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Article *in* Journal of Production Agriculture · April 1997

DOI: 10.2134/jpa1997.0235

Thomas H Deluca
University of Washington Seattle

Denise Deluca
Minneapolis College of Art and Design

Reprinted from the *Journal of Production Agriculture*
Volume 10, no. 2, April–June 1997
677 South Segoe Rd., Madison, WI 53711 USA

Composting for Feedlot Manure Management and Soil Quality

T. H. DeLuca* and D. K. DeLuca

Contemporary industrialized grain and livestock production is characterized by efficient, large-scale confined animal feedlot operations (CAFOs) and equally efficient and large-scale, but separate, grain operations. Though both are highly productive, feedlot operators have come to view manure as a waste management problem, while grain operations face declining soil quality and a reliance on commercial fertilizers to maximize yields. Neither type of operation can be considered sustainable. Cooperative on-farm composting may provide solutions to some of the problems facing our industrialized agricultural systems and render the systems more sustainable. In this paper we view cooperative on-farm composting as the combination and processing of feedlot manure with crop stover to produce a beneficial natural soil amendment and fertilizer for those fields from which the stover was taken. Cooperative on-farm composting would help protect surface and groundwater from nutrient loading, save resources, and help renew social ties within the agricultural community. Composting stabilizes nutrients, kills pathogens and weed seeds, reduces moisture content, reduces odor, and improves physical properties of manure, thereby improving its value as a soil amendment and fertilizer. Although some N in raw manure is lost during composting, the end product differs from raw manure in that it exhibits minimal N loss in storage or after field application. Composted manure can become the primary fertilizer for grain production once the cumulative N mineralization from previous applications reach steady- state. The use of composted manure improves soil quality and greatly reduces total energy consumption compared with the use of commercial fertilizer. A hypothetical example illustrates how compost applications to irrigated corn (*Zea mays* L.) could result in a net energy savings of about 3.3 million Btu/acre, which is equivalent to the energy contained in 19.4 gallons of diesel fuel/acre.

CONTEMPORARY INDUSTRIALIZED livestock and grain production in the USA has provided the world with highly efficient food and fiber production, but at the same time has required enormous chemical and energy inputs, left soils depleted of indigenous nutrients and organic matter, and resulted in wide scale surface and groundwater contamination (NRC, 1993). Industrialized agriculture of the western and midwestern USA can be characterized by efficient, large-scale grain operations and equally large-scale and efficient, but separate, CAFOs. Influenced by the high cost of land, a lack of on-farm animal manure resources, government policies, and a noted decline in soil quality (NRC, 1993), grain producers have come to rely on increasingly large applications of commercial fertilizers to maximize yields. Simultaneously, large scale cattle feedlot operators, faced with increasing pollution potential associated with concentrated animal production, have come to manage manure as a waste product (NRC, 1993). Thus both grain producers and feedlot operators are faced with conditions that are not sustainable: decreasing soil quality and increasing dependence on external sources of nutrients on grain operations, and increasing pollution potential and difficulty handling excess nutrients and organic matter on feedlots.

Smaller scale farming operations that integrate crop and animal production are thought to afford a more sustainable approach to agriculture (NRC, 1989). Integrated farmers, who routinely supply the soil with nutrients and organic matter in the form of animal manure, reduce their dependence on external sources of nutrients and maintain soil quality and thus manage manure as a resource, rather than a waste (Vogtmann, 1984; Widdowson, 1987; Beauchamp, 1993; Phillips and Sorensen, 1993). However, in the near future we are not likely to see large-scale livestock and grain operations divest themselves into small-scale integrated farms because of existing government policies, marketing organizations, and the long proclaimed efficiencies of scale (Strange, 1988).

We suggest that "cooperative on-farm composting" could provide a means of introducing important elements of sustainability within the existing structure of industrialized agriculture. Cooperative on-farm composting could take a myriad of forms, but for the purposes of this paper we define it as the combination and processing of manure from feedlots with crop stover from grain operations to produce compost that would then be used as a beneficial soil amendment on the grain fields that provided the stover. Cooperative on-farm composting brings together large scale feedlot operators and grain producers in a mutually beneficial alliance that serves to increase the sustainability of both operations. The feedlot operators gain an environmentally sound method of managing manure that increases its value as a soil amendment. The grain producers gain a new use for their crop stover that provides them with a soil amendment that will increase soil fertility and quality and decrease their reliance on commercial fertilizers.

To date there has been limited serious discussion of composting as a means of managing manure on CAFOs. This is evidenced by the absence of composting discussions from most livestock management textbooks (Ensminger, 1987) and review articles (Safely, 1994; Sutton, 1994) and the

T.H. DeLuca, School of Forestry, Univ. of Montana, Missoula, MT 59812; D.K. DeLuca, Land and Water Consulting, Missoula, MT 59807. Received 10 May 1996. *Corresponding author (thd@forestry.umt.edu).

Published in J. Prod. Agric. 10:235–241 (1997).

Abbreviations: CAFOs, confined animal feedlot operations.

absence of composting in practice on most CAFOs in the USA. In contrast, composting has historically been a common practice throughout Europe (Pfirter et al., 1981; Vogtmann, 1984) and Asia (King, 1911; Howard, 1943).

The purpose of this paper is to describe and promote cooperative on-farm composting as an alternative means of manure management on large CAFOs and fertility management on large grain operations. Analyses are provided to illustrate the benefits, energetics, and nutrient dynamics associated with composting of cattle manure with corn stover and its subsequent application to cropland.

SOIL QUALITY

The native grasslands of the Midwest and western regions of the USA provided an incredible wealth of fertility that was greatly depleted by a combination of tillage, annual grain harvests, and soil erosion. Although the loss of soil mass and fertility has long been understood to be the result of traditional continuous row crop agricultural practices, the loss of soil quality has only recently been considered important (NRC, 1993; Karlen et al., 1994; Gregorich et al., 1994).

Soil quality is, as yet, an ill defined term. We have chosen to define soil quality as "a set of soil properties that sustain the processes, activities, and diversity of soil macro- and micro-organisms that in turn enhance the proliferation and function of roots of desirable plant species." The set of soil properties that define soil quality include bulk density, water holding capacity, and cation exchange capacity (NRC, 1993). It is thus clear that a decline in soil quality would be largely a function of a decline in soil organic matter content.

Conventional cropping practices in the midwestern USA have led to a significant reduction in the quantity and quality of soil organic matter (DeLuca and Keeney, 1994) as a result of continuous crop production without sufficient return of plant and animal materials. The effect of conventional row cropping on soil has been described as "putting agricultural soils on a white bread diet," in which only cellulosic crop residues and fertilizers are incorporated into soils (DeLuca, 1995). Increasing soil quality through the replenishment of soil organic matter can be achieved through adequate additions of appropriate plant and animal materials to soil (Widdowson, 1987; Magdoff, 1992).

CATTLE MANURE AND COMPOSTING

About 85% of the 10 million cattle on feed in the USA are found on CAFOs with greater than 1000 animals (Eghball and Power, 1994a). It is not uncommon to find individual feedlots processing more than 50 000 animals with some reaching numbers of 500 000 animals (Overcash et al., 1983). At an annual production rate of 11 tons of manure per animal unit (1000 lb liveweight) (Overcash et al. 1983), CAFO operators in the USA are faced with handling over 85 million tons of manure each year; an amount 10 times greater than human sewage production in the USA (Cole and Ronning, 1983). As might be expected, most medium (500–1000 animal units) and large (>1000 animal units) livestock operations consider manure to be a liability rather than a resource (Freeze and Sommerfeldt, 1985; NRC, 1993).

Table 1. Nutrient and soil amendment quality of fresh, feedlot, and composted cattle manure based on values cited in literature.

	Fresh manure		Feedlot manure		Composted manure		
	Range	Avg.	Range	Avg.	Range	Avg.	References†
N, % wet wt	0.4–0.9	0.6	0.3–2.4	1.4	0.6–1.5	1.1	1,2,3,4,5
P, % wet wt	0.1–0.2	0.2	0.1–0.8	0.4	0.3–0.8	0.5	1,2,4
K, % wet wt	0.2–0.5	0.3	0.2–1.4	0.8	2.0–1.5	1.7	1,2,4
Moisture, %	80–90	85	30–70	50	10–50	30	2,4,6
Phenolics, ppm		827		1245		41	7
Pathogens, weed seeds, insect larvae, odors‡		+		+		–	4,5,8,9

† 1. Brinton, 1985; 2. Chaney et al., 1992; 3. Hébert et al., 1991; 4. Overcash et al., 1983; 5. Taiganides, 1977; 6. Rynk et al., 1992; 7. Paul et al., 1994; 8. Pfirter et al., 1981; 9. Mawdsley et al., 1995.

‡ + = present, – = absent or greatly reduced.

Raw Manure

Typical manure management on large CAFOs in the USA involves direct application of manure to nearby fields after some form of stockpiling (Ensminger, 1987). Raw manure has long been valued for its ability to provide plant nutrients and improve soil physical and chemical properties by increasing soil organic matter (Vogtmann, 1984; Gao and Chang, 1996). However, applications of raw manure to grain fields may be discouraged because of the potential for introducing weed seeds, plant and human pathogens, and insect larvae (Overcash et al., 1983; Taiganides, 1977; Pfirter et al., 1981; Mawdsley et al., 1995). Excessive applications of raw manure to agricultural fields can result in nutrient imbalances, P and N loading of surface waters, and nitrate and pathogen loading of groundwater (Swanson et al., 1971; Overcash et al. 1983; Keeney, 1989; NRC, 1993). Other undesirable characteristics of using raw manure as a soil amendment include: (i) relatively variable and unstable nutrient content, (ii) relatively high water content which limits economic hauling distances, and (iii) odor levels that can limit field applications near homes or communities (Overcash et al., 1983).

The N content of manure is greatest when it is fresh, ranging from 2.4 to 5.8% N (dry weight) (Overcash et al., 1983) (Table 1). However, manure is usually stockpiled for much of the year, since manure applications to cropland can only be made following harvest or prior to planting (Ensminger, 1987). Typically, manure is stockpiled on site, then removed from the CAFO and applied to nearby fields when animals are taken to market or once each year, prior to primary tillage operations (Eghball and Power, 1994a). Nutrient losses that occur during storage reduce the value of the manure as a fertilizer. Nitrogen losses in open lot storage range from 30 to 60% (Table 1), primarily as a result of volatilization of ammonia (Sutton, 1994). Phosphorus and K concentrations are also reduced in storage primarily as a result of runoff and leaching (Table 1). The fertilizer value of raw manure declines further after field application. Once applied to the soil surface, N loss from fresh manure is reported to be approximately 15%/d until incorporation into the soil, which not only reduces its efficiency as N fertilizer absence of composting in practice on most CAFOs in the USA. In contrast, composting has historically been a common practice throughout Europe (Pfirter et al., 1981; Vogtmann, 1984) and Asia (King, 1911; Howard, 1943).

The purpose of this paper is to describe and promote cooperative on-farm composting as an alternative means of manure management on large CAFOs and fertility management on large grain operations. Analyses are provided to illustrate the benefits, energetics, and nutrient dynamics associated with composting of cattle manure with corn stover and its subsequent application to cropland.

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(Paul and Beauchamp, 1993), but also eliminates its potential use as a N fertilizer in no-till agroecosystems (Walter et al., 1987).

When stockpiled, manure represents a potential point source contaminant of surface and groundwater including N, P, bacteria, viruses, organic compounds (biologic oxygen demand), and total dissolved solids (Overcash et al., 1983). Paul et al. (1994) also report the highest soluble phenolic compound concentrations in stored manure compared with fresh or composted manure (Table 1). Such compounds are thought to be phytotoxic to young plants or to inhibit seedling germination.

Composted Manure

Composting is an enhanced aerobic and thermophillic biological process in which microorganisms convert a combination of organic materials, such as manure, sludge, paper, food wastes, and crop stover, into a humified material (Rynk et al., 1992). Although feedlot manure may be composted alone (Eghball and Power, 1994b), a cellulosic bulking agent, such as crop stover, is typically added to help aerate the mixture and achieve an appropriate C-to-N ratio (C:N) and moisture content that help to optimize the aerobic and thermophillic decomposition of organic matter to form humus (Rynk et al., 1992; Martin and Gershuny, 1992). Most CAFO managers are aware of composting, but tend to perceive it as too expensive, too labor-intensive, or logistically impossible. However, until recently there has been little serious discussion of composting as a means of cattle manure management in the USA.

Like raw manure, compost can improve soil physical and chemical properties by increasing organic matter while providing plant nutrients. However, during the composting process the C and N present in the manure and crop stover are converted into more stable organic and humified forms. This allows compost to maintain greater nutrient content and lower pollution potential during storage and after application (Brinton, 1985; Hervas et al., 1989; Herbert et al., 1991; Magdoff, 1992). This condition also allows composted manure to be applied to no-till farming systems with little loss of N to volatilization.

Decomposition that occurs during composting also reduces total material mass and volume of the original compost mixture through CO_2 and water loss. The lower moisture content of composted manure reduces handling and hauling costs. Additionally, the aerobic, thermophilic decomposition processes that occur during composting result in elevated temperatures that kill most pathogens, insect larvae, and weed seeds typically found in manure (Taiganides, 1977; Pfirter et al., 1981; Chaney et al., 1992). Composting has also been found to enhance breakdown of pesticide residues (Fogarty and Tuovinen, 1991), inhibit nitrification (Haug and Ellingsworth, 1991), and reduce levels of soluble phenolic compounds (Paul et al., 1994) (Table 1). Applying mature compost to soil has also been reported to suppress the activity of some soil borne plant pathogens (Hoitink and Kuter, 1986; Schueler et al., 1989). Finally, aerobic composting of manure results in less offensive odors than raw manure and the finished compost is often odorless (Pfirter et al., 1981).

Although the N content of compost is generally lower than that of raw manure (Table 1), more of the N in composted manure exists in stable organic forms, thus N losses during storage and during and after field application of compost are minimized (Paul and Beauchamp, 1993). The amount of N lost during composting depends, in part, on the C:N ratio of the compost mixture. Higher C:N ratios generally result in lower N losses to volatilization (Hammouda and Adams, 1987; Al-Kanani et al., 1993); however, a C:N greater than 30:1 can result in net immobilization of N and slow compost maturation (Taiganides, 1977; Rynk et al., 1992; Chaney et al., 1992). Wheat straw, corn stover, or other materials with a high C:N ratio can be added to manure to achieve the optimal C:N ratio in the compost mixture. Crop stover also acts as a bulking agent in the compost mixture which provides structure to the compost mixture for greater natural aeration, thus requiring fewer turnings (Haug, 1993).

Proper aeration of the compost mixture avoids the undesirable characteristics of anaerobic conditions, including slow decomposition rates, build-up of anaerobic by-products, and odors. Nitrogen losses through ammonia volatilization can also be reduced with less frequent aeration (turning) of the compost pile and covering the compost windrows with a breathable cover (SFEP, 1980).

Composting could prove to be the most economically feasible means of manure management on many CAFOs. However, composting requires a commitment of labor, equipment, and space. In some states and under certain conditions, composting operations may require a license or permit. Although finished compost can be a valuable commodity and is even considered a cash crop by some producers, the CAFO operator must have an end-user for the compost to realize its value.

COMPOSTED MANURE AND CROP FERTILIZATION

Commercial fertilizer use has increased dramatically over the past 50 yr, in part as a result of the high cost of land, low cost of fertilizers, promotion of maximum grain production, and the separation of grain and livestock production (NRC, 1989). Although convenient to use, the production of commercial N and P fertilizers is energy intensive (Pimentel, 1993). The high solubility, mobility, and overapplication of commercial fertilizers have also resulted in contamination of water resources (Keeney, 1989; NRC, 1993).

In the following section, we discuss three main advantages of composted manure over commercial fertilizers: (i) application of composted manure increases soil quality while providing plant nutrients; (ii) the slow mineralization of N and P from compost provides plant nutrients through the most active period of plant nutrient uptake (Magdoff, 1992); (iii) the production and use of composted manure represents a significant net energy savings over commercial fertilizers.

Compost and Soil Carbon

The appropriate application of composted manure to soils will lead to a net improvement in soil quality over soils

Table 2. Nitrogen mineralization rates in composted cattle manure cited in literature.

N mineralization rates	Reference
5% per year	Paul and Beauchamp, 1993
9% in the first year	Brinton, 1985
14% in the first year	Hébert et al., 1991
10–20%/yr	Wen et al., 1995
11–29%/yr	Hadas and Portnoy, 1994
30%/yr	Schlegel, 1992
34%/yr	Robertson and Morgan, 1995

treated with only commercial fertilizers and incorporation of resident crop stover (Reginold et al., 1993). In a closed system analysis of crop C returned to soils with or without animal production, Beauchamp and Voroney (1994) demonstrated that soil application of raw manure provides soils with only a small fraction of the total crop C that was removed as grain. The authors go on to point out that if the manure is applied with crop residues as animal bedding (more similar to composted manure), then C return to the soil is maximized and is in excess of the amount removed from the soil as grain.

The manure on most CAFOs originates from an external feed source. Thus the C introduced to the soil through the addition of composted feedlot manure reflects the addition of an external C source. The C added as compost greatly exists in a humified form that would undergo little additional loss as CO_2 compared with crop stover, which would lose about 60% C as CO_2 following soil incorporation (Stevenson, 1986; Hervas et al., 1989). Composted manure would also supply the soil with a more diverse array of C compounds than crop stover alone, which is mainly composed of cellulose (Stevenson, 1986).

Compost and Nutrient Availability

Nitrogen and P mineralize gradually in composted manure, more gradually than in raw manure. A wide range of N mineralization rates have been reported for composted cattle manure and are summarized in Table 2. Based on these reported values, we assumed a highly conservative initial N concentration of 0.9% N (wet weight) in composted manure (Table 1) and a first year mineralization rate of 20% N, followed by 20% in the second year, 10% in the third year, and 5% annually in succeeding years (Table 3).

Since only a fraction of the total amount of each nutrient found in the applied compost is available in the first year of application, the remainder becomes available in years following application. Each year, nutrients available for plant uptake consist of those nutrients mineralized from that year's compost application plus the nutrients continuing to mineralize from past years' applications. With consistent annual applications of compost, more nutrients are available for plant uptake each year until steady-state is achieved. In our example, it would take 12 yr of consistent compost applications before a constant amount of N is available each year. At that time, the sum of nutrients made available each year would be equivalent to the total nutrient content found in the compost applied in 1 yr (Table 3, Fig. 1).

Phosphorus mineralization rates for compost were estimated based on the N mineralization rates provided above. We assumed an initial P concentration of 0.3% in the compost (Table 1) and a P mineralization rate of 60%, 20%, 10%, 5%, and 5% over each year of a 5-yr period, respectively (Table 3). In the example that follows, the compost contains insufficient P to meet the needs of the corn crop, and the remainder of the P requirement would be met using commercial P fertilizers. The nutrient values will vary with manure handling practices. Phosphorus loading of soils may dictate lower composted manure application rates.

Table 3. Assumed N and P mineralization rates and cummulative availability in composted cattle manure.

Year following first compost application	Annual N mineralization rate, %	Cumulative N availability, lb/acre†	Annual P mineralization rate, %	Cumulative P availability, lb/acre†
0	20	24	60	24
1	20	48	20	32
2	10	60	10	36
3	5	66	5	38
4	5	72	5	40
5	5	78	0	40
6	5	84	0	40
7	5	90	0	40
8	5	96	0	40
9	5	102	0	40
10	5	108	0	40
11	5	114	0	40
12	5	121	0	40
13	0	121	0	40

† The total amount of N made available to plants by current plus previous applications of composted manure with annual compost applications of 6.7 tons/acre wet weight (0.9% N and 0.3% P).

Using the assumed mineralization rates described above, annual compost applications of 6.7 ton/acre (wet weight) each year for 12 yr would result in the availability of 120 lb N/acre per yr by the 12th year (Table 3, Fig. 1). After this time, all of the N needs of the corn crop in our example would be met by the composted manure, with no need for additional applications of commercial fertilizer. (During the first 12 yr, the compost would have to be supplemented with commercial N fertilizer).

Energetics of Composted Manure and Commercial Fertilizers

Composted manure represents a significant energy savings over commercial fertilizers. The following example compares the production, transport, and application of composted manure to that of commercial fertilizers on the basis of total energy consumption values. Energetics, rather than costs, are compared for three reasons: (i) energetics remain consistent while economics fluctuate, (ii) commercial N fertilizer use is the largest single energy input to corn production in the USA (Pimentel, 1993), and (iii) energetics represent a more environmentally meaningful estimate of the relative value of compost.

Table 4 presents hypothetical energy consumption rates for supplying the N and P requirements for irrigated corn production using composted manure and commercial fertilizers. For the purposes of this example, the assumed fertilizer requirements are 121 lb N/acre and 45 lb P/acre. Without the application of composted manure, the entire nutrient requirement would be met by applying purchased commercial fertilizers. With the application of composted manure, the entire N requirement would be met by applying compost at the rate of 6.7 ton/acre each year (after achiev-

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The manure on most CAFOs originates from an external feed source. Thus the C introduced to the soil through the addition of composted feedlot manure reflects the addition of an external C source. The C added as compost greatly exists in a humified form that would undergo little additional loss as CO_2 compared with crop stover, which would lose about 60% C as CO_2 following soil incorporation (Stevenson, 1986; Hervas et al., 1989). Composted manure would also supply the soil with a more diverse array of C compounds than crop stover alone, which is mainly composed of cellulose (Stevenson, 1986).

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Phosphorus mineralization rates for compost were estimated based on the N mineralization rates provided above. We assumed an initial P concentration of 0.3% in the compost (Table 1) and a P mineralization rate of 60%, 20%, 10%, 5%, and 5% over each year of a 5-yr period, respectively (Table 3). In the example that follows, the compost contains insufficient P to meet the needs of the corn crop, and the remainder of the P requirement would be met using commercial P fertilizers. The nutrient values will vary with manure handling practices. Phosphorus loading of soils may dictate lower composted manure application rates.

Table 3. Assumed N and P mineralization rates and cummulative availability in composted cattle manure.

Year following first compost application	Annual N mineralization rate, %	Cumulative N availability, lb/acre†	Annual P mineralization rate, %	Cumulative P availability, lb/acre†
0	20	24	60	24
1	20	48	20	32
2	10	60	10	36
3	5	66	5	38
4	5	72	5	40
5	5	78	0	40
6	5	84	0	40
7	5	90	0	40
8	5	96	0	40
9	5	102	0	40
10	5	108	0	40
11	5	114	0	40
12	5	121	0	40
13	0	121	0	40

† The total amount of N made available to plants by current plus previous applications of composted manure with annual compost applications of 6.7 tons/acre wet weight (0.9% N and 0.3% P).

Using the assumed mineralization rates described above, annual compost applications of 6.7 ton/acre (wet weight) each year for 12 yr would result in the availability of 120 lb N/acre per yr by the 12th year (Table 3, Fig. 1). After this time, all of the N needs of the corn crop in our example would be met by the composted manure, with no need for additional applications of commercial fertilizer. (During the first 12 yr, the compost would have to be supplemented with commercial N fertilizer).

Energetics of Composted Manure and Commercial Fertilizers

Composted manure represents a significant energy savings over commercial fertilizers. The following example compares the production, transport, and application of composted manure to that of commercial fertilizers on the basis of total energy consumption values. Energetics, rather than costs, are compared for three reasons: (i) energetics remain consistent while economics fluctuate, (ii) commercial N fertilizer use is the largest single energy input to corn production in the USA (Pimentel, 1993), and (iii) energetics represent a more environmentally meaningful estimate of the relative value of compost.

Table 4 presents hypothetical energy consumption rates for supplying the N and P requirements for irrigated corn production using composted manure and commercial fertilizers. For the purposes of this example, the assumed fertilizer requirements are 121 lb N/acre and 45 lb P/acre. Without the application of composted manure, the entire nutrient requirement would be met by applying purchased commercial fertilizers. With the application of composted manure, the entire N requirement would be met by applying compost at the rate of 6.7 ton/acre each year (after achieving steady-state N availability conditions described above). This composted manure application rate would supply 40 lb P/acre, requiring supplementing with commercial P fertilizer at 4.5 lb/acre.

We used the energy consumption values for the commercial fertilizers estimated by Pimentel (1993) at 37 735 Btu/lb for N and 11 398 Btu/lb for P. These values include the energy consumed during production, delivery, and application of the commercial fertilizers. Energy consumption values used for composted manure were developed for a composted manure mixture of 0.3 lb of corn stover (C:N = 60) to 1 lb manure (C:N = 19) to achieve a C:N of approximately 30:1. The total energy consumed in the entire compost process, from collection of raw materials through field application, is estimated at 33 000 Btu/lb of finished compost. Energy values were estimated based on manure and crop stover handling data (Pimentel, 1993) and municipal solid waste composting data that account for mixing, aerating, sieving, and curing (Diaz et al., 1987). Total energy consumption values for the compost-treated fields also include the energy consumed by the supplemental P fertilizer.

Use of composted manure rather than commercial fertilizer alone to meet the N and P requirements of corn fields near feedlots would reduce annual energy consumption substantially (Table 2). The composted manure plus supplemental phosphate fertilizer would consume less than 2 million Btu/acre under steady-state conditions, whereas commercial N and P fertilizers would consume over 5 million Btu/acre to supply the same plant nutrients. Thus, using composted manure as a fertilizer represents a net energy savings of over 3 million Btu/acre. This energy saving per acre is equivalent to the energy contained in more than 19 gal of diesel fuel per acre. Though these numbers are hypothetical, even large deviations from values chosen to develop this example wouldn't change the fact that the use of composted manure reflects an enormous net energy savings over the use of commercial fertilizers alone.

Table 4. Example of energy consumed in fertilization of irrigated corn with or without composted cattle manure based on annual fertilizer requirements of a 121 lb N/acre and 45 lb P/acre following achievement of steady-state conditions (12 yr of compost application at 6.7 tons/acre).

	Nutrient supplied, lb/acre	Energy consumed, Btu/lb	Energy consumed, thousand Btu/acre
	No compost applied		
Commercial N	121	37 735†	4551
Commercial P	45	11 398†	508
Total			5059
	Compost applied		
Commercial N	0	38 735	0
Commercial P	4.5	11 398	50
Composted manure	13 400	125‡	1680
Total			1730

† Energy consumed in the production and application of fertilizer N, P, and K (Pimentel, 1993).
‡ Energy consumed in the collection, processing, and application of compost (adapted from Diaz et al., 1987, see text for explanation).
§ Compost assumed to contain 18 lb N/ton and 6 lb P/ton.

Example of Energy Savings

As an example of potential energy savings on a larger scale, we considered a hypothetical 25 000 animal CAFO surrounded by corn fields. For the purposes of this example we assumed one animal unit produces 11 tons of manure/yr, thus the CAFO would yield a total of 275 000 tons of manure annually. To make an appropriate compost mixture,

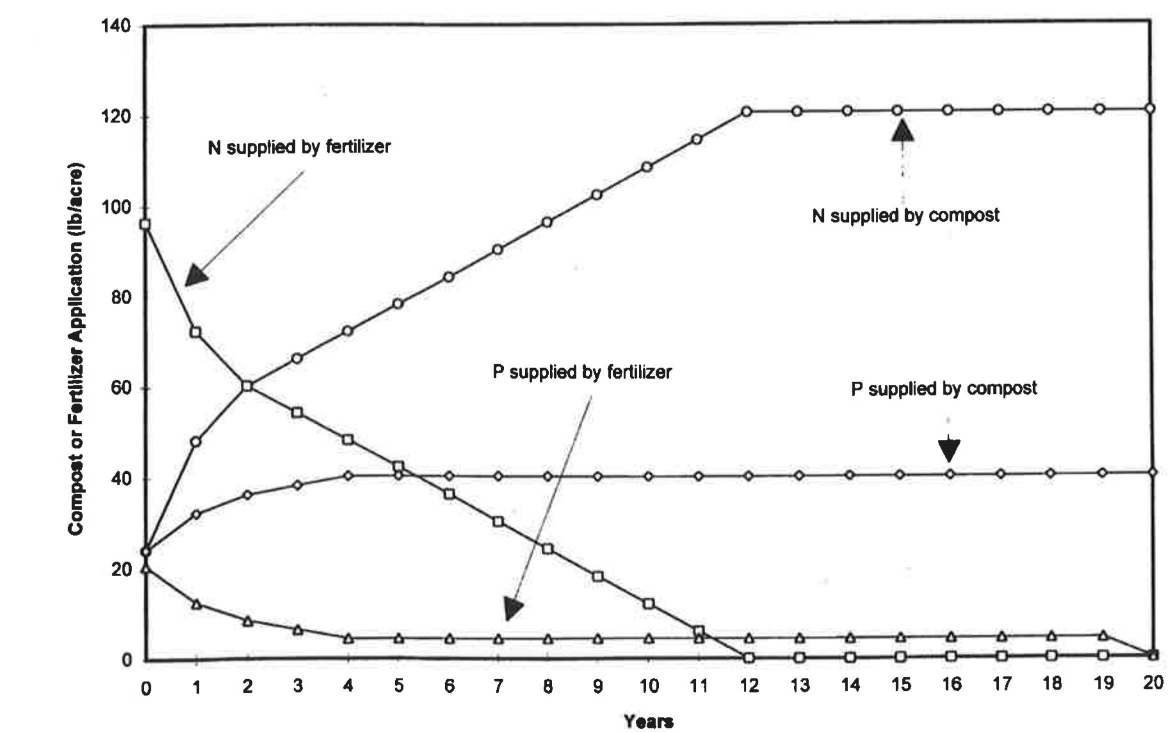

Fig. 1. Nutrient availability for annual compost applications of 6.7 tons/acre and supplemental commercial fertilizers (total N requirement = 120.6 lb/acre and total P requirement = 40.2 lb/acre).

this manure would have to be combined with 82 125 tons of corn stover. Assuming that corn stover following harvest is present at a rate of 4.4 tons/acre (Smil, 1981), 3.9 tons/acre of stover could be removed while leaving 0.5 ton/acre residue on the field for soil protection (Karlen et al, 1984). At this rate, about 21 200 acres of corn would be required to produce the required amount of stover. During the composting process, the manure/stover mixture would lose a portion of both its initial mass and N content. We assumed the finished compost would contain 18 lb of N per ton of finished compost, thus the composted manure from a 25 000-head CAFO could supply the N fertilizer requirements of 21 350 acres of corn (at 120 lb N/acre). This is approximately the same acreage from which stover was removed. Using the per-acre energy savings values presented in Table 4, the composted manure application represents a total energy savings of 4.7×10^9 Btu, which is approximately the amount of energy contained in 27 500 gallons of diesel fuel. Additionally, soils will have received a net increase of 2.8 tons/acre (6.7 tons of compost/acre added, and 3.9 tons of stover/acre removed) total organic mass annually.

The energetics of improved soil quality are not readily estimated, but could be considered as a function of decreased irrigation requirements (increased water holding capacity), reduced fuel requirements for tillage measured (lower soil bulk density), reduced annual nutrient loss (increased soil CEC), and reduced micronutrient requirements (supplied by manure).

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