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Applications in Agricultural and Environmental Management

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Utilization of Municipal Wastes

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I. INTRODUCTION

We have reached a critical stage in the management of our two major municipal waste streams, sewage sludge and solid waste or garbage. As a society, United States citizens are now generating 7.7 million metric tons (mt) of sewage sludge and 165 mt of garbage annually, on a dry weight basis. A substantial increase in these municipal wastes is expected for this decade. In the past, emphasis has been on the ultimate disposal of both wastes through incineration, ocean dumping, and landfilling. Only 10% of our municipal solid waste is recycled (USEPA, 1989a). However, it is somewhat encouraging that more than 30% of the sewage sludge produced is now utilized beneficially on agricultural and nonagricultural land as composted products, and by such application techniques as land spreading and liquid sludge injection (USEPA, 1990a). The ultimate disposal of both wastes has been met with increasingly restrictive and costly environmental regulations, especially for landfills (USEPA, 1990b).

Recently, the U.S. Environmental Protection Agency (USEPA) proposed new standards for regulating the utilization of sewage sludge for safe and beneficial use as a biofertilizer and soil conditioner, and disposal by incineration and landfilling (USEPA, 1989b). The proposed regulations strongly emphasize the protection of public health and the environment. Composting was cited as an acceptable practice to ensure the safe and beneficial use of sludge on land. Meanwhile, hearings have been held by the U.S. House of Representatives' Committee on Agriculture to investigate whether composting and cocomposting—combining certain waste materials such as sewage sludge and yard wastes, or sewage sludge and waste paper, to enhance the composting process and product quality—are viable options for alleviating the mounting municipal waste problem now facing much of the urban sector in the United States (U.S. House of Representatives, 1990).

II. THE SEWAGE SLUDGE SITUATION

The current annual production of sewage sludge in the United States is about 7.7 dry mt, or 64 lb of sewage sludge per capita (Table 1). According to USEPA

Table 1 Sewage Sludge Production in the United States

Yr	Dry metric tons (× 1000)
1978[a]	3,963
1989[b]	7,713
2000[b]	15,000

Source: [a]USDA (1978); [b]USEPA (1989b).

(1989b), this amount is expected to double by the year 2000 owing to increased population growth, stricter wastewater treatment requirements, and improved operation of publicly owned sewage treatment plants. The USEPA (1989b) states that the volume of sewage sludge that we are currently producing for ultimate disposal by landfills and incineration must be reduced if we are to achieve our environmental quality goals and objectives. This indicates that municipalities will need to implement measures to reduce the volume of wastewater generated (e.g., through the diversion of storm water from the sanitary sewer systems) and improve the quality of sewage sludge (e.g., through the abatement of industrial discharge of heavy metals and toxic organics into the sanitary sewer systems). These measures would help to increase the amount of sludge that can be utilized safely and beneficially on land and would decrease the amount that is disposed of in landfills. Currently, about 20% of our wastewater sludges are ultimately disposed of in landfills, contributing significantly to the rapid decrease in landfill capacity throughout the United States (USEPA, 1990a).

About 5% of our sewage sludge is still disposed of by ocean dumping. However, recent legislation by the U.S. Congress will abolish ocean dumping of sewage sludge by our coastal cities in 1992. This could put additional pressure on existing landfills, especially where sludges contain high concentrations of pollutants, such as heavy metals and toxic organic chemicals, and are unacceptable for land application.

III. THE MUNICIPAL SOLID WASTE DILEMMA

As indicated earlier, the current annual U.S. production of municipal solid waste is about 165 mt, which amounts to a per capita annual production of nearly 600 kg (USEPA, 1989a). According to USEPA (1990b), the estimated production of garbage in the United States will increase substantially to about 197 mt by the year 2000, and to 228 mt by 2010 (Table 2). The assortment of materials and their respective amounts that constitute the nation's municipal solid waste stream is shown in Table 3. By far the largest component is paper and cardboard products, which account for approximately 35%, followed by yard waste (grass clippings, leaves, and tree or shrub trimmings) at 20%. These two waste fractions combined with food waste (8.5%) and discarded wood products (4.2%) account for approximately two-thirds of our municipal solid waste, most of which is disposed of in landfills. These four waste materials are all biodegradable under proper conditions and could be composted or cocomposted for beneficial use as biofertilizers and soil conditioners on either agricultural or nonagricultural lands. Of the remaining materials, metals,

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Table 2 Municipal Solid Waste Production in the United States

Year	Dry metric tons (× 1000)
1978[a]	131,519
1988[b]	165,000
2000[b]	197,000
2010[b]	228,000

Source: [a]USDA (1978); [b]USEPA (1990b).

Table 3 Percentage Composition of Materials by Weight in U.S. Municipal Solid Waste (Garbage)

Material	Composition (%)
Paper and cardboard	34.2
Yard waste	19.9
Food waste	8.5
Metals	8.1
Glass	7.1
Plastics	9.2
Wood	4.2
Rubber and leather	2.9
Textiles	2.5
Other	3.4

Source: USEPA (1990b).

glass, and plastics compose about 25% of our solid waste and have considerable recyclable value, especially where municipalities have implemented source separation or curbside collection programs, including paper and yard wastes. Unfortunately, all of these waste fractions usually get mixed together in the garbage collection process, making it even more difficult and costly to reclaim and recycle them as useful products.

According to USEPA (1989a), we are recycling only 10% of our municipal solid waste, while another 10% is incinerated and 80% goes to landfills. Interestingly, the disposal of such large amounts of solid waste in landfills has created a most critical situation for a number of U.S. cities and municipalities (i.e., landfills are filling up). The projected landfill closings in the United States and reduction in landfill capacity is shown in Table 4. These projections indicate that, by the year 2000, there will be a 60% reduction in the number of operating landfills, with a substantial reduction in landfill capacity. Thus, unless new landfills are constructed, we as a society will be unable to accommodate our projected municipal solid waste production through the landfill disposal system. Progressively restrictive environmental regulations by federal, state, and local authorities; rising land costs; and vocal environmental groups have greatly exacerbated the situation (U.S. Congress, 1989).

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Table 4 Projected Landfill Closings in the United States and Reduction in Landfill Capacity

Yr	Operating landfills	Annual intake[a] (mt)
1988	5499	187
1993	3332	131
1998	2720	94
2000	2157	76

[a]Includes municipal solid waste and industrial wastes.
Source: USEPA (1988).

All of this has caused landfill siting and construction costs to increase exponentially. For example, new USEPA regulations will likely require expensive synthetic liners, clay layers under the landfill, and drainage systems to collect effluents. Since landfills are generally developed in stages, the upfront costs could occasionally exceed 10 million dollars (Murphy, 1990). Meanwhile, the average U.S. landfill "tipping fee," or charge for dumping solid waste in landfills, increased from about 11 dollars/ton in 1982 to 27 dollars in 1988. However, in some U.S. cities the disposal costs of solid waste now exceed 100 dollars/ton because of long-distance hauling and high landfill-tipping fees (Sudol and Zach, 1988; USEPA, 1989a). There is little doubt that tipping fees will escalate sharply during the present decade.

IV. STRATEGIES FOR IMPROVED MANAGEMENT AND UTILIZATION OF MUNICIPAL WASTES

As the costs for ultimate disposal of sewage sludge and solid waste through incineration and landfills have increased, there has been an increasing public awareness and a growing consensus that other options are needed (i.e., those that focus on recycling and utilizing these wastes for the benefit of society). The increased cost of disposal has enhanced certain options for recycling and utilization that, heretofore, were not economically feasible. The USEPA has now implemented a program to promote the safe and beneficial use of sewage sludge on land, which features composting, land spreading, and liquid injection for improving agricultural and nonagricultural lands (USEPA, 1989c).

A recent USEPA report (1989a) entitled *Solid Waste Dilemma: An Agenda for Action* seeks solid waste management options that would reduce the amount of waste that we generate. This document sets forth a national-recycling goal for increasing our current rate of recycling municipal solid waste from 10 to 25% by 1992. If successful, this initiative would decrease solid waste disposal in landfills to 55%, and increase the amount being incinerated to 20%. This agenda emphasizes source separation and recycling of paper, metals, glass, and plastics. It also encourages the collection and composting of yard wastes for beneficial use. These wastes, which consist of grass clippings, leaves, and tree or shrub trimmings, are extremely bulky and occupy a considerable volume in landfills. Moreover, a growing number of states have banned the disposal of yard wastes in landfills (Pelzer, 1990). Some municipalities have already implemented projects for collecting and composting of

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yard wastes. The composted materials are sold to gardeners and nurseries or are utilized for civic improvement (e.g., landscaping). This has generated considerable interest in backyard-composting methods (Rodale, 1982).

The USEPA's current focus is on source separation and recycling of commodities of the solid waste stream (i.e., to use waste paper to make more paper, not to make compost; U.S. House of Representatives, 1990). Moreover, if nonbiodegradables, such as metals, glass, and plastics can be separated and recycled as such, and yard wastes can be composted, all on a large scale, the pressure on landfill disposal would be greatly alleviated. Nevertheless, it is likely that many municipalities will be faced with the problem of managing mixed solid waste for some time to come. Thus, research is needed to determine the feasibility, practicability and desirability of cocomposting mixed solid wastes with, for example, sewage sludge. When mixed solid waste is shredded, composted, and screened, the compost product invariably contains fragments of metals, glass, and plastics that might detract from acceptance and use by consumers. Fine-grinding techniques can probably reduce these to a particle size that would largely overcome such objections. Such composts would likely be acceptable for land reclamation purposes; however, their acceptance by agricultural and horticultural producers needs to be determined (U.S. House of Representatives, 1990).

V. COMPOSTING TO ENHANCE THE QUALITY AND UTILIZATION OF MUNICIPAL WASTES

Composting is increasingly viewed as a viable means of processing municipal wastes into acceptable products that can be used beneficially as biofertilizers and soil conditioners (USEPA, 1989a,b,c; U.S. House of Representatives, 1990). A number of the problems associated with the use of raw and unstable organic wastes as soil amendments can be resolved by composting (e.g., malodors, human pathogens, and undesirable chemical and physical properties). Composting is a practice that farmers have used for centuries to convert organic wastes into useful soil amendments. Through composting, organic wastes are partially decomposed, plant nutrients are converted to inorganic plant-available forms, pathogens are destroyed, and malodors are abated.

Composting is a microbiological process that depends on the growth and activity of mixed populations of bacteria, actinomycetes, and fungi that are indigenous to the various organic wastes that are composted (see Chap. 18). Composting can be conducted under either aerobic or anaerobic conditions (see Chap. 20; Gotaas, 1956); however, the aerobic mode is generally preferred, since it proceeds more rapidly and provides for greater pathogen reduction because higher temperatures are attained.

During the early 1970s, scientists with USDA's Agricultural Research Service at Beltsville, Maryland, embarked on a research project to develop a process for rapid composting of sewage sludges that could be easily adopted by U.S. cities and municipalities to accommodate their increased sludge production problem. The method they developed is widely referred to as the Beltsville Aerated Pile Method, whereby sewage sludge is mixed with woodchips as a bulking material and then composted in a static pile with forced aeration for 3–4 weeks. A more detailed description of this process is reported elsewhere (Parr et al., 1978; Parr and Will-

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son, 1980; Willson et al., 1980). This particular version of composting according to USDA can be defined as:

> The aerobic, thermophilic decomposition of organic wastes by mixed populations of indigenous microorganisms under controlled conditions which yields a partially stabilized residual organic material that decomposes slowly when conditions again become favorable for microbiological activity.

There are several fundamental physicochemical parameters that must be at or near optimum levels if aerobic–thermophilic composting is to proceed rapidly and effectively. These are briefly summarized according to several references (see Chap. 18; Parr and Willson, 1980; Poincelot, 1975; Willson, 1989) and include temperature, moisture, aeration, C/N ratio, pH, particle size, microbial inoculants and additives, and contaminants.

When composting begins, the indigenous microorganisms start to utilize the organic materials for available C, N, and other nutrients. As the activity continues, the temperature begins to increase from heat that is generated through microbial oxidations and their respiratory functions. A typical time–temperature relation for composting sewage sludge under optimum conditions by the Beltsville Aerated Pile Method is shown in Figure 1 (curve 1). If any of the composting parameters discussed herein are not at or near optimum levels, then curve 2 is likely to result.

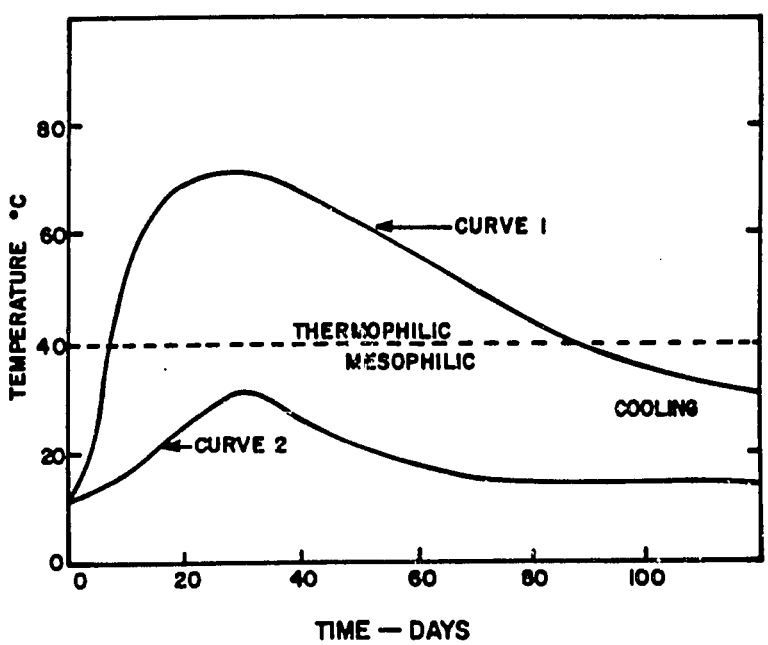

Figure 1 Typical time–temperature relation for composting sewage sludge by the Aerated Pile Method. Curve 1 depicts a situation for which conditions of moisture, temperature, and aeration are at optimum levels for rapid transition from the mesophilic into the thermophilic stage. Curve 2 represents a condition for which certain parameters are deficient or outside their optimum range, resulting in adverse effects on the growth and activity of the indigenous microorganisms.

Under ideal conditions, the internal temperature increases rapidly from the mesophilic to the thermophilic stage, which begins about 40°C. At this point, the mesophilic microorganisms are inhibited by the high temperature, whereas the thermophiles become very active. Eventually, as the available C and other nutrients are depleted, microbial activity subsides, decomposition slows, and cooling occurs. Decomposition of organic wastes is most rapid in the thermophilic stage. Optimal temperatures for sewage sludge composting have been found to range from 60° to 70°C. Pathogen destruction has been shown to occur rapidly in the thermophilic stage according to specific time–temperature functions (Burge et al., 1978).

The optimum moisture content of the waste material for rapid aerobic–thermophilic composting is 50–60% (w/w). If the moisture content is below 40%, decomposition will be aerobic, but slow. If the moisture content is above 60%, there may be insufficient air space to sustain aerobic decomposition, and undesirable anaerobic conditions may prevail.

A continuous supply of O_2 is needed to ensure aerobic–thermophilic composting. The rate of consumption of O_2 by the microorganisms will depend on several other factors, including pile or window temperatures, type of waste material being composted, particle size, and the moisture content.

Probably the most important consideration in composting is the C and N content of the waste material to be composted, usually expressed as the C/N ratio. Since the indigenous microorganisms require C for growth and energy and N for protein synthesis, the rate of decomposition is affected accordingly. Rapid aerobic–thermophilic composting is achieved with C/N ratios between 25 and 35. Lower ratios can result in the loss of N through volatilization as NH_3, whereas higher ratios can slow the composting process. The final C/N ratio of most composted organic wastes would range from 10 to 12, and possibly as high as 15 when large amounts of cellulosic materials are involved (Poincelot, 1975).

The optimum pH for rapid aerobic–thermophilic composting is between 6 and 7.5. However, research has shown that there is a wide pH range over which sewage sludges can be composted, with little apparent effect on the rate of decomposition.

In some cases, grinding or shredding of organic wastes, especially the biodegradable fractions of municipal solid waste, can accelerate the decomposition rate during composting by increasing the surface area for microbial utilization. However, excessive grinding before composting can lead to compaction and poor aeration which, in turn, can cause anaerobic conditions.

There has been considerable debate over whether the addition of special laboratory-cultured microorganisms and certain chemical additives can accelerate the composting process and improve product quality (see Chap. 22). If the C/N ratio of the composting biomass is unusually high, the addition of nitrogenous compounds can often accelerate the process by lowering the ratio and alleviating the microbial demand for N. Municipal wastes such as sewage sludges and yard wastes contain large populations of microorganisms, with a wide range of physiological capability. Thus, it is unlikely that in composting or cocomposting these materials, there would be much benefit from the use of commercial inoculants (Gotaas, 1956; Poincelot, 1975). Nevertheless, when the composting biomass contains substantial amounts of materials having very high C/N ratios, such as wood (700:1), sawdust (500:1), or paper (150:1), and that lack the necessary indigenous microorganisms for decomposing these materials, the use of microbial inoculants

may have considerable merit, even after adjusting the C/N ratio to a desirable level. Research is needed to determine the efficacy of inoculants in the composting of municipal wastes.

Standards for the utilization of composted and uncomposted sewage sludges on agricultural and nonagricultural land were recently proposed by the USEPA (USEPA, 1989b). On the basis of their content of heavy metals and organic pollutants (pesticides and other toxic organic chemicals), the standards require that sewage sludges applied to agricultural land do not exceed the established cumulative pollutant-loading rates. Such standards would also apply when cocomposting sewage sludges with mixed municipal solid waste, or separated fractions therefrom.

VI. THE VALUE OF ORGANIC WASTES AS BIOFERTILIZERS AND SOIL CONDITIONERS

The "value" of organic wastes as biofertilizers and soil conditioners has been the subject of considerable debate, and some clarification is needed. The simplest and most common method of estimating the value of organic wastes is to consider them as substitutes for commercial fertilizers. This is often done by assessing the current market value of the plant nutrients they contain, particularly their macronutrient content of N, P, and K. The value of four common organic wastes (i.e., cattle manure, crop residues, sewage sludge, and municipal solid waste) based on their average macronutrient content is shown in Table 5 (USDA 1978). This kind of evaluation shows that cattle manure is currently worth about 23 dollars/mt, whereas sewage sludge is valued at a slightly lower price of 21 dollars/mt. Crop residues and municipal solid waste have a considerably lower nutrient content and, thus, a lower market value as fertilizer substitutes. The value of the organic component of these and other wastes for improving soil tilth and productivity can be substantial. Unfortunately, the benefits of the organic component are often ignored.

Many organic wastes contain other components besides organic matter and macronutrients (N, P, K) that can contribute significantly to higher crop yields. These include secondary plant nutrients (S, Fe, Mg), micronutrients (Cu, B, Zn, Mn, Mo), and sometimes lime. If these constituents can substitute for essential production inputs, the value of the waste material would increase accordingly. However, some wastes may contain such things as soluble salts and excessive

Table 5 The Value of Some Organic Wastes Based on Their Macronutrient Content

Organic waste	Nutrients (%) N	P	K	Value[a] ($/mt)
Cattle manure	4.4	1.1	2.4	23.47
Crop residues	1.1	0.2	2.0	8.44
Sewage sludge	4.0	2.0	0.4	21.40
Municipal solid waste	0.7	0.2	0.3	3.66

[a]Value per kilogram of N, P, and K was set at $0.30, $0.37, and $0.20, respectively, based on average dealer prices/FOB of fertilizers at Midwest terminal locations, December 1990.
Source: Parr and Colacicco, 1987; USDA, 1978.

amounts of heavy metals and hazardous organic chemicals that can adversely affect soils, plants, animals, and the human food chain. Other materials may have especially high C/N ratios, or unusually high levels of acidity or alkalinity. Such constituents would likely reduce the value of some organic wastes for use as biofertilizers and soil conditioners (Parr et al., 1983). However, composting may still be a viable alternative for these materials by virtue of volume reduction preliminary to ultimate disposal.

In some cases, the organic fraction of a particular waste may have a higher monetary value than that of its total plant nutrient content because of the beneficial effect of organic matter on soil physical properties. This is especially true when organic materials, such as composted sewage sludge and feedlot manures, are used to restore the productivity of severely eroded agricultural soils or to reclaim marginal lands (Hornick, 1982; Hornick and Parr, 1987).

In discussing the value of organic wastes as biofertilizers and soil conditioners, it is often necessary to distinguish between their agronomic and economic values (Parr and Colacicco, 1987). The agronomic value of an organic waste relates primarily to the increase in crop yield or crop quality that is derived from its application. Although there are considerable published data to substantiate their beneficial effects on crop yield, little is known of how they might affect crop quality. Crop yield response to additions of organic wastes is highly variable and depends on the crop, soil type, climatic factors, soil and crop management practices, and the properties of the waste material. In most instances crop yield responses to the application of organic wastes is nonlinear. The greatest yield response is obtained with the first few increments of material, followed by progressively smaller yield increases with additional increments. An example of this is shown in Table 6 from which the greatest yield increase in corn grain was obtained with the first increments of sewage sludge applied to soil (Barbarika et al., 1980; Decker et al., 1977).

As with chemical fertilizers and other production inputs, crop yield response to an organic amendment follows the law of diminishing returns. Thus, the agronomic

Table 6 Effect of Single Applications of Sewage Sludge Applied to Soil in 1972 and Annual Applications of Chemical Fertilizer on Corn Grain Yields

Treatments	Corn grain yields 1972	1973	1974 (× 100 kg/ha)	1975	1976	Average
Sewage sludge[a] (dry mt/ha)						
0	25.1	21.1	6.8	16.2	0.9	14.0
56	55 4	68.7	64.6	54.4	38.5	56.3
112	66.5	102.8	68.7	66.0	67.1	74.4
224	61.2	108.4	76.5	69.4	69.2	76.9
N-P-K Fertilizer[b]	34.3	51.0	57.6	50.1	47.7	48.2

[a]Sewage sludge was applied at the rates indicated (mt/ha, dry weight basis) in 1972 only. No fertilizer was applied other than sewage sludge.
[b]Fertilizer plots received 180 kg/ha of N, 40 kg/ha of P, and 75 kg/ha of K each year of the study. No sewage sludge was applied.
Source: Barbarika et al., 1980; Decker et al., 1977.

value per unit of organic material tends to decrease as application rates increase. This is why the agronomic value per unit of material is higher to the farmer or gardener at low, rather than high, application rates. The nutrient content of most organic wastes of municipal, industrial, or rural origin are generally low and in the range of those listed in Table 5 (Parr and Colacicco, 1987). One option for increasing the agronomic value of organic wastes for beneficial use is to increase their macronutrient content by "spiking" them with chemical fertilizers. Obviously, the value of sewage sludge compost would be considerably enhanced if the N-P-K analysis were to increase from 1-1-1 to 5-5-5.

The economic value of an organic waste or residue to a farmer or gardener is the value of the increase in crop yield or crop quality that is derived from its use. The actual profitability resulting from the use of organic amendments will vary depending on the properties of the material, the cost of transportation and application, and the market value of the crop. An important consideration in establishing the economic value of an organic amendment is the rate at which it decomposes or mineralizes in soil. Organic wastes often have a greater residual effect on soil fertility than most chemical fertilizers because of the slow-release character of their nutrient components. Thus, a significant portion of the economic value of organic wastes as biofertilizers and soil conditioners is their ability to elicit yield responses from succeeding crops. This response must be accounted for to assess the true value of the material.

Barbarika et al. (1980), in their analysis of data from Decker et al., (1977), which is presented in Table 6, estimated that the cumulative economic value resulting from single applications of sewage sludge on corn grain yields could be considerably greater in succeeding years than the value realized during the initial year of application. For example, in this study, the average 5-year corn grain yield obtained from annual applications of N, P, and K fertilizers was 4800 kg/ha. By using the values of the fertilizers presented in Table 5, this represents an annual expenditure to the farmer of about 84 dollars/ha. Regression analysis of these data indicates that a one-time application of 45 mt of sewage sludge per hectare (dry weight basis) would give an average corn grain yield of 4800 kg/ha each year for the 5 years following sludge application. If we assume that fertilizer prices remained about the same, the farmer would spend 420 dollars/ha for fertilizer over a 5-year period. Therefore, the value of the sewage sludge to the farmer would be 420 dollars divided by 45 or 9.33 dollars/mt. If the farmer had to bear the cost of hauling and applying the sludge, the value would decrease accordingly. However, many times these costs are borne by the sewage authority.

VII. UTILIZATION OF MUNICIPAL WASTES AS BIOFERTILIZERS AND SOIL CONDITIONERS

Regular recycling of on-farm organic wastes such as animal manures and crop residues are vital to maintaining the tilth, fertility, and productivity of agricultural soils, protecting them from wind and water erosion, and preventing nutrient losses through runoff and leaching. These materials can vastly improve soil physical properties, such as increased water-holding capacity, soil aggregation, soil aeration and permeability, and decreased soil crusting, compaction, and bulk density (see Chap. 3; Allison, 1973; Flaig et al., 1977; USDA, 1957). In some agricultural situations,

there is a recognized shortage of good-quality on-farm organic materials to provide adequate soil and water conservation (USDA, 1978). Here, composts produced from sewage sludges and biodegradable fractions of municipal solid waste could be used to great advantage.

Soil productivity is defined as:

> The capacity of a soil for producing a specified plant or sequence of plants under a defined set of management practices. It is measured in terms of the outputs or harvests in relation to the inputs of production factors for a specific kind of soil under a physically defined system of management (USDA, 1957).

An important relation that is often overlooked is illustrated in Figure 2. For most agricultural soils, degradative processes such as soil erosion, nutrient runoff and leaching losses, and soil organic matter depletion occur simultaneously with the beneficial effects of soil conservation practices, such as conservation tillage, crop rotations, and recycling of organic wastes and residues (see Chap. 3; Hornick and Parr, 1987). As soil degradative processes intensify, there is a concomitant decrease in soil productivity. Conversely, soil conservation practices tend to offset the effects of the degradative processes and increase soil productivity. Thus, the potential productivity of a particular soil at any point in time is the result of ongoing degradative processes and applied conservation practices. A sustainable farming system is one in which the beneficial effects of conservation practices at least equal, or more than offset, the adverse effects of degradative processes. The most vital component in this dynamic equilibrium is soil organic matter, which enhances soil productivity in so many ways.

Extensive research by the U.S. Department of Agriculture (Hornick et al., 1984) has shown that sewage sludges that are suitably low in their content of heavy metals and toxic organic chemicals can be composted and used safely and beneficially as biofertilizers and soil conditioners. Similar benefits can also be derived from direct land application of uncomposted sludges (USEPA, 1989c). However, the main advantage of composting is producing a stable, humuslike material that can easily be handled, stored, transported, and applied. According to Hornick et al. (1984) good quality sewage sludge composts can be used as valuable organic soil

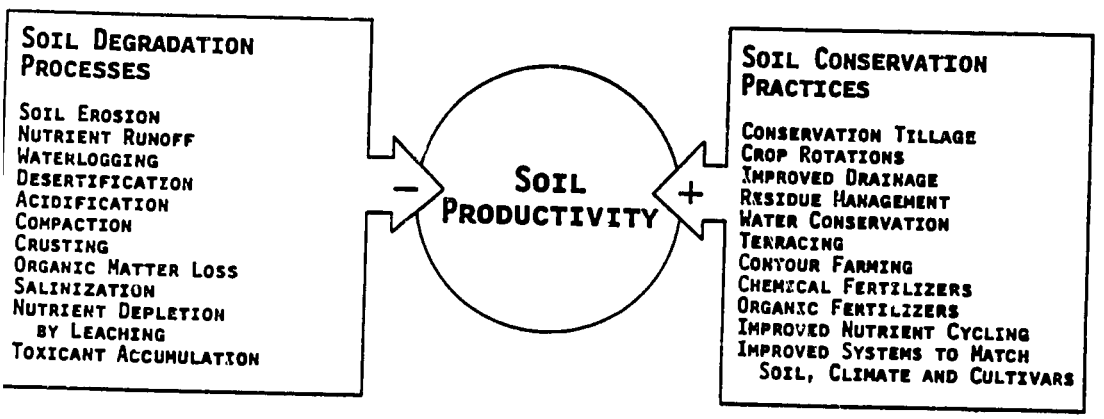

Figure 2 Relation of soil productivity to soil degradative processes and soil conservation practices.

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amendments in (1) production of agricultural and horticultural crops; (2) establishment, maintenance, and production of turfgrasses; (3) formulation of potting media for nursery production; (4) vegetable gardens; and (5) reclamation of marginal and degraded lands.

In utilizing municipal wastes for any of these purposes, one must consider whether their principal objective is to maximize N and P fertilizer benefits, or to improve soil physical properties. Uncomposted sewage sludges have a high nutrient availability index (NAI) and tend to decompose and mineralize rather rapidly in soils, thereby releasing a substantial amount of their nutrients (particularly N and P) for plant uptake. Composted sewage sludges generally have a high organic stability index (OSI) and decompose more slowly in soil, releasing plant nutrients at a comparatively slower rate (Parr and Colacicco, 1987). Materials with a high NAI value would be expected to have a low OSI value, and conversely. Thus, composted or cocomposted sewage sludges and municipal solid wastes would be expected to have their primary value as soil conditioners.

A successful strategy for using composted municipal wastes on land to restore or enhance soil productivity, and particularly that of degraded lands, is to apply a relatively high application of 25–50 mt/ha to improve soil physical properties, and then apply smaller annual applications of 5–10 mt/ha for maintenance. Because the contained nutrients would be released slowly, it is usually necessary to supplement the organic amendments with chemical fertilizers, particularly N, to ensure optimum plant growth.

Many of the properties of organic wastes discussed earlier that affect the composting process can also affect their rate of decomposition and N mineralization in soil. In addition, the rate of decomposition would be affected by the mode or method of application to soil (surface applied, injected, incorporated), the time of application (seasonal and climatic factors), and the rate and frequency of application. The chemical, physical, and microbiological properties of the soil to which the waste materials are applied would also affect the rate of decomposition and N mineralization, as well as immobilization of the mineralized N (Miller, 1974; Rothwell and Hortenstine, 1969; Ryan et al., 1973; Tester et al., 1977).

A substantial amount of our municipal organic wastes could be used beneficially on agricultural lands. For example, the 1985 Farm Bill established the Conservation Reserve Program (CRP), which provided for removal of highly erodible land from crop production for a period of 10 years. Some 14 million ha have now been set aside and planted mainly to perennial grasses and trees. Although much of this land should remain permanently in the CRP, it is estimated that about half of these retired lands could eventually be returned to crop production, some as early as 1996. The proper utilization of municipal wastes on such lands would enhance their productivity and protect them from further degradation, while allowing an acceptable level of crop production.

There are some who believe that agricultural use of composted or uncomposted municipal wastes represents a potentially vast and untapped market. This will depend on the production of high-quality products at prices that are acceptable to farmers. If we are looking to agriculture to help solve our municipal solid waste dilemma, the urban sector will need to make certain accommodations, which include subsidizing much of the cost of processing, transporting, and applying municipal wastes to land. In the future, substantial amounts of municipal wastes could be

utilized as organic amendments to improve the productivity of agricultural soils, and also to reclaim degraded urban lands (Kashmanian et al., 1990). However, research is needed to ensure that these wastes are converted into quality products and utilized in ways that are safe and beneficial to both the urban and agricultural sectors.

VIII. SUMMARY

The United States has traditionally disposed of its municipal wastes (i.e., sewage sludges and garbage) by ocean dumping, incinerating, and landfilling. These options have become increasingly restrictive because of rapidly escalating costs and tougher environmental regulations at the federal, state, and local levels. Some 20% of our sewage sludges and 80% of our municipal solid waste currently goes to landfills, the number and capacity of which will decrease to a critically low level by the year 2000. The total amount of municipal wastes generated represents a national resource of significant economic value, and there are several things our society can do to ensure that they are treated and utilized as such, including (1) source separation and recycling of municipal solid waste fractions, (2) collection and composting of yards wastes, (3) composting and cocomposting of sewage sludges and mixed municipal solid waste and market development for their safe and beneficial use on land, and (4) abatement of industrial waste discharge into sanitary sewers to improve the quality of wastewater sludges for utilization as biofertilizers and soil conditioners. All of these approaches would help to reduce the amount of sewage sludge and solid waste that is now disposed of in landfills.

Research is needed to develop process technology for composting and cocomposting sewage sludges and the biodegradable fractions of the municipal solid waste stream to enhance product quality and acceptability for agricultural and horticultural use. We need to determine the feasibility and practicability of improving the agronomic value of municipal wastes as biofertilizers, possibly through such means as spiking or enriching them with chemical fertilizers. Agriculture could be a potentially large market for use of municipal wastes as biofertilizers and soil conditioners to enhance soil productivity, particularly for marginal and degraded lands. However, the cost of processing, transporting, and applying them to land will need to be subsidized to a considerable extent by our urban society. In view of the rate at which landfill costs are increasing, enhancing the safe and beneficial use of these wastes for agriculture may provide the lowest-cost disposal option.

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