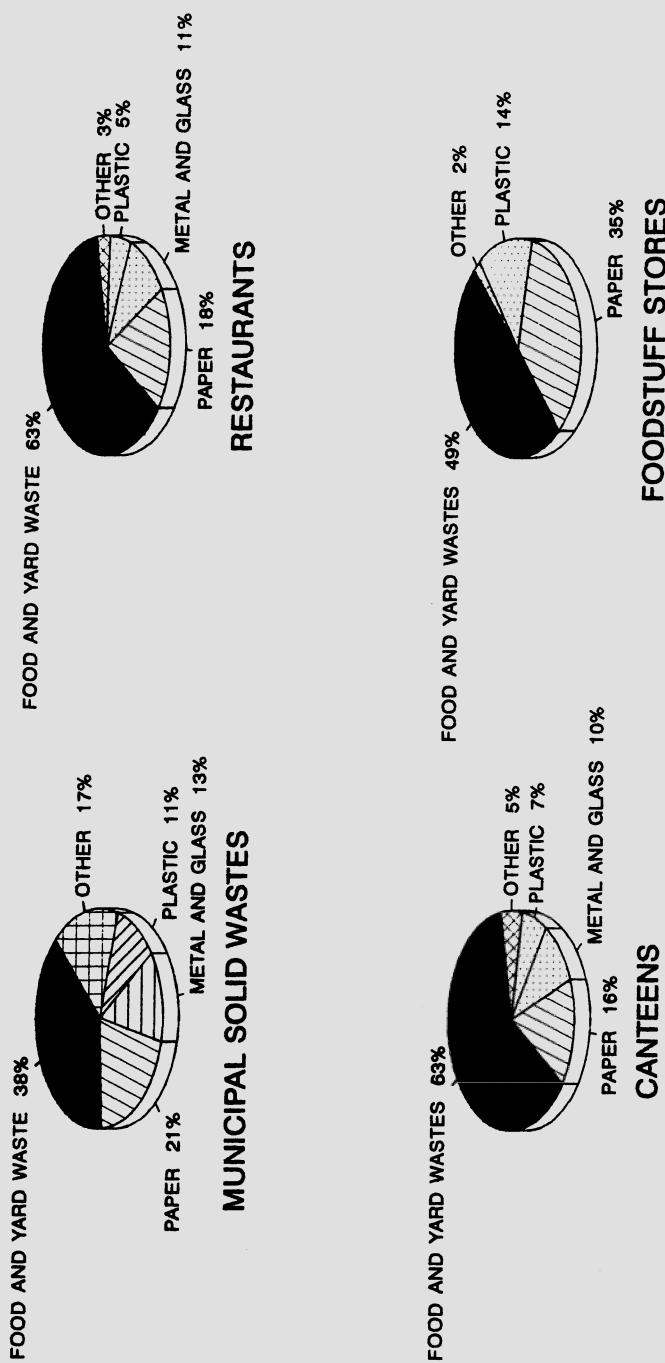


Figure 1 Comparison of Waste Composition

with those of the organic fraction selected from MSW after collection. The latter in fact, being contaminated by heavy metals, is not suitable for high quality compost production.

Organic materials from selected producers, preferably bed with sludges of the food industry, wood debris and agricultural residues, can also make high quality composts. The results prove that an effectively carried out separate collection, both from specific waste producers and from homes, is able to convey to the composting facility little polluted materials (low heavy metal concentration) containing easy-to-remove quantities of glass and plastic. Thus the obtained product will comply with the most severe qualitative standards.

Impacts of Separation on Compost Quality

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Composting treatment reduce the volume of refuse to be dumped in landfills since household waste will thus lose a large portion of its organic components. Correctly implemented, composting is a reliable method of transforming the putrescible organic matter of wastes in to a soil conditioner.

Throughout the fermentation period, it is extremely important to avoid contact between organic and inert matters contained in household refuse, to prevent contamination from heavy metals.

Heavy metals are used in many household products (soap, detergents, cosmetics, packaging, leather and batteries). They are concentrated during the composting process as the organic matter which dilutes them gradually degrades. The metals of greatest concern are those which tend to bioaccumulate, causing short or long term toxic effects to organisms in the environment. Those most commonly regulated include cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), nickel (Ni) and zinc (Zn).

Separation at the source seems to be the best way to reduce inert matter contained in household refuse thereby provides a compost with low heavy metal content.

Source Separated Program

Concerned about the improvements and the quality of the Environment, the Tunisian Ministry of Environment has decided to implement a collection pilot project involving source separated organics. The household separation project for collection and composting started operating in 1994 January in a city of 6,000 inhabitants. The aim of the project is a reduction of the total amount of wastes and the production of compost of better quality as compared with the previously produced municipal waste compost. Each household is given two collection bins. One is green for the organic fraction (food waste, garden refuse, etc...); the other is blue for the inert fraction (plastic, metal, glass, etc...).

After daily collection, 'blue waste' is sorted and either recycled or landfilled. 'Green waste' – 65 percent of the total domestic waste by weight – is transported to an experimental composting plant, designed to process 30 Ton/day. Experiments are performed by research workers of the 'Institut National de Recherche Scientifique et Technique'.

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Experimentation

Two composts were tested in this research. The first of the two – referred as C 1 – was obtained with the usual process: sorting, trituration, screening, fermentation and maturation.. The second of the two composts – referred as C2 – was obtained with a new process: sorting, prefermentation, screening, fermentation and maturation.

The putrescible organic matter obtained through household separation is characterized by a high moisture content which causes – after trituration – compacting during the first 3 weeks of the process. Thereby compromising ventilation inside the biomass and increasing the risk of anaerobic conditions in windrows. To avoid these anaerobic conditions 'C2' was composted without trituration.

Composting was done in windrows that are turned once every week or two. Turning was carried during the entire thermophilic phase to dissipate excess heat. Throughout the fermentation period, temperatures are recorded daily and moisture levels checked weekly.

Compost Product quality

The finished compost produced by this project was analysed for both its fertilizer value as well as any potential contamination that might limit the product's use. Main Characteristics of the compost issued from the source separated household waste compared with the previously municipal waste compost are listed in Table. 1 and Table.2.

Table 1 Compost quality Data

Parameters	Organic waste compost	Municipal waste compost
pH	8,5	8,1
Organic matter (%)	52	40
Moisture content (%)	40	36
% dry matter:		
Carbon	23	17
Nitrogen	2,2	1,0
Phosphorus	0,85	0,6
Potash	0,9	0,7
Calcium	7,5	10
Magnesium	0,43	0,8
Iron	0,4	0,8

Table 2 Metal contaminants in composts

Heavy Metals	Organic waste compost	Municipal waste compost	Guide values for compost in Germany
mg/kg dry matter			
Zinc	440	605	400
Copper	195	346	100
Lead	182	545	150
Cadmium	4,2	4,5	1,5
Mercury	0,9	2,0	1,0
Nickel	7,7	36	50
Chromium	31	52	100

This study demonstrates that contents of total N, P2O5 and K₂O are significantly higher in organic waste compost as compared to Municipal waste compost. Thereby indicate that this material should prove a high quality soil amendment for landscape use.

The results of the metal analysis – standardized to an organic matter of 30% – show that the heavy metal concentration found in the organic waste compost is considerably lower as compared to municipal waste compost.

Considering the trituration parameter, results indicate that it increase significantly heavy metals content in organic waste compost (table. 3).

Table 3 Metal contaminants in organic waste compost

Heavy Metals	Organic waste compost (C1)	Municipal waste compost (C2)
mg/kg dry matter		
Zinc	556	325
Copper	256	135
Lead	178	176
Cadmium	4,7	3,7
Mercury	1,0	0,8
Nickel	10	5,0
Chromium	33	30

Conclusion

Results demonstrate that under practical conditions, source separation composting will lead to a final product of better quality, with regard to the contents of undesirable components.

Nitrogen in Composting: Relevance of the Material and the System Used

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Introduction

The composting of organic wastes rich in easily biodegradable nitrogen compounds leads to the formation, accumulation and subsequent loss of nitrogen mostly through ammonia volatilization (Witter, 1986). Mixing these organic wastes rich in nitrogen with lignocellulosic wastes which have high C/N ratio can result in partial incorporation of N into the organic fractions through immobilization (Bernal et al., 1993). Therefore, selecting the appropriate waste mixture may be an appropriate way of reducing ammonia losses during composting. Frequent turning of the pile may facilitate this NH₃-volatilization (De Bertoldi et al., 1982). It might be possible to control NH₃-volatilization by using the Rutgers static pile system which can also regulate the organic-N mineralization through controlling the pile's ceiling temperature during composting.

Materials and methods

Five composting piles were prepared with the following organic wastes mixtures (fresh weight):

- Pile 1: 95 household biowaste 1 5% sweet sorghum bagasse (turned pile).
- Pile 2: 95 household biowaste 1 5% sweet sorghum bagasse (static pile).
- Pile 3: 34.6 poultry manure 1 65.4% cotton waste 1 1.93 1/kg olive-mill wastewater.
- Pile 4: 32.1 sewage sludge 1 67.9% cotton waste 1 0.94 1/kg olive-mill wastewater.
- Pile 5: 47.2 sewage sludge 1 52.8% maize straw 1 1.76 1/kg olive-mill wastewater.

About 1500 kg of the mixture were placed in trapezoidal piles of 1–1.5 m high with a 2 × 3 m base. Only pile 1 was composted by turning every two days during the first week, twice a week during the second week, and once a week during the rest of the biooxidative phase. The Rutgers static pile composting system was used in the rest of the piles involving on-demand ventilation through temperature feedback control (Finstein et al., 1985). The air was blown from the base of the pile, the timer was set for 30 s. ventilation every 15 min. and the ceiling temperature for continuous air blowing was 55°C. The biooxidative phase of composting lasted for 77, 77, 49, 84 and 63 days in the piles described above, respectively. The air-blowing was then stopped to allow the compost to mature over a period of two months. The piles were sampled weekly during the biooxidative phase. Moisture content was ascertained by drying at 105°C, pH in water soluble extract 1:10 (w/v), organic matter (OM) by loss-on ignition at 430°C during 24 h. Inorganic-N was extracted with 2M KC1, NH4-N was determined by a colorimetric method based on Berthelot's reaction and NO3-N by the ultraviolet technique. Total nitrogen and organic carbon were determined by automatic microanalysis. Losses of organic matter were determined from the initial (X1) and final (X2) ash contents according to the equation (1). Similar equations were used to calculate total and organic-N losses.

$$\text{OM-loss (\%)} = 100 - \frac{100}{X_1} \cdot \frac{(X_1 - X_2)}{(X_2 - 100)} \quad (1)$$

Results and discussion

In pile 1 a substantial amount of NH4-N was produced during the first week of composting (Fig. 1a) and its concentrations were higher than those in pile 2 during the following weeks. At the same time pH values increased in pile 1. These two facts resulted from the faster organic-N mineralization in pile 1 than in 2, as it is showed by the losses of organic-N (56.7 of initial organic-N in pile 1 and 48.1 in pile 2). The total-N concentration decreased in pile 1 indicating great N-losses during composting. These losses are mainly due to NH3-volatilization (Bishop and Godfrey, 1983). N-losses by denitrification were probably very low, since oxygenated condition prevailed in the composting mass during the whole process. Also, very low lixiviation was observed from the piles mainly in those which the Rutgers state pile system was used, therefore NO3-lixiviation was presumably negligible. Losses of N through NH3-volatilization accounted for 59 in pile 1 and 50 in pile 2. The NH4-N nitrification started after 49 days of composting increasing the NO3-N concentration.

Using the Rutgers static pile system instead of the traditional turned pile reduces the organic-N degradation rate as well as the losses through NH3-volatilization. The higher N-losses from the turned pile were due to greater pH values, higher NH4-N production through organic N mineralization and the frequent turning. In the static pile the air was blown from the bottom to the external part of the pile.

The NH₃ and H₂O produced during OM decomposition would be diffused with the air through the pile. Because the surface of the pile was cooler than the interior, the H₂O may condense and NH₃-N be absorbed by the material, helping to prevent N-losses as NH₃-N could be further immobilized or nitrified by the microorganisms.

In pile 4 with sewage sludge the fermentation phase of composting lasted almost double than in pile 3 with poultry manure (Fig 1c,d) indicating higher microbial activity in the former, although both piles had similar organic matter degradation rate (data not shown). Changing cotton waste by maize straw reduced the rate of OM decomposition (69.2 to 54.2 %) indicating the lower biodegradability of the maize straw compared with the cotton waste. Total and organic-N increased with composting in piles 3,4 and 5 due to the concentration effect of the degrading organic-C compounds. Pile 3 had a high initial total-N concentration, 12.5 of which was NH₄-N, this was lost at high rate during the first 14 days as shown by the decrease of NH₄-N concentration and the total-N losses (14 %). The increase in pH during the same period strongly favoured these N-losses. However, in pile 4 only 5 of total-N was lost during 14 days, both NH₄-N and pH values increased until day 49 resulting from the organic-N mineralization. Greater proportion of initial N was susceptible to volatilization in pile 3 than in 4, due to the high initial NH₄-N concentration, high pH and extra ventilation in pile 3, conditions which favoured NH₃ losses (Bhoyar et al., 1979).

Pile 5 had the lowest initial total-N concentration, the greatest C/N ratio and initial pH <7.0. There was a sharp reduction of NH₄-N concentration during the first week, which may be due to N-immobilization since total-N loss was very low and negative organic-N loss occurred (-12.6 %). The mature compost prepared with sewage sludge and maize straw (pile 5) had a total-N concentration similar as those in piles 3 and 4 although the initial mixture had the lowest value. The use of maize straw with a high C/N ratio as a bulking agent was more effective in reducing N-losses during composting than the cotton waste and so enriched the final product. On the other hand, the great amount of NH₄-N brought about by the poultry manure caused high NH₃-volatilization at the beginning of the fermentation process.

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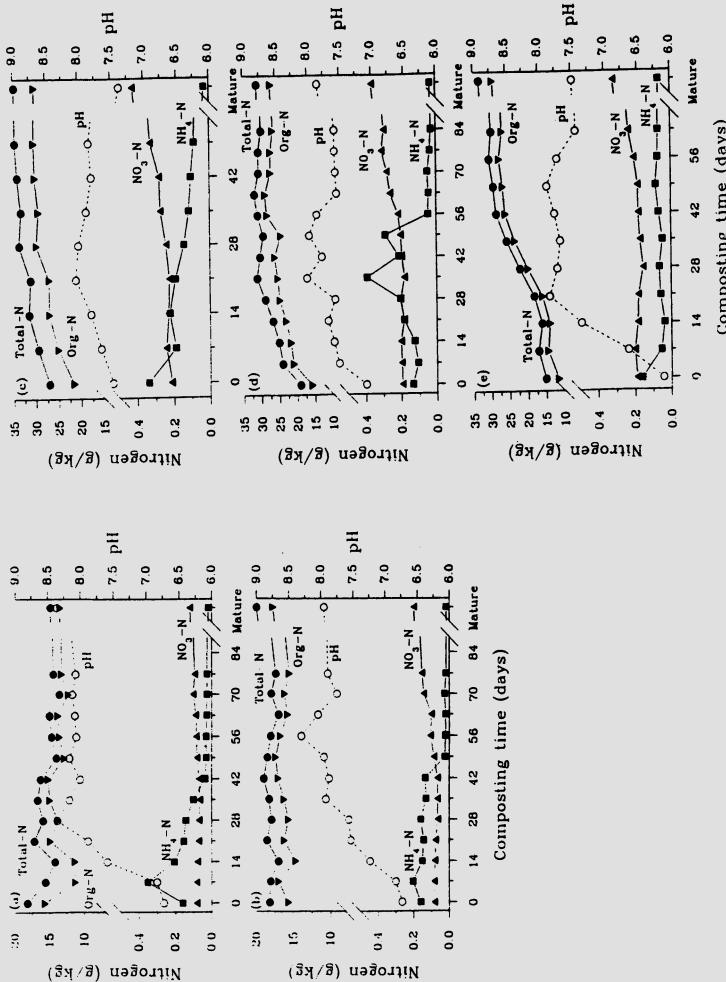


Figure 1 Changes in the nitrogen forms and pH values during composting of pile 1(a), 2(b), 3(c), 4(d) and 5(e).

Estimation of N-release and N-mineralization of Garden Waste Composts by the Mean of Easily Analysed Parameters

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Introduction

Determination of the biomaturity of a compost is a critical point. It can be estimated by chemical analysis or optical measurements (Mathur et al. 1993). N-mineralization and N-immobilisation of composts can be assessed by the method of incubation and by germination tests. However, these methods are time consuming. We therefore compared facile and quick tests with those standard methods.

Material and methods

Samples from 38 garden waste composts from different compost plants were taken at the time as they were given to the farms.

For the incubation test a mixture of 10 vol % compost, 40 vol % soil (loamy loess) and 50 vol % Perlit (vulcanic rock stone) was used. The incubation period was 12 weeks at field capacity and 20 °C. Table 1 shows the analysed parameters.

Results and discussion

N-Release

As shown in figure 1, the 38 garden waste composts release only a small amount of plant available nitrogen. Half of the composts immobilise nitrogen during the 12 week incubation period. The values of the N_{mi_n} incubation are in the average at 2.1% of the total nitrogen content. 13% of the composts would cause N-blockage after application. The values of the N_{min} incubation test are varying between + 8% and - 11% of the total nitrogen content of the composts. The short term and long term availability of nitrogen in the compost is small.

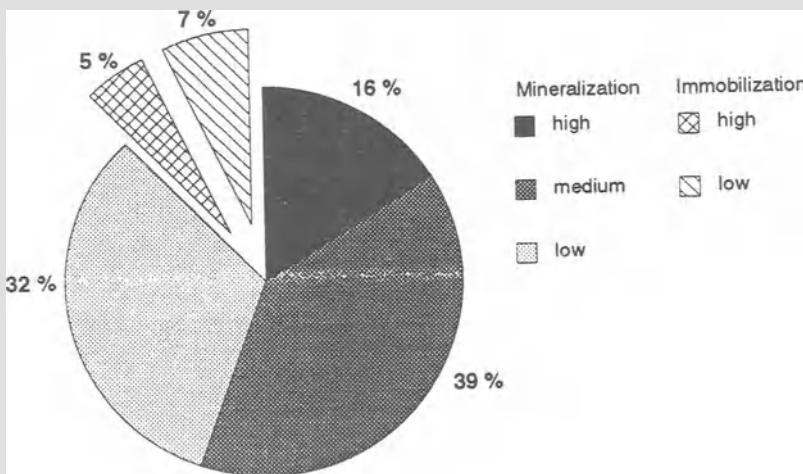


Figure 1 Distribution of the nitrogen mineralization potential of 38 different garden waste composts. Low mineralization: 0–2% of the compost nitrogen has been mineralized, medium: 2–4%, high: 4–6%; low immobilization: 0 till–2%, high: -2 till–11% of the compost nitrogen has been immobilized.

Correlations

Simple correlations show low and only partly significant correlations ($p \leq 0.05$) to the aiming points N_{min} incubation and N-mineralization (table 2). The highest correlations were found between N_{min} incubation and respiration, C and W_{40° with r^2 -values between 0.38 and 0.45. The r^2 -values between N-mineralization and W_{40° , closed cress test and respiration respectively were 0.41, 0.52 and 0.59. The closed cress test shows clearly better correlations to both aiming points than the open cress tests. C/N ratio is correlating to the N-mineralization with a r^2 -value of only 0.21.

Multiple correlations between quick tests, cress tests and carbon content (No. 1–5) are reaching R^2 -values up to 0.66. Similar correlation coefficients can be calculated with chemical analyses (No. 6–9). The optical tests are reaching the highest correlation coefficient. Determining optical parameters is easy and fast, results are available after one week.

Table 1 Parameters to characterize biomaturity of garden waste composts

Parameter	Definition/Method	Remarks
N_{min} incubation	Mineralised nitrogen of the compost $\text{NO}_3^- + \text{NH}_4^+$ during incubation period in % of the N_{kj} of the compost.	Plant available nitrogen at short term
N-mineralization	N_{min} incubation minus N_{min} -content of the compost at the start of the incubation test.	Plant available nitrogen at longer term
C	Carbon content (%) in the dry matter (DM). loss by dry ashing * 0.47.	
N_{kj}	Total nitrogen content (%) in the dry matter (Kjeldalit).	
$C_{sol}, N_{tot\ sol}, N_{org\ sol}$	C, N_{tot}, N_{org} soluble in 0,01 M CaCl_2 extraction of the samples dried at 40 °C (Houba <i>et al.</i> 1986).	Fast mineralizable carbon and nitrogen from the microbial pool.
Respiration	Oxygen consumption of composts at 20 °C in mg O_2 /mg C*day.	Microorganisms in immature composts show increased respiration.
Ammonium test	Quick test with Merckoquant Test sticks in mg/kg DM	Immature composts contain more ammonium, mature composts contain more nitrate.
Nitrate test		
NH_4^+	Ammonium content of the DM analysed by a Ion chromatograph in mg/kg DM.	
Cress test open 100%,	Cress test on 100% compost resp. 50% compost/soil-mixture in open seed pots in g FM/pot	In open pots cress is growing on nearly every substrate.
Cress test open 50%		
Cress test closed	Cress test on 100% compost in closed pots in g FM/pot.	Gaseous emission of composts increase differentiation in closed pots (Naslowski und Grantzau 1992).
W_{40°	Water content of compost samples dried at 40 °C during 48h.	Composts with a high organic matter content have an increased water holding capacity.
$Wf_{210}, Wf_{280}, Wf_{600}, Wf_{700}$	Optical density of the water extract of a compost at a fixed wavelength at 210 nm 280 nm, 600 nm, 700 nm in absorbance/g $C_{compost}$.	Mature composts are less water soluble. More complex compounds absorb light at higher wavelengths (Mathur <i>et al.</i> 1993).
Ws_{280}	Absorption of water extracts stored for 7 days at 20 °C compost/water mixture at 280 nm in absorbance/g $C_{compost}$.	Storage increases decomposing processes.
ED_{400}	Absorption of fresh EDTA-extracts from composts at 400 nm in absorbance/g $C_{compost}$.	EDTA is also solving humic acids from the compost.
T_{20}	Temperature of the compost heap at sampling time at a depth of 20 cm.	Compost heaps show higher temperature during decomposition process.

Table 2 Simple (r^2) and multiple (R^2) correlations between simple tests, specific chemical analyses and N_{min} incubation, N-mineralization; estimation of the analytical expenses and duration

impact value	aiming point			
	Nmin Incubation	N-Minera- lization	Analytical expenses ¹⁾	Duration ²⁾
<i>Simple correlations</i>				
Nitrate test	0.28	0.20	*	*
Ammonium test	n.s.	n.s.	*	*
Cress test (closed)	0.22	0.52	*	**
Cress test (open 100 %)	n.s.	0.17	*	**
Cress test (open 50 %)	n.s.	0.22	*	**
C	0.39	0.33	**	*
N	n.s.	n.s.	**	*
C/N	0.34	0.21	**	*
W _{40°}	0.45	0.41	*	*
ED ₄₀₀	0.25	0.22	*	*
Respiration	0.38	0.59	**	*
<i>Multiple correlations</i>				
1 Nitrate test * Ammonium test	0.33	0.22	*	*
2 Nitrate test * Cress test (closed)	0.38	0.57	*	**
3 Nitrate test * Ammonium test * Cress test (closed)	0.48	0.66	*	**
4 Nitrate test * C	0.57	0.45	**	*
5 Nitrate test W _{40°}	0.64	0.55	*	*
6 %C * %N	0.53	0.39	**	*
7 C/N * W _{40°}	0.56	0.46	**	*
8 T20 W _{40°} Respiration	0.59	0.77	**	*
9 C * N _{tot sol} * C _{sol}	0.69	0.55	***	*
10 C * N _{org sol} C _{sol}	0.63	0.64	***	*
11 W _{g280} * W _{f700} * W _{f210} /W _{f280} * W _{f280} /W _{f600} * W _{s280} /W _{f280} * W _{40°}	0.82	- ³⁾	*	**
12 W _{40°} NH ₄ W _{s280} /W _{f280}	- ³⁾	0.81	**	**
13 ED ₄₀₀ * W _{f700} * W _{s280} /W _{f280} * W _{40°}	- ³⁾	0.75	*	**
14 W _{40°} * W _{s280} /W _{f280} * Cress test (closed)	- ³⁾	0.82	*	**

p ≤ 0.05 n.s. = not significant

1)* low, quick test, simple analyse 2)* 1–2 days 3) missing values: impact values

** medium, routine analyse 2)** 1 week depending from each other.

*** high, specific chemical analyse

Conclusions

The N_{min} incubation method showed that the 38 garden waste composts released only little amount of nitrogen. 12% of the composts would cause nitrogen blockage in the field.

None of the tests was reliable enough to substitute the N_{min} incubation method.

Reliability was clearly improved by combining several parameters.

The preliminary results indicate a better prediction of N-mineralization and N-release with optical parameters than with chemical analyses and cress test.

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Performance Prediction of Composting Processes Using Fuzzy Cognitive Maps

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Introduction

Composting is a process whereby organic matter is decomposed by a mixed population of microorganisms in a warm, moist, and aerobic environment. The process involves the interaction of several parameters which do not behave linearly with time and which have time constants varying between days and weeks. The complexity of the interactions between parameters produces several ecosystems which prohibit accurate modeling of the process in the form of differential mathematical equations. Physical modeling of composting [5] has been done but this imposes several constraints. Thermal balance analysis [6] may give a better insight of the process but performance prediction would not be possible because the equations might not be valid if the operating conditions change as is always the case in practice. On the other hand, engineers and scientists know the causes and effects of many parameters involved in composting. Since we know beforehand what effect (large, small, positive, negative etc.) different parameters have on one another, composting process can be treated as being ‘fuzzy’.

Fit to be fuzzy

Fuzziness describes ‘event ambiguity’ and it measures the degree to which an event occurs, not whether it occurs. Fuzzy logic is a method of easily representing analog processes on a digital computer. It is appropriate to use fuzzy logic when one or more of the control variables are continuous, when a mathematical model of the process does not exist, or exists but is too difficult to encode, or is too complex to be evaluated fast enough for real operation and perhaps above all, when an expert is available who can specify the rules underlying the system behaviour and the fuzzy sets that represent the characteristics of each variable. Composting processes are continuous phenomena that are not easily broken down into discrete segments, and the concepts involved are difficult to model along mathematically or rulebased lines, and as such, fit appropriately into the framework of fuzziness.

Most knowledge is specification of classification and causes. In general the classes and causes are uncertain (fuzzy or random), usually fuzzy. This fuzziness passes into knowledge representations and on into knowledge bases where it leads to a 'knowledge acquisition/processing trade off' [1]. The fuzzier the knowledge representation, the easier the knowledge acquisition and the greater the source occurrence. But the fuzzier the knowledge, the harder the (symbolic) knowledge processing. Fuzzy Cognitive Maps (FCMs) circumvent the tradeoff and have been used to model continuous phenomena [2, 3].

Fuzzy Cognitive Maps

A FCM is a causal network showing domain knowledge in the nodes and edges of a neural network whose architecture is based on the model outlined in Fig1. FCMs are fuzzy signed directed graphs with feedback. The directed edge e_{ij} from causal concept C_i to concept C_j measures how much C_i causes C_j (Fig 2). The time varying concept function $C_i(t)$ measures the non negative occurrence of some fuzzy event. The edges e_{ij} take in the fuzzy causal interval $[-1,1]$. $e_{ij}=0$ indicates no causality. $e_{ij}=-1$ indicates causal decrease or negative causality: C_j decreases as C_i increases and vice versa. $e_{ij}=1$ indicates causal increase: C_j decreases as C_i decreases, or C_j increases as C_i increases

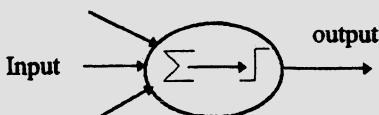


Figure 1

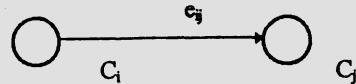


Figure 2

We reason with FCMs as we recall with Temporal Associative Memories (TAMs) [4]. We pass state vectors X repeatedly through the FCM connection matrix E , thresholding or nonlinear transforming the result after each pass. Independent of the FCM's size, it quickly settles down to a TAM limit cycle or 'hidden pattern'. The limit cycle inference summarises the joint effects of all the intermediate fuzzy knowledge.

The algorithm is as follows:

Step 1 – Develop the FCM of the process and generate the causal connection matrix E .

Step 2 – Choose the state vector according to the effect of causal concept we want to study.

Step 3 – Pass the state vector through the FCM matrix to obtain the output.

Step 4 – Threshold the output and clamp the concept under study.

Step 5 – Check if the vector is a fixed point of the FCM. Otherwise repeat steps 3 and 4.

Performance prediction and results

As a case study the effect of forced aeration is investigated using the FCM approach. The FCM of the composting process is shown in Fig 3 where the node C_i , for $i = 1$ to 8, represents the following: C_1 = Moisture Content, C_2 = Temperature, C_3 = Heat Generated, C_4 = Aeration, C_5 = Particle Size, C_6 = Microorganisms, C_7 = Respiration Rate, C_8 = C/N Ratio. The resulting FCM connection matrix E is the 8x8 matrix given in Fig 4.

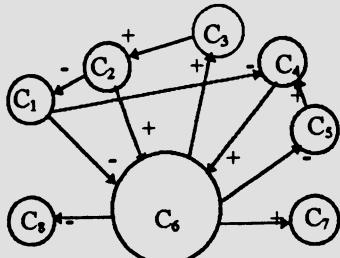


Figure 3

$$E = \begin{array}{c|ccccccc} & C_1 & \longrightarrow & C_4 \\ \hline C_1 & 0 & 0 & 0 & -1 & 0 & -1 & 0 & 0 \\ C_2 & -1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ C_3 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ C_4 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ C_5 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ C_6 & 0 & 0 & 1 & 0 & -1 & 0 & 1 & -1 \\ C_7 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ C_8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{array}$$

Figure 4

For forced aeration, the causal state vector is defined as $X_1 = [0 \ 0 \ 0 \ 1 \ 0 \ 0 \ 0 \ 0]$.

$X_1^*E = [0 \ 0 \ 0 \ 0 \ 0 \ 1 \ 0 \ 0]$, thresholding and clamping the concept C_4 the new state vector X_2 is given by $[0 \ 0 \ 0 \ 1 \ 0 \ 1 \ 0 \ 0]$. Using an arrow to indicate thresholding and clamping, the different steps are executed as follows to reach a fixed point in the FCM:

$$\begin{aligned}
 X_1^*E &= [0 \ 0 \ 0 \ 0 \ 0 \ 1 \ 0 \ 0] & [0 \ 0 \ 0 \ 1 \ 0 \ 1 \ 0 \ 0] &= X_2 \\
 X_2^*E &= [0 \ 0 \ 1 \ 0 \ -1 \ 1 \ 1 \ -1] & [0 \ 0 \ 1 \ 1 \ -1 \ 1 \ 1 \ -1] &= X_3 \\
 X_3^*E &= [0 \ 1 \ 1 \ -1 \ -1 \ 1 \ 1 \ -1] & [0 \ 1 \ 1 \ 1 \ -1 \ 1 \ 1 \ -1] &= X_4 \\
 X_4^*E &= [-1 \ 1 \ 1 \ -1 \ -1 \ 2 \ 1 \ -1] & [-1 \ 1 \ 1 \ 1 \ -1 \ 1 \ 1 \ -1] &= X_5 \\
 X_5^*E &= [-1 \ 1 \ 1 \ 0 \ -1 \ 3 \ 1 \ -1] & [-1 \ 1 \ 1 \ 1 \ -1 \ 1 \ 1 \ -1] &= X_6
 \end{aligned}$$

Since X_5 and X_6 are identical, X_5 is a fixed point of the FCM and the procedure stops. From this we can infer that forced aeration has reduced moisture content (since the first element of vector X_5 , which is C_1 , is equal to -1), raised temperature ($C_2=1$) due to the production of heat ($C_3=1$) resulting from the multiplication of microorganisms ($C_6=1$) causing a rise in respiration rate ($C_7=1$), a decrease in C/N ratio ($C_8=-1$) and a reduction in particle size ($C_5=-1$). This result has been verified experimentally in [7] whereby the effects of forced aeration is analysed experimentally. Using the FCM approach, however, more inferences could be made. Like, before the thresholding and clamping procedure, it is seen that forced aeration causes microorganisms to multiply (C_6 increases to reach a value 3) and if constant supply of air is not maintained the process becomes anaerobic (C_4 reduces). Although this approach gives the final steady state result of the effect of some causal concept, it is evident that certain inferences could be made beforehand as the process evolves. This helps to decide what parameters need to be controlled to prevent degradation of the process.

Conclusion

An FCM model of composting is developed by treating composting processes as fuzzy systems. The model reflects the designer view of the process and it depicts the various causes and effects as available to the designer. The model can be used to predict the performance of composting processes subject to some causes. The effects of forced aeration is studied and the results obtained has been verified in practice thus confirming the validity of the approach used. The technique is simple and the designer does not need to know the dynamics of the process to develop the model. Moreover the approach gives a better insight of the process by depicting the the different interactions that might exist among the states.

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Justification and usefulness of support

Research is being carried out in composting both at the university and at national level. The difficulty in modeling composting processes poses serious problems as to the prediction of its performance under various conditions. Analyzing such a process on a large scale is even more complicated because of the absence of a mathematical model. Consequently, applications of certain control strategies are done on a trial basis. This conference will enable us to find out what other researchers are doing to optimise composting processes and how they are controlling such a complex process. Their techniques can eventually be adapted to works carried by our local researchers.

Biodiversity of Thermophilic Bacteria Isolated from Hot Compost piles

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Introduction

Composting is a self-heating, aerobic solid phase biodegradative process of organic waste materials, making possible its return to the environment as soil fertilizer and conditioner (Finstein & Morris, 1975; de Bertoldi & Zucconi, 1987; Finstein, 1992). Temperature increase involves a rapid transition from a mesophilic to a thermophilic microflora (65–75 °C) within a few hours, providing the pile is regularly aerated or frequently turned.

The present state of knowledge on microbial diversity during the thermogenic phase is surprisingly poor: only a few heterotrophic strains related to *Bacillus stearothermophilus* were identified at temperatures above 60 °C (Strom, 1985a–b).

However, microbial diversity is a prerequisite for the degradation and mineralization of complex organic waste materials (Finstein & Morris, 1975; de Bertoldi & Zucconi, 1987; Finstein, 1992). Active degradation was also observed at temperatures above 60 °C (Schulze, 1962). Therefore, microbial diversity should be expected during this phase.

In this work we tried to isolate thermophilic bacteria by Using a basal mineral medium (Aragno, 1991) supplemented as to isolate bacteria showing three different metabolic types:

Chemolitho-autotrophic, aerobic bacteria:

CO₂-fixing bacteria, using hydrogen or sulfur reduced compounds (thiosulfate) as energy source, and oxygen as respiratory substrate.

Beterotrophic, aerobic bacteria:

using organic compounds such as sugars, organic acids or amino-acids broth as carbon and energy source, and oxygen as respiratory substrate.

Beterotrophic, anaerobic bacteria:

using organic compounds such as organic acids or amino-acids broth as carbon and energy source, and sulfate or nitrate as respiratory substrate in absence of oxygen.

Material and Methods

Organic material from hot (60–75 °C) compost was suspended in sterile basal mineral medium and shaken. Enrichments were performed by parallel serial dilutions (I021210210) in the media and under gas phase as described above. These were incubated for 1 to 14 days at 70 °C for autotrophic cultures and at 65 °C for heterotrophic cultures. Pure colonies were isolated by successive plating on the same media solidified with agar-agar, and then routinely cultivated in liquid cultures.

Germ numbers and types were estimated by phase contrast microscope examination of enrichment cultures performed from serial dilutions and by the ability to form colonies on solid media.

DNA:DNA homologies were measured spectrophotometrically by following the renaturation rates at Tm 220 °C according to De Ley et al. (1970).

Results

We studied hot compost from 10 composting facilities throughout Switzerland: windows, garden piles, and a bioreactor.

We report the minimal and maximal values for germ numbers observed:

Hydrogen-oxidizing autotrophic bacteria: 105 2107

Sulfur-and thiosulfate-oxidizing autotrophic bacteria: 104 2106

Heterotrophic, aerobic bacteria: 107 21010

Heterotrophic, aerobic (sulfate-reducing or denitrifying) bacteria: 102 2107

Actinomycetes: 103 2104

Hydrogen-, sulfur- and thiosulfate-oxidizing autotrophic bacteria

Five strains were Gram-negative rods able to grow with either hydrogen, sulfur or thiosulfate as sole energy and electron donor, and with CO₂ as carbon source. They were not able to grow with the organic substrates tested. Thus, we regard them as obligate autotrophic strains.

These strains had DNA G 1 C content similar to those published for the strains related to *Hydrogenobacter* isolated from geothermal areas and showed high DNA:DNA homology with one of these strains isolated from Tuscany, Italy (Aragno, 1991). Soluble proteins electrophoresis profiles confirmed these results.

Unlike the above mentioned strains, strains THS-4 and TH-102 were able to

grow on acetate or pyruvate as sole energy and carbon source, but they were unable to grow with reduced sulfur compounds such as thiosulfate or elemental sulfur as sole energy and electron source. They showed similar mol G + C and high DNA:DNA homology (74–84%) with *Bacillus schlegelii* (Aragno, 1991).

Heterotrophic, aerobic strains

- A. Most of the strains growing at 65 °C on nutrient broth under air or on basal mineral medium with pyruvate were 4–7 mm-long rods forming terminal, oval endospores. Estimations gave as many as 10⁹ cells per gram dry weight of compost in some samples. DNA:DNA and growth characteristics gave strong evidences for these strains belonging to *Bacillus stearothermophilus* complex.
- B. Three strains were nonmotile, non-sporeforming rods, 3–6 mm long. They grew well at 70 °C on various organic substrates and showed high DNA:DNA homology with the reference strain of *Thermus aquaticus* (65–79%). 12 newly isolated strains are under investigation in our laboratory: estimated numbers reached as many as 10¹⁰ cells per gram dry weight (cf Beffa *et al.*, this issue).
- C. Three strains growing at 65 °C on basal mineral medium supplemented with pyruvate were motile, short rods (0.8–3.2–3 mm) forming central to subterminal, oval endospores. They have not been further characterized yet.

Heterotrophic, anaerobic strains

- A. Six strains growing on basal medium supplemented as described above were nonmotile rods, with differences in size and spore-forming ability. Estimated numbers of colony forming units rose to 10⁵ per g dry weight of compost. The medium containing sulfate and no fermentable sugar suggests a respiratory metabolism with sulfate as the final electron acceptor. No growth occurred under 20% oxygen (air).
- B. Three strains were isolated on nutrient broth supplemented with nitrate. Growth on this medium in absence of oxygen is thought to be due to nitrate reduction (final electron acceptor). The strains resembled those cultivated on nutrient broth under air and one of them proved facultatively aerobic when grown on nutrient broth under air. This is good evidence for these strains belonging to *Bacillus stearothermophilus* complex.

Actinomycetes strains

Two strains were isolated on amino-acids broth at 50 °C and tested for growth on antibiotics according to Amner *et al.* (1988): both strains were insensitive to novobiocin, but growth was inhibited by streptomycin and kanamycin. Along with morphological features, this pattern suggests a close relation with *Thermoactinomyces spp.*

Conclusions

This study presents the first evidence that highly thermophilic chemolitho-autotrophic Bacteria related to *Hydrogenobacter spp* and to *Bacillus schlegelii* are not confined to the highly specialized and sparse geothermal habitats but also occur in compost piles, which are short-term high-temperature habitats. Furthermore, heterotrophic bacteria thriving above 60 °C are not restricted to the single species *Bacillus stearothermophilus*, but include highly thermophilic strains related to *Thermus aquaticus*. Besides, micro-environments deprived of oxygen also permit growth of a diversified anaerobic microflora.

We aim to better understand the functional diversity during the thermogenic phase, suggesting that it is possible to compost at higher temperatures (60–75 °C) for a longer period of time.

Acknowledgments

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Effect of Humic Matters Extracted From Compost and From Leonardite on P Nutrition of Rye-grass

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Introduction

Commercial humic solutions are used in agriculture in order to enhance mineral nutrition of higher plants (Garcia et al. 1993), and especially P nutrition (Gaur 1969). The decisive effect on P dynamics (Rouquet 1988) has often been correlated with the complexing power towards di or trivalent ions, like calcium ions in calcareous soil. In the investigation reported, the effects of two commercial humic solutions on the phosphorus exported by pot grown Italian rye-grass were compared after determining their characteristics.

Material and methods

Humic solutions

Two commercial solutions were used (table I), one issued from compost and one from leonardite after treatment with KOH 1.0M

Table 1 Characteristics of humic solutions used

Humic solution	Humic substances (HS) content			Molecular Weight (MW)	
% total HS (b)	Complexing power towards Ca at various pH mmolc.kg ⁻¹ (c)			pH 5.0	pH 8.0
	g.dm ⁻³ (a)	MW<14000	MW>14000		
Compost	256 (1	63 (2	37 (2	200 (25	1320 (41
Leonardite	264 (1	45 (2	55 (2	680 (28	2000 (39

a: determined by alkaline KMnO₄ oxidation

b: determined by dialyse with Spectra Por membrane Type A MWCO (Molecular Weight Cut Off) 14000

c: assessed by potentiometric and conductimetric measurement (Brun et al. 1994)

Pot experiment

Italian rye-grass (*Lolium italicum* cv *Barspectra*) was grown in a glass house (photoperiod: 16 h, temperatures: 24/19, irradiance: 3000 lux) in pots containing 400g of a calcareous soil (pH H₂O: 8.3, pH KCl: 7.5, available Truog P: 12mg.kg⁻¹) according to the method described by Chaminade (1960). Each pot was sown with 200 seeds. Plants were watered alternatively every two days with 20cm³ of distilled water or 20cm³ of 20mg.dm⁻³ humic solution. Soil moisture was maintained constant at two thirds of the water holding capacity with distilled water. There were four replications per treatment. The first cut took place four weeks after starting the pot experiment and the second cut three weeks after the first. Biomass produced has been dried and analysed in order to determine the yield and phosphorus content.

Results and discussion

There was no significant effect of the treatments on the plant biomass produced which amounted to ca. 600mg per pot for the first cut and 180mg per pot for the second cut. The amount of P exported was expressed in mg per pot (fig 1)

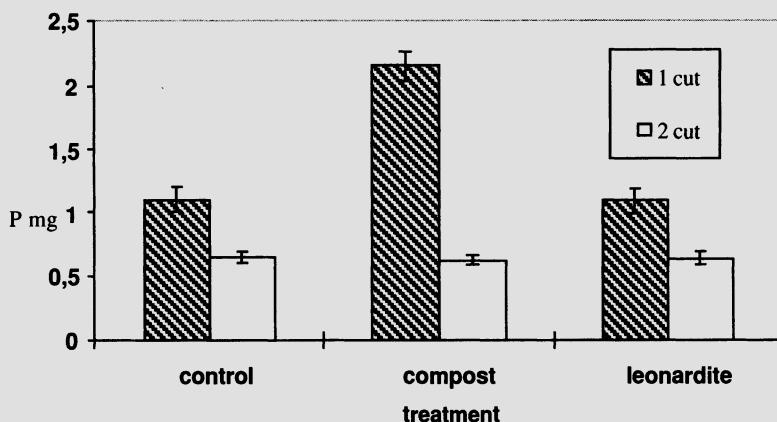


Fig 1 Amount of P exported expressed in mg per pot (average of four replications)

For the two cuts, when leonardite humic solution was used, the P exported by rye-grass was no significantly different from that of the control plants in spite of a higher complexing power towards calcium ions.

For the compost product, the amount of P exported was significantly higher than that of the control plants for the first cut. For the second cut, no more difference was observed.

Under the experimental conditions, we can notice that:

- some humic solutions have no effect on P nutrition in calcareous soil in spite of

- there is no direct relationship between complexing power towards calcium ions and increase in phosphorus uptake by rye-grass.
- low molecular weight molecules seem to be more effective on P nutrition than high molecular weight ones.

Conclusion

The above investigations suggested that the complexing power towards calcium ions is not the only parameter involved in the enhanced P nutrition observed. Humic substances may have some effects on the root system as the uptake of some nutrients can be significantly enhanced. This could explain the effect only on the first cut.

We notice that low molecular weight molecules appear more effective than high molecular ones.

We have also noticed that during the complexation of calcium, the amount of H⁺ released is variable. For compost solution, this amount is highest than for the leonardite one: at pH8 (nearly soil pH) one mole of calcium complexed releases 0.5 mole of H⁺ for compost solution and only 0.2 mole for leonardite solution. This local acidification could perhaps enhance solubilization of insoluble phosphorus forms, like apatite, and then enhance phosphorus uptake by plants.

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The Suppressive Effects of Composted Separately Collected Organic Waste and Yard Waste Compost on Two Important Soilborne Plant Pathogens

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Summary

Each year during the period 1991 to 1994, three different types of input material (yard waste, biowaste and cattle manure) were composted and subsequently evaluated for their suppressiveness towards *Pythium ultimum* and *Phytophthora parasitica* spp.. This was achieved by means of bioassays conducted in a sterilised substratum (sand) employing the host-pathogen systems peas – *P. ultimum* and in non-sterilised substratum (commercial peat based potting mix) applying the host-pathogen systems peas or cucumber – *P. ultimum* and tomato – *P. parasitica nicotianae*.

Amendment of *P. ultimum* inoculated sterilised sand with yard waste- and biowaste compost resulted in a significantly increased yield (fm). This was mainly due to pathogen suppressive biological mechanisms induced by compost. Composted cattle manure showed such an effect only occasionally. In experiments where 90 % of control treatment plants were damped off, compost addition, apart from cattle manure compost, resulted in a reduction of the disease incidence by 30 to 50 %. In bioassays with soils naturally infected with root-rot pathogens of red beet, however, we also observed some suppressive effects of cattle manure compost.

Contrary to cattle manure compost, both yard waste- and biowaste compost show a high level of specific microbial activity, i.e. a high rate of Fluorescein diacetate-hydrolysis per unit microbial biomass. Therefore, micro-organisms originating from both waste composts are better competitors for easily available carbon

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sources. This results in a fungistatic effect towards pathogens since these organisms depend on the same carbon sources. This has been shown by the suppressive effects towards *P. ultimum* of a 50 % yard waste compost amendment of a peat growing media in comparison to non-amended pure peat growing media. The two waste composts have been evaluated in non-sterilised container media in all other above mentioned host-pathogen systems. Yard waste compost application rates between 30 % and 50 % (v/v) resulted in a significant reduction of the disease incidence of at least 45 % for cucumber, peas and also tomatoes. Due to a higher nutrient and salt content of composted biowaste, the application rate of this material was limited to 30 % (v/v), resulting in a reduction of the disease incidence by 10 – 20 %.

With a *St. Paulia* – *P.parasitica* bioassay similar results were obtained during a cultivation period of 14 weeks. Compost amendment of 30 and 50 % yard waste compost, respectively, to a non-sterilised peat growing media significantly prolonged the time until plants died.

Legislative and Scientific Aspects of the Production and use of Vermicompost from Biological Sludges

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Summary

The vermicomposting is a process widely employed for ecological recovery and transformation of biological sludges into 'casting' with a high fertilising value. While practical and scientific aspects of the process have been already studied and, for most part, understood both in laboratory and in pilot experiments, the legislative aspect is, still nowadays, very confused and lacunous. In fact, there are many national (Italian) laws which regulate the composting and vermicomposting and which overlap to regional legislation. Contrasts in defining the wastewaters origin (industrial, urban, municipal or assimilable to the municipal ones), in technical aspects of sludge processing, in final classification and use of 'stabilised' product, are frequently encountered. In this work, attention has been focused on the technical aspects of sludge vermicomposting and on the legislative aspects to classify the product as a 'compost' according to the DPR 915/82.

Introduction

The composting of municipal sludges is possible if a bulk agent (wood chips, straw, etc.) which reduces the water content and improve aeration is added; the process requires energy to turn the organic mass and to finish the product. Composting may be conducted also economically without employing bulk agents, expensive plants and energy, but only using adapted earthworms (i.e. *Lumbricus terrestris*, *Eisenia foetida*, etc.), which may growth under a wide range of temperature (12–35 °C), humidity (35–65 %) (Hartenstein, 1981) and organo-mineral feeding (aerobic and anaerobic municipal or paper mill sludges).

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The action of earthworms is to transform the sludge organic fraction into a 'casting' with a high fertilising value. The fertilising value of earthworm casting and the beneficial effects on crops, have been related to the presence of active mineral nutrients (Ceccanti et al., 1994) and plant growth regulators with phytohormonal action (Tomati et al., 1985).

The aim of this paper is to study the feasibility of sludge vermicomposting, dealing with three main aspects:

1. adaptation of earthworms and process efficiency
2. vermicompost quality and effects on soil and plant
3. legal aspects of sanitization

Results and discussion

The experiment has been conducted in pilot-plant with mixtures of aerobic and anaerobic sludges, these last added at growing quantities (0, 25, 50, 100% v/v); *Eisenia foetida* was used for operating the vermicomposting process. It has been observed that the adaptation of *Eisenia foetida* to the sludges mixtures was quite rapid, even in the presence of relatively high concentration of ammonia (about 170–180 ppm) arising from the anaerobic sludges. Laboratory experiments of vermicomposting, to assess in a quantitative way the adaptation of *Eisenia foetida* to the sludges, have been carried out. These experiments have been conducted stratifying the sludges (mixed in the same proportion as in the pilot-plant) on a sandy loam soil poor in organic matter (< 1.5%) (Peccioli, Pisa – Italy), followed by the addition of earthworms to promote the vermicomposting directly in the soil (in situ).

In figure 1 are reported, in relation to the sludge mixtures (0, 25, 50, 75, 100% v/v of anaerobic sludge), a) the distribution of *Eisenia foetida* in soil-sludge system after one week from the addition of earthworms, b) the residual weight of the sludges which has not been incorporated by the earthworms into the soil after 8 months, c) the metabolic activity (dehydrogenase activity) of the soil at the end of 8 months vermicomposting, and d) the growth test with *Lepidium sativum* on soil samples kept 8 months under vermicomposting 'in situ'.

It is well evident that with the increase of anaerobic sludge concentrations, the number of earthworms increased in the soil, leaving on its surface growing quantities (residual weight) of not-digested sludge. The low microbiological activity measured in the soil populated by a relatively high number of worms, might indicate an acceleration of the composting process. The growth test with *Lepidium sativum* showed that the soils with 25–50% of anaerobic sludge were regenerated in the biological, chemico-physical and nutritional components, while appeared negatively affected by the concentrations of 75–100%.

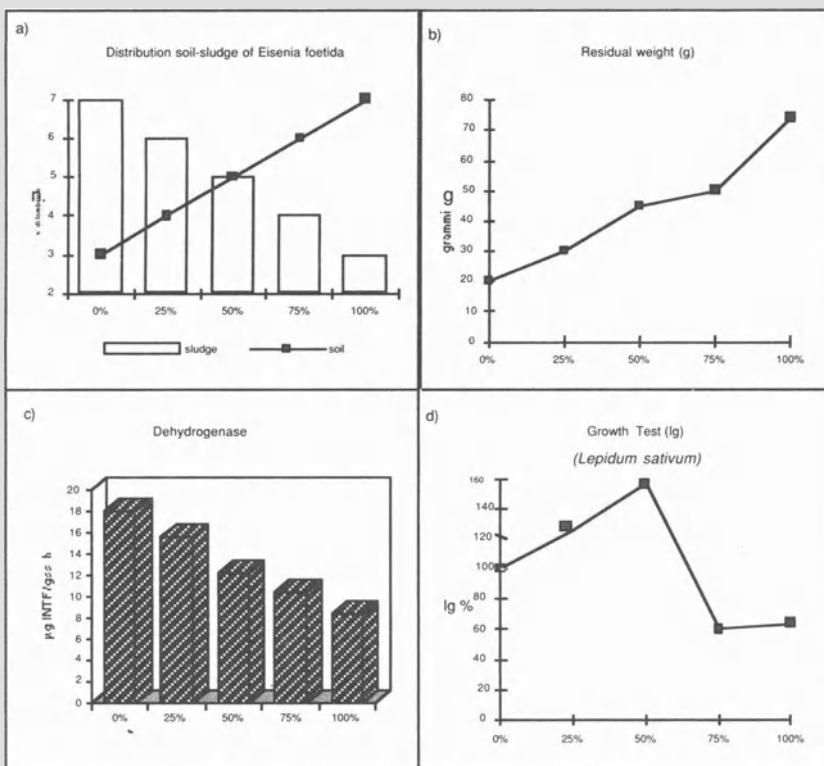


Figure 1.

Once assessed the feasibility of vermicomposting and its positive effects on soil-plant properties, it remains to define better the legislative aspect of the process. In our experiments, the final vermicompost obtained after 8 months of sludge treatment in pilot-plant with *Eisenia foetida* presented chemico-physical and microbiological (absence of pathogenic microorganisms, data not reported) properties which were very similar to or better than those reported by Italian law-standards for composted urban organic fraction (DPR/915/82), vermicompost from animal manures (D.L. 748/84) and for the use of biostabilised sludges (L. 99/92) in soil amendment. No one laws mentioned above, contemplate the 'vermicompost from biological sludges', so that our vermicompost is illegal for two reasons: a) it does not respect the process of composting for the termophilic phase, as stated by DPR 915/82 and b) it is not clearly stated by Italian (n. 690/86) and Regional laws (Tuscany n. 5/86) the origin of wastewaters and sludges to be processed to produce compost or vermicompost. However, there is a possibility to classify as a 'compost', the vermicompost produced from biological sludges, only if a thermosanitarization phase is activated, after worms remotion (Polperio et al., 1994). Thermosanitarization of final vermicompost is possible using ligno-cellulosic

materials (20% and 25% v/v) which started bioxidative reactions so permitting to achieve temperatures over 55°C for at least three days, as reported in the DPR/915/82 (figure 2).

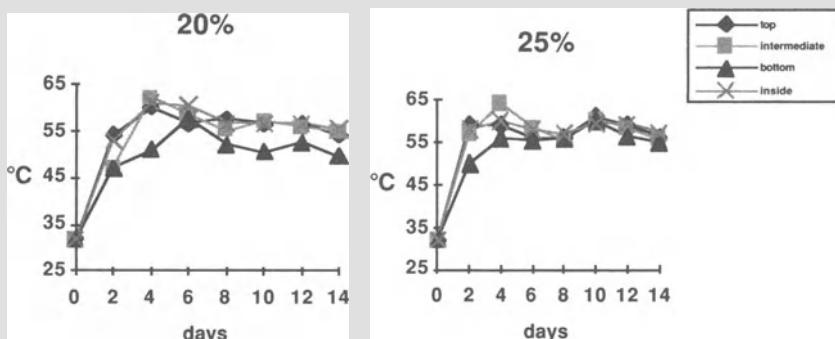


Figure 2 Temperatures measured in different position of piles under hygienization.

The vermicompost after the thermosanitarization can be considered a 'compost' according to the DPR/82 for its toxicological, agronomical and hygienic characteristics; but further studies are necessary to verify the eventual presence and the effects of phytotoxic substances on plant growth and to evaluate the economic aspects for marketing. Clearly, the 'legal suitability' of wastewaters and sludges must be re-defined and the compost must be classified on the basis of its chemico-physical, agronomical and microbiological properties.

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Composting of Fresh Olive-Mill Wastewater Added to Plant Residues

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Introduction

Vast amounts of olive-mill wastewaters (OMW) are produced in Mediterranean countries causing very serious environmental problems either through spreading on agricultural land or storage in ponds. A wide variety of technological treatments are available to reduce their polluting effects and for their transformation into valuable products (Fiestas Ros de Ursinos and Borja Padilla, 1992). However, very few data, if any, have been published on OMW composting. This paper reports a methodological approach for transforming these wastewaters into organic fertilizers by letting them be absorbed by plant waste materials which were later composted.

Materials and methods

Fresh OMW, were absorbed by cotton waste (C) and maize straw (M), to which fresh poultry manure (P) and sewage sludge (S) were added to supply the necessary nitrogen. Three composts (POC, SCO and SMO) were prepared respectively by mixing 65.4% of C with 34.6% of P (fresh weight), with 1930 l/tonne OMW added to the solid mixture during the first 18 days of composting; by mixing the same C carrier plus S (67.9 and 32.1%, respectively), with a lower amount of OMW (943 l/tonne) being added on the first day of composting; and by mixing the M carrier (52.9%) with S (47.1%) to which 1765 l/torne of OMW were added also on the first day of the process.

Three trapezoidal piles 1–1.5m high with a 2.3 m base containing about 1500 kg of every mixture were composted in a pilot plant based on the Rutgers static pile system (Finstein et al., 1985). The air was blown from the base of the pile, the

timer was set for 30s. ventilation every 15 minutes and the ceiling temperature for continuous air blowing was 55 °C. After the biooxidative phase of composting, the air-blowing was stopped to allow the compost to mature over a period of two months. The piles were sampled weekly till the end of the biooxidative phase and once again after the maturation period.

Moisture content was ascertained by drying at 105 °C, organic matter (OM) by loss-on ignition at 430 °C during 24h. Losses of organic matter were determined from the initial and final ash contents according to the equation of Viel et al. (1987). Lignin and cellulose were determined by the American National Standard Methods (ANSI/ASTM, 1977a and b), holocellulose according to Browning (1967), cation exchange capacity (CEC) by Lax et al. (1986) and germination index (GI) by Zucconi et al. (1981). Humic-like substances were isolated by treating compost samples with 0.1 M NaOH, later separating humic (HA) from fulvic (FA) acids by acid precipitation and centrifugation. Samples of whole extracts and FA solutions were analyzed for organic C by automatic microanalysis and C in HA was calculated by subtraction of the above values.

Table 1 Changes observed in some parameters during composting (% d.w.)

Sampling time (days)	Organic-C (%)			CEC (me/100g OM)			GI (%)		
	PCO	SCO	SMO	PCO	SCO	SMO	PCO	SCO	SMO
1	40.7	40.5	47.2	—	85	—	13	75	19
7	39.2	36.6	46.8	104	—	—	—	—	—
14	37.1	35.1	43.9	—	—	27	—	—	—
21	36.0	33.3	43.5	121	—	44	30	—	—
28	35.3	33.0	40.9	—	—	57	—	—	105
35	34.1	33.7	43.3	142	—	—	—	—	—
42	34.6	33.3	43.0	—	140	77	—	78	—
49	33.4	31.7	41.0	149	—	—	45	—	—
56	—	32.1	41.4	—	—	—	—	—	—
63	—	33.7	41.5	—	—	86	—	—	84
Maturity	33.7	29.4	39.4	156	195	110	77	94	91

Results and discussion

As shown in Fig. 1, the fermentation period was shortest in PCO and longest in SCO, the most extended thermophilic phase being observed in the latter compost. The C content decreased as composting progressed in all cases, the highest decrease being in the SCO compost (Table 1). The OM content decreased during composting in accordance with the fall in C, and was responsible for the important weight losses observed (Fig. 2), which reached a maximum value in the SCO compost. Thus, this compost underwent the greatest degree of mineralization, which might be related either to the lower toxic effect on the microorganisms because the quantity of OMW added was the lowest or to a greater microbial activity due to the important load of microorganisms from the sewage sludge. The N content

increased in all composts (Fig. 3), particularly in SMO (N content in the 'mature' compost was almost 120 of the initial value) suggesting some biological fixation at least in this compost. The initial values of the C/N ratio were 16.5 (PCO) 22.4 (SCO) and 33.7 (SMO), although these different values became very similar at the end of composting (9.8, 9.5 and 12.1, respectively).

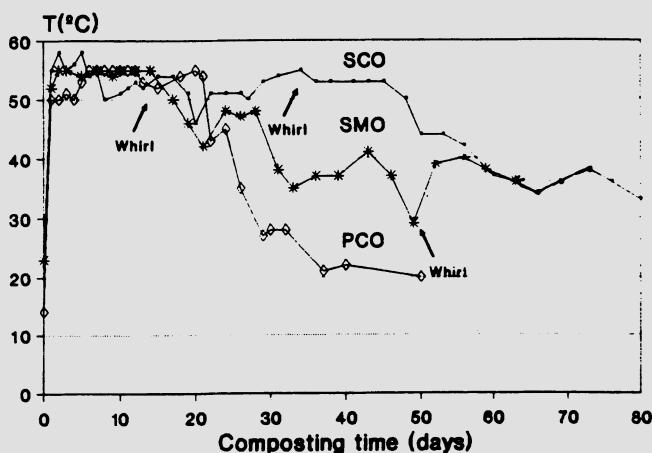


Figure 1 Changes in temperature during composting

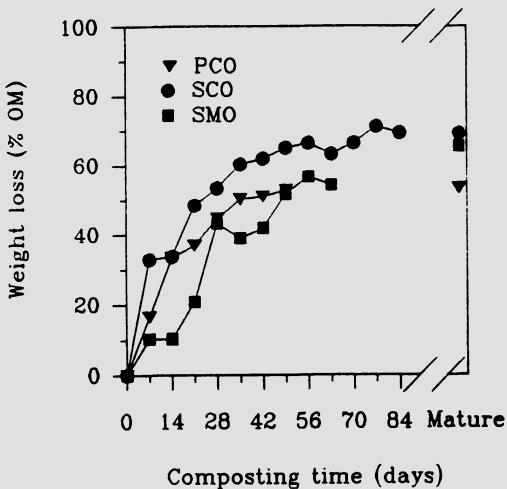


Figure 2 Weight losses during composting

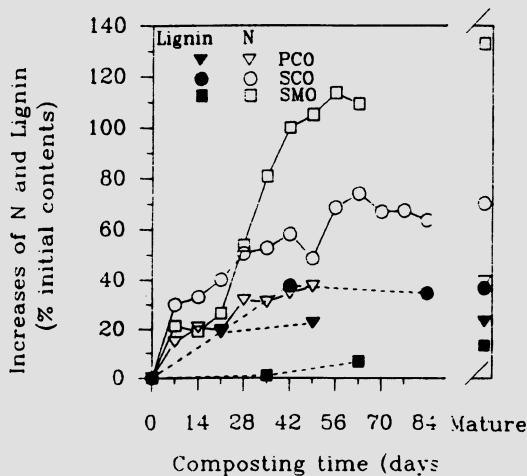


Figure 3 Increases of N and lignin contents during composting

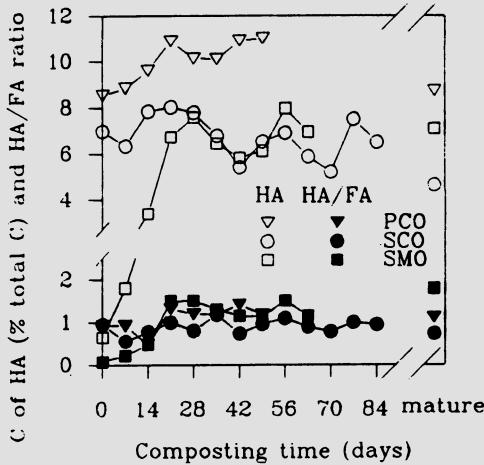


Figure 4 Changes in contents of fulvic (FA) and humic (HA) acids during composting

The lignin content increased during composting in all the cases, the highest increase being detected in SCO and the lowest in SMO (Fig. 3). At the same time, both alphacellulose and hemicellulose contents decreased, the reduction being greatest in SCO and smallest in SMO (data not shown). These results are in good agreement with the already mentioned losses of OM during composting and suggest that lignin is clearly resistant to biodegradation while cellulose was degraded to different degrees by the composting microorganisms, this phenomenon depending on factors such as the type of plant waste, the diverse rate of addition of OMW or the kind of N-source employed to prepare composts (poultry manure and sewage sludge). Because the CEC is related to compost 'maturity', this parameter was determined during composting (Table 1). The highest value was found in the 'mature' SCO compost and the lowest in SMO. However, the greatest CEC

increase during composting was observed in the latter compost, as this parameter increased four times, from 27.3 me/IOOg after two weeks of composting to 110.0 me/IOOg in the 'mature' compost. Increases were less apparent in the SCO compost and were still lower in PCO. The GI generally increased as composting progressed (Table 1), its values being small at the beginning of the process. This was particularly evident in PCO whose GI remained quite low during the first three weeks of composting, probably as a result of the successive additions of OMW to this mixture during the first 18 days of the experiment. However, rather high values of the GI were recorded in SCO from the beginning of composting, which may be related to the low quantity of OMW added to the raw mixture. An intermediate pattern was observed for SMO.

The highest HA content was found in PCO and the lowest in SCO (Fig. 4), this content generally increasing during the first 2–3 weeks of composting. This latter trend was particularly marked in SMO, whose HA content increased from less than 1 at the beginning of the process to 7–8 after week 3. HA content was generally lower in the 'mature' composts compared with the values reached during the active phase of composting. Lastly, the AH/FA ratio remained practically constant during composting, with the exception of SMO which clearly increased, suggesting that more polymerized humic substances were produced during the process.

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Municipal Solid Waste Composting: Chemical and Biological Analysis of the Process

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Abstract

Composting of municipal solid waste (MSW) was studied in an attempt to better understand the composting process and define parameters of maturity. Composting was performed in 1-m³ plastic boxes and the following parameters were measured: temperature, C/N ratio in solid and liquid phase (C/N(s) and C/N(w) respectively), humic substance fractions and contents, dissolved organic carbon (DOC). Spectroscopic method (DRIFT) was used to study the chemical composition of the bulk organic matter (OM). A bioassay based on cucumber plants growth was correlated to other parameters. C/N(w), C/N(s) and DOC showed high rates of change during the first 60 days, then stabilized. Humic acid (HA) content increased to a maximum at 110 days, corresponding to the highest plant dry weight and the highest 1650/1560 (cm⁻¹/cm⁻¹) peak ratios from DRIFT spectra. DRIFT spectra showed that the OM transformed to a more aromatic structure.

Introduction

Problems caused by municipal solid waste (MSW) in modern society have become more severe over the last decade due to increasing amounts of waste and decreasing availability of landfill space (Alter, 1991; Finstein, 1992). Recycling has become an attractive solution for the waste management. For the organic fraction composting seems to be a desirable option having the capacity of reducing the volume and weight by approximately 50% and resulting a product which can be useful for agriculture (He, 1992). One of the main obstacle to successful utilization

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of MSW compost in agriculture is the lack of reliable quality criteria and understanding the OM transformations throughout the process. Proper evaluation of compost maturity is essential for the establishment of such criteria. Therefore, the objective of this paper is to correlate chemical analyses and DRIFT spectra, with plant performance bioassay.

Results and Discussion

Various parameters were followed during composting of MSW. The C/N(s) ratio decreased rapidly from an initial value of 28 in the raw material to 18 after only 20 days. The ratio continued to decrease, albeit less sharply, to 12.2 after 60 days. From this point on the C/N ratio stabilized at a value of about 12 (11.8–12.8) for the remainder of process. The C/N(w) ratio followed a similar trend, exhibiting three phases: (i) rapid decrease from 35 to 8 during the first 20 d; (ii) slower decrease to a value of 6, lasting till 70 d; (iii) days 70 to the end of the experiment, when it stabilizes at value between 5 to 6. The C/N ratio (C/N(w) and C/N(s) as well) in itself appeared to be a non reliable indicator of compost maturity. Although it changed dramatically during the second phase of composting, it did not change significantly during the curing phase.

The compost bacterial population is active only in the liquid phase, thus the DOC concentration during composting can indicate the biodegradability of the OM. The changes in DOC concentration followed a trend similar to that of the C/N ratio, exhibiting same three phases: (i) rapidly decrease from initial concentration of 28.30 g/Kg to 7.40 g/Kg over the first 20; (ii) days 20–60, when the DOC continued to decrease, less sharply, to 2.25 g/Kg; (iii) days 60 to the end of the experiment, when the DOC decrease moderately to 1.00 g/Kg.

HA content increased during composting, reaching a stable value after 110 days at 13.5% of the OM while the fulvic fraction (FF) content, including the fulvic acid and the non humic fraction (FA and NHF respectively), decreased. The increasing level of HA may indicate the degree of humification and the maturity of the compost. The humification index ($HI=HA/FA$) increased to a ratio of 3, and the humification ratio ($HR=HA/FF$) increased to 1.35. These values differ in other, but in general fresh compost contains low levels of HA and higher levels of FA (Saviozzi et al., 1988; Gonzalez, 1993; Ciavatta et al., 1993). During the composting process the FF decomposed whereas the HA level remained stable.

The distinct differences in the bulk DRIFT spectra resulting from composting, was a reduction of the 1560 cm^{-1} peak (amide II) with time probably due to the relatively rapid biodegradation of the amino chain. The aromatic region (1650 cm^{-1}) became sharper during composting. Peaks in the aliphatic region at 2930 and 2850 cm^{-1} decreased, while the 1450 cm^{-1} peak, which represents C–H deformation, increased. Another method of monitoring changes during the composting process is the measurement of the intensity of major peaks and the ratios between them (Inbar et al., 1989). The peaks at 2930 cm^{-1} , 2850 cm^{-1} , 1650

cm⁻¹, 1560 cm⁻¹ and 1050 cm⁻¹ were chosen for these calculations. The ratio 1650/2930 (aromatic C / aliphatic C) increased from 0.88 to 1.10, the ratio 1650/2850 (aromatic C / aliphatic C) increased from 0.79 to 1.54, the 1650/1050 ratio (aromatic C / polysaccharide) increased from 2.39 to 2.80, and the 1650/1560 ratio (aromatic C / amide II bond) increased from 0.94 to 1.52. These increases represent a decrease in polysaccharides, aliphatic and amide components, and an increase in the aromatic structure in the mature compost. The linear correlation between the aromatic to aliphatic peak ratio (1650/2930 cm⁻¹/cm⁻¹) and the C/N ratio had a R²=0.936 calculated for the equation $Y = 1.263 - 0.014X$. This correlation indicate that the DRIFT spectra is a useful and reliable tool in the analysis the composting process.

It was hypothesized that plant growth may serve as an integrative single test for compost maturity (Chen and Inbar, 1993, Inbar et al., 1993). Cucumber plants grown in media containing fresh (14 d) compost (50% v/v) exhibited inhibited growth as compared to plants grown on older compost. The dry weight of plants grown in 110 and 132 d old composts were significantly higher than all the others. These results show that as OM decomposed the compost became a better substrate for plant growth. Only highly mature compost supported better plant growth. A correlation's between plants dry weight and other chemical analysis were correlated. A linear correlation between the 1650/1560 (cm⁻¹/cm⁻¹) DRIFT peak ratio and plant dry weight had R²=0.81 calculated for the equation $Y = 0.81 + 0.54X$. The linear correlation between HA content in OM and plant

dry weight had R²=0.70 calculated for the equation $Y = 3.59 + 7.78X$.

Conclusions

Due to materials and processes complexity the determination of compost maturity is very difficult. Therefore, several parameters are needed to be crossbred. This article proves that DRIFT spectroscopy, together with data on HS provide useful information about the OM transformations occurring during the composting process of MSW. Plant bioassay, level of HA and the 1650/1560 DRIFT peak ratio showed the same trend during composting and can therefor be used as maturity indexes. All those parameters exhibited three distinct phases: (i) rapid decomposition during the first 30 d; (ii) stabilization till day 90; (iii) maturation from day 90 and on. The MSW compost, in our experimental system, was mature and ready to be used as an agricultural substrate after about 110 days of composting.

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Chemical Parameters to Evaluate the Stabilization Level of the Organic Matter During Composting

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Abstract

The stabilization level of the organic matter of compost from MSW has been monitored using the degree of humification (DH), the isoelectric focusing (IEF) and a Bimodal Gaussian Distribution (BGD) of pK of –COOH and phenolic –OH groups of HA. The results obtained show that these methods are able to monitor the processes.

Introduction

Before the application to the soil, the organic matter from composts must be sufficiently stabilized, i.e. decomposable organic compounds must be completely transformed to stabilized substances [11]. Many methods have been proposed to control the quality of the organic matter during composting processes, such as C/N ratio [1], C.E.C. [8], E4/E6 ratio [10], gel chromatography [7], and selected chemical components in water extracts [2]. The determination of the amount of humic substances extracted from samples of different materials [5, 3] and a Bimodal Gaussian Distribution (BGD) model applied to the potentiometric titrations of (HA) have also been proposed [9]. The present work shows the results obtained following the evolution of the organic matter from MSW in piles of compost by using the degree of humification (DH), the isoelectric focusing (IEF) and a study of potentiometric titrations by a BGD model.

Materials and methods

The samples from municipal solid wastes (MSW) were taken from a composting plant near Mantova (Italy) from a static pile of compost stabilized during winter

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for 55 days under a forced-pressure ventilation composting system. The extraction and fractionation of the organic carbon from the were carried out using the methods reported by Ciavatta and Govi [3]. The potentiometric titrations on HA have been performed using the method suggested by Manunza et al. [9]. The degree of humification, i.e. DH% = [(HA+FA)/TEC] x 100, was used as humification parameter. Further details on analytical characteristics of the samples have been reported in a previous paper [4].

Results and discussion

The total organic carbon content (TOC) of the samples composted steadily decreased from 25.0% C at the beginning until 17.1% C at the end of the process (the losses of organic C suggest the occurrence of high microbiological activity). The DH values started at 43% and sharply increased at the beginning of the process, then at the end tended asymptotically to stabilize around 60% (Fig. 1). These values are slightly lower than those found for organic matter extracted from soils, humified peats and well-matured composts [3]. The high DH values at the beginning of the composting process depend on the occurrence during this phase, of humic-like substances that interfere in the separation method of humic substances [3].

In figure 2 are shown the IEF patterns of the organic extracts from compost at the beginning of the stabilization processes and after 55 days. The two patterns show a group of bands in the region from pH 4 to pH 5.3 and a group of well resolved bands in the region from pH 5.3 to pH 6.0 in both samples. Before composting in the region over pH 6.0 there are only two weak bands in the IEF profile of the raw sample (zero days), while in the composted sample (55 days) there are a group of five well resolved bands over pH 6.0. Our results confirm what has been shown by other authors [5], i.e. that the evolution of the organic matter during the composting process leads to the formation of organic compounds which can be identified using the IEF and are characterized by both high molecular weights and isoelectric points.

Figure 3 shows the distribution of pK of humic acids extracted at the beginning (a) and at the end (b) of the composting process. The data obtained from the titration curves have been processed using a BGD model of binding sites. Both curves (a, b) were characterized by two Gaussian distribution of pK of -COOH and phenolic -OH groups. At the beginning of the humification processes (a) the mean pK of the -COOH and phenolic -OH groups were pK = 3.91 and pK = 9.33, respectively, while the total acidity of the -COOH was higher than that found for phenolic -OH groups (198 vs. 120 cmolc 100g⁻¹). After composting the mean pK of the -COOH and phenolic -OH groups were pK = 4.56 and pK = 10.52, respectively and the two areas are of the same order of magnitude (203 vs. 198 cmolc 100g⁻¹). The last pattern is very similar to that found for soil HA.

In conclusion, all the three approaches here used have shown a progressive

humification of the organic matter during composting. This phenomenon can be resumed with i) increasing of the DH values; ii) by a formation of a new group of well resolved bands over pH 6 in the IEF profiles; iii) and finally by a mean pK values of -COOH and phenolic -OH groups very close to those found for soil HA. The stabilization of the organic matter in piles of compost from MSW can be monitored using the DH, the IEF and by a study of potentiometric titrations of HA. It seems reasonable to suggest the use of these chemical methods for an adequate control of the composting processes.

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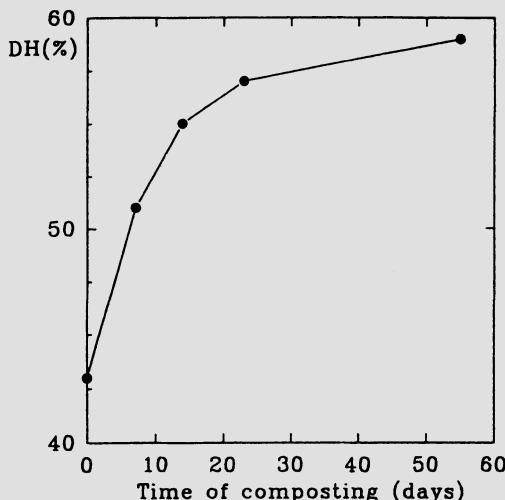


Figure1. Trend of the degree of humification (DH) during the organic matter stabilization processes in composts from municipal solid wastes (MSW).

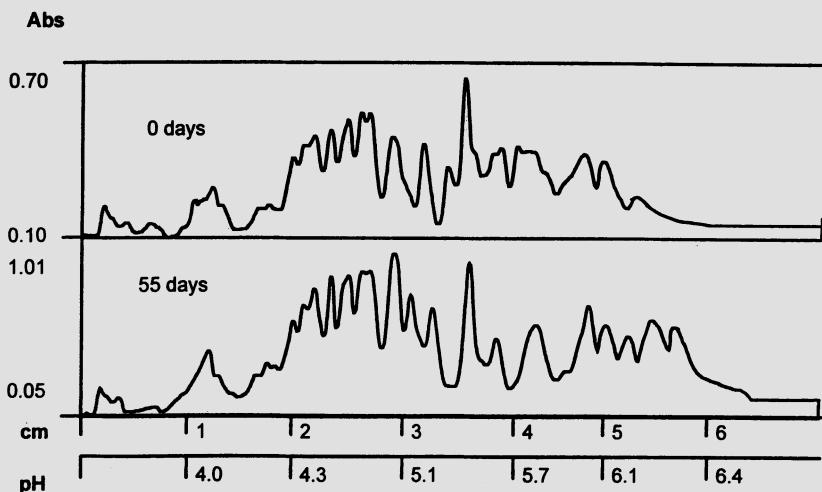


Figure 2. Isoelectric focusing (IEF) profiles of 0.5 M NaOH extracts of municipal solid wastes (MSW) stabilized during the winter season after zero and 55 days of organic matter stabilization processes.

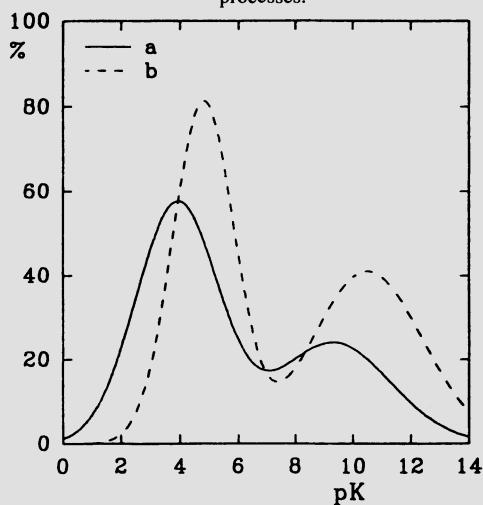


Figure 3 pK distribution of HA extracted from compost samples before (a) and after (b) composting.

Response of Three Compost-based Substrates to Different Irrigation and Fertilization Regimes in Poinsettia (*Euphorbia pulcherrima* Willd.)

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Introduction

Since 1985, the research section of Minoprio Foundation has been testing different composted materials of vegetable origin as components of growing media for ornamental pot plants. The study of the relationship between physical and chemical characteristics of composts and plant quality gave the opportunity to obtain good quality plants in cultivation trials, even by reducing the quantity of peat in the substrate until 1/3 of the total (Lamanna et al., 1991).

The different composition and structure of compost-based substrates, compared with peat-based ones, induced to modify irrigation and fertilization techniques so as to obtain better quality plants; compost-based media generally have a lower water retention capacity; in some cases, they showed greater requirements for nitrogen (N) and a high mineralization rate (Lemaire et al., 1989).

Materials and methods

In 1994 a trial on poinsettia plants was planned (table 1). Rooted cuttings of cvs. 'Peterstar' and 'Supjibi' were potted in four media, respectively a peat-based substrate (control) and three compost-based ones, and plants were cultivated using an ebb-flow irrigation system.

For the trial the following substrates were used:

- a commercial peat-based substrate (T);
- a mixture of a vegetable compost (n. 1) + white peat + perlite (3:2:1 ratio) (V1);
- a mixture of a second vegetable compost (n. 2) + white peat + perlite (3:2:1 ratio) (V2);
- a mixture of a conifers bark compost + white peat + perlite (3:2:1 ratio) (C).

The four media were treated in a greenhouse in following ways:

Table 1 Cultural technique used on Poinsettia cvs. 'Peterstar' and 'Supjibi' during the trial.

Potting:	August, 5.
Pot diameter:	16 cm.
Basic fertilization:	None in peat-based substrate; 140 mg/l N, 160 mg/l P ₂ O ₅ and 180 mg/l K ₂ O in compost-based substrates.
Pinching:	August, 25
Spacing:	6.25 p./m ²
Minimum and ventilation temperature:	18 – 22 °C
EC nutrient solution:	1.2 mS/cm from August, 25 to September, 14 1.8 mS/cm from September, 15 to October, 9 1.4 mS/cm from October, 10 to November, 20 0.9 mS/cm from November, 21 to December, 16
Data collecting:	December, 16

- high irrigation frequency (IF) and N/K₂O ratio = 1:1;
- high irrigation frequency and N/K₂O ratio = 1:1.6;
- low irrigation frequency and N/K₂O ratio = 1:1;
- low irrigation frequency and N/K₂O ratio = 1:1.6;

Irrigation time of plants receiving high IF has been fixed by tensiometers: irrigations began when water tension of the most moistened substrate reached the threshold of 40 hPa.

Plants with high IF were irrigated twice, compared to plants with low IF.

Because of the rich K content of vegetable composts, two different N/K₂O ratios were tested.

Physical and chemical characteristics of the four substrates are reported in table 2.

Table 2 Physical and chemical characteristics of peat-based (T) and compost-based (V1, V2, C) substrates a b.

Characteristics	T	V1	V2	C
Bulk density (g/cm ³)	0.139	0.296	0.306	0.186
Total porosity (% v/v)	91.2	83.7	85.0	89.0
Air capacity at pF 1 (% v/v)	23.3	33.2	27.9	42.7
Available water between pF 1 and pF 2 (%v/v)	27.5	18.4	23.3	17.8
pH	6.0	6.8	6.2	4.7
EC (mS/cm)	1.25	2.19	1.42	0.97
N (mg/l)	165	146	147	106
P ₂ O ₅ (mg/l)	70	54	89	100
K (mg/l)	123	440	208	119
NDI index	1	0.7	0.3	0.2

a Water extraction with 1:1.5 (v/v) ratio.

b With basic fertilization.

The electric conductivity (EC) of the nutrient solution was the same for all substrates and treatments and varied, during cultivation, from 0.5 to 1.8 mS/cm.

At the same time, at the beginning of the trial, in a laboratory the three compost-based substrates were incubated at 21 °C for 4 days, to control nitrogen immobi-

lization by the Nitrogen Drawdown Index (NDI) test (Handreck, 1992).

At the end of cultivation, data on plant height, plant diameter and bracts development were collected and evaluated by analysis of variance. At the same time, foliar analysis for N, P, K, Ca and Mg on bracts of plants receiving high IF were carried out.

Results and discussion

NDI test

Table 2 reports the result of the NDI test on the four substrates. Regarding the peat-based substrate (T) the Nitrogen Drawdown Index was 1 (absence of immobilization). On the contrary, the compost-based substrates revealed different levels of nitrogen immobilization (lower in substrate V1, higher in substrates V2 and C).

Plant growth

During cultivation plants grown on substrate C showed symptoms of N-deficiency and a lower growth in comparison to those cultivated on the other substrates. At the same time, tensiometers revealed that substrates with a higher water retention capacity in laboratory analysis, did not have an analogous behaviour in cultivation trial: the peat-based substrate T, that showed a water capacity between pF 1 and pF 2 much greater than other substrates, during the trial revealed the same irrigation needs as substrate V1 but greater ones compared to the other two substrates.

Tables 3 and 4 show the effects of substrate, irrigation and fertilization on plant height, plant diameter, and bract diameter in cvs. 'Peterstar' and 'Supjibi' at the end of cultivation.

Table 3 Average plant height, plant diameter and bract diameter of Poinsettia cv. 'Peterstar' as affected by substrate, irrigation frequency and N/K₂O ratio.

	Plant height (cm)	Plant diameter (cm)	Bract diameter (cm)
Substrate:			
T	29.9 a	47.9 a	23.7 a
V1	25.6 c	43.2 c	22.5 a
V2	27.9 b	45.9 b	23.3 a
C	24.2 d	41.9 d	21.8 a
Irrigation frequency (IF):			
High IF	30.4 a	49.8 a	24.2 a
Low IF	23.8 b	40.3 b	21.6 b
N/K₂O ratio:			
1:1	27.0 a	45.2 a	23.5 a
1:1.6	27.0 a	44.4 a	22.2 b

Mean separation within columns by LSD test (P £ 0.05).

Table 4 Average plant height, plant diameter and bract diameter of Poinsettia cv. 'Supjibi' as affected by substrate, irrigation frequency and N/K₂O ratio.

	Plant height (cm)	Plant diameter (cm)	Bract diameter (cm)
Substrate:			
T	26.3 b	41.2 b	23.5 a
V1	28.4 a	44.3 a	24.1 a
V2	27.2 b	42.9 a	24.0 a
C	24.1 c	37.9 c	22.5 a
Irrigation frequency (IF):			
High IF	31.4 a	50.2 a	26.4 a
Low IF	21.5 b	32.6 b	20.5 b
N/K₂O ratio:			
1:1	25.3 b	39.2 b	22.6 b
1:1.6	27.7 a	43.8 a	24.4 a

Mean separation within columns by LSD test (P £ 0.05).

Substrates T and V1 allowed us to obtain higher and larger plants, respectively of cv. 'Peterstar' and 'Supjibi'. The influence of substrates T, V1 and V2 on plant growth was different according to varieties; plants of both varieties cultivated on substrate C showed the lowest growth. Bract diameter was not affected by substrate. While substrate C revealed to be subject to N immobilization, substrates V1 and V2, even with a NDI index lower than 1, did not present a remarkable N-deficiency during cultivation.

Plants of both cultivars more frequently watered, showed a better growth and a greater bract diameter in comparison with plants receiving low IF.

N/K₂O ratio had no effect on cv. 'Peterstar', except for bract diameter, which was slightly larger with the 1:1 ratio, compared with the 1:1.6 ratio. In cv. 'Supjibi', on the contrary, a N/K₂O ratio = 1:1.6 led to greater plants and a larger bract diameter than with the 1:1 ratio.

Foliar analysis

Bract analysis on plants receiving high IF (table 5) showed no appreciable differences among the treatments in mineral contents, with the exception of K-content in plants receiving different N/K₂O ratios: on both cultivars there was an unexpected higher K-content in bracts of plants fertilized with the highest N/K₂O ratio (3.4 % d.w. vs. 2.8 % in cv. 'Peterstar' and 3.0 vs. 2.8 in cv. 'Supjibi').

Conclusions

The comparison between laboratory analysis and cultivation trial pointed out that not always there is correspondence between physical characteristics of a substrate and its behaviour in practice.

At the same time, also the NDI test for measuring N immobilization does not seem efficient to describe the nitrogen drawdown for a period longer than 4 days.

Table 5 Bract analysis (% on dry weight) of Poinsettia cvs. 'Peterstar' and 'Supjibi' as affected by substrate and N/K₂O ratio (only plants receiving high IF).

	N	P	K	Ca	Mg
<i>Cv. 'Peterstar'</i>					
Substrate:					
T	2.7	0.5	2.7	0.3	0.3
V1	3.1	0.6	3.4	0.4	0.3
V2	2.6	0.6	3.2	0.4	0.3
C	2.6	0.6	3.1	0.3	0.3
N/K ₂ O ratio:					
1:1	2.7	0.6	3.4	0.4	0.3
1:1.6	2.7	0.5	2.8	0.3	0.3
<i>Cv. 'Supjibi'</i>					
Substrate:					
T	2.7	0.6	3.0	0.4	0.3
V1	2.7	0.6	2.7	0.4	0.3
V2	2.7	0.6	3.0	0.5	0.4
C	2.7	0.6	2.8	0.3	0.3
N/K ₂ O ratio:					
1:1	2.6	0.6	3.0	0.4	0.3
1:1.6	2.8	0.6	2.8	0.4	0.3

For the above-mentioned reasons it would be better, with regard to physical characteristics of substrates, to control irrigation of each individual substrate by tensiometers, according to water tension measurements. Regarding the tendency to immobilize nitrogen by compost-based substrates, it is necessary to test substrates for a longer period of time, at values of temperature similar to those maintained during cultivation.

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Method for the Evaluation of Biodegradability of Packaging in Composting Conditions Proposed by CEN (European Committee for Standardization): a Technical Approach.

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Introduction

The European Directive on Packaging and Packaging Waste, recently promulgated, considers composting as a form of recycling of biodegradable packagings. To become effective the Directive must be endowed with technical tools such as definitions, criteria, and test methods. CEN (Comité Européen de Normalisation), the European Standardisation Committee has established on 1991 a subcommittee (TC261/SC4) named ‘Packaging and the Environment’ to provide the technical and standardization support to the Directive. Within this subcommittee the Working Group 2 (WG2: ‘Degradability’) is defining a test method to measure the biodegradability of packaging in composting conditions. Both this test and ASTM D5338-92 are derived from a proposal of Organic Waste Systems (Gent, B) and based on the measurement of CO₂ evolved by the test substance in conditions simulating the composting environment: aerobic fermentation, solid state, high temperature, and inoculum particularly rich in thermophilic microorganisms (mature compost). In order to verify the accuracy and precision of the method and gather useful data for the final standardization, the CEN TC261/SC4/WG2 has organized a ringtest at European level using cellulose, paper and Biopol, a poly-hydroxyalcanoate, as test materials. In Italy NOVAMONT, a Company actively involved in the development of biodegradable materials, has taken part to the ringtest. A comprehensive description of the results of this testing activity will be soon published by the WG-2. In this presentation we describe the technical approach followed by us to set-up the test procedures and test apparatus.

Materials and methods

Apparatus. Compressed air pressure is reduced by a pressure reduction device to

about 0.5 atm. The air flow is then dehydrated by a silica gel (Fluka, Ch) column and decarbonated by a soda lime (Ohmeda, UK) column. The flow is then split into 12 lines, corresponding to 12 composting reactors. The air flow rate of each line is measured by a rotameter and adjusted by a valve (Flow-Meter srl, I), and leaded to the reactor by means of natural rubber thick tubing (Ascenso, I). The air is fluxed upwards in each reactor (3 litres glass bottles) via an hollow shaft finishing with a 'T'. The reactors are heated in a thermostatic water bath. The exit gas is passed, before measurement, through two vapour traps. The first is a glass bottle at ambient temperature; the second is a water-cooled glass coil. Twice a day, the air flow rate of each line is measured with a precision rotameter (Flow-Meter srl, I) and the CO₂ concentration is measured by an infrared CO₂ detector (Gas Monitor ADC 2000 Series The Analytical Development Company, UK). This instrument makes autozero every ten minutes. The span is checked every 2 weeks using a 1% CO₂ in He calibration mixture (SIAD, I).

Test substances. Cellulose microcrystalline 'Avicel' by Merck. Packaging paper, made with virgin kraft unbleached softwood pulp, by Centre Technique du Papier (France). Biopol, grade D800P, obtained by Zeneca Bio Products (UK). The compost used as inoculum was obtained by a composting plant located in Trento (I).

Test procedure. A mixture of mature compost (600 g, dry weight) and test material (100 g) is introduced in a reactor (about 3 liters) maintained in thermophilic conditions for 45 days and fluxed with a continuous air stream. In these conditions the mixture will produce, by respiration, carbon dioxide. If the test material is metabolized there will be an extra production in comparison with control blank reactors. The mineralisation percentage is the ratio between net CO₂ produced by sample and the amount which could be produced in case of a complete transformation of its carbon into CO₂. The temperature in this experiment followed a profile, according to ASTM D5338-92 test procedures; the final CEN draft prescribes a fixed 58°C temperature. Three replicates for test materials and blanks reactors were used.

Data treatment. The raw data collected during each sampling are the following: date and hour of sampling; reactor identification number; air flow rate (AFR = L/h); CO₂ concentration (% v/v). A home prepared program on '123-Lotus' processes these raw data and gives the cumulative CO₂ production (grams) and the biodegradation (% CO₂/ThCO₂) of each reactor. It calculates: the elapsed time from test start; elapsed time from last measurement. It converts the CO₂ concentration from % (A) to g/L (B) by:

$$B \text{ (g/L)} = A / 22.263 * 44 / 100$$

and works out the CO₂ evolution rate (CER):

$$CER \text{ (g/h)} = B \times AFR.$$

The amount of CO₂ produced during the time interval within two measurements is estimated by multiplying the CER by the elapsed time from last measurement.

The sum of these CO₂ amounts is the total cumulative CO₂ production. The net production is determined subtracting from each total value the corresponding mean CO₂ production of blanks. Finally, the net values are divided by the theoretical CO₂ production and multiplied by 100 to obtain the % biodegradation.

Results & discussion

The total cumulative CO₂ productions of replicates were very similar for each test material. At test termination (46 days) the CO₂ production (+ standard deviation) and biodegradation values (in parenthesis) were: Blanks 35.6+2.3 g; Cellulose 187.8+3.9 g (97.68%); Paper 173.4+4.9 g (88.29%); Biopol 247.3+6.9 g (102.10%). These results indicate that the procedure in spite of being based on sampling (not frequent) rather than on cumulative measurements is accurate. It is also precise. This turns out from the ring test results, which will be published elsewhere in full details. Here we want to remark the following. In order to compare the different results it is helpful to normalize the biodegradation values of each laboratory to the corresponding value of cellulose (considered as reference material with its biodegradation fixed equal to 100%). It turns out that the normalised results of the present study are very close to the ringtest normalized averages: Biopol degradation is 104.1% of cellulose (ringtest average 106.7%) and paper is 89.1% (average 91.3%).

The apparatus installed and experimented in this trial has shown satisfactory features: it is relatively cheap; even if not automatized, it is not laborious and time consuming, at least in comparison with other respirometers (i.e. Sturm test). The CO₂ concentration is determined by an IR gas monitor originally designed to be used as a gas-alarm in cellars and breweries. It turned out to be fast (it takes few minutes to give the final value), precise (as verified by using different calibration gas mixtures) and stable (the drift after many weeks is negligible). The following protocol improvements were adopted. To obtain a regular flow rate at outlet and to facilitate air flow reading, expanded clay balls (used in horticulture and floriculture) were added to the composting mixture to increase porosity of the substrate. Water evaporation was controlled by weighing each vessel periodically and restoring the initial weight by adding water. This to avoid the risk of plugging the rotameters with condensed water by using saturated air as prescribed by the method. The system of CO₂ removal from air stream was nearly depleted at the end of the experiment. The real need of using CO₂ free air is questionable. In future experiments we intend to measure at every sampling the CO₂ concentration entering the vessels (I), the CO₂ concentration at the outlet (O), and correcting the reading: 'net' CO₂ concentration = O - I we will take in consideration only the part of CO₂ which has been produced by degradation. This is applicable only if O>>I.

The CEN method is very interesting because it offers the possibility to know the biodegradation of a material – as CO₂ evolution, namely measuring a clear,

unambiguous parameter – when subjected to environmental and microbiological conditions which reproduce the typical composting conditions. A frequent objection is that in real composting the test material is mixed with fresh waste rather than with a mature, stabilized compost. On the other hand, a fresh solid waste would be unsuitable for this test because it would produce a too high CO₂ background which would mask the CO₂ evolved by test material. A study to understand the influence of the composting substrate on the biodegradation behaviour of solid materials indicated that the test methods based on the use of mature compost can possibly underestimate the biodegradation occurring in fresh waste, i.e. in real composting plants, and are to be considered as conservative test methods (manuscript in preparation).

Effects of the Spreading into the Soil of Olive Mill Wastes on the Physico-chemical Properties of the Humic acids. I. Interaction of natural and Synthetic Humic Acids with Caffeic Acid.

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Introduction

Organic wastes from different sources determine the variation of several soil physico-chemical parameters such as pH, heavy metal content, redox potential, complexing activity and degree of humification, what may affect the soil fertility in a positive or negative way. The organic fraction of low molecular weight is involved in ionic mobilization and humification processes, its presence is particularly important in soils with a low level of organic matter and micronutrients.

As a part of a wider project, whose objective is the evaluation of the modifications that olive mill wastes induce on the structural and physico-chemical properties of humic acids, we studied the interaction between caffeic acid (CAF), a relevant constituent of these biomasses, and natural and synthetic humic acid (NHA and RHA, respectively). In this paper we report on both the interaction between NHA and CAF and the redox properties of the NHA-CAF compound.

Materials and Methods

The NHA were extracted from an Andosol following the procedure of the International Humic Substances Society (HISS). The chemical and physical characteristics of the RHA, obtained via coal oxidation, and of the NHA as well as the analytical procedure for the Iron(II) and Iron(III) determination are reported in previous papers (Rausa et al., 1994 ; Deiana et al., 1995). CAF concentration was measured with an HPLC DIONEX equipped with a HC-ODS/PHA column supplied by Perkin Elmer. The IR spectra were performed on KBr pellets by using a Nicolet 205 spectrometer.

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Results and discussion

The interaction of CAF by NHA was studied by examining the effect of NHA-CAF ratios (keeping constant the amount of the organic material), solution pH and reaction time. In Figure 1 the kinetic curves of absorption of CAF by NHA at pH 2.0, 3.0, 4.0, 5.0 and 6.0 are shown. The plots indicate that at pH 2.0 the absorption of CAF is strongly inhibited, while it is favoured in the 3.0–6.0 pH range. The absorption kinetics at pH 6.0 is slower probably due to the increase of the carboxylate groups concentration of both the NHA and CAF. The concentration of such charged groups is greater than that of the same systems at lower pH values. In these conditions both the humic acids and CAF behave as hydrophilic, negatively charged molecules, thus increasing repulsive forces between them and hampering the formation of aggregates.

Figure 2 reports the amount of CAF absorbed at various initial CAF concentrations at pH 4.0. These plots show that the maximum of CAF absorbed is about 1.73 mmoles g⁻¹.

The CAF interacts very strongly with the organic matrix: in fact, an increase in the H⁺ concentration (pH 2.0) does not cause the release of CAF absorbed. The occurrence of a strong interaction between CAF and NHA is also shown by the reaction between NHA-CAF and iron(III) when compared to that of NHA and NHA-Fe(III) with iron(III) and CAF, respectively. The NHA-CAF and Fe(III) reaction gives a yield in Fe(II) of about 50% after 100 hours of reaction. In contrast, the reduction of Fe(III) by NHA and of the Fe(III) complexed by NHA operated by CAF is complete and occurs quickly. This indicates that the phenolic -OH groups of both NHA and CAF, which are responsible for the reduction of Fe(III) (Rausa et al., 1994; Deiana et al., 1992; 1995), are involved in the NHA-CAF interaction.

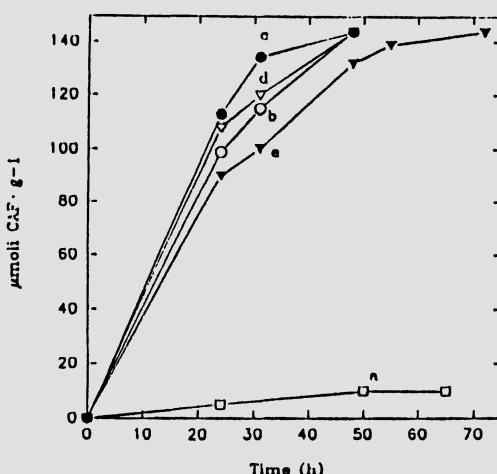


Figure 1. CAF absorption (mmoles g⁻¹), at different pH values, as a function of time in NHA-CAF systems. Starting conditions: 25 mg NHA; 0.01 M NaClO₄ at pH 2.0 (a); pH 3.0 (b); pH 4.0 (c); pH 5.0 (d) and pH 6.0 (e). The initial CAF concentration was 72 mM. Reaction volume 50 mL.

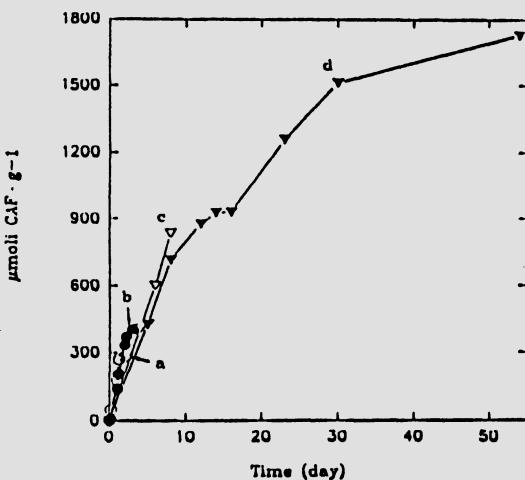


Figure 2 CAF absorption (mmoles g⁻¹), at different CAF concentrations, as a function of time. Starting conditions: 25 mg NHA; 0.01M NaClO₄; pH 4.0. The initial CAF concentrations (mM) were 144 (a), 216 (b), 432 (c), 864 (d). Reaction volume 50 mL.

In order to assess the role of the phenolic groups on the interaction between NHA and CAF we carried out the same tests on RHA, which were chosen because most of their functional groups are constituted by carboxylic and phenolic groups (Rausa et al., 1994). Results obtained by using these compounds confirmed that phenolic groups are involved in the formation of the NHA-CAF adducts.

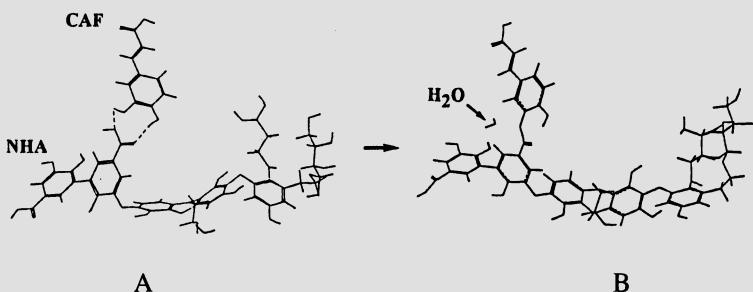


Figure 3 Proposed structure of the NHA-CAF adduct as obtained by QMC.

The IR spectrum of the NHA is similar to that of the NHA-CAF compound, suggesting that a strict interaction occurs between the CAF molecule and the humic substrate.

Preliminary quantum mechanics calculations (QMC) (Fig. 3) show that both the carboxylic and phenolic groups of the humic substances and CAF can be active

in this reaction. In particular two adducts can be proposed: the hydrogen bonded adduct A which evolves to the B adduct with the elimination of a water molecule and a energy lowering of about 50 Kcal mole⁻¹. Further studies at this regard are in progress.

Conclusions

This study, which constitutes a first step in the survey of more complex systems, indicates that humic acids can be used to lower the concentration of phenolic compounds, which can induce toxic effects on the soil microorganisms and plants. However, it is important to underline that both HA and CAF, once that the adduct forms, lose some of their reduction properties.

Acknowledgement

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The use of Dairy Manure Compost for Maize Production and its Effects on Soil Nutrients, Maize Maturity and Maize Nutrition

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Introduction

Maize (*Zea mays L.*) is widely distributed in tropical and temperate regions, being an important cereal used for both human and animal consumption. Inorganic fertilizers can be too costly and out of reach for small producers, being unable to sustain soil fertility and also posing environmental risks of nitrate pollution of ground water table (Maynard 1994).

A production system using renewable resources within the farm was studied, recycling crop and animal residues into organic fertilizer, and aiming at reducing dependence on external inputs. Dairy manure and cereal straw were used to produce compost, and its effects on soil nutritional status, maize nutrition and crop production were studied. Further to results obtained in a previous experiment (de Toledo et al 1994), the possible effect of compost in delaying maize maturity was also examined.

Materials and Methods

A field experiment with forage maize was carried out at Wye College Farm, UK, on Orchard Field (calcareous silt loam soil, pH 8.0). The experiment, drilled on 6th May 1994, compared inorganic fertilizer (as Nitram, 34.5%N) and dairy manure compost at two rates of application. Compost rates were equivalent to Nitram in terms of nitrogen availability (Brinton 1985).

The trial had Nitram at 50 and 100 kg N.ha⁻¹, applied as topdressing in one application only, one week after drilling. Compost (25 and 50 t.ha⁻¹) was uniformly spread on the soil surface and incorporated before drilling. An untreated control was included. Herbicide (atrazine, as Gesaprim, 3 l.ha⁻¹) was sprayed in

all plots for weed control, on the day of crop emergence. A split-plot design with four replicates was used, to allow for a comparison of all the treatments with two maize varieties, LG2080 and Aziz – an earlier maturing variety.

Plots were 3 m wide and 16 m long, and had four rows of maize, with sampling from the two inner rows only. Soil samples were taken in June, August and September for nutrient analyses (total N, NO₃-N, NH₄-N, P, K, Ca, Mg, dry matter and organic matter). Maize samples were taken at three stages of crop development for biomass, leaf area measurement and nutrient analyses (results not presented). Final maize yield and nutrient uptake were determined at harvest (5th October 1994). All data were analysed using analysis of variance.

Results

No difference in soil nutrients was found between varieties LG2080 and Aziz. Results of the mean of the two varieties are shown for soil NO₃-N (Table 1) and soil K (Table 2). Higher soil NO₃-N content ($p < 0.01$) was found under Nitram application, but this was not associated with better maize yields. Plots treated with compost had higher soil K levels ($p < 0.001$), and higher soil total N, P and Mg contents (data not presented). Only traces of NH₄-N were found in soil under all treatments. Soil Ca (1500 mg.kg⁻¹ soil) and soil organic matter (4.5%) were high, varying little within treatments at all samplings. At early stages, soil dry matter was higher ($p < 0.05$) in Nitram treated plots, thus indicating a higher soil water content under compost application. Due to heterogeneity of variance, statistical analyses of soil nutrients were made using log transformed data.

Table 1 Soil NO₃-N levels (mg.kg⁻¹ soil) at three stages (mean of two varieties)

treatments (kgN.ha ⁻¹)	June		August		September	
	mean	log	mean	log	mean	log
control 0	13.4	1.1	5.8	0.8	1.7	0.4
Nitram 50	27.1	1.4	13.5	1.1	4.5	0.6
Nitram 100	35.5	1.5	19.7	1.2	9.4	1.0
compost 50	17.5	1.2	7.3	0.8	4.1	0.6
compost 100	19.7	1.3	8.2	0.9	4.3	0.7
s.e.d.		0.06		0.16		0.12

Table 2 Soil K levels (mg.kg⁻¹ soil) at three stages (mean of two varieties)

treatments (kgN.ha ⁻¹)	June		August		September	
	mean	log	mean	log	mean	log
control 0	184.4	2.2	128.9	2.1	191.6	2.3
Nitram 50	209.0	2.3	104.8	1.9	199.8	2.3
Nitram 100	139.2	2.1	70.4	1.7	195.7	2.3
compost 50	291.2	2.4	163.3	2.2	302.6	2.5
compost 100	476.0	2.6	214.9	2.3	434.2	2.6
s.e.d.		0.12		0.21		0.07

Nitrogen uptake by maize was higher under Nitram ($p < 0.001$) at the high level of application (100 kg N.ha $^{-1}$), but did not differ from compost at the lower level. However, maize had higher accumulation of potassium ($p < 0.001$) in compost treated plots at both levels of application (Table 3). Variety Aziz showed poorer responses in compost treated plots than did LG2080, particularly at the higher level of application, but performed well in plots treated with Nitram.

Table 3 Maize N and K uptake at harvest in above ground plant parts (kg.ha $^{-1}$)

treatments (kgN.ha $^{-1}$)	N uptake variety Aziz		K uptake variety Aziz	
	variety LG2080		variety LG2080	
control 0	112.8	137.9	93.0	118.2
Nitram 50	142.4	126.4	108.3	104.1
Nitram 100	157.0	150.5	102.8	102.4
compost 50	135.1	133.4	118.3	123.5
compost 100	126.2	141.8	117.8	135.1
s.e.d.	10.49	10.49	10.96	10.96

Maize fresh yield was higher ($p < 0.01$) in compost treated plots at both levels of application, and higher in variety LG2080 than in Aziz in all treatments ($p < 0.05$), but no significant difference was found in maize dry yield (Table 4). Variety Aziz had a higher dry matter content (average 38%) than variety LG2080 (average 33%) at harvest ($p < 0.01$), in all treatments.

Table 4. Maize fresh and dry weight yields at harvest (t.ha $^{-1}$)

treatments (kgN.ha $^{-1}$)	fresh weight variety Aziz		dry weight variety Aziz	
	variety LG2080		variety LG2080	
control 0	29.5	37.7	11.7	13.0
Nitram 50	34.6	36.3	13.4	12.0
Nitram 100	33.5	39.4	13.6	12.9
compost 50	36.3	40.7	13.4	13.2
compost 100	34.9	41.7	12.2	13.1
s.e.d.	1.70	1.70	0.78	0.78

Discussion

Nitram treated plots have a higher potential for nitrate pollution of ground water table than compost ones, as the excess of NO₃-N in soil tends to leach (Maynard 1994).

The high levels of organic matter in the soil, and the sensitivity of maize to low soil temperature could have masked the effects of treatments. There might be better responses in areas warmer than UK, and/or with lower soil organic matter content.

The use of an early variety other than Aziz might show a correlation between higher fresh yield and higher dry yield with compost application. Higher fresh yield under compost could be explained by the higher soil water content in com-

post treated plots at early stages, or by the higher accumulation of potassium in maize, as plants well supplied with K show increased uptake of water and reduced water loss (Mengel and Kirkby 1987).

Acknowledgements

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Sewage Sludge Composting: Study of Nitrogen Mineralization Using Electroultrafiltration

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Introduction

Mediterranean areas are specially affected by a soil organic matter decrease due to the drop of agricultural productivity and the deterioration of soil (desertization process, salinization, forest fire, etc.). On the same time, this waste may pollute the pedological environment because of its high contents of heavy metals and plant-damaging organic compounds.

The use of composted waste is an alternative to overcome problems in agricultural use of this material. Composting can reduce the contents of harmful compounds. However, generalizations about the process and the composts produced from different wastes cannot be made, therefore data on each composting process are required.

The composting of sewage sludge has been extensively studied (LOBO et al., 1987; GARCIA-IZQUIERDO et al., 1987; KATAYAMA et al., 1986), nevertheless, the criteria for evaluating the process and the final composts remain subjects for discussion (HAPADA et al., 1980; SAVIOZZI et al., 1986; ZUCCONI et al., 1981; DIAZ-BURGOS and POLO, 1992).

This paper shows an approach to these problems using the electroultrafiltration (EUF) technique. It was used for monitoring transformations taking place in the nitrogenous fractions of two anaerobic sewage sludges mixed with two different additives.

Material and methods

Two anaerobic sewage sludges from a waste water treatment plant of Madrid city (urban: U and industrial: I origin) were mixed with chips (C) from tree pruning or vine shoots (V) in a 2/1 weight ratio (sludge/additive) and composted for 14 weeks. The selection of the sewage sludge was based on the different heavy metal content which may influence the microbial populations mainly responsible for the composting process. The additive was selected in order to reuse the agricultural and urban wastes after the treatment.

Composting was performed by keeping the mixtures under controlled humidity and temperature conditions (28 °C and at water holding capacity) in a thermostated chamber. Sampling was carried out after turning over the mixtures, thus ensuring homogenization and preventing local anaerobic processes, after 1, 2, 4, 6, 8, 10, 12 and 14 weeks of incubation.

Variations of nitrogen compounds were evaluated using the electroultrafiltration technique for monitoring transformations taking place. Different fractions can be distinguished: total N (EUF-N), organic N (EUF-Norg), NO_3^- (EUF- NO_3) and NH_4^+ (EUF- NH_4). The method allowed to evaluate the microbial activity and to determine the availability of nitrogen through the ratios of EUF-Norg/EUF- NO_3 and EUF- NO_3 /EUF-N respectively. The conditions for the electroultrafiltration and the determinations nitrogen fractions in the extracts were reported in a previous paper by DIEZ (1988). The characterization of wastes and compost was carried out by DIAZ-BURGOS (1990).

Results

The analysis of EUF-N evolution curves (figures 1 and 2) enables to differentiate four phases, which present the specific characteristics in function of the sewage sludge type and its additive.

In general, a first phase was characterized by an increase of total nitrogen and nitrate and a decrease of ammonia. This phase implicated a strong oxidation process and a low proteolitic action. The sludge type conditioned the nitrogen availability (table 1) which increased in the case of the urban sewage sludge. For the industrial sewage sludge mixed with vine shoot, this phase was preceded by a reorganization period in which all these fractions slightly diminished. The microbial activity was affected by the additive type: the chips increased the activity while the vine shoots decreased it (Table 1). The later additive had an inhibitor effect (LOBO, 1987) in the first composting stages.

The second phase was characterized by a low change in the nitrogen levels; the EUF- NH_4 fraction disappeared and the availability of nitrogen decreased. A higher microbial activity occurred (Table 1) caused by the microbial flora being replaced, leading to appreciable nitrogen immobilization. In the industrial sewage sludge a decrease in the total nitrogen content was observed. This second phase was retarded 6–7 weeks in the industrial sludge with vine shoot compost. This may be due to a greater presence of heavy metals added and to the initial toxicity of vine shoots compost on the different microbial populations.

This phase predisposes the behaviour of the third phase, which was characterized by an acceleration of the mineralization process. After the microbial population has developed, they act on the short chains of peptones and aminoacids, quickly turning the nitrogenous radicals into nitrates, which contributes to increase the EUF- NO_3 , according to previous experiences (DIAZ-BURGOS et al., 1993; GARCIA et al., 1992). In the urban sewage sludge further effects observed were, the increase of N-availability and the nitrate.

Table 1 Indices of microbial activity and Nitrogeri availability during sewage sludge composting

SAMPLE ¹	Micr. Act. ²	N-availab. ³	SAMPLE ¹	Micr. Act. ²	N-availab. ³
UC1	2,96	0,06	UV1	5,51	0,12
UC2	2,71	0,06	UV2	0,52	0,44
UC4	1,09	0,27	UV4	1,12	0,43
UC6	0,54	0,40	UV6	0,59	0,54
UC8	0,42	0,66	UV8	1,36	0,41
UC10	0,40	0,68	UV10	0,27	0,77
UC12	1,37	0,19	UV12	0,15	0,86
UC14	0,29	0,76	UV14	0,18	0,82
IC1	1,09	0,52	UC1	0,51	0,33
IC2	0,91	0,47	UC2	0,46	0,33
IC4	1,00	0,50	UC4	—	—
IC6	0,39	0,28	UC6	0,28	0,22
IC8	0,57	0,36	UC8	0,56	0,36
IC10	0,53	0,35	UC10	0,48	0,32
IC12	0,53	0,35	UC12	0,44	0,30
IC14	0,84	0,45	UC14	0,36	0,26

(1) The number refers to composting time in weeks. (2) Microbial activity: EUF-Norg/EUF-NO3.
 (3) Nitrogen availability: EUF-NO3/EUF-Nt.

In the last phase (IV) all EUF parameters dropped which was characteristic for the exhaustion of the energy substrate, preventing the nitrifying bacteria from continuing to exercise their function. This phase was not observed in all cases. The crossing of nitrate and ammonium curves was used as a criterion of maturity for the compost (DIAZ-BURGOS et al., 1991; Van de KERKHOVE, 1990). The time needed showed the different behaviour of the compost studied. Only the sewage sludge with chips showed an $\text{NH}_4^+ - \text{NO}_3^-$ crossing point after 6 weeks, which did not occur in the other composts where toxicity affected the EUF-NH4 production from the beginning of composting.

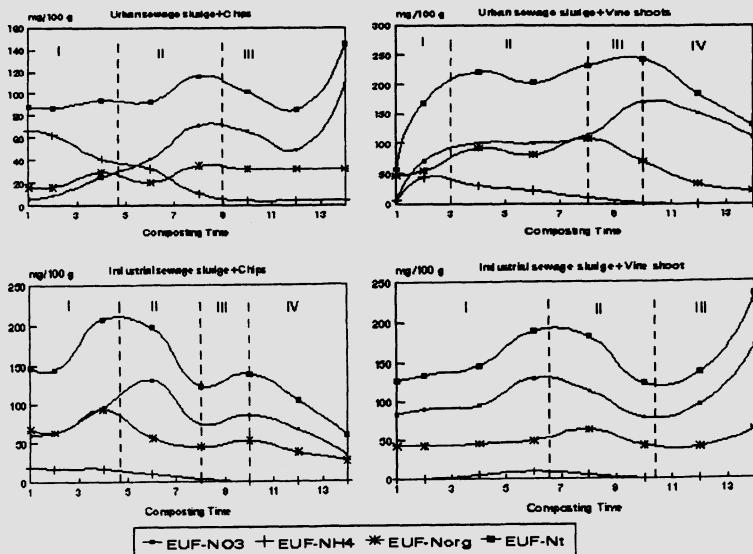


Figure 1 Changes in the EUF Nitrogen fraction with time during composting of municipal sewage sludge

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Co-Composting Process of (Sugarbeet) Vinasse and Grape Marc

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Beet vinasse, a high density liquid waste from the sugar industry, and grape marc, a primary by-product of wine production, could be recycled as fertilizers due to their high OM and nutrient contents. The direct incorporation of grape marc into agricultural land, a common practice, has become a serious problem because degradation products inhibiting root growth are released (Inbar *et al.*, 1991). Furthermore, the direct application of vinasse has also several shortcomings because of its high salinity ($\text{EC } 250\text{--}300 \text{ dS m}^{-1}$), low P content ($\text{P}_2\text{O}_5 \text{ 0.012 \%}$) and liquid dense character (1.3 g cm^{-3}). An alternative to overcome these disadvantages is the co-composting of vinasse with grape marc.

A compost was obtained from a mixture of vinasse, V (2.5% N, 0.06% P_2O_5 , 3.6% K_2O , 27% OM) with grape marc, GM (1.4% N, 0.63% P_2O_5 , 1.16% K_2O , 71.6% OM). Sugarbeet factory lime (F) containing 50% CaCO_3 was added to the mixture to overcome the vinasse acidity (pH 4.7). The proportion of each component in the mixture was 17% of V, 82% of GM and 1% of F, where GM and F are expressed on a dry matter basis.

The co-composting process was carried out in a static pile, under cover, with forced aeration following the Rutgers method with a total mass of ca. 15 metric tons. The pile (3m length x 5 m width x 1.5 m height) was centered over three perforated pipes installed in grooves in the concrete floor. The air required for the process was provided by a blower at a rate of $0.87 \text{ kg O}_2 \text{ h}^{-1}$.

During the co-composting process, samples were taken periodically at two depths (0–30 and 40–100 cm) in three zones of the pile. Temperature was measured in four zones at the same depths. The following parameters were determined throughout the whole process: moisture content, $\text{pH}_{\text{H}_2\text{O}}$ (1:5 w:v), OM, $\text{EC}_{\text{H}_2\text{O}}$ (1:5 w:v), total-N, $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$ and CEC. Macro and micronutrients were measured after 1, 80 and 190 days of composting. Elemental analysis (C, N, and H) of the mixture was carried out before and after composting.

The temperature profiles at two depths in the compost pile are shown in Figure 1. The temperature rose rapidly reaching an averaged value of 53°C at day 8. The thermophilic phase was completed after 54 days of composting. Similar temperature profiles have been described elsewhere (Pérez García and Iglesias Jiménez,

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1984), where the thermophilic phases were too long due to the large size of the piles. The moisture content was maintained during the thermophilic period at around 50%, this being considered the optimum. After 54 days, the mesophilic stage started lasting one month. The compost was then left to mature for the following four months. No water was added throughout the mesophilic and maturing stages. The final moisture content of the compost was 30% being under the maximum water content (40%) permitted by EEC regulation.

The pH increased from 7.1 to a maximum of 9.5 after 25 days of composting. Afterwards, the pH decreased to 8.3, remaining approximately constant during the maturity period. This pH value has been considered as standard for compost stabilization (Poincelot, 1974). The losses of organic matter and nitrogen were calculated by a mass balance following Haug (1980). The OM decreased by ca. 24%. The OM content of the final product was 50%. The N loss accounted for 0.22 moles $\text{NH}_3 \text{ kg}^{-1}$ compost, which represents 15% of the total-N, this loss being similar to that reported by De Bertoldi *et al.* (1982).

The $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ evolutions in the deep samples through the composting process are shown in Figure 2. A high $\text{NO}_3\text{-N}$ content of the mixture at the beginning of composting was observed. This could be attributed to an initial N mineralization of the substrates during their storage because of their high moisture contents in addition to the aeration produced in the conveyance. The $\text{NO}_3\text{-N}$ content decreased from 1066 to 311 mg $\text{NO}_3\text{-N kg}^{-1}$ in the thermophilic period and then, increased up to 697 mg $\text{NO}_3\text{-N kg}^{-1}$ in the mesophilic stage. The $\text{NH}_4\text{-N}$ content increased rapidly from 25 to 958 mg $\text{NH}_4\text{-N kg}^{-1}$ after 10 days of composting. Afterwards, $\text{NH}_4\text{-N}$ content tends to decrease reaching the original values after 180 days of composting.

The evolutions of C/N and CEC are given in Table I. Generally, composts having a C/N<20 are considered mature. However, a C/N<20 cannot be used as an indicator of maturity when a N-rich waste, is added to the compost mixture (Mathur *et al.*, 1993). Nevertheless, the evolution of C/N and CEC, among others, have been used as an index to control the maturity of the final products (Harada *et al.*, 1981). The CEC values increased steadily to reach a constant value of ca. 142 cmol_c kg^{-1} in 4 months. Furthermore, a highly significant linear relationship between CEC and C/N was found: $\ln(\text{CEC}) = 12.18 - 2.93 \ln(\text{C/N})$, $r^2=0.90$ ($P<0.001$). Similar findings have been reported by Inbar *et al.* (1991) during grape marc composting. This relationship indicated that the CEC values could be used for estimating the degree of maturity of this compost.

The N (2.1%), P_2O_5 (0.70%) and K_2O (1.3%) contents of the compost were well above the minimum nutritional specifications described by Zucconi and De Bertoldi (1987). Sodium, Ca, Mg and micronutrient contents for the compost (data not shown) were within the range of similar products (Chen *et al.*, 1988). Lixivation of the macro and micronutrients throughout the composting process was too small to be considered important.

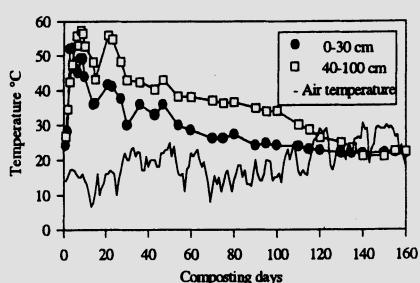
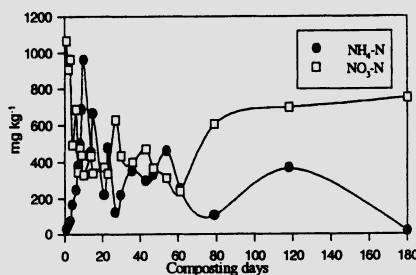


Figure 1 Temperature profile at two depths

Figure 2 Evolution of NO₃-N and NH₄-N during composting

The compost showed a high EC value (11.5 dS m^{-1}) because of the high salinity of the vinasse. Nevertheless, this compost could be added to soils at low rates to avoid detrimental effect of its salinity on plant growth.

The co-composting process of beet vinasse and grape marc followed the classic pattern described in the literature. The compost maturity was achieved in four months. The final product, despite of its high salinity, has a high agriculture value because of its OM, N and K contents.

Tabla 1 Evolution of the maturity parameters

	C/N	C.E.C.* cmolc kg ⁻¹
Day		
1	15.4	66
32	14.6	74
52	13.1	83
79	12.5	124
120	11.5	142
190	11.9	146

*Ash-free material basis

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Chemical Characterization of Three Compost of (Sugarbeet) Vinassee with other Agroindustrial Residues

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Increasing amounts of liquid and solid wastes are produced by the food and agricultural industries in Andalusia. However, the recycling of these residues is not always billed and their elimination, is, at times, an environmental problem. Beet vinassee, a high density liquid waste from the sugar industry, contains high levels of OM (35%), N (3%) and K (3%), which make the vinassee a potential fertilizer. However, the direct application of concentrated vinassee on agricultural land may lead to economical and environmental problems because of high salinity (EC 250–300 dS m⁻¹), low P content (P2O5 0.012%) and its liquid dense character (1.3g cm⁻³). The co-composting of vinassee with other agricultural residues could be used to overcome these disadvantages by producing a compost easily handled with higher P content and lower salinity.

Three composts were obtained from mixtures of vinassee (V) (2.5% N, 0.06% P₂O₅, 3.6% K₂O, 27% OM) with each of the three following agroindustrial residues: grape marc (1.4% N, 0.63% P₂O₅, 1.16% K₂O, 71.6% OM) (compost OC), olive pressed cake (1.03% N, 0.06% P₂O₅, 0.9% K₂O, 71.6% OM) (compost CC), and cotton gin trash (1.45% N, 0.35% P₂O₅, 2.53% K₂O, 67.8% OM) (compost GC). Sugarbeet factory lime (F) containing 50% CaCO₃ was added to the mixtures to increase pH. This was carried out to overcome the vinassee acidity (pH 4.7). The mixtures containing olive pressed cake and cotton gin trash were complemented with leonardite (L) (0.3% N, 0.04% P₂O₅, 0.16% K₂O, 48.7% OM), a low maturity lignite containing 25% (w/w) of humic acids. The proportion of V, GM, OC, CC, F and L for each mixture was as follows: Pile 1: GM (82%) 1 V (17%) 1 F (1%); Pile 2: OC (76%) 1 v (17%) 1 F (1%) 1 L (6%); Pile 3: CC (47%) 1 V (49%) 1 F (1%) 1 L (3%), where GM, OC, CC, F and L are expressed on a dry matter basis.

Co-composting was carried out in static piles, under cover, with forced aeration and in controlled conditions during three months. During the process, the piles were watered regularly to maintain moisture contents to 50% for pile 1, 40% for pile 2 and 40% for pile 3. After this stage, the composts were left to mature during

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the following four months. Samples were taken periodically at two depths (0–30 and 40–100 cm) in three zones of the pile. The following parameters were determined throughout the whole process: moisture content, pH_{H₂O} (1:5 w:v), OM, EC_{H₂O} (1:5 w:v), total-N, NH₄-N, NO₃-N, P₂O₅, K₂O, CEC, Na, Ca, Mg, Fe, Cu, Mn and Zn. The main chemical characteristics of the mixtures before and after composting are shown in Table I. After composting, the lipidic fraction composition of the composts was also determined to study the presence of anthropogenic compounds.

The maturity of the composts was completed after 90 days where the C/N and CEC reached a constant value. The evolution of these parameters, among others, have been used as an index to control the maturity of the final products (Harada *et al.*, 1981). For composts GC and CC, the C/N and CEC values after 210 days of composting were within the values of mature composts (Mathur *et al.*, 1993). This was not the case for compost OC which showed a high C/N ratio and a low CEC value. However, these two parameters did not show any change from day 90 onwards and therefore this compost could be considered mature (Harada *et al.*, 1981).

Table 1. Main chemical characteristics of the mixtures before and after composting.
Pile 1=compost GC, Pile 2= compost OC and Pile 3= compost CC.

	Moist (%)	pH	OM (%)	C/N	N %	NH ₄ -N mg kg ⁻¹	NO ₃ -N mg kg ⁻¹	K ₂ O (%)	P ₂ O ₅ (%)	CEC* cmol _c kg ⁻¹ dS m ⁻¹	EC
Pile 1											
0 days	52	7.1	54	15	1.9	33.0	1066	1.5	0.69	66	11.8
210 days	35	8.3	50	12	2.1	17.0	749	1.3	0.70	146	11.5
Pile 2											
0 days	41	6.8	85	41.6	1.2	34.6	1104	0.8	0.07	53	12.1
210 days	32	8.5	70	34.0	1.0	90.0	174	0.9	0.13	79	12.7
Pile 3											
0 days	42	7.3	65	12	3.2	200	3039	1.9	0.20	72	13.9
210 days	24	8.1	51	8	2.6	534	683	2.1	0.28	137	29.3

*Ash-free material basis

The three composts were under the maximum water content (40%) permitted by EEC regulation. The pH values were stabilized above 8, being these values slightly higher than those reported as optimum for compost stabilization (Nogales and Gallardo-Lara, 1984). However, similar pH values have been reported for composts derived from similar agroindustrial residues (García-Izquierdo *et al.*, 1987).

For the three composts, the OM, total-N, NH₄-N, NO₃-N and K₂O contents were well above the minimum nutritional specifications described by Zucconi and De Bertoldi (1987). Similar results for other agroindustrial composted products have been reported elsewhere (Baca-García *et al.*, 1987). For pile 3, the largest pile, the ammonium accumulation at the end of the process was probably due to a lack of oxygen since the aeration system used was not powerful enough to provide higher oxygen concentration. Furthermore, the ammonium concentration in pile 3 was higher in the samples taken in the deepest zones (data not shown).

For the composts OC (Pile 2) and CC (Pile 3), the P₂O₅ contents were below the minimum required (0.5%) for agricultural use (Zucconi and De Bertoldi, 1987). Nevertheless, the nutritional status and yield of corn on soil fertilized with these composts have been compared with those for soils treated with a mineral fertilizer (Madejón et al., 1994). These authors did not find any significant differences in the P contents in leaves for all treatments, where the amount of P₂O₅ added to the soils with the mineral fertilizer was ten- and five-fold higher than those added with the composts OC and CC, respectively.

The three composts showed a high EC value because of the high salinity of the vinasse. However, these composts could be added to soils at low rates to avoid detrimental effects for plant growth.

Sodium, Ca, Mg and micronutrients contents for the three composts (data not shown) were within the range of similar products (Chen et al., 1988). Lixiviation of the macro and micronutrients throughout the composting process was too small to be considered important.

Analysis of the lipidic fraction for the three composts revealed the absence of anthropogenic compounds which could have been derived from pesticides added to the crops, and therefore they may have been present in the agroindustrial residues used for composting.

From the chemical characterization of these composts, it could be concluded that the co-composting of vinasse with grape marc (compost GC, pile 1) and with cotton gin trash (compost CC, pile 3) resulted in final products with a high value from an agricultural standpoint (rich in OM and mineral nutrients, low C/N ratio and high CEC values). However the compost OC, mixture of vinasse with olive pressed cake, showed a high C/N ratio and a low CEC value to be considered a suitable organic fertilizer. The addition of these composts as organic fertilizers has been tested in field experiments. Soils fertilized with composts GC and CC gave a better quality crop and higher yields than those treated with mineral fertilizers alone (Madejón et al., 1994).

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Monitoring of Organic Matter During Composting

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Introduction

The composting of town refuse is an interesting tool for waste management: compost is a major source of organic matter and fits completely into the framework of the recycling of organic waste. However, in order to be able to spread compost on different soils and to meet the various agricultural requirements, it is necessary to know perfectly the evolution of organic matter and the characteristics of the end-product. The composting process can be divided into two major stages: a rapid degradation of the easily degradable insoluble components into water-soluble compounds, and subsequently the metabolism by microorganisms of the latter and of the less degradable compounds. Many tests and criteria have been experimented for the long term monitoring of organic matter during the composting process as a whole whereas a less attention has been paid to monitoring merely the first stage of the process. Butyric, propionic and acetic acids are water-soluble intermediate compounds formed as organic matter are broken down. A better follow-up of the first stage of the process is necessary to avoid the presence of these phytotoxic compounds (DeVleeschauwer et al., 1981; Cocucci et al., 1989) in the end-product. Whereas volatile fatty acid (VFA) concentration is a parameter which has been widely used to monitor the anaerobic digestion (Azinari di San Marzano et al., 1981; Henson et al., 1986, Mata-Alvarez, 1990) of organic waste, it has rarely been used for the evaluation of the composting process evaluation (Saviozzi et al., 1992). In this work, it is proposed to use the VFA as the means to monitor organic matter during the first stage of composting while, for the characterization of the maturation level, a new index of maturity, based on rapid spectrophotometric measurements, has been proposed in previous works (Prudent et al., 1994, 1995).

Material and methods

The organic fraction of domestic waste underwent accelerated composting (air injection) in a laboratory scale pilot. Classic parameters such as pH, temperature, moisture and total volatile solids, were measured. The volatile fatty acid concentrations of water extracts were determined by gaseous chromatography. The chromatograph was equipped with a capillary column (WCOT) and a flame ionization detector.

Results and discussion

The initial material includes 66% water and its content in total volatile solids represents 70% of the dry weight (d.w.).

In the first experiment (E1) the beginning of the biological process takes place almost immediately. This is attested by a rapid decrease of the pH to 4.5, linked to an increase in temperature (Fig. 1 and 2, curves E1). After the acidic phase, pH increases and then, after 7 days, stabilizes at a (Fig. 1 and 2, curves E1). After the acidic phase, pH increases and then, after 7 days, stabilizes at a value of approximately 8.5. After about 10 days, the temperature reaches its maximum and levels (thermophilic phase, $T = 65^{\circ}\text{C}$). These phases correspond to the hydrolysis of the easily biodegradable compounds and to the maximum rate of volatile acid production (Fig. 3). The concentrations of acetic acid are greater than those of propionic and butyric acids.

Between days 10 and 15 a drop is observed in the temperature curve. This drop is generally attributed to a depletion of easily decomposable material and is an index of waste stabilization. However, observation of the volatile fatty acid curves (Fig. 3) shows that during the same period acetic, propionic and – more intensively – butyric acids are accumulated. A slight decrease of pH is also noticeable. These results are linked to the decrease, during the same period, of the water content (Fig. 2) to a critical value (less than 50%). With the re-establishment of favourable conditions the temperature increases and the concentrations of volatile fatty acids again fall below detection limits. When stabilization is achieved, about 25 days after the beginning of the experiment, volatile fatty acids are undetectable and temperature returns to ambient level. As observed in anaerobic digestion, the transient accumulation of volatile fatty acids is a response to stress and to change in environmental conditions.

Another experiment (E2) is conducted with a high water content, around 75%. In these conditions pH remains acidic for a longer period and after a slight increase, temperature levels at 40°C (Fig. 1 and 2, curves E2). During the same time, butyric acid accumulates while acetic acid concentrations decrease to very low values indicating that the biodegradation process is blocked (Fig. 4). Such a high water concentration is incompatible with the structure of the material. It is probable that water fills the interstitial spaces and the circulation of air is limited

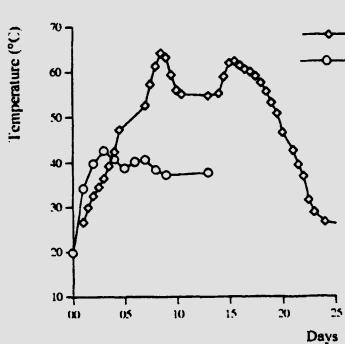


Figure 1 Evolution of temperature versus time.

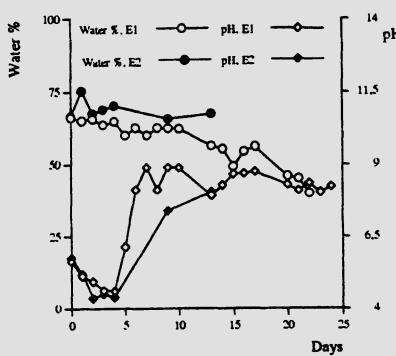


Figure 2 Evolution of PH and water percentage versus time.

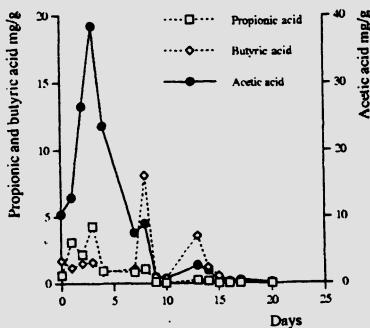


Figure 3 Evolution of VFA concentration versus time (E1).

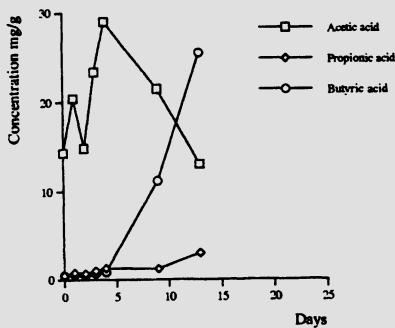


Figure 4 Evolution of VFA concentration versus time (E2).

by its diffusion in the aqueous phase which is a slow process. Local anaerobic conditions appear which slow the breakdown of intermediate degradation compounds down and favour their accumulation. However the persistence of unfavourable conditions can lead to harmful concentrations of volatile fatty acids, what is observed in this experiment.

Conclusion

Usually volatile fatty acid concentrations are measured to evaluate the phytotoxicity of the end-product. The results obtained in this work show that, as in anaerobic digestion, accumulation of these compounds, whether transient or not, is a response to an environmental stress. It is a more reliable parameter than those generally used and is well adapted to the monitoring of organic matter during the

mesophilic and thermophilic phases of accelerated composting. It allows a rapid intervention for the re-establishment of favourable conditions.

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Effects of Bulking Agents in Composting of Pig Slurries

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The large amounts of slurry wastes produced in intensive farms cause serious disposal and pollution problems. Composting of slurries from animal waste offers an answer to odour nuisance and water pollution associated with their management. The aim of this research was to carry out a preliminary laboratory study trying to transform slurries into compost so they can be used as horticultural substrates, organic soil conditioners or fertilizers.

Experimental

The experiments were performed in 1 l. volume vessels (dewar glass) thermically isolated (fig. 1). The vessel lid was equipped with an air inlet and outlet, and a hole for inserting 1 J type thermocouple and there is a false perforated floor to foster the air diffusion at the bottom. Compressed air was supplied to the system at a constant pressure in ventilation cycles of 75 sec. every 15 min. Air was scrubbed of CO₂ by means a 200 ml. NaOH 1N trap.

Temperature was monitored via thermocouples type J placed at the compost matrix center and registered continuously in a hybrid register SEKONIC SD-100 M.

Carbon dioxide evolution was measured as an indicator of microbial respiration (Anderson, 1982) using 200 ml. NaOH 1N.

The selfheating efficiency of pig slurry mixed with different agricultural and forest wastes (straw, pine bark, pine needles, fern and oak leaves) at two different ratios (2:1 and 5:1 w:w) has been tested. These materials behave as bulking agents reducing the slurry moisture content, supplying C for the C/N ratio improvement and avoiding N losses.

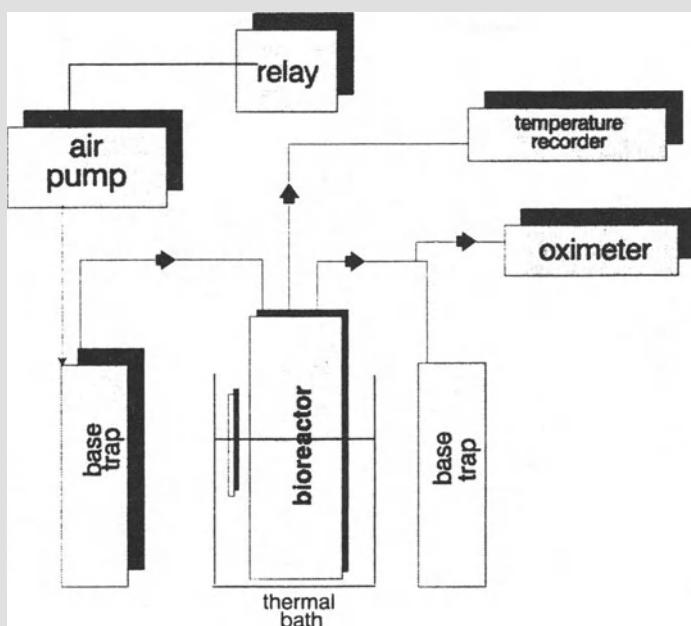


Figure 1 Diagram of composting laboratory simulator

Table 1 Some chemical characteristics of the pig slurry

Moisture (%)	81,45
Total Solids (%)	18,55
Ashes (%)	71,68
pH (H ₂ O)	8,7
Conductivity (mS.cm ⁻¹)	4,4
Total Nitrogen (g.kg ⁻¹)	14,81
NH ₄ (g.kg ⁻¹)	39,29

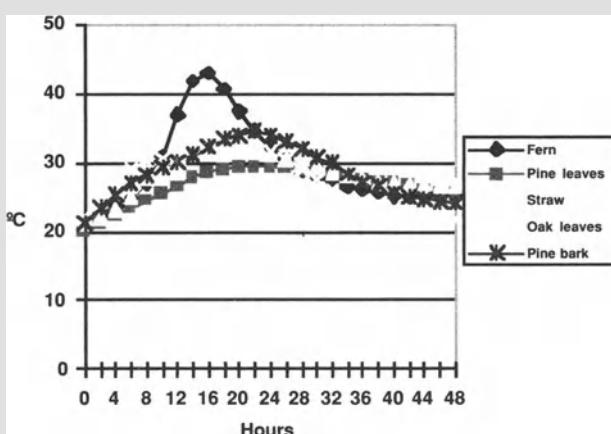


Figure 2 Temperature evolution of pig slurry mixed with different agricultural and forest wastes (2:1 w:w)

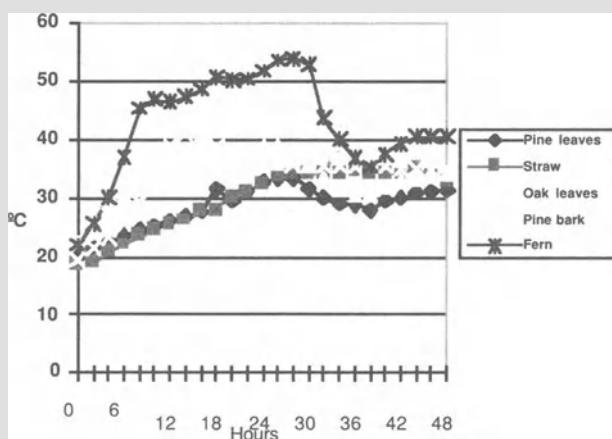


Figure 3 Temperature evolution of pig slurry mixed with different agricultural and forest wastes (5:1 w:w)

Table 2 Initial and final chemical characteristics of pig slurry mixed with different agricultural and forest wastes (2:1 w:w)

	MOISTURE %		pH 1:10		NH4 g.kg ⁻¹		Cond. mS.cm ⁻¹		CO ₂ %		NH ₄ %	
	initial	final	initial	final	initial	final	initial	final	initial	final	initial	final
2:1												
pine needles	54,96	54,85	8,40	8,50	8,47	7,21	0,93	0,66	3,57	3,57		
oak leaves	65,4	58,30	8,30	7,73	9,10	7,93	0,90	0,53	4,92	4,92		
pine bark	60,72	62,82	8,40	8,21	9,34	11,02	0,88	0,70	3,43	3,43		
fern	57,14	58,21	7,90	8,50	7,90	10,61	1,90	1,45	9,42	9,42		
straw	57,02	58,49	8,20	8,60	7,33	7,00	1,62	1,56	5,41	5,41		

Table 3 Initial and final chemical characteristics of pig slurry mixed with different agricultural and forest wastes (5:1 w:w)

	MOISTURE %		pH 1:10		NH4 g.kg ⁻¹		Cond. mS.cm ⁻¹		CO ₂ %		NH ₄ %	
	initial	final	initial	final	initial	final	initial	final	initial	final	initial	final
5:1												
pine needles	71,11	70,21	9	8,85	8,47	7,21	0,93	0,66	3,57	3,57		
oak leaves	68,69	68,24	8,78	8,66	9,10	7,93	0,90	0,53	4,92	4,92		
pine bark	70,42	70,90	8,9	9,01	9,34	11,02	0,88	0,70	3,43	3,43		
fern	68,87	71,99	8,9	9,15	7,90	10,61	1,90	1,45	9,42	9,42		
straw	69,55	71,20	69,55	71,20	7,33	7,00	1,62	1,56	5,41	5,41		

In spite of in 2:1(w:w) mixtures the moisture contents are the most appropriate for composting processes, the fermentative activity does not reach the thermophilic phase in none mixture, probably due to the thermic exigencies of the microreactor.

Nevertheless, increasing the amount of slurry (mixtures 5:1 (w:w)), in spite of that the moisture contents exceed the 70%, the thermophilic phase was reached in the microreactor in three mixtures: fern, straw, and oak leaves.

This let us to propose that for composting of pig slurry it is possible save large

amounts of bulking material, because composting works in spite of the moisture surpasses the limits advised by Haug (1985). The different bulking materials improve the composting process in function of their major or less facility to be degraded, and then, the best results have been obtained in the mixtures with fern, straw and oak leaves. This preliminar study offers an important information for batch scale experiments in which we are involved actually.

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Sewage Sludge Composting with Thermopostage™ Process (The Platform of Arenton Haute Savoie, France)

(MICHEL DURILLON*, CHRISTINE FONTAINE, HUGUES BAZAN** , CLAUDE PREVOT***)**

Landfillings restrictions and more stringent regulations on product spread on the fields oblige sludges and wastes producers to improve practices and quality.

In that context, composting process appears to be a good way for sludge and waste disposal.

The aim of that paper is not the description of the biological process, applied for a long time for waste treatment: existing composting places designed with windrow system are in operation on large area with or without forced aeration. Depending on waste characteristics and parameter control, trouble like bad smells, polluted leakages could occur during active and aging phase of the process; Few years ago, appeared new composting concepts based on the total process control .

THERMOPOSTAGE™ is one of these new concepts, under 3 years operation for sludge treatment, on the Arenton waste water plant, near Annecy (Haute-Savoie, France).

THERMOPOSTAGE™ process is based on the use of mobile reactors, making the system modular and easily adapted to the amount of sludges or wastes to be processed : this approach guarantees flexible operation and a clean site.

Description of the composting unit

In a previous workshop, the dewatered sludge, issued from a belt press, is mixed with sawdust, pine barks or recycled compost, providing an optimal porosity necessary for this forced and controled aeration process.

Mixing operation is the most important one on a composting unit : sludge to carbonaceous elements ratio is adapted to sludge dryness and rheological characteristic. In Arenton place, the volumic ratio sludge/sawdust/recycled compost or

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barks is on average 1/1/1. Doubled shaft with paddles mixing systems are amongst the best devices to obtain suitable porosity and avoid any anaerobic fermentation in the reactor.

Then, the mix is loaded in the biological reactors which are transported to the aeration site by a lorry. These 30 m³ reactors, are equipped with an air distribution system at the bottom, included a leachate collector. Each reactor is well closed to confine any odorous compounds.

During 3 weeks, sludge mixed with co-elements is aerated under succion; air flow-rate is regulated to maintain an inside temperature level nearly by 70°. In aging and drying period, reactors are continuously blown during one or two weeks. Centralized succion and aeration pipes, equipped with automatic valves, are connected on each reactor; duration and frequency of succion or blowing period can be adapted on an hourly basis.

Compost is then screened – if barks elements have been used – and stored for further aging or sold for agricultural reuse and as soil remediation product.

Mixing, loading, and screening operations are managed by an automate so the presence of operators on the composting plant is limited.

Design parameters

The waste water plant of Arenton received a 35000 population equivalent effluent with a high food industry ratio.

The composting site of Arenton located on the same plant, is now designed to treat 2500 m³/ year of dewatered anaerobic digested sludges with a dryness comprised between 23 to 26 % .

For this capacity, 15 composting biological reactors are needed ; This modular process will permit to double the capacity just by adding 15 others reactors .

2500 m³ of dewatered sludges will produce from 3500 to 4000 m³ of compost with a dryness between 40 to 50%, odour – free, stable and hygienized ; this compost reaches the french regulations on heavy metals for agricultural reuse.

New developments

THERMOPOSTAGE™ process is well adapted for others organic wastes treatments such as greenwastes and sorting household wastes. Additional water can automatically be spread on mixture inside reactors to sufficient humidity level for optimal micro-organisms development. Each reactor is easily connected to a biological or chemical odour treatment if necessary. Tests are carrying on to optimize mixing operation and ratios between wastes and co-elements ; thus we propose now a well experienced technology for sludge and organic wastes stabilization and ecological disposal.

Biodegradation of 'Thiram' in Composting Process

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G. ZORZI*****

Foreword

Composting is proposed as a solution capable of meeting the twofold requirement of giving a correct solution to the disposing of waste biomasses and waste of different origins, pursuing recovery and valorization standards, while producing plenty of cheap organic fertilizer.

The composting treatment of agrofood residues is an interesting means of recovering to agronomic ends such waste whose landfill disposal is becoming more and more expensive and whose improper management can cause environmental pollution.

In the recent past years the main chemical firms dealing with cereal seeds for agriculture have had to undertake heavy expenses to solve the problem of disposing of left-over materials.

Within this context 'Eco-Pol Spa' has worked out a test programme in order to check whether the chemically treated matter is fit for composting, judging both the specific degradation of the fungicidal employed and the agronomic quality of the resulting product (compost).

Materials and Methods

The test programme has employed maize seeds ('Zea mays') furnished by 'Pioneer Hi-Bred Italia Spa'. They have been treated with THIRAM (tetramethylthiuramdisulphide) dose: 15 gr/ql expressed on 48% a.p. : dithiocarbamate generally used in the treatment of seeds, bulbs and tubers to protect them against *Tilletia caries* and *Ustilago maydis* by performing a contact action on the treated surface (Engst - Schnaak 1974).

The degradation system chosen by 'Eco-Pol Spa' is composed by an accelerated biooxidation phase (20 days) in horizontal reactor equipped with an overhead

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– travelling crane fitted with two conveyors. The mass front is 80 mt long and 10 mt wide. Its maximum height is about 1,8 mt. Odours, that may be produced, are properly treated with an ozone emission control system. After the thermophile phase, the biomass is arranged in windrows having triangular cross section (4,4 mt wide x 1,9 mt high) on outdoors covered curing areas for a period of about 50 days. A turning machine equipped with two horizontal rotors keeps the masses revolving thus granting constant layer – turning and proper gas – turnover in every point.

The programme settled on the composition of the following mixture.

- 60% maize seeds ('Zea mays') treated with THIRAM;
 - 20% biological sludge
 - 20% lignocellulosic residues
- pre-fermented mixture

Wooden material has been properly shredded to 15–20 cm pieces.

Temperature, moisture, ph, a.p. concentration and phytotoxicity have been checked by monitoring the whole process.

The biooxidation treatment included a set of mechanical turnings planned as follows: during the thermophile phase every 3 days till about the 20th and then every 5–7–10–12–14–15 days until the end of the process.

Sampling consisted in the taking of 10 sub-samples from the centre of the mass and along the diagonal.

Analytical determination of dithiocarbamate in maize seeds

The method that has been employed is provided for in M.U. n.118, vol. I°.

It bases on the hydrolysis of dithiocarbamate in an acid environment: it develops carbon sulfide that is fixed with Cullen's reagent (copper acetoacetate and diethanolamine) after sodium carbonate and benzene wash.

The quantitative determination is carried out by means of spectrophotometrical measurement at 435 nm of the resulting coloured compound.

The calibration standards have been predetermined adding to untreated seeds known quantities of Thiram which have subsequently been submitted to the same treatment of the samples.

The conversion factor, employed to transform the result in ppm of Thiram , is 1,57.

Results

The check of data (fig. 1) underlines interesting results as to Thiram biodegradation in the composting process. The temperature profile recorded during the process shows the thermophile phase followed by a mesophile one one marked

by a specific microbial microflora.

After about 20 days from the beginning of the process the concentration of Thiram decreases passing from 28,8 ppm to about 3 ppm; then it decreases slower according to the temperature.

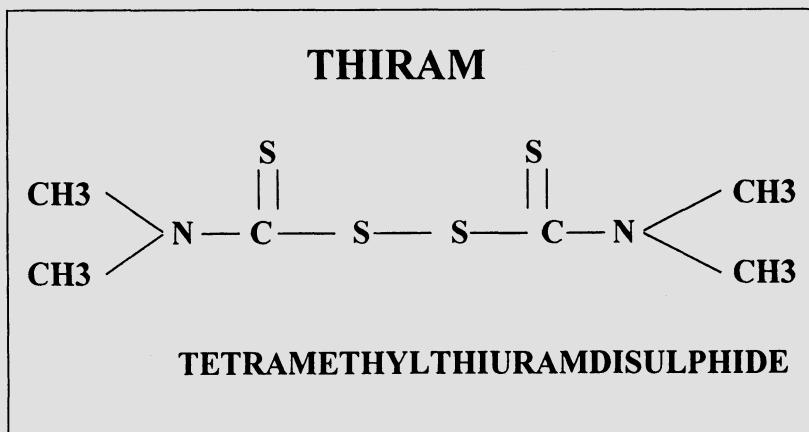
From table n.1 can be inferred an increase in the concentration of the active principle in the first days of the process, increase which was certainly due to the sampling of a heterogeneous mixture (seeds, biologic sludge, lignocellulosic residues). The presence, in the mixture, of a fungicidal such as Thiram did not affect the progress of the process, ruled by different microbial groups and finally solved in a more than average lapse of time (about 75 days).

The matter has undergone phytotoxicity tests to check the agronomic suitability and the results are completely favourable. The analytical characteristics of the compost obtained from treated material underline the full stability of the organic component, low content of pollutants, balanced C/N ratio, low salinity.

Conclusions

The compete analysis of the obtained data allows the following remarks:

- maize seeds from Thiram fungicidal treatment can be profitably composted, thus removing them from the amount of waste meant for landfill incinerator;
- Thiram biodegradation occurs only during the thermophile phase, in the first days of the treatment; the above mentioned matter is thus allowed to be considered fit for composting as any other agrofood waste;
- the quality of the compost obtained from the biooxidative transformation of the test matter is considered good both for its agronomic properties and for its degree of environmental security;



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Figura 1

BIODEGRADATION THIRAM

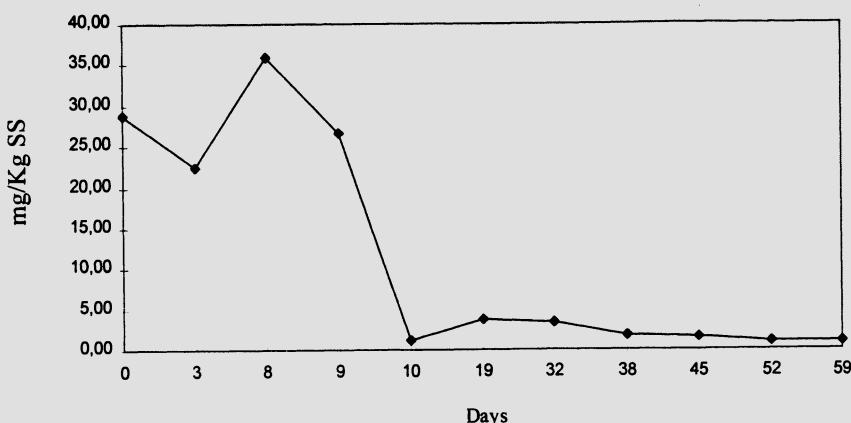
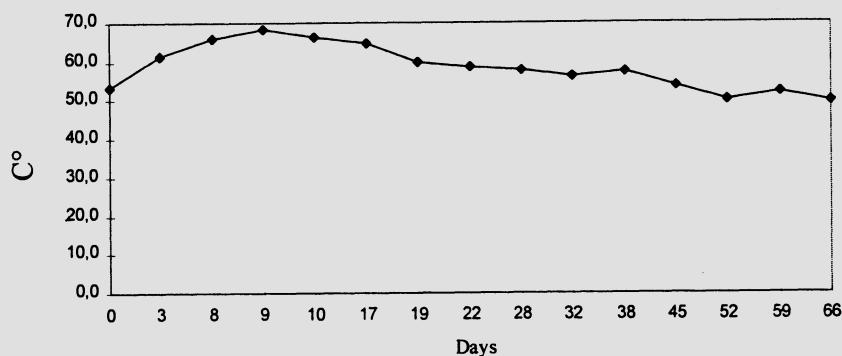


Figura 2

TEMPERATURE VARIATIONS DURING THE PERIOD



ANALYTICAL CHARACTERISTICS OF COMPOST COMPARED TO OTHER ORGANIC CONDITIONERS

	COMPOST	MANURE	PEAT
MOISTURE (%)	42,7	72,3	61,6
pH	6,4	8,38	5,8
EC ($\mu\text{S}/\text{cm}$)	500	2424	630
ORGANIC CARBON (%)	26,48	36,7	41,9
ORGANIC MATTER (%)	45,65	63,2	72,2
C/N	13,1	18,8	44,1
N (%)	2,02	1,93	0,95
P2O5 (%)	1,7	1,73	0,24
K2O (%)	1,4	1,78	0,18
Cu (mg/Kg)	13	54	19
Pb (mg/Kg)	9,9	32	9
Col (mg/Kg)	< 1	< 1	< 1
Zn (mg/Kg)	45	245	47
Ni (mg/Kg)	4,8	10	4
Cr (mg/Kg)	6,6	30	42
Germination index (%)	85	63	88

(ALL VALUES ARE EXPRESSED ON A DRY MATTER BASIS WITH EXCEPTION OF
MOISTURE – PH AND EC)

First Experiments of Compost Suppressiveness to Some Phytopathogens

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Compost can be used in floriculture and in horticulture within integrated and biological disease control programs (1–2–4). It is in fact well known that vegetables and ornamental plants are often damaged by pathogenous fungi causing damping off and root rot.

Thanks to studies on waste recovery and recycling which I.P.L.A. started long ago, some composts were examined in order to verify if compost utilization in agriculture and floriculture could have a useful repressive function.

Two lines of research were followed:

1. cultivation trials in pot, under temperature and moisture controlled conditions, in order to evaluate compost repressive action against: *Phytiuum ultimum* on cucumber and beet; *Rhizoctonia solani* on bean and basil; *Fusarium oxysporum f sp. basilicum* on basil.
2. compost microbiological evaluation by isolating microorganisms and testing their antagonistic capacity by means of in vitro and in vivo (pot) experiments.

Materials and methods

In pot experiments: the following composts were tested:

Compost A = from municipal sewage sludges and poplar bark

Compost B = from industrial sludges and poplar bark

Compost C = from poplar bark

Compost D = from the organic fraction of MSW.

P. ultimum and *R. solani* inocula were obtained by growing their mycelium on a sterile medium made of corn and hemp seeds; to breed *F. oxysporum f sp. basilicum*, conidia-in-casein hydrolyzate suspensions were prepared, which were then dispersed in talc and let to dry. Composts were mixed to a soil conducive to pathogens in percentages of 25% and 50%; 100% of the same soil was used as control. Test plant sowing was carried out soon after pot inoculation. The trials were organised on the basis of 2 tests for each compost, and each test was repeated three times. Disease severity was checked by noting down number of emerged plants, and by later subdividing them into healthy and dead plants.

The second line of research aimed at isolating some compost microorganisms such as *Trichoderma* spp. strains by successive dilutions (up to 10²¹⁰) and using selective substrates. The suppressive activity of *Trichoderma* spp. strains (1761, 1769, 1780), isolated respectively from composts A, B and C, was tested *in vivo* by means of pot trials. For this purpose a sterile substrate conducive to pathogens was infested using *Trichoderma* spp. mycelium, and *P. ultimum* inoculum. Cucumber plantlets, used as host plants, were seeded soon after infesting the substrate with the pathogen and the antagonist.

Results

Table 1 shows the results of plant disease suppression bioassays carried out in pots for some phytopathogens. In trials on cucumber grown on a soil-compost mix infested by *P. ultimum*, percentages of emerged plantlets are not very dissimilar in the test pots and in the control. In the case of green beet with *P. ultimum*, the number of emerged plantlets was greater on compost-soil mixes (especially composts A and B), than in the control. Post-emergence damages were also reduced with the exception of C25.

All tested composts proved to repress damages due to *F. oxysporum* f.spp. *basilicum* on basil before and after plant emergence. On basil again a reduction of damages due to *R. solani* was also observed with composts A25, B50, C25 and D50 before plant emergence; with composts B50, C25 and D50 after plant emergence. On bean symptoms of *R. solani* disease were limited in all trials. Suppressiveness was stronger after plant emergence especially with compost C25. *P. ultimum* damages to *Impatiens* were restrained. Suppressiveness was rather intense with all composts at all percentages with the exception of D25.

As for the second line of research see table 2. One can notice that the use of *Trichoderma* spp. strains isolated from composts A(1769), B(1780) and C(1761) limits damages due to *P. ultimum* on cucumber before emergence. The most active strain is n° 1761.

Conclusions

The tested composts generally showed a good disease control in all trials with pathogen inoculation. The best results could be obtained with the most mature composts, it is thought in fact that during the maturation process substances such as antibiotics are produced inhibiting phytopathogen development (3).

All composts with the exception of D proved suppressive to *F. oxysporum* on basil. Trials *in vivo* using *P. ultimum* were satisfying both for green beet, for cucumber and *Impatiens*. Damages due to *R. solani* could be limited in trials where basil and bean had been seeded especially with composts B and C.

Encouraging results were attained in *in vivo* trials as to the antagonistic action of

Table 1 Compost suppressiveness to some phytopathogens

	Cucumber	<i>Phytophthora ultimum</i>		<i>Impatiens</i>		<i>Fusarium oxysporum</i>		<i>Rhizoctonia solani</i>	
		Green beet	emerged plants/%	emerged plants/%	healthy plants/ emerged plants %	emerged plants %	healthy plants/ emerged plants %	emerged plants %	healthy plants/ emerged plants %
COMPOST DOSES	emerged plants %	healthy plants/ emerged plants %	emerged healthy plants/ emerged plants %						
A 25	77 a	52 abc	11 abcd	9 abcd	78 e	76 e	83 de	82 f	59 cde
A 50	100 d	93 c	14 de	12 cd	70 de	66 cd	75 def	44 abcd	39 ab
B 25	93 bcd	72 bc	12 cd	8 abc	70 de	66 cd	79 cde	37 a	33 a
B 50	97 cd	97 c	11 abcd	7 abc	78 e	74 e	74 bcde	52 abcd	44 abc
C 25	87 bcd	85 bc	7 abc	4 a	68 cde	64 cd	75 bcde	62 de	60 cd
C 50	87 bcd	85 bc	6 a	5 ab	68 cde	64 cd	71 bcd	57 cd	38 ab
D 25	83 bcd	80 c	10 abcd	7 ab	22 a	10 a	65 abc	58 cd	39 ab
D 50	87 bcd	73 bc	7 ab	5 ab	74 e	7-2 e	67 abcd	52 bc	35 ab
Control	80 abcd	4 a	7 abc	4 a	48 bcd	24 ab	55 a	27 a	42 abc

Means followed by the same letters are not significantly different ($p < 0.05$).

some *Trichoderma* spp. strains isolated from composts. Strain n° 1761 suppressiveness to plant disease further confirmed the results of in vitro tests.

The research was carried out with the cooperation of DI.VA.P.R.A. – Phytopathology Institute of the Faculty of Agronomy of Turin University – and with the financial contribution of Piedmont Region Government.

Table 2 Suppressiveness of *Trichoderma* spp. strains n° 1780, 1769 and 1761 to *P. ultimum* in pot trials with cucumber

Strains	Emerged plants %	Healthy plants/Emerged plants %
1780	63 b	57 bc
1769	67 b	37 ab
1761	70 b	70 cd
Control	37 a	13 a

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Reduction in Phytotoxicity of Olive Mill Waste by Incubation with Compost and its Influence on the Soil-plant System

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Key words: Alpechín, organic matter, phytotoxicity, compost.

Summary

Olive mill waste waste (alpechín) is a liquid agroindustrial residue produced during the extraction of olive oil. Disposal of waste water is a problem because of its phytotoxicity and difficulty of handling. We tried to eliminate the phytotoxicity of alpechín by absorbing it on composted organic matter and posterior incubation. When this waste water was absorbed on compost, a great part of its phytotoxicity was chemically neutralized, and also had positive effects on plant growth. These effects increased with time of incubation of the alpechín/compost mixtures.

Introduction

Disposal of agricultural wastes in order to improve the use of existing resources and to reduce environmental risk, has become a critical concern in many areas of the world (Janer del Valle, 1980). Composting satisfies the health and aesthetic aspects of waste disposal by destroying pathogens. In addition, the product is agriculturally beneficial as a soil conditioner and fertilizer (Baca et al., 1992)..

In Spain, where about 30% of world's olive oil is produced . Its liquid residue: alpechín (olive mill waste) represents one of the most important polluting residues of the mediterranean countries. However, it is rich in mineral nutrients and could be a perfect candidate to be used as a fertilizer (Gallardo-Lara & Pérez, 1990). The addition of this waste water directly to soil has harmful effect on plant development by the presence of polyphenolic substances, which have also a high biotoxicity (Martínez Nieto et al., 1993).

Soil biotic activity is the driving force in the degradation and conversion of

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exogenous materials, transformations of organic matter and evolution of soil structure. This activity plays a primary function in nutrient cycling and supports plant life (Dick, 1992). The aim of this study was to try to neutralize the biotoxicity of alpechín by absorbing with a composted organic matter followed by subsequent incubation periods with and without parallel plant growth.

Materials and Methods

The soil (S) in our experiment was a silty loamy plough layer; with an organic matter content of 3.5%. The organic materials used were: Alpechín (A) with 2% of dry matter, compost of cotton waste (C) with 72% of volatile solids. The treatments were: Soil (C), soil-compost-alpechín (SCA), and soil-alpechín (SA). The proportions of mixtures utilized were: 80:15 (v:v) soil-alpechín with or without 15:5 (v:v) composted cotton waste. Data were obtained at the beginning of the experiment and after 12 days (equilibration) and after 50 days of incubation with and without parallel plant growth; the incubation with parallel plant growth was performed in 100 ml plastic pots where seeds of *Lactuca sativa L.* were planted. The experimental design was: 1 plant/pot and 5 repetitions by treatment. The assay was performed in a greenhouse under controlled conditions of light, temperature and humidity.

Total extractable organic carbon (TEC) and the humification index were determined following the methodology of Sequi et al., 1986. Biomass content was determined by the F-E method proposed by Brookes et al., (1985), and carbon and nitrogen contents following the methods proposed by Vance et al., (1987) and Joergensen and Brookes, (1992), respectively.

Results and Discussion

Plant development was practically blocked in the treatment incubated with alpechín (Table I). The presence of this waste water produced a strong inhibition of plant growth. Nevertheless, in the SCA treatment, plants grew better than the controls, probably because this substrate not only neutralized the alpechín phytotoxicity but also acted as a fertilizer.

Table 1 Dry weight of shoots of plants grown for 50 days.

	Control	SA	SCA
Dry weight	0,428	0,031	1,206

Total organic carbon (TEC) extracted in alkaline solution remained constant throughout the experiment in the control and in SCA (Fig. 1A). The addition of the C+A mixture increased the TEC considerably but this increase remained constant as index of stability in the new equilibrium created. Most of the alpechín was prob-

ably neutralized chemically from the beginning and the biotoxic activity reduced as can be see by the biomass content in fig. 1B. This biomass was probably reduced initially but fastly recovered at the end of the process. The treatment where the alpechín was incorporated to the soil presented a initial high TEC, which decreased after 12 days considerably, probably by different ways: volatilization, recombination with SOM or biological activity. The soil biomass was strongly reduced initially when the waste water was added and slowly recovered up to the values found in the soil during the studied period.

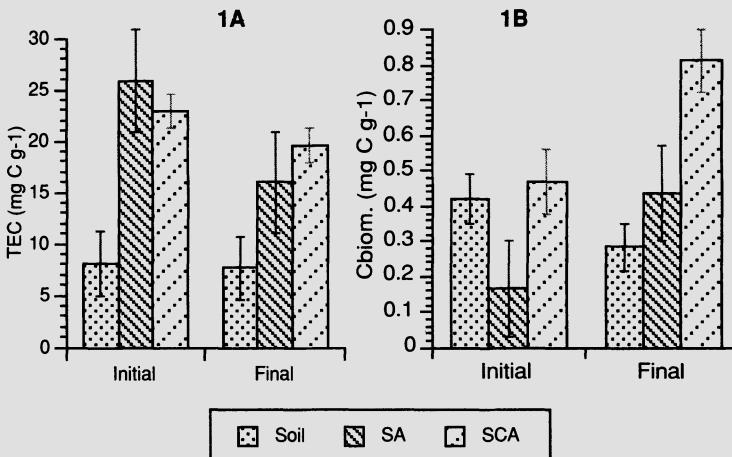


Fig. 1A Total organic carbon (TEC) extracted in alkaline solution at the beginning and the final phase in the three treatments. Bars indicate standart error.

Fig. 1B Biomass carbon content determined by the F-E method at the beginning and the final phase in the three treatments. Bars indicate standart error.

At the end of the incubation period, changes observed in TEC in the treatments, with soil (S) and soil suplemented of alpechín (SA), were independent from the fact that the incubation was carried out with or without plants (fig. 2A). The SCA treatment did not change its TEC when the incubation was developed without plant growth from the beginning (equilibration value) but the presence of plants caused significative decrease of the TEC content. Parallelly, biomass did not change in any treatment after the incubation without plant (fig. 2B). Nevertheless, the presence of the plant roots resulted in an increase of biomass of three times in the soil (S) and in the SCA treatments. Root exudates satisfied nutrient requirements for biomass development increasing its content in control treatment and its activity in SCA treatment to degrade available organic matter as can be see in the TEC decrease found in SCA (fig. 2A).

Humification index

The index indicated the state of equilibrium of the soil organic matter when adding into soil. In S and SCA treatments, this index did not change appreciably during

the experiment indicating that the original organic matter in the soil and that added as C+A were in adequate state of transformation. Nevertheless, in the SA treatment, this index changed appreciably through the equilibration and posterior incubation period passing from values like 1.6 to values near to 0.2, lower of that founded in soil or SCA treatments indicating that the organic matter of this treatment was not yet stabilized (Table II). The decrease in the humification index at the end of the experiment in SA treatment, when plants were grown in the mixture, is the consequence of the high polyphenolic content of alpechín and of its phytotoxicity, which did not allow the increase in HI consequent to plant growth. An intermediate effect was observed in SCA as could be reasonably expected.

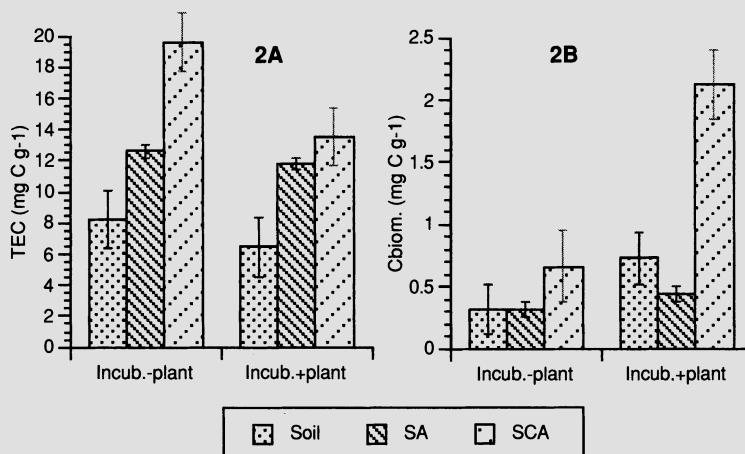


Fig. 2A Total organic carbon (TEC) extracted in 0.1M alkaline pyrophosphate at the end of the incubation period of 50 days with and without plant growth. Bars indicate standard error.

Fig. 2B Biomass carbon content determined by F-E method at the end of the incubation period of 50 days with and without plant growth. Bars indicate standard error.

Table II. Humification index (HI) in the treatments with and without plant growth.

Treatments	Control	SA	SCA
Initial	0.5	1.6	0.8
Final	0.5	0.6	0.7
HI (without plant)	0.5	0.6	0.6
HI (with plant)	0.58	0.25	0.54

Conclusions

The toxicity of alpechín was neutralized when this waste was added to soil mixed with composted organic matter.

Plant growth was better on soil amended with compost plus alpechín showing that this substrate can act as an organic fertilizer.

Soil microbial biomass was negatively influenced when alpechín was added directly to soil.

Acknowledgements

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An Assessment of the Agronomic Value of Co-composted MSW and Sewage Sludge

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GEORGE VANTARAKIS¹ and ANDY GROENHOF²**

Introduction

Modern crop production in Europe does not have sufficient farm animal waste by-products to maintain crop yields at current levels and as a consequence relies heavily on the use of cheap easily available mineral fertilizers. A deterioration in soil organic matter and soil structure has been a consequence of intensive crop production and is especially evident with intensive cereal production. In the UK the area of cereal production has reduced slightly in the last 2 years due to CAP Reform measures and the introduction of set-aside policy but there has been a marked increase in the area of arable fodder crops grown particularly forage maize. Traditionally forage maize is grown in the UK without the use of much fertilizer but with the use of large quantities of farm animal waste particularly cow slurry. However, the expansion of the area of forage maize now exceeds cow slurry availability.

Agriculture offers one of the largest disposal routes for biodegradable human waste streams provided that attention is paid to toxicity factors in the waste streams. Properly composted materials offer an alternative fertilizer source to crop growers and a material that has the capability to improve soil structure and stability with repeated usage.

This paper reports the results of two years of field experimentation using forage maize to assess the value of co-composted Municipal Solid Waste (MSW) and Sewage Sludge.

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Materials and Methods

Compost

The compost used was supplied by Ecological Sciences Ltd and was produced by composting a 50:50 mixture (by weight) of non-separated MSW and sewage sludge (Groenhof *et al* 1995). The compost was manufactured at Chelston Meadow COWS project site in Plymouth, Devon in Autumn/Spring 1992/3. The material destined for the second year of trials was stored on a concrete pad without cover until use in 1994.

Analysis of the compost revealed sub-toxic levels of heavy metals and high levels of available nutrients especially nitrates and potash (See Table 2 Parkinson *et al* 1995)

Field Trials

The effect of applying compost to field trials of forage maize was assessed. The trial was repeated in both 1993 and 1994 using fresh land for the 1994 trial. In addition the residual effects of the 1993 treatments were assessed by growing maize on the same plots during 1994 but without additional applications of compost or fertilizer (this trial is designated as 1994R).

A randomised block field trial design was used with a total of 16 plots per trial divided into 4 replicate blocks each with 4 treatments. The experimental treatments were a factorial combination of fertilizer and compost (Table 1)

Plots measured 12m x 3.75m and comprised 5 rows of forage maize (variety Cyrano) plants (row width 0.75m). Seed population sown was 12 per square metre. Plots were surrounded by guard rows of discard maize. All plots were harvested by hand with sub-samples taken for dry matter determination and dry matter partitioning analysis. Non-destructive records of crop growth and development were made throughout the growing seasons.

Table 1 Experimental treatments

Compost application			
Fertilizer Application	None	None Control	50t/ha Compost only
	N:P ₂ O ₅ :K ₂ O 125:63:63 kg/ha	Fertilizer only	Compost + Fertilizer

Results

Total crop yields and grain yields are given for each trial in Table 2. There were differences in yield between the two years of the investigation with higher yields in 1993 compared to 1994. Differential responses to the treatments were obtained in

the two trial years with compost applications performing better in 1993 than in 1994 but over the two years the mean effect of compost applications was equal to or slightly better than the use of mineral fertilizer and when applied in conjunction with fertilizer consistently improved crop yield by a factor of 30% compared to fertilizer alone. This improvement was 25% with respect to grain yield.

Other significant results obtained were the raising of establishment percentage in 1993 with the application of compost which was correlated with higher soil water content. Faster development of the crop was recorded where compost was applied in 1993 as well as higher leaf area index and leaf chlorophyll content. In the 1994 trial these effects were also recorded with the highest yielding treatments Compost + Fertilizer and Fertilizer only.

Results of nutrient movement in the soils under the various treatments is given elsewhere (Parkinson et al, 1995).

Table 2 Dry matter yields of maize for 1993 and 1994 grown with and without compost and fertilizer and residual effects (R) in 1994. Within a trial differences which are smaller than the LSD (Least Significant Difference) are not significant.

Total Crop Yields t/ha					
	Control	Fertilizer only	Compost only	Compost +Fert.	LSD 0.05
1993	8.81	9.12	12.83	12.65	1.40
1994	5.58	9.06	6.39	10.88	1.24
Mean	7.20	9.09	9.61	11.77	
1994(R)	7.59	7.60	7.97	7.71	1.01
Grain Yields t/ha					
	Control	Fertilizer only	Compost only	Compost +Fert.	LSD
1993	3.73	3.85	5.50	5.18	0.71
1994	2.75	4.51	3.15	5.24	0.73
Mean	3.24	4.18	4.33	5.21	
1994(R)	3.80	3.78	3.99	3.74	0.91

Discussion

There were significant improvements in yield when compost was used in 1993 and the yield improvements were associated with improvements in crop establishment and crop growth with taller plants, with larger leaves and a higher chlorophyll concentration when compared to control plants and fertilizer only plants. This was indicative of a nutrient effect on the crop particularly a nitrogen effect. In 1993 the compost applied at 50 t/ha was capable of supplying all of the nutrient needs of the crop since when compost and fertilizer were applied together there was not a significant further increase in yield. The same increases in yield due to compost application were not evident in 1994 with the crop yields significantly below the yields when fertilizer alone was used. This was also attributed to a nutrient effect (negative) since compost treated plants showed smaller plant size, smaller leaf area and lower chlorophyll contents. When the results of the two years

are meant a positive effect of the compost comparable to using fertilizer was recorded and when compost and fertilizer were applied together then a substantial increase in crop and grain yield over fertilizer alone of 25 to 30% was obtained.

These results indicate that the nutrient content of the compost and in particular the nitrate content, was lowered substantially during the storage of the compost from 1993 to 1994. It is evident that if compost is to be stored outside over winter then there can be a very large reduction in its fertilizer value for agriculture. This has serious consequences when composting companies are faced with large quantities of compost to store from one year to another.

The assessment of the residual effects of the compost between years showed that a nutrient effect was non-existent in the second year after application. It appeared that there was no sustained breakdown of compost to release nutrients in the second year after application. There was a significant site effect with the 1994R control yield being significantly higher than the 1994 control yield.

It is concluded that compost derived from co-composted MSW and sewage sludge does have a beneficial effect on the yield of forage maize but that the benefit can be variable. In order that such composts can be marketed to agriculture in the UK then emphasis must be made of their nutritive value in the first year of application. Furthermore, their main use would be as a fertilizer replacement and as such an accurate estimate of their N:P:K value must be made so that farmers can adjust application rates according to the needs of their crops.

Acknowledgements.

The University of Plymouth and Ecological Sciences Ltd gratefully acknowledge the financial support of the DTI EUREKA scheme for support with the 1994 trials.

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New Bulking Agents for Composting Sewage Sludge (*pteridium* sp. and *ulex* sp.), a Laboratory Scale Evaluation

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Introduction

In Galicia (NW of Spain) there are wide extensions of forest destined to wood exploitation. *Pteridium* sp. and *Ulex* sp. are two common scrub species and they became into forestry wastes when cleaning works are made to minimise burning risks.

The implementation of EU rules regarding sewage treatment is increasing the amount of sewage sludge for disposal in the region. Composting could be a cheap solution for co-disposal of sewage sludge and forestry waste. For testing the self-heating capacity of sludge mixed with forest residues composting experiments were performed using a reactor vessel with forced ventilation.

Material and Methods

Composting reactor is a cylindrical vessel of 15 litres of volume, made of PVC and thermo-isolated with several layers of cork sheet and closed up by a polypropylene lid airtight with a neoprene gasket.. The vessel is located into a box isolated with expanded polystyrene

Through the lid of the vessel four termocouples measured and continuously recorded the temperature of the composting mass. CO₂ and NH₃ evolved were collected into gas traps and the final gas emission was chemically determined. After gas traps, oxygen percent is recorded by a paramagnetic oxymeter (Fig. 3).

Air is supply by a compressor through the base of the composting vessel. Air supply is controlled by a timer until the mass reach 55°C. The program of the timer is 75 seconds ventilation on and 15 minutes ventilation off. When the system reaches 55 °C air is supply by temperature feed-back control.

Air dried forest wastes were mixed with sewage sludge to get an initial moisture content of 60% wet weight and the proportions in dry weight of each component were: Ulex/sewage sludge = 3 : 1 and Pteridium/sewage sludge = 5.5 :1.

When composting finished the composting mass was separated in three layers, air dried, finely ground and analysed. The measured parameters were % Moisture (Mois), pH, Conductivity (C_{ond}), Total (N_{ke}), Ammoniacal (NH_4) and Oxidized Nitrogen (N_{ox}), %Carbon (C), Water-soluble (C_{ws}) and Extractable Carbon (C_{ex}), Humic (C_{ha}), Fulvic (C_{fa}) and No humic fractions (C_{nh}), Humification index by Sequi et al. (IH), K, P, Fe, Mn, Zn, Cd, Pb, Cu, Ni.

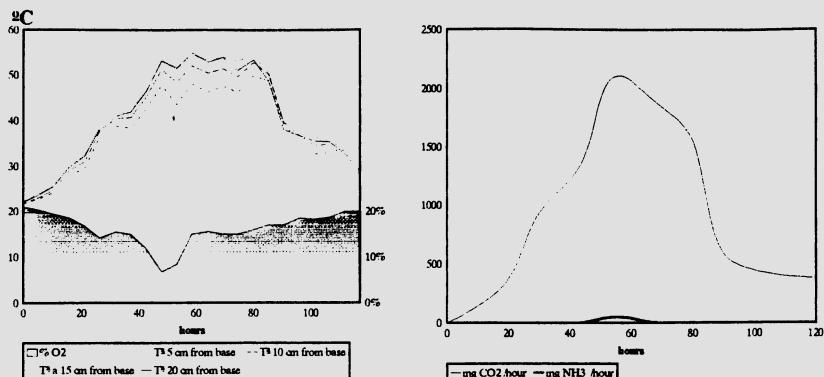


Figure 1 Evolution of temperature, % Oxygen and Production of CO₂ and Ammonia in Pteridium-sewage sludge experience.

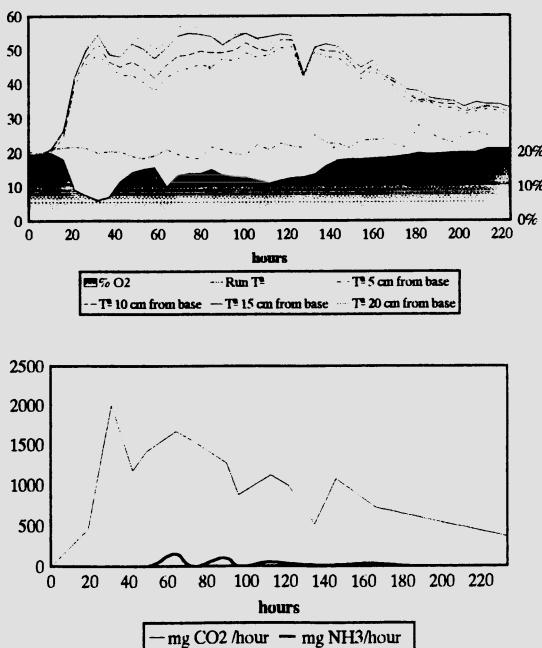


Figure 2 Evolution of temperature, % Oxygen and CO₂ and Ammonia production in Ulex-sewage sludge experience.

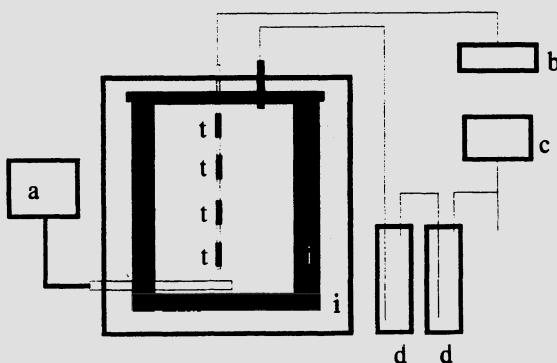


Figure 3 Diagram of laboratory composter a) air supply. b) temperature register. c) oxygen register d) gas traps. i) isolation t) termocouples.

Results

The evolution of Temperature, CO₂, NH₃, and Oxygen are reported in the figures 1 and 2 and the change of chemical parameters along composting in the tables 1–3.

Both mixtures showed similar temperature profiles. Three phases typical of composting with forced ventilation are clear. For heating phase (0–40 hours) the temperature increase to thermophilic values, CO₂ evolved is correlated with temperature ascent. Oxygen into the mass reach values below 10 % at the end of heating phase when temperature is close to 50°C. Low oxygen values point that air supply by the timer is not enough for meeting biological demand.

Heating phase is followed for a period with temperature controlled by feed-back (40–120 hours for Ulex mixture and 40–80 hours for Pteridum mixture). Temperature profile is constant and a clear stratification, with lower part colder than upper, is established. Under temperature control, oxygen values always remain above 10% guaranteeing aerobic conditions and oxygen in excess of biological demand.

Table 1

Final moisture of the Pteridium-sewage sludge mixture	Final moisture of the Ulex-sewage sludge mixture
Upper layer : 74.9 %	Upper layer : 71.0 %
Center layer : 58.8 %	Center layer : 50.8 %
Base layer : 56.2 %	Base layer : 46.4 %

Cooling phase begins when biological activity decreases due to substrate depletion or other environmental factor became critical. Along cooling phase CO₂ and

temperature gradually turn to surrounding values.

Duration of temperature control phase is longer in Ulex mixture than Pteridium because Ulex mixture contains more sewage sludge and so more time is needed for biological conversion.

Moisture stratification is clear for both mixtures (Table 1). Ventilation and temperature stratification lead to a graduation in moisture content with higher values in the upper layer. This effect is widely reported in the literature as typical of forced ventilation systems.

Emissions of Greenhouse and Environmental Relevant Gases by the Decomposition of Organic Waste from Households

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Introduction

Composting is an aerob process. Aerob microorganisms need at least an oxygen-concentration of 3 Vol.-% to take part on the degradation of organic matter. If the oxygen-concentration is getting too low, anaerobic organisms become dominant. They produce odor and greenhouse gases. To avoid this effect all instruments must be used to increase the O₂-concentration in the plant.

Factors influencing the O₂-concentration in the plant

The concentration of oxygen in the air of the plant is depending on the microbial activity (O₂-user) and the gas-exchange between the atmosphere and the plant. There are four possibilities to influence the O₂-concentration in the plant:

- mixing the input-materials to provide the structure of the plant; by this way a better gas exchange can take place
- limiting the size of the plant to render a diffusion of oxygen into the center of the plant
- turning the plant
- active aeration

You can find quite a lot of functional systems for an active aeration, but the financial costs are too high for small composting yards.

There are cheaper possibilities to ensure the oxygen concentration in the plant, for example by optimising the handling of the process.

Size of the plant

Triangular plants have a good supposition to ensure a sufficient O₂-level in all parts of the plant. Between 3 and 21 Vol.-% O₂ of the O₂-concentration is corresponding to the CO₂-concentration in a linear model. By measuring the CO₂-concentration all dates can be transformated into Vol.-% CO₂. The triangular plant was three weeks old and built up with 50 % organic wastes from the households and 50 % structural material. Only in the center of the plant the CO₂-concentration is nearly 20 %, so that anaerobic processes can not be excluded. By plants of this form there is obviously a special circulation: air streaming into the plant from the side, being warmed up in the plant and exhausting at the top of the plant. This circulation leads to a continuous gas exchange between the plant and the atmosphere.

Turning and structure-material

Gas exchange is the result of turning the plant. During the turning oxygen is streaming into the plant. As we could see in other experiences, turning the plant is necessary for mixing the organic material to make new surfaces for microorganisms. On the other side it does not ensure a continuous oxygen concentration for the aerobic microorganisms. A sufficient oxygen concentration is only possible by limiting the size of the plant, by enough structure material in the mixture or by active radiation.

Odor emissions by composting

Carbondioxid- or oxygen concentration in the air of the plant give information about the situation of the aerobic microorganisms. One main problem by composting organic wastes in open compost-yards in Germany are odor emissions. To evaluate the emission-potential of odor, the concentration of H₂S and Total Organic Carbon in the plant has been measured. H₂S is a odor compound. Between the TOC-concentration and olfactory measurements there is a correlation. With triangular plants and a structure material part of 60 Vol.-%, the turning interval is influencing the formation of H₂S and TOC in the plant.

Olfactory measurements of the odor-concentration in the exhausting air confirm these results: With short turning intervals (e.g. one day) the process is starting quickly and also the peak of the odor-concentration is reached very early. It stays on a low level and is falling soon. With the turning interval of 3 days, the increasing period is starting later, and the peak is a little bit higher. With the turning interval of seven days the increase of the odor-concentration in the exhausting air starts later and the peak is lower. But there is a higher concentration of odor compounds in the exhausting air for a period of almost 3 weeks.

Another factor influencing the building of odor compounds is the part of structure

material in the plant. Plants formed with organic waste from households only, develop a high emission potential of H₂S and TOC. As other experiments showed, only a part of 20 Vol.-% structural material is reducing the formation of H₂S and TOC very effectively. With usual mixing rates for open triangular plants between 40 and 60 Vol.-% structural material, the formation of H₂S and TOC is very low which means low emission rates by this plants.

Emissions of greenhouse gases by composting

Odor is a great problem for composting-yards which haven't got enough distance to their neighbourhood, but it has got less environmental relevance. Greenhouse gases such as CO₂, CH₄ and N₂O do not disturb anybody, but they might have an global importance. To estimate the importance of the emission of greenhouse gases by composting organic wastes, we measured the emission rates from the plants and during the turning of the plant.

Methods

The emission rates of the surface of the plant were measured with the closed-chamber-method. To get the emission during the turning of the plant, a turning machine has been modified: On the top of the machine a radiator was installed, which could exhaust the air streaming of the plant during the turning. The radiator was as strong, that it was possible to ensure, that no gas could escape at the front- or the backside of the turning machine. In the tower on the other side of the radiator it was possible to measure the air-flow of the exhausting air. At this place an aliquote of the exhausting air was separated for analysing the gas-concentrations in a mobile laboratory.

Results

The example of N₂O shows, that the emissions of the greenhouse gases are depending on the part of structure material in the plant. With growing parts of structure material the N₂O emissions got less. The part of N₂O that was emitting during turning was low compared with the part emitting of the surface of the plant. With CO₂ and CH₄ the same results were reached. The importance of the emission of greenhouse gases is shown by the following example: If all organic waste in Germany would be treated by composting, the emission of CH₄ would rise for 0.5% of the actual emission from agriculture.

The Compost Information Kit – Business Tools for Success

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Introduction

Composting is Mother Nature's original form of recycling. Simply, composting is the controlled biological decomposition and conversion of solid and liquid organic materials into a humus-like product. Managed composting, while somewhat limited in the U.S. since the green revolution, is a popular and successful animal waste and plant residue management option world-wide. It is more preferable to landfilling, incineration and roadside dumping. The benefits of the act of composting include a reduction in volume of compost inputs, destruction of pathogens, reduction in weed seeds, the degradation of many potentially harmful organic compounds, the binding-up of high-nitrogen materials such as manures, and the production of a useful soil amendment.

While most composting of organic materials is done involuntarily via unattended degradation (e.g. grasscycling or on the forest floor), the organized composting industry in the U.S. is growing. Stueteville and Goldstein (BioCycle, 1994) estimate a growth rate of these semi-commercial operations at about 35 percent per year since 1988. This translates into nearly 3,000 yard waste composting facilities in 1992, up from about 800 in 1988, and about 320 biosolids composting projects by the end of 1993. This is to say nothing of the many new on-farm composting operations which are springing up across the Nation everyday.

To the person who is involved with the regulation, production or sales of compost every day this new growth is not surprising, yet a proactive approach to compost use and sales education will do much to stem the tide of any compost surpluses. A collection of sales tools, *The Compost Information Kit*, has been developed to help aid compost marketers in their quest for profitable sales and manageable levels of product.

The Compost Information Kit

In a first of its kind study for the Composting Council (formerly known as the Solid Waste Composting Council), Potential U.S. Applications for Compost, gave a general estimate of the potential volume of compost that could be used in the U.S. – over a billion cubic yards per year (1992). Although many in the business question that figure, due to the rather low buyer knowledge in the U.S. about the value of compost and the ability to charge for such a relatively unknown product, what most people will agree on is that the market could be very, very large. Thus there is the potential on the one hand to produce more compost than a particular local economy could handle and yet on the other hand all that compost could potentially be easily absorbed if consumers were informed about compost's value. The solution then would be to provide learning aids to help compost producers effectively sell their high quality product.

The Composting Council has developed a Compost Information Kit to help inform sellers and buyers of the benefits of compost. The kit includes a slide rule to estimate compost use rates; a compost-use brochure for the bulk buyer; a compost-use brochure for the homeowner; a wall chart which explains the marketing of compost, and finally a compost business financing guide.

To illustrate the nature of the Kit, below are selected, miniaturized 'stages' of the wall chart. The idea of the chart is to give compost producers an educational tool which can be readily accessed and used to inform staff and clients. The entire Kit is this user-friendly.

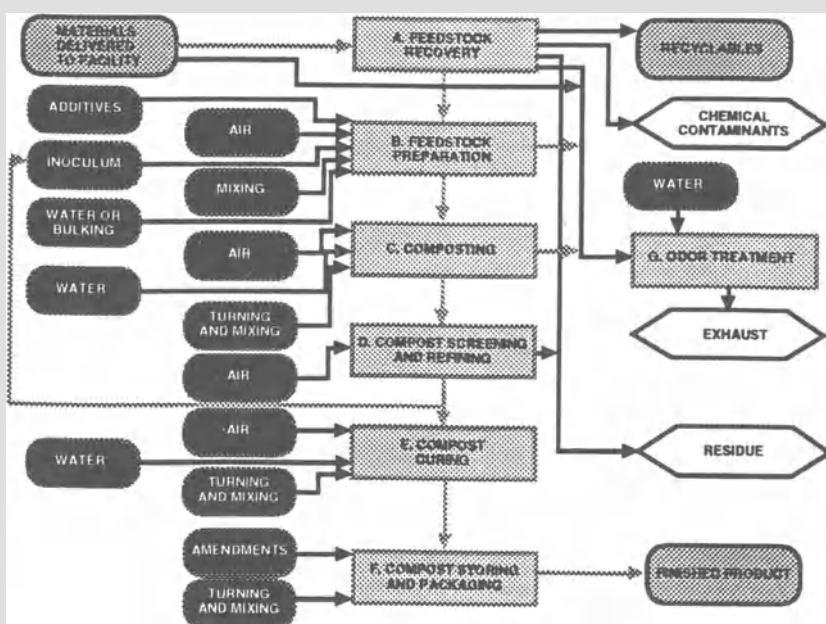
Potential Sources of Compostable Inputs			
Food Processing Residue	Bark	Livestock manure	
Manure and Agricultural Residues	Cardboard	Paper mill sludge	
Forestry and Other Residues	Crop residues	Peat moss	
Biosolids (Sewage Sludge)	Fertilizer and urea	Sawdust & shavings	
Leaves, Brush and Yard Trimmings	Fish processing residue	Seaweed & other aquatic plants	
Source-Separated Municipal Solid Waste	Fruit and vegetable residues	Septic & sewage sludge	
Municipal Solid Waste	Grass clippings	Slaughterhouse & meat packaging wastes	
Other Industrial Compostable By-products	Leaves	Spoiled hay	
Biodegradable Packaging Materials	Lime	Straw	
Animal Mortalities	Newspaper	Wood ash	
	Soiled paper products	Wood chips	

Source: 1992, Rynk, Rodale Press Inc.

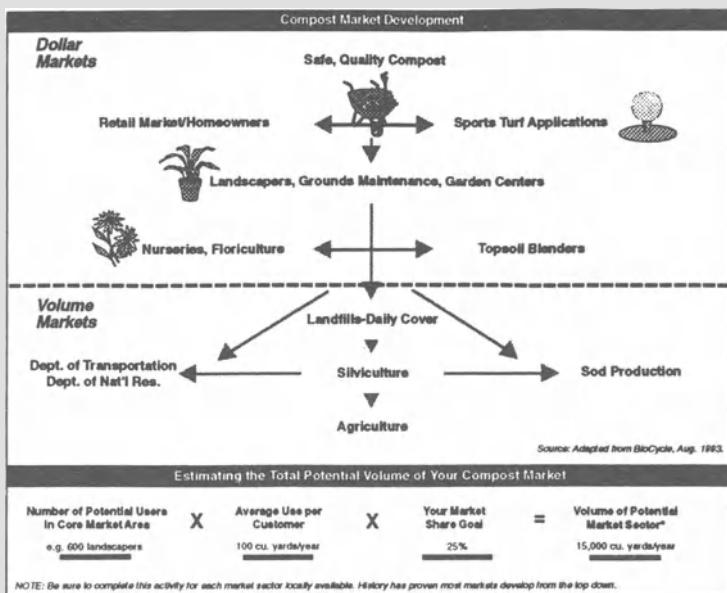
Estimate the Total Potential Volume of Compostable Inputs and Their Processed Value*				
How Many Tons are Expected	Convert Raw Tons to Yards	Account for Shrinkage	Total Yards Out	
_____ Tons X	3 Yards in 1 Ton in	X 1 Yard Out 5 Yards In	= _____ Yards	

*NOTE: The above reduction rates are based on yard trimmings only. Appropriate shrinkage figures should be used for each organic material. Many materials equate to 1 ton in = 1 yard out.

Stage 1 Identify Compost Feedstock



Stage 3 Producing Compost



Stage 5 Available Markets

Information and Activities to Consider			
Educational Information <ul style="list-style-type: none"> • Scientific evidence of quality/performance • Instructions for use • Economic or other benefits • Join Composting Council 	Research & Development <ul style="list-style-type: none"> • New formulations and technologies • Continuous finished product testing • Plant responses in various soils 		
Testimonials <ul style="list-style-type: none"> • Where has it been used? • Who has used it? • How have they used it? • What are the results? 	Demonstrations <ul style="list-style-type: none"> • City parks • Road strips • Major theme parks • Community gardens • Schools and campuses • Open houses • Compost demonstration site sponsorship 		
Pricing Strategy <ul style="list-style-type: none"> • Available substitutes • Penetration pricing • Market-share pricing • Long-term considerations 	Adapt Project Specifications to Allow for Compost Use <ul style="list-style-type: none"> • Work with landscape architects • Work with building specification departments • Work with DOT/DNR agencies 		
Advertising <table border="0" style="width: 100%;"> <tr> <td style="vertical-align: top; width: 50%;"> <ul style="list-style-type: none"> • Magazines • Direct Mail • Newspapers • Radio and TV </td> <td style="vertical-align: top; width: 50%;"> <ul style="list-style-type: none"> • Trade Shows • Associations • Conferences • Word of mouth </td> </tr> </table>	<ul style="list-style-type: none"> • Magazines • Direct Mail • Newspapers • Radio and TV 	<ul style="list-style-type: none"> • Trade Shows • Associations • Conferences • Word of mouth 	Product Refinement & Market Targeting <ul style="list-style-type: none"> • Niche products for new markets • Superior service • Equipment rental for applications • Technical support
<ul style="list-style-type: none"> • Magazines • Direct Mail • Newspapers • Radio and TV 	<ul style="list-style-type: none"> • Trade Shows • Associations • Conferences • Word of mouth 		
Promotions <ul style="list-style-type: none"> • Specials • Campaigns • Giveaways • Contests 	Sales Skills <ul style="list-style-type: none"> • What's in it for your customer? • Understanding product features and benefits • Customer needs analysis 		

Stage 9 Marketing & Education

The Compost Information Kit can be purchased from The Composting Council, 114 South Pitt Street, Alexandria, VA 22314 USA. Phone (703) 739-2401 / Fax (703)739-2407. Funding for the Kit's development was provided by the University of Hawaii via USDA-CSRS Grant 91-COOP-6159.

The Development of Low-Input, On-Farm Composting of High C:N Ratio Residues

D. B. CHURCHILL, W. R. HORWATH, and L. F. ELLIOTT

Abstract

The field straw windrow composting study showed that a minimum of two turns and natural rainfall was required to reduce straw residue volume by 80% or greater in 16 to 21 wk. The decomposition of the high C:N ratio straw residue is contrary to established composting methodology where a C:N ratio of 30:1 or less is thought to be required to compost grass straw. The microbial biomass required more C and less N to function in the thermophilic treatment compared to the LT treatment. The microbial biomass N requirement was less than 4% of total straw residue N in both treatments. The low N requirement of the decomposer biomass indicates that the form or compartmentalization of N is more indicative of substrate quality than the concept of combined substrate C:N ratio. The increased requirement of the thermophilic biomass for C resulted in an increase in the decomposition of the lignin fraction compared to the LT treatment. The increased lignin fraction decomposition was detected through changes in the element composition of this fraction. For these reasons, the composting of grass straw residue is feasible without initially lowering the C:N ratio. Composting has value both as an avenue of straw disposal and for its potential for utilization in the cropping system. Volume reductions of straw windrows in this study were as high as 88% over 32 wk making in-field composting a viable straw disposal alternative to open field burning.

Key words: low-input, composting, ryegrass, microbial biomass, crop residues, lignin

Contribution of the USDA-ARS, in cooperation with the Agricultural Experiment Station, Oregon State University, Corvallis, Oregon, 97331 (Technical Paper No. ; D. B. Churchill, W. L. Horwath, and L. F. Elliott, USDA-Agricultural Research Service, National Forage Seed Production Research Center, Corvallis, OR 97331

Introduction

Crop residues are critical contributors to processes that maintain soil quality and conserve nutrients. Recently, public concern for the environmental consequences of open field burning of grass seed straw has led to legislation that severely restricts this practice (Mackey 1991). Utilization of grass straw in the field, such as by shredding and chopping, have been investigated (Young et al., 1993), but these approaches are unsatisfactory for some grass species. Alternate straw management practices are needed to preserve grass seed yields, to control pests, and to develop sustainable cropping systems. The low-input, on-site composting of grass seed straw and other crop residues is an attractive alternative to thermal and mechanical residue removal (Churchill et al., 1995a). However, composting of organic material is thought to require a C:N ratio of 30:1 or less (Biddlestone et al., 1987; Golueke 1991; Hammouda and Adams 1987). Development of a low-input grass straw composting system would provide an avenue for straw utilization.

Materials and Methods

Field study

The threshed perennial ryegrass straw was collected into windrows approximately 2 m high by 6 m wide. Timing of windrow turns in the Willamette Valley was based on site access and on having at least 3 wk between consecutive turns. To determine the minimum number of turns required to produce a spreadable compost material, windrows were turned 0, 2, 4, or 6 times with a commercial compost turner throughout the rainy season during the winter of 1992–93. The study was repeated in the winter of 1993–94 using a tractor-mounted, front-end loader for turning. Procedures and analyses are described by Churchill et al. (1995a).

Laboratory study

Perennial ryegrass straw was incubated at 25°C and 50°C and analyzed as reported by Horwath and Elliott (1995b).

Results and Discussion

Field study

Greatest straw windrow volume reduction occurred with two or more turns of the straw (Figure 1). The majority of the volume reduction occurred after 16–21 wk of composting. At the end of the study (after 32 wk) the final volume of the zero-turn plots was significantly greater ($p<0.05$) than plots turned two, four or six times. The C:N ratios of the straw decreased from 57:1 to 16:1 by March 11 which was about 28 wk after initiation (Table 1). However, appreciable rainfall did not occur until late October, 10 wk after the windrows were formed. These results

suggest that growers composting this type of straw can achieve near-maximum volume reduction with as few as two turns. During this study, it was noted that when the straw was turned, straw windrow temperatures increased rapidly. Adequate moisture must also be present. During the winter of 1993–94, the compost was turned with a tractor-mounted, front-end loader and the same results were obtained (D. B. Churchill, unpublished results).

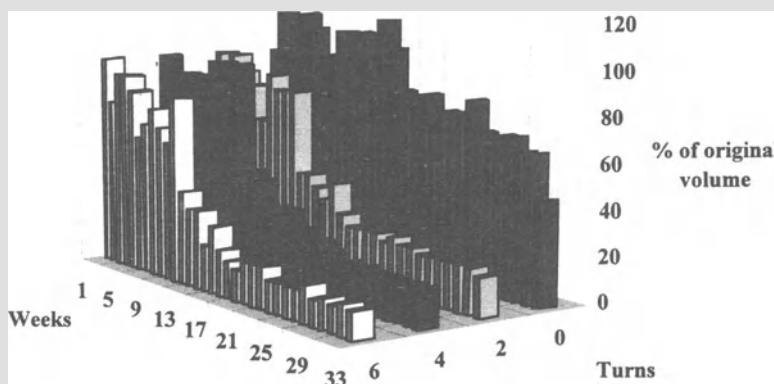


Figure 1 Percent of original volume remaining straw windrows with 0 to 6 turns (Churchill et al., 1995).

Table 1 Long straw turning dates showing accumulated rain fall, plot number, date sample was taken and C:N ratio.

DATE TURNED	PLOT No.	ACCUMULATED RAINFALL (mm)	SAMPLE DATE	C:N
10/29/92	2, 4, 6	22.10	8/18/92	57/1
12/9/92	6	250.70	12/8/92	49/1
1/13/93	*2, 4, 6 (combined)	375.16	1/26/93	22/1
3/11/93	4, 6	511.05	2/23/93	16/1
4/20/93	6	684.78	3/30/93	15/1
5/17/93	4, 6	759.97	4/27/93	16/1
6/15/93		887.48	5/25/93	16/1

* Combined three windrows into one for each of the turned treatments

During the composting process, internal temperatures of the straw windrows pile increased. Temperatures of 55–60°C for a period of a few minutes to a few days are considered sufficient to kill most types of seeds and disease propagules (Biddlestone et al., 1987; Golueke 1991). Sustained temperatures of 50°C or more were attained in the straw windrows turned a minimum of 4 times. More recent studies have shown that weed seeds and disease propagules were destroyed during the composting process (Churchill et al., 1995b, In press).

Laboratory study

Microbial biomass C was highest (22 mg of C g⁻¹ straw) after 3 d of incubation in both the LT and HT treatments (HT treatment maintained at 25°C for first 5 d) (Figure 2a). Microbial C in the LT (low temperature) treatment remained relatively constant through 20 d and then declined to 8 mg of C g⁻¹ straw by 45 d (Figure 2a, Horwath and Elliott 1995a). Microbial biomass C production lagged after the 5-day incubation at 25°C, then peaked and gradually decreased to 4 mg of C g⁻¹ straw after the temperature was increased to 50°C in the HT (high temperature, Figure 2a).

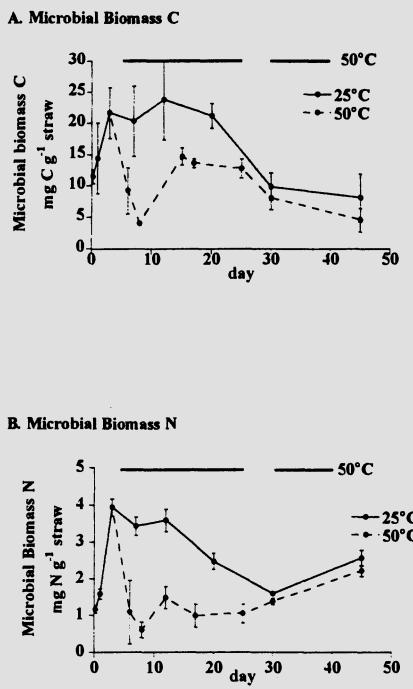


Figure 2 Microbial biomass C (A.) and N (B.) in the LT and HT treatments during a 45 d incubation. Lines indicate the duration of the 50°C HT treatment. Standard deviation of the mean shown as line bars, n=3 (Horwath and Elliott 1995a).

Microbial biomass N increased to 4.0 mg of N g⁻¹ straw after 3 d in both the LT and HT treatments (Figure 2b). In the LT treatment, microbial biomass N remained unchanged during the first 12 d, declined to 1.7 mg of N g⁻¹ straw by 30 d and increased to 2.8 mg of N g⁻¹ straw at the end of the incubation. In the HT treatment, microbial biomass N declined to less than 1 mg of N g⁻¹ straw after the temperature was increased to 50°C and then gradually increased to 2.1 mg of N g⁻¹ straw at the end of the incubation. The increase in microbial N may indicate

an accumulation of microbial by-products and humic substances since microbial C declined constantly in both treatments (Hammouda and Adams 1987). Carbon mineralization occurred rapidly in the LT and HT treatments (Figure 3a). The amount of C mineralized was 185 g and 210 g of C kg⁻¹ straw in the LT and HT treatments, respectively. Initially, the straw contained 400 g of C kg⁻¹ (Horwath and Elliott 1995b). The majority of C mineralization from both of the temperature treatments (LT and HT) occurred by 20 d. The similarity in straw C mineralization in the LT and HT treatments was explained by relating the C mineralization activity to microbial biomass C (Figure 3b). The respiratory quotient (total C mineralized/microbial biomass C) for the HT treatment was approximately twice that of the LT treatment. In the LT treatment, the increased C mineralization was associated with respiratory activity not an increase in the size of the microbial biomass. The thermophiles appeared to require less biomass C and N than mesophiles to decompose approximately twice as much C per unit of microbial biomass.

Nitrogen in the lignin fraction increased 12% in the LT treatment and 16% in the HT treatment (Table 2). The loss of lignin H was similar to C in both treatments. The mass of O remained similar to undecomposed straw lignin O in the HT treatment and increased to 127% in the LT treatment. The constant or increased level of O and loss of C and H indicated that 94% of the lignin fraction was oxidized or altered during the decomposition process. Reviews of degradative reactions during the decomposition of lignin have indicated that O content increases through the oxidative splitting of side chains and oxidative ring cleavage to form carboxylic acid groups (Kirk 1971; Flaig et al., 1975; Chang et al., 1980; Crawford 1981; Kogel-Knabner 1993).

Table 2 The concentration of elements in the initial lignin fraction and the percent remaining for the LT and HT treatments. Standard deviation of the mean shown in parentheses.

Treatment	C	H	O	N
Day 0		g kg ⁻¹		
265.8	640.2 (51.9)	(44.5) 12.1	81.9 (1.4)	(6.2)
	% remaining of original			
LT	75.0 (0.4)	75.1 (0.9)	126.5 (5.5)	111.6 (9.2)
HT	61.3 (0.3)	60.0 (0.8)	98.2 (3.7)	116.1 (6.7)

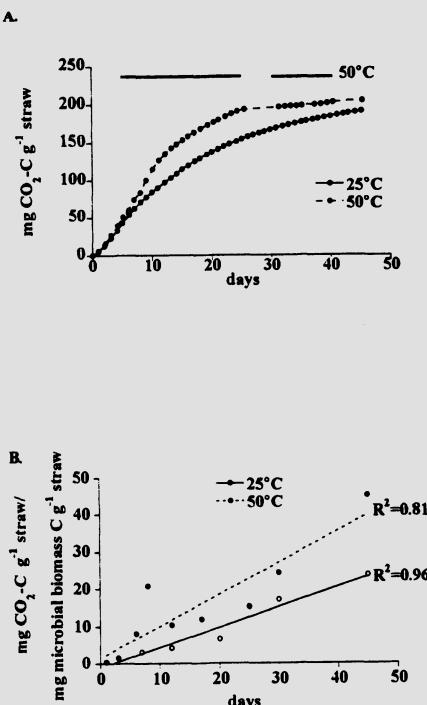


Figure 3 C mineralization (A.) and respiratory quotient (B.) is shown for the LT and HT treatments during a 45 d incubation. Lines indicate the duration of the 50°C HT treatment. Standard deviation of the mean shown as line bars are not shown when smaller than symbols, n=3 (Horwath and Elliott 1995a).

Acknowledgment

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Decentralized Compost-Management: Case-Study of a District of 77.000 Inhabitants – the ‘Kulmbach Model’

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Summary

The following case study evaluates the development of a system of separate collection and composting of ‘greenwaste’(from garden- and park–areas) and ‘biowaste’(from the separate collection of municipal solid waste) in an Administrational District around the city of Kulmbach in Northern Bavaria/Germany. Greenwaste is brought by the citizens to decentralized, farm-based compost-sites. Biowaste is collected by the municipality in a separate ‘bio-bin’ and brought to biowaste-compost-places, which are connected to greenwaste-sites.

Seven years after start 17.500 tons per year, or 170 kg per citizen are recycled on 14 compost-places and two biowaste-sites. Costs per input-ton are low, citizens accept the sites well, the system is modularly adaptable to changing requirements and can be directed by one central office.

Introduction to the Case Study

The following case study resumes the past 7 years of a system of separate collection and recycling of organic municipal waste fractions, which was developed in a region in Northern Bavaria/Germany, an ‘administrational district’ (called ‘Landkreis’) around the city of Kulmbach. The district has 77.000 inhabitants with a city center of 30.000 and rural communities of 47.000 citizens.

The District Administration (‘Landratsamt’) is legally responsible for all the municipal waste management, recycling policy, contracting and finance for this purpose.

In 1987 the District Administration decided to stop incinerating *greenwaste* (organic waste from garden, park and landscaping areas, like grass and branches).

Instead of this a compost-site was installed on farm ground.

After short, the site was so well received by the public that successively 14 compost-sites were put into place. The district administration contracted farmers to build and run the sites on a long-term contract basis. The locations had to be well accessible from public roads and spread over the district, so that each citizen can reach one within a ten-minutes drive by car.

The quantity of recycled greenwaste increased from 500 tons in 1988 to 16.200 tons in 1994. This represents ca. 156 kg of Greenwaste from private households per citizen in 1994.

In 1991 a *pilot-project* for the separate collection and recycling of biowaste was started (mainly kitchen waste, mainly of botanical origin, food left-overs in small quantities, separately collected in a 'bio-bin'). The aim was to introduce, study and improve:

- the introduction-campaign for the citizens,
- the administrative measurements (regulations, fees)
- questions of hygiene and odours of the 'bio-bin'
- the logistic costs
- the recycling/composting process.

In 1993 an introduction campaign of the 'bio-bin' for all the district citizens was run and two biowaste-compost-places were installed - next to existing greenwaste compost-sites.

In 1994, the first year of the 'bio-bin', 1377 tons of Biowaste were collected, respectively 59 kg per each citizen connected to this system. (Many citizens chose to do 'garden-composting' as alternative to the bio-bin.)

Basic Comparison: Centralized or Decentralized Composting Systems

Centralized System

One or more complete districts are linked to one central processing-/compost-plant. This is dimensioned for input of up to 100.000 tons/year. These plants are fully enclosed and automated. The radius of the connected area is up to 50 km.

Decentralized System

One District splits its area and installs small compost-sites, directly accessible for citizens (max 10 minutes drive by car) and thus provides a short and direct way for organic materials to be recycled close to agricultural areas.

Table 1: Basic Overview: Decentral and Central Composting Systems

	Decentral	Central
Greenwaste		
Input Material/ Collection	'Bring-System', citizens bring greenwaste directly to site, no input-transportation	citizens deliver to 'Recycling yard' Transport to site
Processing	open piles low costs	plant should be enclosed
Final Product/ Distribution	directly to fields or: local marketing as soil conditioner	transportation to farms extra or: regional marketing system
Biowaste		
Input Material/ Collection	Municipal Pick-Up-System in separate garbage-bins	Municipal Pick-Up-System in separate garbage-bins
Processing	open winrows, if necessary under roof intensive winrowing with specialized machinery	automated and fully enclosed plant/system high investment cost and energy consumption per ton
Final Product/ Distribution	to fields or: local marketing as soil conditioner	transportation to farms extra or: regional marketing system

Chosen Solution for the Kulmbach District: Decentral

14 Compost-Sites for Greenwaste

These consist of areas for cars, fresh material, shredded materials and for further composting-stages and storage. Piles are turned by payloaders.

Final-products: fresh or ripened compost, sometimes screened and sold.

The sites in Kulmbach for greenwaste are open, fenceless, without collection of fees. Fees for the citizens are included in the annual garbage fee. Input comes very clean.

2 Biowaste-compost-places for biowaste (one of them also for Industrial Biowastes)

These consist of areas for the intensive rotting-process, storage areas open and under roof. Intensive winrowing on small winrows using a winrow-turner. Process-Management according to O2-consumption, frequent measurements and analyses during composting to optimize the rotting-process and to have early information on features of use. Final material: fresh, ripened, screened and classified compost-types, depending on use. According to Bundesimmissionsschutzgesetz (Federal Law for the Control of Gaseous Emissions) and 'Technische Anleitung Siedlungsabfall' (Technical Instruction for Waste Management) these plants with less than 0,75 tons/h input-capacity (ca. 6300 tons/year), are regarded as 'small' and thus, only the requirements of building-regulations have to be met. This accelerates the application-process for building-permissions considerably.

Management

Initially, during the pilot-phase, single contracts were made between the administration and the greenwaste-sites. Later – for the biowaste-compost-places – one central ‘Compost-Ring-Company’ was founded to have one single partner for the administration.

Greenwaste

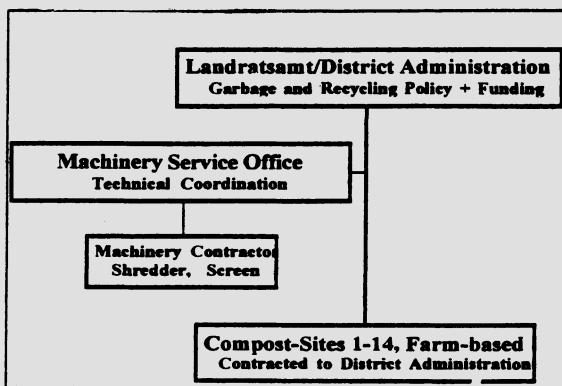


Figure 1 Management of Greenwaste-Composting in Kulmbach District

The District Administration contracts farmers, who build the site on agricultural ground, well accessible from public roads. Contracts include: investment, maintenance, all services of running the place, composting and spreading into fields. The ‘Machinery Service Office’ does all technical and contractual coordination.

Biowaste

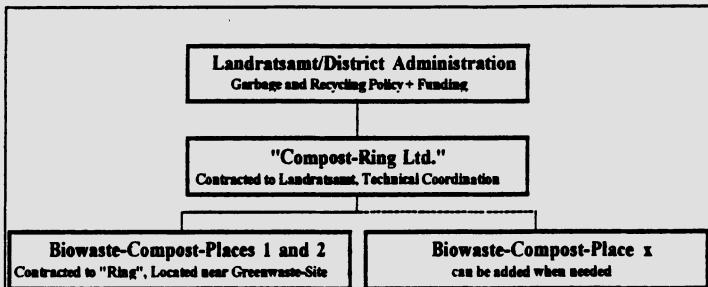


Figure 2 Management of Biowaste-Composting in Kulmbach District

The District Administration contracts the ‘Compost-Ring-Company’ (Limited Company), which in turn contracts the biowaste-sites. These sites are run as independent companies owned and run by farmers owning already a greenwaste com-

post-place. According to the quantities of biowaste collected, more of these 'modules' can be installed. Payment by tonnage input.

Quantitative Development of Composted Input between 1987 and 1994

Fig. 3 illustrates the total-input of organic waste-materials into all decentral compost-places per year. These figures demonstrate the immense potential of garbage-diversion. Especially the large portion of greenwaste is relatively easy to collect and process, the quantities of biowaste from the bio-bin are considerably smaller than in alternative centralized systems.

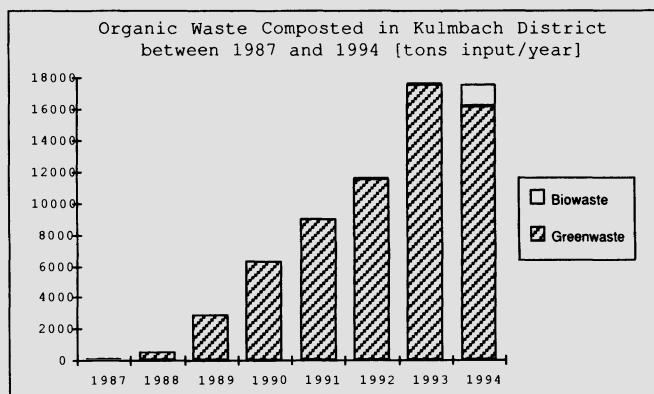


Figure 3 Development of Organic Waste Composted between 1987 and 1994
Source: Landratsamt Kulmbach, 1995

Conclusions

This case study of an Administrational District in Northern Bavaria/Germany – a region of 77.000 inhabitants shows, that a decentralized compost-site-system can:

- collect, process and re-use a majority of municipal organic waste materials
- achieve a high acceptance by the citizens – ('our site'-effect, few 'disturbing materials')
- supply a low cost-base
- be very reliably run by farmers
- be easily installed and managed by one central-office
- be adapted modularly to the changing needs of environment – and waste-policies
- strongly contribute to environmental protection: save landfill space, reduce climatically dangerous methane-release from dumps.

Microbial Succession in a Technical Composting Process

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Introduction

During the process of composting, organic material is turned into the stable final product compost. It is performed by microorganisms causing the degradation and conversion of the organic material. Therefore, the main target of processing is to create optimal living conditions for the microorganisms.

The assignment of this study was to observe the succession of some groups of microorganisms from the delivery of separately collected biowaste to finished compost. Investigations were carried out in June and August 1994 at the composting plant in Beilstein (Hessen). The composting system used is the Herhof-Rottebox.

Herhof technique

The Herhof-Rottebox is a fully encapsulated system. Approximate 60 cubic meters of biowaste can be decomposed under controlled conditions. Air is directed into the composting matter through holes in the floor. For heating the material up, circulation air is used. Normally fresh air with a higher oxygen content than circulation air is pressed through the filled box. With the expelled air carbon dioxide, some organic compounds like organic acids, which tend to have a penetrate smell, and humidity leave the box. The organic compounds are condensated out in a heat exchanger and are removed together with the air humidity. The final stage of the air treatment is a biofilter.

Experimentel Disgine

124 tons of separately collected biowaste were mixed with 28tons of green matter and shreddered to a defined particle size of approximate 150mm. This material

was filled in four Herhof-Boxes and the decomposition process was started. During 6 days the organic matter had a temperature of about 45°C. The material was then heated up to 60°C for 3 days. This is the hygienization phase. After cooling down, the fresh compost was taken out of the box.

For a second passage, the fresh compost was crushed in a hammer mill. This is essential to create new surface area for the microorganisms. Water was also added for a optimal moisture content of the compost. This preparation is called „dynamic step‘. In the second passage, the process temperature was 45°C during 9 days. After these 9 days of decomposition, the dynamic step was repeated. In the third passage, the temperature was 40°C. After 7 days, the further decomposition was stopped, resulting in a finished compost (according to the standards of the Federal Quality Commision RAL-Gütesiegel).

During the decomposition time of 26 days compost samples were taken as follows:

- at the end of the first decomposition passage (after 10 days).
- at the end of the second decomposition passage (after 19 days).
- at the end of the third decomposition passage (after 26 days).

Samples were also taken from the shreddered input material, which was mixed with green matter.

The samples were analysed qualitatively and quantitatively for the following procaryontic and eucaryontic microorganisms.

- aerobic bacteria (medium: Plate Count Agar)
- anaerobic bacteria (medium: Columbia 5% SB)
- aerobic sporogenous bacteria (medium: Columbia 5% SB)
- anaerobic sporogenous bacteria (medium: Columbia 5% SB)
- Enterobacteriaceae (medium: VRBD-Agar)
- mold (medium: YGC-Agar)
- yeast (medium: YGC-Agar)

The following compost parameters were also analysed (according to the instructions of the Federal Quality Commission RAL-Gütesiegel).

- pH-value
- water content
- decomposition degree
- loss on ignition

Results

Aerobic and anaerobic bacteria

The highest quantity of aerobic and anaerobic bacteria were measured in the input material of the first box-passage. After the first passage, both values of total count

were decreased. The reason for the decreased number of bacteria is the hygienization phase at the end of the box-passage. It is unknown, if the amount of bacteria increases before the hygienization phase begins.

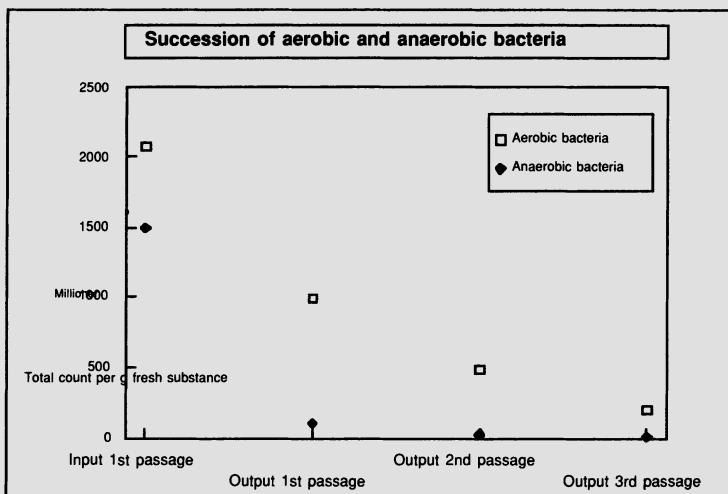


Figure 1 Succession of aerobic and anaerobic bacteria.

At the end of the next two box-passages (including dynamic step) the amount of bacteria were decreased continuously. This was happened without a further hygienization step. A clear result is a considerable drop in the total number of anaerobic bacteria. Based on the aeration, the anaerobic species are selected out. The ratio between aerobic and anaerobic bacteria was increased drastically. At the beginning of decomposition the ratio was nearly 1. This means, that the number of anaerobic and aerobic bacteria was nearly equal. At the end of the decomposition, we measured more than thirty times more aerobic bacteria than anaerobic bacteria. The effectiveness of the hygienization step can be seen from the number of Enterobacteriaceae. The amount of this group of microorganisms, which are able to live under aerobic and also under anaerobic conditions (facultatively aerobic), decreased after the hygienization step to a 10th of the input number. At the end of the third decomposition passage, the amount of Enterobacteriaceae was only 1% of the amount of the input material.

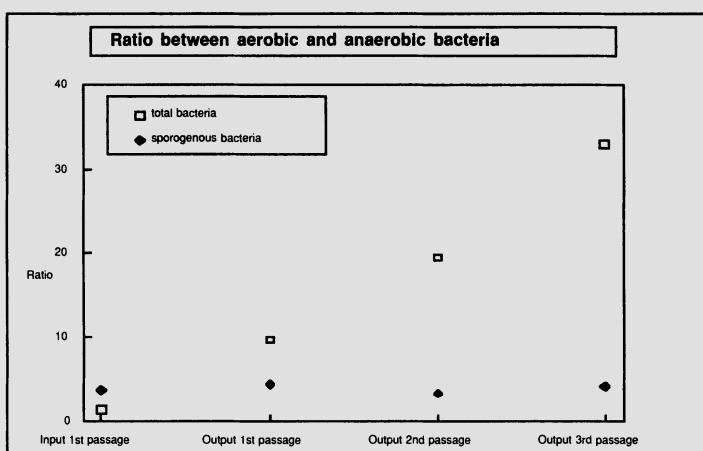


Figure 2 Ratio between aerobic and anaerobic bacteria.

Yeast and mold

Yeast and especially mold, grow much slower than bacteria, but both can grow under conditions which are unfavourable for most bacteria. In our investigations, the number of yeasts were the highest in the input material. After the first box-passage, only 5% of this amount could be detected. At the end of the second step, yeasts are quasi eliminated.

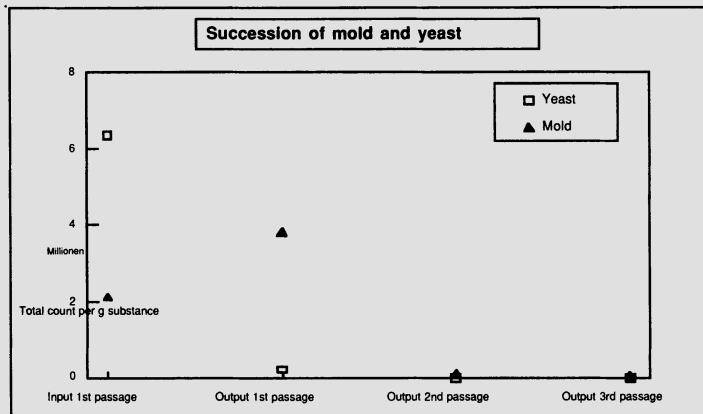


Figure 3 Succession of mold and yeast.

In our investigations, the number of yeasts were the highest in the input material. After the first box-passage, only 5% of this amount could be detected. At the end of the second step, yeasts are quasi eliminated.

In comparison with all measured microorganisms, the highest contents of mold were found in the output material from the first box-passage. That means that mold not only survived the hygienization step (probably as spore), but multiplied during

the first 10 days. This could be seen by opening the door of the box: a white carpet of mold covered the compost. After the second box-passage, mold was minimized. Aerobic and anaerobic sporogenous bacteria

In order to avoid death under unfavourable living conditions, some bacteria can form spores, which germinate and grow under better living conditions. In our investigations, neither the aerobic sporogenous bacteria, nor the anaerobic sporogenous bacteria have been effected through the different living conditions inside the box.

Living conditions inside the box

The changes in the amount of the examined microorganisms groups can be explained with the changing environment inside the box. Not only the temperature is decisive for the succession. Physical and chemical parameters are important, but also the relationships between the microorganisms.

pH-value

At the beginning of the decomposition, the pH-value is about 5,5. During the collection of organic material in households, the organic waste is often deposited under anaerobic conditions. This is the reason for a relatively high concentration of organic acids in the input material with a corresponding low pH-value. The anaerobic conditions promote the anaerobic organisms while the low pH-value promotes the yeasts. During the decomposition, the pH rises to a basic value. Together with the aeration, the higher pH stimulate the aerobic bacteria.

Water content

Indeed, not the water content in the organic material influences the microorganisms, but the water activity (the water activity a_w is a size for the availability of water). Distilled water has the $a_w = 1$). For microorganisms, a high water content is essential. Most bacteria particularly need a high a_w value. The majority of yeasts and also mold are somewhat less sensitive to a lowering of a_w . In order to promote the growth of microorganisms, water was added during the dynamic step.

Decomposition activity

The main target of decomposition is the decomposition of the so-called easily degradable organic matter. As easier a matter is degradable, as easier this matter can be used as nutrition for microorganisms. During decomposition, organic material is decomposed to carbon dioxide, water, and energy. This signifies a decreasing amount of feed for the microorganisms.

Résumé

The succession of some groups of microorganisms were investigated during a 3-stage-box-passge (System Herhof).

- Along with modified living conditions, the population density of this microorganism groups has also changed.
- Population density of all microorganisms were the highest in the input material, except the amount of mold.
- Because of the aeration, the aerobic bacteria were promoted, while the growth of anaerobic bacteria were slowed down.
- The low pH-value at the beginning of the decomposition supported the yeast growing.
- The hygienization phase killed most Enterobacteriaceae and yeasts.
- At the end of the box decomposition, the compost was a finished compost according to the Federal Quality Commision (RAL-Gütesiegel).

Assessment of Compost Maturity

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Abstract

For composting firms, compost producers and compost users it is very important to measure the compost maturity, cause of process control, process optimization, comparison of the process efficiency of different composting systems and application effects of the compost itself. Founded on experiments in aerated and non-aerated composting systems new aspects for the assessment of stabilization during biowaste composting have been achieved.

It could be shown that the parameters respiratory activity and self heating rate are influenced by organic acids. This dependency seems to be the most important reason for the failures made in the measurement for compost maturity.

Based on these results the suitability of the parameters to characterize the real rotting process can be shown. Also suggestions for improvement are given to minimize the failures and to increase the transferability and the quality of the results.

Introduction

During biowaste composting it is very important to have standardized parameters with reliable methods to assess the stabilisation during biowaste composting. The degree of compost maturity can help

- to optimize and to control the composting process (Minimization of composting time, required area and working costs),
- to guarantee the effectiveness of the system,
- to assess the process efficiency of different composting systems,
- to ensure the quality and the application effects of the product (fresh compost or mature compost)

Based upon the research of Jourdan (JOURDAN (1988)) the LAGA established

the self-heating test and the respiration activity test for the assessment of compost maturity (LAGA M10, 1985). The maximum heat (Tmax) produced in a 1,5 l Dewar-vessel (self-heating test) and the oxygen consumption in four days (respiration activity AT4) classify the compost in five degrees of maturity (I – V) called „Rottegrad (RG)“ [fresh compost (RG II–III) and mature compost (RG IV–V)].

The suitability of these parameters to characterize the real composting process must be questioned because several experiments showed that there are difficulties in correlating the two parameters with other methods for the assessment of stabilisation during biowaste composting. It happened that during an aerated composting process the degree of maturity (RG) suddenly decreased from V to II when the compost was no longer aerated. SIHLER und BIDLINGMAIER (1992) showed that the degree of maturity could vary between II and V although the degree of decomposition was higher than 50–60%. Furthermore in a parallel inter-laboratory test of the „Bundesgütegemeinschaft Kompost e. V.“ (BIDLINGMAIER, W., MAILE, A.; 1994) the degree of composting determined by the self-heating test was emphasized as an particularly critical parameter. One third of the laboratories definitely overestimated the degree of maturity.

One reason for this could be that these two methods were not usable for biowaste compost because they were evaluated on garbage and sewage sludge composts.

The following results give suggestions to minimize the failures and to increase the transferability and the quality of the assessment of compost maturity.

Methods

Different methods for the assessment of compost maturity of biowaste compost have been investigated in aerated and non-aerated composting systems. The main parameters tested were the respiration activity, self-heating rate, BOD₅ and COD of the water extract, degree of decomposition, C/N–, NH₄–, NO₂– and NO₃– ratio. To get the optimum humidity in the compost sample for the biological tests the so-called „Faustprobe (fist-check)“ from the BGK (1994) was used.

Results

Influence from very easy degradable, water soluble substances on the parameters self-heating rate and respiratory activity.

Beyond the „classical“ parameters the BOD5 and the COD from the water extract of the compost sample were investigated. It was proved that the appearance of these water soluble substances have a very big influence on the self-heating rate and respiratory activity and so the characterization of the real rotting process was

not possible. To minimize this influence, a modified parameter, the corrected respiration activity AT_{4korr} was introduced.

$$\text{AT}_{4\text{korr}} = \text{AT}_4 - \text{BOD}_5$$

Fig. 1 and Fig. 2 shows the composting process by different parameters in a non-aerated static pile composting.

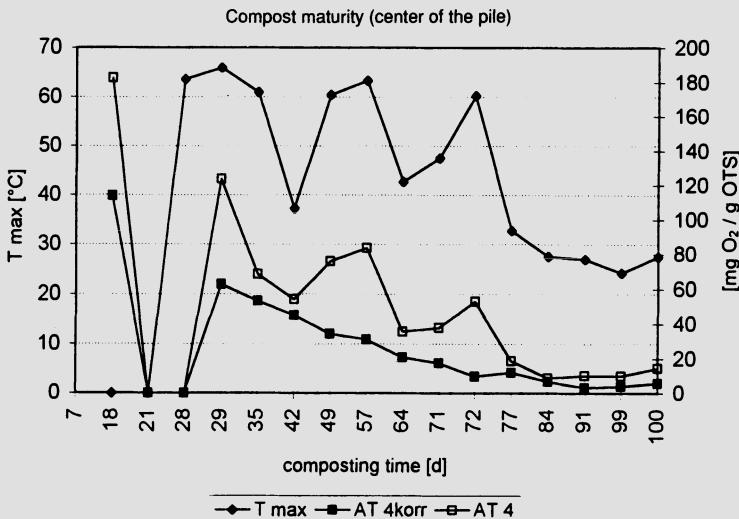


Figure 1 Assessment of compost maturity samples taken on the center of an non-aerated static pile

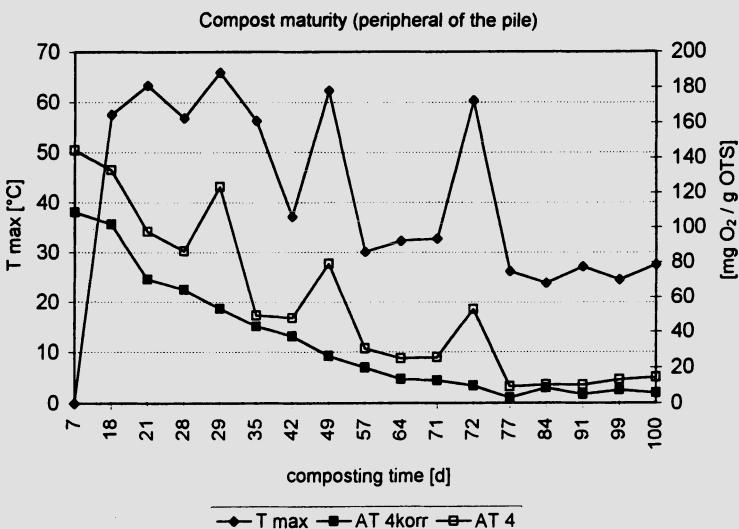


Figure 2 Assessment of Compost maturity. Samples taken from the periphery of a non-aerated static pile

It could be shown that

- the self-heating test and the respiration activity were extremely influenced by this BOD₅- fraction so that the real degree of compost maturity could not be classified.
- high production of heat in the self-heating test after 5 weeks of composting depends on the existence of a great BOD₅- fraction. Water soluble substances are necessary for the heat production.
- The place where the sample is taken from (anaerobic zone in the center of the pile or aerobic zone on the periphery of the pile) and the time when the sample is taken [i.e. before or after a mechanical composting process (e.g. sieving, shreddering, turning over)] have an influence on the amount of the BOD₅ and as a consequence also on the degree of maturity (e.g. before shreddering RG IV, after shreddering RG I).
- only the modified respiration activity [AT4korr] characterizes the real rotting process.

Characterisation of the BOD₅ - fraction

Parallel the examination of the compost eluate on DEV H21, modified from Kapp (1984), characterized the amount of organic acids in this fraction. The theoretical oxygen demand of these organic acids (acetic-, propionic-, butric- and valeric acid) was nearly 90% of the BOD₅ of this fraction. It could be said that mainly these organic acids caused the high oxygen consumption in the respirometric test and the heat in the self-heating test.

The concentration of these organic acids vary extremely during the composting process in dependence of the availability of oxygen for the microorganisms. The organic acids could be built or degraded in-between hours by the microorganisms. As a consequence samples with a long lasting sample transport under aerobic conditions will be overestimated in the degree of maturity (versus RG V) (because of strong microbiological degradation of these organic acids) compared to the same sample tested immediately. On the other hand it is also possible that a good aerated sample during a long transport under anaerobic conditions will be underestimated in the degree of maturity (versus RG I) because of the increase of organic acids being formed by the hydrolysis of organic compounds by microorganisms.

Special features in aerated systems

The strong dependency of the tests on organic acids mentioned above could also be found in aerated systems. But in contrast to non-aerated systems there is the possibility of stripping these water soluble organic components out of the pile by air. This leads to an overestimated compost maturity (versus RG V). Experiments which tested different post composting conditions after an aerated

pre composting on the assessment of compost maturity showed that without aeration the degree of maturity RG decreased (versus RG I) in different times.

First results pointed out: in the same period of time the degree of maturity decreased (versus RG I) the more the higher the water content and the temperature and the lower the availability of oxygen in the post composting was. In addition to this it should be mentioned that the shorter the time of pre composting is the more decreases the degree of maturity.

Table 1 shows the change of the respiration activity under different conditions during post composting.

Thereby it is very interesting that these conditions have not only an influence on the existence of organic acids (increase of the BOD₅), they also could increase the AT_{4korr}. To explain this phenomenon further scientific research will be carried out.

Table 1 Simulation of an non aerated post compostion following an aerated compostion

composting time [d]	original sample			sample after 7 days 20°C non-aerated s			sample after 7 days 40°C non-aerated			
	[mgO ₂ /gOTS]	AT ₄	BOD ₅	AT _{4korr}	AT ₄	BOD ₅	AT _{4korr}	AT ₄	BOD ₅	AT _{4korr}
17	63,8	25,8	38,0	93,0	26,9	66,1	116,2	49,0	67,2	

Problem with the method (LAGA M10)

Further tests which are not presented in this paper show that

- the adjustment of water content of the compost sample according to LAGA M10 (35 % for the self-heating test and 50% for the respiration test) is not applicable. Better results to reach the optimum humidity have been achieved by using the so-called 'Faustprobe (fist-check)'.
- the degree of maturity determined by the respiration activity is lower (versus RGI) than determined by the self-heating test. Therefore a new definition of the scale seems to be necessary.

Summary and new prospects

The examination of the maturing process during biowaste composting in non-aerated and aerated systems showed that the parameters self-heating test and respiration activity can be extremely influenced by organic acids. This can lead to an incorrect assessment of compost maturity dependent of external factors like time of sample taking (influences of operations during the process), non-homogeneity of the pile, sample transport and -preparation and composting technique.

This influence can be minimized by more exactly studying the respiration activity and by using the modified parameter AT_{4korr}. As the organic acids are decomposed under aerobic conditions inbetween 48 hours, the respiration activity should

be measured after that period of time. The extention of the test time (or higher microbial activity because of higher test temperature) can increase the amount of organic registered (2%–10%) in the test, which leads to a better characterization oft compost maturity.

Furthermore buffer systems /mineral media can be used for obtaining comparable conditions.

Nevertheless other methods, using material specific isolation and analytics, should be taken into consideration to get relevant and valuable information about the degradability of the material and for the assessment of compost maturity.

Taking the uncertainties mentioned above into consideration the quality of the method of assessing process efficiency and compost quality, based upon the self-heating test and respiration activity, has to be questioned.

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Accelerated Composting in Tunnels

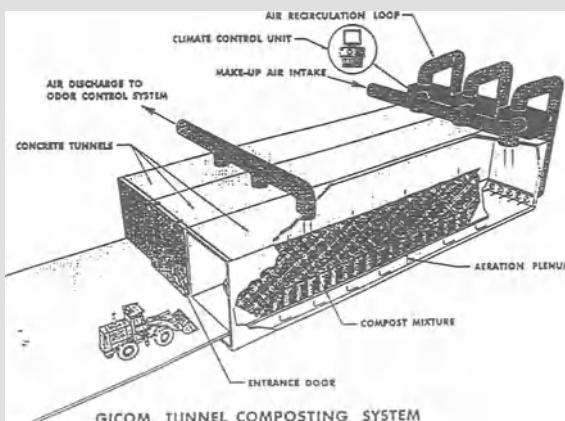
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Gicom B.V. is developing and designing facilities for composting in tunnels. The composting process is fast, the system is closed, and the process control is optimized. The Gicom tunnel composting system is able to transform a variety of organic waste streams into compost, such as:

- biowaste (source separated domestic waste)
- municipal solid waste
- sewage sludge
- industrial sludges
- manure
- anaerobic digestion process residues
- contaminated soil

Since 1991, some 20 full-scale facilities for composting of biowaste or sludge, designed by Gicom, has been built or are under projection. They are located in the Netherlands, Germany, Spain, Austria and the United States. The treatment capacities range from 8.000 tons/year to 100.000 tons/year.

The Gicom tunnel composting system is based on accelerated batch composting in a closed box: the tunnel. The tunnel is divided by a patented perforated floor into two parts; the aeration plenum and the process room. The process air is blown from the plenum through the perforated floor into the process room where the composting takes place.



Biowaste is transformed into compost in two steps of together three weeks. The normal overall mass reduction is 60%. The content of dry matter in the compost is around 70%. When composting sewage sludge, the total loss of weight is about 85% after 14 days. The dry content of the composted sludge is about 60%.

The percolate is recirculated, and normally there is no wastewater effluent at all. Also the process air is recirculated, and is cleared from ammonia and odour by use of a scrubber and a biofilter prior to being let out. The environmental impact of a Gicom tunnel composting facility is thus minimized.

The recirculation of the process air makes it possible to obtain an excellent process control. The climate in each tunnel is measured and regulated by a process control computer. All computer systems used are developed by Gicom. The following parameters are monitored for each tunnel:

- compost temperature
 - air temperature and humidity
 - oxygen/carbon dioxide concentration
 - fresh air flow
 - recirculation air flow
 - static pressure

The results of the measurements are sent to the Gicom process computer, where they are compared with setpoint data. On basis of these comparisons, the process computer controls the climatisation unit. The climatisation unit, which is also used in the mushroom growing industry, is used at more than 180 plants all over the world.

Each Gicom composting facility is individually designed, to suit the needs of the client, including waste stream quantity and quality, the compost quality required and the economical situation.

The advantages with the Gicom tunnel composting system can be summarized as follows:

- excellent process control
- decreased detention time to produce compost
- flexibility towards input material and end products
- sophisticated odour control
- no devices in the process room - no corrosion
- working area separated from process area
- automatic process handling
- no waste water effluent
- fully enclosed active processing
- re-use of process energy
- world wide experience with full scale plants

Composting of Organic Garden and Kitchen Waste in Open-air Windrows: Influence of Turning Frequency on the Development of *Aspergillus fumigatus*

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Introduction

Composting at industrial scale (installations treating . 100 tons per year) is increasingly used in Switzerland for the stabilization of organic waste and the recycling of humogenic materials. In 1992, 320.000 tons of garden and kitchen waste were treated in 150 composting sites, 80% thereof treating more than 1.000 t/a (1). Even if mature composts are generally of satisfactory quality, the process itself could often be considerably improved. Our research team is currently involved in a three-year study that aims at optimizing the thermogenic phase of composting processes, in order to ensure a good thermo-hygienization (elimination of allergenic and pathogenic micro-organisms, e.g. the thermotolerant mold *Aspergillus fumigatus*) and to improve the number and diversity of the thermophilic micro-organisms. This will lead to a rapid degradation of the organic material. By this, phytotoxicity hazards can also be avoided.

If the composting process is not correctly managed, it can induce the proliferation and dispersion of potentially pathogenic and/or allergenic, thermotolerant or thermophilic molds and bacteria, among which the most widespread is the mold *Aspergillus fumigatus*. Spore numbers exceeding 106/m³ air were measured at composting sites, especially during the turning of the windrows (2). This represents a bio-hazard for the personnel working at the composting site, but also for people living in the close vicinity of it. *Aspergillus fumigatus* is not only an opportunistic pathogen which can cause infections (aspergilloma, infectious aspergillosis) in immuno-depressed people, but also a powerful allergen, provoking immunoallergic diseases like allergic broncho-pulmonary aspergillosis and allergic alveolitis. Immunoallergic responses of individuals depend on their genetic disposition, on the frequency of exposure and on the number of inhaled spores(3).

For our study, we are working together with several industries, representing some of the most frequently used composting systems in Switzerland:

- About 2/3 of the compost in our country is produced in classic, open-air windrow systems. The windrows are mostly turned with specialized windrow

turning machines, the size of the trapezoid heaps is thus given by the dimensions of the turning machine (normally 3–4 m wide, and 1.5 m high). If necessary, water can be added to the compost during the turning.

- 1/10 of the compost is produced in boxes, which are either roofed or are inside a closed hall. An aeration system, controlled by the temperature measured inside the heaps, provides air to the compost to ensure sufficient oxygenation. Several automatic systems are used to turn the heaps, water can be added to the compost. Box composting is mostly used in larger composting plants.
- At several composting sites anaerobic fermentation of mainly unstructured, moisture-rich kitchen waste is done prior to composting. The biogas produced is used to turnish energy (electricity and heat) to the composting plant.

At the different composting sites of our industrial partners, we investigated the occurrence, the growth conditions and the dispersion of molds and bacteria during the whole length of the composting process, from the fresh substrate to the final compost. The results demonstrated a hygienization effect or, on the contrary, a colonization potential in function of the nature and composition of the initial substrate, the composting system and management, the stratification of the composting mass, the physico-chemical parameters (temperature, oxygenation, moisture, pH) and the degree of maturity.

In this paper, we will show the results of an experiment conducted at a classic open-air windrow composting plant, as this system is most currently used in Switzerland. The aim of this experiment was to monitor, during 8 weeks, the bacterial biodiversity and the thermohygienization towards *Aspergillus fumigatus*.

Material and Methods

At the composting site of Grenchen (SO), two windrows were put up, both 3.3 m wide, 1.2 m high and 25 m long (= 50 m³), consisting of 70% green waste, 10% kitchen waste, and 20% shredded wood. The initial C/N ratio was 25–28.

Windrow A was turned 5 x/week (= intensive management), windrow B was turned 1 x/week moderately extensive management) with a specialized windrow turning machine. Samples were taken daily for the first two weeks and then every second to third day, from the surface of the windrows (lateral at – 20 cm) and from the center (lateral at – 60 cm).

Temperature evolution was monitored on-line.

Colony forming units (cf) of *Aspergillus fumigatus* in compost were enumerated on Malt Extract Agar with antibiotics (Streptomycin and Novobiocin), after incubation at 40 °C for 48h. Results were expressed as cfu/g dry weight of compost.

Results and discussion

Figures 1A (intensive management) and 1B (extensive management) show the temperature evolution in the center and at the surface of the compost.

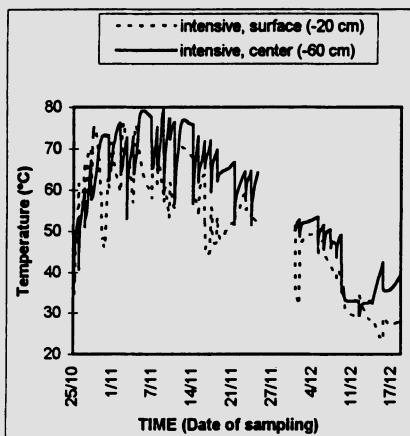


Fig. 1A

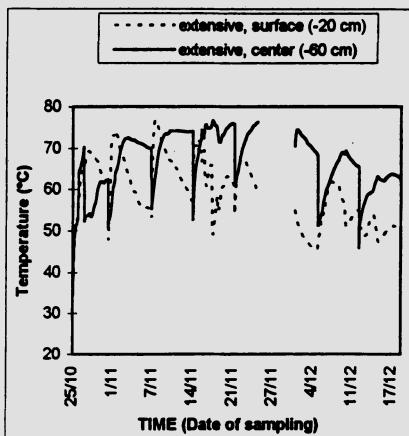


Fig. 1B

In the intensively treated compost, temperatures rose faster, more homogeneously, and reached higher values than in the extensively treated one. There, surface temperatures exceeded only momentarily (after the turnings) 70 °C, and fell for the rest of the time below 60 °C. Peak temperatures were reached after 2 weeks of composting for windrow A, and after 4–5 weeks for windrow B.

Figures 2A (intensive management) and 2B (extensive management) show the concentration of *Aspergillus fumigatus* in the center and at the surface of the compost.

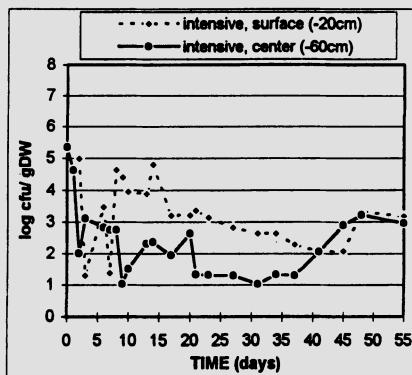


Fig. 2A

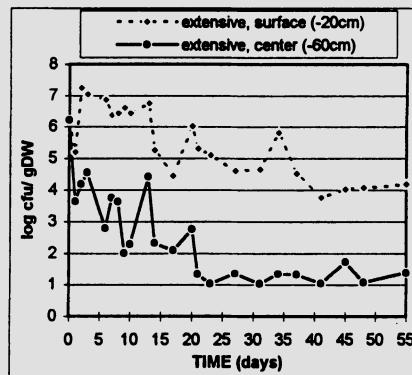


Fig. 2B

Concentration of *Aspergillus fumigatus* were low (between 10 and 100 cfu/gDW of compost) at the center of both windrows, after 2 weeks of composting. However, at the surface, *Aspergillus fumigatus* counts were > 10.000 cfu/gDW during the whole composting process for the extensively treated windrow.

Measurements of the concentration of *Aspergillus fumigatus* spores and mycelium dispersed in the air 2 m behind the turning machine showed also clearly lower values when the intensively treated windrow was turned (results not shown).

Conclusions

- Daily turnings of compost effected a faster temperature rise in the windrow compared to turnings carried out only once a week. Also, degradation of organic matter, as shown by the temperature decline after three weeks of composting, was favored by an intensive treatment.
- Due to the frequent mixing of the composting material in the intensively treated windrow, *Aspergillus fumigatus* counts were low at the center as well as at the surface of the windrow. Whereas for the extensively treated windrow, a strong proliferation of *Aspergillus fumigatus* was observed in the colder surface layers.
- The lower *Aspergillus fumigatus* counts in the intensively turned windrow were reflected in the lower concentrations of mold propagates measured in the air during the turning of this windrow.
- Health risks for the personnel working on the composting sites can be diminished by an intensive treatment of the compost.

Acknowledgments

This research was funded by the Swiss National Science Foundation (grant 5002-038921) and by Alfred Muller AG, Baar and BRV SA, Bôle; Bühler AG, Uzwil; Compag AG, Gossau (SG) and Zweckverband Kompostier-anlage Kreuzlingen-Tägerwilen; Vollenweider Reisen und Transporte AG, Grenchen.

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Sugarbeet Fertilization with Three (Sugarbeet) Vinassee Composts

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The recycling of the organic wastes from different industries could satisfy the increasing demand for organic materials in agriculture and horticulture.

Beet molasses are used as raw material for production of alcohol by distillation. For each litre of alcohol, nearly fifteen litres of a dark brown effluent known as vinassee are generated. The high salt content of the vinassee produced in the south of Spain limits its use for animal feeding. Therefore the use of this waste as fertilizer is being studied at present (López et al., 1993). Vinassee has three major problems for direct application as fertilizer: (i) high salt content (EC 250–300 dS m⁻¹), (ii) low P content (P_2O_5 0.012%) and (iii) its liquid dense character (1.3g cm⁻³). These problems may be overcome through the co-composting of vinassee with agricultural solid wastes, thus obtaining a compost which can be used as fertilizer.

In this paper, the effect of deep fertilization with three vinassee composts as an alternative to traditional mineral fertilizer on sugarbeet is considered. Nutritional status, yield and quality of sugarbeet cultivated in a sandy loam soil fertilized with three vinassee composts and a mineral fertilizer were compared.

Three mixtures of vinassee and agricultural solid wastes were co-composted in static piles with forced aeration during four months. The initial proportion of solid wastes and vinassee were: Compost G: grape marc (82%) + sugarbeet factory lime (1%) + vinassee (17%); Compost O: olive pressed cake (76%) + sugarbeet factory lime (1%) + leonardite (6%) + vinassee (17%); Compost C: cotton gin trash (47%) + sugarbeet factory lime (1%) + leonardite (3%) + vinassee (49%). The chemical analysis of the three composts is shown in Table 1.

Some relevant characteristics of the soil at two different depths (20 and 40 cm) are given in Table 2. Field experiments were carried out in duplicated plots of 10 × 15 m, in which five treatments were tested. Each plot were subdivided in four subplots from where plants and roots samples were taken. The following doses for treatments were applied: TG 14,000 kg ha⁻¹ of G; TO 22,000 kg ha⁻¹ of O, TC 15,000 kg ha⁻¹ of C; TF 600 kg ha⁻¹ of a 9–18–27 N–P–K mineral fertilizer. Treatments TO and TC were complemented with 158 and 122 kg ha⁻¹ of P_2O_5 as superphosphate, respectively. A treatment, TB, without fertilization was used as control. All treatments, except TB, received two top dressings of urea (46% N),

equivalent to $2 \times 90 \text{ kg ha}^{-1}$. Sugarbeet c.v. Taurus was the test variety used for the experiment. Plant material was collected at 33 and 164 days after sowing. Mineral elements in leaves were analyzed according to Jones et al., (1990). The data were analyzed by ANOVA and the differences between treatments were compared by Tukey's test.

Table 1 Chemical composition of the compost (Oven-dry basis)

COMPOST		G	O	C
Moisture	%	31	25	18
N-Kjeldahl	%	2.10	1.00	2.60
Plo5	%	0.70	0.13	0.28
K20	%	1.30	0.90	2.10
0M	%	50	70	51
Ha	%	1.70	1.30	2.40
Ca	%	2.80	1.90	1.30
Mg	%	0.30	0.20	0.40
C/N	%	12	34	8.2

The nutrients contents in leaves at 33 days after the sowing did not differ significantly among treatments (data not shown). The N, P, K, Ca, Mg and Ha contents in leaves at 164 days after the sowing are shown in Table 3. The nutrient contents in composts and mineral fertilizer treatments were higher than for TB treatment. For the compost treatments, the sodium contents were similar to that of the mineral treatment, despite the high Ha contents of the composts. Nutrient contents were within the usual ranges reported for similar climate conditions (Cantos, 1988).

Table 2 Analytical characteristics of the soil

PARAMETERS		DEPTH(cm)	
		0-20	20-40
Sand	(%)	79.4	81.3
Silt	(%)	10.6	9.7
Clay	(%)	10	9
pH (H_2O)		8.1	8.2
CaCO_3	(%)	8.8	7.2
OM	(%)	0.8	
Kjeldahi-N	mg kg^{-1}	676	675
Available-P	mg kg^{-1}	16	
Available-K	mg kg^{-1}	175	205

Sugarbeet root yields for all treatments are shown in Figure 1. There was an apparent treatment effect on sugarbeet root yield. Plots fertilized with either of the composts or the mineral fertilizer gave significantly higher yields than plots without fertilization. For treatments TG, TC and TF, sugarbeet root yields were three-fold higher than for treatment TB, while the sugarbeet root for treatments TO was only two-fold higher than for treatment TB. No significant differences on sugarbeet root yield were observed between each of the three compost treatments and

the mineral fertilizer treatment. The production of sugar followed the same pattern, where the highest sugar production was obtained for treatment TG (Figure 1).

Parameters indicating the quality of sugarbeet juice for sugar production were determined following the standard methods of the British Sugar Company (Table 4).

Table 3 Nutritional content in the ear leaf at 164 days after the sowing

TREATMENTS	N %	P %	K %	Ha %	Ca %	Mg %
TB	3.93 a	0.33 a	3.30 a	2.81 a	1.11 a	0.90 a
TG	4.83 c	0.41 c	4.34 c	3.68 b	1.28 a	1.41 c
TO	4.60 bc	0.37 ab	4.53 ab	4.37 c	1.13 a	1.08 b
TC	4.88 c	0.40 bc	3.94 bc	4.32 c	1.03 a	1.33 c
TF	4.53 bc	0.38 bc	4.09 bc	4.08 c	1.11 a	1.18 b

Values following by the same letter in the same column do not differ significantly ($P < 0.05$).

Table 4 Sugarbeet quality

TREATMENTS	Red. sugar* %	Sugar %	Na meq/100g	K meq/100g	α -aminoacid meq/100g
TB	0.17 a	15.9 a	2.67 a	5.71 a	0.55 a
TG	0.15 a	15.8 a	3.07 a	6.41 bc	1.45 ab
TO	0.18 a	16.3 a	2.71 a	5.79 ab	1.30 ab
TC	0.16 a	16.6 a	3.01 a	7.01 c	2.01 b
TF	0.14 a	16.6 a	3.50 a	6.60c	2.06 b

Values following by the same letter in the same column do not differ significantly ($P < 0.05$).

* Reducing sugar.

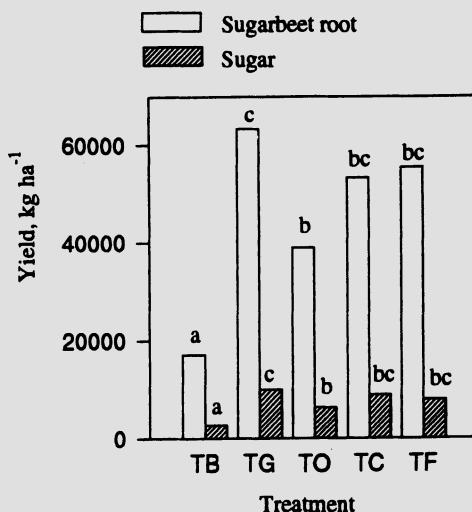


Figure 1 Yield of sugarbeet root and sugar for the different treatments. Means of data columns for each yield with same letters are not significantly different ($P < 0.05$).

There were not significant differences among treatment on the percentage of reducing sugar, sugar and Ha contents in beet root. For treatments TG, TC and TF, the K contents were significantly higher than for TB.

The negative influence that high N fertilization may produce on the technological sugarbeet quality (Draycott, et al., 1977) was not apparent since the aminoacid contents for composts and mineral fertilizer treatments were lower than the normal value (6.4 meq/100g) for sugarbeet under similar climate conditions (Cantos, 1988).

Results highlighted the use of compost as an alternative of traditional mineral fertilizer. Compost of vinasse and agroindustrial wastes had not detrimental effects on sugarbeet (yield, nutritional status and quality). Best results were observed for vinasse-grape marc compost (G).

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Waste Collection Utility Development

MAGAGNI A. and TOSETTI A.

Introduction

The CEC Directive 271/91 requires more stringent nitrogen and phosphorous standards in the wastewater discharged from treatment works. The reduction of the heavy eutrophication problems in several European areas of the Mediterranean Sea (high Adriatic Sea) is a priority task, and the action is oriented at reducing the MSW (Municipal Solid Waste) addressed to land fills and /or incineration by increasing the performances of wastewater treatment plants.

This aspect, together with the necessity to find a solution to the urban solid waste disposal service, has led to the recovery of not very recent already-made projects that can propose new developments.

The solid waste collection utility (collection, transport and treatment phases) is organized in a different way from the urban liquid waste that is treated through the city sewer system.

In the F.U.S. 20 project the organic waste is treated through the sewer system, after trituration effected under the domestic wash-basin. Then wastewater are carried to a depuration district plant, where water and organic fraction are separated. In fact, the action planned by F.U.S. 20 project must be preceded by transferring the source sorted municipal solid waste from the traditional road pick up system to the sewer line introducing food waste disposer in a quarter of Padova, and educate the families to use it properly.

Chronicle and feasibility development

In the '60 in the U.S.A. there was already the food waste disposer (particular tests were carried out in Los Angeles and in New York more recently).

In California it was given up for problems of water supplying. In fact great delivery of water was required to obtain the necessary fluency to the disposer operation, because waste is made for about 60/70% of dry elements.

The F.U.S. 20 project concerns only organic waste both in the domestic treatment and in its utilization, requiring a low water quantity.

Today it is a topical subject as far as waste collection is concerned, to consider

both the selective collection of humid waste and dry waste.

In the same way it is proposed the water 'carrier' and triturated waste but only for the humid elements.

Project aims

This research programme is focused on the possibility to realize an effective integration between the anaerobic solid waste treatment process and the biological wastewater treatments processes.

The aim of this project can be divided into two options.

- 1) The first option is mainly based on the optimisation of the BNR through anaerobic fermentation of the organic fraction of municipal solid waste. The objectives are to increase the concentration of volatile fatty acid in the influent, approaching the activation of the high-rate phosphorous release kinetic (doubling the speed of this section of the process) and to check the effectiveness of the internal carbon source production. In the project it will be made use of an existing small wastewater plant (3.000 E.I. Equivalent Inhabitants) where the incoming flowrates are wastewaters of an experimental civil area, in which all houses have food waste disposer to discharge the organic fraction of municipal solid wastes into the sewage. The proposal is to experiment the wastewater plant into two different configurations either utilising readily biodegradable carbon or slightly biodegradable carbon produced by the food waste disposer source sorted organic fraction of municipal solid wastes. This fraction could be obtained following two strategies:
 - a) using a balancing tank, located at the head of the plant, in which the fermentation processes will be performed in no strictly anaerobic conditions;
 - b) adopting an anaerobic fermenter, in which the primary sludge which contains high percentages of organics coming from the shredding of organic fraction of municipal solid waste, will be fermented in a mesophilic range of temperature.

The second option is mainly devoted to the energy balance of the wastewater plant and regards the possibility of co-digestion between the source sorted organic fraction of municipal solid waste coming from the families through the comminutors in the sewers and sewage sludge. This choice can be adopted by treating the mixed sludge (the shredded organic fraction of municipal solid waste and the sludge normally produced in the wastewater facility) using the anaerobic process.

Expected results

The results expected from these actions are related to the improvement of the performances of these biotechnologic techniques applied to the environmental protection. The two options previously described could give an important verification on a semi-real scale. In particular, these are the expected results:

- information about the sewers network behaviour when the source sorted organic fraction of municipal solid waste is added to the normal flowrate. Design guidelines commonly used by american engineers assume a BOD load of 100 gr. per person per day where municipal solid waste are used and BODS load of 80 gr. where municipal solid waste are not used.
- the wastewater inlet reachable concentration, in terms of increase of readily biodegradable carob (and especially specific, in terms of acetate and volatile fatty acids concentration) obtainable though the addition of source sorted organic fraction of municipal solid waste to the normal flowrate using this approach;
- an effective evaluation of the improvement of performances in a conventional configuration wastewater treatment plant and in a biological nutrient removal configuration: more specifically to verify that it has been reached the high-rate kinetic about phosphorous release and acetate uptake described by Wentzel (1988);
- the feasibility of an energy recovery which allows an important reduction of management costs of the integrated process adopting the approach of the co-digestion of source sorted organic fraction of municipal solid waste and sewage sludge.
- to elucidate mechanisms governing both the hydrolysis of particulate substrates and the biological excess of phosphorous removal.
- the production of fuel gas from the supercritical wet gasification facility with a max of 20% organic fraction in the liquid phase, and in particular :
- production of a very clean gas easy to use in any kind of internal combustion engine without ignition trouble;
- possibility to feed the reactor with a organic fraction containing a few parts of paper and plastic;
- short reaction time (5:10 min.) with the possibility to treat waste materials in small size reactors close to the production of waste.

Suitability of Composted Household Waste of Helsinki Metropolitan Area for Agriculture

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Introduction

The number of inhabitants in Helsinki metropolitan area is 850000. They produce annually over 300000 tons of municipal waste, of which about one third is of rapidly decomposable biological origin. In April 1993, collection of source separated household waste and municipal biowaste was started in a large scale in the area by the the Helsinki Metropolitan Area Council (HMAC). This study is a part of the larger project conducted by the HMAC and the Technical Research Centre of Finland (VTT) which will find out ways to recycle the source separated biowaste. The aim of the present study was to clarify the suitability of the biowaste for agriculture with the aid of physico-chemical analyses and pot experiments which were carried out by the Agricultural Research Centre of Finland (MTT).

Material and methods

Source separated household waste was composted with wood chips in a volume ratio of 2 : 1 in windrows (2.5 m × 50 m × 40.0 m) in a sanitary landfill of Ämmässuo. Since August 1993, the ratio was 1 : 1. At first, a turning cycle was three weeks and since December 1993, two weeks.

During the present study, 12 composts were studied. Ten samples from different-aged, 2, 4, 6, 8, 9, 10, 12 and 18 month old, composts were analysed for general characteristics and for total and soluble macro- and microelements. Furthermore, two samples, one from a drum compost and another from a sewage sludge compost, were studied in a similar way. During the growing seasons of 1993 and 1994, experiments with barley (*Hordeum vulgare* L.) were carried out in Kick-Brauman pots in outdoor conditions supplied with watering. Compost fertilization respecting the application rates of 24 and 96 tons ha⁻¹ DM was studied in

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finesand (6 liter of soil/pot) with or without N supplement. Comparisons were made to NPK-fertilization and no fertilization.

Results

Pot experiments indicated that household waste composted for 2 or 4 months was unsuitable for agriculture due to inhibiting effects on barley growth. These composts considered as unmature had a high $\text{NH}_4\text{-N}/\text{NO}_3\text{-N}$ -ratio and a pH less than 7. Household waste composted for 6, 8, 9, 10, 12 and 18 months had not growth inhibiting effects on barley and seemed to be suitable for cereal cultivation. When the soil received only compost fertilization at application rates of 24 or 96 tons DM ha^{-1} , green mass yields of barley were of the same low level as without any fertilization. When the compost fertilization was supplemented with N, grain and straw yields of barley reached or even exceeded those obtained with NPK-fertilization. In addition to this, compost fertilization supplemented with N had positive effects on the quality of the yields increasing the concentrations of P, Cu and Zn in grains. In general, compost fertilization increased soil humus content and fertility and decreased soil acidity.

Fertilizing value of the composts seems to be based on P and especially on K, but to a lesser extent on N. Mean concentrations of total N, P and K in the eight household composts suitable for agriculture were 17, 5 and 19 g kg^{-1} DW, respectively. Only 2.5% of N, 35% of P and 55% of K was in a soluble form, on the average. In addition to this, these composts contained Ca 23.1, Mg 3.2, Na 2.0, Al 20.4, Fe 8.4 g and Mn 211 mg kg^{-1} DW and B 2.6 mg l^{-1} of air dried material. Mean pH(H_2O) of the composts was 7.5, humus content 41% and C/N -ratio 14. Concentrations of heavy metals of all the 12 composts studied were very low: Hg 0.171, Cd 0.57, As 7.8, Ni 7.3, Pb 40, Cu 81 and Zn 182 mg kg^{-1} DW, on the average. The concentrations were clearly lower than the limit values set for soil improvers by the Finnish government in 1994: Hg 2.0, Cd 3.0, As 50, Ni 100, Pb 150, Cu 600 and Zn 1500 mg kg^{-1} FW. In general, solubility of most nutrients and heavy metals in composts decreased, when the composting time proceeded.

Conclusions

Household waste composted in windrows for 6 months or more seem to be mature and suitable for agriculture. These composts also meet the quality requirements set by the authorities for soil improvers. The composts can be considered as PK-fertilizers rather than as NPK-fertilizers. In addition to this, they are good liming and soil improving agents. Research results obtained in the present study give support to recycling of household waste in agriculture which, in turn, will proceed sustainable development in the society.

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Effects of Compost on Soil Biological Fertility and Maize (*zea mays*) Production

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The use of compost for sustainable agriculture can suitably furnish the nutrients to plants and improve the soil fertility in terms of biological and chemical status. Effects of compost have been evaluated during the maize growth season as changes in the forage yield, the soil microbial biomass content, the soil metabolic quotient and the availability of nitrogen. Soil was analysed in correspondence of four different maize growth stages (1st sampling before compost and inorganic N application, 2nd sampling during stem elongation, 3rd during flowering and 4th during milk maturity of maize).

Methods

Forage maize (var.LG2080) has been grown with different treatments: 1) composted manure (50 t ha⁻¹); 2) composted manure (100 t ha⁻¹); 3) nitram (100 kg N ha⁻¹); 4) and nitram (200 kg N ha⁻¹); 5) control (no fertilizer). Soil samples have been taken at 5–10 cm of depth (6 subsamples for each block). The CO₂ evolution of soil, needed in order to estimate the metabolic quotient, has been determinated by trapping in 1N NaOH, according to Badalucco et al (1992). The fumigation-extraction method was used to estimate the soil microbial biomass content (Jenkinson 1988) in maize trials. Experimental blocks were replicated 3 times.

Results

Table 1 Carbon-Biomass at different maize growth stages.

Standard deviation never exceeded 13% of the mean value; ds= dry soil.

Treatments	1st sampling µg C g ⁻¹ ds	2nd sampling µg C g ⁻¹ ds	3rd sampling µg C g ⁻¹ ds	4th sampling µg C g ⁻¹ ds
Control	305.22	286.28	245.31	273.30
Compost 50	305.22	325.34	296.14	299.32
Compost 100	305.22	360.00	266.27	355.00
Nitram 100	305.22	272.27	361.92	246.43
Nitram 200	305.22	336.74	324.75	331.11

Table 2 Metabolic-Quotient of soil microbial biomass at different maize growth stages

Standard deviation never exceeded 15% of the mean value; ds= dry soil

Treatments	1st sampling µgCO ₂ h ⁻¹ g ⁻¹	2nd sampling µgCO ₂ h ⁻¹ /Bc	3rd sampling µgCO ₂ h ⁻¹ /Bc	4th sampling µgCO ₂ h ⁻¹ /Bc
Control	0.006421	0.006636	0.006382	0.007317
Compost 50	0.006421	0.008893	0.007068	0.009410
Compost 100	0.006421	0.014586	0.006422	0.007593
Nitram 100	0.006421	0.006904	0.007140	0.008210
Nitram 200	0.006421	0.006751	0.007092	0.007704

Table 3 Yield of maize

Standard deviation never exceeded 18% of the mean value.

	Control	Compost 50	Compost 100	Nitram 100	Nitram 200
Forage yield dry weight txha ⁻¹	4.10	3.16	5.70	5.13	6.50

Conclusion

After compost application, during stem elongation of maize, both soil microbial biomass (Table 1) and its activity increased (Table 2), whereas in soil treated with inorganic fertilizer these two parameters were not significantly different from control (no fertilizer application). At flowering stage of maize the metabolic quotient was not significantly different between treatments presumably because the plant uptake induced a considerable competition with soil microbial biomass. As a general trend all treatments showed an increase of microbial biomass at the end of maize cycle, probably due to the new substrate for microorganisms came from rhizodeposition and plant tissue senescence. The forage maize production was higher with inorganic fertilizer application (Nitram 200 kg ha⁻¹), the improvement of soil biological activity after compost application had not repercussion on plant productivity in terms of forage maize yield (dry weight).

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The Effect of Municipal Waste Compost on the Development and Viability of Ascarid Eggs.

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Abstract

Ascariasis effects approximately one quarter of the world's population and is particularly prevalent in developing countries. As improvements in sanitation in most of these countries becomes more widespread, composting of human excreta and sewage sludge has become a popular and cost effective method for the disposal of these products, as well as offering a valuable source of organic fertiliser. If, however, the composting process is not properly controlled there may be a potential risk from pathogen and helminth infection to workers handling the compost and consumers of foodstuffs grown on land treated by the compost.

The work carried out has examined the effect of compost on the development and the viability of ascarid embryos within their protective eggshell, in an attempt to establish any mechanisms which may be involved in the destruction of these eggs. *Ascaridia galli* eggs were used as a model for *Ascaris lumbricoides* eggs. These were suspended for a period of two to three weeks in compost and micro-organism free compost extract, as well as in distilled water controls. In the first set of experiments, approximately four week old municipal waste compost was used, while in the following set of experiments approximately one week old compost was used. The results showed that both the one week old and the four week old compost extract retarded the development of the *Ascaridia galli* eggs suspended in them. This effect was seen to be more pronounced in the one week old compost extracts. No such delay in the development of the *A. galli* eggs was observed in the micro-organism free compost media. In spite of the observed delay in the development of the *A. galli* eggs suspended in the compost media, the viability of the eggs was unaffected. The observed delay in development was thought to have resulted from some form of microbial and/or fungal activity which would be present within the compost suspensions but not the micro-organisms free environments.

Introduction

Ascariasis is believed to effect one quarter of the worlds population causing 1 million cases of morbidity and 20 000 cases of mortality per year (Crompton *et al.*, 1985). The disease is caused by the presence within the intestine of a human host of an adult nematode worm *Ascaris lumbricoides*. If two or more adult *A. lumbricoides* worms are present inside an intestine, male and female, eggs are produced and passed in the faeces of the human host, in a single-cell state (plate 1). This disease may then be transmitted through the ingestion an egg once it has developed to its viable state (plate 2). Ascariasis is most prevalent in areas of poor sanitation, primarily in the developing world. With improvements in sanitation in these countries, composting of excreta, sewage sludge and municipal waste has become popular being seen as an effective method for their treatment (Mara & Cairneross, 1989). If the composting of these materials is carried out successfully, the final product offers a valuable, pathogen free, organic fertiliser. However, if the process is not properly controlled, then there may be a risk from pathogens, including Ascaris. Due to the resistant nature of Ascaris eggs, the presence or absence of the eggs in a compost can be used as an indicator of the pathogenic nature of the compost (Feechem, *et al.*, 1981). Present literature indicates that Ascaris eggs are destroyed by exposure to temperatures in excess of 50 °C for a period of greater than 1 day, this should easily be attained during thermophilic composting (Feechem, *et al.*, 1983). However, no mechanism other than heat has been thoroughly investigated as having any effect on Ascaris eggs during the composting process. A better understanding of how composting effects Ascaris eggs may lead to a re-examination of the temperature ceilings presently used, which may in turn have implications in operation time and costs.

The work carried out for this paper has begun to examine weather factors other than temperature may be contributing towards the degeneration of Ascaris eggs during composting.

Methods

The effect of four week old and of one week old municipal waste composts on the development and viability of *Ascaridia galli* eggs were examined. *A. galli* eggs (eggs of the chicken ascarid) were used as a model for *Ascaris lumbricoides*. For each 'compost' sample under test, 5 g. of compost was suspended into 50 ml. of distilled water to which several thousand *A. galli* eggs were added. The effect of 'compost' and 'filtered compost' samples were compared to a control of distilled water. Each 'filtered compost' sample of 5 g. of compost added to 150 ml. of distilled water was filtered through a 0.45 (m. membrane before the *A. galli* eggs were added. To the 150 ml. volumes of distilled water used as controls several hundred *A. galli* eggs were added. All the samples (three of each type) were placed in a shaking incubator at 30 °C and aerated constantly (see fig. 1). This set-up was

used in an attempt to simulate actual composting conditions without water or air becoming limiting. From each sample sub-samples were taken on a regular basis. These were examined to assess the stage of development of the *A. galli* eggs from the sub-sample, before being incubated for 28 days in 0.1N H₂SO₄ at 28 (2°C under non-oxygen limiting conditions, after which the sub-samples were re-examined and the viability determined.

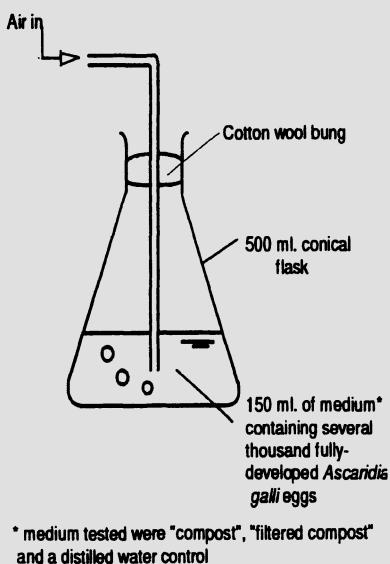


Figure 1 Example of apparatus used for one sample

Results and discussion

The 4 week old compost

On initial examination of the *A. galli* eggs from the 'compost' sub-samples the process of cell-division and development from single-cell zygotes to fully-developed larvae was observed. However, this rate of development when compared with that of the *A. galli* eggs from the 'filtered compost' and the distilled water control sub-samples, was retarded. By the end of the 14 day sampling period, not all the eggs examined from the 'compost' sub-samples had reached full-development. When compared with the distilled water control and 'filtered compost' samples (fig. 2a), significantly fewer fully-developed eggs were found from the 'compost' environment than from the distilled water control and 'filtered compost' environments, which were found to be similar to one another with respects to the percentages of fully-developed eggs observed ($p < 0.05$). However, no significant differences were found between the increasing percentages of degenerate eggs found from the three environments (fig. 2b).

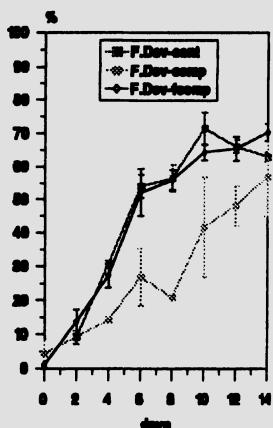


Figure 2a

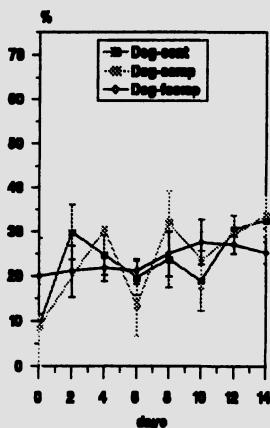


Figure 2b

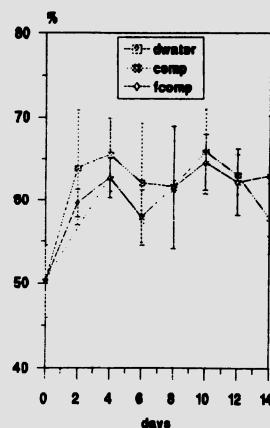


Figure 2c

Figure 2a, b and c. Showing the percentages of fully-developed (a), degenerate (b) and viable (c). *A. galli* eggs observed in the sub-samples from the 4 week old municipal waste compost experiment.

Following the 28 days incubation period, the percentages of fully-developed, viable *A. galli* eggs found from the control, 'filtered compost' and 'compost' environments were all found to be constant ($p < 0.05$), with mean percentages of 63, 60 and 60% and were shown to be statistically similar to one another ($p < 0.05$) (fig. 2c).

The 1 week old compost.

The development of the *A. galli* eggs from the 1 week old 'compost' was retarded when compared with the eggs sub-sampled from the distilled water control and 'filtered compost' environments. Over the 18 day sampling period the increasing percentage of fully-developed eggs was significantly smaller from the 'compost' sub-samples than from the 'filtered compost' and control, which were found to be significantly similar to one another ($p < 0.06$) (fig. 3a). The percentages of degenerate eggs significantly increased over the sampling period in all the environments ($p < 0.05$). Most degenerate eggs were observed in the 'compost' environment, while fewer were observed from the 'filtered compost' and control (fig. 3b).

After the 28 day incubation period, no significant differences were found between the percentages of fully-developed, viable eggs from the three environments ($p < 0.05$) (fig. 3c). The percentages of fully-developed eggs found in all environments were found to be statistically constant with mean percentages of 35, 49 and 36 % from the distilled water control, 'filtered compost' and 'compost' environments, respectively.

Comparison between 1 week old and 4 week old composts.

A comparison of the trends in percentages of fully-developed and degenerate *A.*

galli eggs from the 1 week old and the 4 week old composts was undertaken. Allowances were made for the fact that the experiments were carried out on different occasions and had different controls. Comparing the 'compost' environments prior to incubation, a larger percentage of fully-developed *A. galli* eggs and fewer degenerate eggs were found in the sub-samples taken from the 4 week old compost. After incubation, a greater percentage of eggs from the 4 week old compost were found to be fully-developed and viable.

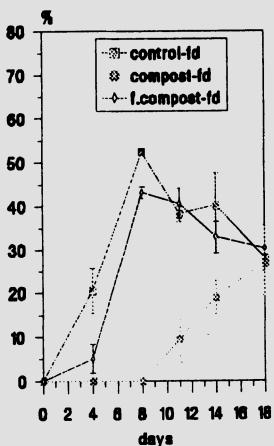


Figure 3a

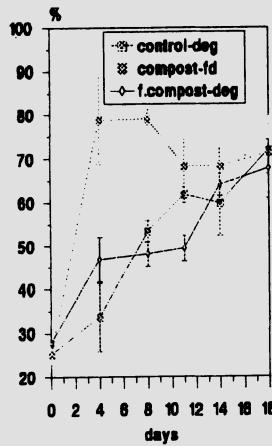


Figure 3b

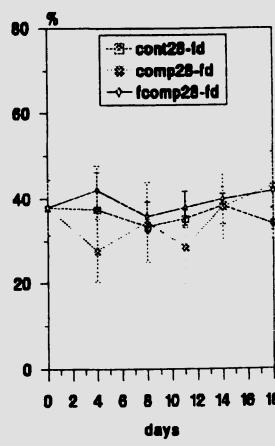


Figure 3c

Figure 3a, b and c. Showing the percentages of fully-developed (a), degenerate (b) and viable (c) *A. galli* eggs observed in the sub-samples from the 1 week old municipal waste compost experiment.

The retarded development of the *A. galli* eggs only under the compost conditions during both experiments, was thought to be a result of the actions of the micro-organisms present in the compost. This was believed to be the case as the development of the eggs suspended in the 'filtered compost' were unaffected by their environment. The 'compost' and 'filtered compost' differed primarily from each other by the presence and absence of micro-organisms.

From the results, it appeared that something within the 'compost' environment and not within either the 'filtered compost' or distilled water control was responsible for the retarded development of *A. galli* eggs.

Once the eggs had been removed from the 'compost' environment and placed in favourable conditions for incubation (in 0.1 N H₂SO₄ for 28 days at 28 °C under non-oxygen limiting conditions), the delay in development was overcome and the observed viability was similar to those eggs exposed to the control and 'filtered compost' environments. The most probable explanation for these observations is that it was the result of microbial action from within the compost environment. It was not believed that the chemical composition of the compost played a role in the delayed development. If this had been the case, one might expect the development of the eggs exposed to the 'filtered compost' conditions to be similar to those from the 'compost' conditions and not that of the distilled water control, as was

observed. The maturity of the compost also was seen to have an effect on the rate of retardation. The more mature the compost, the less the retarding effect it had. This may be explained by the greater microbial action that would be expected during the earlier stages of composting. Specific oxygen uptake rates (method as described by Robinson, 1991, with minor adjustments) were determined for the two composts. The 1 week old compost showed a greater uptake rate than the 4 week old compost, indicating a greater amount of microbial action taking place in the less mature compost.

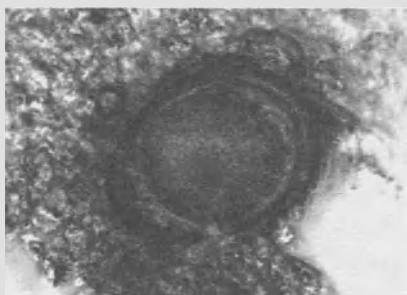


Plate 1 single-cell, undeveloped ascarid zygote



Plate 2 Fully -developed, potentially viable ascarid ova

Conclusions

Compost was shown to have the effect of retarding the development of ascarid eggs for a short period of time. This delay in development of the eggs was greater when the eggs were exposed to more immature compost. Once the eggs were removed from the 'compost' environment and placed into more favourable incubation conditions, the delay in development was overcome and the eggs developed to viable, potentially infective eggs.

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Fate of Lawn Care Pesticides During the Composting of Yard Trimmings

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There is a growing emphasis on the composting of yard trimmings because of governmental bans on land-filling and incineration of leaves, grass and brush in many parts of the U.S. A primary concern with the composting of yard trimmings is the lack of knowledge about the fate of commonly used lawn care pesticides during composting. The purpose of this report is to summarize our recent findings on the fate of the most widely used lawn care pesticides 2,4-D (2,4-dichlorophenoxy acetic acid), Diazinon (O,O-diethyl O-[2-isopropyl-4-methyl-6-pyrimidinyl] phosphorothioate) and Pendimethalin (N-1-[ethylpropyl] 3,4-dimethyl 2,6-dinitrobenzamine) during the composting of yard trimmings.

The extent of 2,4-D, Diazinon and Pendimethalin mineralization, incorporation into humic matter, volatilization, and sorption during the composting of yard trimmings was determined using a laboratory scale compost reactor system described previously by Michel *et al.* (1995). Yard trimmings (2:1 leaves:grass, w/w) were amended with ^{14}C -ring-labeled pesticides at levels usually seen soon after application on grass (10–20 mg/kg dry weight) and water was added to 60% moisture content. The reactor system was programmed to rise from 25 °C to 60 °C over an eight day period and remain at this temperature through day 50. The amount of [^{14}C] remaining in the composts was determined by oxidizing samples and trapping the evolved $^{14}\text{CO}_2$. The extent of pesticide volatilization was determined by passing the exhaust gas through two polyurethane foam traps which were extracted with organic solvents and counted as described by Michel *et al.*, (1995). The distribution of the unmineralized pesticide in various fractions of the compost matrix was determined by sequential extraction of the compost as described by McCall *et al.* (1981). The organic solvents used were: ether for 2,4-D, chloroform for Diazinon, and hexane for Pendimethalin. The amount of [^{14}C] in the humin fractions was determined by oxidizing the extracted compost and trapping and counting the evolved $^{14}\text{CO}_2$. The molecular weight of the humic transformation products in the NaOH extracts was determined by gel permeation chromatography as described by Michel *et al.*, (1995). To determine the potential

for pesticide residue leaching from compost, 10g of the [¹⁴C] pesticide amended composts were pressed with a soil press until no more liquid was expressed and the [¹⁴C] present in the expressed liquid was determined.

Results showed that during composting, 46% of the organic matter (OM) present in the yard trimmings was lost as CO₂, and the compost was stable, with an oxygen uptake rate of 0.09 (mg O₂/g OM/h), and was well humified (humification index = 0.39).

The 2,4-D mineralization was 48% after 50 days of composting. Most of the remaining 2,4-D was transformed into high molecular weight humic compounds or was unextractable (Table 1). In autoclaved control composters, the distribution of 2,4-D remained relatively unchanged as compared to the initial distribution indicating that the mineralization and humification processes were microbially mediated.

Diazinon was not readily mineralized and underwent transformation to products which were water soluble and potentially leachable (Table 1). Thinlayer chromatographic analysis of the water soluble extracts revealed that most of the added Diazinon was converted to the metabolite isopropyl-methyl-hydroxy-pyrimidine (IMHP) by day 10. Two other metabolites, the appearance of which coincided with an increase in the rate of mineralization of Diazinon in the compost, were also observed. About 20% of the ¹⁴C from the ¹⁴C Diazinon was present in the NaOH extractable fraction (Table 1). As with 2,4-D, the ¹⁴C in this fraction had a molecular weight much higher than the parent compound.

Pendimethalin was not readily mineralized and a large fraction (65%) was transformed into unextractable residues during composting (Table 1).

Table 1 Distribution of [¹⁴C] 2,4-D, Diazinon and Pendimethalin in various compost fractions

Fraction	Pesticide ^{a,b}					
	2,4-D		Diazinon		Pendimethalin	
	Initial	Final ^c	Initial	Final ^c	Initial	Final ^c
¹⁴ C-CO ₂	0	47.7 ± 6.7	0	10.9 ± 2.9	0	13.3 ± 4.9
Volatiles	0	0.4 ± 0.2	0	0.18 ± 0.1	0	2.5 ± 2.9
Organic ^d	92.4 ± 2.6	1.3 ± 0.5	82.9 ± 6.7	0.8 ± 0.2	66 ± 8.7	8.2 ± 5.5
Water	3.4 ± 2.2	2.5 ± 0.5	6.7 ± 0.4	36.3 ± 6.6	1.0 ± 0.3	3.9 ± 0.6
NaOH ^e	3.7 ± 0.7	29.1 ± 2.4	4.9 ± 4.4	19.8 ± 3.8	0.3 ± 0.5	6.6 ± 1.0
Unextractable	0.5 ± 0.1	19.5 ± 4.6	5.5 ± 0.6	31.9 ± 1.6	32.6 ± 9.4	65.4 ± 3.6
Recovery ^f	100 ± 4	97 ± 10	91 ± 4	90 ± 11	90 ± 2	96 ± 18

a-Values represent % distribution of added ¹⁴C ± standard deviations for triplicate composters divided by recovery.

b-The initial amount of the pesticides added was 11 mg/kg of 2,4-D, 10 mg/kg of Diazinon and 10 mg/kg of Pendimethalin on a wet weight basis.

c-Final composts after 50–54 days of composting in laboratory scale compost reactor.

d-Organic solvents used were ether (2,4-D), chloroform (Diazinon) and hexane (Pendimethalin).

e-0.1 M NaOH + 0.1 M Na Pyrophosphate.

f-% Recovery equals the amount of radioactivity in the fractions divided by the initial amount of ¹⁴C added.

Leachates from large-scale yard waste composting facilities are of concern since these may contain pesticide and other residues which could contaminate ground water. Although much of the added radioactivity from the ^{14}C pesticides remained in the final compost, much of the parent compound has either been transformed or mineralized or both and less than 2% of the original Diazinon, 1% of the 2,4-D, and 5% of the Pendimethalin was extractable using organic solvents. None of the pesticides was volatilized to any significant extent during composting, even at 60 °C. Most of the 2,4-D was bound to the water insoluble component of the compost matrix and was not readily leachable. Diazinon metabolites on the other hand became more water soluble and in the final compost, more than 30% of the applied ^{14}C was found in the expressed compost liquid. On the other hand, negligible amounts of the Pendimethalin were present in the expressed compost liquid after day 1.

In conclusion, the commonly used lawn care pesticides 2,4-D, Diazinon and Pendimethalin have very different fates during yard waste composting. 2,4-D is rapidly mineralized and transformed into high molecular weight compounds and very little of the added 2,4-D appears to be leachable during composting. Diazinon, on the other hand, is not readily mineralized but appears to undergo rapid transformation to water soluble metabolites during composting. Pendimethalin is converted primarily into unextractable residues. Our results also indicate that active mineralization of 2,4-D and biotransformation of Diazinon and Pendimethalin occurs at thermophilic composting temperatures of 55–60 °C.

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Characterization and Composting of Source-Separated Food Store Organics

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Composting of food store organic wastes is an attractive alternative to incineration, or disposal of these wastes in land-fills. In this study, the total wastes as well as the organic wastes generated by individual departments in a typical U.S. food store were quantified and characterized and the organic fraction of the wastes was composted with leaves to determine the qualities of the finished compost.

The volumes of total wastes generated at a representative food store which currently recycles corrugated cardboard, aluminum, plastic pallet wrap, wood pallets, polystyrene, meat scraps, plastic grocery bags and out-dated and damaged items was determined. The total amount of wastes generated was $1.90 \pm 0.32 \text{ m}^3/\text{d}$ which represented an average of $0.35 \pm 0.03 \text{ m}^3/\text{employee/week}$ and with an average bulk density of 79 kg/m^3 . Paper bags and boxes used by customers to return cans and bottles, and waste generated at check-out stands (bottle/front end) constituted the greatest portion of waste ($0.53 \text{ m}^3/\text{d}$) by volume. However, this waste had a low bulk density (13 kg/m^3) and accounted for only 6% of the total mass of waste generated. The produce, bakery, and delicatessen departments, respectively, accounted for 32%, 26%, and 21% of the total store waste by weight, and had high bulk densities of 241, 105, and 116 kg/m^3 .

The wastes collected from each department were sorted and weighed to determine the relative amount of organic and non-compostable material produced in each department. The results showed that organics account for an average of 81% of the total wastes generated. In general, the compostable fraction was more dense than the non-compostable fraction (which was largely plastic containers and plastic film) such that only 64% of the total waste on a volume basis was compostable.

The organic fractions were reduced to a particle size of between 3 to 30 mm using a garden shredder and/or hammer mill. The moisture contents varied between 6.6% (bottle return/front end section) and 83% (produce section) and the organic matter contents were high (> 93%). Organic wastes from the delicatessen, dairy and bakery departments had C:N ratios of 21, 21 and 17, respectively. The

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floral and produce department wastes had C:N ratios of 31 while the bottle/front end department organics had a C:N ratio typical of paper wastes (C:N = 52:1).

The organic waste fractions were mixed in relative proportion to the total volume of these wastes produced by the food store chain as a whole and the moisture content was adjusted by adding dry leaves and water to give an initial moisture content of 55%. Three feed stocks were composted; the store organics alone, and 1:1 (Mix 1) and 1:2 (Mix 2) mixtures of store organics and leaves. Composting was done in a controlled laboratory scale compost reactor system which simulates the temperature (60 °C) and aeration environment found during windrow composting of yard trimmings (Michel *et al.* 1993).

The food store organics alone made a poor compost feed stock in that less than 1% of the organic matter was converted to CO₂ during the first 10 days of composting. A strong fatty acid odor developed and the oxygen uptake rate, an indicator of microbial activity, was relatively low (0.9 mg O₂/g OM/hr) as compared to a value of 2.3 mg O₂/g OM/hr for fresh leaves and between 1.5 and 1.9 mg O₂/g OM/hr for Mixes 1 and 2, respectively. The low initial pH (4.8) of the store organics did not change during the first ten days of composting. The slow composting rate for the store organics may have been due to this low pH which would be expected to inhibit microbial growth. Because of the poor composting properties, the composting of the food store organics alone was stopped after 10 days.

At the end of 54 days of composting, 60% of the organic matter originally present in Mix 1 and 47% of that present in Mix 2 was lost. The rate of organic matter loss from Mix 2 was relatively rapid even after 54 days of composting, while the loss of organic matter from Mix 1 slowed considerably after 40 days. The pH of the mixes climbed to pH 8.1 within 10 days and remained at that level through the end of the composting run.

Table 1 Characteristics of composts produced from two mixes of food store organics and leaves

Characteristic	Mix 1 (1:1) ^{a,c}	Mix 2 (1:2) ^{a,c}
Organic matter content (%)	53	54
Carbon (%)	27.8	28.8
Nitrogen (%)	2.3	1.8
C:N ratio	12	16
pH	8.15	8.20
Nitrogen loss (%)	25	17
Total phosphorus (%)	0.35	0.24
Total potassium (%)	0.91	0.50
Soluble salts (mMho)	4.75	2.34
Sodium ^b (ppm)	510	210
Chloride ^b (ppm)	2042	986
Stability (mg O ₂ /g OM/h)	0.09	0.19
Humification Index	0.19	0.22

a-Values are averages for replicate composters.

b-Values are averages for duplicate experimental runs determined by the water saturation method (Wade and Krauskopf 1983).

c-Mix 1 contained leaves:stores organics 1:1 and Mix 2 contained leaves: stores organics 2:1 on a dry weight basis.

The characteristics of the final composts produced from Mixes 1 and 2 (see Table 1) indicated that both Mixes had undergone extensive changes during the 54 day composting period. The GM ratio of the final composts was 12 for Mix 1 and 16 for Mix 2, down from the initial values of 32 and 36, respectively. At the end of composting, approximately 5 mg of nitrogen was lost per gram (dry weight) of Mix 1 but only 1.5 mg of nitrogen was lost per gram of Mix 2.

An analysis of the total amount of various mineral nutrients present in the finished composts from the two mixes showed that Mix 1, which contained 50% store organics, had roughly twice as much sodium, potassium and phosphorus as Mix 2, which contained 33% store organics (Table 1). Water saturation extracts (Warnke *et al.*, 1983) of the finished composts from Mixes 1 and 2 both had low levels of nitrate and acceptable levels of phosphorus (Warnke and Krauskopf, 1983). The levels of magnesium, calcium and potassium, which compete for similar uptake sites in plants, were relatively unbalanced. Unacceptably high levels of available potassium, sodium, and Chloride were observed in both finished composts (Table 1).

The composts were stable and well humified after 54 days of composting. Mix 1 had an oxygen uptake rate of 0.09 while compost derived from Mix 2 had an O₂ uptake rate of 0.19. Both Mix 1 and Mix 2 had humification index (Sequi *et al.*, 1986) values of less than 0.4 indicating that both samples were well humified.

In conclusion, a large proportion (81% by weight) of food store wastes are compostable organics. These organics have a high bulk density, a high moisture content, a low C:N ratio and a low pH which make them difficult to compost without amendment. Amendment of store organics with leaves at a 1:1 and 1:2 ratio led to rapid rates of organic matter conversion, and the production of a stable and well humified compost end-product. The final composts produced were rich in mineral nutrients; however, the relative amounts of these nutrients were somewhat unbalanced. High salt levels were associated with higher levels of food store organics in the composting mix.

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Heavy Metals Determination in MSW Merceological Classes and Derived Compost

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Introduction

Heavy metals (HM) are both hazard to human health and risk to the environment, the presence in composts has been established as the main problem involved in their use. The HM that are considered in Italian legislation are As, Cd, Cr, Cu, Hg, Ni, Pb, Zn and limits are fixed for them in the compost and in soil (Ref. 1). This paper deal with the HM content in Municipal Solid Waste (MSW), the relative distribution in the different merceological classes and the influence of each class on the compost characteristic. This is a focal point to select the method to reduce HM content (possible methods are for example: discarding screening fraction, preselection of waste, collection of refuse in separate bins, treatment technology to produce compost poor in HM) (Ref. 2, 3).

In this paper were considered samples of wastes collected in three areas, characterized by a different human activities, in the Province of Mantova, North Italy. Generally is very difficult to realize a correct balance Input/Output of HM in a wastes treatment plants due to the heterogeneity of the original material, different humidity percentage, different organic content, presence of hazardous wastes. This explains the difficulty in obtaining statistically meaningful samples on which carry out the pollutants trace analysis (Ref. 4).

To obtain a correct balance is necessary to use a correct methodology, including the following step: knowledge of the characteristics of refuse; principal productive activities in the area; diffusion of waste's separate collection; merceological analysis of material in input to the composting plant; analytical analysis for determination of content in HM in each MSW merceological class; evaluation of HM presence in the final product (compost); knowledge of technological condition and working process of plant.

Experimental

In the province of Mantova sixtynine towns are involved in the 'CIME' consortium, and in this area were collected the samples of waste analyzed refered to three town: city of Mantova, main city of the province (about 150.000 inhabitants), S.Benedetto Po, (characterized by a high penetration of pubblic separated collection of refuse), and Revere, (where the agriculture is the prevailing activity). The composition of waste was determined as indicated by official methods (Ref. 5), and the analysis were conducted as reported in bibliography (Ref. 6). The merceological classes composition is reported in Tab.1.

Table 1 MSW merceological composition (1992)

Merceological Class	Province of Mantova %	Italy %
Umidity	39	35
Textiles- Wood	11	9
Waste size 0 -20 mm	18	10
Paper – Cartboard	23	28
Plastic – Rubber	13	15
Metals	5	5
Glass	3	5
Organic substances	26	28

Materials as batteries, glasses, papers, pharmaceutical products are collected separately in the three town considered and in S. Benedetto Po the pubblic collection is extended to some patrts of wood and textile also.

The contents of HM in the different merceological classes is reported in Tab.2 . After the treatment of refuse in the preselection plant (DANEKO), the output material used to prepare the compost was composed respectively by 55% of waste size from 0 to 20 mm, 41% by organic substances and 3% by other classes of material (wood, paper, cartboard). During the composting process, the mass is subject to a relevant contraction of volume and weight (3:1) that caused a concentration of contaminants in the final product.

The teoric HM values estimated on the basis of HM content in the different merceological classes , the analytical values obtained and the law limit values(Ref. 1) are reported in fig.1. . No significative differences are found between teoric and mean analytical values for copper, nickel and lead, while for zinc the difference is significative. The maximum analytical values registered for Cadmium, Chromium and Nickel are near to teoric values. Arsenic and Mercury are present in compost in very low quantity (Ref.3)

Table 2 Heavy metals in MSW merceological classes (mg/kg)

Merc Cl.	Area	As	Cd	Cr	Cu	Hg	Ni	Pb	Sb	Zn
MSW	S. Ben	1,1	5,1	239,4	709,6	2,8	102,6	86	1,8	709
	Revere	4,8	0,7	41,8	37,5	12,0	46,9	62	0,3	38
	Mantova	1,4	0,1	4,2	37,9	11,7	2,1	118	n.d.	38
	Mean	2,4	2,0	85,1	261,7	8,8	50,5	89	0,7	262
waste size 0–20	S. Ben.	1,6	15,0	59,9	184,0	3,6	258,6	155	1,3	184
	Revere	1,8	1,2	24,6	34,7	4,8	20,6	56	0,2	35
	Mantova	4,4	0,5	1,5	82,0	25,5	2,9	106	0,1	82
	Mean	2,6	5,5	28,7	100,0	11,3	94,0	106	0,5	100
textiles	S. Ben.	0,9	3,8	41,3	27,9	n.r.	18,2	123	2,4	28
	Revere	n.d.	1,1	302,9	42,3	7,8	14,8	45	n.d.	42
	Mantova	1,4	1,4	n.d.	30,0	8,0	2,7	50	2,8	30
	Mean	0,7	2,1	114,7	33,4	5,3	11,9	73	1,7	33
wood	S. Ben.	n.d.	3,7	n.r.	22,7	3,3	31,2	15	0,6	23
	Revere	n.d.	0,3	4,5	17,2	5,7	n.d.	60	n.r.	17
	Mantova	n.d.	0,1	1,2	10,9	3,9	n.d.	75	n.d.	11
	Mean	n.d.	1,4	1,9	17,0	4,3	10,4	50	0,2	17
paper	S. Ben.	2,8	6,2	n.d.	150,7	n.r.	19,6	51	0,2	151
	Revere	1,7	0,7	8,6	19,7	6,5	4,9	98	0,2	20
	Mantova	n.d.	n.d.	n.d.	16,9	9,9	n.d.	96	n.d.	17
	Mean	1,5	2,3	2,9	62,4	5,5	8,2	82	0,1	62
cartb.	S. Ben.	0,8	2,8	23,1	25,0	n.d.	25,7	36	1,7	25
	Revere	0,7	0,6	n.d.	29,7	2,1	n.d.	n.d.	0,6	30
	Mantova	n.d.	n.d.	0,9	66,4	5,2	7,8	45	n.d.	66
	Mean	0,5	11,1	8,0	40,4	2,4	11,2	39	0,8	40
film pl.	S. Ben.	2,7	5,7	n.d.	117,7	5,7	12,7	278	3,4	118
	Revere	0,2	0,8	47,8	31,2	6,9	29,7	216	3,9	31
	Mantova	2,5	n.d.	45,0	18,0	3,4	n.d.	806	n.d.	18
	Mean	1,8	2,2	31,0	55,7	5,3	14,1	433	2,4	56
hard pl.	S. Ben.	n.d.	4,6	n.r.	28,6	2,8	179,7	91,	4,9	29
	Revere	n.d.	n.d.	18,5	32,9	1,8	n.d.	34	3,8	33
	Mantova	n.d.	0,7	n.d.	18,1	n.d.	n.d.	35	5,7	18
	Mean	n.d.	1,8	6,2	26,5	1,5	59,9	53	4,8	27
org. sub.	S. Ben.	0,2	5,0	26,6	44,6	8,9	22,0	53	n.r.	45
	Revere	22,4	0,9	19,3	31,7	2,2	12,2	31	n.r.	32
	Mantova	n.r.	n.r.	5,3	29,0	10,3	2,3	33	0,14	30
	Mean	7,5	2,0	17,1	35,4	7,2	11,9	39	0,05	36

Legend n.d. = not detectable

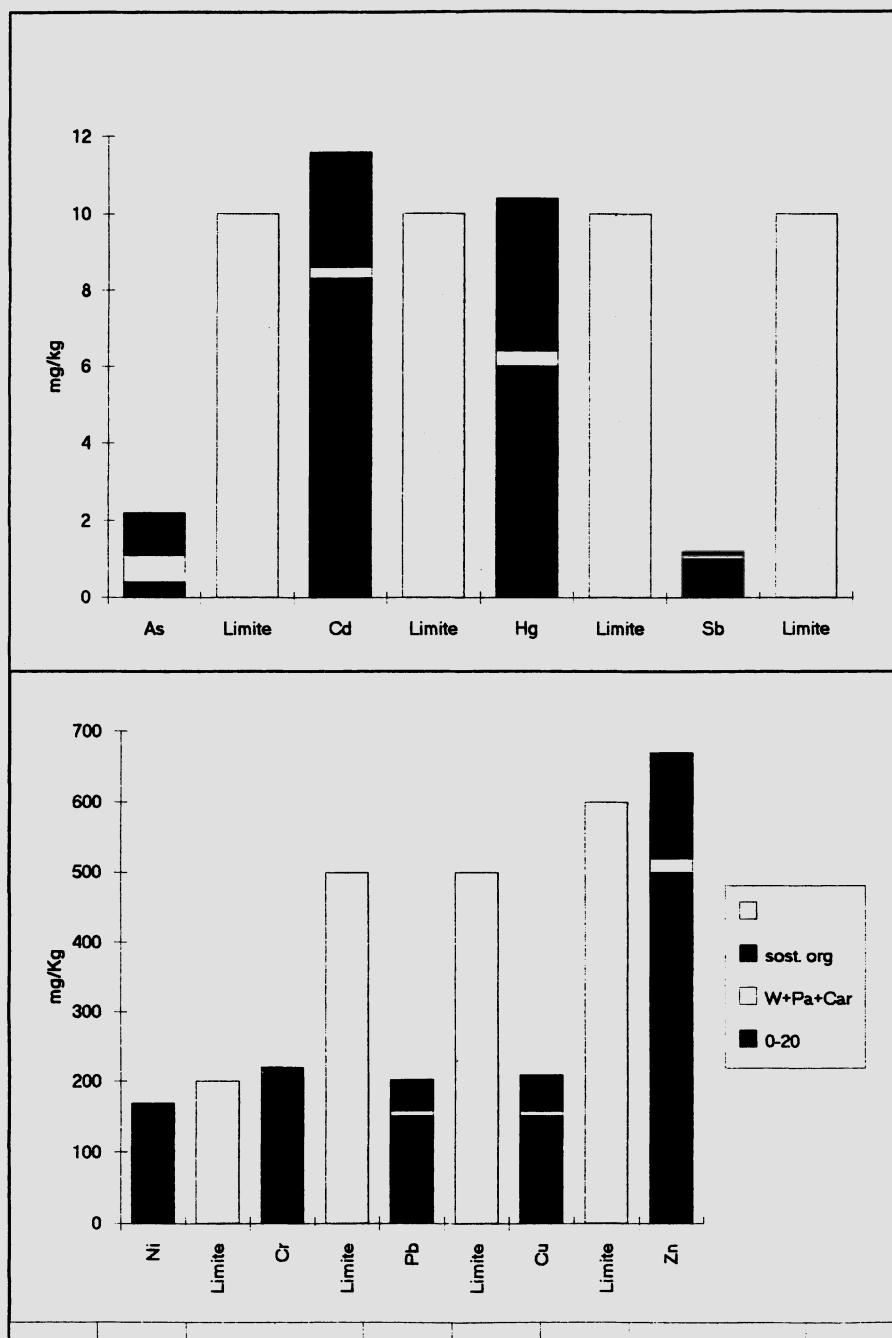


Figure 1 HM teoric values estimated/law limits

Conclusion

The nature of the heavy metals in municipal refuse influence the amount of HM in compost; fine fractions of refuse (<10 mm) are responsible for most of the heavy metal burden. In addition, batteries (mercury, cadmium and zinc), leather (chromium), paint (chromium, cadmium, lead, cadmium), plastics (cadmium) and paper (lead) have fallen under suspicion. Other studies (Ref. 3) find that 'the native organic fraction' >40 mm, purified manually from remaining paper, plastics, glass, visible metal pieces and other nonorganics was characterized by high concentrations of Pb, Zn, Hg, Cu and Cd. Further information concerning the nature of the heavy metals in the dense fraction was obtained by microscopical examination: metallic particles and particles of metallic oxides were found in the dense fraction of <8 mm, 8–40 mm and >40 mm organic material as well as in the corresponding fraction of paper and plastics.

Potential lead sources are: pieces of lead-foil (e.g. from caps of wine bottles or from polaroid films), silver tinsel, bullets of air-guns, solder. Copper was mainly found as wire and as particles of brass (small cog-wheels, snap fasteners, zip fasteners, refills of ball pens). Zinc was found as foil-pieces and as brass. It is important to note, that small particles as pieces of copper wire was found in the <8 mm material as well as in the >40 mm material.

High amount of HM in compost seem to be the main problem related to inorganic pollutants. Fine fraction of refuse (<20 mm) are responsible for most of the HM burden (Ref. 8).

In order to reduce the heavy metal content in compost the possible measures are :

- separation of magnetic sensitive material
- separation of sieve fractions e.g. rejection of the <10 mm-material
- processing of matured compost (e.g. stoner or air table)
- public collections of domestic hazardous wastes
- another method of separating heavy metals from the remaining waste is to take advantage of their high density using air classification.

In addition there are some attempts to separately collect the non-polluted organic fraction (wastes from kitchen and garden).

Compost from municipal refuse poor in heavy metals can be obtained by different attempts. The most promising are separate collection of biomass and sophisticated technology for waste treatment using the physical properties of metals (such as their high density). Intensive public heavy metal collection (e.g. by small plastic bags) is useful in addition to 'traditional' composting plants.

This paper represent an approach to understand the sources and fate of HM in composting process and to prevent contaminations between correct input materials, composting techniques, working process of plants to refer law limits.

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***Giardia* Die Off in Anaerobically Digested Wastewater Sludge During Composting**

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Introduction

In the Perth metropolitan area, sludge from primary and secondary treatment is anaerobically digested in a two phase, mesophilic process, before being dewatered by belt press or centrifugation. Currently, all of the sludge produced is either stored on site, or composted by contractors and sold as a soil amendment. The composting processes and the quality of the marketed product are currently not subject to regulation. However, sludge use guidelines are expected to be released, which will specify a range of requirements for sludge based products intended for land application.

Previous research by Gibbs et al. (1994) and Hu (1994) has suggested that current sludge composting practices by at least one commercial operator in Perth are inadequate for pathogen destruction and result in a product which contains levels of salmonellae which are above the levels set in US EPA, Queensland and New South Wales sludge guidelines for sludge products suitable for unrestricted marketing (Beavers, 1993; Ross et al., 1991; Sieger, Hermann, 1993).

Research was undertaken to assess and optimize compost substrates containing anaerobically digested sewage sludge in terms of maximising pathogen die-off. Substrates were composted in small scale reactors, prior to selecting promising substrates for larger scale studies. The concentrations of a number of micro-organisms were monitored, including salmonellae and faecal coliforms. This paper focuses on *Giardia* die-off during anaerobic sludge composting in the small scale reactors.

Methods

Composting. Substrates were composted in 30 litre, insulated, polyethylene bins. Humidified air was passed through the bins at a rate of $1 \text{ l}.\text{min}^{-1}$ below 55°C . At

temperatures above 55 °C, air flow was increased to 3 l.min⁻¹. The system was developed for research by Hofstede (1994).

Six mixtures were selected in order to achieve initial C:N ratios (TOC:TKN) of greater than 20, moisture contents of between 50 and 60% and an approximately 3:1 ratio of bulking agent to sludge by volume. Substrate 5 contained unamended sludge to act as a control. A mixture of red mud (a bauxite refining residue) and 10% gypsum was added to substrates 6 and 8 to assess its effect on pathogen die-off.

Table 1 Compost mixtures used for pathogen die-off experiments

Material (kg)	1	2	3	4	5	6	7	8
Sludge	7.55	6.61	6.78	4.94	10	10	5.53	5.53
Skimmings	—	—	0.68	—	—	—	—	—
Brewery Waste	—	0.66	—	—	—	—	—	—
Grass Clippings	—	—	—	0.49	—	—	2.6	2.6
Sawdust	—	—	—	—	—	—	1.3	1.3
Shredded Tree Waste	3.3	3.3	3.3	3.3	—	—	2.6	2.6
RMG	—	—	—	—	—	1.11	1.05	—
GM ratio	23.0	31.98	34.74	39.32	7.48	7.48	19.51	19.51
Moisture Content	60.27	59.44	58.22	53.92	79.3	73.22	59.01	64.19

Sampling. Samples were made up of approximately 20 × 25g sub-samples, taken randomly throughout the top two thirds of the compost mixture. Samples were taken with sterile spatulas or forceps and stored in sterile 2 litre plastic beakers. Samples were homogenized by adding 500 ml of sterile PBS (phosphate buffered saline) and mixing with a long sterile spatula or a sterilized hand held kitchen blender. Samples were analyzed for total and volatile solids (APHA et al., 1989) and pH (1:10 dilution).

Microbial analysis. Giardia, faecal coliform and faecal streptococci concentrations in the homogenate were determined using the method described by Gibbs et al. (1993).

Results and Discussion

The temperature, pH and solid loss of each compost substrate is summarised in table 2. Temperature profiles of compost mixtures were below those specified in the US EPA sludge use guidelines for processes for the further reduction of pathogens, despite efforts to optimize starting conditions. This appeared to be due to a lack of insulation in the small scale bins. A 100m³ enclosed forced aeration static windrow of substrate 2 maintained temperatures through out of greater than 55 °C for five days (unpublished data).

Samples for microbial analysis were taken at the start of composting, after the completion of the thermophilic phase, and one week after the end of the ther-

mophilic phase. Giardia concentrations in mixtures 1–8 are shown in figure 1. The variation in initial concentrations is a result of dilution effects and variations in cyst recovery associated with the method used (60–99%, unpublished data).

Table 2 Summary of compost performance of substrates 1–8 in small scale reactors

Substrate	Temp. (Max.)	Days Temp. > 55 °C	Days Temp. > 45 °C	Min. pH	Max. pH	Total Solid Loss (kg)
1	46.1	0	3.12	6.55	8.40	0.08
2	52.9	0	1.38	6.65	8.67	0.48
3	57.6	0.33	2.00	678	9.02	0.38
4	52.3	0	4.17	7.35	8.46	0.23
5	31.1	0	0	7.10	8.31	0.38
6	26.7	0	0	7.02	8.15	0.68
7	52.7	0	1.62	6.64	8.06	0.38
8	59.0	0.79	1.67	6.5	8.18	0.68

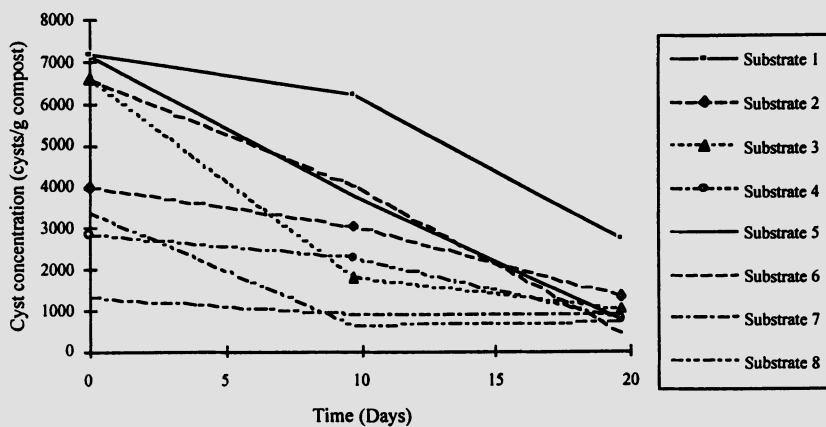


Figure 1 Giardia concentrations in compost substrates over time

For runs 1–8, final concentrations of Giardia cysts remained high, ranging from 4.8×10^2 cysts g⁻¹ to 2.76×10^3 cysts g⁻¹. According to Gibbs et al. (1993), an individual ingesting 100 viable cysts has a 25% chance of contracting Giardiasis. At the highest level observed in the final product, 0.04g of compost contained 100 cysts. Unfortunately, the viability of the isolated cysts could not be determined due to the lack of a suitable method, although only intact cysts were counted.

No significant correlation between the concentration of Giardia cysts at the end of the composting process and the concentration of indicator organisms (fecal coliforms and fecal streptococcus) was observed (Mort 1995).

No significant differences between individual treatments (including a sludge only control) and die-off rates, log reduction times or final cyst concentrations were identified. High temperatures and moisture loss did not appear to promote

the reduction of Giardia concentrations in the compost. Cyst concentrations and log cyst concentrations for each sample were pooled and compared to a range of factors such as moisture content, volatile solids, pH, faecal coliform and faecal streptococci concentrations. Again, no significant associations were identified. No effect on Giardia reduction from the addition of RMG was observed. However, differences between initial and final concentrations across all bins were significant (Mort, 1995).

Using the same methods as were used in this study, Gibbs et al., (1994) examined Giardia die-off in stored sludge over one year. In the first four weeks, a rapid decrease in Giardia concentration from an average of 4000 cysts per gram of sludge to 1000 cysts per gram was observed. Interestingly, after 60 weeks, Giardia concentrations remained around 1000 cysts per gram.

Conclusions

Based on this short term study, composting as a means of reducing Giardia cyst concentrations does not appear to be any more effective than simply storing the sludge over a similar period of time. Greater cyst destruction may occur in larger, more insulated systems which allow high temperatures to be maintained over longer periods.

Although Gibbs and Ho (1993) found that one of the greatest risks associated with sludge re-use was Giardia infection, the validity of monitoring Giardia cysts in a compost system has not been established. A means of testing the viability of Giardia cysts in sludge samples needs to be developed before the significance of cysts in garden products can be assessed, particularly given some reports that the viability of seeded cysts under mesophilic anaerobic digester conditions is reduced by 99.9% (Van Praagh et al., 1993; Gavaghan et al., 1993).

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Effect of Sweet Sorghum Bagasse Compost on Sweet Sorghum Productivity in Pots.

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Abstract

The main purpose of this work is to study the effect of sweet sorghum bagasse compost application on biomass production of sweet sorghum (*Sorghum bicolor* (L.) Moench cv Dale). Biomass production was studied in terms of dry matter and stalk sugar content, at the end of the crop cycle. The addition of compost to soil produced significant increases on sorghum productivity with regard to the control. Best results have been achieved with the composts obtained from a sweet sorghum bagasse and pig manure mixture (30t/ha). In this case, the aerial dry biomass increments with regard to the mineral fertilizer treatment was 37%, where the irrigation was 2/3 of the available water.

Introduction

In the late years, sweet sorghum is being considered as a potential alternative crop for energy and industry (1) mainly because it can yield high biomass productivities as well as fermentable sugars.

Sugar extraction from sorghum stalks provides a cellulosic residue - bagasse- as byproduct. This residue represents about a 40% of the plant fresh weight and its elimination and recycling through composting has a great interest.

Different kinds of composts were obtained by using the bagasse of sweet sorghum as the main substrate when mixed with other types of residues. In general, all the products obtained had physical, physico-chemical and chemical characteristics suitable for being used in agriculture. However, it should be taken into account that physico-chemical characteristics of sorghum compost only provides an approximate information about its capacity as a fertilizer, because it is only

possible to obtain a more accurate idea of the compost efficacy through the vegetal response. According to this, this work has been focused to the study of the effect that these composts could produce on a sorghum crop.

Materials and methods

In order to study the effects of compost addition to soil on sorghum growth and productivity. *Sorghum bicolor* vr. Dale was grown in 32 l capacity pots in open land. A poor soil from an agronomical point of view was used (pH 7, 0.6% organic matter, 0.05% total nitrogen and 6.5 and 25 ppm assimilable P and K respectively, texture: 68% sand, 26% silt and 6% clay). Two different composts were used. One of them was obtained from sweet sorghum bagasse and sewage-sludge mixture (SBSS) (75% organic matte, 39% carbon, 3% total nitrogen, 2% P₂O₅, 0.7 K₂O, pH (1:5 w/v water extract) 5.3, electrical conductivity (1:5 w/v water extract) 2.98 mmhos/cm) and the other one from bagasse and pig manure mixtures (SBPM) (75% organic matter, 37.6% carbon, 3% total nitrogen, 3.7% P₂O₅, 1% K₂O, pH 6.0, 3.4 mmhos/cm electrical conductivity).

Composting was performed in turning piles. The doses of compost from sorghum bagasse and pig manure added to the soil were 15 and 30 t/ha whereas in the case of the compost from sorghum bagasse and sewage sludge only the 15 t/ha dose was applied. In all cases, pots were supplemented, when it was necessary, with N, P, K mineral fertilization up to complete the following equivalent doses: N 120 Kg/ha, P₂O₅ 90 Kg/ha and K₂O 90 Kg/ha, considering that the annual availability of nitrogen, phosphorous and potassium from compost was taken to be equal to one third of the total N, K, and P contents. In order to study the influence of composts addition on the soil water retention, two different irrigation regimes were utilized (1/3 (I_{1/3})and 2/3 (I_{2/3}) available water). Fifteen pots were tested for each treatment.

Unamended soils was used as a control. The crop was stablished on May 26th 1994 at CEDER in Lubia (Soria, North-central Spain Region) the harvesting was made on October 11th 1994.

The effect of compost was studied concerning to the following parameters: a) biomass production, results were expressed in Kg dry matter/m² and b) stalk sugar content. Sugar content were determined by HPLC. Results were expressed in percentage on stalks dry weight basis (glucose+saccharose+fructose).

All data were subjected to an analysis of variance (ANOVA).

Results

Compost obtained out sorghum bagasse and pig manure mixture, at 30t/ha dose, yielded highest productions either in total or aerial dry biomass in both irrigation rates, even yields higher than those reached with inorganic fertilizer were obtained

(table I). When 15t/ha of this compost was added the yield obtained was similar to those reached with the inorganic fertilizer.

Table 1 Roots dry weight (RDW), aerial dry weight (ADW), total dry weight (TDW) production and total sugar content (TSC) percentage.

Irrigation rates		CONTROL	INORGANIC FERTILIZER	SBPM 15t/ha	SBPM 30t/ha	SBSS 15t/h
I2/3	RDW kg/m ²	0.7c	1.4b	1.6ab	1.4ab	1.1c
	ADW kg/m ²	1.4c	3.4b	3.5b	4.5a	2.7b
	TDW kg/m ²	2.2d	5.1b	5.1b	6.2a	3.8c
	TSC (%)	17.2a	21.3a	20.3a	22.8a	21.0a
II/3	RDW kg/m ²	1.0c	1.9a	1.6b	1.5b	1.1c
	ADW kg/m ²	1.4b	3.5a	3.6a	4.4a	3.8a
	TDW kg/m ²	2.5c	5.6a	5.4a	5.8a	3.9b
	TSC (%)	17.3a	20.6a	20.4a	19.6a	20.0a

Figures followed by same letter in the same line are not significant different (p<0.05).

These results are similar to those reported by other authors (2).

Lowest yields were obtained when compost from sorghum bagasse and sewage sludge mixture at a 15 t/ha dosage was applied, that could be due to the compost itself or to a lowest organic matter mineralization rate, for this reason it could be necessary further studies in next years, in order to study the residual effect of the organic matter in the soil.

No significant differences were found between the two irrigation rates, except as far as roots are concerned when mineral fertilizer was used. Higher yields were obtained with the lowest irrigation rate.

Figure 1 shows the effect of the type of fertilization on the aerial dry biomass yield respect to the control (non amendment). When compost SBPM was utilized at a loading rate of 30t/ha the aerial biomass production is three times higher than the control, which resulting in 37% increasing yields compared to chemical fertilizer addition.

Concerning to stalk sugars production no significant differences between treatments and irrigation regimens, were observed. These results are similar to those obtained by Dercas and cols (3).

Sugar concentration ranged about 20%. Their production is considered far below the results cited in literature for this cultivar. This could be due to the low temperatures registered by September-mids (average temperatures lower than 10°C) what could have been resulting in that the cycle were not finished and then, the metabolism for sugar production had not been produced. Alternatively, this result could be related to an insufficient potassium fertilization.

To conclude, and according to the results obtained it can be said that compost utilization as soil amendment could reduce the amount of commercial nitrogen fertilizer applied, since the yields obtained with the assayed composts were similar or even higher to those obtained when inorganic fertilizer was used.

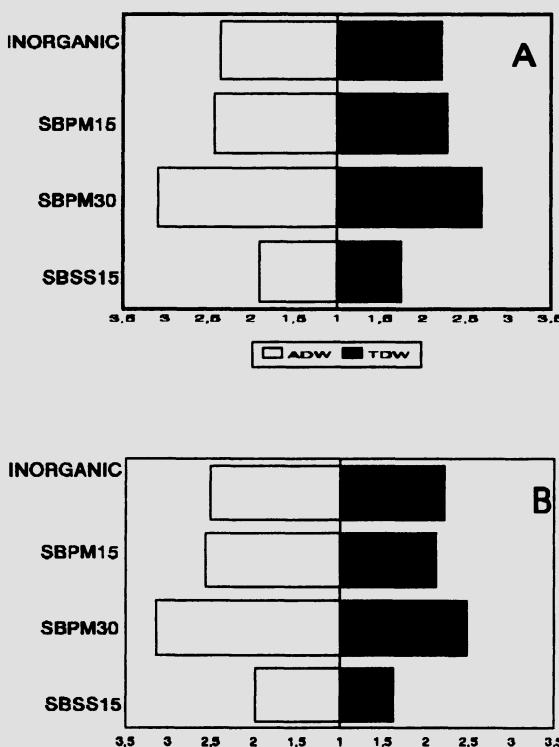


Figure 1 Relative values compared to the control(treatment biomass productivity/control biomass productivity)

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The Compodan Composting Process Features Rapid Process Set-off, Uniform Process Conditions and a Built-in Biofilter.

LARS KROGSGAARD NIELSEN

The composting plants for source separated household waste in Aarhus, Denmark, and Creusot-Montceau, France, are designed for the newly developed and patented Compodan process. The plant in Aarhus was put into operation in March 1995. The Compodan process features rapid process set-off, uniform process conditions and a built-in biofilter. In the reactor, the waste admitted on a daily basis is decomposed in 35 days.

The reactor is divided into at least 4 no-separated zones according to the extent of decomposition. The waste is introduced into zone 1 and compost is removed from zone 4, after being transported through the zones.

For the Compodan process a special aeration system design is applied. The process air from zones 2 and 3 is sucked out and recirculated to provide uniform process conditions in the compost.

Part of the air recirculated from zone 2 is blown through zone 1 from the bottom to heat the incoming waste so that the process sets off rapidly.

All exhaust air is sucked out through zone 4 and emitted into the atmosphere through a stack. The exhaust air is replaced by fresh air from the surroundings. Zone 4, which contains the most stable compost, thereby functions as a biofilter incorporated into the reactor where the filter material is continually renewed.

The air supply to zones 2 and 3 is adjusted according to a temperature set-point which ensures optimum decomposition. By sucking the process air down through the material an average air temperature is measured for each zone.

The Compodan process is developed on the basis of previous test results with one-way air injection (temperature set-points) and a dynamic model that simulates the composting processes in general. The dynamic model calculates the mass balance of decomposition of volatile solids, evaporation of water and amount of air injected to keep a steady temperature. The energy balance is calculated of energy generated from the decomposition, energy loss to heat up the air and waste, to evaporate the water and for conduction.

Compodan-process

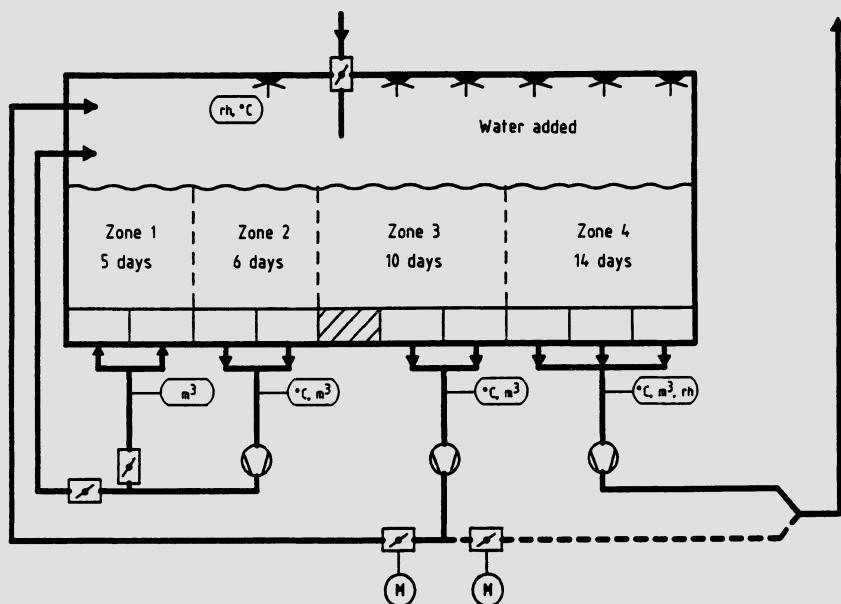


Table 1 Results of a static model for the air parameters of the Compodan process per metric ton of waste.

		zone 1	zone 2	zone 3	zone 4	zone 5
Retention time	days	5	6	10	14	-
VS decomposition	% of VS-start	10	19	14	5	-
Air flow	m ³ /h	3.5	10.5	10.5	9.5	-
Air flow	m ³ /(h*dry ton)	9.0	26.9	26.9	24.4	-
Energy to air	kJ/h	393	1124	828	296	-
Energy to air	kJ/kg	111	104	76.1	29.9	-
Temperature, air	°C	60	55	55	55	47.6
Relative humidity, air	%	99	98	90	76	100
Water, air	kg/kg	0.152	0.112	0.101	0.0836	0.0792
Enthalpy, air	kJ/kg	457	346	319	273	244

A static model for the air parameters in the Compodan process has been developed for the 4 zones and the air chamber over the compost (zone 5). Results of a calculation with the model based on data from Aarhus are shown in table 1.

Air flow through zones 2, 3 and 4 is calculated to be 10.5, 10.5 and 9.5 m³/(h*ton added waste) of which 3.5 m³/(h*ton added waste) is led to zone 1. In zone 5, air temperature is 47.6°C and relative humidity exceeds 100%.

The calculation is based on the assumption that the waste received contains 40% DS, of which 65% VS, and based on a retention time of 5, 6, 10 and 14 days, respectively, a corresponding VS degradation of 10, 19, 14 and 5%, respectively, and a relative humidity of 99, 98, 90 and 76, respectively in the 4 zones. The assumptions are shown in bold in table 1.

Until now no empirical data from the plant in Aarhus are available about the

relative humidity in the process air. It seems reasonable that the value is dependent on the water content in the compost. Therefore a mathematic equation describing the relative humidity as a function of water content in the compost is used. Other variables such as the structure of the compost, the air velocity through the compost and the temperature may influence as well.

Based on the assumption that the compost contains 65% DS, the model calculates the water balance (per ton of waste); 610 kg H₂O in waste, 85 kg H₂O is generated during the respiration (0.7 kg H₂O/kg VS decomposed), 106 kg H₂O is added to fit the energy balance, 657 kg H₂O evaporates and 144 kg H₂O is found in the compost.

The energy balance shows that a total of 2385 MJ/ton of added waste is produced and 179 MJ is introduced with the air. 2266 MJ is refound in the exhaust air as the major part of the energy produced is consumed for evaporation of water. 167 MJ is used for heating of the waste and only 131 MJ is lost to conduction as the reactor is presumed to be insulated.

It is planned to combine the static and the dynamic model to achieve a dynamic model for the Compodan process. The model must incorporate empirical data about water evaporation to predict the relative humidity in the process air.

Demonstration of the Influence of Mg Vermiculite on the Activity of Cellulosic Agents and Diazotrophs During Composting of Lignocellulosic Residues

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Introduction

Adsorption and desorption properties, of a magnesian vermiculite (VMg), have been used to follow the dynamic of the NH_4^+ ion ,which has been produced during the ‘cellulolytic-diazotroph’ association appeared during the aerobic fermentation of a mixture of wheat straw and poplar sawdust. This fermentation has been regularly followed for three months in a mini digestor, and temperature, ventilation, pH, humidity, and C/N ratio of macro-elements were controlled. The same is done for the associative activity of cellulolytics and diazotrophes (NUNTAGIJ, *et al.*, 1989). However, if fermentation is not carried out under optimal conditions, there is a loss of ammoniacal nitrogen, and that often occurs during large scale composting of organic residues (MARTIN, 1991). Clay properties can be used to control this loss. Four types of vermiculites are chosen to do so: a natural vermiculite (VMg), an NH_4^+ saturated vermiculite (NH_4^+), a calcium and ammonium-saturated vermiculite, only in exchangeable position (VCaNH_4^+) and a vermiculite having exchangeable oligoelements (VMgCaCuCoMnZn).

Material and methods

- The aerobic fermentation is done in a horizontal mini digestor (2,4 litres)
- The lignocellulosic substrate is a mixture of wheat straw sieved to reach 2 mm and poplar sawdust grinded to reach 5 mm (3:1 w/w), to which has been added supplementary nutrients to facilitate the microbiological activity;
- The inoculum (1,5g) comes from a mixture in a process of being composted;—
The magnesian vermiculite has a cation exchange capacity of 120 meq/100g and a period of 14.4 Å (ANDRE,1972). The granulometry of the tinsels is located between 200 and 500µm thus, lateral outer surfaces are negligible rel-

ative to interfoliar inner surfaces. Moreover, the size of these clay particules allows them to be better recovered in the straw-sandust mixture.

- CO_2 : the quantity of CO_2 discharged is determined by weighing absorption tubes filled with Soda lime (with Self-indicating).
- Decomposition rate: it is obtained by the ash rate
- Nitrogen: the nitrogen rate is expressed in relation to the initial dry matter

Results and discussion

The CO_2 productions, the variations of the organic matter decomposition rate and the nitrogen content are represented in figure 1. It has been observed that:

- in the presence of ammonium-'saturated' vermiculite ($\text{VNH}_4\text{1}$) after the first peak of CO_2 production, identical to other fermentations one (9.5g $\text{CO}_2\text{Mg MS/j}$) with or without vermiculite (reference), due to glucose and the more easily biodegradable molecules consumption (De LASSUS, 1986), the microbiological activity remains very weak (between 2 and 3g/Kg of MS/j) between the 10th and the 120th day the final organic matter decomposition rate reaches 20% but no nitrogen fixation is observed.%o
- in the presence of magnesian vermiculite, calcium-ammonium vermiculite and vermiculite having oligoelements, global activity is close to the reference one the decomposition rate is near 50% the molecular nitrogen fixation began about the 25th day (VMg) or the 30th day ($\text{VCNH}_4\text{1}$, VMgCaCoCuMnZn). The total quantities of fixed nitrogen reach 3.6%o for VMgCaCoCuMnZn , 3.7%o for VMg and 4.2%o for VCaNH41 , which have to be compared to the 3.5%o of the reference. Total outputs of nitrogen fixation are 8.8 mg N/g of consumed substrate (C.S) for VMgCaCoCuMnZn , 9.2 mg N/g. C.S for VMg and 10.0 mg N/g. C.S for $\text{VCaNH}_4\text{1}$, to 7.4 mg N/g C.S for the reference.

The NH_4^+ interfoliar content varies with time, according to the type of vermiculite (Tab. 1); with VNH_4^+ , the content decreases from 70.7 to 53.3 meq/100g in 120 days, i.e. a 17.4 meq/100g V loss with VCaNH_4^+ , it decreases from 46.9 to 54.5 meq/100g, i.e. a 8 meq/100g V gain; with VMg and VMgCaCoCuMnZn , it increases from 0 to 22.2 and 19.6 meq/100 g V, i.e. a 2.5 increase during the same period of time.

All these results (total microbial activity, N₂ fixation and interfoliar content) show that there is a relation between microbial activities and interfoliar content:

- in the presence of an interfoliar NH_4^+ -saturated vermiculite, microorganisms use in priority interfoliar NH_4^+ nitrogen and diazotrophs do not fix N₂.
- in the presence of a VCaNH_4^+ , VMg or VMgCaCoCuMnZn vermiculite, the absence or a lack of organic or mineral nitrogen, after a week of activity, favour the N₂ fixation. This fixation is all the more efficient since the nitrogen which is liberated, during the metabolism, as NH_4^+ , is put into the interfoliar spaces.

This situation is temporary (ANDERSON et al, 1985) (and here again proved using VNH_4^+) like all exchangeable (Mc CALLA, 1939) or non exchangeable (Van BRAGG et al, 1980) mineral elements.

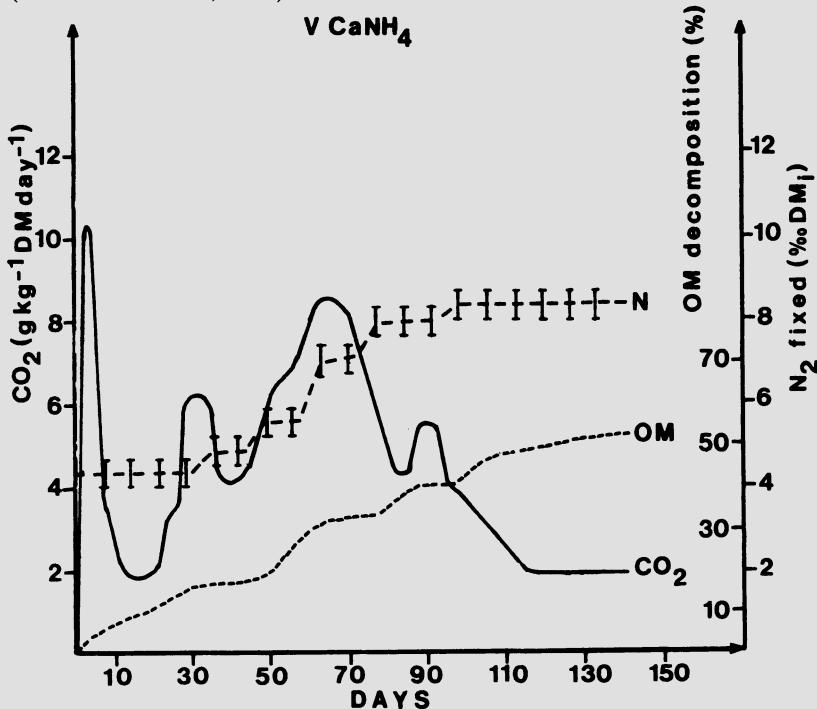


Fig. 1 CO_2 production; organic matter (OM) decomposition; N_2 fixed, in a 1:3 w/w straw:sandust mixture with VCaNH_4^+

Table 1 The NH_4^+ interfoliar content with the time and the type of vermiculite

VERMICULITE	NH_4^+ interfoliar (meq/100g V)					
	0j	20j	30j	60j	90j	120j
V	—	—	—	—	—	—
VNH_4^+	70.7	—	58.4	55.3	54.3	53.3
VCaNH_4^+	46.9	48.0	51.6	54.5	54.5	—
VMg	0	ε	10.0	12.5	16.1	22.2
VMgCaCoCuZn	0	ε	9.3	11.5	14.3	19.6

Conclusion

The presence of vermiculite was therefore shown to improve diazotrophic microbiological activity. This was partly due to the release of certain interfoliar mineral elements (Ca^{++} , mg^{++} and oligoelements) and partly to the storage of NH_4^+ , thereby permitting distribution of the nitrogen supply to plants over time and attenuating the risks of pollution due to poor control of chemical nitrogen fertilization.

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A Comparison Between Chemical and Biological Index for Measuring Compost Quality

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Introduction

Although technologies for making compost are well developed, index for assessing the quality of product is a difficult issue. There are several parameters in the literature and the subject have been reviewed several times. Some problems related with topic of compost quality or maturity are the wide diversity of substrates which can be composted, the wide number of index proposed and the lack of results of applying the index to compost from different origins and nature. In our point of view the main difficult is the lack of a patron.

The poster presents a comparison between chemical and biological methods reported in the literature when are applying to compost from different origins and nature.

Material and Methods

Four types of samples were analysed:

- a) Fresh biodegradable fraction of Municipal Solid Waste (**1a**) and mixed Municipal Solid Waste before composting (**2a**)
- b) Compost from mixed Municipal Solid Waste with <2 mm grade and 90 day of composting (**3c,3d,3e**), <20mm grade and 15 days of composting sample (**2b**). Sample (**1b**) have a <20 mm grade and 15 days of composting. Samples coming from pilot plant experiments applying static and turning composting.
- c) Sewage sludge mixed with forestry waste after 7 days of composting (**3f**).
- d) Commercial samples of vermicompost made from animal manure (**2c,3a,3b**).

Chemical determinations were: C/N, Oxidable Carbon, Ammoniacal Nitrogen, Extractable and Water soluble Carbon, Fulvic and Humic fractions and ratios. The

biological test was the germination index developed by Zucconi *et al.* (1981) for *Lepidium sativum*. Determinations were made with water soluble extract diluted to 30%.

Table 1 Chemical characteristics of samples.

	1a	1b	2a	2b	2c	3a	3b	3c	3d	3e	3f
Cox %dw	39	25	24	33	23	23	17	14	14	8	35
N %dw	2.4	2.2	1.0	0.9	1.4	1.9	1.3	1.7	1.2	0.9	1.1
N-NH ₄ mg/Kg	400	902	276	70	<10	<10	108	74	70	60	669
N-NOx mg/Kg	38	154	30	<10	59	<10	1498	45	20	273	32
pH	6.1	7.1	6.7	7.3	6.4	5.8	7.2	8.0	7.8	7.8	6.0
Cond. mS/cm	11.2	10	3.8	4.0	2.6	4.4	3.0	2.8	1.4	2.4	0.5
C/N	16	11	24	36	16	12	12	8	11	9	32

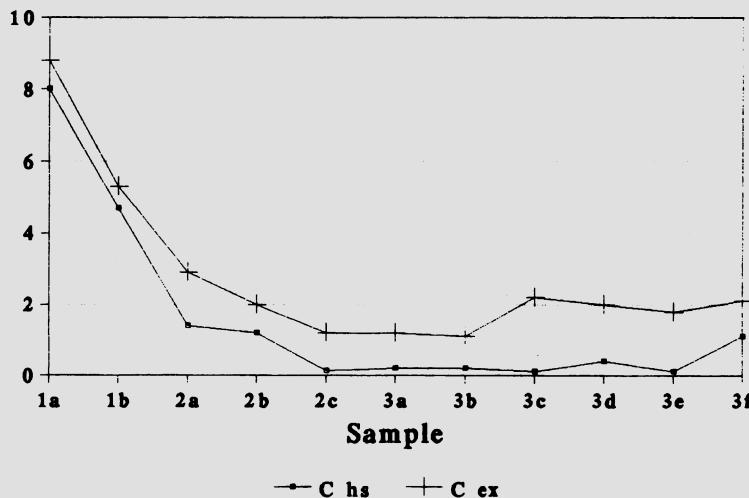


Figure 1 Values for Water-soluble Carbon (C hs) and Extractable Carbon (C ex)

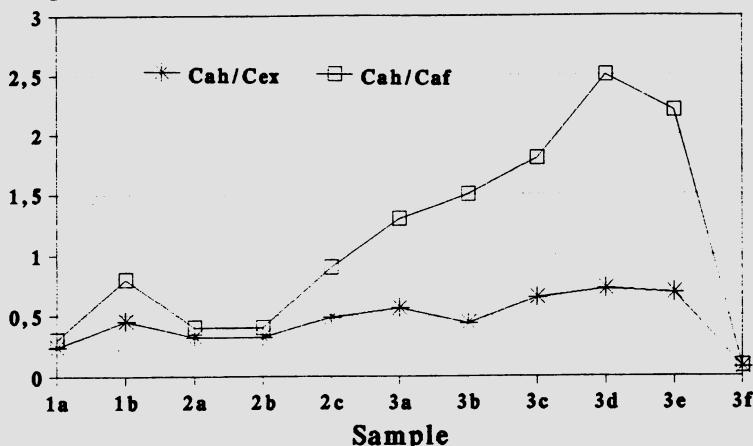


Figure 2 Values for Humic Carbon/Fulvic Carbon ratio Cah/Caf and Humic Carbon/Extractable Carbon/Extractable ratio Cah/Cex

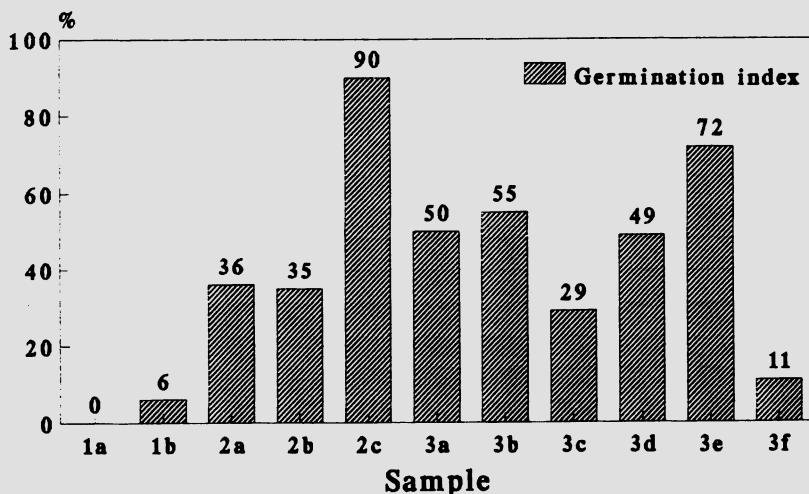


Figure 3 Values for Germination index

Results

Figure 1 and 2 show sample values for some maturity index reported in the literature and Figure 3 show values for Zucconi *et al.* germination index. Samples can be divided into three classes. Class 1 samples are in the first stages of composting and show high values for water-soluble, extractable Carbon, and low values for Humic Carbon/Extractable Carbon and Fulvic Carbon/Humic Carbon ratio. Class 3 samples show low values of water-soluble, extractable Carbon and Humic Carbon/Fulvic Carbon ratio. Samples of Class 2 have halfway values between other class. Class 2 and 3 samples are compost and is difficult to choose a value of chemical index for classifying Class 2 and 3 as mature because chemical index change stepwise. Often in the literature, time of composting is choosing as pointer of maturity, and chemical values at the end of composting as reference values. However it can lead to misunderstanding; samples 3c and 3e have identical composting time with different values for Humic Carbon/Extractable Carbon ratio.

When germination index is applied for classified samples, results are not so clear. Some samples can be classified as mature with chemical index but not if germination index is employed. Samples 3d and 3e have quite similar values for organic matter composition however different seed response. Identical response can be reported for samples 2c and 3a. For sample 3f, 1a and 1b high values of Ammonical nitrogen, salt content can be explain the differences between chemical and biological behaviour.

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Sewage Sludge – Soil Conditioner and Nutrient Source: I. Phosphorus availability and its uptake by ryegrass (*Lolium perenne L.*) grown in a pot experiment

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Abstract

The plant availability of municipal sewage sludge-borne phosphorus (MSS–P) and its effects on various soil P forms were investigated in a pot experiment using single superphosphate P (SSP–P) as the standard P source. Unlimed (control) and limed (pH 6.64, 7.19) samples of a silt loam soil [$\text{pH}(\text{H}_2\text{O}) = 5.72$] were mixed with 134 mg P kg⁻¹ dry soil in the form of SSP or MSS, labelled with ³²P tracer and grown with ryegrass (*Lolium perenne L.*). After harvesting the rye-grass plants at the earring stage, the soils were sampled and extracted sequentially with resin in the Cl⁻ form followed by 0.5 M NaHCO₃ (pH 8.5), 0.1 M NaOH and 1.0 M HCl solutions for P analysis. The sum of resin- and NaHCO₃-P levels as well as NaOH- and HCl-P levels were designated as the labile and nonlabile P pools, respectively. Relative MSS–P uptake established by ³²P tracer averaged 8% (range 7.4–8.9), whereas the corresponding average MSS–P uptake established by the difference method was 7.5% (range 3.8–14.5), with lower values recorded in the limed soils. Liming and applications of SSP and MSS significantly ($P = 0.05$) increased soil levels of resin- and inorganic NaHCO₃-P. Liming decreased organic NaOH-P levels, whereas organic NaHCO₃-P and HCl-P levels did not significantly ($P = 0.05$) differ from that in the control treatment. MSS–treatments were, on average, less effective than the corresponding SSP–treatments at elevating the labile P pool sizes, whereas they were more effective than the latter at increasing nonlabile P pool sizes.

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Introduction

Household and industrial wastes are being produced at rates that exceed society's present capacity to safely dispose of them. Municipal sewage sludge (MSS) can be incorporated into agricultural land to improve soil physical properties and nutrient supplies, provided that it does not contain unacceptable amounts of toxic elements, such as heavy metals (Vigerust & Selmer-Olsen, 1985). Our objective was to assess the value of MSS as a source of phosphorus (P) for plants.

Materials and methods

Soil samples were taken from the 0–20 cm layer of a silt loam soil: pH in water 5.72, contents of clay, silt and sand = 33.4, 56.9 and 1.0% respectively. (Crops respond to P application on this soil.) Single superphosphate (SSP), the standard P source, or MSS stabilized with FeCl₃ and containing 3.34% total P and 27.7% total organic C, the test P source, was applied to four replicates each of 1 kg unlimed and limed soils at a rate giving 134 mg P. In addition, 400 mg N and 400 mg K kg⁻¹ dry soil pot⁻¹ were applied to each replicate. Treatments were as follows: unlimed, limed (pH 6.64), limed (7.19), unlimed + SSP, unlimed + MSS, limed (pH 6.64) + SSP, limed (pH 7.19) + SSP, limed (pH 6.64) + MSS and limed (pH 7.19) + MSS. Carrier-free (³¹P) solution (Haak, 1993) had been added to all pots five days before ryegrass (*Lolium perenne* L.) seeds were sown. After harvesting the ryegrass plants at the earring stage, the soils were sampled and extracted sequentially with resin in the Cl⁻ form followed by 0.5 M NaHCO₃ (pH 8.5), 0.1 M NaOH and 1.0 M HCl solutions for P analysis. Analytical details are described elsewhere (Otabbong & Persson, 1994). The sum of resin- and NaHCO₃-P levels as well as NaOH- and HCl-P levels were designated as labile and nonlabile P pools, respectively. The relative effect of the adding of MSS-P on labile P pool was calculated as follows: [(labile P level in MSS-treatment)/(labile P level in corresponding SSP treatment)]* 100. Similar calculations were conducted for nonlabile P pool. The relative MSS-P uptake was computed using the ³²P technique and difference method (D-method).

Table 1 Comparision of relative MSS-P uptake by plants established using the ³²P-technique and the D-method, with SSP-P used as the standard P source

pH(H ₂ O)	³² P-technique	D-method
4.98	7.7	14.1
6.64	8.9	3.8
7.19	7.4	4.5
Mean	8.0	7.5
LSD _(0.05)	0.6	2.9

Table 2 Effects of pH(H₂O), SSP- and MSS-P on soil levels (mg kg⁻¹ dry soil) of resin- and NaHCO₃-extractable P fractions (labile P-pool = ΣP-L)

pH	P-addition	Resin-P	NaHCO ₃ -P		ΣP-L	Relative value
			Inorganic	Organic		
4.98	Nil	41	75	185	301	100
6.64	Nil	55	62	171	288	96
7.19	Nil	56	76	144	276	92
4.98	SSP	93	119	197	409	136
6.64	SSP	124	105	166	395	131
7.19	SSP	128	106	167	401	133
4.98	MSS	71	121	191	383	127
6.64	MSS	75	98	167	340	113
7.19	MSS	66	110	162	338	112
CV%		5	5	5	—	—
LSD _(0.05)		11	9	15	—	—

Table 3 Effects of pH(H₂O), SSP- and MSS-P on soil levels (mg kg⁻¹ dry soil) of HCl- and NaOH-extractable P fractions (nonlabile P pool = ΣP-NL)

pH	P-addition	HCl-P	NaOH-P		Σ(P-NL)	Relative value
			Inorganic	Organic		
4.98	Nil	138	216	345	699	100
6.64	Nil	148	204	272	624	89
7.19	Nil	147	191	209	547	78
4.98	SSP	135	260	317	712	102
6.64	SSP	179	248	279	707	101
7.19	SSP	150	219	213	582	83
4.98	MSS	132	300	339	771	110
6.64	MSS	145	313	277	735	105
7.19	MSS	146	292	219	657	94
CV%		5	3	7	—	—
LSD _(0.05)		22	41	39	—	—

Table 4 Relative effects (%) of MSS-P on labile and nonlabile P pools

P pool	pH(H ₂ O) value			Average
	4.98	6.64	7.19	
Labile	94	86	84	88
Nonlabile	108	104	113	108

Results and discussion

Up take of MSS-P

The relative magnitude of MSS-P uptake by the plants established by the 32P technique was fairly similar (7.4–8.9%) regardless of the soil pH (Table 1), with the highest value recorded at a pH of 6.5. These results are in agreement with those published elsewhere (Kelling et al., 1977). Our results suggest that to obtain a level of P uptake similar to that reached in soil receiving a given amount of SSP-P, about ten times as MSS-P would be needed. However, the results sharply contrast with the ones established by the D-method, which ranged from 3.8 to 14.1 and indicated that MSS-P uptake decreased in the limed soils. This indicates that MSS-P solubility decreases in response to increasing pH relative to SSP-P.

Liming and applications of SSP and MSS markedly increased soil levels of resin- and inorganic NaHCO₃-P (Table 2). Organic NaHCO₃- and HCl-P levels did not significantly ($P = 0.05$) change relative to the control treatment, whereas organic NaOH-P levels decreased (Table 3). The latter P fraction was probably mineralized and subsequently entered the labile P pool.

On average, MSS-treatments were less effective than the corresponding SSP-treatments at elevating the labile P pool sizes, whereas they surpassed the latter at elevating the nonlabile P pool sizes. This pattern of effects was expected, however, and reminds that of phosphate rock and fused phosphate which solubilize slowly in soils (Otabbong & Persson, 1992, 1994). The P in the standard fertilizer, SSP, is in the form of CaHPO₄ which is soluble in water, whereas P in the test fertilizer, MSS, was predominantly in the form of FePO₄ which is soluble in alkaline solutions.

Concluding Statement

Based on the results presented in this paper, it is concluded that MSS-P solubilizes slowly and can, therefore, be used for corrective P-fertilization.

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Composting of Fresh and Pond-Stored Olive-Mill Wastewater by the Rutgers System

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Introduction.

In the Mediterranean areas a great stream of liquid waste, roughly estimated in about 10 million tons, is yearly produced by olive mill industry in a short rainy season (November–February). In spite of the existing laws, olive mill wastewaters (O.M.W.) are often disposed of in the environment or collected in lagoons, with a consequent pollution linked to odours, insect proliferation and sludge production. To solve the problem, both clearing and recycling have been proposed (Fiestas Ros de Ursinos & Borja Padilla, 1992). At present, recycling rather than cleaning seems to be the most suitable solution. From the standpoint of the waste recycling for agronomical uses, the direct disposal onto soil has been taken into consideration (Andrich et al., 1992; Riffaldi et al., 1993).

The aim of this study is to verify the efficiency of the composting process for transforming both fresh and stored O.M.W. into compost to supply onto soil as organic fertilizers.

Materials and methods.

Two different mixtures:

MSO: 53.0% maize straw + 47.0% sewage sludge + fresh O.M.W. 1.765 l/Kg.
MOs: 11.1% maize straw + 88.9% stored O.M.W.

were composted in two trapezoidal piles of 1–1.5 m high with a 2 × 3 m base in a pilot plant based on the Rutgers static pile system (Finstein et al., 1985). The air was blown from the base of pile, the timer was set for 30 s. ventilation every 15 minutes and ceiling temperature for continuous air blowing was 55 °C. After the biooxidative phase of composting, The air-blowing was then stopped to allow the compost to mature over a period of two months. The piles were sampled weekly

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till the end of biooxidative phase and, once again, after the maturation period. Moisture content was assayed by drying at 105 °C, organic matter (OM) by loss-on ignition at 430 °C for 24 h., total nitrogen (Nt) and organic carbon (Co) by automatic microanalysis, cation exchange capacity (CEC) by BaCl₂ at pH 8.1. NH₄-N was extracted with 2 M KCl (1:20 w/v) and determined by a colorimetric method based on Berthelot's reaction. Humic-like substances were isolated by treating compost samples with 0.1 M NaOH, later separating humic from fulvic acids by acid precipitation and centrifugation. Both extractable organic carbon and fulvic acid-like carbon (C_{fa}) were analyzed by automatic microanalysis. Humic acid-like carbon (C_{ha}) was then calculated by difference. Nitrogen fixation was determined by gas chromatography according to Cacciari et al., (1989) on compost samples (1 g d.w.) incubated for 72 h. at 30 °C in NaCl 0.9% (25 cc). Losses of OM and Nt were calculated from the initial and final ash contents according to the equation of Viel et al., (1987). Phytotoxicity was determined according to Zucconi et al., (1981). Phenols are extracted according to Balice et al., (1985) and detected by a ¹H NMR Bruker AMX 600 operating at 600.13 MHZ.

Results and discussion.

The biooxidative phase of the two piles lasted different time, 9 weeks for MSO and 13 weeks for MOs. As a consequence, a lower mineralization occurred in MSO in comparison to MOs (Fig. 1). A great OM loss was recorded for MSO during the first four weeks of the composting process probably depended on the abundance of indigenous micro-organisms present in the sewage sludge and their fast growth, which provoke vigorous attack of the labile organic compounds (Iglesias & Pérez, 1992). Later, the OM mineralization continued in both piles, the effect was more pronounced in the MOs mixture.

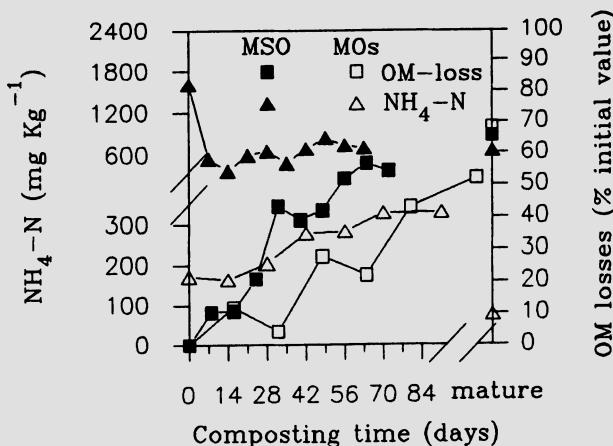


Fig. 1 Losses of organic matter and changes in ammonium nitrogen during composting.

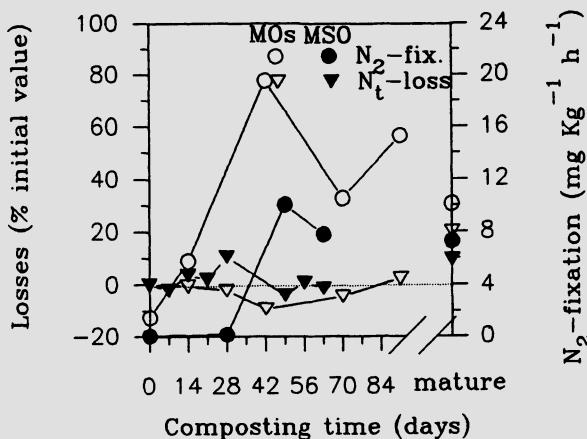


Fig. 2 Losses and fixation of nitrogen during composting.

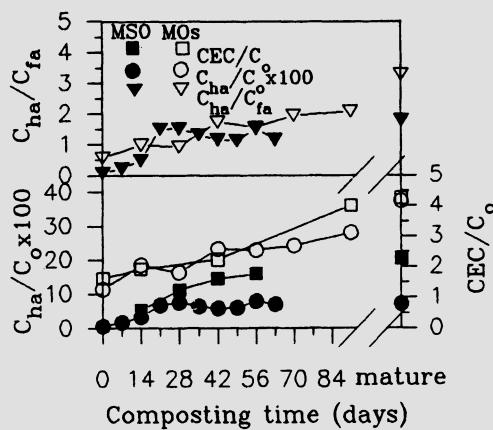


Fig. 3 Evolution of humification parameters during composting.

As a result of the N mineralization, the evolution of the NH₄-N content strongly depended on the OM losses in both piles (Fig. 1). An important reduction of the NH₄-N in MSO was observed during the first week coinciding with a nearly insignificant loss of N_t (Fig. 2), which may be related to N organization by microbial immobilization of the NH₄-N (Bernal et al., 1993; Mahimairaja et al., 1994). Because N is mainly lost as NH₃ by volatilization during composting (Bishop & Godfrey, 1983), losses of N_t were lower in MOs than in MSO in agreement with the lower concentration of NH₄-N in the former compost. N fixation occurred in both piles (Fig. 2), detecting increases of N_t when temperature was lower than 40 °C (from day 42 to 56 in MSO and from 28 to 63 in MOs).

Biological fixation of N was also higher in MOs than in MSO in good agreement with the lower NH₄-N content in the former pile during the process. According to De Bertoldi et al., (1983), temperatures higher than 40 °C and high amounts of NH₄-N inhibit biological fixation of N.

As shown in Fig. 3, an increase of the Ch_a/C_{fa} ratio was observed in both mixtures as composting progressed, MOs exhibiting a higher value of the ratio than MSO after maturity. The above findings could be explained by the progressive formation of polycondensated substances derived from the lignin fraction of raw refuse materials and metabolic compounds from the microbial biomass, and/or a progressive degradation of substances present in the fulvic acid-like fraction (Iglesias & Pérez, 1992). An increase was also detected in the Ch_a/C_o × 100 ratio during process as well as in the CEC/C_o ratio, both changes indicating rising humification of composts with progress of composting. As reported by Lax et al., (1986), rise of the latter ratio should be related to the generation of new carboxilic and hydroxy-phenolic groups by decomposition and oxidation of the OM, processes which certainly occur during composting.

As reported in Table 1, phytotoxicity in MSO ceased in the 4th week while lasted till the 13th week in the other mixture, values of the germination index (G.I.) being clearly higher than 50 in both mature composts, which means an appropriate degree of maturity as reported by Zucconi et al., (1981).

Table 1 Changes in G.I. of the mixtures during composting

Days	0	14	28	42	63	91	mature
MSO	19.6	—	105.4	—	83.6	—	91.3
MOs	0.0	4.9	—	41.0	—	66.2	69.8

Phenols disappeared during the composting process, as showed by ¹H NMR spectra. The phenolic compounds present at the beginning of the composting processes, made evident by the peaks in the 7.5–6.5 ppm region, were not any more detectable in the spectra performed at the end of the biooxidative phase in both piles (data not shown).

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Behaviour of Biodegradable Mater-BI ZI01U Plastic Layers in a Composting Pilot plant.

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Introduction

The European Parliament and the Council of the European Union have recently finalized a Directive on Packaging and Packaging Waste. This foresees that, no later than five years from the date by which the Directive must be implemented in national law, between 50–65% by weight of the packaging waste should be recovered from the waste stream through recycling, reuse, or incineration with energy recovery. Recycling will cover the 25–45% of the totality of packaging materials contained in packaging waste. Composting is considered as a form of recycling of biodegradable packagings and it will have an important role in the rational management of waste. The definition of the criteria by which a material can be considered as compostable and recycled by composting is, therefore, a topical issue. International organisms such as the ISR/ASTM, CEN, ORCA have been constituted with the aim to define the compostability criteria. The fundamental requirements are: biodegradability, absence of negative effects on the quality of the compost, absence of negative effect on composting process. The first two conditions are determined at laboratory scale following the mineralisation of the test material and analysing the final compost quality. The laboratory data and the effect on the process should be verified in a composting plant.

The Mater-Bi ZI01U of NOVAMONT is a multipurpose biodegradable thermoplastic product and its biodegradation has been well studied at laboratory level. Biodegradation measured by the ASTM D 5338–92 test was 105 + 7 % while cellulose (reference) was 89.4 + 6.8% (J.Boelens, 1992). Terrestrial toxicity tests and physical-chemical characterization of the compost showed the absence of negative effects due to Mater-Bi degradation (work in progress). Biodegradation determined with a test described in the 12/7/1990 Italian Decree was higher than food-contact paper, in compliance with the prescriptions of the decree (Molinari, 1993). An analysis of Mater-Bi ZI01U has evidenced the absence of heavy metals (Bottazzini, 1994).

Aim of this field trial was to prove that the Mater-Bi ZI01U, added to the organic waste at a realistic concentration, neither damages the composting pro-

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duction nor affects the final compost quality (chemical, physical, and phytotoxicological parameters) and that degrades at a rate compatible with the composting process.

Materials and methods

The composting plant located in Limidi di Soliera, Modena Italy, belonging to the AMIU (Municipal Waste Treatment Department) of Modena , is a 3 meters wide and 60 meters long trench, inside a greenhouse, and endowed with a turning machine moving on a track. The composting mix was formed by: source separated organic waste (SSOW) daily collected at the fruit and vegetable market of Modena; food scraps from restaurants and canteens; shredded trimmings of plane-trees. Rectangular sheets of Mater-Bi ZI01U (100–150 cm²; thickness 450 µm) were introduced in the composting mass. Two composting experiments were run, in sequence, in this work: SSOW 3 (April-September 1994) and SSOW 4 added with Mater-Bi at a concentration of 0.12% (June-November 1994). The composting processes lasted about 4 months. During the first two months, corresponding to the thermophilic phase, the composting mixtures were left in the horizontal trench reactor and mixed frequently (2–3 times weekly). Subsequently, in the maturation phase, the mixtures were removed under a shelter and turned 2–3 times in total with a caterpillar.

Results and discussion

The composting process named SSOW 4 was not impaired by the ZI01U sheets added to the organic waste. Both composting masses underwent to a strong aerobic degradation process. The analytical data concerning the two composting runs (pH, total solids, volatile solids, total Kjeldahl-nitrogen, ammonia nitrogen, total phosphorus, heavy metals, total organic carbon) did not differ significantly, showing that the Mater-Bi addition did not affect either the composting process or the composition of the final product. All the values, but the pH, were within not only the limits prescribed by the Italian law in force, but also within the new more restrictive limits outlined in a draft bill. The composts obtained in the two trials were both of high quality as shown by the humification parameters (Extractable Organic Carbon, Humic acids, Fulvic Acids). The germination index of SSOW 4 compost was even higher than the control (SSOW 3) indicating the absence of phytotoxic compounds affecting the *Lepidium sativum* germination.

The degradation of Mater-Bi sheets was monitored very frequently by inspection of the composting mass. Apparently the degradation happened during the thermophilic phase. At the end of the process a manual search was carried out screening 3 aliquots of compost (about 20 Kg each) to find Mater-Bi residues with a thin mesh (6 mm). The identification of the oversize fraction was rather difficult

because the residues were of tiny dimensions, dark and dirty of compost. The residues, tentatively recognized as Mater-Bi, were pooled, weighed, and treated with CH_2Cl_2 , a solvent typically used to extract the synthetic part of ZI01U (poly-epsilon-caprolactone). No matter was extracted. Then, the residues were treated with pancreatin to digest residual starch. A 55.08% weight loss was detected. The final residues had a fibrous, vegetable appearance. These findings would exclude that the oversize fraction detected in sampling is composed by Mater-Bi residues. However, even assuming that the residues are Mater-Bi we can estimate a final degradation of 98.9%. In fact residue recovered was 3.787 g out of 57.6 Kg of compost screened, in total. Applying this ratio to the total mass of final compost (5100 Kg) we can estimate a total of 335 grams of residues present at the end of the process, representing the 1.1% of the initial amount. The Mater-Bi degradation level is extremely high but is based on a visual, qualitative approach. Without the mineralization data collected at laboratory scale it would have been impossible to discern whether this disappearance was just due to solubilisation or disintegration processes rather than to a real biodegradation. On the other hand, degradation data produced at laboratory scale are always susceptible of criticisms if not substantiated by field results. A systematic study to find a correlation between the laboratory scale results and the fate in a real composting plant would be of great advantage in this field because it would simplify the testing activities. The present work is a piece of information towards this objective. The findings of this work have been obtained using an initial Mater-Bi concentration of 0.12% (w/w). This amount, low in terms of weight, it is rather high by a visual point of view. Therefore, it was possible to easily follow the degradation. In any case, we consider that this amount is a realistic estimate of the concentration of the degradable plastics in biowaste feedstocks in a near future. This assumption is based also on the fact that household waste, source of degradable plastics, is usually mixed with other feedstocks devoid of plastics, such as sludge, wood residues, leaves etc. decreasing the final plastics concentration. Higher amounts will have to be tested if degradable plastics concentration factually found in composting should prove to be much higher than the 0.12 %, checked in this work.

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The Emilia-Romagna Experiment in Animal Manure Composting

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Introduction

Animal manure, with the exception of poultry, generally has a low fertilizer content. Consequently spreading cost is higher than chemical fertilizers. The organic matter content of animal manure is not good enough to raise its fertilizer value; in fact the low degree of humification helps little in raising the soil organic matter content. Composting is a good way of improving the fertilizer value of animal manure. This paper presents the results of a series of experiments performed by the C.R.P.A. and supported by funds from the Emilia-Romagna Region, Agricultural Department.

Materials and Methods

Table 1 shows the composition of the animal manures submitted to composting tests.

With regard to pig slurry we performed composting tests of the solid fraction resulting from centrifugal separation of raw slurry (referred to as SFC from now on); as bulking agents we used straw and wood chips. With regard to dairy cattle manure we performed composting tests of the solid fraction resulting from a press-screw separator and of the straw bedding used in bedded areas with and without addition of slurry coming from concrete surfaces (paddock, feed areas...).

We also carried out a composting test of the dewatered sludge (DS) (with a belt filter press) coming from a purification plant (anaerobic + aerobic reactors) treating pig and beef cattle slurry; as bulking agents we used wood chips. With regard to poultry manure we performed composting tests both with manure from laying hens (with or without in-house drying) and with litter from broilers.

We have begun and are still involved in composting tests of biomass beds (wood

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Table 1 Composition of the animal manures submitted to composting tests

	SFC (n = 68)	Cattle solid fraction (n = 21)	Cattle straw bedding (n = 7)	DS (n = 1)	DS dried manure (n = 52)	Laying hens manure (n = 30)
	x	s	x	s	x	s
TS	25.6 (%)	3.5	23.1 (% TS)	3.5	22.9	1.8
VS	71.2	14.6	86.5	5.2	75.6	3.6
TKN	3.7 (% TS)	0.78	1.59 (% TKN)	0.43	2.93	0.33
NH4-N	34.8 (% TKN)	11.0	19.2	9.1	33.8	7.7
P	3.42 (% TS)	0.82	0.44	0.35	0.8	0.16
K	0.66 (% TS)	0.19	0.89	0.54	4.39	0.37
TOC	40.8 (% TS)	4.9	40.9	4.6	37.5	1.5
C/N	11	6	26	11	13	5
Cu	(mg/kg TS) (mg/kg TS)	288 1235	144 543	23 153	17 75	- -
Zn						-

x = average; s = standard deviation

SFC = solid fraction from centrifuging of pig slurry.

DS = dewatered sludge with a belt filter press from a purification plant treating pig and beef cattle. (*) = 1 sample

shaving and wood chips from municipal yard waste) with the addition of pig slurry.

The majority of the trials were carried out in an experimental composting plant consisting of a horizontal pit reactor, complete with greenhouse cover, turning machine equipment on wheels and aeration system. The pit is 3m wide and 60m long, maximum height of loaded material is 1m. The trials with dairy cattle manure were carried out at three dairy cattle farms on uncovered concrete surfaces. The windrows were turned with a bucket loader or with tractor-drawn turners. The trials with laying hens slurry and with poultry litter were done at two composting farm plants

Results and Discussion

All the composts show a good content of fertilizer elements and a better degree of humification than may be found in composts without animal manure. The heavy metal content is generally low, only with SFC and DS we found a higher copper and zinc content; in the future this content should be reduced as substitute products (probiotics and organic acids) are beginning to be used in animal feed as well as ways of administering the food which improve the pigs ability to adsorb Cu and Zn.

Values of pH and salinity are often higher than those of municipal sludge compost; this can be a problem for the utilization as peat substitute in growing media.

Animal manure composting trials showed that, with these materials, owing to their rapidly degradable organic matter content, a rapid start in the composting process with a fast rise in temperature is easily obtained.

The SFC contains about 25–30% of the total nitrogen, mostly in organic form, present in the raw pig slurry. During composting a part of the organic nitrogen becomes ammonia which is lost in part into the atmosphere on account of the high temperatures created within the heap. The amount of nitrogen volatilized as ammonia may even reach up to 35% of the initial nitrogen present. High ammonia losses reduce the agronomical value of the compost, contribute to the pollution of the atmosphere and affect acid rain production.

Nitrogen losses during composting may be reduced by adding zeolites, on account of their high cation exchange capacity and their remarkable ammonium ion selectivity, which can reduce the amount of free and therefore volatilizable ammonia. Two trials were carried out: in the first we added zeolite (55% phillipsite and 10% chabasite) at a rate of 20% (in weight) of the SFC and in the second at a rate of 10%. We obtained a substantial reduction of nitrogen losses in the heaps with added zeolite. In the first trial nitrogen losses decrease from 35.8% to 5.3% and in the second from 29.8% to 19.7%. The second test is more interesting from an economical point of view in that whilst using a coarser, more varied and therefore cheaper zeolite, ammonia emissions were significantly reduced.

The first results of the composting tests of biomass beds (wood shaving and

Table 2 Average composition of the composts obtained

	SFC + wood chips	SFC + straw	Cattle solid fraction	DS + wood chips	laying hens dried manure + straw	Cattle straw bedding	Cattle straw bedding + slurry
pH	7.55	8.28	8.28	7.32	9.76	-	-
TQ (% ST)	49.89	59.99	39.5	45.33	71	63.89	56.3
VS (% ST)	71.07	59.15	75.0	52.65	43	36.55	33.11
TKN (% HTK)	2.96	3.68	3.13	2.55	2.18	1.59	1.75
NH4-N (% HTK)	20.95	22.55	0.94	1.47	6.14	5.74	6.74
C/N	10	8	13	8	13	15	14
P (% ST)	2.53	3.40	0.70	3.55	2.24	0.57	0.62
K (% ST)	0.68	1.68	1.20	0.98	4.38	3.66	3.52
Cu (mg/kg ST)	143	166	41	543	93	-	-
Zn (mg/kg ST)	744	972	468	1170	502	-	-
Pb (mg/kg ST)	4	2	-	8	3.6	-	-
N (mg/kg ST)	27	18	-	20	9	-	-
Cd (mg/kg ST)	0.26	1	-	0.10	0.06	-	-
Cr (mg/kg ST)	64	67	-	15	17	-	-
Hg (mg/kg ST)	0.09	0.25	-	0.31	0.18	-	-
G.I. (%)	90	79	-	90	78	-	-
C.E.C. (mS/cm)	1.7	2.6	0.6	1.6	5.7	-	-
TOC (% ST)	30.1	31.1	39.7	21.6	23.0	19.8	20.0
TEC (% ST)	13.3	16.13	24.93	13.95	11.4	-	-
HA + FA (% ST)	10.2	11.71	18.85	9.22	8.18	-	-
NH (% ST)	3.1	4.42	6.08	4.73	3.22	-	-
HI	0.31	0.38	0.32	0.51	0.39	-	-
DH	76.6	72.6	75.61	66.09	71.8	-	-
HR	33.8	37.65	47.5	42.65	35.6	-	-

G.I. = germination index

wood chips) with the addition of pig slurry, show that it is difficult to treat one square metre of bed with more than the daily slurry production of one pig. In order for it to gain interest from an economic point of view such a solution needs improvements.

With regard to dairy cattle slurry the composting tests of the solid fraction resulting from a press-screw separator show an improvement in the agronomic value of this solid fraction; in these trials the nitrogen losses, as ammonia, are low, about 6–19% of the total input.

Composting tests of the straw bedding, with addition of slurry coming from concrete surfaces, show that straw bedding can absorb the slurry produced and that the compost has good agronomic value. In this case the nitrogen losses are about 15–25% of the total input.

In the farm plant treating laying hens slurry (TS = 20%) mixed with chopped straw (bought at a high price) at the ratio 12:1 (w:w), satisfactory dehydration of the product at the end of the process was difficult to obtain during wintertime. In the case of laying hens slurry mixed with poultry litter (ratio 1.2:1, w:w) or in-house dried layers manure mixed with straw (ratio 4.8:1, w:w), when it was possible an adequate mixing ratio with cellulosic materials, the humidity and porosity of the starting matrix allowed an optimum composting process.

The major unsolved problem with poultry manure composting are the heavy nitrogen losses through ammonia volatilization, which have relevant environmental pollution concern, together with odour nuisance problems in the vicinity of the plants which are common.

The high temperature and pH reached in the first stage of the process, the low C/N ratio of the mixture, the high manure nitrogen content in ammoniacal form are the mean causes of these losses, which amounted, in our trials, to between 50 to 65% of initial nitrogen content, both with liquid manure and with the in-house dried type. For this reason it is advisable to build poultry manure composting plants as closed reactors with the possibility of introducing exhaust air treatment systems.

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Composting Wastewater Sludges Without the Addition of Bulking Agents

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Abstract

Untreated wastewater sludges have been successfully composted without the addition of bulking agents - straw, paper, green or municipal wastes - to form a stable soil conditioner.

The advantages of this process are the minimal loss of nutrients, linked with a reduction in organic and volatile matter and moisture content. There are savings associated with construction, handling, transport and distribution costs.

This material is one of a range of products manufactured by the company for beneficial reuse in agricultural land. If deregulation of current sludge legislation occurs, it is anticipated that this product will be in demand for other markets.

Following successful trials at Horsham Wastewater Treatment Works, Sussex, Southern Water has formed a partnership with Sevar GmbH, Brackett Polcon and Tilbury Douglas Construction to build a pilot plant to 2000 tonnes of dry solids per annum of dewatered wastewater cake at the new Weatherlees Wastewater Treatment Plant on the East Kent Coast, at a cost of £3M.

Introduction

Southern Water is one of 10 water companies formed in 1989 when the industry was privatised. It provides 625 million litres of clean water and removes, treats and disposes of 1300 million litres of wastewater in an area of 4000 square miles. The current wastewater sludge production is 62000 tonnes of dry solids per annum, increasing to 134,000 tonnes by 1998 when an EU Directive stops the discharge of untreated wastewater into the sea.

The Recycling Group was formed in late 1993 to develop a strategy for the future treatment and beneficial reuse of bioproducts in the agricultural industry. The disposal of untreated sludges is deemed unacceptable due to limited agricul-

tural outlets, odour nuisance and high transport costs.

The proposed bioproduct range will include those formed from digestion, drying or composting untreated sludges.

Southern Water had tried various forms of composting since 1978, using straw, municipal or green waste with wastewater sludge. However, the main disadvantage of all previous experiences has been the addition of bulking agents which increase civil, handling and transport costs. In addition, the use of municipal wastes gives rise to contamination from glass, plastic and metals. There is also concern over the consistency and reliability of supply of these bulking agents linked with additional transport movements and costs associated with raw materials and finished products. To overcome these major constraints, it was concluded that the only solution would be to compost wastewater sludge without the addition of bulking agents. A search by Southern Water identified Sevar GmbH as the only company offering a composting process that did not involve the addition of bulking agents. Already well known for sludge drying and composting in Germany, Sevar and their UK sister Company Brackett Polcon were commissioned for a major pilot scheme at Southern Water's Horsham Wastewater Treatment Works to demonstrate and develop their process for sludge only composting. During the Summer of 1994, this was successfully accomplished.

Tilbury Douglas, a major UK Civil Engineering and Mechanical Construction organisation, were then brought into the team as project managers and main civil contractors to help commercialise the process.

The Process

During the 1980's, Sevar GmbH developed a composting process based on research work by Prof Wolfgang Baader. Animal wastes including the litter were compacted into briquettes that were placed in composting towers or cells. The temperature within the cell rose to 70+°C and after 5–7 days the contents were cooled by force of air ventilation (using a blower). At the same time, moisture within briquettes was also lost due to evaporation. The treated briquettes were removed and then crushed, screened and graded, before distribution to various markets. When necessary lime was added prior to pelletisation to increase product range.

Following a visit to Schwege, Northern Germany, to see the process in operation, the briquetting and associated machinery was installed at Horsham Wastewater Treatment Works. The plan was to dry a quantity of cake sludge to 90–92% dry solid content, grind and back blend with other cake sludge to form a pliable mixture suitable for forming the briquettes. However, due to the fibre content of the sludge, this proved impossible.

After several alternative arrangements were tried the final preferred solution was simply to partially dry the untreated sludge cake to 50% DS in a low temperature Sevar dryer and place it directly in the compost tower. Careful control of

ventilation ensured a rapid rise in temperature in excess of 70°C with little malodour being vented into the atmosphere. After 8–10 days, the box was emptied and the contents windrowed in the conventional manner, with careful control on moisture and temperature. This process was continued for a period of up to 12 weeks, when a stable product was obtained. Storage over a further 3–4 months has proved beneficial, with a further reduction in organic and volatile content. This work has been replicated several times, the results always being within acceptable statistical limits.

For the commercial size plant a double size composting cell has been developed with the tower divided into two zones by means of pin rollers to form a false floor.

In the upper zone the temperature rises to around 70°C for at least two days. The raw compost is aerated, if required, at intervals. Forces aeration is not necessary due to the material preparation processes. Offgas purification is carried out via a compost filter. After a residence time of ca. 5–6 days there follows a steady transfer by turning of the pin rollers to the lower zone.

In the lower zone re-heating upto ca. 60°C occurs and the first fungal growth. This locks in the odour producing material. After a further residence period of 5–6 days the fresh compost produced is removed from the compost towers led by means of a chain scraper conveyor to the windrowing area.

This double composting arrangement further improves final compost quality.

Results

The feed and end products were analysed for solids, organic and volatile content, nutrients, potentially toxic elements and pathogens. Based on the test results, there was a reduction in organic and volatile matter from approximately 80% down to 54%. The moisture content can be controlled by the frequency of turning after the second maturation stage, and is normally less than 40%. Nutrient content – Nitrogen, Phosphate and Potash was only marginally reduced. Pathogens – E-coli, Streptococci and Salmonella were virtually eliminated following retention of the material at temperature in excess of 65°C for 5 days. Potentially toxic element concentrations increased in direct proportion to the destruction of organic and volatile matter.

The final product is light and friable, with a bulk density of approximately 0.55 at a moisture content of 35–40%.

The results were so encouraging that Southern Water have decided to proceed with a large demonstration plant of 2000 tonnes of dry solids per annum capacity to be located at Southern's new Weatherlees Hill Wastewater Treatment Works. This contract will be done by Tilbury Douglas, Sevar and Brackett Polcon and will be in full operation in October 1995. Its total value is approximately £3M.

Discussion

The composting process of wastewater sludges can be successfully accomplished without the addition of bulking materials providing the moisture content is reduced in the initial stages. Careful control of ventilation during the first stage limits odour problems and assists with the retention of nutrients, especially Nitrogen. Seeding the material placed in the composting cells with previously treated sludge rapidly enhances microbiological activity.

It was also noted that following a storm, when the partially matured product was saturated with rain water, elutiation of certain metals had taken place, especially Copper, Zinc and Molybdenum.

Uses

Pot trials are currently being undertaken by ADAS to determine suitability of the product for various crops. Subject to these results, plot and crop trials are expected to be completed for 1996. Deregulation of current sludge legislation will broaden market opportunities to include horticulture, amenity and perhaps even the domestic outlets.

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The Potential Use of Composted Waste Materials for Cuttings

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Summary

The rooting response of three ornamental shrub species (*Weigela florida*, *Deutzia gracilis*, *Kolkwitzia 'Pink Cloud'*) was tested in media made of pharmaceutical, village waste and farm yard manure composts.

The properties of media were analyzed to investigate factors which are of most importance for the development of roots. Special attention was given to the measuring of the physical properties of the media due to their crucial importance for root development.

Farm yard manure compost and village waste compost have proved to be suitable materials for rooting media. Pharmaceutical compost is not suitable for wider use due to its physical properties and high electrical conductivity.

Introduction

Different materials have been used to propagate cuttings. Peat is material most commonly used and forms the basis of many different propagation media. The use of peat is accompanied with some problems: the price of horticultural peat is high and the resources are limited.

The aim of this report was to investigate properties of some alternative materials based on composted waste materials and to evaluate possibilities for their practical use as rooting media for cuttings.

Materials and methods

The rooting media were made of three types of composted waste materials: pharmaceutical compost (PHC) made of the waste material remained after production of antibiotic tetracycline in chemical industry, village waste compost (VWC) made of organic waste collected in the village of Wye (England) and farm yard manure

compost (FYMC) made of cattle manure from the dairy farm. The composts were obtained from Wye Controlled Composting Unit (Kent, England).

All composts were leached prior to use with 3–4 times its volume of water in order to decrease high content of soluble salts which is usually accompanied with these types of materials. The composts were mixed with different proportions of grit so that nine mixes of 'compost media' were made. The standard rooting medium made of peat, perlite and grit acted as control medium.

The media used in the experiment were:

PHC + grit 1:1 vol. (PH 1);	VWC + grit 1:2 vol. (VW 3);
PHC + grit 1:1.5 vol. (PH 2);	FYMC + grit 1:1 vol. (FY 1);
PHC + grit 1:2 vol. (PH 3);	FYMC + grit 1:1.5 vol. (FY 2);
VWC + grit 1:1 vol. (VW 1);	FYMC + grit 1:2 vol. (FY 3);
VWC + grit 1:1.5 vol. (VW 2);	peat + perlite + grit 4:5:1 vol. (P/P).

The rooting response of three ornamental shrub species was tested *Weigela florid*, *Deutzia gracilis* and *Kolkwitzia 'Pink Cloud'*.

Table 1 Rooting results of cuttings

Medium	<i>Weigela florid</i>		<i>Deutzia gracilis</i>		<i>Kolkwitzia Pink Cloude'</i>	
	Rooting %	Mean dry weight of roots	Rooting %	Mean dry weight of roots	Rooting %	Mean dry weight of roots
PH 1	95.0	98.2 bc	87.5	51.7 c	62.5	47.9 c
PH 2	97.5	94.6 bc	100.0	50.4 c	77.5	48.3 c
PH 3	95.0	88.8 bc	97.5	65.0 abc	67.5	58.3 bc
VW 1	100.0	120.6 ab	97.5	57.7 bc	80.0	75.8 abc
VW 2	100.0	104.8 bc	100.0	77.8 a	95.0	74.0 abc
VW 3	87.5	100.0 bc	97.5	64.9 abc	92.5	78.7 abc
FY 1	92.5	95.6 bc	100.0	54.4 c	95.0	70.5 abc
FY 2	95.0	82.6 c	87.5	53.7 c	92.5	68.5 abc
FY 3	95.0	116.2 abc	97.5	64.5 abc	87.5	92.2 ab
P/P	97.5	149.7 a	100.0	73.6 ab	92.5	101.5 a

Means in the columns followed by the same letter do not differ significantly at P = 0.05 (Duncan's Multiple range test).

Special attention was given to the measuring of the physical properties of the media due to their crucial importance for the root development. In order to measure air space (AS), easily available water (EAW) and total porosity (TP), porous plate apparatus was used. Different suction pressures (10, 50, 100 cm) were applied on the samples of the media and the volume of outflow water was recorded. Different properties were calculated on the basis of measuring and explained by the methods of de Bocht and Verdonck (1972).

Table 2 Physical properties of rooting media

Medium	BD (g/cm ³)	PD (g/cm ³)	TP (% vol.)	AS (% vol.)	EAW (% vol.)
PH 1	1.05	2.34	55.2	11.7	8.2
PH 2	1.08	2.39	54.9	15.8	6.6
PH 3	1.20	2.44	50.9	13.4	3.3
VW 1	0.89	2.37	62.5	18.2	8.1
VW 2	0.96	2.42	60.4	22.5	3.5
VW 3	1.05	2.46	57.4	22.7	4.2
FY 1	0.95	2.22	57.3	17.5	2.7
FY 2	1.01	2.29	55.9	21.6	3.2
FY 3	1.09	2.35	53.7	22.8	2.8
P/P	0.27	1.87	85.6	18.7	15.7

BD – Bulk density; PD – Particle density; TP – Total porosity;
AS – Air space; EAW – Easily available water.

Results and discussion

The results of the rooting responses are presented in table 1. The results of media analysis are presented in table 2.

Although the highest mean dry weight of the roots for *Weigela florida* cuttings was recorded in control (P/P) medium (149.7 mg), high values were also recorded in village waste compost media, especially in VW 1 (120.6 mg). Both VW 1 and P/P medium have well balanced ratio of air space (AS) and easily available water (EAW).

The highest mean values of dry weight on *Deutzia gracilis* cuttings were in VW 2 (80.3 mg) and P/P (73.5 mg) media. Within media made of same compost the highest values of dry weight were for cuttings rooted in the media with high values of air space. For *Deutzia gracilis* cuttings EAW was not determining factor as for *Weigela florida* cuttings; they had more compact but fibrous root system which was able to uptake enough water for root development. The medium which provided the best conditions for root development (VW 2) had a very high value of air space – 22.5.

Many authors state the importance of air for root development but the opinions differ as to how much air is necessary in the media to sustain satisfactory growth. Acceptable volumes of air space within propagation media have been suggested at levels of 10–15% (Lee and Paul, 1976), 15% (Puustjarvi, 1969) and 20% (Arnold, 1973). The amount of air needed for root development depends however on species and it is difficult to give values of air space that would describe ideal medium.

From species tested in this experiment, *Kolkwitzia 'Pink Cloud'* and *Deutzia gracilis* cuttings responded better when the air space was high. That was also important for *Weigela florida* but for these cuttings, available water was the factor which greatly influenced the root development.

The problem for rooting process was expected to be due to the high electrical conductivity (EC) usually associated with waste materials. The electrical conductivity of VWC (4.13 mS cm^{-1}) and FYMC (5.62 mS cm^{-1}), after the composts were mixed with grit, did not have any detrimental effects to plants. The electrical conductivity of PHC (10.86 mS cm^{-1}) was much higher and since the rooting response in these media was generally inferior to the other media, it is possible that the high EC affected the root development.

Conclusions

The composts made of village waste and farm yard manure waste materials, mixed with certain proportions of grit, provide good properties for the rooting of cuttings.

Village waste compost is more suitable for making the rooting media due to the higher range of its pores which are releasing water at different pressures. Farm yard manure compost has more crumb structure and forms porous media with lower range of available water. The potential use would be in mixing these composts for making the rooting media which would combine their good properties.

Pharmaceutical compost does not provide good conditions for root development due to its physical properties and high electrical conductivity.

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Inalca Experiment in Composting of Slaughter House Organic Wastes

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Introduction

The trials were carried out by the CRPA on behalf of INALCA SpA at one of the biggest slaughter houses in Italy situated in Castelvetro, near Modena, where an average 500 head of beef cattle are slaughtered daily. They show a desire to introduce composting technology into a reality where a demand for quality is essential for the success of the technique.

The experimentation carried out between December 1992 – August 1993 was to involve the composting of a mixture of two of the organic residues regularly produced during the slaughtering process: organic wastes from the press-screw separator, obtained from the purification plant and ruminal content removed from the workplace, pressed and collected in the same container where the press-screw wastes come together.

Materials and Methods

The experimentation was divided into two test cycles and took place during two different seasons: a winter cycle (Dec '92 – Apr '93) and a spring-summer cycle (May – Aug '93). In order to obtain starting material with the right characteristics, straw residues obtained by chopping up discarded wooden pallets and pine trimmings collected during the upkeep of local parks and gardens were added to the waste sludge mixture and ruminal content. The mixture was made according to accurate volume or weight ratios (table 1).

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Table 1 Volume or weight ratios between woodchip and sludge during the winter cycle (Dec. '92 – Apr. '93) and the spring-summer cycle (May – Aug. '93).

Trials	Woodchip/sludge (1)		Turning	Covered
	Weight (%)	Volume		
1° A	—	—	NO	NO
C B	86	2 : 1	NO	NO
Y C	41	1 : 1	YES	NO
C D	43	1 : 1	YES	YES
L E	24	1 : 2	YES	NO
E F	23	1 : 2	YES	YES
2° I	—	—	NO	NO
L	16	1 : 2	YES	NO
C M	18	1 : 2	YES	YES
Y N	13	1 : 3	YES	NO
C O	12	1 : 3	YES	YES
L P	26	1 : 2	YES	NO
E Q	10	—	YES	NO

(1) sludge: waste sludge and ruminal content mixture.

Thirteen triangular piles were formed on a waterproofed concrete base, one for each of the trials proposed, 6 in the first cycle and 7 in the second.

The composting cycle took four months; two were necessary for the active or thermophile stage during which time the heaps were turned once a week, and two months were needed for the stabilization-maturation of the product.

Results and Discussion

In heaps where straw residues were added the temperature trend testified to the evolving process of aerobic decomposition which was highly esothermic. The composting process did not start in the heaps where the woodchip was not added and the heaps were left unturned ($T^o < 40^\circ\text{C}$).

The temperature trend tended to be somewhat regular when (in heap P) pine trimmings were used. Moreover, average temperatures were rather higher compared to other heaps in the second cycle, especially during the maturation stage. The only unsuitable hypothesis of all those tested, on account of the mixture and management criteria was test B which was carried out with a considerable ratio of woodchip. The objective was to obtain a mixture with a porosity which would mean that turning was no longer necessary, but in the end the degradation process turned out to be incomplete and unsatisfactory.

All the composts obtained (table 2) were the result of good agronomic quality. The macroelement content (N, P and K) is rather interesting. As far as the microbiological aspect is concerned, salmonella tests proved negative in all the products, thereby confirming the hygienising effect of the composting. The results obtained with the germination sample (GI values higher than 70%) confirmed the absence of phytotoxicity in the final products, already found in many cases at the end of the thermophile stage. On the basis of the confrontation with the qualitative

limits set by the law in force about compost (D.P.R. n. 915/82) and about agricultural use of the waste sludge (D.Lgs n. 99/92) it emerges that all the composts produced are well within the parametres set by the law, even for the heavy metal content.

Further research was done on some of the composts obtained regarding the stabilising grade of the organic substance by determining some parametres of humification also fixed by national laws on fertilisers (Law of 19 October 1984, n. 748 and later indications and integrations Suppl. Ord. to the G.U. n. 29 of 4 February 1991).

The grade (DH) and humification rate (HR) highlighted excellent progress in the P heap with values grown progressively in time. However, the humification course in other heaps was more irregular, presumably because of the lack of homogeneity of the compost material (excessively rough fractions).

Determining the initial and final weight of the different heaps meant that it was possible to quantify the reduction that took place and which ended up being between 60 and 80% of the initial weight of the mixtures used in the process. More precisely, water loss averaging between 60 and 90% was observed compared to the initial content (excluding the rainwater for the uncovered heaps) and the loss of volatile solids was between 15 and 71%. The low reduction of volatile solids seen in some of the heaps during the second cycle is likely to have been caused by the microbial mineralisation activity due to the high level of dryness already reached at the end of the first stage of the process.

As far as total nitrogen is concerned, the relative mass weight highlighted a variable loss of between 43 and 65% compared to what was initially contained in the heaps. Ammonia concentrations in the vicinity of the heaps both in the static phase and during the turning of the heaps were checked weekly with the aid of a phial gas revealer (the totalising type DRAGER Polymeter). The highest value recorded, equal to 35 ppm corresponds to the maximum for limited periods of exposure (TLV-STEL) proposed by the ACGIH (American Conference of Governmental Industrial Hygienists) responsible for hygiene in the workplace and this value is recognised as a guideline by the national UUSSL. As such this is a reassuring result for the worker responsible for managing the heaps.

On the whole the results obtained were positive and encouraging. The materials treated seem particularly suited to the composting treatment. The presence of ruminal content would appear to influence positively the biochemistry of the process. The process worked by adding quantities of straw residues varying between 40 and 10% of the sludge weight thereby proving to be quite flexible. Finding out the minimum mixing limits is extremely important in that the quantities of woodchip at stake for future applications of the process are somewhat high. The good results obtained using the plant trimmings meant that a new category of residues which can substitute woodchip pallets was identified and, what is more, it is easily found and has similar disposal problems. In addition the trimmings give a higher quality product compared to the pallet woodchip.

Table 2 Characteristics of the composts.

	C	D	E	L	F	M	N	O	P	Q	D.P.R. n. 915/82 n. 99/92	DLG n. 915/82 n. 99/92
pH	6.6	7.0	6.8	6.9	7.4	7.3	7.3	7.2	7.4	7.5	6-8.5	-
TS (%)	36.9	54.5	40.8	31.7	75.4	91.4	58.5	91.2	39.9	71.7	55	-
VS (%) TS)	89.4	85.5	85.7	82.4	90.2	88.4	83.8	86.3	80.6	84.9	-	-
TKN (% TKN)	2.20	1.91	1.77	2.49	2.29	2.63	2.38	2.40	3.23	2.27	>1	>1.5
NH4-N (% TKN)	3.02	4.41	0.55	0.42	2.78	3.82	1.00	5.61	0.78	3.56	-	-
TOC (% TS)	43.8	44.8	43.1	41.8	43.4	44.2	45.7	44.3	39.6	42.1	-	20
C/N	20	23	24	17	19	17	19	20	15	20	<30	-
P (% TS)	0.71	1.06	0.88	1.04	0.66	0.76	0.95	0.98	1.14	1.07	>0.22	0.4
K (% TS)	0.23	0.40	0.40	0.25	0.27	0.23	0.27	0.23	0.72	0.23	>0.33	-
G.I. (%)	78	83	82	100	74	108	105	55	85	85	-	-
Cu (mg/kg TS)	26	44	75	53	30	71	29	88	71	34	600	1000
Zn (mg/kg TS)	190	311	277	203	262	420	201	438	435	197	2500	2500
Ni (mg/kg TS)	-	26	-	8	19	-	40	10	16	200	300	-
Pb (mg/kg TS)	-	6	-	6	10	-	6	4	<1	500	750	-
Cd (mg/kg TS)	-	0.8	-	-	0.6	1.0	-	1.6	0.9	0.14	10	20
Cr (mg/kg TS)	-	32	-	-	21	16	-	30	22	6	510(*)	-
Hg (mg/kg TS)	-	1.16	-	0.25	0.30	-	0.85	0.34	0.25	10	10	-
Salmonellae (MPN/g TS)	0	0	0	0	0	0	0	0	0	0	0	0
DH (%)	80.7	80.4	79.6	-	68.4	68.5	-	72.9	89.2	75	-	-
HR (%)	20.9	25.7	24.7	-	17.3	15.5	-	29.4	34.2	22.5	-	-

(*)_ 500 mg/kg TS for Cr (III) e 10 mg/kg TS for Cr (VI).

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The Influence of GFT–Compost Extracts¹ on the Motility of Juveniles of *Heterodera Schachtii* in Vitro

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Abstract

Organic material has undeniable an influence on the soil ecosystem, including the population of soil nematodes. In this experiment, the influence of GFT–compost extracts on the motility of juveniles of *H. schachtii* is investigated. As reference Hoogmeerturf (a white peat) extract was taken, because there is no suppressive character against nematodes described for peat.

A significant ($p = 0,05$) reduction of the motility of juveniles of *H. schachtii* was determined from day 1 to day 4 after adding GFT-compost extract against as well the control (water) as the Hoogmeerturf extract (reference). The reduced motility couldn't be explained by the concentration of organic acids.

Introduction

This experiment, where the influence of GFT-compost extracts on the motility of juveniles of *H. schachtii* is investigated, is part of a greater study in which the usefulness of rest materials (wastes) for the biological control of plant pathogens is investigated (RYCKEBOER and COOSEMANS, 1994).

On the one side the composting process has an antipathogenic activity (nematodes and fungi were killed during the composting) and on the other hand compost has an antipathogenic potential (DITTMER et al., 1990; DITTMER, 1991; HOITINK and FAHY, 1986; HOITINK et al., 1976).

One of the aspects of GFT-compost would be an activation of the soil life. This results in a shifting of the present organisms, namely a stimulating of the saprophytic organisms. A measure for this could be the proportion of plant parasitic and non plant parasitic nematodes. From this we can conclude that the addition of organic material lead to a decline of the plant parasitic nematodes (STIRLING, 1991).

On the other hand there are some chemical components (allelochemicals) of which the nematicidal character is known, such as thiophenyls (for example terthienyl), cucurbitacin, alkaloids, phenols and tannins, isothiocynates, organic acids (for example aspartic acid), also nitrites and nitrates, ammonium, H₂S, etc. (HASAN, 1992; RYCKEBOER and COOSEMANS, 1994; SEGERS, 1989).

MALEK and GARTNER (1975) report the suppression of some plant parasitic nematodes after the use of bark compost. The attack by rootknot nematodes *Meloidogyne hapla* en *M. incognita* in tomato was inferior on plants growing in bark compost than in peat as container substrate. The development of the population of *Pratylenchus penetrans*, *Trichodorus christiei* and *Helicotylenchus* spp. was inhibited in bark compost, but stimulated in peat. After adding compost to potting mixtures, the populations of Cephaloidea and Rhabditidae (useful, saprophytic nematodes) growth (HUNT et al., 1973). SEGERS (1989) made a table with a general view of organic materials which have or don't have any nematicidal activities. Spiteful, the rate of success is in some cases a subjective estimation. Although, we can write that some components of organic material have some influence on the soil life. Application of organic amendments can be a kind of biological control.

HASAN (1992) reports the use of various concentrations of water/organic solvent extracts of different parts of plants to kill nematodes under laboratory conditions. Analogous to this we conducted an experiment with GFT-compost.

HUNT et al. (1973) determinated the influence of water extracts of municipal refuses on the plant parasitic nematode *Belonolaimus longicaudatus*. Water extracts from saturated composted municipal refuse rendered sting nematodes, *B. longicaudatus*, immotile after immersion for 12 hr. Extract concentrated to 33% of its original volume rendered all of the 50 sting nematodes tested immotile in 3 hr. The fact that immotility doesn't result automatically in death is illustrated in the following text: over 80% of the nematodes exposed to the organic fraction for 6 hr and over 60% of those exposed for 24 hr regained motility within 1 hour after being placed in distilled water. However, after 144 hr in the organic fraction of compost extract, no nematodes regained motility when transferred to distilled water (HUNT et al., 1973).

Pot experiments of SZCZECH et al. (1993) showed no inhibitory effect of earthwormcompost (= vermicompost) on the development nor on diseases caused by the nematode species *Heterodera schachtii* en *Meloidogyne hapla*.

In summary we can say that not all kinds of compost are even successful in the suppression of plant pathogens, here in special nematodes. Compost type and maturity as well as the composting method have an influence on this quality (HOITINK and FAHY, 1986).

Because there were strong indications of a nematicidal character of GFT-compost in an preliminary experiment with *Steinernema carpocapsae*, it was certainly meaningful to control if this approach also goes up for *H. schachtii*. We can work on different levels: (1) is there an influence on the hatching?; (2) is there an influence on the vitality of the cysts?; (3) is there an influence on the free living juveniles of *H. schachtii*? In this experiment we control if the last influence exist.

Materials and methods

In petri plates with a diameter of 5,5 cm a quantity of J2 of *H. schachtii* has been diluted in distilled water. Before this plates got any treatment we first counted the number of motile and non-motile nematodes. After this, extracts (extraction time: 1 day) or distilled water were conjugated with two different concentrations (proportion extract/nematode solution 1/1 or 1/2). On regular moments the vitality of the nematodes has been evaluated.

The incubation was at 20 °C. The number of replications was 5 for the GFT-compost and peat extracts, and 3 for the controls.

For the statistical processing (analysis of variance) SAS (Statistical Analysis System; the General Linear Models Procedure) was used. With the Bonferroni t-test pairwise comparisons were conducted on the 95% confidence level (NETER et al., 1990).

Because organic acids have a nematicidal character, the concentrations of some acids were measured.

Results

Table 1 (appendix I) gives the proportional number of motile (vs. living) juveniles in function of the treatment and the incubation time. In this experiment we count 26 observations for each day. The R-squares of the used GLM-model in function of the time are: on day 0: 0,00 (= initial, namely the motility on day 0 is 100 % for every treatment); on day 1: 0,642262; on day 2: 0,714219; on day 3: 0,884476; on day 4: 0,953748. In other words, with increasing time, the quality of the model rises.

The most interesting pairwise comparisons are shown in table 2 (Bonferroni t-test, appendix II), with the upper en the under limit of the confidence interval (95% or p = 0,05).

In the figures 1 and 2 (appendix III) the motility percentages are shown in function of the treatment (respectively 1/2 and 1/1 vol. proportion) and in function of the time. Table 3 (appendix III) shows the content of 4 organic acids as well as the EC (Electric Conductivity) and the pH.

Discussion

The tables (1 and 2) and the figures (1 and 2) show an obvious influence of GFT-compost extracts on the vitality of J2 of *H. schachtii*. Extracts of GFT-compost give already on day 1 a serious, significant reduction of the vitality, as well for the dilution 1/1 as 1/2 and opposite H₂O (control) as the extracts of Hoogmeerturf. After day 4, Hoogmeerturf gives a significant reduction of the motility, but only for the dilution 1/1.

The results hold only for *H. schachtii*, and can not directly be transferred to all nematode species (SAYRE et al., 1965).

That other factors than the organic acids play an important role in the mortality of *H. schachtii*, is clearly illustrated in table 3. With this table we can't explain the higher mortality of the juveniles in the GFT-compost extracts, unless the pH-effect plays an important role on the ionization condition of the fatty acids.

In vitro GFT-compost has a clear nematicid character when compared with peat extracts. This was illustrated by relative higher concentrations. Now the question rises in which proportion GFT-compost in vivo has a nematicidal character. For this an in vivo experiment has been conducted.

Table 1 The mean motility (number of motile nematodes expressed as % of the total number of nematodes) of *Heterodera schachtii* in function of the treatment (ml extract/ml nematode solution) and the time, the number of observations, the standard deviation, and the minimum and the maximum motility

Day	Treatment*	N (obs.)	Mean motility	Std. dev.	Minimum	Maximum
0	H ₂ O-1/1	3	100,0	0,0	100,0	100,0
	Turf-1/1	5	100,0	0,0	100,0	100,0
	GFT-1/1	5	100,0	0,0	100,0	100,0
	H ₂ O-1/2	3	100,0	0,0	100,0	100,0
	Turf-1/2	5	100,0	0,0	100,0	100,0
	GFT-1/2	5	100,0	0,0	100,0	100,0
1	H ₂ O-1/1	3	100,0	0,0	100,0	100,0
	Turf-1/1	5	91,8	7,4	81,1	100,0
	GFT-1/1	5	65,5	23,8	46,2	100,0
	H ₂ O-1/2	3	99,5	0,8	98,6	100,0
	Turf-1/2	5	99,9	0,3	99,3	100,0
	GFT-1/2	5	71,4	11,7	58,9	84,4
2	H ₂ O-1/1	3	91,9	8,3	83,4	100,0
	Turf-1/1	5	77,4	12,9	62,6	97,2
	GFT-1/1	5	37,1	22,5	11,1	65,4
	H ₂ O-1/2	3	80,8	4,1	76,2	83,6
	Turf-1/2	5	85,4	4,6	80,8	91,5
	GFT-1/2	5	35,1	26,0	7,7	75,0
3	H ₂ O-1/1	3	86,7	4,9	83,4	92,4
	Turf-1/1	5	68,8	4,1	62,6	73,6
	GFT-1/1	5	14,4	9,4	2,8	28,4
	H ₂ O-1/2	3	78,8	4,8	73,9	83,6
	Turf-1/2	5	74,1	7,1	66,1	83,7
	GFT-1/2	5	26,8	21,6	7,7	55,6
4	H ₂ O-1/1	3	86,7	4,9	83,4	92,3
	Turf-1/1	5	66,5	4,5	62,6	73,6
	GFT-1/1	5	9,5	10,6	1,6	27,6
	H ₂ O-1/2	3	78,8	4,8	73,9	83,6
	Turf-1/2	5	71,8	6,4	66,1	78,8
	GFT-1/2	5	14,4	10,2	4,1	30,0

*H₂O = distilled water; Turf = Hoogmeerturf extract; GFT = GFT-compost extract

Table 2 'Pairwise comparisons' of the treatments in function of the time (*H. schachtii*)

Day	Comparison*	Upper limit	diff. between means	Under limit	Sign.**
0	H ₂ O-1/1 – GFT1/1	0,0	0,0	0,0	
	H ₂ O-1/1 – Turf-1/1	0,0	0,0	0,0	
	Turf-1/1 – GFT1/1	0,0	0,0	0,0	
	H ₂ O-1/2 – GFT1/2	0,0	0,0	0,0	
	H ₂ O-1/2 – Turf-1/2	0,0	0,0	0,0	
	Turf-1/2 – GFT-1/2	0,0	0,0	0,0	
	H ₂ O-1/1 – GFT1/1	4,6	34,5	64,4	*
	H ₂ O-1/1 – Turf-1/1	-21,7	8,2	38,1	
	Turf-1/1 – GFT1/1	0,4	26,3	52,2	*
1	H ₂ O-1/2 – GFT1/2	-1,8	28,1	58,0	
	H ₂ O-1/2 – Turf-1/2	-30,3	-0,3	29,6	
	Turf-1/2 – GFT-1/2	2,6	28,5	54,4	*
	H ₂ O-1/1 – GFT1/1	13,9	54,8	95,7	*
	H ₂ O-1/1 – Turf-1/1	-26,4	14,5	55,4	*
	Turf-1/1 – GFT1/1	4,9	40,3	75,7	
2	H ₂ O-1/2 – GFT1/2	4,8	45,7	86,6	*
	H ₂ O-1/2 – Turf-1/2	-45,5	-4,6	36,3	
	Turf-1/2 – GFT-1/2	14,8	50,3	85,7	*
	H ₂ O-1/1 – GFT1/1	44,7	72,3	99,9	*
	H ₂ O-1/1 – Turf-1/1	-9,8	17,8	45,4	
	Turf-1/1 – GFT1/1	30,5	54,4	78,3	*
3	H ₂ O-1/2 – GFT1/2	24,4	52,0	79,6	*
	H ₂ O-1/2 – Turf-1/2	-22,9	4,7	32,3	
	Turf-1/2 – GFT-1/2	23,4	47,3	71,2	*
	H ₂ O-1/1 – GFT1/1	58,3	77,2	96,1	*
	H ₂ O-1/1 – Turf-1/1	1,3	20,1	39,0	*
	Turf-1/1 – GFT1/1	40,7	57,0	73,4	
4	H ₂ O-1/2 – GFT1/2	45,6	64,5	83,3	*
	H ₂ O-1/2 – Turf-1/2	-11,9	7,0	25,9	
	Turf-1/2 – GFT-1/2	41,1	57,5	73,8	*

*H₂O = distilled water; Turf = Hoogmeerturf extract; GFT = GFT-compost extract;

**Significance p = 0,05

Table 3 The pH (H_2O , 1/5 vol.), EC*, and the content of organic acids (mg/kg) of Hoogmeerturf and GFT-compost

Substrate	pH	EC	acetic acid	propionic acid	iso-butyric acid	butyric acid
GFT-compost	7,8	2,835	59,32	7,34	2,11	2,12
Hoogmeerturf	5,5	0,144	221,00	25,01	2,91	2,94

*EC(mS/cm; 1/5 vol; 25°C)

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The Suppression of *Penicillium Digitatum* by Extracts of GFT-Compost*

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Abstract

There is a suppressive character described for several kinds of compost against soil borne pathogens (fungi). In this experiment there was a suppression of *Penicillium digitatum* in vitro after addition of extracts of GFT-compost or Hoogmeerturf (a white peat). Although there are only a few sources who reports a suppressive character of peat. The suppressive character of GFT-compostextract was a result of the high bacterial activity, while the great number of fungi (i.a. *Trichoderma* spp.) were responsible for the suppressive character of GFT-compost. The use of microfiltrations allowed to distinguish between the biotical and abiotical factors responsible for the suppression. The autoclavation of the Hoogmeerturfextract destroyed the suppressive character; in contrast the GFT-compostextract maintain his suppressive effect after autoclaving as a result of the allelochemicals.

Introduction

The purpose of this experiment was to check if GFT-compost extracts have a influence on the *P. digitatum* mycelium growth. Various composts may suppress fungal diseases (CHEN et al., 1988; HOITINK and FAHY, 1986; SZCZECH et al., 1993). STINDT and WELTZIEN (1988) found an inhibition of the conidia germination and the development of the germination tube of *B. cinerea* after the use of several compost extracts. Further they found a increasing suppression with increasing extraction time.

Research on suppression of *Rhizoctonia* damping-off has shown that microbial populations within media containing CHB (composted hardwood bark) are respon-

* GFT-compost is the result of the composting of the organic fraction of household and garden waste (biowaste)

sible for disease control (NELSON and HOITINK, 1982; NELSON and HOITINK, 1983). STINDT and WELTZIEN (1988) found that extracts of composted organic material losses their activities after sterilisation by filtration with a cellulose-acetate membrane filter with a pore size of 0,2 µm. With other words, the biocontrol is depending on the antagonistic organisms, who are removed by heating or microfiltration (0,2 µm). The same filter with a pore size of 12 µm has no influence on the activity.

But the influence of chemical inhibitors (allelochemicals) may not be underestimated. Inhibitors with fungicidal activity have been found in media amended with composted hardwood bark as well as in those amended with pine bark. The nature of the chemicals involved is being investigated (HOITINK, 1980).

A different influence on both factors by increasing temperature or temperature treatment can be expected. According to MILLIPORE (1991) would a 0,2 µm microfiltration remove the bacteria and a 1,2 µm filtration the algae, fungi and protozoa. When the compostextracts of different kinds of composts were autoclaved, the suppressive character disappears (MANDELBAUM et al., 1988; STINDT and WELTZIEN, 1988). The extraction proportion was in this experiment 1/5 (vol) and the extraction time 1 day.

HARDY and SIVASITHAMPARAM (1991) found a various effect, after adding of non-sterile and sterile extracts to cornmeal agar (CMA) or wateragar (WA) on the mycelium growth of *Phytophthora* *nicotianae* var. *nicotianae*, *P. drechsleri* and *P. cinnamomi*. The mycelium growth of the three studied *Phytophthora*-species was greater for the non-sterile nursery mix (NM)-extracts added to CMA. The opposite was found for *P. cinnamomi* and *P. drechsleri* when non-sterile composted eucalyptus bark (CEB)-extracts were added to CMA. The mycelium growth on CMA, which contain non-sterile CEB-extracts, was smaller than on CMA enriched with sterile CEB-extracts. Consequently, these authors conclude with a great evidence that a specific inhibitory effect go out from the microorganisms in the non-sterile CEB, which not occurs in the CMA. But the effect was not common, because the mycelium growth was not reduced on CMA when non-sterile NM-extracts were added.

Further, they postulate that biotical factors of CEB were responsible for the inhibition of the sporangium formation and abiotical factors the sporangium formation stimulates. But the biotical factors were dominant. It is clear that the factors present in the extracts, which are responsible for the suppression of the fungi, in connection with the kind of compost and extraction time not easily can be defined. The results of STINDT and WELTZIEN (1988) show that the action depends on the biological activity of the extract. Every kind of compost will have an other microbial composition after extraction. According to HOITINK et al (1977) is the suppressive effect of bark compost probably due to chemical and biological rather than physical factors. Connected with that there can appear several antagonistic activities, antibiosis, concurrence or other fenomes. KUTER et al. (1983) determined a relation between species and disease suppression. Disease suppression was not associated with a single fungal taxon. Furthermore, quantita-

tive differences in sample populations isolated from suppressive and conducive container media indicated that the lack of suppression in some media was due to factors limited development of high populations of *Trichoderma* or interfered with the antagonistic activity of these fungi. The maturity of the compost has an influence on the antagonistic activity (BOLLEN, personal communication).

Materials and methods

GFT-compost or Hoogmeerturf was diluted in autoclaved, distilled water with an extraction proportion of 1/5vol. Every extraction was repeated three times.

The whole was shaken for 1 day, this was followed by (micro)filtrations, respectively 1) Whatman 5; 2) 5 µm MF-Millipore membrane filter; 3) 1,2 µm MF-Millipore membrane filter; 4) Nalgene Bottle Top filter 0,2 µm. From each filtrate there was a part (1 or 5 ml) plate out with 10 ml Potato Dextrose Agar (PDA) 1/5, with a proportion filtrate/PDA: 1/5. To the control plates autoclaved, distilled water was added. A dose pump was used by 50 °C to fill the petriplates. After coagulation with the culture medium there was an inoculation with *P. digitatum*, therefore of *P. digitatum* growing on a culture medium of Water Agar were 3 mm plots made and put upside down to the PDA plates. The mycelium growth by 21 °C from this plots was followed in function of time. The number of observations was for 1 ml extract conjugation equal to 21 (3 extractions with 7 replicates for each extraction), for 5 ml extract conjugation 9 (3 extractions with 3 replicates).

For the statistical processing (analysis of variance (ANOVA)) was the statistical computing package SAS (Statistical Analysis System) used. With the Bonferroni t-test pairwise comparisons were carried out on the 95% confidence level ($p=0,05$) (NETER et al. 1990). For this a confidence interval was made an upper and under limit, as well as a difference between the means, expressed in table 2. Only the most interesting pairwise comparisons were restrained.

Results

In table 1 (see appendix 1) is respectively illustrated: the mycelium growth (in cm) as mean of the three extracts of *P. digitatum*, the number of observations (N), the standard deviation, and the minimum and maximum growth of the fungus, after 3 and 6 days. Every treatment receive a code. The first figure in this code stands for the number of ml extract (or H₂O) that was added to the plate, on the second place the substrate (G = GFT-compost; T = Hoogmeerturf), on the third place the way of sterilisation (0 = Whatman 5, 1 = 3 µm, 2 = 1,2 µm, 3 = 0,2 µm, A = autoclaved).

Table 2 (see appendix 2) gives for the pairwise comparisons of the mean *P. digitatum* growth for 3 and 6 days with the difference between the means, the under and upper limit of the confidence interval on day 3 and 6.

The R-square of the used GLM-model was for day 3 0,973920, for day 6 0,978644.

For the Hoogmeerturf extracts as well as the GFT-compost extracts there is a clear suppression of *P. digitatum*, in function of the way of sterilisation.

How smaller the pore size of the filter, how more microorganisms were filtrated out, what resulted in a smaller suppression of *P. digitatum*.

The biotic factors responsible for the suppression are either different for peat and GFT-compost: the suppression of the *P. digitatum* growth for Hoogmeerturf was a result of the growth of antagonistic fungi (i.a. *Trichoderma* spp.), while bacteria are responsible for the suppression in case of GFT-compost. This conclusion is not clear in the preceding tables, either photograph 1 (GFT-compost extracts) and 2 (Hoogmeerturf extracts) illustrated this clearly (see appendix 3). Note beside the difference in mycelium growth, a clear difference in the kind of the microbial cultures between both substrate extracts.

Discussion

The suppressive character of white peat was already shown or reported by different authors (HOITINK and FAHY, 1986; TAHVONEN, 1982a; TAHVONEN, 1982b; WOLFFHECHEL, 1988). Because the used Hoogmeerturf a white peat is, is the suppression as a result of the use of this peat understandable.

Although Hoogmeerturf a suppressive character shows, is the suppression of *P. digitatum* by GFT-compost in most cases significant greater than the peat. On day 9, *Penicillium* could not colonize the whole plate when 5 ml autoclaved or 0,2 µm extracts of GFT-compost were added. All the other plates with the same extract addition (1 ml) and these with peat extract could colonize the plate well. So, we can conclude the following: (1) GFT-compost has a suppressive character as a result of biotic factors, but abiotic factors (allelochemicals) seem also to play a role, as showed by autoclaving. These allelochemicals give the compost also a kind of phytotoxicity, as shown in another experiment. (2) For a higher concentration of GFT-compost extract (5 ml vs. 1 ml) in the medium is there also a higher concentration of colloids, salts, ..., in the medium, what resulted in a higher suppression as a result of abiotic factors. For the biotic factors plays the initial concentration of the extract a smaller role because of the great multiplication rate of the microorganisms. The different pigmentation after adding of GFT-compost extract show clearly the stress of the fungus.

According to HARDY and SIVASITHAMPARAM (1991) varied the mycelium growth with leachate, agar type and the fungi.

This experiment shows a clear suppression of *P. digitatum* after adding of GFT-compost extract to the medium. A specific sensitivity of several soil borne fungi is not excluded. Further research about this subject is going on and can give more clearness.

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Appendix 1**Table 1** The mean mycelium growth of *P. digitatum*, the number of observations (N), the standard deviation, and the minimum and maximum growth of the fungus, after 3 and 6 days

Treatment*	DAY NR. 3					DAY NR. 6				
	N	Mean	Std. dev.	Min.	Max.	N	Mean	Std. dev.	Min.	Max.
Nothing	10	2,43	0,09	2,3	2,6	10	5,76	0,12	5,6	6,0
1H2O-A	21	2,52	0,13	2,4	2,8	20	5,52	0,17	5,3	5,8
1G-A	21	2,37	0,08	2,2	2,5	20	5,40	0,28	4,8	5,8
1G-3	21	2,52	0,14	2,3	2,8	21	5,65	0,35	5,0	6,2
1G-2	21	0,30	0,00	0,3	0,3	21	0,30	0,00	0,3	0,3
1G-0	21	0,30	0,00	0,3	0,3	21	0,30	0,00	0,3	0,3
1T-A	21	2,51	0,08	2,4	2,6	21	5,70	0,38	4,6	6,2
1T-3	21	2,59	0,13	2,3	2,9	21	6,13	0,21	5,8	6,5
1T-2	21	0,98	0,35	0,5	1,9	19	2,29	0,86	1,0	4,0
1T-0	20	1,04	0,18	0,7	1,4	10	1,58	0,31	1,2	2,1
5H2O-A	9	2,32	0,10	2,2	2,5	9	4,88	0,12	4,7	5,1
5G-A	9	1,73	0,12	1,6	2,0	9	3,13	0,17	2,9	3,3
5G-3	9	1,73	0,12	1,6	2,0	8	3,01	0,27	2,5	3,3
5G-2	9	0,30	0,00	0,3	0,3	9	0,30	0,00	0,3	0,3
5G-0	9	0,30	0,00	0,3	0,3	9	0,30	0,00	0,3	0,3
5T-A	9	2,37	0,07	2,3	2,5	9	5,31	0,21	5,0	5,6
5T-3	9	2,51	0,08	2,4	2,6	9	5,58	0,17	5,4	5,9
5T-2	9	1,33	0,39	0,8	1,8	9	2,44	0,88	1,4	3,9
5T-0	9	0,82	0,07	0,7	0,9	9	0,82	0,07	0,7	0,9

*Every treatment receive a code. The first figure in this code stands for the number of ml extract (or H₂O) that was add to the plate, on the second place the substrate (G = GFT-compost; T = Hoogmeerturf), on the third place the way of sterilisation (0 = Whatman 5, 1 = 3 µm, 2 = 1,2 µm, 3 = 0,2 µm, A = autoclaved).

Appendix 2

Table 2 Pairwise comparisons of the mean *P. digitatum* growth for 3 and 6 days with the difference between the means, the under and upper limit of the confidence interval on day 3 and 6.

Comparison*	DAY NR. 3			DAY NR. 6		
	Upper limit	Under limit	Diff. betw. means	Upper limit	Sign.	Under limit
		Sign.				Diff. betw. means
1H2O-A - Nothing	-0,12	0,09	0,31	-0,74	-0,24	0,26
1H2O-A - 1T-A	-0,16	0,01	0,19	-0,59	-0,18	0,22
1H2O-A - 1T-3	-0,24	-0,06	0,11	-1,02	-0,61	-0,21
1H2O-A - 1T-2	1,37	1,55	1,72	*	2,82	3,23
1H2O-A - 1T-0	1,31	1,48	1,66	*	3,44	3,94
1H2O-A - 1G-A	-0,02	0,15	0,33	-0,29	0,12	0,53
1H2O-A - 1G-3	-0,17	0,00	0,18	-0,54	-0,13	0,27
1H2O-A - 1G-2	2,05	2,24	2,40	*	4,82	5,22
1H2O-A - 1G-0	2,05	2,24	2,40	*	4,82	5,22
1T-A - 1G-A	-0,04	0,14	0,31	-0,10	0,30	0,71
1T-3 - 1G-3	-0,11	0,07	0,24	0,08	0,48	0,88
1T-2 - 1T-2	0,50	0,68	0,85	*	1,58	1,99
1T-0 - 1T-0	0,56	0,74	0,92	*	0,78	1,28
5H2O-A - Nothing	-0,37	-0,11	0,15	-1,48	-0,88	-0,29
5H2O-A - 5T-A	-0,31	-0,04	0,22	-1,04	-0,43	0,18
5H2O-A - 5T-3	-0,46	-0,19	0,08	-1,31	-0,70	-0,09
5H2O-A - 5T-2	0,72	0,99	1,26	*	1,82	2,43
5H2O-A - 5T-0	1,23	1,50	1,77	*	3,44	4,06
5H2O-A - 5G-A	0,32	0,59	0,86	*	1,13	1,74
5H2O-A - 5G-3	0,32	0,59	0,86	*	1,24	1,87
5H2O-A - 5G-2	1,75	2,02	2,29	*	3,97	4,58
5H2O-A - 5G-0	1,75	2,02	2,29	*	3,97	4,58
5T-A - 5G-A	0,37	0,63	0,90	*	1,57	2,18
5T-3 - 5G-3	0,51	0,78	1,05	*	1,94	2,57
5T-2 - 5T-2	0,77	1,03	1,30	*	1,53	2,14
5T-0 - 5T-0	0,25	0,52	0,79	*	-0,09	0,52
						1,13

*Every treatment receive a code. The first figure in this code stands for the number of ml extract (or H₂O) that was add to the plate, on the second place the substrate (G = GFT-compost; T = Hoogmeerturf), on the third place the way of sterilisation (0 = Whatman 5, 1 = 3 µm, 2 = 1,2 µm, 3 = 0,2 µm, A = autoclaved).

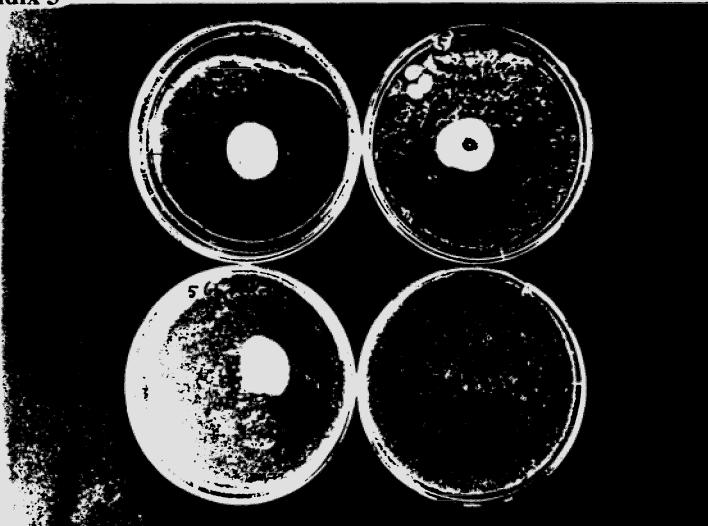
Appendix 3

Photo 1 The *P. digitatum* mycelium growth 6 days after inoculation in the plates enriched with GFT-compostextract (5ml/10 ml medium) (upper left: autoclaved extract (diameter mycelium: 3,1 cm); upper right: 0,2 µm-extract (3,3 cm); under left: 1,2 µm-extract (0,3 cm; the spot visuable by this treatment is not mycelium growth, but condens); under right: Whatman 5 extract (0,3 cm); The control (autoclavated water, not shown): 4,88 cm.



Photo 2 The *P. digitatum* mycelium growth 6 days after inoculation in the plates enriched with Hoogmeerturf-extract (5ml/10 ml medium) (upper left: autoclaved extract (diameter mycelium: 5,1 cm); upper right: 0,2 µm-extract (5,4 cm); under left: 1,2 µm-extract (2,3 cm); under right: Whatman 5 extract (0,8 cm); The control (autoclavated water, not shown): 4,88 cm.

Cation Exchange Capacity of Manure-Straw Compost – Does Sample Preparation Modify the Results?

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Abstract

Effective cation exchange capacity (ECEC) of mature manure-straw compost was determined by saturation-exchange method. Analysis was carried out on either fresh or dried and ground composts.

Drying of the sample increased ECEC values, whereas drying accompanied with grinding did not seem to have any effect on ECEC, as compared with ECEC values analyzed from fresh compost.

This study implies that ECEC determined of samples which are dried and ground describes well the actual cation exchange properties of the mature manure-straw compost, and that fresh compost can also be used for CEC determinations.

Introduction

Cation exchange capacity of matrix, for example soil or compost, describes the quantity of negatively charged sites on this matrix and thus its ability to hold positively charged ions. Its importance as one of the variables used for determining maturity of composts is widely accepted (Mathur et al. 1993, Inbar et al. 1991, Harada and Inoko 1980).

Sample preparation modifies its visual appearance and chemical properties such as solubility of nutrients. The aim of this research was to check, if drying and grinding of mature manure-straw compost has profound effects on its effective cation exchange capacity.

Material and methods

Material was drum compost of manure-straw mixture, cured for ca. 3 months in a pile.

Pre-handled composts for cation exchange capacity analysis were: 1. field moist

compost; weight field moist and CEC was determined at once, 2. dried compost; weight field moist and dried in oven at 40 C before analysing CEC, and 3. ground compost; dried in oven at 40 C and ground prior to weighing for CEC determination.

Effective cation exchange capacity was determined by saturation-exchange method (Saharinen et al. 1995).

Results and Discussion

Methods of sample preparation (drying, grinding) profoundly affected the visual appearance of the compost sample. The fresh manure-straw compost had considerably large aggregate sizes and was heterogenous in nature, and drying made its aggregate structure extremely fragile. With grounding the dried compost was thoroughly homogenized.

Drying affects various chemical properties of samples, for example solubilities of elements. Results of this study showed a slight increase in ECEC values due to drying (Table 1), which suggests that more exchange sites may have become exposed. In addition it was established that sample size (1 to 2 grams) did not have any effect on these results (Table 1).

Table 1 Effective cation exchange capacity of fresh and dried compost (drum compost after curing for ca. 3 months in a pile), determined from sample sizes of 1g and 2g

Sample	ECEC meq/100g dw	
	fresh	dried
compost (1g)	69.4 2.2	72.5 2.3
compost (2g)	69.9 1.0	72.0 2.3

Grinding is hypothesized to give overestimated ECEC-values. This was not verified in this study, as ECEC-values of dried and ground compost (67.1) did not significantly differ from those of fresh compost, as it had a considerably smaller standard deviation (0.4), due to its homogeneity, than the former.

I conclude from the results of this study that pre-handling of a compost sample does not significantly modify ECEC data, and that the data gained from ground samples reasonably well describes the cation exchange properties of the compost. Even fresh composts (as such or dried after weighing) can be used for CEC determinations, but then special concern must be taken to prevent possible corruption of the data due to accidental drying of the samples during handling and weighing procedures of the fresh samples. This study though does not exclude the possibility that drying and grounding change characteristics of the exchange sites even though the capacity of the mature manure-straw compost to hold positively charged ions is not noticeably modified.

Acknowledgements

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Vermicomposting Solid Paper Pulp Mill Sludge: a Three Stages Biodegradative Process.

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Introduction

The treatment of wastewater generated through paper pulp production produces large amounts of sludges; management of these residues constitutes an important environmental problem for this industry. To date, most of these sludges were land-filled or incinerated, but this only constitutes a partial solution. Incineration in the biomass boiler produces toxics and ashes and requires energy supply from these factories, and landfilling is not reliable for a long time. Thus, this waste should be recycled and exploited like an important source of organic matter.

In addition to solid paper pulp mill sludge (SPPMS) is a problematic organic refuse, it is a very steady waste, with a very slow decomposition rate. Although there are many types of SPPMS depending on manufacturing processes and wastewater treatments, they usually show high moisture content, C:N ratio, and pH which are barriers to its degradation.

Previous research showed that bioconversion is possible simply amending the SPPMS in mixture with other materials rich in nitrogen under suitable conditions. This pretreatment represents a physical, chemical and biological amelioration. In this way the C:N ratio and macronutrients levels are titrated, and, at the same time, an important microorganisms population is inoculated. Using these mixtures to feed earthworms, a rapid transformation and high growth rates are obtained; then, vermicomposting could be a good method for SPPMS biogradation with a low technology system, despite its high initial moisture content.

The aim of this communication was to discuss the particular biodegradation process that SPPMS amended with pig slurry undergoes for a three months vermicomposting.

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Materials and Methods

Fresh SPPMS was directly obtained from the primary wastewater treatment after the filtering press of E.N.C.E. (Empresa Nacional de Celulosas), Lourizán, Po. (Spain). This factory utilizes *Eucalyptus globulus* Labill. wood to produce virgin kraft paper pulp. Table I shows the main characteristics of the sludge and slurry.

SPPMS mixed with pig slurry in a ratio 4:1 (dry weight) has been used in a vermicomposting experiment for 90 days; 30 Kg of this initial mixture was inoculated with *Eisenia andrei* Bouché, 1972 from our laboratory stock. Temperature, moisture and ashes content, oxygen, leachate production, pH and conductivity were measured periodically; samples to analyse several parameters were taken: TOC (Total Organic Carbon); TKN (Total Kjeldhal Nitrogen); TEC (with alkaline sodium pyrophosphate); water soluble carbon (WSC); non humified (NH, labile non phenolic) and humified (humic -HA- and fulvic -FA- acids) organic fractions (Sequi *et al.*, 1986); crude fibre (CF) (AOAC, 1965) and fibrous compounds of Goering & Van Soest (1970) (neutral detergent fibre -NDF-, acid detergent fibre -ADF- and acid detergent lignin -ADL- fractions).

Results

SPPMS is a very steady waste (Table I), with a basic pH, high moisture content, and high C:N ratio and fibre content; C:N ratio dropped only until 240 after one year. These difficulties to biological treatment might be ameliorated by physical, chemical and biological pretreatment. Pig slurry resulted to be a good amendment in order to fit C:N ratio to suitable values in the initial mixture.

Table I Main analytical characteristics of pig slurry and SPPMS used in the experience.

	pH	E.C.	Moisture	Ash	TOC	TKN	N-NH4	C:N	TEC	WSC	CF
SPPMS	9.3	0.32	81.1	5.4	51.5	0.20	0.01	257	2.09	0.91	70
Pig Slurry	8.7	4.40	81.5	28.3	34.1	3.92	1.48	8.7	4.31	0.66	16

(all in percentage of dry weight, except pH, and conductivity in dS.m⁻¹)

With regard to substrates mineralization, Table II summarizes the evolution of some organic matter parameters. TOC decreased and TKN increased reaching a final suitable ratio for agricultural purposes. C:N ratio evolution showed different slopes, firstly a rapid decrease during the first month, and then slowed down. WSC sharply increased (five times) within first 30 days, dropping to less values than initial ones. TEC increased along the experience according to the humification process. NH evolution was in agreement with WSC one. For HA and FA big increments were observed, with the highest pick in the last month for HA.

Table II Evolution of some organic matter parameters in the sustratum during the experience.

	IM	10 days	20 days	30 days	60 days	90 days
V.S.	89,9	89,2	84,7	84,4	84,8	77,2
TOC	49,6	47,9	45,6	41,86	41,6	40,7
TKN	0,8	0,98	1,18	1,9	2,17	1,72
C:N	62	49	38,6	21,6	19,2	23,6
WSC	0,77	1,457	2,39	4,28	3,83	0,5
TEC	3,37	4,14	6,01	8,22	9,01	9,29
NH	0,94	1,97	3,25	5,14	4,58	1,21
FA	0,65	0,51	0,63	0,7	1,1	1,1
HA	1,5	1,56	2,17	3,08	3,22	6,78

Days from the begining; V.S.: volatile solids, IM: initial mixture, the rest of abbreviations are in the text; data are shown as percentage of dry weight

ADF-ADL (cellulose of Goering & Van Soest) is a similar technique to CF (Table III), and show quite well how the polysacharides degradation occurs, which are the fundamental component of the waste and the initial mixture. The lysis of fibrous compounds was faster within the first 30 days, since that moment it went down; final value is four times less than initial one. The experimental time resulted to be too short to allow the degradation of the lignins, this explains why the fraction identified as ADL was increasing, reaching an important value at the end, probably due only to loss of organic matter.

Table III Evolution of the fibrous compounds in the sustratum.

	IM	10 days	20 days	30 days	60 days	90 days
CF	61,05	53,9	45,3	25,8	26,6	16,35
ADF-ADL	61,76	56	40,8	21,8	20,1	19,21
ADL	9,59	11,82	14,43	17,74	18,5	27,98

Days from the begining; IM: initial mixture, the rest of abbreviations are in the text; data are shown as percentage of dry weight.

Table IV shows the evolution of some usual biodegradation indexes. All these indexes are useful to assess and discuss evolution of organic wastes during its degradation and stabilization.

Table IV Evolution of some degradation indexes in the sustratums during the experience.

	IM	10 days	20 days	30 days	60 days	90 days
HI	0,43	0,95	1,15	1,35	1,08	0,15
HG	64,5	50,1	46,78	42,8	46,96	84,8
HR	4,5	4,32	6,17	9,06	10,1	19,36
FA/HA	0,43	0,32	0,29	0,23	0,31	0,16

Days from the begining; IM: initial mixture, the rest of abbreviations are in the text.

Discussion

Degradation dynamic of this process is not the habitual one in vermicomposting; it is a mesophillic process, however there are some great physical and chemical changes in the substratum. We could say that it is a three steps bioconversion process with two different degradation rates. The initial steady waste becomes into a very unstable material, after a fast and strong breakdown showing low exoteric activity. Then, it is slowly stabilized until to become a mature vermicompost. Humification Index (HI), a good indicator of changes trends, reflected shows these steps.

During the first phase of destabilization, the higher mineralization rate took place due to the lysis of structural polyssacharides; supplyng simple molecules (NH and WSC), and a lower C:N (from 60 to 21). After 30 days it results in a very unstable material, as the indexes and the organic matter fractions proved.

During the second phase or stabilization one, the humification of easily digerible compounds take place. FA increase during the previous phase, while HA showed a continuos increment, this produces a decrease inthe AF/AH ratio in this phase.

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Evaluation of Turned and Static Pile Systems on Toxicity of Water Extracts of Biowastes

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Introduction

The degree of compost maturation has been widely studied in the water-soluble fraction (Chanyasak et al., 1982; Riffaldi et al., 1988; Garcia et al., 1991). Since it is there that the main biochemical transformations undergone by the microorganisms in organic matter take place. Therefore, phytotoxic substances, such as organic fatty acids of low molecular weight, ammonia and phenols and their degree of degradation during composting should be evaluated in this aqueous phase.

The aim of this work is to compare the evolution and to asses the maturity of two piles composted by the static forced ventilation system and by windrow.

Material and methods

Two composting piles were prepared with a household biowaste and sweet sorghum bagasse mixture at a volume ratio of 50:50 (95% and 5% fresh weight) with a C/N ratio of 17.7. One was composted by the Rutgers static pile system (C_1) and the other by the traditional turned pile (windrow) (C_2). The timer in the static pile was set for 30 sec. ventilation every 15 minutes, and the ceiling temperature for continuous air blowing was kept at 55 °C. The biooxidative phase of the fermentation period lasted 11 weeks and the maturation time was a further 8 weeks in both piles. The windrow pile was turned every two days during the first week, twice a week during the second week, and once a week during the rest of the biooxidative phase.

The evolution of the composting processes was studied at the following times: 1) starting time, 2) end of the thermophilic phase (5 weeks), 3) end of the active

phase (11 weeks) and 4) after maturation (19 weeks).

Water extracts were obtained with 4 gr (fresh weight) and 30 ml of water by shaking for 30 minutes at room temperature, centrifugation at 7000 rpm and then filtering through Millipore 0.45 µm filter paper (Chanyasak and Kubota, 1981). The following analyses were performed on the water extracts: water-soluble carbon and total nitrogen by elemental microanalyzer, ammonia by the colorimetric method based on Berthelot's reaction, and nitrate by ion chromatography. The organic-N was calculated by subtracting the amount of inorganic-N ($\text{NH}_4\text{-N} + \text{NO}_3\text{-N}$) from the total-N in the extract, phenols by Folin Ciocalteu's method, carbohydrates by the anthrone method, low molecular organic acids by HPLC and the germination index by the method of Zucconi et al., (1982).

Table 1 Water extract parameters as indicators of the compost process

sampling time (weeks)	Org-C (%)	carb (%)	Total-N (%)	Org-N (%)	$\text{NH}_4\text{-N}$ (%)	$\text{NO}_3\text{-N}$ (%)	Org-C/Org-N
C_1	5.51	3.66	0.46	0.36	0.10	n.d.	15.30
	1.71	0.36	0.35	0.24	0.11	n.d.	7.12
	0.76	0.32	0.25	0.09	0.02	0.14	8.44
	0.43	0.20	0.25	0.07	0.02	0.16	6.14
C_2	5.51	3.66	0.46	0.36	0.10	n.d.	15.30
	1.22	0.37	0.24	0.15	0.09	n.d.	8.13
	0.53	0.15	0.12	0.09	0.01	0.02	5.89
	0.28	0.10	0.13	0.05	0.01	0.07	5.60

n.d.: Not detectable.

carb: carbohydrates.

Table 2 Water extract parameters as indicators of compost phytotoxicity.

sampling time (weeks)	Ace (%)	Pro (%)	But (%)	Phenols (%)	$\text{NH}_4\text{-N}$ (%)	G.I. (%)
C_1	1.61	0.74	1.01	0.22	0.10	25.2
	0.19	0.18	0.15	0.19	0.11	49.4
	0.09	n.d.	n.d.	0.06	0.02	76.4
	n.d.	n.d.	n.d.	0.04	0.02	90.4
C_2	1.61	0.74	1.01	0.22	0.10	25.2
	0.04	0.09	n.d.	0.15	0.09	92.2
	n.d.	n.d.	n.d.	0.07	0.01	90.8
	n.d.	n.d.	n.d.	0.03	0.01	73.7

n.d.: Not detectable.

Ace: Acetic acid; Pro: Propionic acid; But: Butyric acid.

Results and discussion

A high degradation rate was observed in the water-soluble carbon and carbohydrates (Table 1). The former had an initial value of 5.51 and, at the end of the thermophilic phase (5 weeks), the degradation was of 69.0 and 77.9 for 4 and 4, respectively. After this time the degradation rate decreased, and the final level of water-soluble carbon in the mature compost was 7.8 and 5.1 of the initial values respectively. The greater degradation rate observed in C₂ could have been due to water-soluble carbon losses through leaching, since the high temperature reached, more than 70 °C (Fig 1), required a high amount of water for an adequate degree of humidity to be maintained for composting.

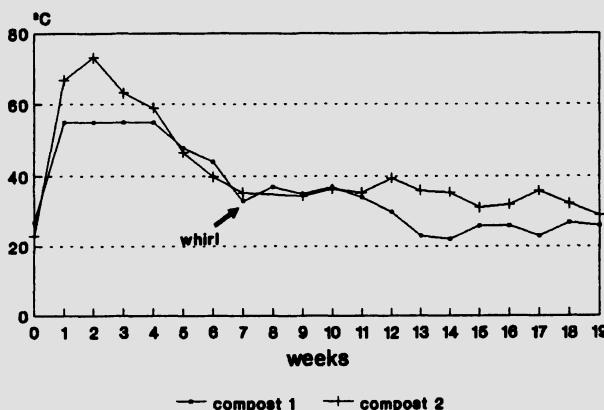


Fig 1 Temperature evolution of composts

The highest degradation rate of the soluble carbohydrates was during the first 5 weeks and by the end of the composting period the values were negligible.

The evolution of N-compounds was similar in both piles. The org-C/org-N ratio indicated that both composts were mature after 19 weeks, although the turned pile showed a value which may indicate that it was mature at the end of the active phase (11 weeks), as a result of its lower water-soluble carbon content. Chanyasak and Kubota (1981).

Table 2 shows parameters indicating the degree of phytotoxicity. Of the volatile fatty acids, acetic acid was produced to a higher degree than propionic and butyric acids, although all of them degraded rapidly during the composting process particularly in C₂. By week 11 only the acetic acid was detectable in C₁. Phenols, which are also considered phytotoxic, were degraded at a similar rate in both piles. The evolution of NH₄-N showed a similar pattern in both piles. Its presence in a compost indicates a low degree of maturity, but a very low concentration was found in both composts after 11 weeks of composting.

The initial germination index reflects the clearly phytotoxic effect of a high level of volatile fatty acids and NH₄-N. Such phytotoxicity ceased after the ther-

mophilic phase (5 weeks) in C2, whereas in C₁ could be considered as non-phytotoxic after week 11.

The analysis of a water soluble extract has been revealed as a very useful method for studying compost phytotoxicity. However, care must be taken when the turned pile composting system is used, because of possible leaching. The water soluble carbon lost through leaching in the turned pile could be the reason for an org-C/org-N ratio close to six earlier than in the static pile, indicating its earlier maturity. Chanyasak and Kubota (1981). The mature products of both piles had no inhibitory or toxic effect upon soil fertility since the GI of both was above 50%.

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Maximizing Both Compost Quality and Yield

PHILIPPE SHAUNER – Procter & Gamble

It is generally accepted that even with a source-separated feedstock, the presence of nuisance materials will result in a compromise between compost quality and yield. Plants will typically produce either a low yield of high quality compost, or large amounts of lower quality compost. This poster describes how refining by selective grinding can produce both maximum yield and top-quality compost.

The project

The district of Bapaume, France, has pioneered selective kerbside collection for compostable waste: kitchen and garden waste, paper, cardboard, disposable diapers and soiled paper products are collected once a week in a green biobin. The program has been running successfully for more than four years and demonstrates several advantages associated with the collection of all paper in the biobin:

- efficiency of the collection system (household waste is split into two near-equal fractions),
- paper absorbs leachate within the biobin, reducing odours and seepage
- paper provides the structural material required during the composting process,
- the system does not rely on recycled paper markets.

Although the feedstock is based on a wide ‘biowaste’ definition, more than 95% of the collected material is compostable.

Full-scale experiments have shown that, after a controlled indoor window composting process, the compost meets all European heavy metals standards and is pathogen-free.

The problem

To meet the most demanding end-markets, such as home-gardening products, the compost must also be free from sharp or cutting pieces and visual impurities, especially plastic film. The problem is to remove these residual impurities without reducing compost yield.

The solution: Selective grinding

Using a hammer grinder fitted with a 20 mm-grid and a special novel aperture:

- compost is reduced to small particle size (< 3 mm),
- residual glass and stones are pulverized so are no longer sharp or visible,
- plastic pieces are little affected by the treatment so can be easily removed.

Subsequent sieving produces 3 fractions:

- 8–50 mm: plastic film fragments (2,1%)
- 3–8 mm: insufficiently degraded paper suitable for recycling within the composting process (9,1%)
- 0–3 mm: high quality compost (88,8%)

These experiments were carried out jointly by Procter & Gamble, Gondard Sovadec, and Michel Nougaret, consultant.

Fresh and Composted Pea-nut Shells Microflora

MAMADOU AMADOU SECK*; GÉRARD KILBERTUS**

Summary

Fresh and composted pea-nut shell microfloras qualitative and quantitative compositions were studied to accelerate the pea-nut shell aerobic composting by adding 'starters' stocks. The isolated germs are well suited to the Senegalese climatic conditions and many fungi have interesting cellulolytic possibilities. This work was completed by observations using a scanning electronic microscope.

Introduction

Composting is a woody substrate microbiological transformation, accelerated by appropriate ventilation favouring the anaerobic germ catabolic activity, and by adding nitrogen and phosphates in particular enabling the product C/N to be carried to an optimal value favourable to the protein synthesis.

As cellulosys and lignolysis possibilities govern the substrate mineralisation, it is important to know the quantitative and qualitative compositions of the present microflora.

In some cases, the addition of 'Culture starters' has to be contemplated to accelerate the process (KILBERTUS, 1985).

To this end, a microbiological study and a scanning electronic microscope observation were carried out on fresh peanut shells and composted shells for 22 days, according to the technique described by SECK and KILBERTUS (1988).

MATERIAL AND METHODS

Material used

The peanut shells come from a cooking oil factory set up in Dakar. Fresh shells and composted shells were used in this study (SECK and KILBERTUS, 1988).

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2. Microbiological analysis

Suspensions dilutions were achieved on the two categories of shells, and then sowed on:

- gelose nutritive culture medium (8 g of nutrient broth, 15 g of gelose for one liter of water) in order to seek the bacteria.
- gelose malt (15 g of malt extract, 15 g of gelose for one liter of water) to bring the fungi to the fore.

To determine the bacteria, use were made of the following works

- BERGEY'S manual (1974)
KILBERTUS and SCHWARTZ (1981)
KILBERTUS *et al.* (1977)

The fungi were determined thanks to the works by :

- ELLIS (1971, 1976)
BARRON (1972)
DOMSCH *et al* (1980)
REISINGER *et al* (1970)

In parallel, some sowed boxes were subjected to UV exposures with the hope that the possible effect of intense sunshine on the microorganisms will be revealed.

Observation using a scanning electronic microscope

The samples were fixed at the OsO₄ for 1h30, dehydrated in acetone increasing concentrations baths, dried at the critical point, then gold metallized.

Results

Total microflora

The dilutions suspensions carried out on the two shell types show that the total microflora of the fresh products (FS) is significantly higher than that of the composted material (CS): respectively 370.55 against 15.71×10^6 germs per gram of substrate dried at 105 °C for 24 hours (Table 1).

These differences can be linked to the substrate trophic quality: the fresh shells being likely to free a great deal more hydrosoluble products than their composted homologue, as shown by the clearly darker tint of the FS aqueous extracts.

Many experiments, with other materials, further proved that the first stages of their decomposition showed the highest number of germs (KILBERTUS 1969, 1985, BROUSSE 1983, SIFI 1984).

2. UV effects on the fresh and composted microflora

As the Sahelian grounds are subjected to strong doses of UV radiations, it has seemed interesting to check their action on the microflora present on the fresh and composted shells. To this end freshly sowed petriboxes were exposed at increasing exposure durations to the UV (fig. 1).

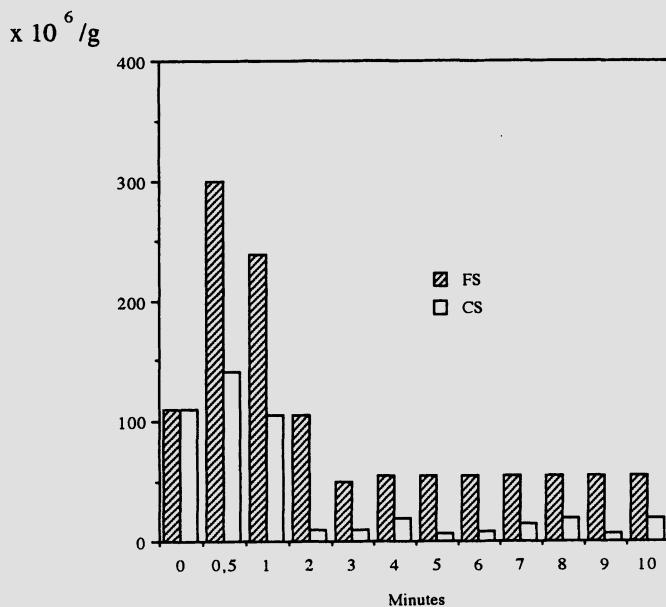


Figure 1 Total microflora evolution exposed to ultra violet radiation

Table 1 Total microflora (on nutritive culture median) $\times 10^6$ germs per gram of shells dried at 105 °C for 24 hours

FS	46.4	113.9	440.0	415.0	581.0	601.0
CS	9.9	36.5	13.7	6.8	11.6	-

Average: FS (fresh shells) 370.55
CS (composted shells) 15.71

In the case of the fresh shells, very important stimulation of this microbial population can be observed with treatments inferior to 1 mn. Above, the germ number decreases to get stabilised between 50% and 60% of the initial population. Those percentages are still very high and suggest the presence of abundant microorganisms likely to resist to the noxious effect of electromagnetic radiation.

The results obtained with the CS, are similar to the previous ones, but at the end of the experiment, only 10 of the initial population are found. It has therefore to be admitted that the quality of the CS microflora is different from that of the FS.

Fresh and composted shell flora

Bacteria (Table 2)

The microflora is qualitatively poor: 4 species out of the FS and 5 out of the CS. The FS population is dominated by the prokaryotes belonging to the Bacillus king: *B. megaterium* and a Bacillus with deforming central spore. These 2 germs represent more than 50% of the population. The remainder includes *Micrococcus luteus* and *Arthrobacter* sp (*Arthrobacter flavescens*).

Table 2 Bacteria present on the FS on the CS

Fresh shells	Composted shells
<i>Bacillus megaterium</i>	
<i>Bacillus</i> sp	
<i>Arthrobacter flavescens</i>	<i>Arthrobacter flavescens</i>
<i>Micrococcus luteus</i>	<i>Micrococcus luteus</i>
	<i>Micrococcus luteus</i>
	(<i>Sarcina lutea</i>)
	<i>Bacillus subtilis</i>
	<i>Bacillus sphaericus</i>

The last two bacteria are also found on the CS where they are accompanied with *Bacillus subtilis* and with *Bacillus sphaericus*.

The *Bacillus* predominance (particularly on the fresh shells) has to be attributed to their endospore producing possibilities which not only protect them against the radiations but also enable them to survive when there is no water. The importance of these microorganisms has, however, to be minimized, for their possibilities of attacking the woody tissues are reduced. In wood for example, only punctuations and tracheids can be metabolized by the germs (GREAVES 1969, ELFRASJAH 1988). Thus, they probably only develop at the expense of the by products resulting from the fungus activity.

Fungi (Table 3)

The main species encountered on the FS are recorded on table 3. *Neurospora sphaerica* prefers the hot regions (DOMSCH *et al.* 1980). It was signalled in particular by KOBAYASI *et al.* (1968) in Ruvenzori. It is capable of decomposing the cellulosis (AGRAWAL *et al.* 1974) and producing anti-viral substance (STAR-RAT and ADHOSING (1967).

The presence of *Rhodotorula* is not surprising either as this yeast resists well to the UV. The other germs (*Penicillium* sp, *Mucor* sp) as well as the sterile white mycelium, all, except the last one, with strong sporulation are not protected by melanoid pigments. They are, however, frequently seen on fresh organic matter, at the very beginning of the organic fragment decomposition (DICKINSON and PUGH 1974).

Table 3 Fungi present on the fresh (FS) and composted (CS) shells

Fresh shells	Corn posted shells
<i>Aspergillus</i> blanc	<i>Aspergillus</i> blanc
<i>Penicillium</i> sp	<i>Penicillium</i> sp
<i>Nigrospora</i> sp	<i>Nigrospora</i> sp
Sterile white Mycelium	Sterile white Mycelium
<i>Rhodotorula</i> sp	<i>Rhodotorula</i> sp
	<i>Trichoderma</i> sp
	<i>Ulocladium</i> sp
	Sterile brown Mycelium
	<i>Pithomyces</i> sp
	Sphaeropside
	<i>Fusarium</i> sp

A part from Aspergillus, all these eucaryots were also isolated from composted shells. Furthermore, the following are also seen then:

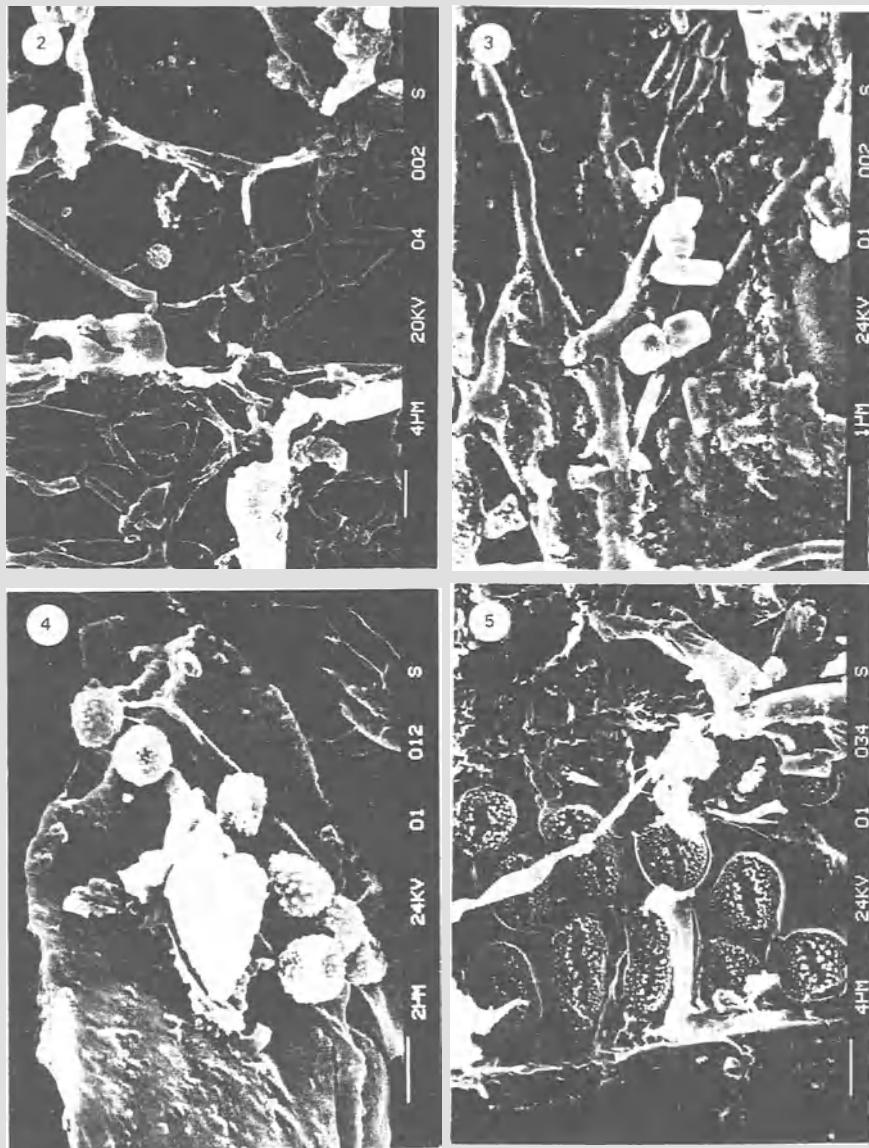
- Ulodadium sp some species of which are met in tropical and subtropical areas (ELLIS 1976). They are able to decompose cellulosis (WHITE *et al.* 48) they also very well resist to UV (DURREL and SCHIELDS 1960).
- Trichoderma sp: the species belonging to this kind are and their growth is optimum in lighting conditions close to UV. Finally their cellulolytic aptitudes are well know (NEMEC 1969).
- Pithomycus sp: these fungi are equally stimulated by radiations close to UV (NEMEC 1969).
- As well as a melanised wall sphaeroside, a sterile brown mycellium, a green Aspergillus and finally a Fusarium.

Scanning electronic microscope study

In the case of fresh shells, the fragments surfaces are covered with many hyphes (fig. 2) or fungi spores (fig. 3). The bacteria appear rarer (fig. 4). Finally, punctuations observations do not reveal microorganism presence. This result tallies with REISINGER and KILBERTUS's theory (1980) which states that the first stages of vegetal matter biodegradation are ensured by the fungi, with the procaryots only massively intervening when decomposition is advanced.

In the case of composted shells, hyphes and bacteria entanglement is often observed (fig. 5), the bacteria are locally numerous (fig. 7) and the punctuations are often colonized (fig. 6). Finally, the spiralled vessels residues are abundant, meaning cellulosis advanced decomposition. The phenomenon by procaryots has already been reported by ELFRAJSHAJ, in a study on epicea (1988).

In the latter case, the alteration signs show that mineralisation has already started and that the compost has reached maturity.

Fresh shells (FS)**Fig. 2 Presence of hyphes and fungi spores on the surface of fresh shells****Fig. 3 Bacteria and hyphes****Fig. 4 Fungi (probably penicillium)****Fig. 5 Non attacked punctuations**

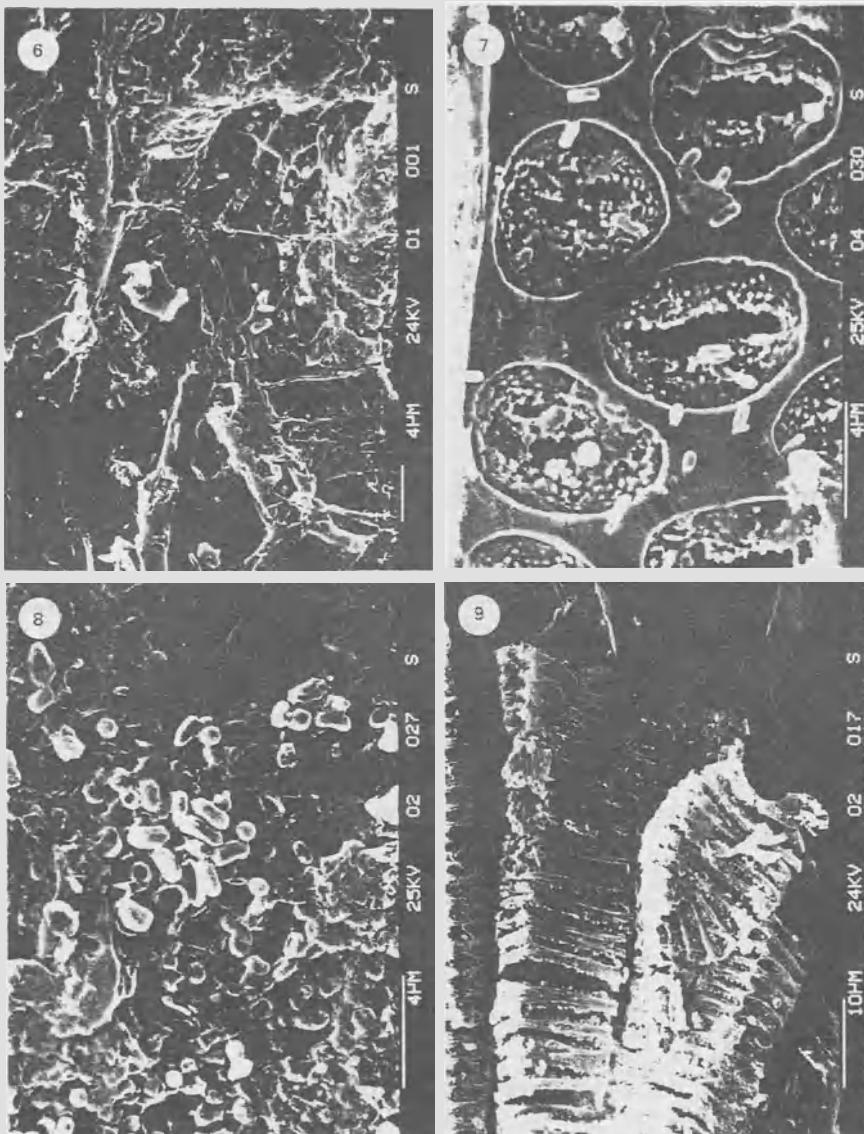
Composted shells (CS)

Fig. 6 Composted shell surface genuine aspect. Presence of hyphes and bacteria

Fig. 7 Punctuations attacked by bacteria

Fig. 8 Local pile of procarysts

Fig. 9 Spiralled vessel residues



Conclusions

The total microflora evolution is according to the one obtained in the course of the composting of other woody substrates, with in particular high presence of germs during the initial phase.

From a qualitative point of view, the present bacteria either produce endospores or are chromogenous and therefore protected against solar radiation and partly against dessication.

The shell mycoflora is characterized by species famous for being resistant to UV (*Rhodotorula*, *Ulocladium*, organisms with dematiated spores (*Nigropora*) or with pigmented mycelium (sterile brown mycelium). Again, they are germs particularly well adapted to high sunshine conditions.

If the enzymatic possibilities of the fresh shells flora remain modest, the composted shells microflora is often specialised on the cellulosis decomposition: *Trichoderma* and *Ulocladium* in particular. Here, the phase is certainly our of advanced biodegradation. As the mineralisation is active then, the microbial transformation of the substrate has gradually to put at the disposal of the plant many mineral elements necessary to its development.

Scanning electronic microscope observations confirm these results, especially the partial disappearance of the little or not ligneous tissues.

The presence of this specialized microflora which is well adapted to the local climatic conditions, allows the manufacturing of 'starters' media that will permit to put in order the manufacturing process of composts designed for Sahelian soils to be contemplated.

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Heat Transfer in Composting Systems

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Abstract

In order to control the composting process, microbially generated heat must be removed from a pile. This is to prevent the temperature of the substrate, which is a good thermal insulator, from reaching levels inhibitive to the resident microbial population. A model of the heat transfer mechanisms responsible for the removal of any excess heat has been constructed. The heat transfer mechanisms involved are convection and conduction, with radiation effects being assumed negligible.

An energy balance has been constructed for the energy transfers into, within and out of a composting system. These three components of the energy balance equate to the change in energy stored within the system, which dictates the temperature within the composting substrate. Separate equations have been developed for each of these components, leading to a complete mathematical energy balance for a composting system. This balance is taken over an instant in time and is expressed as rate equations, in J/s.

Introduction

The main process control in a composting system is the self limiting interaction between heat generation by the resident microbial population and the temperature rise this causes within the pile. The heat generation occurs throughout the pile and some of the energy will be transferred to the surroundings, i.e. the surface on which the pile stands and the atmosphere. The main mechanism by which the heat generation-temperature interaction is controlled is pile ventilation. In a positive pressure aerated static pile the ventilative airflow oxygenates the pile material and also removes surplus heat to maintain a non-limiting pile temperature. This entails preventing the pile temperature rising above 60 °C, after which the microbial population becomes inhibited, (Carlyle & Norman, 1941). Keeping the pile temperature within certain limits ensures that microbial heat generation, which results from substrate decomposition, occurs at a high rate, promoting rapid and efficient composting. In other words, after a few weeks of composting a good end product

will have been obtained which, provided the appropriate temperature-time profile has been achieved, will be free of pathogenic micro-organisms.

Heat transfers

It is important to understand the way in which heat transfers occur within a composting system so that the process can continue to be refined and improved. A uniform pile temperature will promote even decomposition and drying, although temperature gradients are unavoidable. Finstein *et al* (1980), determined the heat transfer mechanisms operating within a composting system. The relative proportions of the total heat lost by each heat transfer mechanism were calculated for an aerated static pile (ASP) by measuring heat inputs and outputs to the system. They calculated that of the total heat loss from a pile 88% was due to vaporisation, 10% to dry air convection and 2% to conduction, with radiant heat transfers being assumed negligible. In such a system, where most of the heat loss is due to the evaporation of water, heat loss is closely related to pile drying. However, physical models cannot reveal the relative rates of the heat transfer mechanisms, nor which of them are taking place at different stages of the composting process. They treat a composting system as a 'black box' model, without considering what processes are actually at work inside the pile.

Heat transfer mechanisms and heat transformations within a composting system can be defined verbally. This is done by constructing a heat energy balance for a composting system as a whole, over an instant in time. Assuming that no heat is lost through radiation, the energy balance is as follows,

$$\begin{aligned} & \text{heat transferred into the system by the inlet air -} \\ & \text{heat transferred from the system by conduction and convection +} \\ & \text{heat generated by the microbial population =} \\ & \text{change in heat stored within the composting substrate} \end{aligned}$$

Figure 1 shows diagrammatically what needs to be included in a model of heat transfers of a composting system. It shows how different heat transfer mechanisms work together within the composting system. The role played by each of the heat transfer mechanisms varies throughout a composting run, depending on the configuration of the system. It is impossible, however, to depict the relative importance of each of the heat transfer mechanisms on a block diagram. This should be demonstrated by the model of the system.

Heat generation

Heat transfers into and out of a composting system are further complicated by the microbial heat generation within the substrate. In order for composting to occur, four components are necessary: organic wastes, micro-organisms, water and oxygen. The reaction occurring during the composting process is as follows:

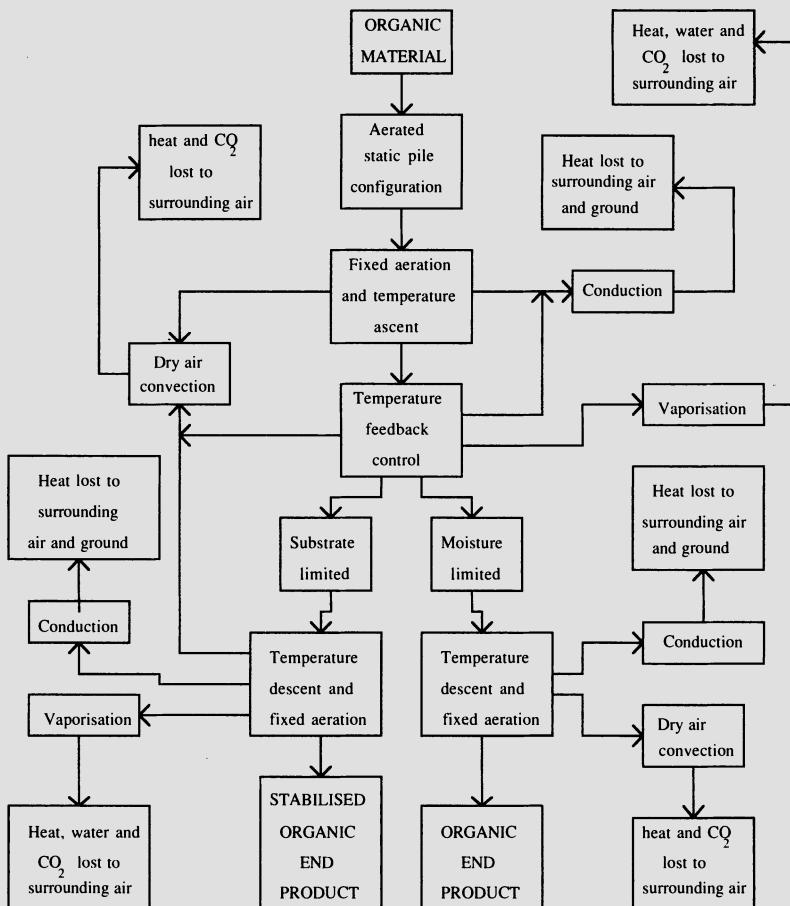
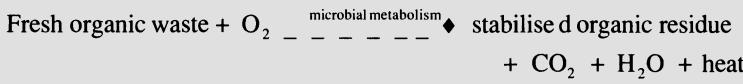


Figure 1 Block diagram showing heat transfers in an ASP system



It is important to know how much heat is generated within the pile by the microbial population. It is this heat that needs to be removed to prevent temperatures inhibitive to the resident microbial population from building up in the substrate. Some work has been done on measuring the microbial heat output of a variety of biodegradable substrates. Carlyle & Norman (1941), studied the heat outputs from straw, and Walker & Harrison (1960) and Rothbaum (1961), from wet wool. Finstein *et al* (1980), measured heat output from a sewage sludge and woodchip mixture in a field scale pile of the Rutgers ASP configuration. Their value of heat output was 0.0368 J/g(volatile solids).s at 50°C. Miller (1984), used a bench scale

apparatus which measured conductive and convective heat losses. The average heat output from a sludge and woodchip mixture was 0.0144 J/g(v.s.).s when temperatures were between 50 and 60°C. Rahman (1984), used micro calorimetric techniques to measure the calorific power of sewage sludge mixtures. The average heat output of sewage sludge was 0.0134 J/g(v.s.).s at 50°C.

Discussion

In order to be able to model heat transfers within a composting system, it is necessary to have a good understanding of the composting process as a whole. The extent of microbial heat generation and factors affecting the rate of this reaction, such as temperature and moisture limitations, need to be known in order to evaluate how much heat needs to be removed from a composting system. It is also important to know which heat transfer mechanisms are dominant, and how they interact with the process configuration and process controls, such as aeration, of the composting system in question.

Once a thorough understanding of all the constituent parts of the problem has been achieved, the process of building up a model of heat transfers can begin. Mathematical equations can be constructed to fit into the verbal model of heat transfers in a composting system. These mathematical equations can then be used to simulate the temperature profile within a run of the composting system under consideration.

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A Microcosm System to Determine the Gas Production of Arable Soils Amended with Different Composts

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Introduction

The disposal of compost on arable soils is expected to be an appropriate method for restoring a large quantity of compost. The potential climatic change as a result of the atmospheric increase of CO₂ and N₂O leads to the question, if mineralisation and humification due to the disposal of compost effects CO₂ and N₂O production and release into the atmosphere.

To quantify the gas production of different composts after addition to three different soil substrates a microcosm system containing 144 columns was constructed. The subject of the paper is to describe the construction of a low price microcosm system in comparison to the automated microcosm system, e.g. the system described by HANTSCHEL (1994). This system allows a high number of replications or variations of experimental conditions, such as temperature etc., to be carried out.

Construction of the microcosm

Figure 1 shows the construction of the individual microcosm in detail. Each column of the microcosm system consists of a PVC tube with a diameter of 0,2 m and a length of 0,4 m. At a level of 0,05 m a filter plate with a void diameter of 5 µm (DURST Filtertechnik, Besingheim, Germany) is fixed with silicon paste. The sieved soils (<4 mm) at a defined water content (in this case 50% of the maximum waterholding capacity) are filled into the columns. After each 10 cm addition of soil, compaction is forced by thumping the column ten times from 20 cm height to a stable base. The upper 10 cm is a defined mixture of raw and mature compost (sieved through 10 mm sieves) with soil substrates. For comparison, the microcosm can also be filled with soil material (30 cm soil) only.

The gas fluxes can be measured in each column at regular intervals. Therefore, they are closed by a gastight PVC-cover, containing a pasted silicon septum for sampling and a ventilator for mixing the gas phase before sampling. At the opposite site of the PVC cover a gas outlet is provided, closed by a rubber stopper, for gas exchange before accumulation of gas in a defined time interval. The volume of each microcosm is about 13 liter. The filling height of 0,3 m corresponds to the ploughed horizon of soils. However, other volumes are also possible.

Sampling

The gas sampling consists of a series of consecutive steps:

1. closing of the microcosms,
2. gas exchange in microcosms,
3. evacuation of vials and gas sampling for blank values,
4. closure microcosm for defined time interval,
5. mixing of gas phase,
6. evacuation of vials and gas sampling, and
7. opening of the columns.

The gas samples are stored in 10 ml glass vials (CS Chromatographie service, Langerwehe, Germany) before gas chromatographic measurement of CO₂ and N₂O. The vials are closed with a PTFE-coated rubber septum and have to be evacuated to a pressure of 25 mbar before sampling. This is done by a EDWARDS rotary vacuum pump. Do not evacuate the vials more than two hours before using them.

For gas exchange the columns are closed with the PVC cover, septum and rubber stopper are removed. The air in the void volume is exchanged by blowing through synthetic air (containing ca. 150 ppm CO₂) for exactly one minute. Then the cover is closed completely with septum and stopper. Immediately, two vials are filled for blank value determination, using a bothside pointed needle, pricked first through the septum on the column and then through the vial.

Depending on the gas production rates the columns have to be kept close for different time intervals. Before sampling the gas phase is homogenised by the built-in ventilator for 20 sec, then two vials are filled. Because of the vacuum in the vial it will be filled automatically with the air of the void volume. After sampling the vials filled with gas can be stored for two weeks. The closing interval as well as the sampling depend on the gas production rate.

Measurement of CO₂ and N₂O

The amounts of CO₂ and N₂O are measured using a gas chromatograph HEWLETT PACK-ARD 5890 SERIES II (TCD, packed column, detector temper-

ature 110°C, column temperature 50°C, carrier gas He 5.0). Calibration of the GC is made using a calibration gas mixture of 1000 ppm CO₂ and 400 ppm N₂O. The detector linearity is checked with an additional 5000 ppm CO₂ calibration gas.

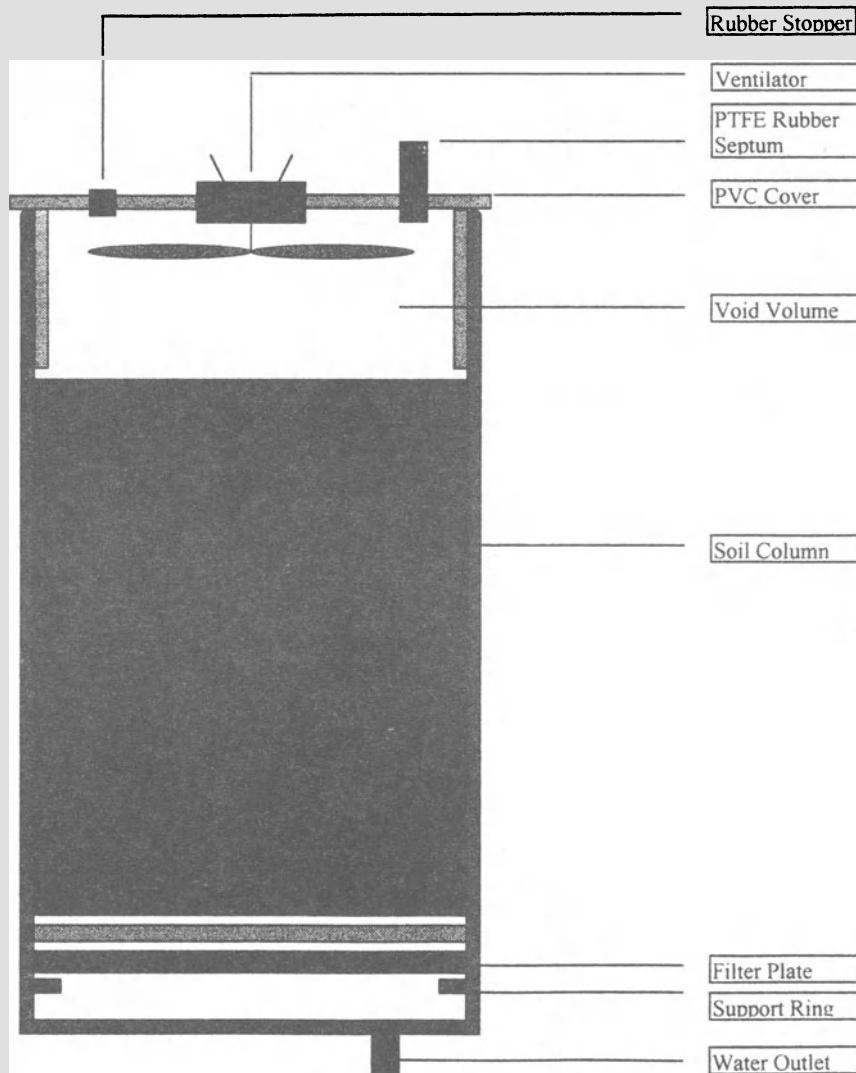


Figure 1 Model of the Microcosm

Blank values and samples are determined by injecting 250 µl using a gastight syringe (HAMILTON). Each measurement at the GC takes 15 minutes. For large sample amounts we propose to use an automatic sample injector.

Conclusions

The microcosm columns described here provide a suitable low-cost system to study the gas production of soils after addition of compost.

Because of the discontinuous gas measurement the columns can be placed in climate chambers under controlled conditions or any other suitable place, e.g. in a greenhouse.

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Improvement of the Composting Process

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Introduction

Improvement of composting efficiency is still an important research topic. Several authors have tried to define the optimal temperature for composting (Waksman et al., 1939; Jeris and Regan, 1973; Suler and Finstein, 1977). It is often assumed that thermophilic organisms are more efficient than mesophiles. Schulze (1962) showed that it is possible to maintain a composting process continuously in the thermophilic phase. Ventilation induced through temperature feedback system (Rutgers strategy) shows a higher decomposition rate than fixed ventilation (Beltsville strategy) (MacGregor et al., 1981). Blower operating either to pull or push air into the pile (Haug, 1980), drawing air from the base or the core of the pile (Mercedes et al., 1994) and the recirculation of the air in a reactor (Miller et al, 1990) have been tried to reduce the heterogeneous conditions common to piles. The aim of the present research is to compare the conversion of dry matter under self-heating conditions (with a preset temperature limit) with composting at the optimal temperature.

Material and Methods

Composting system. The composting system is composed of 6 reactors immersed in a refrigerated water bath. Each reactor is a 2 liter cylindrical vessel (working inside height of 23 cm and diameter of 9 cm), made of heat resistant glass, and with a perforated plate at the bottom to distribute air supplied from a compressor. Air circulates continuously in each reactor at a constant flowrate (250 ml/min) providing a CO₂ concentration of less than 10% in outlet air when the biological activity is most intense. The outlet air is cooled to room temperature before passing into a CO₂ infrared analyser and a mass flowmeter. Thermistors are placed at different depths in the composting mass and temperatures are read every hour with

a data logger. CO_2 and flowrate measurements are also recorded. A scheme of the installation is presented in figure 1.

Composting operation. The system operates under adiabatic and fixed temperature conditions. When the temperature reaches a preset value (40°C), the adiabatic experiments are conducted like the fixed temperature runs. The adiabatic runs are accomplished through a temperature controller that maintains the water temperature slightly below the temperature of the mass. In the fixed temperature trials, a thermistor placed in the centre of the mass and linked to the bath temperature controller imposes a mass temperature (40°C) by heating or cooling the water. The experiments are carried out to a CO_2 concentration in the outlet gas less than 1%. Substrate. The substrate is a mixture of whole rice hulls, finely ground rice hulls and rice flour in a fresh weight ratio of 50:34:16. This substrate was used by Hogan et al. (1989) to demonstrate a physical model of composting. The substrate is 87% volatile solid content and is well composted with 60% of moisture (adjusted with tap water). No seed is used. Previous experiments show that moisture content does not change during the composting process, pH has a typical evolution and the optimal reaction temperature for this mixture is 40°C .

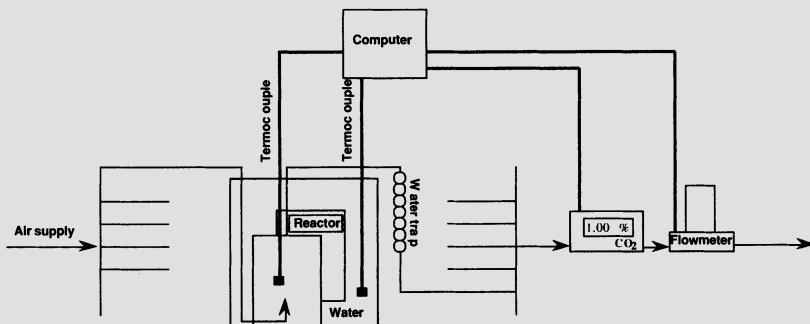


Figure 1 Scheme of the composting system

Conversion of dry matter. As CO_2 is measured continuously, its evolution rate (expressed as g/h) is used as an indicator of the microbial activity. The conversion of dry matter (X) at time t, expressed as a percentage or gram of dry matter degraded per gram of dry matter present in each run, is calculated by the equation

$$X_t = \int r_{\text{co}2} / DS_0 * Y * 100$$

where

$\int r_{\text{co}2}$ is the CO_2 produced until time t (gram)

DS_0 is the initial dry matter (gram)

$Y = (DS_0 - DS_f) / \int r_{\text{co}2}$ is the gram of dry matter degraded per gram of CO_2 produced

DS_f is the final dry matter (gram)

Results and Discussion

The change in temperature, CO₂ evolution rate and conversion of dry matter in the adiabatic and fixed temperature experiments are shown in figure 2.

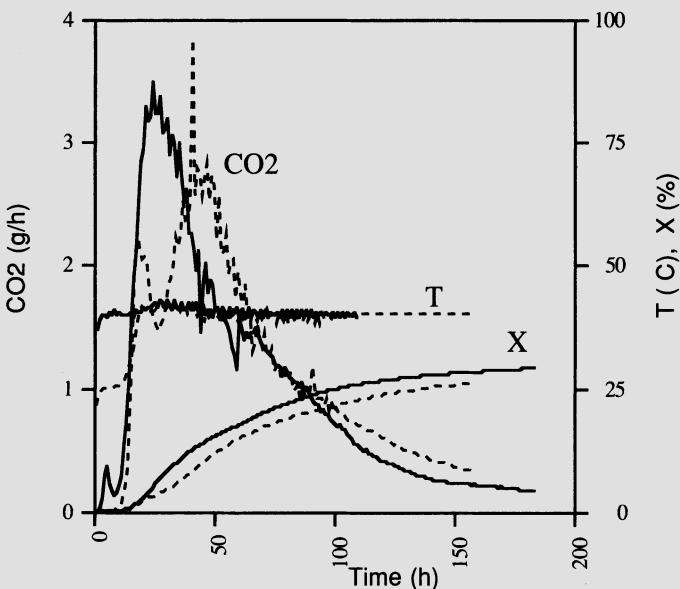


Figure 2 Composting on adiabatic (dotted line) and fixed temperature conditions (solid line). Temperature is measured at the core of the mass

The pattern of CO₂ evolution rate is similar: two peaks followed by a gradual decline in production. The lag phase is shorter in the fixed temperature than in selfheating runs. Temperature accelerates the start of the microbial activity. Schulze (1962), found that the initial phase of the composting process can be eliminated by operating continuously in the thermophilic phase. The slow temperature rise in the selfheating reactor favours the increase of the first CO₂ peak while pre-heating at 40°C favours the second one.

The conversion of dry matter is higher when the mass is preheated to 40°C: 25% in comparasion to 21% after 100 h of composting. Bach *et al.* (1985), working with sewage sludges at 60°C with isothermal and autothermal reactors reached the same conclusion: higher temperatures accelerate the composting process and the difference is reduced in time because the available organic matter controls the microbial growth rate in the end of the composting process. In the continuously composting system, higher conversion may be more important since fresh substrate is always available.

The temperature difference between the upper and bottom zones of the reactor is lower than 2°C in the Bach *et al.* experiments. The same difference is detected in the adiabatic temperature system but when 40°C is reached in the core of the

mass, a vertical temperature gradient appears and differences of 8°C at the CO₂ peak can be reached. Despite these differences in temperature, the conversion of dry matter increases when the substrate is preheated.

In composting, the decomposition of the organic matter is a dynamic process accomplished by a succession of microorganisms. Further research has been done on the factors which affect this succession and the role of temperature in the process.

Acknowledgements

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Use of MATER-BI ZF03U Biodegradable Bags in Source-separated Collection and Composting of Organic Waste.

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Introduction

The 5/29/91 Italian Law by Decree foresees the source-separated collection and composting of MSW organic fraction. This implies the distribution of containers for the collection of the wet matter. The direct use of bins is not well accepted by the public because of aesthetic and hygienic problems. A specific composting bag i.e. waterproof, weight and tear resistant, easily tied after use to contain bad odours, and biodegradable is preferable. Paper bags show a poor resistance to wetting and tearing, are bulky and not easily tied. The normal polyethylene bags are not biodegradable. When torn by the bags-breakers before composting they form not sievable fragments which end up into the compost as not biodegradable inerts. Biodegradable plastic composting bags are supposed to be a solution because they combine the biodegradability of paper with the physical properties of plastics. Mater-Bi ZF03U film was specifically developed for the production of composting bags and its biodegradability well studied at laboratory scale. Biodegradation measured by the ASTM D 5338-92 test was 78% while cellulose (reference) was 85% (J.Boelens, 1992). Terrestrial toxicity tests and physical-chemical characterization of the compost showed the absence of negative effects due to Mater-Bi degradation (De Wilde and Boelens 1992). Biodegradation determined with a test described in the 12/7/1990 Italian Decree was higher than food-contact paper, in compliance with the prescriptions of the decree (Molinari, 1994).

The present study had the following main objectives: verification of the acceptance of composting bags by the users; verification of compostability; effect of Mater-Bi on the composting process and on the compost quality.

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Materials and methods

The collection was performed in 5 supermarkets, 3 canteens, 1 refectory. The Mater-Bi bags had the following dimensions: height: 89 cm; width: 73 cm; weight: 65 g; thickness: 30 µm. The colour: light background, red chequered. The selection and collection period lasted three weeks (from 12th to 30th July, 1993) with 3 passages a week. Questionnaire were distributed to the users. Three windrows were prepared at the composting plant (Trento). *Windrow 1 (W-1)*: Simulation of the action of a dilacerator device with the tearing of Mater-Bi bags filled with organics. *Windrow 2 (W-2)*: The control, added with composting paper bags. These bags, because of reduced dimensions and of a general distrust of users, have been introduced directly into the mass. *Windrow 3 (W-3)*: Simulation of the action of a knife mill, cutting Mater-Bi bags into 10 x 10 cm pieces. The final composting mix was obtained by adding some extra organic matter besides MSW: sludge from a municipal depurator; poplar barks; fruit scraps; grass mowing. The mix had an apparent density of 0.6 ton/m³, humidity around 68% and a C/N ratio near to 27. Empty bags were introduced to reach the fixed amount of 38 Kg of bioplastics, established assuming that the whole matter of each windrow (60 m³) was delivered in 100 litres bags. In total, 585 bags were introduced into the W-1 and W-3, while 543 paper bags, corresponding to 38 Kg were introduced into W-2.

Four steel frames each containing a piece of Mater-Bi bag and a piece of paper bag, closed between two metal nets, were introduced into W-3 with the purpose to easily recover and identify the two materials during the process.

The transforming matter was turned with a composting turning machine at days: 0, 2, 5, 12, 16, 20, 29, 34, 54, 79.

Results and discussion

The rating on the bags was generally satisfactory. Some users stated to be very pleased and, in some cases, even to prefer these bags to the polyethylene ones. However, in other cases the following defects were noticed. Rupture at the seal (too thin; a more robust sealing was then adopted). Lateral tearing caused by sharpened objects (the cause of this problem was the excessive longitudinal orientation of the film. In a subsequent experience conducted at Kornenburg, Austria, with improved filming and sealing conditions the acceptability vs. paper bags was 87%). Poor resistance at temperature around 60°C (after this complaints the bags were marked with a warding explaining the proper use and storage conditions). Dimensions: the bag did not rest to the bottom of the containers.

The temperature trend of the three windrows was similar: a short lag phase followed by a long thermophilic phase (6–8 weeks). A concomitant increase of pH, electrical conductivity, ashes content, and a phytotoxicity decrease was noticed in all the windrows as a result of the progressive mineralization and stabilisation of organic matter. The windrows with Mater-Bi (W-1 and W-3) and the windrow with

paper (W-2) did not show any significant difference imputable to the different nature of the bags, even though the degradation of organic matter resulted more intense in W-1 because of an initial difference in its composition. The ripe compost, refined at 10 mm and analysed, showed valuable agronomical features, namely: absence of phytotoxic factors; neutral pH, a good amount of stabilized and sufficiently humified organic matter; high levels of nitrogen and phosphorus; optimal humidity level. An high salt levels was noticed, due to the organic fraction of MSW. The heavy metals concentration was low and in full accordance with the limits fixed by the law in force and to the standard outlined in a draft amendment of the law 748/84. At the end of process a sample of 40-50 litres of refined compost was isolated and subdivided into sub-samples and visually checked for possible Mater-Bi residues in W-1 and W-3, and for paper residues in W-2. No fragments, either Mater-Bi or paper, were found. The same survey was done on similar volumes of oversize fractions, with the following results. W-1: 23.75 g of Mater-Bi out of 45 litres of oversize fraction. W-2: 0 g of paper out of 53 litres. W-3: 12.40 g of Mater-Bi out of 40 litres. These data, if related to the total raw compost production achieved (35 m^3), represent an estimate of the residues present at the end of the process, before sieving. In W-1 the biodegradation estimate is 70.85% by weight; in W-3 the estimate is 82.87%. Therefore, film shredding before composting (W-3) improves degradation. The mincing treatment increased the surface and reduced the possibility of adhesion of foils each other. On the contrary, the whole film underwent to the action of the turning machine, which reduced it to long and curled shreds, diminishing in that way the free surface. The Mater-Bi residues conserved such a dimension to be completely removed with the oversize fraction. The materials sorted out by sieving can be re-introduced upstream in the cycle. This makes possible a further degradation of Mater-Bi. The degradation of Mater-Bi in the frames was faster than paper. After 20 days Mater-Bi degradation was already massive while paper seemed not altered at all till day 44. In any case, the metallic net prevented the mechanical action of the turning machine which seems to be important to fast biodegradation.

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Oil-Mill Wastewater Sludge Composting

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Abstract

In this work, oil-mill wastewater sludge composting has been carried out.

Different lignocellulosic residues (straw, wine shoots, olive branches and olive husks) have been mixed with the sludge in order to obtain a suitable moisture and C/N ratio.

In all cases, during composting an important organic matter degradation was observed. Results obtained showed a high extent of cellulose degradation indicating a very important microbial activity on the substrate, while the lignin attack was very light.

Introduction

The disposal of olive oil-mill wastewaters represents a relevant and yet unresolved agricultural and environmental problem for olive oil producing countries. These wastewaters are characterized by a relatively high content of organic carbon that can be recycled with enormous advantages for the typically organic matter poor soils of the Mediterranean area.

Since fresh organic matter contained in this residue may result in more adverse than beneficial effects on global soil fertility and due to antimicrobial and phytotoxic effects reported for this residue (1), it could be necessary to carry out a previous transformation process.

At the present work, sludge transformation through composting has been proposed like an alternative, because composting is a reasonable, economic and safe way to obtain an organic amendment from very different kinds of organic residues. Moreover, composting allows the raw material nutrients to be kept and to become useful.

Table 1 Characterization of the residues utilized in the oil-mill wastewater sludge composting.

	Moisture (%)	C (%)	N (%)	P ₂ O ₅ (%)	K ₂ O (%)	Na ₂ O (%)
Oil-mill wastewater sludge	68.0–97.2	52.4–64.3	1.6–2.9	0.27–1.63	2.0–1.3	0.04–0.11
Olive branches	7.0	49.3	1.4	0.18	0.72	0.01
Straw	7.7	42.5	0.4	0.11	1.4	0.02
Wine shoots	6.0	48.0	0.6	0.12	0.48	0.03
Olive husks	3.0	49.9	1.3	0.16	1.30	0.03

Materials and methods

First of all, a characterization of the main substrate – oil-mill wastewater sludge – was carried out. The oil-mill waster came from German Baena oil-mill (Córdoba, Spain) and this residue was flocculated with Z-50 (commercial product).

Different mixtures of this sludge with other lignocellulosic residues were achieved. Mixtures transformation through composting was evaluated at laboratory scale in a climatic chamber.

Lignocellulosic residues utilized for the mixtures were: wine shoots, straw, olive branches and olive husks. Main characteristics of these residues are shown in table 1.

These residues were mixed with the oil-mill wastewater sludge in a 1:1 (w/w) ratio, on a dry weight basis.

Experimental composting of the sludge obtained from the flocculation was performed in 5 l capacity PVC containers in a climatic chamber. It was used a temperature program which reproduces the temperature fluctuations recorded during the active decomposition phase, or stabilization phase of a composting pile. C/N ratio of all the mixtures was adjusted to 35. Analysis of the parameters measured during the composting process were carried out by conventional laboratory tests (2).

Results

In previous studies performed with a mixture made of oil-mill wastewater and straw or wine shoots, flocculant used showed not to inhibit the composting process (no showed data) (2).

Table 2 only shows the results corresponding to the evolution of different parameters at the initial, medium and final times determined during the composting of different mixtures assayed test. It can be seen that there is a clear decrease of carbon, as well as an increase of nitrogen which is due to a concentration effect as a result of the degradation of non nitrogenous organic matter, which originates a loss of weight and, therefore, a relative increase of nitrogen concentration.

Table 2 Evolution of main characteristics during composting process of oil-mill wastewater sludge mixed with: straw, olive branches, and olive husks

Mixture	Time month	Moisture (%)	Organic matter (%)	Carbon (%)	Nitrogen		P ₂ O ₅ (%)	K ₂ O (%)	Loss of weight	pH
					Nit. ppm	NH ₄ ppm				
Straw	0	75	92	54	1.5	2392	1949	0.78	1.1	6.0
	6	77	83	45	3.1	2174	2579	0.94	1.7	8.4
Olive Branches	9	14	83	40	2.7	647	670	2.79	1.9	8.2
	0	66	91	52	1.6	963	1444	0.46	0.7	5.6
Olive husks	6	76	83	45	3.3	2121	2418	0.71	1.4	8.4
	9	17	78	40	3.1	637	644	1.49	1.4	8.3
Olive husks	0	62	94	52	1.8	1399	1445	0.22	0.6	5.4
	5	41	92	44	2.2	580	513	0.36	1.0	6.4
Olive husks	7	9.6	91	43	2.1	370	420	0.33	1.2	6.2

In all cases there was an increase of the organic matter degradation, although in olive husks and oil-mill wastewater sludge mixture the organic matter mineralization was less. pH increase up to reach alkaline values (higher than 8), except to the mixture with olive husks.

Given that the ammonium concentration got after 6 month was a high one, which could be related to the high pH values found, the product was allowed to evolve in a natural way outside a climatic chamber for a two months maturation period.

On the other hand, a decrease of the lipid fraction with regard to the original material was observed, nevertheless, in the case of hydrosoluble this decrease was not so powerful (2). Regarding the substrates used, a clear decrease of cellulose was observed (67% and 80% degradation for mixtures of wastewater sludge and straw and olive branches respectively) the lignin fraction being the most degradation resistant fraction (25.5% and 37% degradation for mixtures of wastewater sludge and straw and olive branches respectively). Percentages of degradation both for lignin and for cellulose were lower in the case of a mixture with olive degradation both for lignin and for cellulose were lower in the case of a mixture with olive husk (20.8% and 43.7% respectively).

Final products achieved after the composting of the wastewater sludge resulting from flocculation with straw and olive branches can be considered as mature ones after 9 months from the beginning of the process, while that coming from the mixture with olive husks is mature after 7 months. In relation to the phytotoxicity tests, the high toxicity against germination showed by wastewater is progressively surpassed during composting. Germination index values higher than 90 have been got.

Cation exchange capacity values show that products obtained could be considered as mature since in all of the cases they were higher than 100 meq/100 g.

With regards to nitrogen, phosphorous, potassium and magnesium contents in final products, values over the acceptable minimum values were achieved, according to specifications recommended by the EC for mature compost.

On the other hand, total phenol contents is 82.8% lower for the mixture with straw, 73.8% lower for the mixture with olive branches and 61.5% lower in the case of a mixture with olive husks, and perhaps this lower diminishing is due to the less time of composting.

To conclude, and in spite of these results, it would be convenient to complete this study with vegetal response tests since physico-chemical characteristics of compost give only a approximate information on the fertilizing capacity thereof, and it is the plant that is going to have a final response.

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Sugarcane Filtercake Compost Influence on Tomato Emergence, Seedling Growth, and Yields.

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Abstract

Tomato (*Lycopersicon esculentum* Mill.) ('Sunny') seeds were sown in Speedling trays filled with sugarcane filtercake (a waste byproduct of sugarcane processing), plug-mix, field soil (sandy), compost:soil mixture (1:1, v:v) under greenhouse conditions. Mean days to emergence, final percent emergence, or mean days to fully expanded cotyledons were not different among treatments. In a second study, tomato 'Sunny' transplants were placed in 3.7 L pots filled with compost, field soil, or compost:soil mixture (1:1, v:v) under greenhouse conditions. After 25 days, plant grown in compost, or compost:soil mixture had heavier shoots and roots, thicker stems, and taller plants than plants grown in field soil. In a field study, 'Sunny' plants were transplanted in plots without and with compost (224 mt·ha⁻¹) at 0, 76.5N-67P-140K, or 153N-134P-280K fertilizer rates. Early and total marketable yields, shoot heights, diameters, and weights were higher in plots with compost than without compost, regardless of fertilizer rates. These results suggest that plots with incorporated sugarcane filtercake compost produced higher tomato yields and larger plants than plots without compost.

Introduction

Several benefits of composts incorporated into vegetable crop production systems have been reported. Composts can be a potential alternative to polyethylene mulch (Roe, et al. 1994), serve as biological weed control (Roe, et al. 1993), and reduce soil borne diseases (Hoitink, et al. 1993).

Composts can also serve as an additive source of organic matter and nutrients, particularly in soils that are inherently low in fertility. Compost usage in vegetable planting systems may result in a reduction of commercial inorganic fertilizer rates, reduced nutrient leaching, and increase water holding capacity.

The purpose of this experiment was to evaluate a compost ('Compost') derived from the natural byproduct of sugarcane processing mills on tomato seed emergence, seedling growth, and yields.

Materials and methods

Greenhouse experiment 1. Speedling trays (5 cm x 5 cm x 5 cm invert pyramid cells, 72 cells per tray) were filled with sugarcane filtercake compost (a waste byproduct of sugarcane processing mills) (Grand, 1972), plug-mix (Metro Mix 220, Grace Sierra, Milpitas, CA), field soil (Oldsmar fine sand; sandy, siliceous, hyperthermic Alfic Arenic Haplquods), or 50% field soil:50% compost (v:v). Tomato 'Sunny' seeds were sown in each tray (1 seed/cell) with 1 tray (72 cells) per treatment. A randomized complete block design was used with each treatment replicated four times. Percent emergence was recorded daily and seedling plant height were measured 9 days after seeding. Mean days to emergence (MDE) was calculated by the formula of Gerson and Honma (1978). Mean days to fully developed cotyledons were recorded. Shoots and roots (washed free from the adhering soil or media) were weighed and shoot:root ratios calculated.

Greenhouse experiment 2. Plastic pots (3.7 L) were filled with compost (described in expt 1.), field soil (described in expt. 1), or 50% compost:50% field soil (v:v). Tomato 'Sunny' transplants (4 weeks old) were planted into each pot (1 plant/pot). A randomized complete block design was used with each treatment replicated ten times. Plant height (cotyledonary node to growing tip) and stem diameter (just below the cotyledon node) were measured 25 days after planting. Shoots and roots (washed free from adhering soil or media) were dried at 65°C for 3 days, dry weights recorded, and shoot:root ratios calculated.

Field experiment: A field experiment was established at the Agricultural Research and Education Center on 30 September 1994. Soil classification was the same as described in Greenhouse experiment one. Polyethylene covered raised beds (15.2 cm high, 1.1 m wide), with or without compost (compost) (224 mt ha^{-1} ; 39% moisture) into the beds, were constructed. Fertilizer was applied at 0N-0P-0K, 76.5N-67P-140.5K, or 153N-134P-280K (mt ha^{-1}) (our normal fertilizer rate) resulting in 6 compost-fertilizer treatment combinations. 'Sunny' transplants (5-week-old) were planted in the center of each bed, 61 cm apart, with a plant population of 7,689 plants/ha. Each plot consisted of 15 plants with the center 10 used for yield and shoot growth data. A randomized complete block design with each treatment combination replicated four times was used. Shoot height (cotyledonary node to growing tip) was measured on 13 October, 1994. Marketable yields (fruit > than

USDA grade 6X7) were counted and weighed during each of 6 weekly harvests beginning on 15 December 1994 through 19 January 1995. Total marketable yields, early marketable yields (mean of first three harvests), and mean fruit size (g/fruit) were calculated. Shoot diameter and weight (without fruits) were measured on 20 January 1995.

Statistical Analyses: Analyses of variance were conducted on all measured and calculated data for each experiment. Treatment means were separated by Duncan's multiple range test, 5% level.

Results and discussion

The compost was a relatively stable compost with a C:N ratio of 13.5 (Table 1). Calcium content (5.3%) is considered relatively high with a moderate N content (2.52%) with other major and minor elements relatively low (Table 1) compared to other composts..

Percent emergence, MDE, and mean days to fully expanded cotyledons did not differ among treatments (Table 3). Seedling roots and shoots were heavier when grown in plug-mix than in field soil, compost, or compost:soil mixture (Table 3). Shoot:root ratios were higher for plants grown in compost or mixture of compost:soil than plugmix or soil.

Tomato transplants grown in pots for 25 days with compost or a mixture of compost and field soil produced plants with thicker stems,taller plants, and heavier shoots and roots than plants grown in field soil (Table 2). Plants grown in compost or a mixture of compost and soil had higher shoot:root ratios than plants grown in soil (Table 2) suggesting that more photosynthates were proportionally translocated to the developing shoots than the roots for plants grown in compost.

In the field, tomato plants grown with compost ($224 \text{ mt}\cdot\text{ha}^{-1}$) produced taller plants (30 days after transplants) and thicker stems with heavier shoots (100 days after transplanting) than the control, regardless of fertilizer rate (Table 4). Early (first three harvests) and total marketable fruit yields were higher in compost plots compared to the control (Table 4). The significant compost X fertilizer rate interaction for mean fruit size (g/fruit) (Table 4) resulted from an increase in fruit size in plots with Compost and 0 or higher fertilizer rate but not at the moderate fertilizer rate.

Overall tomato yields were less than half of those commercially produced on a ha in Florida (1992–93 means $41524 \text{ kg}\cdot\text{ha}^{-1}$) (Florida Agricultural Statistics Service, 1994). The lower yields may have been attributed to the unusual rainfall (20.9 cm on 29–30 October, 1994) during the season resulting in leaching of nutrients. However, compost may have contributed to reducing soil nutrient leaching, thereby resulting in higher tomato yields, regardless of the fertilizer rate. Further investigations with compost are currently being performed under more optimum growing conditions.

Table 1 Nutrient content, pH, and electrical conductivity (EC) of compost.

pH	6.66	Zn (ppm)	239
EC (millinsho)	2.07	Cu (ppm)	218
N (%)	2.52	Mn (ppm)	324
C (%)	34.0	Fe (ppm)	4108
C/N ratio	13.5	Na (ppm)	309
K (%)	0.08	Cd (ppm)	1.75
P (%)	0.94	Pb (ppm)	23
Ca (%)	5.3	Ni (ppm)	5.75
Mg (%)	0.34		

Table 2 Percent emergence, mean days to emergence (MDE), mean days to fully expanded cotyledons, shoot and root weights as influenced by compost for tomatoes. (Greenhouse experiment 1.)

Treatment	Mean Days to		Cotyledon Expansion (days)	Plant ht ^z (mm)	Shoot wt ^z (mg/plant)	Root wt ^z (mg/plant)	Shoot:root ratio
	Emergence (%)	MDE (days)					
Compost	87.0	4.72	6.47	75.2b ^y	247b	36b	7.0a
50% Soil:50% Compost	85.0	4.49	6.37	78.0b	254b	33b	7.6a
Plug-mix	90.5	4.35	6.17	110.8a	383a	74a	5.3b
Soil	85.8	4.55	6.33	59.3c	110c	40b	2.9c

^zdata measured 9 days after seeding.^yMean separation by Duncan Multiple Range Test, 5% level.**Table 3.** Mean tomato dry weights of shoots and roots, plant heights, and shoot:root ratios as influenced by compost. (Greenhouse experiment 2.)

Treatment	Stem diameter (mm)	Plant height (cm)	Shoot weight (g)	Root weight (g)	Shoot:root ratio
Compost	2.57ay	4.86a	1.43a	0.24a	5.99a
50% Soil:50% Compost	2.61a	4.73a	1.53a	0.28a	5.70a
Soil	2.04b	4.12b	0.40b	0.19b	2.20b

z Data measured 25 days after transplanting into 3.7 L pots.

y Mean separation by Duncan Multiple Range Test, 5% level.

Table 4. Marketable tomato yields, shoot heights, diameters, and weights as influenced by compost.

Compost (C) (mt.ha ⁻¹)	Fertilization (F) (kg.ha ⁻¹)	Marketable yields (kg.ha ⁻¹)				Shoot characteristics:		
		Early ^Z	Total	Fruit size (g/fruit)	Height ^Y (cm)	Diameter ^X (mm)	Weight ^X (kg/plant)	
0	0	566	2,212	150	20.8	10.1	0.22	
224	0	3,486	12,188	180	58.0	16.4	1.19	
0	76.5N 67.5P 140.5K	524	6,535	195	25.5	14.1	0.75	
224	76.5N 67.5P 140.5K	2,658	15,008	194	49.3	17.0	1.57	
0	153N 134P 280K	1,972	6,568	164	28.7	14.1	0.77	
224	153N 134P 280K	2,920	16,979	192	52.0	17.8	1.85	
Significance				**	**	**	**	
C				**	**	NS	**	
F				**	**	NS	**	
C X F				*	NS	NS	NS	

^{**}, *NS Significant at the 1 (^{**}) or 5% (*) levels or nonsignificant (NS).

Z Early marketable yields are the total of the first three harvests.

Y Plant height was measured 30 days after transplanting.

X Shoot diameters and weights were measured just after final harvest.

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Composting of Bioreactor Waste From Softwood Processing

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Introduction

Production of Medium Density Fibreboard (MDF) from a mix of softwoods involves steam treatment and physical degradation of raw-materials to produce wood fibre for bonding. While the process is typically energy-efficient, using waste materials for steam generation, there may be an excess of wood wastes. In addition, effluent from washing and wood chips has to be treated. This involves a multistage process of filtration, Dissolved Air Flotation (DAF) and Activated Sludge processing. The mixed waste solids are typically belt-pressed and disposed to land-fill.

At the same time there is potential for organic soil conditioners and alternatives to peat. In the UK a significant market exists for peat-like mulching materials. Bragg (1990) noted that approximately 0.5 million cubic metres of peat are used in the UK by landscape / amenity industries. However, the proportion applied directly to land as mulch has not been defined. Softwoods have long been known for phytotoxicity which has been exploited in mulches or removed by uncontrolled composting (Aaron, 1976). The woodwaste solids produced by the MDF process are brown in colour and of a dense, clay-like, nature. Material is biologically very active and so unsuitable for immediate use as a peat substitute. Trials to assess stability of the material, its compostability and any potential phytotoxicity were carried out.

Materials and Methods

Woodwaste solids were loaded into replicated 57 cm x 57 cm x 117cm bins of nominal 380 litre capacity. Compost chambers were of galvanised steel mesh, loosely insulated with expanded polystyrene. Palletised bins were then placed

within an insulated temperature controlled room of approximately 20x volume. Temperature was initially boosted within the room to initiated composting. After day 1 no further external heat was applied. Temperature of composts was monitored by dataloggers (Logit: DCP Microdevelopments, Cambridge, UK). Gas evolution was assessed by monitoring air withdrawn from perforate void chambers buried within compost bins (Gastec Ltd., Yokohama, Japan). Composts were aerated by switching material from bin to bin on levelling-off of temperature compared to the previous 24 hours or on a fall in temperature compared to ambient. Material was assessed for phytotoxicity by bioassay against a range of commercial and weed seeds under controlled conditions at $18^{\circ}\text{C} + 1^{\circ}\text{C}$.

Material was assessed for stability by palletising bagged material and logging temperature and gas evolution over approximately 6 months. The use of wood-waste as a mulch material for amenity areas was assessed in replicated plot trials. Comparison was made with other composted materials typically used for this purpose.

Results and Discussion

Material was initially phytotoxic against a range of species. This was reduced approximately four fold for some species by composting ($p<0.05$). The composting process completed a normal profile of pasteurisation and conditioning (Figure 1), reaching a peak of $58 - 60^{\circ}\text{C}$ for approximately 4 days. Chemical analysis showed a change in nutrients over the composting period, with volatilisation of nitrogen as ammonia. Initially nitrogen was considered to be bound as microbial-N, from the DAF and activated sludge processes, which was mineralised to ammonium-N and oxidised to nitrate-N in the stabilised end product (Table 1). Ammonia was detected within compost bins in a similar pattern.

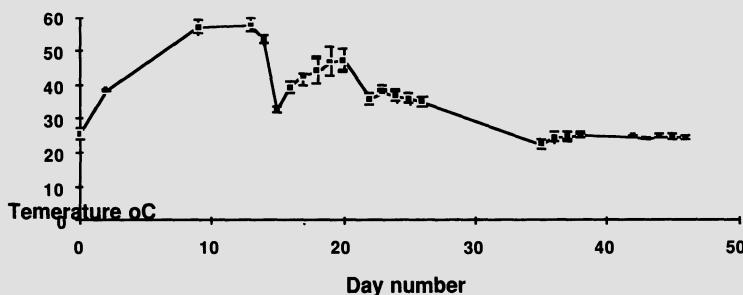


Figure 1 Temperature profile of composted bioreactor woodwaste

Table 1 Typical characteristics of composted bioreactor woodwastes (Mean of 3).

Week	pH	EC (S/cm)	NH ₃ -N mg/l	NO ₃ -N mg/l	P mg/l	K mg/l	Mg mg/l	%AFP
1	7.0	432	<1	<1	4	42	16	NA
2	8.0	556	298	298	1	90	5	14.7
4	8.6	571	374	417	7	90	2	19.1
5	7.4	435	65	231	4	108	12	19.3
6	7.3	352	<1	124	1	90	14	15.3
7	7.3	357	<1	91	1	102	12	17.2

Volume of material reduced during composting, by approximately 35% over a six week period. Use of material in comparison to Spent Mushroom Substrate (SMS) and bark as a soil mulch revealed that phytotoxicity was expressed as weed suppression, both when surface applied and incorporated. Weed species were affected to different extents by mulching, supporting evidence of bioassays for differential species susceptibility ($p<0.05$) (Table 2).

Use of SMS as a mulch has been widely recommended (Rupert, 1995). In these trials it resulted in greatest reduction in weed growth, however this effect was not carried-over to the subsequent season. Weed growth on plots mulched with wood-waste reverted to similar levels of weed growth compared to controls. Plots mulched with bark showed the lowest weed growth, demonstrating natural phytotoxicity of softwoods (Aaron, 1976). Weed numbers were greatest where SMS had previously been applied and the percentage of ground cover by weeds also greatest for this treatment ($p<0.001$), suggesting release of nutrients by the compost.

Table 2 Total weed seedlings per 0.5m² (mean of five samples per replicate plot)

Species Bark mulch	TREATMENT				ns	**
	Control SMS	Woodwaste mulch	Woodwaste incorporated			
Poa annua	19.8	3.0	12.0	0.0	1.2	**
Sonchus aleraceus	12.61	2.40	4.20	4.80	0.00	***
Cerasteum fontanum	40.8	21.6	28.8	13.2	4.2	*
Senecio vulgaris	4.20	0.60	1.80	0.00	0.60	***
Lamium purpureum	12.6	10.8	25.8	26.4	1.8	ns
Urtica urens	53.5	19.8	39.6	16.2	10.2	ns
Capsella bursa-pastoris	84.1	8.4	8.4	6.0	1.2	***
Veronica officinalis	33.6	8.4	19.2	10.8	1.2	*
Chamaenerion angustifolium	5.41	0.00	1.20	0.60	0.00	ns
Cardamine amara	10.8	1.2	3.0	1.8	0.00	ns
Matricaria matricarioides	0.60	0.00	0.00	0.00	0.00	ns
Total weeds	278.0	76.0	144.0	80.0	20.0	**

The use of composting to predict the suitability of materials for use as mulches has been demonstrated. The application of the test material to soil can be safely carried-out in the knowledge that phytotoxicity is biodegradable and that no long-term pollutants would be added to the soil. However, it should be noted that further analysis of product variability and heavy metals is recommended (Jackson,

Merillot and L'Hermite, 1992). Composting served to stabilise the material with reduction in ammonia evolution. Storage of palletised, shrink-wrapped dried material in plastic bags (approximately 30 litre capacity) was satisfactory. Temperature of palletised material remained close to ambient. No hydrogen sulphide, phenolic gases, low molecular weight volatile hydrocarbons nor ammonia was detected. Carbon dioxide reached 1100 ppm within pallets and oxygen (1%) indicated a slow rate of metabolism in stored material.

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Effect of Moisture Content on the Composting of Pig-Manure Sawdust Litter Disposed From the Pig-on-Litter (POL) System

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Introduction

The pig-on-litter system, known as in-situ composting, has been developed as one of the recommended methods in Hong Kong to treat pig waste. The system utilizes a mixture of sawdust and a commercial bacterial product as the bedding material on which the pigs are raised, and the pig excreta are decomposed within the bedding material. After 10–13 weeks, the spent pig-manure sawdust litter is removed from the pig pens. This spent litter contains high concentrations of organic matter, nitrogen, phosphorus, potassium and trace elements, and also a significant amount of active microbial biomass, which is similar to an immature compost. In order to improve the quality of the spent litter, further composting to reach maturity is essential. Moisture is one of the most critical factors in controlling the rate of composting and the maturity of the product. Water provides a medium for the transport of dissolved nutrients for the metabolic and physiological activities of microorganisms. Very low initial moisture values would mean early dehydration of the pile which will arrest the biological process giving a physically stable but biologically unstable compost (Bertoldi et al., 1983). On the other hand, high moisture values may produce anaerobic conditions due to water logging. However, the effect of different moisture contents on composting of spent litter and their changes throughout the composting process are not yet understood. Therefore, the study aimed (1) to investigate the changes in the nutrients and organic matter of the spent litter at different stages of composting, and (2) to evaluate the effect of different initial moisture content of the spent litter on this composting process.

Materials and Methods

The spent litter was collected from pig pens employing the pig-on-litter system (Tam and Vrijmoed, 1990) for 12 weeks with 40 piglets raised inside the pig pen.

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The spent litter was mixed homogeneously and piled up in an open shed for further composting and maturation. Three piles of the spent litter with initial moisture content adjusted to 50% (Pile A), 60% (Pile B) and 70% (Pile C) were set up. Each pile was triangular in shape, about 2 m in width at the base and 2 m in height. The piles were turned over twice a week using a front loader tractor. The changes of air temperature and the temperature of each pile at a depth of 60 cm were monitored twice a week (before turning). Composite samples taken from 5 symmetrical locations of each pile were collected immediately after piling (pre-expt.), right after the initial adjustment of the moisture (Day 0), then weekly until the end of the composting process (91 days). The spent litter was analyzed for the content of cation-exchange capacity (CEC) (Inoko and Harada, 1981), ash and total carbon, ratios of C:N humic:fulvic (HA:FA) acid, and different forms of N (Page et al., 1982)

Results and Discussions

The temperature values of piles A, B and C were 50 °C, 44 °C and 30 °C respectively after the moisture content of each pile was adjusted at day 0 (Fig. 1a). Thereafter, the patterns of temperature changes in piles A and B were similar. Temperatures of both piles rose dramatically to about 64–69 °C by day 4 and these readings were maintained until day 21 (thermophilic stage). The temperatures declined slightly and were maintained at a lower level from day 26 to day 57 (cooling stage), but then further dropped slowly to 30 °C (ambient temperature) from day 60 until day 91 (maturing stage). Pile C followed the same trend of changes but the maximum temperature achieved during the thermophilic stage was significantly lower (56–59 °C). Its temperature also dropped more rapidly at day 57 and started to level off by day 67.

The changes in total carbon, ash and total nitrogen of all piles were very similar during the whole composting period. The carbon content decreased as composting proceeded, from an initial value of 52% to about 51% during the first 56 days of composting (Fig. 1b). This decrease was due to the disappearance of easily decomposable organic constituents (Tam and Vrijmoed, 1990). From day 63 onwards, the carbon contents of all piles stabilized at around 50% until the end of the composting period. On the other hand, the ash content increased gradually with time from an initial 9.8% to 12.3% during the first 56 days of composting and stabilized at a level of 12.5% until the end of the composting period. It has been reported that the increase in the ash content of composted materials is due to the accumulation of minerals and rapid degradation of organic materials during composting (Tam and Vrijmoed, 1993). The initial total N of all piles was about 1.8–2.0% (Fig. 1d). As composting proceeded, the total N of all piles increased. The total N values increased from an initial 1.8% to about 2.9% by day 60 and were maintained at this level until the end of the composting process. The NH₄⁺-N content decreased (Fig. 1e) while the NO_{x2}-N increased (Fig. 1f) revealing that the spent

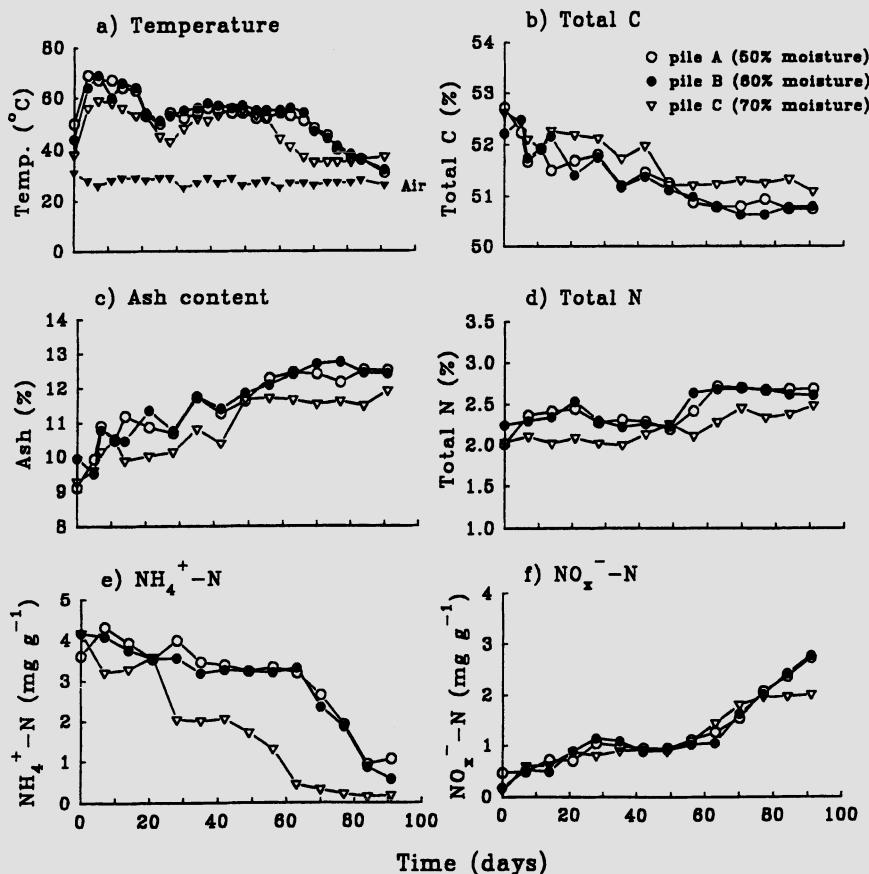


Figure 1 Chemical changes in the spent pig litter during the composting process

litter became more mature. In general, Pile C had lower Total N, ash and NH₄⁺-N content throughout the composting process than piles A and B, indicating that the higher moisture content reduced the rate of composting. During the composting, the CEC increased while C:N decreased with time (Table 1). The CEC values of all piles rose to a value greater than 60 meq 100g⁻¹ by day 35 indicating that the spent litter became mature. The HA:FA values of all piles were stabilized after day 56 in all piles with values of about 0.36–0.39. Starting from day 60 onwards, the content of CEC, ash and total carbon, and ratios of C:N and HA:FA became stabilized in all piles, suggesting that all 3 piles reached maturity at day 60. Initial moisture content did not significantly affect the quality of the mature product.

Table 1 Changes in CEC, C:N and FA:HA ratios in the spent pig litter during composting

		Day 0	Day 14	Day 21	Day 35	Day 56	Day 77	Day 91
CE C	Pile A	39.19	49.27	53.29	81.44	93.35	98.89	97.14
	Pile B	38.87	47.47	50.06	85.72	95.27	93.13	95.63
	Pile C	39.27	49.24	50.01	77.78	87.78	91.23	88.70
C:N	Pile A	26.19	21.32	21.33	22.18	21.06	19.06	18.93
	Pile B	23.26	22.24	22.24	23.06	19.37	18.88	19.50
	Pile C	25.87	25.91	25.91	25.93	24.30	21.95	20.60
HA:FA	Pile A	0.43	0.28	0.30	0.29	0.39	0.38	0.39
	Pile B	0.37	0.37	0.32	0.35	0.39	0.37	0.40
	Pile C	0.32	0.30	0.25	0.23	0.36	0.37	0.38

Conclusion

In general, all piles had very similar chemical properties during the whole composting period despite of differences in initial moisture content. Two months is sufficient for converting a spent litter from the POL system to a mature compost for land application.

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The Effect of Composted Vegetable, Fruit and Garden Waste on the Incidence of Soilborne Plant Diseases

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Abstract

The influence of compost prepared from vegetable, fruit and garden waste (*vfg* compost) on disease incidence caused by *Phytophthora cinnamomi* and *Rhizoctonia solani* from woody ornamentals was assessed in bioassays with lupin and cucumber as test plants, respectively. Peat-perlite mixtures amended with *vfg* composts of different maturity levels and of two compost plants were suppressive to *P. cinnamomi*. Amendment of 20% long matured compost suppressed *R. solani*, whereas amendment of shortly matured compost did not. In a radish bioassay damping-off by *R. solani* was even increased when 20% compost without additional maturation after delivery was added to potting soil. Availability of cellulose affected the suppression of *R. solani* by compost.

Introduction

In the Netherlands an increasing amount of compost is produced from separately collected vegetable, fruit and garden waste (*vfg*) waste of individual households. The compost is used in agriculture and its application in potting mixtures for container-grown woody ornamentals is pending. An important feature for use of compost is its effect on pathogens already present in soil or potting mixture.

We studied the influence of *vfg* compost on two major pathogens of woody ornamentals, *Phytophthora cinnamomi* the cause of foot rot in coniferous trees and *Rhizoctonia solani* causing rot of cuttings in Ericaceae and Rosaceae. As disease symptoms appear sooner on herbaceous plants than on the woody host plants, lupin was used as bioassay host for *P. cinnamomi*, isolated from *Chamaecyparis*, and cucumber for *R. solani*, isolated from *Cotoneaster*.

The *vfg* compost was obtained from two commercial compost plants, coded P and C, with enclosed composting systems. The freshly sieved product was used

after different periods of maturation.

In this paper the results of different bioassays to assess the suppressiveness of vfg compost will be presented. The significances of differences are based on analysis of variance of data per time of assessment ($P<0.05$).

The effect of vfg compost on development of *Phytophthora cinnamomi* in container medium

Bioassay

Lupinus angustifolius cv Kubesa was used as a test plant in the bioassay. As inoculum an earth-meal culture of *P. cinnamomi* was mixed through the substrates (1% v/v). The substrate mixtures consisted of: a) 0% compost, 85% light peat (Kekkila Finnpeat), 15% perlite, b) 10% compost, 75% peat, 15% perlite, and c) 20% compost, 65% peat, 15% perlite.

One day after preparation of the mixtures, pots of 200 ml were filled with the substrates. Four lupin seeds were added to each pot. Plants with symptoms were counted and stem parts were placed on P₁₀VPH-agar (Tsao and Guy, 1977) to verify infection by *P. cinnamomi*.

Three experiments were performed:

Expt 1, using compost P after 3 weeks additional maturation;

Expt 2, using compost C after 5 weeks additional maturation, and

Expt 3, using compost P immature (3 days after delivery by the compost plant), compost C mature (1 week maturation, but already stable at delivery) and compost P mature (10 weeks additional maturation), with two inoculum levels (0.1% and 1.0%).

Results

Expt 1 and 2. The incidence of infected plants eight days after sowing was reduced by the addition of 20% of both vfg composts tested. The composts used were relatively stable (self-heating to around 20 °C). Addition of 10% compost had no significant effect on disease incidence.

Expt 3. Eleven days after sowing disease incidence was reduced in all substrates amended with 20% compost. With the immature compost also the 10% dose reduced the proportion of diseased plants. Disease incidence was higher in the highest inoculum level, the effect of compost was the same for the two levels (no interaction). In the non-amended peat-mixture 75% of the plants was diseased at the highest inoculum level, the percentage was reduced to 35 (im 99% in the non-amended substrate and was still significantly reduced in the compost-amended substrates to around 80%).

After 24 days the difference between the inoculum levels was not significant anymore. The mean incidence was 99% in the non-amended substrate and was still significantly reduced in the compost-amended substrates to around 80%.

The effect of vfg compost on mycelial growth of *Rhizoctonia solani*

Bioassay

In commercial nurseries the fungus grows over the soil surface in trays with cuttings covered with polyethylene sheets. Therefore, we developed a bioassay in which mycelial growth from a point source was measured under similar conditions. The isolate of *R. solani* used was pathogenic on *Cotoneaster*, *Pyracantha*, *Erica* and *Juniperus*. It was tested for its pathogenicity on different herbaceous plants to find a cheap and fast-growing test plant. This led to the choice of cucumber as a test plant, showing discolouration and soft rot of the stem base resulting in damping-off.

In shallow trays five rows of 16 cucumber seeds were sown. After emergence of the seedlings the first one in every row was inoculated with a mycelial plug from the edge of a growing colony of the fungus. At different periods after inoculation the number of infected seedlings in each row was counted. Per tray the mean distance of growth and infection by the fungus was determined. Stem pieces of rotted seedlings were placed on water agar with 50 µg ml⁻¹ oxytetracycline to verify infection by *Rhizoctonia*.

The substrate mixtures consisted of: a) 0% compost, 85% light peat (Kekkila Finnpeat), 15% perlite and b) 20% compost, 65% peat, 15% perlite. Two batches of long-matured P and C compost (5 and 7 months maturation) were tested, batch 2 of both composts was also tested after only four weeks maturation. In two of the experiments the influence of extra available cellulose was determined.

For an isolate of *R. solani* pathogenic on radish the influence of addition of mature and fresh compost to potting soil was compared with the addition of sand in an assay with radish and inoculum mixed through the soil.

Results

Amendment of the peat-perlite mixture with matured composts (5 and 7 months additional maturation, the same batch) significantly reduced the growth of *R. solani* over the substrate during the 16 days of the experiment, up to 35–75% at day 16 (Fig. 1). With a second batch of 5-months matured P and C compost this effect was repeated. When these second batches had matured for only 32 days, the mean distance of growth of the fungus was larger on the compost-amended substrates than on the non-amended ones, although this difference was not significant.

Addition of low amounts of extra cellulose to the substrates resulted in a different response of *R. solani* for the two compost-amended substrates. With 4-weeks matured compost P the growth of the fungus was increased, whereas with 4-weeks matured compost C it was decreased. When the same composts had matured longer, the addition of cellulose did not have a significant effect.

In the radish bioassay it was found that 20% fresh compost caused an increase

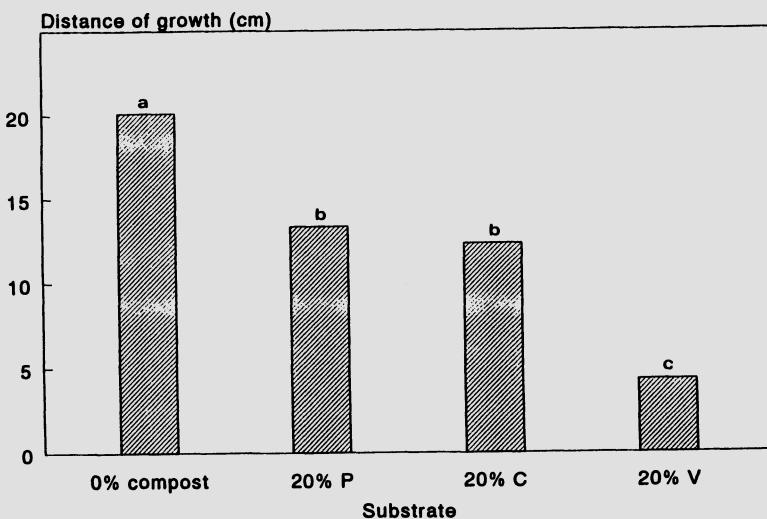


Fig. 1 Effect of vfg compost on growth of *Rhizoctonia solani* in peat-mixtures planted with cucumber, assessed 15 days after inoculation. Three 7-months matured composts, coded P, C and V, were used. Different letters indicate differences at $P<0.05$.

in damping-off of radish, whereas 20% of mature compost did not affect disease incidence compared to the 20% sand treatment.

Conclusions

For two major soilborne pathogens of woody ornamentals we found alternative herbaceous test plants for use in bioassays for assessment of the influence of compost on growth and infection of the pathogens. The choice of lupins as an assay plant for *Phytophthora cinnamomi* was derived from Pratt and Heather (1972) and Hoitink et al. (1977). In bioassays both pathogens were suppressed by addition of two types of vfg compost to the growth media.

Addition of both fresh and matured vfg compost to a common container mixture consisting of light peat and perlite rendered it suppressive to *P. cinnamomi*. In prior experiments with one of the two composts this was also found for *P. nicotianae* on tomato (Coolman, unpublished).

There is substantial evidence that the microbial activity in the substrates is, at least for the greater part, responsible for the effect found; competition for nutrients and/or antibiosis affected mycelial growth in tests for antagonism in the laboratory (Tuitert, unpublished). The mechanism of 'general suppression' against fungi like *Phytophthora* and *Pythium* was discussed extensively by Hoitink, Boehm and Hadar (1993). The pH of compost-amended substrates was slightly increased, but

not to such an extent that it can explain the results. The problem in estimating the microbial factors of the effects by comparing disease suppression in natural and sterilized compost is that the process of sterilization causes many nutrients to become available from the dead biomass. Addition of the sterile compost, rich in nutrients, to the substrate mixture will lead to rapid recolonization by the resident microflora.

Container mixtures amended with 20% *vfg* compost were suppressive to *R. solani*. Suppression was found when additionally matured compost was used, but not with compost –from the same batch– which had matured only four weeks after leaving the compost plant. In the radish bioassay it was found that fresh compost even increased disease incidence. Therefore, the use of long matured *vfg* compost should be recommended, at least when infestation of the soil with *R. solani* is likely to occur. An increase in suppression of *R. solani* with increasing age of the compost was also found with a completely different type of compost, namely composted hardwood bark (Nelson and Hoitink, 1983).

The exploratory experiments on the effect of cellulose showed that the amount and availability of cellulose influenced the type of effect of compost on *R. solani*. Several factors may be responsible for the difference in response to cellulose, both microbiological (composition of the microflora) and organic (amount of resident cellulose, glucose and other organic compounds). Nitrogen contents in the two composts were at the same level.

The mechanism of suppression of *R. solani* by mature *vfg* compost remains to be elucidated. An adequate indicator for compost maturity in relation to disease suppressiveness is looked for.

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The Experiment of the A.M.I.U. of Modena (Italy) in Composting Sewage Sludges and Source Separated Organic Wastes

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Introduction

An important tool in reducing appreciably the flow of disposable refuses and landfilling problems is recycling by composting organic wastes collected by Municipalities, in order to obtain soil conditioners.

A small-scale composting plant built on behalf of the Ministry of the Environment at the organic wastes treatment facility in Soliera (Modena, Italy), was managed in co-operation with the Municipal Wastes Treatment Department of Modena (AMIU) and the Research Centre for Animal Production (CRPA) of Reggio Emilia, with the aim of testing various mixtures of organic by-products.

Materials and Methods

The plant is a reactor pit, closed inside a greenhouse, 3 metres wide and 60 metres long, with a 1 metre maximum height of loaded material, equipped with a turning machine moving on rails. It has a treatment capacity of about 1000 ton/year of fresh material.

The trials campaign started in 1992 and since then several composting runs have been performed with mixtures of municipal dewatered sewage sludges (SS) (35 runs) or bio-wastes source collected (BW) from vegetable markets and restaurants (6 runs), with the addition of different organic agro-industrial by-products as bulking agents.

The bulking agents were: straw cattle litter from the Livestock Market in Modena, woodchips and shredded pieces from trimmings from public garden and parks, chopped barks and grape-stalks.

In table 1 the types of materials treated and the mixing ratios tested are summarized.

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Table 1 Mixing ratios of the bulking agents added to sewage sludges and bio-wastes. The ratios are expressed, by volume, dryer/wetter (in brackets the extreme values).

Materials	Cattle litter	Chopped bark	Wood chip trimmings	Shredded trimmings	Grape-stalks
SS	1.5+2.0 (0.7-2.3)	1.5 (1.0-2.0)		1.2-1.4 (1.0-2.0)	0.5*
BW	0.4-0.6		0.4-0.5	0.4-0.6	

+ in summer; ° in winter; * only together with a dryer bulking agent.

The retention time in the reactor (bio-oxidative phase) ranged from 30 to 60 days, according to the seasonal period which influences the decomposition rate. The turning schedule was usually once or twice a week. During summertime it was necessary, in some cases, to moisten the composting mass in order to avoid a slowing down of the process due to an excessive drying of the mass.

Process temperatures were monitored during each trial and samples of the various mixtures were collected at the following stages: the loading of the reactor, the end of the bio-oxidation and the end of the curing period. The main chemical and physical parameters, the heavy metal contents and the humification parameters were determined from these samples.

Results and Discussion

The experimentation made it possible to look into various problems related to the composting process and to produce good quality composts with different analytical characteristics.

Major process difficulties occurred during winter time, because of low outdoor temperatures which slow down the organic matter decomposition rate. In particular, the mixture sewage sludge + cattle litter was problematic, due to the high humidity of both components, the low porosity and the lack of structure of the mix. It seems advisable to use this bulking agent just in more favourable seasons. However with adequate mixing ratios with barks and trimmings (so as to reach at least 35% TS) and reduced turning schedules it was possible to operate satisfactorily during winter too. Moreover, in summer, the process could set out with mix TS content even as low as 25%.

The compost produced shows good characteristics for agricultural use; organic matter and nutrient contents were considerably higher than M.S.W. composts not collected separately (table 2). The thermophilic phase assured the inactivation of pathogens such as *Salmonellae*, which was never found in the final products.

Table 2 Average composition characteristics of the composts produced.

Parameters	Sewage sludge + straw litter		Bio-wastes + straw litter		Bio-wastes + wood wastes
		+ wood wastes		+ wood wastes	
samples	(n°)	16	19	2	4
pH		7.0	7.1	8.9	8.6
TS	(% wb)	41.0	59.9	52.9	67.8
VS	(% TS)	49.8	48.1	57.6	65.2
TKN	(% TS)	2.0	1.6	2.6	1.9
TOC	(% TS)	28.5	28.6	28.0	32.2
C/N		15	18	11	17
Ptot	(% TS)	1.3	0.8	1.0	0.4
Ktot	(% TS)	1.8	0.9	3.9	2.0
Germ. Index	(%)	63	69	68	84
C.E.C.	(mS/cm)	3.4 *	2.0 *	3.6 *	2.2 *

* determined only on 2 samples

The composts produced are suitable as a substitute for various organic soil conditioners in field use, but the relatively high values of pH and salinity, noticed especially in the bio-waste composts, suggest a blending with earth for floriculture and garden use.

The humification parameters (table 3), measured only on last year's trials samples, show the typical trend, from the start to the end of the process, which testify to the increase of the humified organic matter.

Heavy metal concentration in every compost was lower than what is allowed by Italian law for compost use and agricultural utilization of sewage sludge, especially in the case of source collected bio-wastes (table 4).

Table 3 Average humification parameters of the composts.

Table 4 Average heavy metals contents of the compost produced.

Parameters	Sewage sludge		Bio-wastes		DPR	DL
	+straw litter	+wood waste	+straw litter	+wood waste	915/82	99/92 limits
samples (n°)	15	17	2	4		
Cu (mg/kg TS)	229	236	95	80	600	1000
Zn (mg/kg TS)	1325	1046	450	322	2500	2500
Pb (mg/kg TS)	159	129	5	7	500	750
Ni (mg/kg TS)	49	47	19	8	200	300
Cd (mg/kg TS)	2.0	1.5	1.4	0.3	10	20
Cr (mg/kg TS)	129	128	36	28	510	
Hg (mg/kg TS)	1.6*	6.6*	0.2*	0.4*	10	10

* determined only on 2 samples

Mass weights were taken to evaluate the loss of the materials during the composting process in the reactor, due to the organic matter decomposition and the water evaporation. Very different results were obtained between cold and hot seasons. The yield of compost related to the starting mixture weight (w.b.) ranged from 0.4 to 0.7, with an average value of 0.5.

In overall esitimated management costs, taking into account the present experimental management which involves scale diseconomy, the production costs ranged from 95 to 115000 Lit/ton of produced compost. The most relevant entry was the labour and machinery operators cost (66%), followed by materials transport and supplies (29%) and energy expenses (5%).

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Possibilities for Biological Control of *Pythium* Root Rot in Ornamental Bulb Culture with Composted Organic Household Waste

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Pythium is a soil-borne fungus which causes root rot in several bulb crops. To reduce the use and dependence on fungicides, non-chemical control methods have to be developed.

Pythium is a potentially fast growing fungus which is relatively susceptible to competition by other microorganisms. A light infestation in non-sterilized soil causes moderate root rot, whereas the same infestation in sterilized soil leads to severe disease development. Pot experiments were performed to study the impact of several cultural practices on *Pythium* root rot in bulbous iris in relation to the condition of the soil microflora. Flooding and soil fumigation are generally applied in ornamental bulb culture to control some diseases and weeds. Flooding, however, does not kill *Pythium*. Flooding of infested field soil resulted in enhanced root rot compared to the non-flooded treatment. A similar effect was found when *Pythium* was introduced after soil fumigation. Infestation of fumigated field soil resulted in enhanced root rot compared to infestation of non-fumigated soil. In absence of other microorganisms (previously heat-sterilized soil) flooding and fumigation treatments had no effect on the disease development, indicating the crucial role of the microflora in the adverse effects of flooding and fumigation.

Apparently *Pythium* benefits from the elimination or disturbance of the soil microflora by sterilization, flooding, or fumigation. To restore the natural disease suppression in treated soils the effect of adding composted organic household waste was investigated. Application of compost in ornamental bulb culture is limited to 6 ton/ha (dry weight) every year or 12 ton/ha once in two years. The equivalence of 12 ton/ha for pot experiments is approximately 1% w/v compost. This very low percentage is not likely to induce additional suppressiveness into naturally colonized field soil. In biologically disturbed soils, however, small amounts of matured compost may effectively serve as inoculum of a broad spectrum of microorganisms which induce general suppressiveness. After the composting process the compost was incubated during five weeks to mature at 20°C and a moisture content of 50% (w/w). The compost was ploughed weekly.

Addition of 1% matured compost to heat-sterilized soil one week prior to infes-

tation with *Pythium*, resulted in a reduction of the pathogen population and the disease development compared to treatments without compost or with sterilized compost. Further experiments are performed to determine the effects of compost application after flooding or fumigation of field soil. Results of these tests are not yet available.

The application of composted organic household waste in ornamental bulb culture may render a solution to the undesirable side effects of flooding and fumigation.

Mineralization of Three Agro-industrial Wastes by an Acid – Producing Strain of *Aspergillus Niger*

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Introduction

The possibility of practical use of rock phosphate as a fertilizer has received significant interest in recent years. Unfortunately, rock phosphate is not plant available in soils with pH greater than 5.5–6 and even when conditions are optimal, yields are as a rule lower than those obtained with soluble phosphate (1). It has been repeatedly shown that low-molecular organic acids can strongly increase phosphorus solution concentration by mechanisms involving chelation and exchange reactions. Filamentous fungi are widely used as producers of organic acids and particularly *Aspergillus niger* and some *Penicillium* species have been experimented in fermentation systems or inoculated directly in soil in order to solubilize rock phosphate (2–5).

The objective of this study was to select the best combination between *A. niger* and three agroindustrial wastes for further application in rock phosphate solubilization.

Materials and methods

Organism. The strain of *Aspergillus niger* NB2 was used in this study, maintained on potato-dextrose agar slants.

Culture media and fermentation conditions. Three agroindustrial lignocellulosic wastes, rice hulls (RH), sugar beet waste (SB) and alperujo (ALP – a waste material obtained from olive oil extraction processes), all ground to 1 mm fragments, at concentrations of 10 % and 20 % were used as substrates for static fermentation in 50 ml Czapek's solution. After sterilization at 120°C/30 min, experiments were

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carried out in 250 ml Erlenmeyer flasks (in triplicate) inoculated with 1.2×10^7 spores/flask. Rock phosphate (12.8% P) at a concentration of 3.0 g/l was added when necessary. Experiments were performed at 30°C for 20 d.

Analytical methods. Mycelial growth was determined by drying the mycelium, carefully separated from the fermentation medium and washed, in an oven at 100°C, and then weighted. Medium pH was measured with a glass electrode and titratable acidity was determined by titrating each sample to pH 7.0 with 0.1 N NaOH. Weight loss of lignocellulose during the fermentation process was calculated on ash content basis according to Kumar & Sign (6), and presented as a percent of mineralization. Lignin, cellulose and hemicellulose contents were measured according to the method of Goering & Van Soest (7). Phosphorus content was determined by molybdoavanado-method (8).

Results and discussion

In the present study *A. niger* grew well on all tested materials but the filamentous fungus showed different level of growth depending both on the type lignocellulosic substrate and its concentration (Table 1). SB at concentrations of 10 % and 20 % appeared to be the best material, which provided a mycelial growth of 1.0 g/fl and 1.24 g/fl respectively, followed by ALP and RH. The amount of mycelial mass grown per day increased as the concentration of each substrate increased. On the other hand, the growth and activity of *A. niger* were influenced by the composition and degree of complexity of substrates. For this reason, the mineralization percent was lower than 39 % and 21 % for RH and ALP respectively, and higher than 56 % for SB.

Table 1 Growth, titratable acidity and mineralization after 20-day cultivation of *Aspergillus niger* on RH, SBW and ALP.

Substrate/ concentr (%)	Biomass acidity (g/flask)	Y (g/d)	Titratable (mmol/l)	Mineralization (%)
RH/10	0.63	0.032	11.1	38
RH/20	0.70	0.035	9.3	21
SB/10	1.00	0.051	53.0	69
SB/20	1.24	0.062	42.0	56
ALP/10	0.78	0.039	10.7	21
ALP/20	1.07	0.053	7.3	18

The initial pH value of 6.5–7.0 significantly decreased to about 3 after one week of fermentation in flasks with RH and SB, and 3.5–4.0 when the substrate was ALP but thereafter it increased slightly. The final titratable acidity was detectable in media with RH and ALP and significantly higher when the substrate was SB. The

maximum level of mineralization, about 69 %, was achieved by *A. niger* on the 10 % concentration of SB which correlated with the results of more detailed analysis of its composition although a part of this material was degraded during the sterilization (data are not presented).

In general, polysaccharides do not give good yields of organic acids without some pretreatment because of the slow rate of hydrolysis and low level of sugars. On the other hand, large amounts of solid substrates resulted in low acid-producing activity due to the inherent problems of this type of fermentation including maintenance of moisture level, aeration and agitation, parameters which are of great importance in organic acid production.

A separate experiment was carried out with 10 % SB supplemented with 3 g/l RP (Table 2). The results indicated a rapid mycelial growth in the beginning of the fermentation followed by a slow growth phase. An increase of the titratable acidity to 72 mmol/l was observed during the first 10 days which resulted in a solubilization of 76 % of the insoluble phosphate but the final amount of acidity decreased later to 48 mmol/l. Although the process was directed towards the biomass growth, the level of acidity obtained by *A. niger* on sugar beet waste was sufficient to overcome the neutralizing effect of rock phosphate. The results also showed that the process of solubilization increased after the active growth phase. However, as the amount of fungal biomass continued to increase slowly, the determined solution phosphate probably corresponded to that amount which was not consumed by the mycelium.. This speculation should not be surprising bearing in mind that when trace metals are not limiting, the additional phosphate results in prolongation of mycelial growth and changes in the fungal metabolism. It was evident that the presence of rock phosphate added directly to the fermentation medium affected the behaviour of *A. niger*, particularly its growth and citric acid production. The latter accounted for about 2/3 of the titratable acidity at the end of the process and further work should be performed to study the changed fungal metabolism and the nature of acidic metabolites different from the main acid released by the mycelium.

Table 2. Mycelial growth, titratable acidity and RP solubilization by *Aspergillus niger* cultivated on SB.

Time (d)	Biomass (g/flask)	Titratable acidity (mmol/l)	Phosphate concentr. (mg/ml)	% of total phosphate (%)
3	0.57	38	47	12
6	0.68	60	172	44
10	0.77	72	292	76
15	0.89	58	276	71
20	1.20	48	224	58

It is of significance which model of application of *A. niger* would be performed further for improvement of plant growth - inoculation directly into soil-SB-RP mixture in order to ensure a sequential release of soluble phosphate, or to provide preliminary solubilization by a fermentation process as described in this work.

Acknowledgments

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Organic Waste Treatment – Composting: A Comparative Study on Language usage and Terminology Italian – German – English

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Summary

This paper presents the short-term results of a comparative study on language usage and terminology relating to the organic waste treatment method of composting. Approximately 210 terms and their definitions regarding biology, process performance, composting techniques, engineering, starting materials and final product of composting as well as waste management in general are analysed and compared in three language systems.

Introduction

Over the last few years internationally renowned experts have been repeatedly stressing the need for concrete actions that could encourage the wider use of compost in Europe. It has been recognised that promoting the recovery of organic waste through composting requires the setting of appropriate standards on process performance and product quality. Hence, an important task will be the formulation of clear definitions which should reduce approximation and misunderstandings and achieve international consensus. This task demands efficient cooperation between experts and regulatory authorities at national and EC-levels.

Efficiency certainly depends on the usage of clear and homogeneous technical terminology which often seems lacking in this sector. The temporal and substantial differences in the development of composting technology and in the introduction of some important measures within the various nations (i.e. separate collection of the organic fraction from households and commercial/industrial sources), as well as the diversity of classification and specification methods for process and product have been leading to many non-equivalent definitions between the different languages. Along with the lack of equivalence comes the lack of specificity, clarity and consistency of several definitions due to the difficult legislative situation of compost production and marketing which is one of confusion and mistrust.

Objectives

The main objective of this study is to examine and compare the patterns of convergence and divergence among the basic composting-related terminologies and definitions in three languages in order to identify cases of non-equivalence, ambiguity or inconsistency, hence, sets of equivalents and therefore justifiable translations.

The study was started due to the proposal of carrying out a terminological research on the subject 'Waste Treatment', put forward by the 'Interpreter's and Translator's Institut' of the University of Trieste (Italy) and the 'Terminology Section, Directorate of Translation and Terminology of the European Parliament'. Because of its vastness the investigation field was limited to the biological treatment of organic wastes and mainly to composting. For the purpose of the faculty the study's objective is to enable interpreters and translators (or any other lay person) to rapidly achieve all indispensable information on the subject as well as the basic terms and their equivalents in the other languages for the sake of a correct comprehension and reproduction of the message. For experts it may provide a useful contribution to the debate on definitions and specifications for compost production as well as to the development of a clear and homogeneous international language.

Methodological approach, materials and structure

The present study has been evolving through various stages:

- study of the subject from a conceptual point of view
- selection of approximately 210 concepts
- identification of the existing assignments of terms to concepts in the various languages and investigation on the existing relationships of the concepts concerned
- (present stage) interlingual comparison in all three language directions.

Technical inputs, advice and comments are constantly received from experts belonging to the different language areas.

The special language of composting is being analysed and compared in its technical and legal aspects. For this reason, terms and definitions were chosen on the basis of the current national laws, guidelines and/or standards and EEC-regulations regarding compost production as well as recent reports, proceedings of symposia and scientific articles in Italian, German and English. As far as the German language is concerned it has been considered necessary to analyse and compare the German legislative system with the Austrian system, since at EC-levels the composting related legislation in Austria, one of the newest EU-member states, is presently considered to be one of the most complete and detailed ones.

The study is structured into three main parts:

- a) general introduction to the subject of composting. Following aspects are considered:
 - general aspects on waste management and solid wastes (i.e. waste classification)
 - biology of composting (i.e. description of biodegradation)
 - feedstock (i.e. characteristics and preparation; separate collection)
 - process performance (i.e. parameters)
 - composting techniques and handling equipment (i.e. windrow vs static pile composting; turning equipment)
 - end product 'compost' (i.e. classification of different compost types)
 - compost quality (biological and chemical product testing)
 - fertilizers (classification; the agronomical use of compost as organic soil conditioner)
- b) linguistic analysis:
 - description of the legislative situation relating to compost production and its effects on language usage
 - introduction to the use of the glossary with special reference to its graphical structure and the methodological criteria
- c) glossary – the body of the glossary is formed by the technical terminology, graphically visualized in the introduction which therefore functions as linguistic context. The glossary provides the following data according to the standards DIN and ÷NORM on terminological analysis and terminography as well as the advice given by the terminology section of the European Parliament:
 - definitions and explanatory notes – they are given in all three languages; where possible definitions are quoted directly; the explanatory notes give general information on particular legislative, technical and linguistic aspects (i.e. grammatical differences, redundancy) as well as eventual cases of ambiguity (due to polysemy or synonymy), inconsistency (due to non-equivalence), obsolescence and improper language usage; these characteristics are also graphically signalized (i.e. {-} for improper use or obsolescence)
 - synonyms – their equivalence degree in relation to the main entry, which may be signed as preferential term, is also graphically signalized (i.e. {<} for a synonym which has a more specific meaning than the concept relating to the main entry)
 - the sources, whether direct or indirect, of definitions, synonyms and explanatory notes are always rigorously quoted and listed in the bibliography
 - the terminological body of the glossary is structured in several thematic groups introduced by schemes which visualize the interrelations between the various terms. Cross references and an alphabetically ordered index of the terms and their synonyms allow an easy consultation of the glossary.

Short-term results and discussion

The special language of composting in the three analysed language systems shows an elevated degree of heterogeneity and complexity, starting with its multidisciplinary nature which derives from a number of established sciences, such as biology, chemistry, agronomy and engineering. The presence of some neologisms (i.e. the Italian term 'rifiuti verdi', the German term 'kalte Vorbehandlung') and a certain semantic instability (i.e. the terms 'compost', 'closed systems') due to the constant scientific and technological progress as well as the changes induced by the new environmental politics in Europe show a very interesting linguistic evolution which contributes to the terminological complexity.

At present, heterogeneity and complexity are principally fruits of the difficult legislative situation of composting which, mainly in the view of production and marketing of quality compost, is one of confusion and discordance. The main characteristics of this situation are the following:

- lack of clear and detailed guidelines at international levels (as far as the Italian terms 'compost' and 'compostaggio' are concerned, the Italian decree D.P.R. 915/82 on waste in general and the national law L.N. 748/84 on fertilizers are an example for legal and terminological incongruence and obsolescence)
- varying application of different quality criteria and different specification degrees (i.e. Germany and Austria distinguish three classes of compost quality, while Italy distinguishes only one class and Great Britain none at all)
- lack of coordination between the environmental policy of the European Community and the various member states (although EC-directives generally have an obligatory character, the procedures of accomplishment are left to the member states' discretion; since each state has its own particular environmental policy the strength of which differs greatly due to the socio-economic and cultural configuration, the terms of application are quite variable)
- lack of a common strategy in the research on compost production and in the formulation of standards and eco-labelling systems at international level (still too many questions are open, the interests involved are so numerous and the points of view are too vexed).

On the linguistic and terminological level this situation explains the origin of a language usage which is often ambiguous or even incorrect (i.e. the use of the terms 'fermentation' or 'aerobic fermentation' in reference to the biooxidative process of composting). The correct usage of technical terms certainly depends on other aspects too, such as the competence and the scientific field of origin of the speaker or author. Clear and homogeneous terminology, however, can only be achieved if a term, whenever possible, is permanently assigned to a concept or vice versa in an unambiguous way, so as to avoid the phenomena of polysemy and synonymy which are the origin of ambiguities, therefore misunderstandings and incorrect uses.

Conclusion

The results reported here attest the importance and need of clear and homogeneous regulations on compost production and marketing at national and EC-levels (governmental and non-governmental) as a means of creating monoreferentiality and thus terminological homogeneity.

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Effects of Application of Municipal Solid Waste Compost on Horticultural Species Yield

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Introduction

Composting as a means of waste recycling in order to produce organic fertilizer has long been practised by farmers. Agronomic interest in compost is due to its elevated nutrient and organic matter content. However compost could have an adverse impact on account of its salinity or the presence of pathogens or toxic metals. Numerous studies on this last aspect have shown that heavy metal content in compost treated plant does not differ significantly from the control (Massantini et al., 1988; Stilwell, 1993). The agronomic trials carried out on compost have shown conflicting results for marked variability in composition, type of species grown and pedoclimatic characteristics of the trial area (Del Zan, 1989; Edwards et al., 1993; Paris et al., 1986). The purpose of the present research was to study the direct and residual agronomic effects of compost from treated municipal solid waste on horticultural species.

Materials and methods

Trials were carried out during the years 1990–1991 at Acciaolo (Pisa, Italy). Soil physical-mechanical and chemical characteristics and chemical composition of organic materials applied (referred to dry matter) are listed in the following table 1:

A split plot design was adopted. The main treatment (4 levels) was represented by the control, two doses of compost and manure. The secondary treatment (2 levels) was presence or absence of mineral fertilization. These 8 treatments were replicated 4 times in 40 m² plots.

The trials were carried out as follows, with an identical experimental design for the different crops and in the two years.

Table 1

		Soil	Compost	Manure
Sand	%	68	—	—
Silt	%	23	—	—
Clay	%	9	—	—
Chemical reaction	(pH)	7.9	8.9	8.9
Residue 105°C	%	—	65	21
Organic matter (Lotti met.)	%	1.2	21	66
Total N (Kjeldahl met.)	%	0.2	1.1	2.4
Total P ₂ O ₅	%	0.2	0.7	2.0
Avail. P ₂ O ₅	ppm	63	380	2050
Total K ₂ O	%	0.3	0.5	3.5
Avail. K ₂ O (int. met.)	ppm	36	4332	29952

First year:

Spinach (cv 'Melody'), lettuce (cv 'Jory'), tomato (cv 'Sunny') and potato (cv 'Spunta'). The main treatment was compost application at doses of 43.2 and 86.4 t·ha⁻¹ and manure at 60 t·ha⁻¹.

Second year::

a) lettuce and tomato: crops were repeated on the same plots of the previous year without additional fertilization, in order to assess the residual effect of the previous year's treatments.

b) spinach: organic fertilizer doses were triplicated (129.6 t·ha⁻¹ and 259.2 t·ha⁻¹ for compost and 180.0 t·ha⁻¹ for manure), in order to assess the negative and positive effects of fertilizer.

Organic materials were applied immediately prior to plowing (35 cm). Compost supplied by the ECOSUD S.p.A. factory of Massa was used. Mineral fertilization consisted in 120 kg·ha⁻¹ of N, 150 kg·ha⁻¹ of P₂O₅ and K₂O on all crops except those used for residual effect assessment.

Dry and fresh matter production and the corresponding percent N content of the commercial product were determined on each crop. Results were subjected to analysis of variance separately for each of the 7 experiments.

Results and discussion

None of the characters examined presented a significant interaction between main and secondary treatment in any of the 7 experiments. Therefore only mean effects, where significant, will be discussed.

First year

Spinach. Compost application at doses of 86.4 t·ha⁻¹ (table 2) led to greater dry

matter production (3.6 t ha^{-1}) as compared to manure (+ 10.4%) and the control (+ 11.8%). Mean mineral fertilizer effects were a marked increase in fresh matter (80.1 %) and a decrease in percent dry matter content. Consequently, only a slight increase in dry matter was recorded (+10.4 %). In addition, following application of mineral fertilizer, nitrogen concentration increased from 4.1 to 5.5 %.

Lettuce No appreciable differences were observed in this crop following organic fertilizer application. In contrast, mineral fertilizer induced a noteworthy increase in weight of both fresh (from 11.3 to 23.1 t ha^{-1}) and dry (from 0.6 to 0.9 t ha^{-1}) biomass, a decrease in percent dry matter content and an increase in whole plant nitrogen concentration (from 2.6 to 3.0 %).

Potato Potato tuber production and composition showed little influence of treatments applied. Only a slight increase in nitrogen concentration following mineral fertilizer administration was observed (from 1.4 to 1.6 %).

Tomato In this species, application of manure resulted in higher fruit production only at the fourth harvest as compared to compost or the control (tab.1). Mineral fertilization led to more abundant production in the first part of the productive cycle. However, in the later harvests, no appreciable effect of these fertilizers could be detected. Dry matter nitrogen concentration was found to be increased as a result of mineral fertilization (from 2.4 to 2.7 %).

Second year

Spinach Application of manure (180 t ha^{-1}) led to higher fresh matter yield (table 2) as compared to the control (+ 62%) and also as compared to single dose compost (+ 30%). In addition, application of double dose compost resulted in higher production than the control. However, with manure and double dose compost, the lowest values of percent dry matter content were observed. Nitrogen content was found to be decidedly lower in the control than in treatments with organic matter. The mean effect of mineral fertilization showed a marked increase in fresh (from 21.1 to 36.0 t ha^{-1}) and dry matter production (from 2.6 to 3.1 t ha^{-1}) and in nitrogen percentage (from 3.1 to 4.2 %), as well as a notable decrease in dry matter content (from 12.3 to 8.6 %).

Lettuce and Tomato In both cases, quanti-qualitative production presented no statistically significant differences attributable to residual effects of the previous year's treatments.

Table 2 First year: mean effect of organic matter treatments on spinach leaves and tomato fruits.

	YEAR 1990			YEAR 1991	
	Spinach		Tomato 4° harvest	Spinach	
	dry weight (t·ha ⁻¹)	dry weight (t·ha ⁻¹)	fresh weight (t·ha ⁻¹)	dry matter %	nitrogen %
Control	3.2 a	13.5 a	21.6 a	11.6 c	3.2 a
Compost dose 1	3.4 ab	16.1 a	26.9 ab	10.4 b	3.7 b
Compost dose 2	3.6 b	14.7 a	30.5 bc	8.5 a	3.9 b
Manure	3.3 a	19.8 b	35.0 c	7.7 a	3.7 b

Conclusions

- Single dose organic fertilization (first year) produced an appreciable effect only on spinach. In particular, compost applied at the higher dose (86.4 t·ha⁻¹) led to an increase in dry matter production as compared to the control.
- Fertilization at triplicated doses (second year) led, on spinach, to an increase in dry matter production (41 %) compared to the control. However, a considerable decrease in percent dry matter was also induced.
- The expected effect of mineral fertilization in inducing an increase in production and nitrogen content was almost always observed. In addition, in winter crops (spinach and lettuce) a marked decrease in dry matter content was also recorded.
- Organic and mineral fertilization applied during the first year had no effect on quanti-qualitative production characteristics of tomato and lettuce in the second year. Residual effects were therefore absent.

In conclusion, it should be emphasized that the type of compost studied showed low short-term nutrient element availability. Its use should therefore be accompanied by mineral fertilization.

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Properties of Phosphomonoesterases and β-glucosidase in Compost Extracts

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Background

During composting, animal and plant debris is modified by mineralization and humification through a wide variety of biological and biochemical processes. Extracellular enzymes in composts are constituents of the biochemical decomposition, catalyzing reactions in which nutrients are released for later use.

Acid and alkaline phosphomonoesterases are enzymes catalyzing the hydrolyse of organic P esters to orthophosphate, which is a key reaction in the mineralization of organic phosphorus. β -glucosidase is active in cellulose decomposition, and is thus important enzyme when plant debris, like straw, is composted.

Hardly any studies have been made on the enzymatic activity in composts. Godden et al. (1983, 1986) monitored urease, cellulase, invertase and alkaline phosphatase activities during cattle manure composting, and Garcia et al. (1993) have measured phosphatase activity and kinetics of both fresh and composted urban wastes, but the temperature response of enzymes in composts have not yet been discussed.

Aims

- 1) to calculate the kinetic and thermal properties of acid and alkaline phosphatase and β -glucosidase enzymes in extracts of manure composts of varying maturity
- 2) to find out, if these properties can be useful as an index of compost maturity.

Material and methods

Composting of cattle and big manure mixed with barley straw was performed in a continuously working, automatically by computer controlled horizontal drum

composting system in several replicates as previously described (Vuorinen & Saharinen, manuscript). The used composts of varying maturity: 1) a material after the digestion of seven days in the composter, called a raw compost, 2) the same material after maturing three or five weeks in an indoor heap 3) after maturing of two months, 4) after maturing of three months

Compost extract was made by shaking 40 g fresh, freezed composts with 90 ml distilled water 1 h in an overhead shaker at 4°C, the homogenate was filtered through Labox 25 laboratory filter system (made by Larox Ltd), the total volume of the filtrate was made up to 150 ml with distilled water.

Acid and Alkaline Phosphomono-esterase activities were assayed according to Vuorinen & Saharinen (in press). Compost extract (0.5 ml) was mixed with 2.5 ml *p*-nitrophenyl phosphate (Sigma) in 1.5 x Modified Universal Buffer, pH 4.8 or 9.0. After incubation 0 and 30 or 60 min in a water bath at 30, 40 and 50°C with shaking, enzyme activity was halted by the addition of ice cold diethyl ether and rapid cooling in an ice bath. Concentrations of the product were calculated based on *p*-nitrophenol standards for each compost extract (Vuorinen 1993). The substrate concentrations for kinetic studies ranged 0.62 to 62.3 mM. All measurements were made in three replicates and substrate controls without enzyme were always included.

The kinetic properties of the enzyme were calculated using reciprocal plots for linear transformation of the basic velocity curve: Eadie-Hofstee plot, a plot of V_0 against $V_0/[S]$ (Segel, 1975). β -GLUCOSIDASE activities were measured as above, but *p*-nitrophenyl- β -D-glucopyranoside (Sigma) used as a substrate, concentrations ranged 0.60 to 60 mM. PROTEIN CONCENTRATIONS of the extracts were determined by Lowry procedure (Sigma, protein assay kit).

Results

In the extracts of raw composts, the end products of the drum composting system, the activities of both acid and alkaline phosphomonoesterase were low and measurable only with extreme high substrate concentrations. The affinity of the enzymes to the substrate were very low, also at high temperatures. V_{max} values of both acid and alkaline phosphomonoesterase increased during maturing in heaps and remain constant in mature composts. Alkaline phosphatase had higher V_{max} values than acid, but acid phosphatase had a stronger temperature dependence. K_m values of acid phosphatase increased with increasing age of the compost (Tables 1 and 2).

β -glucosidase activity was also very low in raw manure-straw composts and it was not possible to calculate the kinetic parameters. During thermophilic phase in the maturing heaps V_{max} values were the highest and at the same time the temperature dependence was the strongest (two fold increase in V_{max} per every 10°C increase in temperature). V_{max} values were decreased in the extracts of three

months old compost, and increasing incubation temperatures had then only slight effect on V_{max} values of β -glucosidase (Table 3).

CONCLUSIONS

Activities of β -glucosidase, acid and alkaline phosphomonoesterase were lowest in the extracts of the raw manure-straw composts, digested only seven days in a drum composting system. During maturing in the heaps V_{max} values of all the studied enzymes increased, but the V_{max} of β -glucosidase was not stable.

The temperature response of all the enzymes varied with varying age of the compost being the strongest in the early stages of the maturing, while the initial temperatures in the experimental heaps were also highest. Acid phosphomonoesterase maintained its temperature dependence also in mature composts.

High phosphatase activity in compost extracts, strong temperature response and high K_m values of acid phosphomonoesterase - can be considered as signs of the maturity of the compost.

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Table 1 Kinetic properties of acid phosphomonoesterase in extracts of two manure-straw composites (standard deviations in parenthesis).

	Vmax ^{a)} Km ^{b)}	30°C R ²	Vmax ^{a)} Km ^{b)}	40°C R ²	50°C R ²	Vmax ^{a)} Km ^{b)}	R ²
compost 1							
raw	.09 (.01)c)	nd	.34 (.00)c)	nd	1.27 (.01)c)	nd	
5 weeks	.39 (.03)	.92 (.17)	.692	.86 (.08)	1.84 (.36)	2.05 (.24)	.630
2 months	.22 (.02)	2.15 (.33)	.767	nd	1.55 (.20)	6.32 (.18)	
3 months	.26 (.02)	1.37 (.28)	.669	.68 (.06)	2.29 (.41)	.704	.690
						1.58 (.24)	.538 (.127)
compost 2							
raw	.09 (.00)c)	nd	.38 (.00)c)	nd	nd		
3 weeks	.35 (.04)	3.04 (.52)	.705	.74 (.08)	2.21 (.48)	.618	.440 (1.05)
2 months	.35 (.02)	9.99 (.80)	.957	.96 (.08)	9.74 (1.08)	.862	10.43 (1.80)
3 months	.28 (.03)	4.59 (.99)	.704	.82 (.05)	10.8 (.88)	.926	2.65 (.21)
							28.2 (2.8)

a) $\mu\text{mol p-nitrophenol/mg protein}/60 \text{ min}$

b) mM

c) initial velocities, V₀; Vmax not available

Table 2 Kinetic properties of alkaline phosphomonoesterase in extracts of manure-straw compost (standard deviations in parenthesis).

	Vmax ^{a)}	30°C Km ^{b)}	r^2	Vmax ^{a)}	40°C Km ^{b)}	r^2	50°C Vmax ^{a)}	Km ^{b)}	r^2
compost 1									
raw	.03 (.00)c)	nd		.13 (.02)	14.7(4.0)	.695	.32 (.00)	28.6(.6)	.998
5 weeks	.38 (.03)	1.64(.25)	.769	.79 (.06)	2.23(.31)	.798	1.06(.05)	3.06(.23)	.934
2 months	.59 (.02)	1.89(.15)	.928	1.03(.05)	2.07(.22)	.874	1.45(.09)	1.98(.24)	.843
3 months	.61 (.05)	4.20(.69)	.806	1.21(.04)	1.58(.21)	.822	1.23(.05)	1.95(.23)	.850
compost 2									
raw	nd	nd		nd	nd		nd	nd	
3 weeks	.80 (.07)	3.46(.54)	.760	1.61(.11)	3.58(.40)	.862	2.35 (.11)	3.96(.31)	.925
2 months	.83 (.07)	2.89(.45)	.757	1.36(.06)	2.85(.23)	.921	1.72(.12)	3.20(.38)	.847
3 months	.87 (.06)	2.30(.29)	.830	1.58(.09)	2.75(.28)	.883	1.71 (.12)	2.64(.35)	.817

a) $\mu\text{mol p-nitrophenol/mg protein}/60 \text{ min}$

b) mM

c) initial velocities, V₀; Vmax not available

Table 3.
Kinetic properties of β -glucosidase in extracts of manure-straw compost (standard deviations in parenthesis).

	30°C Km ^{a)}	r ²	V _{max} ^{a)}	40°C Km ^{b)}	r ²	50°C V _{max} ^{a)}	Km ^{b)}	r ²
compost 1								
raw	.04 (.00)c)	nd	.10 (.01)	2.49 (.31)	.835	nd	nd	
5 weeks	.51 (.03)	1.13 (.15)	.94 (.05)	1.61 (.14)	.906	1.90 (.10)	1.95 (.20)	.879
2 months	.30 (.01)	1.74 (.17)	.892	.53 (.02)	1.24 (.11)	1.00 (.05)	1.29 (.18)	.842
3 months	.06 (.01)c)	nd	.31 (.01)	4.57 (.46)	.933	.42 (.02)	2.17 (.18)	.924
compost 2								
raw	.09 (.00)	1.12 (.14)	.857	.16 (.01)	.76 (.13)	.770	nd	
3 weeks	.68 (.04)	1.04 (.15)	.797	1.41 (.05)	1.34 (.11)	.915	2.49 (.11)	.62 (.14)
2 months	.46 (.01)	.59 (.05)	.917	.71 (.03)	.63 (.08)	.814	1.01 (.05)	.72 (.10)
3 months	.30 (.01)	.66 (.05)	.932	.52 (.03)	.85 (.12)	.796	.59 (.04)	.73 (.19)

a) $\mu\text{mol p-nitrophenol/mg protein}/60 \text{ min}$

b) mM

c) initial velocities, V₀; V_{max} not available

The Effect of Red Mud on Metal Mobility in Anaerobically Digested Primary Sludge During Composting

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Introduction

Anaerobically digested primary sludge (ADPS) refers to the residue obtained after digestion of settled solids from primary wastewater treatment and contains significant levels of pathogens and heavy metals. Disposal of ADPS to land requires composting to reduce pathogens. Land disposal is restricted by total heavy metal content in the sludge. Total metal levels in the sludge can increase during composting as the associated organic matter is decomposed. Heavy metals in the sludge (eg copper), during anaerobic digestion are present in their insoluble reduced forms such as sulphides. During composting, the metals in the sludge become more soluble due to the oxidation of sulphides to sulphates. In addition, decomposition of organic matter and acidification as a result of sulphide oxidation during composting can increase metal mobility in the sludge (Qiao, In Progress). Land application of this compost could thus result in a significant mobilisation of metals into the soil from the compost. The accumulation of metals in soils may result in phytotoxic effects or harm consumers of the contaminated crops (Garcia et al., 1990). In addition, groundwater can also be contaminated by heavy metals leaching into the water table.

Reducing the mobility of heavy metals in ADPS will reduce the risks associated with heavy metal contamination. The addition of bauxite refining residue (red mud) to a mixture of anaerobically digested primary and secondary sludge with sawdust and woodchips prior to composting has shown to reduce the mobility of heavy metals (Qiao et al., 1993). Red mud may also reduce metal mobility in ADPS compost.

The aim of this research was to reduce the mobility of heavy metals in ADPS during composting by the addition of red mud.

Materials and methods

ADPS was mixed with the following materials (in kg) to form four different mixtures: (I) wastewater skimmings (2.12) / ADPS (5.59) / chaff (1.50), (II) sawdust (1.49) / ADPS (4.50) / chaff (1.30), (III) wastewater skimmings (2.23) / ADPS (5.59) / green waste (2.18) and (IV) sawdust (1.81) / ADPS (5.03) / green waste (1.96). These materials were used as they were readily available and had suitable C/N ratios as composting amendments for the sludge.

Each mixture was composted with and without red mud. The amount of red mud added was 10 of the solids content of the sludge (20.7%) used in each mixture. Sand was added to the control mixtures in place of red mud to compensate for the metal dilution effect of red mud. The proportions of materials used in mixtures I to IV were based on calculations to obtain a C/N ratio of 20 and moisture content of 50%.

The mixtures were composted utilising the laboratory scale facility developed by Hofstede (1994). Monitoring of temperature and effluent oxygen and carbon dioxide gas was carried out for each mixture independently on a continuous basis. Composting temperatures were controlled at 55 °C by varying aeration rates between 1 and 3 l/min.

Compost samples were taken at the start, after 5 days and then every 4 days for a 21 day period. Analysis was carried out to determine total metal content, CaCl₂ extractable metals (leachable metals) and DTPA extractable metals (plant available metals). The metals were cadmium, copper and zinc. Moisture content, ash content, pH, soluble organic matter and carbon and nitrogen content was also determined (APHA, 1985). Fresh compost samples were used to avoid the effect of drying on metal speciation (Qiao et al., 1993).

Results and discussion

Leachable zinc may exist in forms associated with organic matter or be in free ionic form. Red mud reduced leachable zinc to a greater extent than soluble organic matter in mixture IV (Table 1). The reduction in soluble organic matter on day 21 was 9% for mixture IV. This suggests that zinc not associated with organic matter was immobilised by red mud. This has also been found by Hofstede and Ho (1991). Leachable copper was only reduced in mixtures III and IV. The results in mixtures I and II were too variable between day 0 and 21 to assess the effect of red mud on copper mobility (Wong, 1994).

Leachable cadmium levels were below detection limits in all mixtures. Leachable metals generally formed less than 10% of plant available metals. Plant available metals were generally about 5% of total metals. Hence the metals in the mixtures were mostly immobile which is in agreement to the findings by Garcia et al., 1990.

Red mud reduced plant available metals. Plant available copper was consistently

reduced by red mud only in mixtures III and IV (Table 2). This reduction is not due to pH effects as the DTPA extractant solution used was buffered at 7.3. Red mud could have reduced plant available metals by either (i) extracting metals bound to the compost substrate followed by strong adsorption to red mud cation exchange sites or (ii) binding to the compost substrate containing the metals (Wong, 1994).

Table 1 Effect of red mud on reducing leachable zinc

Metal	I		II		III		IV	
	Day 0	Day 21						
Cu	ND	-8	ND	-63	32	24	18	22
Zn	13	46	59	21	42	0	21	53

ND Below detection limit

Table 2 Effect of red mud on reducing plant available metals

Metal	I		II		III		IV	
	Day 0	Day 21						
Cd	33	33	60	5	-6	23	15	5
Cu	96	-21	9	16	93	86	71	39
Zn	54	29	21	46	-1	23	29	22

Table 3 Total metal levels in mixtures with red mud (mg dry matter)

Metal	I		II		III		IV	
	Day 0	Day 21						
Cd	3.5	3.3	2.7	2.7	2.7	2.9	2.0	2.3
Cu	500	513	29	448	400	55	92	16
Zn	29	29	89	600	655	97	66	09

Table 4 General composting parameters for mixture IV

Parameter	With red mud		Control	
	Day 0	Day 21	Day 0	Day 21
pH	6.8	7.3	6.2	6.6
Soluble organic matter (mg O/l)	1225	645	1225	710
Carbon to nitrogen (C/N) ratio	20	13.5	18	15
Organic matter (%)	49.1	40.8	42.8	39.6

The total metal content increased during composting due to the loss of organic matter during the process (Table 3). Total cadmium, copper and zinc levels in red mud were 3, 81 and 16 mg/kg respectively. Total cadmium, copper, and zinc lev-

els in the sludge were 12, 1855 and 2426 mg/kg respectively (Wong, 1994). Hence addition of red mud to ADPS will not increase total levels of these metals.

The decline in the C/N ratio in mixture IV indicates the loss of carbon in relation to nitrogen, which is common during composting. The reduction in organic matter content is due to the loss as products of respiration in composting (Table 4).

Conclusion

The addition of red mud to ADPS before composting reduced the metal mobility in the sludge. This has the potential to reduce the impact of metals on the environment after land application of compost.

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Physical, Chemical and Biological Quality of Four Lombricomposts

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Abstract

The physical, chemical and biological properties of four lombricomposts, obtained from cow dung, press-filter cake, coffee pulp and green residues, with the aid of the earthworm *Eisenia fetida* were studied.

Except green residues, lombricomposts were produced with pH between 8.4 and 8.9, explained perhaps due to the lack of leaching during the process. The highest earthworm population was reached with coffee pulp and the best bacterial population was found in cow dung. The weight of aggregates retained for sieve No. 10 was high except in the case of green residues. The filter-press cake showed the best content of nutrients, followed by cow dung, coffee pulp and green residues.

Introduction

The aim was to characterize the lombricomposts obtained from different organic residues, to orient its adequate use in agricultural processes.

There are great volumes of cow dung, filter-press cake, coffee pulp and grass residues in the Cauca Valley zone. These four substrates origin four lombricomposts, that differ in their physical, chemical and biological quality. This research about characterization has been developed in Palmira during the last six years.

Ferruzzi (1986) proposed a table for a categorization of lombricomposts, taking as criteria, any chemical properties as pH, nutrient content, presence of heavy metals and the bacterial charge.

Petrussi (1988) ignores that table, and claimed for a criteria that indicates the quality of lombricompost and then, assure the success of their use. In 1990, Varela and Urueña partially used the Ferruzzi table to categorize lombricomposts that originated from coffee pulp. Martínez (1991) utilized it for lombricompost obtained from flower export residues and validate these categories with a production trial of pompon flower. In a theoretical paper, Gómez (1993) explored the

quality criteria to configure a physical, chemical and biological profile, with the incorporation of physical characterization proposed by Ryser et al (1988) for compost obtained from kitchen and garden wastes.

Experimental procedure

In wood boxes 0.5 x 0.5 x 0.25 m. the four residues referred before were deposited. The boxes were installed in shadow and 200 adult earthworms *Eisenia fetida* were placed in each box. A plastic mesh was placed on top as protection from rodents. Two volumetric irrigations by week were made, so as not to cause leaching. When visual inspection could not distinguish the original waste, the process is over. It occurred first in filter-press cake and coffee pulp. Many weeks after it occurs in cow dung and grass residues. The lombricompost were carried to the laboratory for physical, chemical and biological analysis. A test for pathogenicity of *Fusarium* in tomato plants for the pulp coffee lombricompost, was realized.

Results

The cuadre 1. resumes the average of four replications.

The cow dung lombricompost has the highest value of both of bulk and particle density. All lombricompost didn't reach the value of 0.3 of bulk density proposed by Ryser et al (1988). The yoder test indicated a high structural stability in water. The pH showed alkalinity except for grass residue, explained by the lack of leaching during the process and doesn't conform to the idea that lombricompost tends towards neutrality.

The organic matter reached very high values, superior than obtained by Martínez (1991) and Varela and Urueña (1990) the coffee pulp lombricompost was rich in nitrogen and potassium, the filter-pres cake is rich in phosphorus, calcium, iron, copper and manganese; the cow dung in magnesium. For this concept, the best lombricompost originated from filter-press cake and the worst one comes from grass residues.

So far, the highest earthworm population occurred in coffee pulp substrate, material that presents *Fusarium*, but without pathogenicity to tomato seedlings. The bacterial count was high in filter-press cake.

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Table 1 Physical, Chemical and Biological Properties of Four Lombricomposts.

	Substrate			
	Cow Dung	Filter-Press Cake	Coffee Pulp	Grass Residue
Bulk density (g/cc)	0.99	0.76	0.73	0.72
Particle density (g/cc)	2.11	1.99	1.64	1.78
Porosity (%)	52.90	61.60	55.10	59.50
% retention mesh 10	95.47	99.48	99.25	61.82
Organic matter (%)	65.30	68.30	42.00	47.10
pH	8.42	8.50	8.90	6.67
N (%)	1.82	1.49	3.07	2.22
P	1.15	1.89	0.59	0.44
K	3.59	0.63	3.49	0.98
Ca	1.94	2.96	1.19	1.23
Mg	1.41	0.89	0.34	0.47
Na (ppm)	1925.00	890.00	795.00	1875.00
Cu	64.00	99.00	53.50	43.00
Zn	176.00	143.00	27.50	182.00
Fe	8982.00	16805.00	1053.00	2396.00
Mn	334.00	424.00	167.00	117.00
B	48.00	46.00	20.70	32.70
Earthworms/m ²	700.00	1225.00	4550.00	447.00
Bacterial count	4.34	76.10	17.43	43.56
Fusarium presence	0	0	X	0
Fusarium pathogenicity	0	0	0	0

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Integration of ‘Biopol’ into Biowaste Composting

A Summary of the Composting Studies carried out by PlanCo Tec and the University of Kassel in Germany.

Introduction

Composting may be defined as the ‘aerobic biodegradation of organic material to form primarily CO₂ ’water and humus’. It is a natural process which has been practised in our agricultural communities for many hundreds of years and by many of us in our own ‘backyard’ compost piles to generate a clean, valuable soil conditioner.

Up to 60% of municipal solid waste may be organic in nature and a significant proportion of this is suitable for composting. In order to make the best use of this organic material it is essential that the quality of the finished compost is adequate for the intended use.

Although there are as yet no internationally agreed standards, many countries have national quality standards for finished compost. These control issues such as the concentrations of heavy metals and foreign matter content (eg stones, broken glass etc.).

If these high quality standards are to be routinely achieved through the composting of municipal waste it is important that waste is pre-sorted prior to composting. ZENECA BioProducts actively supports the promotion of source separated biowaste composting and the development of composting at all levels of technology from source separated biowaste thorough yard-waste to back-yard composting. Increases in the amount of composting at these levels will result in a significant diversion of material from landfill. Most countries in Europe are now actively promoting the development of a composting infrastructure and the number of households with access to source-separated biowaste composting is set to rise significantly in the next 5–10 years (see Appendix 2 for more details).

Over a period of two years several series of composting studies, using ‘BIOPOL’, have been carried out by the Ingenieurgemeinschaft Witzenhausen (igw-Kompostverwertung/PlanCoTec) together with the University of Kassel in Germany. The studies involved incorporating ‘BIOPOL’ into biowaste material

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for both pilot scale composting trials and for routine compost plant operation. The pilot scale studies were conducted to establish the factors affecting 'BIOPOL' degradation and the full scale composting trials evaluated any interactions arising from the degradation of 'BIOPOL' products in a composting system. The tests covered all the requirements of the test matrix for biodegradable materials stipulated in the draft of LAGA's amended M10 in Germany.

Composting of 'Biopol'

Initial pilot scale work used standard 'BIOPOL' test material (DIN 32 conical chips) and was conducted to establish how 'BIOPOL' degrades under various composting conditions and to what extent the optimum conditions for biodegradation of 'BIOPOL' correspond with standard conditions of organic waste composting. The resulting composts were evaluated in plant tolerance studies according to RAL-GZ 251.

Parameters such as temperature, moisture levels and C/N ratio of the initial compost material were evaluated. The data shows that 'BIOPOL' resin is compostable over a wide range of temperatures and moisture levels. The maximum rates of biodegradation of 'BIOPOL' occurred at a temperature of 60°C and a moisture level of 55%.

The optimum, initial C/N ratio of the organic waste was 18:1. These optimum conditions for 'BIOPOL' correspond well with the optimum composting conditions for traditional biowaste material and are therefore similar to the standard conditions in most larga scala composting facilities.

Parameters such as the extent and frequency of turning did not influence the rate of biodegradation of 'BIOPOL' resin. The various grades of 'BIOPOL' (HV content and the levels of plasticiser) evaluated did not affect the rates of biodegradation during composting. Consequently, using the most favourable composting conditions, corresponding to the optimum composting conditions for biowaste materials, 'BIOPOL' resin was completely degraded within 10 weeks. The 'BIOPOL' had become fully incorporated as part of the compost.

The addition of 'BIOPOL' resin to compost does not diminish the quality of the final product as judged by seedling growth and chemical analysis. Plant growth studies were compared using control compost and 25% w/dry wt 'BIOPOL' compost. A pass rate is considered to be a plant yield of >90% of that observed with the control material.

Using the respective composts prepared from the above degradation tests and with final mixtures containing 25% of the test compost relative yields were about 125% of that seen with the control compost. Chemical analysis showed no significant changes of organic matter, matrix nutrients or heavy metals in the resulting compost form the pilot scale trials.

Further practical scale studies were then carried out using 'BIOPOL' bottle, both whole and shredded, of varying wall thickness (1000(m – 2000(m). These

studies were conducted during routine operation of 3 compost plants employing different composting techniques.

1. Fully enclosed, organic waste windrow composting, with automatic turning.
2. Initial contained, intensive composting with subsequent composting on table windrow with turning.
3. Composting on triangular windrows with manual turning.

These tests cover the requirements of the test matrix for biodegradable materials contained in the draft of the amended M10 of LAGA.

'BIOPOL' was either mixed with the biowaste material in bags, or added directly to the compost material in the plants to give a final concentration of 1% w/w. The composting periods in all the tests were between 12 and 19 weeks in accordance with normal operating procedures. The studies showed that with all the thicknesses and quantities used, 'BIOPOL' resin was rapidly degraded during practical composting providing favourable composting conditions were maintained. This result applied to all the composting systems evaluated.

Under the most favourable composting conditions the 1000/m 'BIOPOL' fragments degraded rapidly and at an equivalent rate to that obtained in the model studies discussed previously. Unfavourable composting conditions, in particular low oxygen contents between 10–12% by volume, delayed 'BIOPOL' degradation. However, complete degradation was still possible during normal composting periods, providing there were no additional restricting conditions such as high temperatures ($>70^\circ\text{ C}$).

Since the operation of all compost plants at optimum conditions cannot be guaranteed, the maximum recommended wall thickness for a bottle made solely from 'BIOPOL' (or other moulded item) is 700/m to ensure complete degradation during normal composting periods.

Further chemical analysis on the quality of the 'BIOPOL' composts obtained from the composting trials confirmed the work discussed earlier. It has been concluded that any negative influence of 'BIOPOL' addition to composts can be excluded. A high 'BIOPOL' addition ($>15\text{--}20\%$) again improved the quality of 'average' bio-composts in particular with respect to heavy metals such as Pb, Cd and Cr. As with previous results the quality of the compost produced using 'BIOPOL' did not impair plant growth.

Summary

Composting is nature's way of recycling. It is an environmentally beneficial technique for the recovery and recycling of organic bio-wastes. 'BIOPOL' has been demonstrated to rapidly degrade under a wide range of composting conditions, giving rise to a compost of high quality. The compost studies described above and carried out by PlanCoTec in conjunction with the University of Kassel have concluded that 'BIOPOL' meets all the requirements of suitability testing for

biodegradable materials, for inclusion in composting, made by LAGA in the draft of the amended M10.

An independent, expert opinion on the 'Processing of the biodegradable material 'BIOPOL' in 'biowaste composting' is included in Appendix 1 in both German and English.

This work was partly funded by the Lower-Saxon Ministry of Economy, Technology and Transport.

A comprehensive report has been compiled by PlanCoTec giving full details of the work carried out and copies can be made available from SAFTA SpA, on request. All enquiries should be addressed to Vittorio Roncoroni, SAFTA SpA, Via Arda, 11, 29100 Piacenza, (Tel. 39.523.5981 – Fax 39.523.597060).

Additional Papers

Parallel session A3: Round Table on legislation

W.A. VAN BELLE – ORCA Procter & Gamble E.T.C.

General

Only two papers were presented at this session, the major part of the session was devoted to the round table discussion on the subject of legislation dealing with composting, compost feedstocks and compost usage.

Papers presented

Dr J. Walker of the US Environmental Protection Agency presented a very comprehensive paper on the US EPA approach and methodology to determine acceptable pollutant loads in bio-solids. The objective is to provide adequate protection for so called Highly Exposed Individuals (HEI) from reasonable effects of pollutants in bio-solids (heavy metals-pesticides- herbicides etc.).

The methodology involves exploring 14 pathways of exposure, of which the most restrictive pathway is selected to arrive at an acceptable limit for the pollutant in question.

Comments: The only comment on this excellent paper is that in several European countries, when it concerns compost application to soils, the concept of so called multi-functional soils has been adapted. Taken to the extreme, this can mean that heavy metals applied to soil equals heavy metals uptake by plants, so that in effect a steady state condition is arrived at. Needless to say that this approach results in significant lower heavy metal limits allowed in compost, compared to the US EPA approach. This has been discussed at length at several other conferences, no more need to be said about it, within the context of this symposium.

Dr A. Piavaux of EC DG XI presented a paper on European Legislation for compost production and usage. This was a fairly easy task for Dr. Piavaux since at present there is no EU legislation, and apparently none will appear in the foreseeable future.

A glimpse of hope was raised by Dr. Piavaux, when he announced a call for tender by the European Commission for a study collecting information on composting technology-marketing and existing legislation in the European Member States today. This might be the first step in a process towards a draft proposal Directive for composting in the EU.

We do appreciate the effort of Dr. Piavaux in this endeavour and ORCA will support this.

Round Table on Legislation

Participants to the Round Table:

- Mr W.A. Van Belle ORCA (Chair)
- Dr G. Brunelli Ministry of Environment
- Prof P. Sequi Ministry of Agriculture
- Dr C. Incocciati Italian Federation Municipalities
- Dr A. Trombetta Director Waste Management – Region Piemonte
- Dr L. Franz Director Waste Management – Region Veneto
- Prof M. de Bertoldi Closing Statement

After a brief introduction by the chairman, two questions were put to the members of the Round Table for debate:

- 1) What can we do to advance the cause of composting in Europe?
- 2) What would be the role of legislation?

The debate was very animated, while most participants were from Italy, the experience, arguments, conflicts are relevant for almost all of the European countries. Following is a summary of the debate:

On question number 1: advancing the cause of composting in Europe.

It is quite clear that today in Europe, in most countries the task of establishing composting as an *essential part* of a modern waste management system that is sustainable for the future, and affordable for the people, is led by a relatively small number of dedicated people in municipalities, regional authorities with the assistance of a well established group of scientific experts-academici, and this without the overt support of national authorities.

Most of the citizens, participating in a composting operation, intuitively understand that treating biodegradable waste and returning the resulting end product (compost) to enrich the soil, from which they originate, *must* be beneficial for the environment. It is also the only waste treatment system that can be organised, operated and the end product marketed at the local or regional level by the municipality. It is also clear that the science of composting itself and its beneficial impact on the soil and plants is well established in Europe, thanks to the dedicated efforts of a select group of scientists in Europe and the US, most of them attending this symposium.

And yet, during the debate, the sense of frustration of the panel members was quite clear, progress on composting is slow in many countries in Europe, apparently one country (France) appears to have given up on composting altogether.

On question number 2: what would be the role of legislation?

In the absence of specific legislation dealing with composting and compost, the whole operation becomes either illegal or subject to existing legislations vaguely

related to composting e.g. waste handling – fertiliser legislation which automatically results in *conflict situations* that cannot be solved at municipal-regional level without exceeding their level of authority.

Today, specific legislation or specific encouragements in the form of subsidies for composting exists only in a few European countries, either at national level or regional level, it is also true that in these countries, composting has been advancing steadily

– Austria		National level	
– Belgium	Flanders	Regional level	
– Germany	Länder	Regional level	only 4: Baden Wurtenberg Hessen Nordrhein Westphalen Rheinland Pfalz
– Netherlands		National level	

In many EU member countries at the national level, the legislators are busy nowadays translating the recent packaging directive into national legislation. This will require in the end significant funds in the form of taxpayer money. Also at the national level, the authorities will have to implement the 89 directive on incinerator emissions (95–96 target date).

National authorities are faced in the nearly future with a loss in incinerator capacity (those who can not be upgraded) and the need for a significant amount of funds to achieve compliance with the EU Directive on the remaining capacity, plus eventual new installations for making up the loss in capacity, *if that is what they want to do*.

In my opinion, herein lies an opportunity for firmly establishing composting in Europe. Composting of a source separated household biowaste fraction on a *nation-wide* basis diverts 30–50% of household waste from landfill, where they do not belong, or from incineration, where they do not burn. This organic fraction transformed into compost can be returned to the soil, from which it originated, and maintain the organic contents of soils, without which no sustainable plant life is possible.

In Europe, 15 million people in the Netherlands, approximately 15 million people in Germany, Flanders and Austria are there to testify that this is achievable on a large scale.

In the Netherlands alone, nation-wide biowaste composting, saves the installation of eight incinerators (200.000 tonnes/year capacity each) at a fraction of the cost for state-of-the-art incineration, and as far as the authorities are concerned, with full consent of the citizens, which is not always the case for new incinerator installations.

It appears to me that the time is right to enter the *public debate* on this important issue, which will be vital for the future of composting in Europe.

Legislation in the European Union on compost production and use

A. PIAVAUX, European Commission, DGXI Environment

The evolution of Waste Management policy in the texts:

Introduction

The policy of environmental protection has been developing in the European Union for more than 20 years. Two phases can be distinguished in that period: During the first one environmental policies considered basically curative action and a sectoral approach (air, water, waste not soil, or practically not!) for the solution of existing problems. In most cases this meant a transfer of pollution from one medium to another.

In the second phase the strategy of the Union changed to a multi-media and multi-sectoral pollution control policy.

The 4th Action Programme (1987-1992)

In terms of waste management this new approach was first described in the 4th Environmental Action Programme adopted by the Council in 1987. In that Programme insistence was already particularly made on recycling:

It is the Commission's view that of all the actions that are necessary in the field of waste management, perhaps the more important in the long term would be to achieve a much higher rate of reuse and recycling of wastes than is the case at present.

The Waste Management Strategy (1989)

This Commission's view expressed in 1987 has been further elaborated in the Commission's Communication to the Council on Waste management Strategy (1989). In this document recycling and reuse (in other words bringing waste back into the economic cycle) are considered to be the best way of preventing or reducing adverse environmental impacts.

So, in a global approach even if the final goal is the protection of the environment, further emphasis than before has to be put on economic considerations, like

the costs of industrial treatment, disposal processes, and related operations like collection, sorting, transportation, taking also into account the outlets for products obtained from recycling.

Following the same rationale, recycling and reuse can take a variety of forms including regeneration, raw materials recovery and even energy conversion (in that sense, certain incinerators are recyclers!). The choice of the variety to be used should be based on the aim of reducing the quantities of waste to be disposed of and the recovering of raw materials and energy.

The Commission concluded the chapter concerning recycling by underlining the means to be promoted:

- research and development on reuse and recycling techniques,
- optimizing collection and sorting systems,
- reducing the external costs of reuse and recycling, and
- creating outlets for the products of reuse and recycling.

To be fully effective, those measures should be accompanied by incentives such as deposits on returnable items, and taxes, evidently non discriminatory or out of proportion with the aim.

The 5th Action Programme (towards sustainable development, 1993-2000)

In the 4th Action Programme as in the Communication of 89, two things were missing: *who will do what*, or if you prefer who is the actor in each target sector. Those aspects were completed in the 5th Action Programme, presently running.

For the first time, a lot of people are really considered as the *actors* in waste management:

- the *authorities*, of course, who have a decisive role by the adoption and implementation of legislative, technical and economic measures;
- the *companies* which have to internalise their waste management costs develop clean technologies and products, and integrate environmental considerations into their management policies;
- and, last but not least, the public, who as consumers, and as producers of waste, and also as responsible for the environmental quality and able to influence policies and decisions they will have to apply, need education and information.

Having mentioned the actors, I automatically mention the main *sectors*: manufacturing industry as generator of goods which finally will become waste, other industries and services using raw materials, developing products or providing services: all have their part of responsibility in the management of generated waste.

This approach helps us in the elaboration of the concept of shared responsibility to ensure a good waste management policy based on three basic principles:

- the one of *proximity*: waste has to be treated as nearest as possible of its production location,

- the one of *self-sufficiency*: at least at the level of the Union, all waste has to be treated or disposed of in the Union territory without any exportation to third countries (Regulation 93/259). As far as possible, this principle applies within each Member State with some kind of solidarity between them.
- and also the principle of subsidiarity as defined in the Edinburgh Summit in December 1992 (after Rio!): decisions are only taken at the level of the Union if at that level they are more effective than if they were only taken at the level of Member State or even at the regional level.

Is this evolution translated into acts?

It is nice to go though texts. But was this evolution translated into facts?

I do think is was. Not necessarily in what is called the ‘Framework Directive on Waste’ which only ask “Member States to ensure that...” this or that measure is taken, but more explicitly in, for example, the recently adopted Directive on Packaging and Packaging Waste which fixes percentages of recovery and recycling. Those percentages will only be reached if all of us play the game of trying to treat or at least sort our own waste.

The same goal is aimed in the proposed Directive on Landfilling of Waste in which the Commission proposed to the Council to internalize all costs of landfilling, including the ones of rehabilitation after closure and the ones of a guarantee funds to ensure all cases of pollution even 30 years after the closure.

But the evolution is much better illustrated by our Priority Waste Stream approach. This process consists in putting altogether around a table all interested parties in the Union (Member States, producers, commercial trade, suppliers of raw materials, consumers, environmental organisations, regional and local authorities, ...and, allow me, the Commission) to discuss together and identify the gaps to be filled for a better environmental protection during the life (from production to disposal) of a product.

Gaps having been identified, strategies have to be elaborated and proposals for actions or measures have to be decided for application by the right people at the right level.

We have already launched six working groups on different streams: used tires, end of life vehicles demolition waste, electric and electronic ones, healthcare waste and chlorinated solvents (is now left aside, due to the adoption of the Montreal Protocol).

The two first (used tyres and vehicles) have already finished their work, and the Commission will soon propose measures to be taken at its level.

What about organic waste?

In the present legislation, the only adopted Directive by the Council concerning

organic waste, is the directive 86/278 on the use of sewage sludges on agricultural lands. As you know this Directive is only concerned with heavy metals.

But we all know that heavy metals are only a part of the composition of waste water treatment sludges. Even after a secondary treatment, not only chemical elements but organic matters or pathogens are or may be present in those sludges.

Furthermore, after '86 another directive was adopted in '91, concerning waste water treatment plants. In its article 14, it refers to sludges. In my opinion the reference that sludges have to be disposed of following the best environmental approach, was a call or possibly a cry to research people 'Please find for us the best means to use all sludges covered by this Directive'.

It opens a door for composting of organic waste and for possible legislation about it. OK, legislation on waste is my professional work, but, as I earlier made a reference to the subsidiarity principle, I will add here that I am not searching work for myself.

Finally, my only intention is to draw your attention concerning composting interests to the fact that recycling is only feasible if:

- first you create a sufficient infrastructure to receive all the waste you want to be recycled,
- and secondly, you have a sufficient market for your recycled products.

As far as infrastructure is concerned, it is to the Member States with industry to create the organisation of collect and sorting systems.

I am not that sure about the market, because the consumer of the product wants to be convinced that the recycled product is as effective as chemical fertilizers, and at a competitive price.

At the Union level, we can only propose rules about quality, fixing limit values for hazardous substances in the different types of compost consequently, following the intended use and quality rules for the feedstock of composting plants. A study on the state of the art in the Union will be launched in the next weeks. It will constitute a first step towards an eventual harmonization of existing national legislation with the view of creating the best conditions for the development of an internal market ensuring the best possible environmental protection.

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Additional Papers

Biological treatment, the perfect eco-efficient tool in a sustainable integrated waste management

BERT LEMMES, Managing Director, ORCA

The intention behind the session was to avoid the possible overfocussing on the specific composting/biogasification problem, and to avoid the kind of composting euphoria or megalomania that has caused very serious harm to the acceptance of biological treatment in the past.

We only have to think back about the experiments with total MSW-composting, that produced an end-product that one could never call compost. Some people still advocate this strategy as a pure reduction and stabilisation-process, with an end-product called 'STABILAT' (in German) or stabilised matter. (See contribution Paul Bardos.)

But apart from that, the general tendency goes in the direction of source-separated collection, and the biological treatment of the separated organic fraction.

To oversimplify, it boils down to the question of principle whether we should try to compost as much as possible or *impose* a sufficient level of self-discipline on the sector to treat only that part of the organic resources, that will lead ultimately to the production of a valuable product 'compost' and to achieve this result in an **eco-efficient** manner.

We are faced in politics and legislation with the choice between waste and non-waste and a lot will depend on the final decision concerning this issue. But for the sake of this discussion, we will continue to use the definition of recyclables and organic matter as waste for the time being. Nevertheless I want to stress already now that a basic change should be made in the thinking and therefore in the wording and definitions.

We should start calling 'waste' what is definitively 'wasted' and should adopt the positive philosophy of 'RESOURCES-MANAGEMENT' instead of 'waste-management' for all the fractions that can eco-efficiently be recovered.

We are faced with choices in resource-management about how to deal with the organic fraction. Biological processes are one of several means of dealing with this part of the secondary resources, but there are obviously others.

The integration of composting, anaerobic digestion or biogasification and stabilisation into an overall recovery strategy, not only seems the logical way to go but will avail itself the only solution for specific fractions of the waste stream if we want to achieve the recovery targets that will be imposed.

To help the European legislators prepare decisions and mandates to implement biological treatment as a solution, it is necessary to provide a rational framework and a matrix to judge the opportunity of the solution.

This framework will have to take into account:

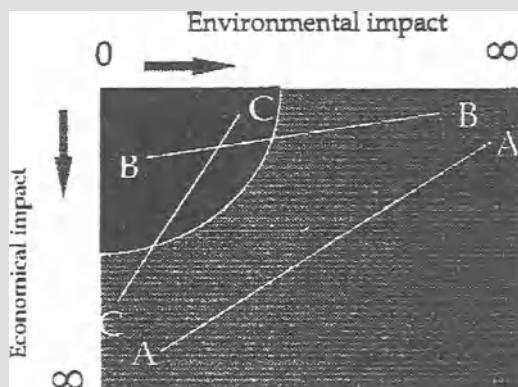
- 1) The specific objectives of the waste management (local-regional constraints, etc.)
- 2) The broad environmental merit via the LCI's and LCA's
- 3) The economic merit: → impact on the primary production
→ social acceptability and ease of implementation

This should enable the decisionmakers to determine the eco-efficiency of their strategy.

**Eco-efficient would mean in this case: *eco-logically sound*
*eco-nomically viable***

Example

Operating Eco-efficiency



Legend: Project A Big ecological impact but very expensive
Project B Big Ecological impact and low price
Project C Small ecological impact and very expensive

Black section is the operating window that can assure eco-efficient sustainable activity

We acknowledge that in the end the decision will remain political, but we can proactively create an *operating widow* to point out to the authorities that any decision outside this operating widow would be unreasonable and certainly not sustainable.

A lot will depend on the definition of the waste and its separation in different fractions.

Depending on the collection system, the source separation system, the fraction of grey waste could go from 100% (as in some areas using mass burn-technology) → to only 10% after source separation and pre-treatment.

The more efficient the separation, the smaller this grey fraction will become and the more important the **diversion from landfill** will be. But, whatever we do, we admit that there will always be a grey fraction. But this has to be as small as possible.

Dealing with that issue, **Paul Bardos** exposed a possibility to implement the *co-treatment of this grey fraction with industrial wastes in order to reduce the volume and stabilise and sanitise the waste to be landfilled*. At the same time the possibility to recover biogas, and the detoxification of hazardous substances.

Two other aspects of well managing the landfill, where it avails itself unavoidable, were addressed by **Prof. Cossu and Dr. Muntani**. The former addressed the problems with the containment in landfilling and the treatment of the percolate.

This discussion put the finger on every sore spot in the whole waste management strategy.

'How do we estimate the long-term environmental impact of a landfill and the economical implications of its sanitation afterwards.'

'How do we reflect this in the actual landfill-levies and do the existing or revised landfill levies such as in the UK reflect the real cost for providing an acceptable solution.'

Dr. Muntani addressed a different issue of landfilling by advocating the use of compost to avoid some of the engineering problems in well-managed landfills. According to him compost can function as a filter, a buffer, an absorbent in landfills to avoid the problems with leachate (among others) by binding toxic ingredients.

From the landfills we turned our attention to the solutions that are provided respectively by recycling of dry matters and the use of R.D.F. and P.D.F. in co-combustion processes.

Julia Hummel presented the pioneering work done by ERRA in setting up a database to collect data in a dozen pilot cities and to design a number of analyse-tools to interpret those data.

'The motivation and participation ratios for the source separation schemes and the cost for collection and separation are especially interesting for our sector as we are confronted with the same problems.'

For this reason ORCA and ERRA will join forces in the very near future and combine their information and the processing of the data with this data-base to achieve a global view on the recovery-issue and to put these data at the disposal of the decision-makers. The collaboration with a university and a number of motivated researchers will guarantee the academic and scientific accuracy of these data and make this a tool of high value to the EU, OECD and other authorities, faced with the elaboration of mandates in this complex sector.

Martin Frankenhaeuser of Borealis advocated the reduction of the grey fraction by extracting the recyclables first, *splitting the waste into a dry and a wet fraction.*

This proves once more that the different technologies can be complementary with a common denominator: *good source separation*.

The colours of state of the art composting were defended by: **George Savage**, of California Recovery, who advocated the use of the C/N ratio as a possible tool to judge the efficiency of process design.

At the same time he focused the attention once more on the *importance of the waste characterisation on the quality of the final compost*.

Going deeper into the problem of the definition of biowaste and broadening that definition by adding a paper fraction, **Bruno De Wilde** of Organic Waste Systems N.V. (OWS), Belgium, provided us with a clear insight in the **advantages of paper inclusion in composting**. As there are (among many others):

- reduction in salts
- more organic content
- better compost

The complete text of this research-project is available in the ORCA Technical Publications.

To close this compost section, **Karel Mesuere** commented and analysed the compostability criteria elaborated by **ORCA** as a framework to define the acceptable feedstock for state-of-the-art composting, and in order to make a quality compost.

These criteria create the link between the biodegradability (as tested in the labs) and the practice of composting, by integrating parameters that are relevant to the operations of composting/biogasification-plants. At the same time these criteria are scientifically correct and take into account the technical, biological and economical factors of the different processes. This very important work has been reviewed by a Peer-Review-Committee consisting of the leading authorities in the academic world and has therefore also been accepted by different authorities to form the framework for future legislation.

This publication is also available in the ORCA Technical Publications.

Last but not least, **Peter White**, Procter & Gamble Ltd., UK, author of the book *Integrated solid waste management* showed us in his exposé, apart from the well-known advantages of biological treatment, the necessity to optimise biological treatment, to optimise source separation and to optimise the whole system, in order to reduce overall environmental impacts and to make integrated waste management economically sustainable.

Through LCI and LCA, we can create tools to model the options, even if questions will always remain concerning the validity of socio-political parameters and their evaluation in the overall LCI. At least we will have a more comprehensive view on the problem that will help us design a possible solution, that will always have to be a **custom made**, local or regional solution.

He warned us once more for the **danger of isolating systems or technologies that will distort the total picture and shift the problems and advocated the integrated waste management approach**.

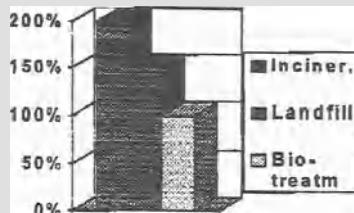
Conclusion

I just want to close this report, by urging all you ladies and gentlemen to do the same. Biological treatment, our technology (including the correct applications of biodegradable materials and products) has so much to offer, that we should not try to pretend it has no limitations

We most certainly have an economical, ecological and socio-psychological advantage over the other waste-treatment options, so why avoid the challenge to situate our technologies in an overall sustainable integrated waste-management system.

Cost-relation Waste-treatment

- ◆ Taking into consideration a similar environmental impact
- ◆ landfill
- ◆ incineration with energy recovery
- ◆ biological treatment



relate as shown here

Lets sit together with the representatives of the other resource-recovery technologies, and discover where we are complementary, where competitive, to ensure an overall better result and the recovery of valuable resources and energy.

ORCA Compostability Criteria: A Framework for the Evaluation of Feedstock for Source-Separated Composting and Biogasification

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Session: 'Composting as an Integrated System of Waste Management'.

Abstract

Source-separated biowaste composting and biogasification are receiving growing interest as waste recovery technologies because they have significant potential to contribute to waste diversion from landfills while producing valuable end-products such as biogas and/or soil improver with fertilizer value (compost). Organic waste constitutes between 20 and 70% of the municipal solid waste (MSW) stream in EU countries. Vegetable, fruit and garden wastes (VFG) are commonly accepted for composting, but only account for about 3/4 of total organics in the MSW stream. Organic waste other than VFG primarily constitutes paper based products and could include 'biopolymer' waste components in the future as well. Therefore, inclusion of all organic waste fractions into the biowaste definition could further enhance the role of composting and biogasification within integrated waste management systems.

Currently, no technically-based and broadly accepted set of guidelines are available to select paper or other organic waste products for composting or biogasification. To assess the acceptability of waste products for source-separated composting, the Organic Reclamation and Composting Association (ORCA) set out to develop a comprehensive framework of criteria and testing strategy guidelines.

Four criteria were identified as being essential to construct a consistent and adequate framework for the purpose of biowaste definition. The ORCA Compostability Criteria focus on 1) environmental safety, 2) compost quality, 3) plant compatibility and 4) landfill diversion. Testing strategy guidelines were developed for each criterion based on a tiered approach, ranging from lab-scale to full-scale or field testing. These criteria and testing strategy guidelines are intended to assist waste management authorities in searching for an optimised balance between 1) maximising the diversion of organic material from landfills, 2)

minimising the overall solid waste management costs and 3) producing a high-quality, marketable end-product.

Introduction

Modern integrated waste management (IWM) include four major interrelated avenues for waste handling ranging from material recycling, biological and thermal treatment to landfilling (Figure 1). Because of legislative, environmental, and practical considerations, the direct landfilling of waste in EU countries will increasingly be phased out and landfill practice will be used only in integration with biological and thermal treatment methods as final depository for sorting residues, nuisance materials or incinerator ashes. Therefore, material recycling, as well as biological and thermal treatment are starting to play an increasingly important role in European solid waste management practices as direct landfilling of waste is phased out and landfill capacity is decreasing.

Maximising landfill diversion and optimising the role of the other IWM elements requires two essential strategies: 1) optimizing the handling and processing of the various fractions of the solid waste stream according to their unique characteristics at minimum environmental and financial cost and 2) setting up appropriate and effective sorting and collection systems for these fractions either at the household level or at a central facility. In this context, source-separated biowaste composting and biogasification take on a unique position because these technologies can handle a relatively large fraction of MSW at competitive cost while producing a high-quality, marketable endproduct.

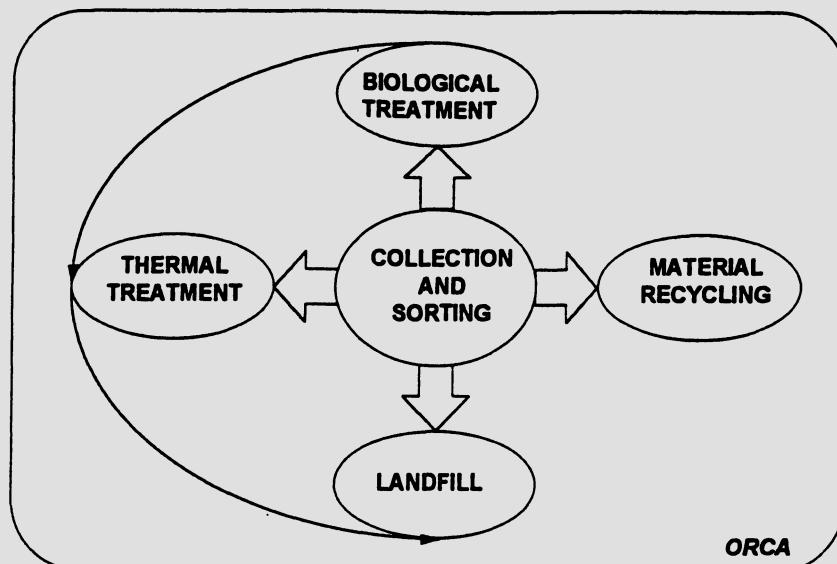


Figure 1 Biological treatment (composting and biogasification) in integrated solid waste management.

Organic waste typically constitutes between 20 and 70% of the municipal solid waste stream in EU countries [1,2]. The weighted average composition of MSW in EU countries indicates that nearly 40% of MSW consists of food and garden waste (Figure 2). It is this so-called vegetable, fruit and garden waste (VFG) fraction that is commonly accepted for state-of-the-art source-separated biowaste composting and biogasification and its separate collection is increasingly embedded as a mandatory requirement in waste laws of European countries. Nevertheless, the VFG fraction only accounts for about 70-80% of the total organic fraction in the MSW stream. Organic waste other than VFG primarily consists of paper-based products and packaging which are part of the 'paper/board' fraction as well as the 'rest' fraction. It also could increasingly include 'biopolymer'-based waste components in the future.

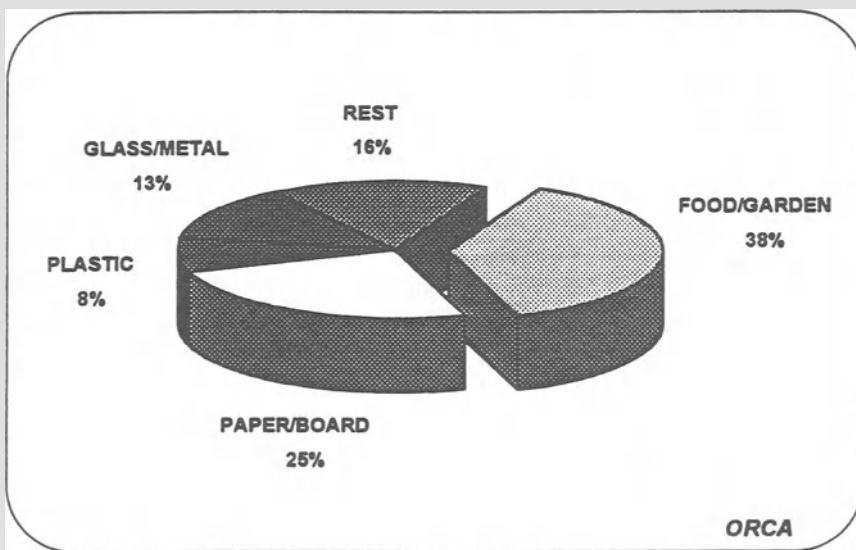


Figure 2 Weighted average composition of MSW in EU countries (calculated from ref. [1]).

Most of the 'paper/cardboard' fraction should not be considered for composting because of an existing and still growing infrastructure for material recycling. Nevertheless, a significant part of it is often soiled with moisture and food residues and therefore not necessarily fit for cost-effective and high-quality material recycling. This non-recyclable paper fraction, accounting for about 5-10% of the waste stream, has been proven to be a suitable feedstock for composting and biogasification. In fact, its value and benefits for the composting process and quality are increasingly well-supported [e.g., 3,4,5]. In addition, there are a number of paper-based products in the 'rest' fraction, such as tissues, towels and hygiene paper products, accounting for about 1-5% of the waste fraction. These products are largely organic in nature and therefore not a-priori incompatible with composting/biogasification. Finally, we may see an increasing number of

biopolymer-based products on the market in the future, formulated specifically with composting and biogasification as disposal options in mind. Considering these additional fractions as potential feedstock components would therefore enable waste authorities to divert an additional 5-15% of the MSW stream from landfilling through composting and biogasification technologies (Table 1).

FRACTION	VFG FEEDSTOCK	TOTAL POTENTIAL FEEDSTOCK
FOOD/GARDEN	38%	38%
NON-RECYCLABLE PAPER (paper fraction)	—	5-10%
NON-RECYCLABLE PAPER AND OTHER ORGANICS (rest fraction)	—	1-5%
35-40%		45-55%
ORCA		

Table 1 Potential waste fractions for composting/biogasification feedstock.

As a bottomline for these introductory remarks, it can be conclude that, in defining biowaste, it may be worthwhile as a general rule to search for a balance between 1) maximising the diversion of organic material from landfills by taking into account the intrinsic and unique characteristics of waste fractions other than food and garden waste, 2) minimising overall solid waste management costs and 3) producing a high-quality, marketable endproduct.

However, with the recognition of a potential growing role of composting/biogasification within IWM systems also comes a need. The need to answer the question: which criteria should be adopted to assess the acceptability of waste products other than food and garden waste? To address this need, ORCA's Technical Committee set out to develop a basic set of criteria and testing strategy guidelines.

ORCA Compostability criteria

Four sets of criteria and assessment requirements are proposed for evaluating the acceptability of waste products for biowaste recovery (Figure 3) [6].

The *first* and foremost criterion requires that the environmental safety of the waste product be demonstrated in the context of composting/biogasification. This means that the waste product should not adversely affect 1) biological activities

during composting/biogasification, 2) biota in compost-amended environments, and 3) the physical and chemical properties of compost-amended soil [7]. This criterion requires both detailed fate data (in particular in relation to biodegradability) as well as effect data at anticipated short- and longterm exposure levels. *Secondly*, addition of a waste product to the feedstock for composting/biogasification should not adversely affect the quality of the compost produced as specified by different national or international compost quality standards and parameters or local market-driven demands [8]. *Thirdly*, processing of a waste product must be compatible with the physical operations in a composting facility or newly planned

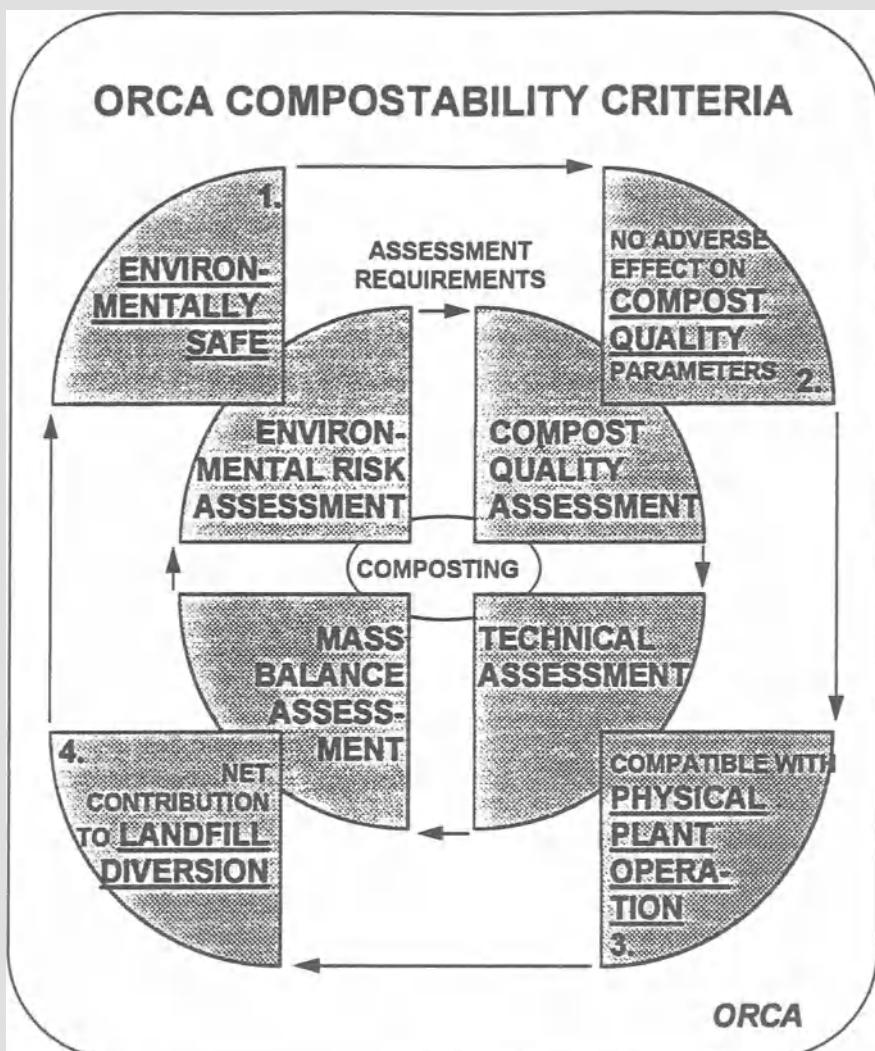


Figure 3 ORCA Compostability Criteria overview.

operations should take into account technical requirements of the envisaged feedstock. This criterion ensures that addition of a waste product to the feedstock does not adversely affect the operational procedures or maintenance needs of the composting/biogasification facility. *Finally*, inclusion of a waste product in the biowaste definition must result in a positive contribution to waste diversion from landfill at an overall cost locally justifiable versus alternative waste management options.

Taken together, this loop of criteria is thought to form a consistent and adequate framework within which one can start to assess the acceptability of waste products for biowaste recovery. However, in order to actually evaluate a waste product against these criteria, criteria-specific assessment requirements are needed.

Putting the ORCA criteria to use

The evaluation of a waste product for composting is based on criteria-specific assessments (Figure 1). The overall outcome of the assessment procedures must take into account accumulative weight of evidence that a waste product complies with the ORCA criteria, rather than it meeting a number of simplistic pass/fail limits.

For the assessment of the above criteria, it is recommended to adopt an overall testing strategy which includes both laboratory and pilot/full-scale investigations with field studies (Tables 2-5). In test execution it is recommended to follow standardised tests (OECD, ASTM, CEN, DIN, etc.) if available, but allowance should be made to complement such tests with customised test designs, if needed. The *laboratory-scale testing* should be aimed primarily at developing basic, high-quality data for a given waste product and/or its material components with respects to 1) fate, including biodegradability, 2) toxicity to biota in compost and compost-amended soil matrices, 3) physical disintegration, and 4) effects on regulated compost quality parameters. The *pilot/full-scale investigations* should be aimed at confirming data generated at the laboratory-scale. In addition, such tests should evaluate the practical processibility under larger scale operating conditions by assessing the impact of the addition of a given waste product to the feedstock on key process parameters (both biological and mechanical). Finally, the pilot/full-scale investigation should produce a compost sample which can be used in field phyto-toxicity testing. In the following, the assessment guidelines for each criterion are discussed in further detail.

Environmental Safety Criterion

Environmental safety in the context of composting/biogasification means that materials or waste products should not adversely affect the environment in which they are handled, processed and ultimately applied, i.e. during waste collection or sorting, compost processing and final compost application to soil. Specifically,

this means that the waste product should not adversely affect 1) worker's safety and health at a facility, 2) biological activities during the active composting or biogasification stage, and 3) biota and physico/chemical properties of compost-amended environments.

To assess this criterion a tiered testing strategy is needed to generate, on the one hand, detailed fate data, in particular in relation to the biodegradation of the product materials, and on the other hand effect data for representative target organisms at estimated exposure levels. Biodegradability should of course form a focal point in this assessment, because it is generally expected to be the primary fate mechanism for those waste product materials which will enter the final compost. On the other hand, it must be understood that biodegradability does not, in and of itself, provide full-proof reassurance for environmental safety. Mostly, it reduces the time of maximum exposure and minimizes the potential for accumulation. So, biodegradability must be assessed as a fate mechanism in this broader context of environmental safety considerations.

The type of questions to be addressed in an environmental safety assessment for this purpose are summarized in Figure 4. *Fate assessment* requires developing an understanding of what ultimately happens to a substance when it is released into the environment and predicting the concentration in relevant environmental compartments [9]. In the context of waste product evaluation for composting, it means the following questions must be addressed (Figure 4):

- What is the predicted environmental concentration (PEC) of the waste product in the feedstock, i.e. at the point of entry of the composting facility?
- Does the product physically disintegrate and does it become part of the final compost? Or are certain waste product components removed during pre-treatment?
- For those product materials entering the final compost: does biodegradation occur and to what extent?

Once compost is applied to soil, an additional set of questions have to be answered (Figure 4):

- Does continued biodegradation occur and at what rate is the biodegradation completed?
- Are persistent intermediates or residues formed?
- What is the predicted environmental concentration (PEC) of waste product materials and compounds under conditions of repeated compost applications?

The effect assessment, on the other hand, requires developing an understanding of the impact of the waste product or materials on selected representative organisms and environmental parameters at the predicted environmental concentration [9]. For the purpose of environmental safety assessment in the context of composting/biogasification, it means one needs to evaluate effects in a composting facility on 1) worker's health during collection and handling and 2) the health of the microbial community in the active composting stage (Figure 4). With regard to

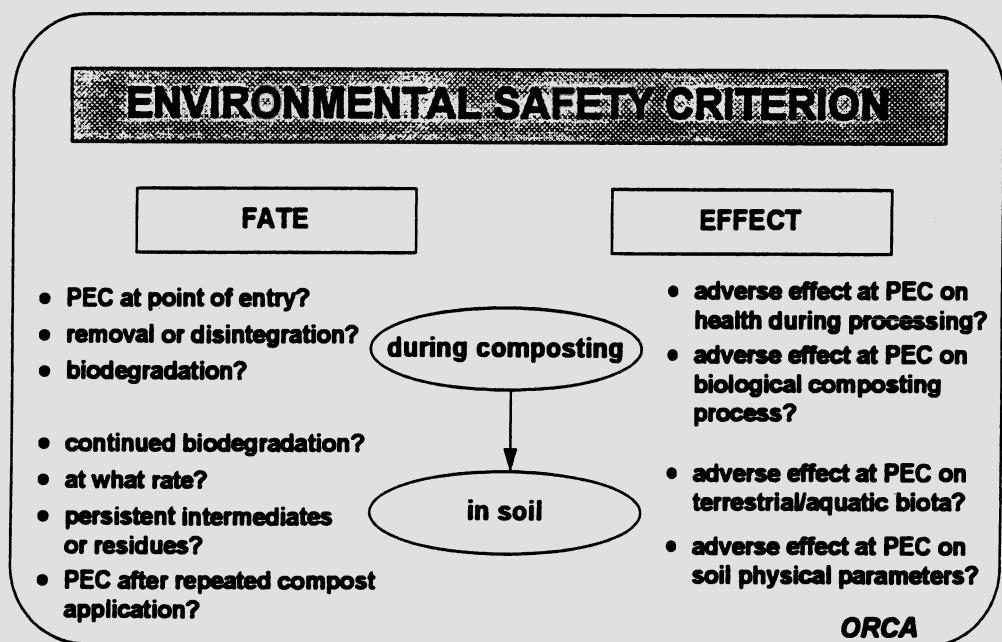


Figure 4 Key aspects of environmental safety assessment of waste product materials in context of composting/biogasification.

the soil environment, it requires measuring effects and on representative terrestrial and possibly aquatic biota as well as impacts on basic soil physical parameters (Figure 4).

The data sources and testing levels required for this purpose will range from relatively simple to more sophisticated: from simply gathering literature data to more elaborate and cost-intensive full-scale facility and field trials (Table 2).

At the very initial level, data gathering will be limited to 1) company data on maximum predicted market volumes and product composition, and 2) available literature data on toxicity and biodegradation for the product materials or ingredients (Table 2). These data can then be used to quantify initial estimated exposure levels for the waste product or materials in the feedstock and the compost-amended soil.

As a second tier, laboratory testing will virtually always be needed and involve both screening and confirmatory testing, in particular for documenting biodegradability as the primary fate mechanisms (Table 2). At the screening level, one needs to understand 1) the degree of physical/chemical disintegration of the product materials under simulated composting conditions (as measured for example by weight loss and loss of tensile strength), and 2) the inherent biodegradability of the waste product materials, i.e., whether a material can be ultimately biodegraded under a certain set of conditions (as measured by simple in-vitro batch respirometric methods such as Sturm and OECD inherent biodegradability type tests using powdered samples in aqueous medium). Confirmation of these screening

data requires additional respirometric methods which use solid matrices and are designed to simulate composting, biogasification or soil conditions. At this confirmatory stage we are interested to answer the question whether the material is practically biodegraded in the compost and terrestrial habitats in which it is discarded and whether the rate of degradation is similar to the projected rate of loading. One example of a useful tool in such an approach is the ASTM D5338 test. Occasionally, confirmation will require the use of isotopically labeled materials to conclusively document the mineralization of the material to CO₂ or CH₄, or as assimilation of decomposition residues into microbial biomass or stable humus substances. Finally, confirmatory testing at the lab-scale requires an effect assessment and quantification of terrestrial and possibly aquatic toxicity.

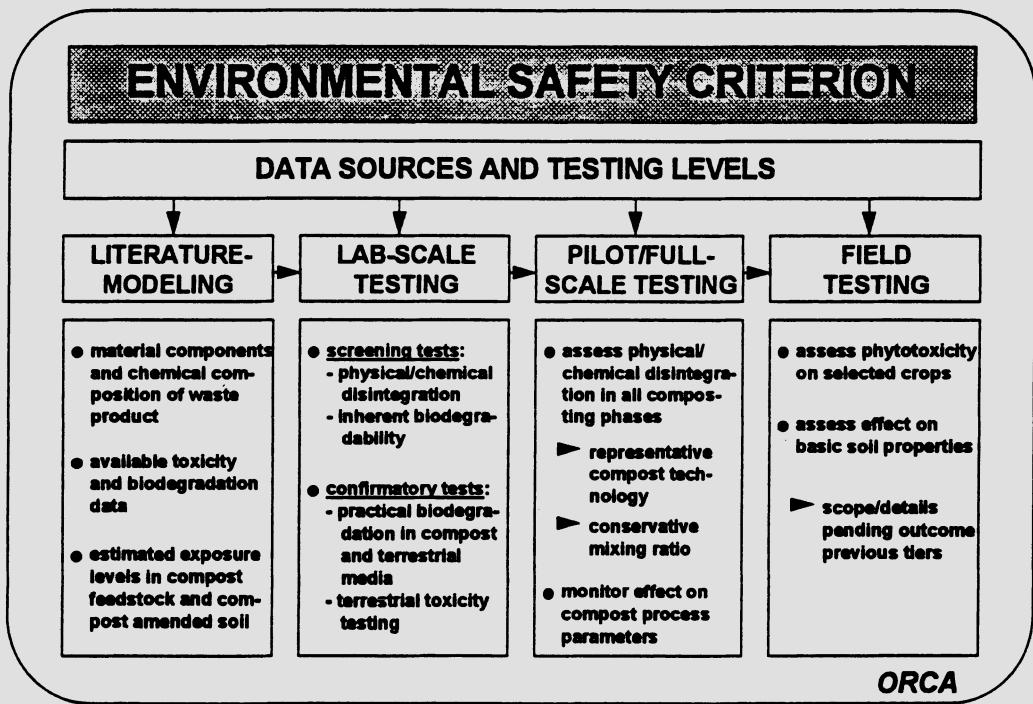


Table 2 Data sources and testing levels for ORCA Environmental Safety Criterion assessment.

Because of the wide diversity in compost technologies, pilot- or full-scale trials using technologies representative for the geography of interest are needed (Table 2). They are essentially needed to confirm that physical/chemical disintegration indeed occurs as the waste product moves through the successive composting phases and to ascertain that the waste product becomes an indistinguishable part of the finished compost under practical operation conditions. A second objective in this higher tier testing level is to assess the effect on the microbial community in the active composting stage, as measured indirectly by unusual variability in process parameters such as temperature, pH, and oxygen uptake or CO₂

evolution. In some cases, where high exposure levels in compost feedstock are expected and lab-scale toxicity testing is not conclusive, some form of field testing will be required, involving, for example, phytotoxicity trials on selected crops. An excellent overview of biodegradability testing methods for synthetic materials in the context of composting/biogasification is provided in reference [10].

Compost Quality Criterion

The compost quality criterion stipulates that including a waste product in the feedstock definition should not adversely affect regulated compost quality parameters nor the marketability of the compost. The lack of consistent and uniform compost quality regulations across Europe will require to take into account local or national regulations or guidelines according to the area of interest for the feedstock definition.

The testing strategy will again involve a range of tiers and can be done in conjunction with the environmental safety test set-ups by adding the quantification of effects on applicable compost standards as an additional endpoint. Separate field testing for certain waste product categories may however be required because changing sorting and selection rules at the household level may adversely affect nuisance levels, and therefore possibly compost quality. Therefore, field testing in this context requires co-collection trials which can also provide the input feedstock for pilot or full-scale testing in the context of other criteria assessments.

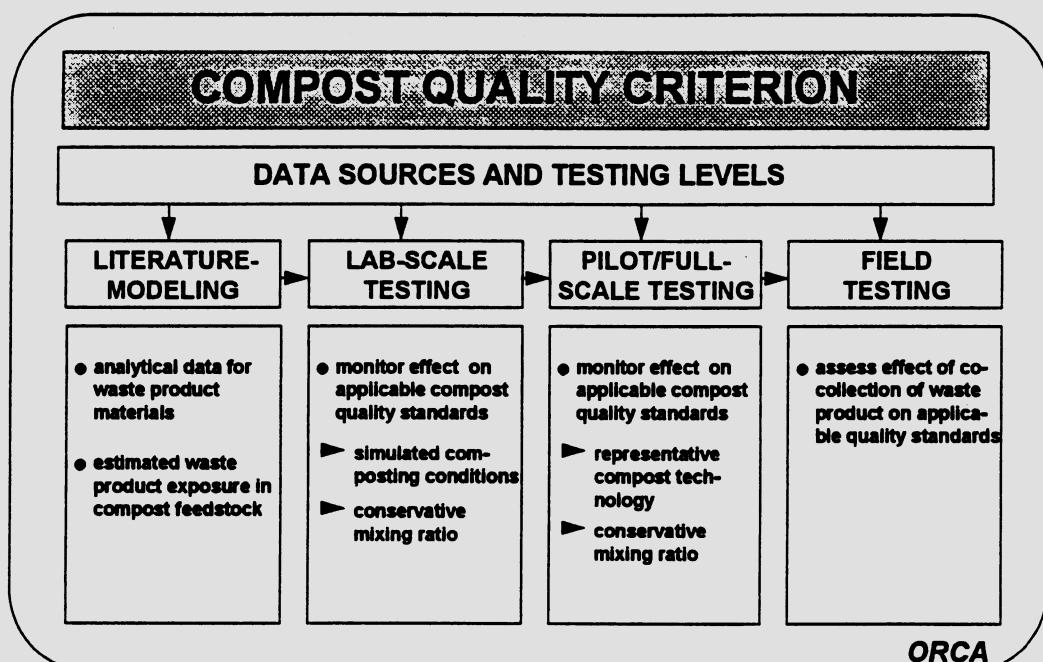


Table 3 Data sources and testing levels for ORCA Compost Quality Criterion assessment.

Plant Compatibility Criterion

Waste products will often differ significantly in their physical form, composition and morphology from vegetable fruit and garden type waste. This will certainly affect their compatibility with the physical operation of composting or biogasification facilities and requires an assessment of the impacts on the sustainability of facility operations and maintenance needs.

From a testing point of view, only a very limited understanding can be achieved on these questions at the laboratory scale. For example, laboratory-scale screening tests could include the assessment of the physical/chemical degradation of the waste product in terms of weight loss, particle size, loss of integrity and changes in tensile strength. However, such tests typically do not provide conclusive and reliable results because the complexity of physical plant operation is not adequately taken into account.

Realistically speaking, one will have to review the technologies in the geography of interest, select representative pilot or full-scale models for the key process phases (pretreatment, active composting, and refining), and monitor or quantify the effect on typical operational and maintenance parameters, ranging from water and energy requirements to possible downtime of machinery. This type of testing will be of high importance for more complex waste products or waste products which differ significantly in their physical form and size from regular VFG waste.

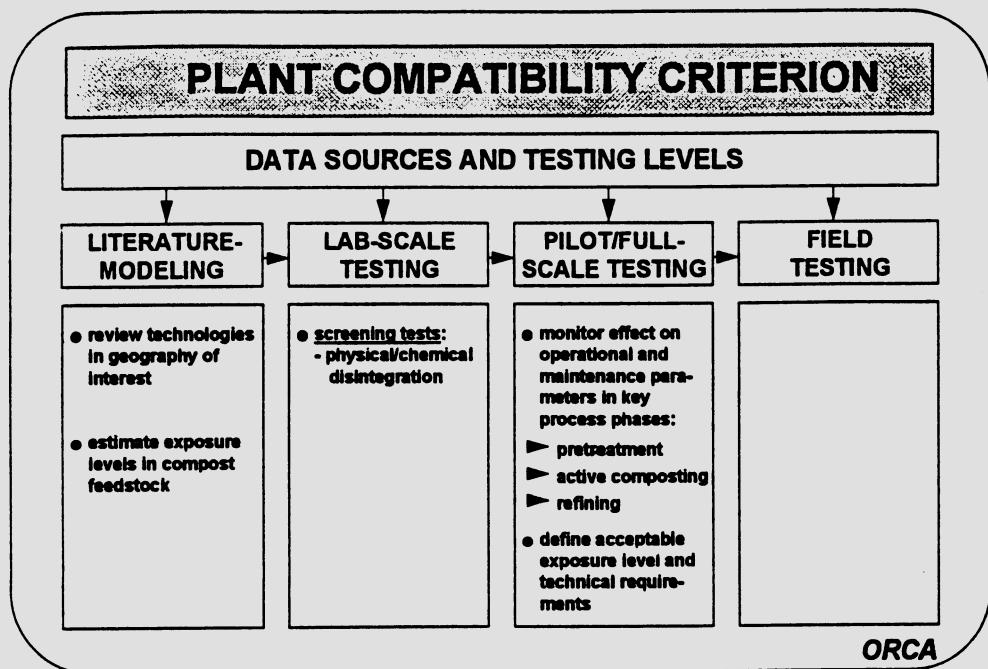


Table 4 Data sources and testing levels for ORCA Plant Compatibility Criterion assessment.

Landfill Diversion Criterion

Finally, it must be ascertained that adding the waste product to the feedstock contributes to an overall improved landfill diversion rate. While such a requirement may appear odd at first glance, it is certainly very relevant when one considers that a waste product may never enter the final compost because it is screened off during pretreatment due its physical form or size, or because a waste product either contains or induces during collection an excessive amount of nuisance material which has to be removed. Since experience teaches that each percent of nuisance material causes about an equal amount of compost to be lost, assessing the overall landfill diversion rate is an important and very relevant requirement.

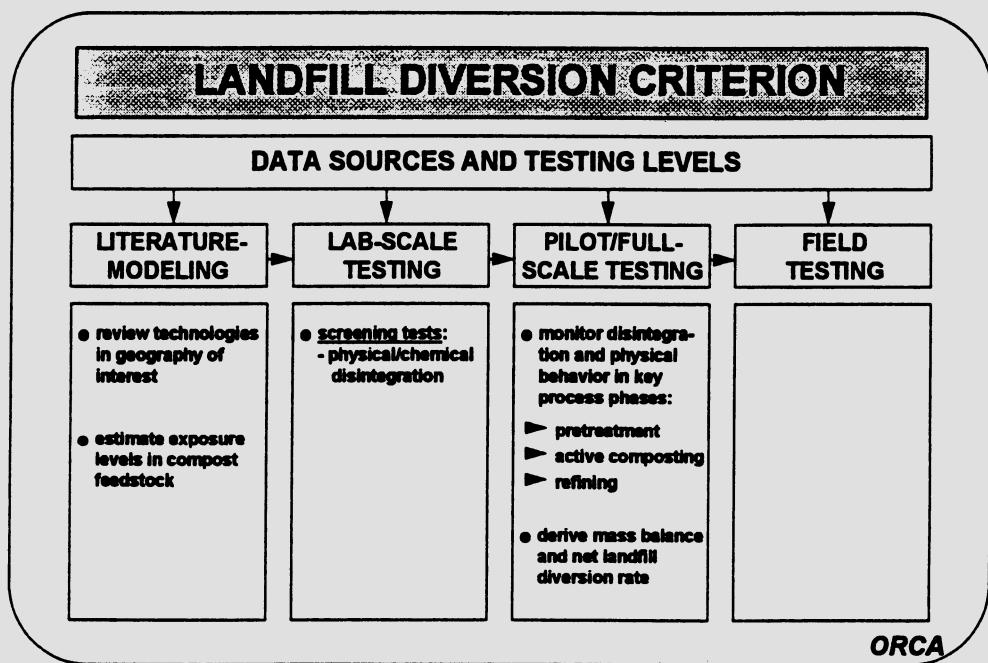


Table 5 Data sources and testing levels for ORCA Landfill Diversion Criterion assessment.

From a testing point of view, reliable mass balance data must be acquired, primarily at the pilot or full-scale testing level using representative technology models for each of the key process phases. Such data can certainly be acquired in conjunction with pilot or full-scale testing for the other criteria assessments. An important piece of the puzzle in this context also can be derived by examining the nuisance level in feedstock material from co-collection field trials conducted in the context of the compost quality criterion.

Summary

When defining biowaste feedstock for composting, one must generally search for a balance between maximising the diversion of organic material from landfills, minimising overall solid waste management costs and producing a marketable compost. In this context it may be desirable to expand the VFG biowaste feedstock to include paper and biopolymer-based waste components. The criteria and testing strategies described here are intended to provide a broad conceptual framework on key factors to assess for the composting/biogasification feedstock definition.

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