Chapter 1

LEADING CONCEPTS TOWARDS VITAL SOIL

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Abstract

This introductory chapter gives an analysis of the basic elements of a vital soil, of soil protection policies and monitoring options. The background to this approach is the increase in soil functions and an overexploitation that has resulted in conflicts as well as in concern for the consequences for human health, the health of soil, and soil sustainability. These functions and their complexity are described in some detail to show the complex nature of the soil scientist's task (Chapter 2-10), assess the state of the art and assess monitoring options. Soil ecology started from phenomenology, describing the phenomena observed in the field, with a strong emphasis on the dynamics of single species. Now it is gradually entering a phase of understanding and elaboration: research based on the formulation of hypothesis. Major research items are derived from the observation of fluctuations in numbers and activities in space and time. In soil vitality, stability and the restoration of a solid state of functional diversity is of critical importance. It is important to know how many years it may take before the restoration of certain processes, functions or desired ecosystems will be completed. Vegetation may require hundreds of years and similar time frames may also be necessary for soil microflora and soil invertebrates. However, in the case of larger animals or top-predators it may take longer.

Of the threats to soil that have been recognized worldwide like erosion, contamination, decline of organic matter, sealing, compaction, salinization, flooding and landslides, and loss of biodiversity, the impact of soil contamination is discussed extensively. Furthermore, we also deal briefly with current political thinking on soil protection. The consideration of soil protection proceeds from the principle of multi-functionality in which the maintenance of each potential function must be secured for the benefit of future generations. This has meant a more tailor-made approach that is related to a realistic use of the potential of a specific soil at defined sites set in the perspective of high costs and the impacts of the remediation actions. In the European Soil Strategy currently being developed, the prime aim is to adjust existing policies that have a side effect on soil to a common strategy towards soil protection.

Soil in all its diversity of structure and processes demands an integrated approach to both monitoring and research. Soil combines abiotic and biotic processes in a static, dynamic and structural way. Monitoring and studying biodiversity from a functional perspective is a major item.

1.1 Vital soil for a vital world

1.1.1 Soil is the solid basis of life

Soil is the solid basis of the world and society. Vital soil is essential for a vital world. Soil provides the basis for houses, roads and industries, enables crop to be grown and food to be produced, as well as harbouring groundwater supplies, producing and recycling organic material, and storing and recycling organic waste.

These different types of functions have all too easily become combined. By steadily putting higher demands on each function, problems have been created that threaten sustainability. Hence, choices have to be made concerning the combination of functions that fit best in specific circumstances. What is appropriate for sites that have been impaired by increased levels of nutrients and what should happen to sites that should have been preserved better because of their pristine character.

For centuries we have effectively used the multiple benefits derived from primary production, to produce plants, food and fodder. More recently, secondary production has continued to develop with new technologies to recycling the elements and purify soil and groundwater.

What happens when one of the soil's natural functions becomes heavily exploited? If a support function becomes maximized because the soil surface has been sealed with bricks or concrete, other functions will be hampered. Soil life under these sealed soils will be reduced because of reduced moisture content and so the capacity to clean rapidly disappears. However, local people are convinced that rainwater will be re-routed to other non-sealed areas, where incoming rainwater will increase and with all probability, surpass the natural infiltration capacity of the soil. The result may well be torrential surface flows that can lead to landslides and soil erosion. Bulldozing soils, deep-ploughing and topping up soils with sandy layers to improve the support-functions can also destroy soils natural structure and lead to all kinds of erosion.

In agriculture, the nutrient supply has been maximized through the application of animal manure and chemical fertilizers to such an extent that groundwater locally has become overloaded with nutrients. In a number of European countries, for example, this has resulted in groundwater with nitrate levels that fail to meet the requirements set for health, and to surface water with increased nutrient levels. Monocultures and lack of crop rotation result in heavy pesticide use to ensure crops are protected. Incidental overdosing can result in elevated pesticide contents in ground and surface water.

To make a potentially long story short, combining soil functions or piling them up in the same area with the result that they are over-exploiting, together with accidental spills and illegal dumpings has lead to a growing concern about human and soil health. As a result legislation has been put in place to deal with these new developments. As far as soil health is concerned law should be developed on criteria based on natural functioning.

When soils are treated in a proper way and their characteristics used optimally, they can be developed sustainably. This does not imply that all functions have to proceed at the same speed everywhere, but it does mean that all functions remain possible at all places, the so called multi-functionality of soil.

Bearing all these aspects in mind, measuring and monitoring soil quality must include the physical and chemical processes involved in the formation of the abiotic part of the soil, and the biotic processes, carried out by multiple life forms in their natural habitat. These include mutual interactions over soil issues that challenge soil scientists' knowledge, experience and understanding and suggest that soil properties should be seen as key items in soil sustainability. So practice and policy obtain monitoring tools for protection. The aim of this book is to contribute to soil policy and practice but in the context of the knowledge generated by the scientific world tentatively and schematically illustrated in Figure 1.

This introductory chapter gives a historical analysis of the basic elements of a vital soil, and the elements of soil protection policy. A basic view is given as an introduction to the more detailed views of soil scientists. Among the threats to soil recognised in Europe such as erosion, contamination, decline of organic matter, sealing, compaction, salinization, flooding and landslides and the loss of

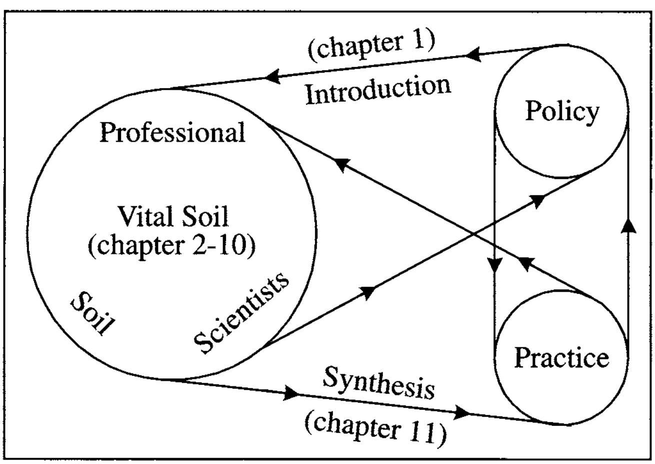


Figure 1. *The view of professional soil scientists spinning off to policy and practice*

biodiversity, special attention is given to biodiversity, organic matter and soil contamination. Basic monitoring aspects will then be referred to and discussed. In this way I hope to pave the way for the specialist in the arts of vital soil.

1.1.2 Historical awareness of vital soil

Scientific awareness

Soil science is the study and description of the processes in which geological bedrock material is transformed into a layered mixture of inorganic (mineral) and organic compounds. It describes the physical character of this mixture in relation to gas and water management. It also describes its nutritive value for agriculture, its supportive power for constructions (buildings, dikes and tunnels) and its filtering capacity for drinking water. We have also been using our soils as sink and, implicitly, as clean-up facilities. This reflects the present situation in which mankind has been using, managing and adapting soils for its own wealth and well-being. Consequently, a system has to be developed and applied that measures the qualities of our soils in terms of their present use value, bearing in mind their potential uses and our commitment to using our soils in a sustainable way. This system should also include the methods by which we measure these qualities and, implicitly the impacts on these qualities. This thinking and approach can be observed in the development of soil policy.

Policy awareness

Soil protection policy started in the 1970s, considerable later than water and air protection policy. These actions were triggered by the desire to protect the multiple functions of soil, and were speeded up by a number of soil contamination incidents in different parts of the world. These incidents differ in character and consequently resulted in different policy accents. Compare for instance the Superfund-problems in the United States with the brown fields in the United Kingdom, the industrial hotspots in Germany and the problem of diffuse over-fertilization and acidification of soils in the Netherlands. Major elements in soil protection have been:

- impacts on human health, translated to uptake of contaminants in food crops and in drinking water;
- impacts on dispersal of contaminants, especially in relation to groundwater, but also in relation to evaporation from soils under buildings;
- impacts on soil ecosystem, measured by ecotoxicological effects on soil biota and bioaccumulation in terrestrial food chains.

Of these three elements the impacts on the soil ecosystem have been given the least attention. In many countries extensive research programmes on ecotoxicological impacts have been carried out on the effects of hazardous concentrations (HC5 or HC50 methods). However, there has been considerable debate about the application of the statistically derived HC5-method, the use of reference levels, and ways of assessing the impacts of natural elements like heavy metals.

Another fierce debate has been about the protection of the multiple functions of the soil. Should all potential functions be maintained so that an affected soil be allowed to recover its natural status, or should a present function be standardized and recovery levels set accordingly?

Presently soil policies are moving towards a functional approach, translated into soil use standards for various types of land use. In the EU, policies on the maintenance of soil quality and soil remediation are merging into the new EU Soil Strategy (EU Commission, 2002). According to this strategy, remediation based decision support programmes like Clarinet and Caracas will lead to Risk Based Land Management. As a consequence it can be foreseen that the EU Water Directive will get a complementary EU Soil Directive. Table 1 shows historical landmarks in soil protection policy in European countries.

1.1.3 Reconstruction of soils

As a result of natural soil forming processes, soils have evolved into specific layered profiles, depending on the original mineral bedrock material, local environmental conditions and related soil life. Tillage and reclamation have changed this very considerably for instance when sometimes the ground is

Table 1. *Examples of historical landmarks in soil protection policy in Europe*

Council of Europe	1972	European Soil Charter
Denmark	1990	Act on Waste Deposits (revision older Act)
	1992	Environmental Protection Act (update)
Germany	1985	Federal Soil Protection Act
	1989	Contaminated Land inventory
Norway	1955	Land Act (general soil protection)
	1988	Plan of Action of Contaminated Sites
The Netherlands	1971	Draft Act on Soil Protection
	1983	Soil Clean-up Guidelines
	1987	Soil Protection Act
United Kingdom	1971	Town and Country Planning Act
	1974	Control of Pollution Act
	1990	Environmental Planning Act

ploughed very deeply. Materials are consistently being added to the soil to maintain or improve its nutritive or supportive values, such as organic rich top soils, manure in various forms, town waste refuse and the large-scale addition of mine waste.

So, next to a variety of natural soil types, there are various kinds of anthropogenic soils, which may even result in such typical soils as city soils, waste dump soils, and copper-loaded vineyard soils. These soils have been used as constructs rather than the natural system they are in essence.

1.2 Basic scientific assumptions and the underpinning role of soil scientists

1.2.1 Basic assumptions

When the protection of soils and the maintenance of their qualities in view of sustainable development is the basic aim of policy and management, soil structures and processes have to be sustainable. Research must therefore focus on providing the knowledge required to answer basic questions such as what aspects have to be protected and conserved; to what extent are disturbances allowed; what kind of timeframe has to be used when defining reversible impacts (when is it irreversible), what is effective resilience and recovery; has the observed structural diversity (the richness in species called biodiversity as well as the heterogeneity of various soil types) a role in robustness, resilience and recovery; and how will all these 'conserving' activities be interpreted in the perspective of natural adaptation and restoration.

1.2.2 Vitality as combination of internal structure and resistance to external impacts

Using vitality of soils as a base, the first question is how to characterise vitality. The best description is: "vitality is the long-term ability to maintain a proper functioning of the soil system through a diversity of processes and organisms that carry out these processes". Maintenance includes robustness, flexibility and resilience to overcome adverse impacts and events. Essential is the ability to recover and regain the composition and functioning of the soil system. Therefore, vitality is a combination of different elements: Vitality = Robustness, Resilience, Recovery + (structural & functional) Richness, or in short: V = 4 x R.

1.2.3 Resilience, Robustness and Recovery

Resilience, robustness and recovery can be characterized as the features of ecosystems that show how they react to disturbances and the extent to which they return to normal after a limited period. Disturbances in the form of fluctuations in numbers or activities of organisms have been described in different ways. Orians (1974) distinguished five types of stability: constancy, amplitude, persistence, inertia and elasticity. These can be expressed for instance as different reaction patterns in time under undisturbed or disturbed conditions (Eijsackers; 1983) (Figure 2). Without an external impact, systems can either fluctuate marginally (Constancy) or continue to fluctuate to some extent. Moreover, systems can fluctuate with large or small amplitudes (Amplitude). For each type the most stable situation is indicated with "+s", the less stable with "-s". With an external impact the system can hardly be changed (Inert, also called Robust) or the system can come back to its original equilibrium condition after a longer or shorter period (Elasticity, also called Resilience). The system can persist or die out. It can also reach a new equilibrium level after a disturbance (not in this picture). Typical robust systems function naturally under heavy or steady pressure, like riverbanks or coastal zones. Also at the species level there are clear differences in robustness of species. For example, the earthworm species *Lumbricus rubellus* occurs in all kinds of natural and disturbed systems and has a low sensitivity to contaminants (Eijsackers, 1996).

For the assessment of disturbance, quantitative elements are relevant, such as how long does it take in time to come back from an extreme (= maximum or

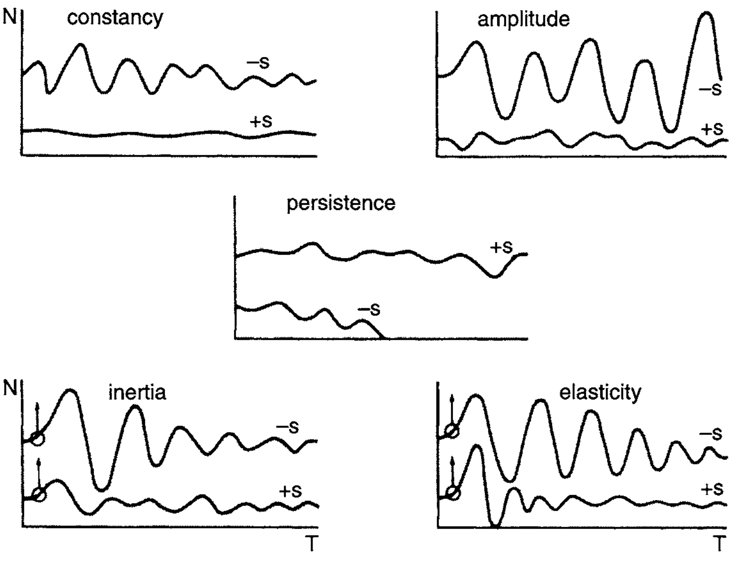


Figure 2. *Types of stability expressed as fluctuation pattern of a certain number or activity (N) over time in undisturbed or disturbed conditions (a vertical arrow), either in a low stable (-s) or a high stable (+s) system (Eijsackers, 1983).*

minimum) situation to a more or less normal (= medium) situation, to what extent can the system be brought out of its original situation by an extreme event (height of the amplitude of fluctuation) yet still be able to return to the normal situation, what characteristics govern the recovery of an area.

Many attempts to quantify those questions can be found in old (before 1987) and recent literature. An elegant exercise comes from Domsch et al. (1983), who used reproduction rates expressed in generation time to quantify the recovery of soil bacteria. Generation time expresses the general rate of metabolism and hence the rates of all kinds of restorative processes.

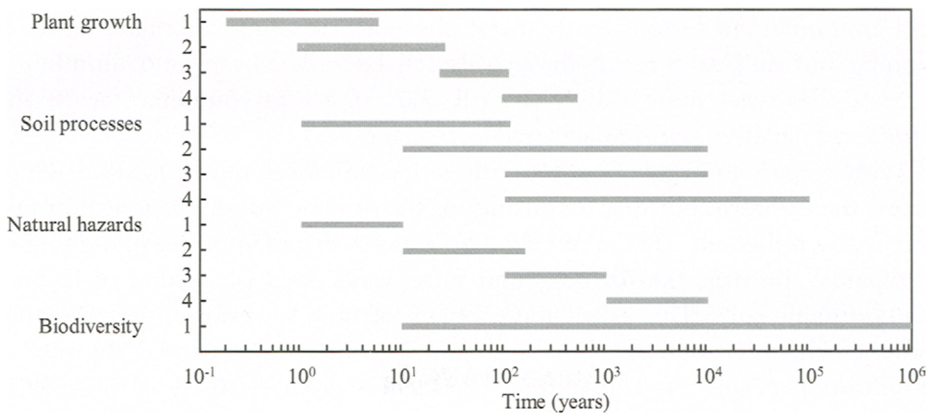
To investigate the relation between amplitude and the duration of fluctuations, Domsch et al. (1983) studied fluctuations in soil bacteria numbers under a variety of situations including natural adverse conditions such as flooding. Results showed that fluctuations in general comprise a reduction of 90%. Hence, natural fluctuations up to one order of magnitude can potentially return to normal. Vegter (1988), Eijsackers et al. (1988) and Van Straalen and Van Rijn (1998) observed similar fluctuations in groups of soil-fauna.

A simpler approach is to look at the seasonal fluctuations for soil organisms. Earthworms will take one season to recover from low numbers caused by summer dryness or winter cold (van Rhee, 1973). Jones and Hart (1998) concluded that earthworms are capable of recovering completely from a reduction percentage of over 90% caused by non-persistent chemicals (half-life < 50 days) within one year. With persistent pesticides (half-life > 50 days) only limited recovery was evident after one year.

Another element in measuring natural recovery is the spatial re-invasion of a depleted area. Soil animals are mobile, and are able to move around in a directed way. Depending on their size and charge and on the moisture content of the soil, soil bacteria can be passively transported in groundwater (Bengtsson, 1997). Earthworms can crawl over the soil surface for distances of many meters. The lateral dispersal of earthworms in a year is approximately ten meters in soil that had never been inhabited by worms before (Hoogerkamp et al., 1983). Springtails and earthworms make a distinct choice when offered a gradient of increasingly polluted soil (Bengtsson et al., 1994; Eijsackers, 1981). Surface-active soil animals like beetles cover distances of several hundred meters per day. There are many more publications on dispersal rates, colonization and recolonization of soil animals in all kinds of soil systems, all showing the capability of soil biota to disperse and recolonize depleted areas.

1.2.4 Sustainability in relation to time

Fresco and Kroonenberg (1992) have indicated the ranges of various natural development and recovery processes, for soil processes, for biodiversity and natural hazards (Figure 3). It shows that the sustainability of soil forming processes has to be assessed over periods that vary from one year to thousands of years. For most managers in practice and policy these are unimaginable periods of time. When we look at recovery of biodiversity by re-invasion or repopulation ranges become shorter: 1-10 years for microflora and invertebrates and 10-100 years for higher plants and animals. To be practical it could be decided to take a time period of one century. In fact the 'oldest' soil monitoring cases go back to Darwin's studies, "The formation of vegetable mould through the action of worms" (1888), and the long-term fertilization experiments started in Rothamsted in the UK in 1880 (Johnston et al., 1986).



Plant growth:
1. length of one growth cycle of annual crops
2. length of one growth cycle of perennial crops
3. length of growth cycle of production forest
4. average biomass turnover rates of tropical rainforest

Soil processes:
1. time needed for complete erosion of topsoil
2. time needed for severe nutrient depletion by leaching in humid tropics
3. the same for severe nutrients depletion by leaching in the temperate zone
4. time needed for formation of fully developed topsoil

Natural hazards:
1. frequency interval between gentle floods in alluvial areas
2. the same for large disastrous floods
3. frequency interval for andesitic volcanic ash falls
4. the same for destructive volcanic eruptions

Biodiversity:
1. time needed for restoration of microflora, invertebrates, macrofauna and macroflora after major disturbance

Figure 3. *Time needed for sustainable development of various biotic and abiotic processes (modified after Fresco and Kroonenberg, 1992)*

1.2.5 Sustainability, in relation to acidification and organic matter content

A critical look at the management of soil resources leads to the conclusion that soils are 'consumed'. Due to the natural breakdown of bedrock there is a continuous supply of minerals and for a long time this has been seen as an ever-lasting supply. In recent decades, the limitations of that supply have become evident and can be observed in the exhaustion/depletion of three main steering characteristics: the acid buffering system, the maintenance of organic matter levels and the structure and texture (due to soil erosion and compaction) of soils. Since organic matter plays a central role in the structure and functioning of soil ecosystems, this issue will be treated in more detail, to explain its complexity and to underline the fact that knowledge is available. Many data from the research already carried out in the period 1960-80 are valuable for testing new hypotheses.

The acid buffering system mainly consists of three systems: carbonate, silicate and aluminium buffer systems. In particular, in sandy areas with a high acid ammonia and nitrous oxide input, the quick reacting carbonate buffer is running out and as a result these soils fall back to silicate and aluminium systems that react more slowly. It will take longer to counteract acidifying inputs and negative acid-impacts will last longer.

With respect to organic matter, cultivation enhances mineralization which means the chemical burning (oxidising) of the organic humus supplies formed over many millennia. This mineralization process began after the ploughing of grasslands, the irrigation of bogs and mires, and deep ploughing of layered sandy/organic soils. This raises the problem of how to restore organic matter content, when calculations show that mineralization rates exceed the rate of humification (Table 2). The humus production (gain) is 0.1% of the yearly primary production, whereas the percentage yearly humus loss is 1 - 2%. This is 30 and 60% for periods of a few to 60-80 years (Table 2).

Long-term experiments in three agricultural systems with different amounts and types of organic matter input (Figure 4), showed that considerable extra external inputs of 13,500 kg organic manure per hectare (system III) were necessary to maintain the organic matter content of the soil. In Systems I and II there was a slow consistent decrease of 15% over 32 years. The total supply from different sources was 19,000 kg in System I, 34,000 kg in System II and 45,500 kg in System III.

Continuous loss of organic matter without supply from other sources may lead to soil erosion. It is a problem in bare areas where plant cover does not prevent the upper soil from being washed or blown away by wind or water. This occurs in arid zones, but also to a lesser extent in temperate and flat areas.

Table 2. *Gain of soil organic matter due to plant production and humification, and loss due to soil cultivation (Van Veen and Kuikman, 1990; Eijsackers and Zehnder, 1990; Cole et al., 1989)*

Humus production in grassland			
Yearly net primary production		2.8 ton $ha^{-1} y^{-1}$	
0.1% (resistant to mineralization) contributes to organic matter		0.028 ton org. C $ha^{-1} y^{-1}$	gain
Humus loss due to mineralization in a prairie soil 40 years after start of cultivation			
Sandy soil 8-16 ton org. C ha-1		0.2-0.4 ton org. C $ha^{-1} y^{-1}$	loss
Loamy/clay soil 10-26 ton org. C ha-1		0.22-0.65 ton org. C $ha^{-1} y^{-1}$	
Some other examples of org. C loss after cultivation virgin soils			
US Sandy prairie soil after 40 yr. cultivation		42-54%	
US Loamy-clay soil after 40 yr. cultivation		36-54%	
US grassland after 25 yr. cultivation		56%	
US virgin forest soil after 3 yr. cultivation		33%	
Canada grassland after 60 yr. cultivation		50-60%	
Canada grassland after 60-80 yr. cultivation	(0-15 cm)	57%	
Canada grassland after 60-80 yr. cultivation	(40-80 cm)	20%	

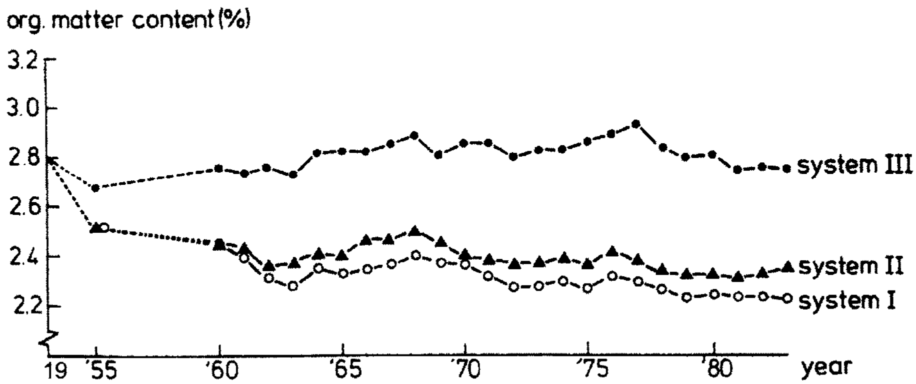


Figure 4. *Soil organic matter content in three crop rotation systems receiving different supplies of fertilization and manuring over the period 1952-1984 (modified after Kooistra, Lebbink and Brussaard, 1989).*

I. mineral fertilisers

II. mineral fertilisers + green manure

III. mineral fertilisers, ley and farmyard manure

Next to the structure lost because of the actual disappearance of the top surface layer, there is a loss of soil texture due to mechanical forces like the trampling of wet clayey soils.

From a perspective of sustainability these general examples show how difficult it is to maintain the main soil systems at their natural levels: the chemical system (pH-buffering), the bio-organic system (the organic matter content) and the physical system (loss of soil structure by erosion). It is difficult to realize improvement in conditions of deterioration. Therefore, an important question in relation to sustainable development is, how the temporal development of soil properties and processes can be defined in such a way that it is not only helpful in general policy and political discussions, but can also provide ways of bringing them under control in management and research.

1.2.6 Diversity in relation to functioning

One of the most intriguing and enigmatic questions in soil life studies has been the relationship between species diversity and soil process functioning (Anderson, 1975). Many studies have shown that soil systems continue to function even with a greatly impoverished soil organism diversity, when only a few species are active. Many scientists have queried whether a large proportion of species was in fact superfluous (redundant). But why then, has such great species diversity, as observed in soil, been developed during evolution? There are several explanations, such as the enormous horizontal and vertical spatial heterogeneity and huge variety in habitat scale and environmental conditions. This variety, combined with some general ecological feeding strategies - saprophages (consuming dead organic matter), phytophages (consuming living plant and root material) and predators (consuming living animals) - may have lead to the pleomorphous composition of soil life as simplified in Figure 5. Although already known for decades, this information has serious consequences for monitoring that has to be carried out at considerably different scales.

Another explanation for apparent redundancy is that physiological functioning may differ at 'micro food level' and under various environmental conditions. Therefore, maybe the majority of organisms in the soil will be inactive or resting. Over 90% of micro-organisms are normally resting and in soil fauna high numbers and high activities are interlinked with periods when numbers are much smaller and there is a low level of activity (Eijsackers et al., 1988). Functional diversity is the subject of the world-wide biodiversity debate. As Hopkin (1999) asked: "Are we using diversity as a probabilistic event because we cannot recognise the structure behind it? If so next to species

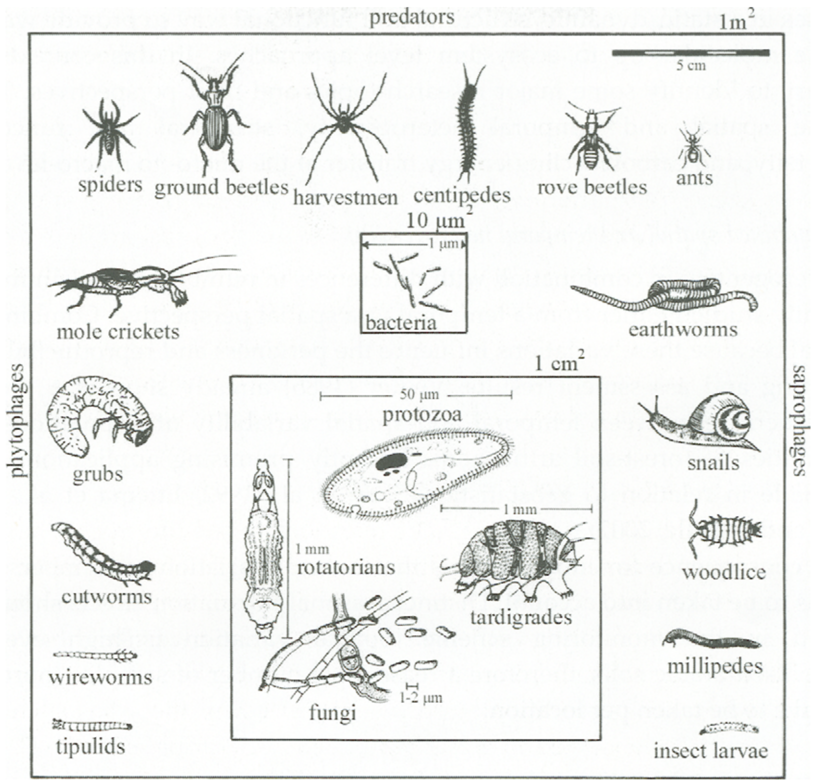


Figure 5. *Composition of a soil fauna selection, arranged according to feeding type (left phytophages, upper predators and right saprophages), size of the animals indicated, and habitat size expressed as various squares (modified after Van der Drift, 1963)*

diversity we should study functional and life form diversity. And next to the study of fixed diversity 'patterns' we should study the total continuous process, because one of ecology's prime interest is to describe and predict the probability of things happening".

1.3 Major research topics; the challenge to integrate

Monitoring the soil in all its diversity of structures and processes demands an integrated approach because policy and politics perceive the soil only at the highest level of integration - the generic responses of the soil system. Measurement is most precise and sensitive at the species level and further down to the gene-level. An integrated approach combines abiotic and biotic processes in a static, dynamic, structural and functional way to provide ways to combine molecular up to ecosystem level approaches. In this context it is necessary to identify some major research topics and their perspectives. These combine spatial and temporal heterogeneity, structural and functional biodiversity, and carbon cycling/energy transfer at the micro- to macro-level.

1.3.1 Combined spatial and temporal heterogeneity

Soil heterogeneity in combination with differences in numbers of soil animals is frequently studied either from a temporal or a spatial perspective. Combination is logical because these variations influence the perkiness and reproducibility of monitoring and assessment results. Vegter (1985) already showed a linearly related increase between temporal and spatial variability of populations and communities of forest-soil arthropods. Recently promising applications have been made in relation to geostatistics (Stein et al., 1992, Ettema et al., 2000; Ettema and Wardle, 2002).

The consequence for monitoring is that natural variation in numbers over time has to be taken into account. Distinct seasonal fluctuation effects should be included in the monitoring scheme. Spatial variation is high even in homogenised arable soils, therefore a reasonable number of samples (normally 5-10) have to be taken per location.

1.3.2 Structural and functional biodiversity

Classical biodiversity is based on the taxonomic characteristics of the number of species. Hopkin (1997) made a plea for studying biodiversity from a functional perspective: how do species function and optimize their survival and what consequences does this have for their life-form. By addressing the potential and actual specific functionality of organisms, succession will be better understood as well as the way ecosystems recover after disturbances. This may lead to a better understanding of the resilience of ecosystems in general. Approaches like the functional classification of soil fauna into 'leagues' as suggested by Faber (1991), and the distinction of twelve life history tactics of soil micro arthropods (Siepel, 1994) should be used to obtain a better understanding of structural and functional biodiversity, especially in relation to disturbances in the soil's environment.

For monitoring purposes this scientific knowledge could be used to identify the functional species groups to be monitored.

1.3.3 Carbon cycling/energy transfer at the micro- to macro-level

Litter decomposition is a classical issue in soil studies, especially the stepwise comminution and further mineralization of litter by soil fauna and micro-organisms in an intimate interaction. This has been extensively studied for various litter types, soil communities and ecosystems in the International Biological Programme (IBP) both in the 1970s and subsequently.

The conservation of carbon in the organic pools in the soil plays a prominent role within the climate debate and the soil threats debate. The formation of organic material has its origin in plant growth. The development of vegetations in relation to their specific carbon assimilation pathways (primer of humus formation) should also be monitored during long periods of time. These kinds of differences also comprise functional parameters like litter breakdown and carbon sequestration.

1.4 The impact of soil contamination

Since soil contaminants such as heavy metals and persistent pesticides have for some time been considered chemical timebombs they get special attention.

1.4.1 Potential, immediate and derived impacts

When assessing the impacts of soil contamination one has to distinguish between potential, immediate and derived effects. Potential effects are the aim of the present preventive and normative approach, based on laboratory experiments measuring the effective dose (ED) on defined species. ED50 is an effect dose at which 50% of the exposed animals or 50% of the activity level of a process is hampered. These experiments are standardised tests. The exposure is maximum and there will be an immediate response when the tested compound is toxic.

In nature animals provide their own living areas and due to heterogeneity there will be spots free of contaminants. From these safe spots (refugia) non-affected individuals can re-invade a contaminated area after the contamination level has started to decrease. Decreases in organic contamination levels are mainly due to contaminant degradation or contaminants gradually binding to soil constituents, resulting in bound residues. Inorganic contaminants, such as heavy metals and nutrients, may also bind or be rendered insoluble, depending on the environmental conditions. Consequently, the bioavailability of contaminants under natural conditions may be lower than under experimental conditions.

When there is no immediate effect derived impacts can still occur, because reproduction is hampered with a resulting decrease in population. Another possibility is that individual organisms become less mobile and unable to feed themselves sufficiently or alternatively they become more mobile and as a result become over-exposed to predators.

To assess the negative impacts of soil contaminants in a generalised way the various soil contaminating substances are roughly divided into heavy metals, organic contaminants such as Persistent Organic Pollutants (POPs) and nutrients. Heavy metals comprise those metals that occur most commonly in the highest amounts: zinc and copper, essential elements for life-processes, and lead and cadmium that are non-essential elements. Similarly the nutrients referred to are mainly nitrogen, phosphorus, and sulphur. Most POPs are chemical compounds (such as insecticides) made by man that have been emitted into the environment.

The response of organisms to natural substances is generally depicted as an optimum curve: small amounts have a positive effect that increases to a certain optimal level. When the amount is increased further, the response will become negative and toxic.

Biodegradation of organics may take place under aerobic and various anaerobic conditions, depending on the structure of the compound. Degradation capacity is not unlimited. When a huge dose is deposited on the soil the toxic impact might be so massive that microbial life becomes eradicated. Only after re-succession from outside do area degradation processes return. Anaerobic conditions, that occur at high groundwater levels or in deeper soil layers, have a positive effect on binding and precipitation of anorganic compounds. Ploughing and harrowing causing aeration of the soil will have a positive effect on the availability of heavy metals.

1.4.2 Soil contamination in relation to other stressors

The mechanical cultivation of soil also has a negative impact on soil biota. Earthworms for instance are sensitive to soil cultivation and in normal agricultural practice cultivation does more harm than the use of pesticides (Edwards; 1989).

Van de Bund (1979) carried out an extensive monitoring-study on 18 farms for several years in order to study the impact of agricultural practices on springtails and mites. The influence of soil type was small in relation to the crop type or crop rotation. Cultivation causes direct physical damage to and vertical re-distribution of the soil fauna. Van de Bund showed clearly that springtails and mites are sensitive to changes in soil organic matter and in particular soil moisture, which may be exemplary for the whole soil fauna. Also Krogh (1994) ranked agricultural systems according to their habitat quality for springtails, Collembola (expressed as range in numbers). He distinguished habitat quality on the basis of crop, crop age, and soil treatment.

Chemical stress factors effectively played a more minor role than soil cultivation and the bareness of the soil surface. In ecosystems these stress-factors do occur naturally together with ecological stresses like food shortage, competing species and predators.

1.5 Monitoring

Monitoring is the measurement of a number of pre-selected variables at a fixed pattern of locations at fixed times. Soil description has a long standing history as far as monitoring activities and soil description is concerned. Up to now the European Soil Bureau (part of the EU Joint Research Centre) collects, harmonises and distributes soil information from countries all over Europe.

Soil ecosystem monitoring has been part of a number of research programmes in various countries (e.g. MATS and ISA in Sweden, Bodenuntersuchungsprogramm and SPP Umwelt in Switzerland, SPBO in the Netherlands). Programmes especially aimed at monitoring soil biota and functions, also in relation to above ground ecosystems, have been developed and started but so far not fully executed (e.g. Observatoire des Sols in France, MATS in Sweden and EMEP in US). The relatively small-scale Dutch soil biology monitoring programme, set up in addition to the soil quality network, has been running on a number of Dutch farms for several years.

In rural (agricultural) areas monitoring is common and remediation monitoring is primarily a feature of urban life. For reasons of public interest and communication sound and simple explicable characteristics should be monitored there. Comparing data form contaminated areas with clean references is strongly recommended. For instance in the Netherlands abiotic reference sites were collected by Edelman in the early 1970s (Edelman and De Bruin, 1986) and used in the Dutch reference values. This could be combined with soil biological reference monitoring such as springtail sampling in forest soils (Vegter, 1985), or soil ecosystem studies of arable or forest soils (Brussaard et al., 1990; Berg et al., 2001).

It would be worthwhile in my opinion to re-assess these kind of data on the composition of the soil and its soil life and to compare it to current levels and to relate them to contaminated sites. On a global scale a wealth of reference data is available from the International Biological Programme.

In order to provide adequate support for soil policy and management a few parameters are needed rather than a whole set of parameters, specified according to soil type and pattern of use or contamination. However in order to pin-point the results, monitoring a specified set might be expected to reveal the fullest results. In principle, assessments should be made at the highest relevant ecological integration level: the ecosystem, which responds much slower than individual species or sub-individual biochemical biomarkers. Moreover, it reflects a greater soil surface than specific communities or species.

In monitoring systems developed so far, a mixture is used of sub-individual biochemical biomarkers, relevant for biochemical processes, individual characteristics of a specific species, community characteristics like the biomass or performance of earthworms as a group, or the functional group composition of nematodes, and general ecosystem processes like primary production. These kinds of composite or integrative characteristics are not always effective in bringing the message across. Endangered, attractive or ecological key-species could be chosen as representative, because these send a direct message to the public. Unfortunately, soil life, despite its wealth of species in all forms and colours, offers no attractive pet species for the man in the street. Earthworms are one of the candidate groups, since they are well recognised and have a clear function in soil as diggers, litter comminutors and provide food for other species. However, we have to realize that key or indicator species can also be misused by over-generalising the relations between specific ecosystem conditions, species communities and types of contamination (Eijsackers and Løkke, 1996).

Generally, a classic list of prerequisites is provided as far as the practical and logistic aspects of monitoring are concerned. The monitoring procedure must be reproducible, but also ecological relevant. It must of course be easy and cheap! Given the variability in soil type, and the heterogeneity in the soil, it is preferable to sample homogenous soil locations such as arable, grassland, park and garden soils. The sampling locations should be of sufficient size. Using relatively small locations (6x6 m) for extensive sampling of soil and soil life turned out to work negatively in the longer term (> 10 years) as shown by Edwards and Brown (1982) and Bembridge et al. (1998).

1.6 Way forward

It is clear that soils are complex systems. Hence, measuring, monitoring and assessing the quality of their structure and processes can only be achieved in an integrated way. The following chapters provide the ingredients for such an approach. They provide a vision on specific elements, their importance and how to measure and monitor soil quality. Most of the background data required are already available and can be used to build a tailored confection approach. Integration and assessment must be carried out at the scientific level, and subsequently interpreted and implemented at the policy level.

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