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EVALUATION OF SLUDGE, COMPOSTED SLUDGE, AND FLY ASH FOR THE GROWTH OF TURF AND CONTAINER PLANTS

A Thesis Presented

By

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EVALUATION OF SEWAGE SLUDGE, COMPOSTED SLUDGE, AND FLY ASH FOR THE GROWTH OF TURF AND CONTAINER PLANTS

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CHAPTER I

INTRODUCTION

In recent years public attention has focused on the growing problem of waste management. Legislation enacted and amended within the last decade reflects concern for environmentally sound waste disposal methods. The Clean Air Act Amendments of 1970 (Public Law 91-604) and 1977 (PL 95-95), the Resource Conservation and Recovery Act of 1976 (PL 94-580), and the Clean Water Act of 1977, as well as various state regulations, all emphasize efficient energy utilization, conservation, and recovery (U.S. EPA, 1979). Although currently in the United States a willingness exists to relax some environmental legislation, national policy or preference is unlikely to become one of laissez-faireism regarding the management of wastes. Thus, efforts to control the flow of materials that enter our environment and ourselves will undoubtedly continue.

While the enforcement of environmental legislation abates the indiscriminate discharge of potentially hazardous materials into our environment, it has effected large increases in the quantity of wastes to be managed. Sewage sludge and fly ash are two waste products that have been thus affected. Sewage sludge is composed of the solids that settle from suspension in the treatment of wastewater. Upon the achievement of secondary wastewater treatment throughout the United States, as required by Public Law 92-500, about nine million metric tons of sewage sludge will be produced each year (U.S. EPA, 1977). Fly ash accumulates as the particulates are removed from the stack gases in coal burning facilities. If national coal usage escalates as projected, over 200 million metric tons of fly ash could accumulate annually (Brackett, 1973).

Presently sewage sludge is managed by dumping or discharging into the oceans, incinerating, landfilling, spreading on cropland or designated land, and composting with about 50% of the sludge ending up on land (U.S. EPA, 1977). Many wastewater treatment facilities simply store sludge in lagoons without any further management plans. Most fly ash produced in the United States goes into landfills or lagoons and only about 15% is used in concrete and asphalt production and roadbed stabilization (Brackett, 1973). The ecological and economic problems associated with these disposal strategies has given us cause to review and abandon some of them. Utilization of these waste products in agriculture not only may be possible but also advantageous from the standpoints of disposal, plant growth, and soil stabilization.

Numerous examples of positive effects of sewage sludge and fly ash in agricultural systems have been reported. Sludge improves soil physical and chemical properties by adding organic matter and nutrient elements that are essential to plant growth (Epstein, Taylor, Chaney, 1976, Khaleel, Reddy, and Overcash, 1981).

Composted sewage sludge has been examined for its effects on soils and crops and improvements in both have been reported (Epstein _et al_., 1975, Mays _et al_., 1973, Sanderson and Martin, 1974). Beneficial effects of fly ash in soils are also both physical and chemical (Phung _et al_., 1978, Chang _et al_., 1977, Plank and Martens, 1973), and plant growth can be positively affected.

The use of sludges and ashes in agriculture is certainly no panacea. Many potential environmental and health risks are inextricably involved with land application of these materials. Sewage sludges typically contain from 2 to 8% N (Epstein, Taylor, and Chaney, 1976). Much of this N is available to soil microorganisms which can convert bound, organic N to free, inorganic N ions in sufficient quantities and at sufficient rates to cause high nitrate concentrations in crops and soils. In addition, the leaching of significant quantities of the nitrate thus generated can cause contamination of groundwater.

This potential for high levels of nitrate in soils, water, or plants due to application of sludge has been deemed by some to be the short-term limiting factor in the use of sludge on land (King and Morris, 1974). Many organisms that are pathogenic to humans are present in sewage sludge (Golueke, 1977, U.S. EPA, 1977), and may present a significant health hazard if crops grown on land amended with sludge are to be eaten raw or if soil conditions allow the movement of the pathogens into groundwater supplies (Christensen, 1977). Many sludges contain persistent organic chemicals of undetermined toxicity (Marcus, Taffel, and Pitts, 1978), and the use of sludge on land can be a way of recycling these contaminants into the food supply (Selinek and Braude, 1976). Numerous studies have demonstrated uptake by plants of sludge-borne heavy metals (Chaney, 1973, Cunningham, Keeney, and Ryan, 1975a, 1975b, Hinesly _et_ _al_., 1977, Kirkham, 1975). Those heavy metals known to be potentially dangerous to plants and consumers are cadmium, copper, molybdenum, nickel, and zinc (U.S. EPA, 1976).

The trace element content of fly ashes, although quite variable, is generally greater than the recipient soil (Hecht and Duvall, 1975). Thus, addition of fly ash to soil frequently results in accumulation by plants of some potentially toxic elements (Jastrow et al., 1981, Furr et al., 1976). These trace elements not only may accumulate to phytotoxic levels (Martens et al., 1970), but also to levels that may be dangerous to animals or people consuming the crop (Furr et al., 1976). Fly ash has also been shown to increase soil salinity, sometimes to levels that can damage the crop (Elseewi, Bingham, and Page, 1978), and to reduce the uptake and function of elements that are essential to the normal growth of plants (Rees and Sidrak, 1956).

The United States Environmental Protection Agency has placed a high priority on agricultural utilization of wastes, especially sewage sludge, as a disposal alternative (U.S. EPA, 1979). Research in this area has been carried out with such a diverse array of crops and soils in various environmental regimes, that it is difficult if not impossible, to draw many broad conclusions from the available data. The large variability in background hazards present in conventional cropping systems complicates the assessment of their manifestation in systems that have been amended with wastes (U.S. EPA, 1977). In view of the lack of generalizable predictions concerning environmental and health risks and benefits associated with the use of wastes on agricultural lands, each potential receptor system must be evaluated regarding its capacity for waste absorption with consideration given to human health impacts and future land productivity. Hence, a case study approach to waste management is advocated (U.S. EPA, 1976). The use of sewage sludge and fly ash in systems that are not linked to the food chain would minimize adverse health impacts and may represent the more sensible means of waste utilization in agriculture.

This research will focus on the use of sludge, composted sludge, and fly ash for the production of ornamental plants in containers and for the establishment of a turf grass in the field. Specifically, the contributions of these waste products to soil fertility and plant growth and composition will be evaluated. Because the use of sludge and fly ash may occasionally be a viable alternative in systems linked to the food chain, an assessment of the hazards from trace elements and nitrate resulting from their use will be made.

LITERATURE REVIEW

Greenhose and Nursery Uses of Sludge and Compost

Many growers of greenhouse and nursery crops culture ornamental plants in containers. They are continuously in need of inexpensive, uniform, and readily available sources of organic matter to extend, improve, or replace soils used in potting mixes. Sphagnum peat has been widely used in combination with other soil amendments (Baker, 1957). The expense of peat has resulted in a shift by many growers to other materials (Joiner and Conover, 1967). Some of the materials that have been investigated for their utility as organic amendments include ground or composted barks (Airhart et al., 1978, Sterret and Fretz, 1977, Haynes and Goh, 1978, Gartner et al., 1973), various plant and animal remains and processing wastes (Shanks, 1974, 1976, Sprague and Marrero, 1931, Brown and Pokorny, 1975, Einert, 1972, Hileman, 1979). These amendments have generally been shown to be beneficial; yet, limited availability restricts their utility. In the case of bark, variability in the product is a problem (Van Hof, 1978, Johnson, 1978). Sewage sludge is increasingly available from wastewater treatment plants and many studies have shown the value of composted sludge as an amendment for soil containing and soilless plant growth media (Wooton, 1977, 1981, Gouin, 1977a, Gouin and Walker, 1977, Gogue and Sanderson, 1975, Sanderson 1975, 1980, Sanderson and Martin, 1974, Fuller et al., 1966, Touchton and Boswell, 1975). The utility of composts lies not only in the property of supplying nutrients to crops (Gogue and Sanderson, 1975, Elseewi, Bingham, and Page, 1978 Chaney et, al., 1980, Dowdy and Larson, 1975), but also in improving aggregation, water retention, and bulk desity of soils (Mays, Terman, and Duggan, 1973, Epstein, Taylor, and Chaney, 1976, Gouin 1977b, Gupta, Dowdy, and Larson, 1977, Kladivko and Nelson, 1979). Yield and quality of crops are reported to be improved when soils are amended with composts containing sludge (Purves and Mackenzie 1973, 1974, Gouin 1977a, Gouin and Walker 1977, Sanderson and Martin, 1974). In addition, the cost of composts containing sludge can be competitive with that of alternative materials such as peat and bark (Alpert, Epstein, and Passna, 1979). Sludge composts can be produced with the uniformity desired by the greenhouse and nursery industry by using a standardized method of composting developed by the Agricultural Research Service and modified by other workers (U.S. EPA, 1977, Epstein and Wilson, 1976, Wilson and Walker, 1973). The method utilizes aerobic and thermophilic conditions to stabilize a blend of sludge and woodchips, sawdust or other carbonaceous material. If sewage sludge compost were used in place of organic amendments and soil substitutes currently used in the Boston, Massachusetts area, the demand of the greenhouse and nursery industry could be met or exceeded by sludge produced at Metropolitan District Commission facilities (Marcus, Taffel, and Pitts, 1978).

Use of Sludges and Composts on Roadsides and Disturbed Lands

In order to minimize maintenance work on highway cuts and slopes and other disturbed areas, rapid revegatation and permanent cover are essential. Vegetative cover minimizes soil erosion by lessening the impact of raindrops, binding soil particles together, and slowing the flow of water across the soil surface. Many types of plants including grasses, legumes, and woody plants have been tested for their adaptability for soil stabilization and persistence (Bennett, 1971, Hamilton, Zak, and Havis, 1975, Zak *et al.*, 1972 Zak *et al.*, 1976). Grasses are frequently used alone or in combination with legumes to establish a quick, dense, and lasting ground cover that may later yield to planted or naturally encroaching shrubs and trees (U.S. EPA, 1976, Jones, Armiger, and Bennett, 1975, Zak *et al.*, 1977). Ultimately in selecting plants for revegetation one considers their ability to thrive in existing conditions of fertility, erosion potential, and climate. Once established, a healthy cover requiring little maintenance is desirable.

Unfortunately, exposed sites are often not suited for the establishment or maintenance of plants unless the soils are amended. Hauling good topsoil to an area for seedbed improvement is expensive and may not be possible due to limited available quantities or prohibitive cost. Consequently, research has been undertaken to determine the feasibility of producing an artificial soil that could substitute for or amend soils at sites to be revegetated and reclaimed (Gemmel, 1972, Schulte and Converse, 1977, Zak *et al.*, 1977). Sewage sludge and composts have been shown to be effective soil ameliorants by supplying nutrients to plants, improving the microclimate for seed germination, decreasing the bulk density, and improving water retention (Garcia, *et al*., 1974, Hill and Montague, 1976, Mathias, Bennett, and Lundberg, 1977, Stout, Bennett, and Mathias, 1978, Kahleel, Reddy and Overcash, 1981). Fly ash has also been examined for its utility as a soil amendment that can increase the pH of the soil (Adams, Capp, and Gilmore, 1972, Bennett, Armiger, and Jones, 1976, Zak *et al*., 1977), improve water retention and movement (Chang *et al*., 1977), and supply nutrients to plants (Elseewi, Bingham, and Page, 1978, Martens *et al*., 1970, Schnappinger *et al*., 1975, Plank and Martens, 1973).

Uses of Sludge and Composts on Cropland

The accumulation of sludge-borne heavy metals in plants and soils is a primary and long-term hazard associated with the disposal of sludge on cropland. Many researchers report increased concentrations of trace elements in soils when sludge is applied at several rates (Allaway, 1968, Anderson and Nilsson, 1972, Gaynor and Holstead, 1976, Hinesly *et al.*, 1977, Jones *et al.*, 1975, Jones Hinesly, and Ziegler, 1973, Lunt, 1953). The availability of these metals and accumulation in the food chain is influenced by a number of factors that have been the subjects of extensive study.

The pH of the soil is one of the most important factors controlling the availability to plants of trace elements (Bolton, 1975, John and Van Laerhoven, 1976, Cunningham, Keeny, and Ryan, 1975, Dowdy and Larson, 1975a, 1975b, Hahn and Kroontje, 1973, Santillan-Medrano and Jurinak, 1975, Zimdahl and Foster, 1976, Hodgson, 1963). The evidence indicates that at pH values less than 6.5 the heavy metals are generally available for uptake by plants.

Organic matter present in the soil or added with sludge may also influence the availability of trace elements to plants by the reversible association of metals with cation exchange sites and chelation in organic complexes (Leeper, 1972, Lindsay, 1972, Fuller, 1977, Holtzclaw *et al.*, 1978, Stevenson and Ardakani, 1972). Heavy metals may form chelates with short-chain organic acids that increase their solubility (Leeper, 1972, Lindsay, 1972, Fuller, 1977) or with humic and fulvic acids that reduce their solubility (Lindsay, 1972, Tan, Morris, and King, 1971). The ephemeral nature of organic matter has complicated research into its role in mediating metal availability. Debate continues as to whether the decomposition of organic matter in sludge results in increases in the availabilities of constituent metals (Haghiri, 1974, Leeper, 1972, Fuller, 1977, Chaney, 1974, Sims and Boswell, 1978, Dijkshoorn and Lampe, 1975).

The water content of the soil will also affect metal solubility by its effects on the oxidation-reduction status. The greater the water content of a given soil, the more reducing conditions will be and the greater will be the solubility of heavy metals (Bloomfield and Pruden, 1975, Engler and Patrick, 1975, Kirkham, 1975). However, sulfate-reducing bacteria can produce significant concentrations of sulfide under reducing conditions. Precipitation of metal sulfides, e.g. CdS, HgS, PbS, ZnS, may then occur and cause a decrease in the levels of these metals in solution (Sims and Patrick, 1978, Alexander, 1977).

Hydrous iron and manganese oxides in the soil are thought to exert the principal control on the fixation of cobalt, copper, nickel, and zinc by adsorbing, precipitating, and occluding these metals (Jenne, 1968, Leeper, 1972, Ellis and Knezek, 1972, Korcak and Fanning, 1981). Since these oxides commonly occur as coatings on particles, they are capable of exerting chemical activity exceeding that which would be expected from their total concentrations (Jenne, 1968). Thus the presence of even small amounts of iron and manganese oxides, and to a lesser extent aluminum oxides, may represent a trap for contaminant heavy metals.

Although the chemical composition of fly ashes varies considerably, they commonly contain large amounts of aluminum and iron occurring as silicates, oxides, and sulfates (Plank and Martens, 1973), with a lesser amount of manganese oxides (Theis and Wirth, 1977). Numerous trace metals including arsenic, cadmium, chromium, copper, lead, nickel, and zinc have been determined to be associated with iron and manganese oxide sinks that are abundant in fly ash (Theis and Wirth, 1977). The addition of fly ash to soils has been shown to reduce the uptake and accumulation of zinc by plants even though the fly ashes contained appreciable zinc (Schnappinger _et al_., 1975, Elseewi, Bingham, and Page, 1978). This effect was due to the liming property of the ashes which resulted in a reduction in the solubility of zinc and other heavy metals. Also possibly the zinc was rendered less available to the plants by complexation with aluminum, iron, or maganese oxides in the fly ash.

Research designed to calculate maximum rates of application of sludge to cropland made use of the relative and cumulative toxicities of different metals on a zinc equivalency basis (Chaney, 1973). It may be more appropriate to determine long term loading rates of sludge based on the concentration of heavy metals on an individual basis (U.S. EPA, 1976, Kelling _et al_., 1977, Mitchell _et al_., 1978). The quantity of sludge to be used in individual applications should be determined with consideration given to the nitrogen content of the sludge (U.S. EPA, 1977, King and Morris, 1974). Ultimately sludges to be utilized on cropland need to be subjected to analysis for nutrient elements and heavy metals and other toxic substances before discreet applications can be made. Putrescible and readily decomposable organic matter in the sludge should be allowed to oxidize or stabilize before being spread on land to minimize odor problems. Alternatively, the method of application should provide for the incorporation of the sludge in soil. Site characteristics such as slope, drainage, and depth to groundwater must be considered in order to minimize the runoff and percolation of contaminants into streams and groundwater supplies.

As the costs of fertilizers increase, changes in policy and preference may result in a significant desire to use more organic and inorganic wastes as nutrient carriers to supply at least a part of the needs of our crops. The impact of sewage sludge on the commercial fertilizer market in the United States would be relatively insignificant, however. Even if all of the sludge produced in the nation were to be applied to cropland, only 0.6% of the nitrogen, 3.2% of the phosphorous, and 0.4% of the potassium currently supplied by commercial fertilizers would be added in the sludge (U.S. EPA, 1979). Furthermore, only approximately 0.5% of the cropland in the United States would be involved if our entire sludge production were to be applied at rates designed to meet the total nitrogen requirement of crops grown on the affected land (U.S. EPA, 1976). However, in areas of the country where agricultural land is scarce, the Northeast, for example, proportionately more of the cropland than needed nationwide would be needed to dispose of sludge in this way. It has been estimated that if all of the sludge produced in Massachusetts in 1985 were to be disposed of on cropland, about 30% of this land would be required to receive a sludge containing 1% available nitrogen if it were applied to meet the crop requirements for this element (U.S. EPA, 1976). Thus, the potential local significance of sludge in the food chain could be considerable for places like New England.

CHAPTER II

PREPARATION OF COMPOSTS

Materials and Methods

In July, 1978, domestic sewage sludges from the wastewater treatment facilities at Amherst and Sunderland, Massachusetts, were obtained for use in the studies. The sludge from the plant at Amherst was a filter cake of approximately 20% solids as determined by drying the moist cake to constant weight in a forced-draft oven at 55 C. The cake was produced by subjecting a mixture of primary and secondary sludges to vacuum filtration. The Sunderland sludge was a mixture of primary and secondary sludges but had been dried in a sand bed. It was a granular material of approximately 80% solids, determined as above, and approximately 13% organic matter and 87% sand on a dry weight basis. The percentage of organic matter was determined by ashing the dried material in a crucible at 500 C overnight and determining the loss of weight upon ignition. The sludge from Amherst was blended with woodchips, fly ash, and cinders (bottom ash) for composting in windrows. The fly ash was obtained from the coal-burning powerplant operated by the Massachusetts Electric Company at the Brayton Point station at Somerset, Massachusetts. The woodchips and cinders were obtained locally from a saw mill and from the coal-burning power plant at the University of Massachusetts at Amherst. Sludge from the Sunderland treatment facility was not composted but was stockpiled for land-spreading at a later date. No appreciable heating, i.e. decomposition, of the stockpiled material was observed. Four different blends were made of the Amherst sewage sludge, woodchips, fly ash, and bottom ash, and their constituents are shown in table 1.

Table 1. Materials in composts

Compost	Sludge	Fly ash	Woodchips	Bottom ash
	parts by volume			
A	1			1
B	1		1	
C	1	1	1	
D	1	1	1	1

Analysis of the sludges and composts are shown in tables 2 and 3. Analysis of total N was performed by semi-micro-Kjeldahl digestion with NH_3 distillation into boric acid (Stubblefield and DeTurk, 1940). The NO_3^- analyses were done electrometrically with Cl^- removal by $AgSO_4$ (Barker, 1974). In preparation for analysis of the other elements, 1.000 g samples of dried and ground sludge or compost were dry ashed in a porcelain crucible at 450 C overnight. The ash was dissolved in concentrated HCl, evaporated to dryness and baked for one hour on a hot plate. The residue was redissolved in 2N HNO_3 and quantitatively transferred to a 25 ml volumetric flask. The analyses of K, Ca, Mg, Cd, Cr, Cu, Ni, Pb, and Zn were done by atomic absorption spectroscopy with deuterium arc background correction for Cd, Cr, Ni, and Pb.

The composting process was monitored by measuring the internal temperature of the windrows at a depth of approximately 45 cm by means of a probe-type thermometer. The measurements were made at approximately

Table 2. Concentrations of selected macronutrients in sludges and composts

	Total N	NO^{-}_{3}-N	P	Ca	Mg
	% dry weight				
Amherst Sludge	2.1	0.02	0.9	6.2	0.3
A	0.8	0.01	0.5	1.5	0.2
B	1.0	0.01	0.6	2.7	0.4
C	0.3	0.01	0.2	1.5	0.4
D	0.3	0.01	0.2	1.1	0.5
Sunderland Sludge	1.1	0.02	0.5	0.5	0.4

Table 3. Concentrations of selected micronutrient and potentially toxic elements in sludges and composts

	Cd	Cr	Cu	Ni	Pb	Zn
	ppm dry weight					
Amherst Sludge	5	210	1900	95	200	680
A	3	100	610	40	105	590
B	4	170	870	40	125	570
C	2	55	240	50	40	200
D	1	55	230	50	45	210
Sunderland Sludge	2	25	500	35	55	340

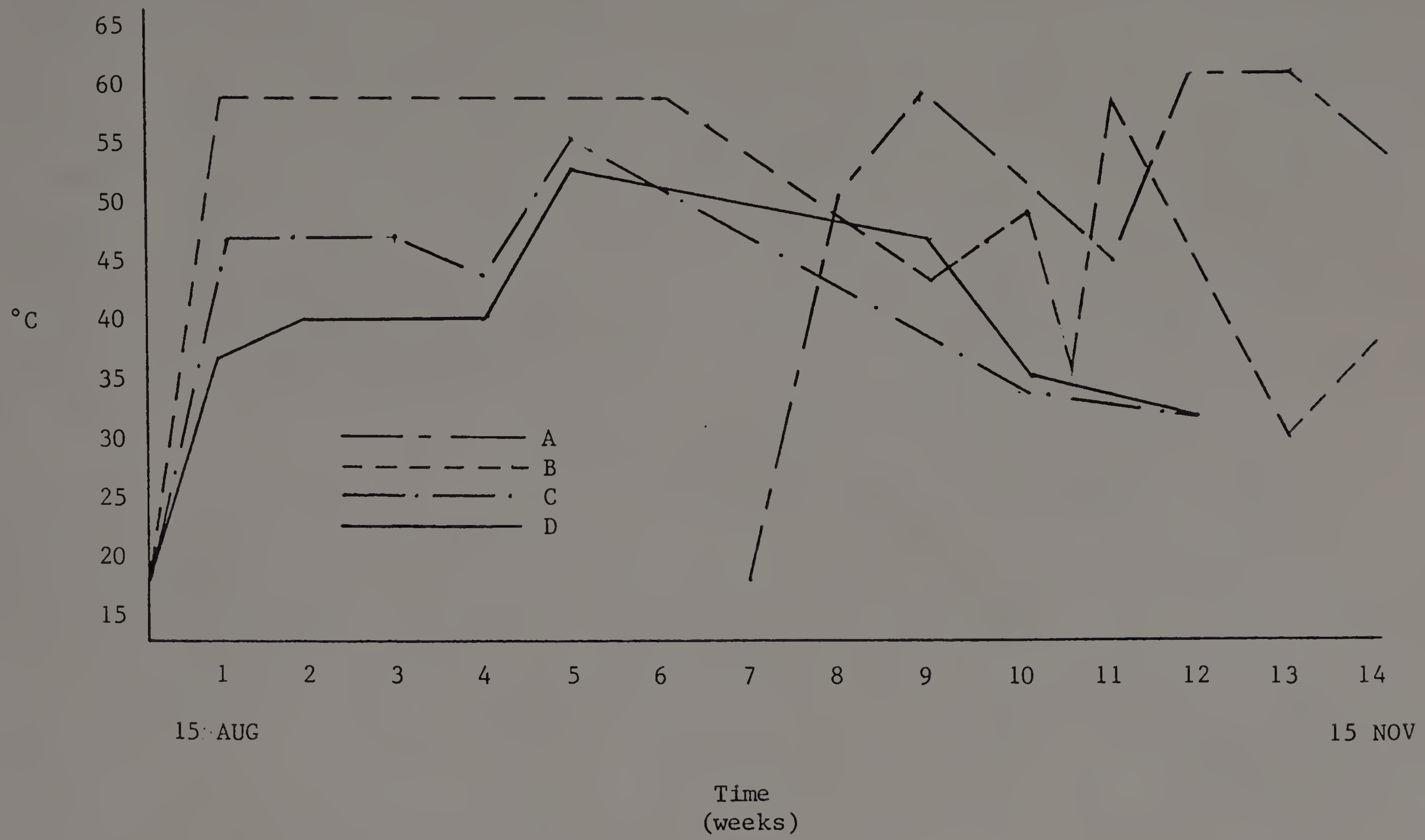
weekly intervals when the probe was inserted into each windrow in at least six points over its surface. The windrows were constructed with a slightly concave top to facilitate moisture collection and were approximately 2.5 m wide at the base, 1.5 m high, and varied in length from 5 to 7 m. Aeration of the windrows was accomplished by turning with a front end loader at time intervals which varied for each pile. A pile was turned when the average temperature dropped by 5 to 10 C from some previously observed plateau of higher temperature. There were instances where piles were turned when it was estimated that additional aeration might increase the rate of decomposition.

Results and Discussion

Figure 1 depicts the course of time versus temperature for each blend of materials in windrow. The highest temperatures reached were 60 C and 58 C in piles A and B, respectively. These temperatures are at or above the thermal death points for many common pathogens and parasites (Golueke, 1977). Temperature maxima were held for about five weeks for A and B and for about one week for C and D. The higher temperatures achieved, longer periods of temperature maintenance, and the longer duration of composting for mixtures A and B, probably reflect the greater fractions of organic matter and nitrogen in these windrows compared to C and D. Composts A and B contained 50% sludge volume; C contained 33% and D, had 25%.

Moisture and aeration, in addition to nitrogen and organic matter contents, affect the rate and extent of decomposition of organic materials. After 10 weeks of composting in windrows, C and D did not reheat after being turned. This observation indicates that the dropping and leveling off of temperatures at this time was not due to a limiting supply of oxygen since its replenishment did not cause a reheating of the pile. The piles remained moist throughout the study although no quantitative measurements of this parameter were made. Probably the amount of available N and organic matter were limiting the process of decomposition.

Figure 1. Time vs. temperature of windrows



In contrast to the 10 week composting period for C and D, pile B was still undergoing decomposition after 14 weeks as shown by the increase in temperature after turning the windrow at week 13. This observation would seem to indicate that there was adequate N and readily decomposable organic matter remaining at this time. Compost A was not constructed until the other composts had been decomposing for seven weeks. A temperature of 60 C was observed in A during its seventh week of composting indicating that rapid decomposition was occuring probably at this time. The large air spaces in this pile resulting from the use of cinders up to 5 cm in diameter may have allowed air from the exterior of the pile to infiltrate and create a more abundant supply of O_2 than that which existed in the other piles. Since woodchips were not included in this mix a narrower C:N ratio would have existed than in the other mixes. This condition would create an environment where more N would be available per unit of carbon and, coupled with an abundant supply of O_2, would ensure the activity of the microbes that were decomposing the material. Time to stabilization for this mixture, could it have been measured, would probably have been the least of all four blends since there was less carbon per unit of nitrogen. Thus microorganisms would deplete the carbonaceous substrate before nitrogen could limit their activity.

After 12 weeks of composting, mixes C and D were stabilized since they did not reheat after they were aerated. Mixes A and B would have continued undergoing decomposition after the 14th week had they not been moved. When deposited at the new site, these piles were merely dumped in high, narrow piles that may have been of insufficient cross-sectional area to allow them to insulate the interiors. Thus with the onset of freezing weather the piles froze. In addition, O_2 may have been limiting further decomposition as the crushing force of the weight of a tall pile could force a reduction in intersticial volume and express air from the pile. The use of the static-pile composting method (U.S. EPA, 1977) obviates problems with reheating resulting from moving or turning windrows during periods of sub-freezing temperature. The need to turn windrows is eliminated since air is forced into the pile. Thus, the interior of a composting mass need never be exposed to low temperature until it is stabilized. Windrows might be mechanically aerated during periods of sub-freezing temperature and go on to decompose provided that they are reconstructed properly. When turning windrows the material should receive a tumbling action rather than a compressive one to ensure adequate intersticial volume and O_2 concentration. The reconstructed pile should be about 1.5 to 2.0 m high and as wide as convenience or mass of material dictates (Golueke, 1977).

CHAPTER III

EVALUATION OF SLUDGE AND COMPOSTED SLUDGE AS ARTIFICIAL LOAMS OR SOIL AMENDMENTS

Since topsoil or loam may be scarce or expensive, scientists have tested the feasibility of making an artificial soil or of using materials other than topsoil as amendments to an existing soil for the establishment of plants used in erosion control or in land reclamation (Gemmel, 1972, Schulte and Converse, 1977, Zak *et al*., 1977).

In this research, two domestic sewage sludges, four composts (each containing sludge), fly ash, and conventional fertilizers were compared to unamended soil to evaluate their efficacy in establishing a stand of Kentucky-31 tall fescue (*Festuca arundinacea* Shreb). While the principal objective was to assess the growth and plant cover produced by the treatments, other parameters including trace elements and nitrate accumulation by the plants were measured in order to assess risks from the use of sewage sludge and fly ash as soil amendments. In addition, the placement of the amendments on the surface or within the soil was evaluated for its effect on the growth and mineral composition of the fescue.

Materials and Methods

The cropping area for the study consisted of a plot with Hadley fine sandy loam (Typic Udifluvent) according to the Franklin County, Massachusetts Soil Survey (U.S. Department of Agriculture, 1967). The 595 m^2 area had not been tilled or limed for at least 15 years and had moss as its principal cover. The soil pH was 4.4. In July, 1979, the plot was plowed to a depth of approximately 16 cm and then rotovated and lightly disked to cut some of the moss. Three days later the area was levelled with a roller. An area of 24.4 m X 24.4 m was staked off and divided into four blocks that were 12.2 m X 12.2 m. Each block was divided into 25 plots that were 1.5 m X 1.5 m with 0.6 m border strip between plots. Treatments were applied in a randomized complete block design on 16 July 1979 and were as described in table 4. The amendments were allowed to equilibrate with the soil for two weeks during which time some weeds, especially crabgrass, were able to establish themselves. At this time, one week before seeding, glyphosate was sprayed on the area at a rate of 274 g a.i./ha. The fescue seed was spread with a drop-type spreader at a rate of 252 kg/ha on 8 August 1979. The seed was then raked into the surface of the soil, and the area was covered with tobacco netting and irrigated.

The tobacco netting was removed and samples of the soil were taken to a depth of 15 cm and dried on a greenhouse bench on 18 August.

On 11 September the quality of the stands of fescue was evaluated visually on a scale of one to five. The color of the foliage and the

Table 4. Description of treatments in artificial loam study

	Treatment	Description
Applied to surface of soil	A_1	5 cm of compost
	B_1	5 cm of compost
	C_1	5 cm of compost
	D_1	5 cm of compost
	Sn_{A1}	Sunderland sludge (448 kg N/ha; 46t sludge/ha)
	Sn_{B1}	Sunderland sludge (56 dry t/ha)
	B_1+FA	3.3 cm compost + 1.7 cm fly ash
	C_1+FA	3.3 cm compost + 1.7 cm fly ash
	BA_1	2.5 cm bottom ash
	BA_1+LNPK	2.5 cm bottom ash + 112 kg N/ha 10·10·10 + 4878 kg/ha limestone
	W_1	2.5 cm woodchips
	W_1+LNPK	2.5 cm woodchips + 112 kg N/ha 10·10·10 + 4878 kg/ha limestone
Incorporated with soil	A_2	5 cm of compost
	B_2	5 cm of compost
	C_2	5 cm of compost
	D_2	5 cm of compost
	Sn_{A2}	Sunderland sludge (448 kh N/ha ; 46t sludge/ha)
	Sn_{B2}	Sunderland sludge (56 dry t/ha)
	Am_A	Amherst sludge (448 kg N/ha; 21t sludge/ha)
	Am_B	Amherst sludge (56 dry t/ha)
	B_2+FA	3.3 cm compost + 1.7 cm fly ash
	C_2+FA	3.3 cm compost + 1.7 cm fly ash
	FA_2	5 cm fly ash
	LNPK	112 kg N/ha from 10·10·10 + 4878 kg/ha limestone
	SOIL	Hadley fine sandy loam

Table 5. Amounts of N, P, and K supplied by sludges at fertilizer and disposal rates and by 10-10-10

Nutrient carrier	N	P_2O_5	K_2O
		kg/ha	
10-10-10	112	112	112
Amherst sludge			
fertilizer (21t/ha)	448	380	30
disposal (56 t/ha)	1120	950	75
Sunderland sludge			
fertilizer (21 t/ha)	448	513	59
disposal (56 t/ha)	616	705	81

height and coverage of tillers were evaluated subjectively while attempting to assign equal weight to each characteristic. Samples of the foliage were taken on 19 October by tossing a 25.5 cm diameter ring into each plot and cutting the foliage on tillers within the ring to a height of 4 cm above the surface of the soil. Samples of the soil in each plot were taken to a depth of 15 cm and dried on a greenhouse bench on 23 October. On 29 November another three sets of samples were taken at 0 to 5, 5 to 10, and 10 to 15 cm into the soil and dried on a greenhouse bench.

The harvested tissue was weighed, rinsed in deionized water,dried in a forced draft oven at 55 C to constant weight, and ground to pass a 20-mesh sieve in a Wiley mill.

Total N in leaves was determined by semimicro-Kjeldahl digestion using HgO as a catalyst, and with NH_3 distillation into boric acid (Stubblefield and DeTurk, 1940). Measurements of NO_3^- in leaves were done electrometrically with Cl^- removal by $AgSO_4$ (Barker, 1974). The ashing procedure consisted of digesting 1.000 g of dried, ground tissue in concentrated HNO_3 and 30% H_2O_2.

Determinations of Ca, K, Mg, Cd, Cu, and Zn were made by atomic absorption spectroscopy on the tissue that had been digested. Deuterium arc background correction was used for the Cd determinations.

The pH of the air-dried soil samples was measured electrometrically. The soil was suspended in a 0.01 M $CaCl_2$ solution in a 1:2 (soil: $CaCl_2$) ratio, and the pH of the suspension was measured with a glass electrode with one hour of equilibration after stirring.

Results and Discussion

The dry weights of the fescue produced by each treatment are presented in table 6. Some non-orthogonal comparisons of selected groups of treatment means for dry weight are shown in table 7. The greatest yield of dry matter was produced by treatment Sn_{B2}, followed by B_2, Am_B, and Sn_{B1}. These results may be due to the facts that the greatest amounts of N and P were supplied by treatments Sn_{B1}, Sn_{B2}, and Am_B. The sludge amendments allowed production of more fescue dry matter than the unamended soil regardless of the mode or rate of application of the sludge. Both sludges produced yields exceeding that from LNPK fertilizer when applied at the disposal rate. However, table 7 shows that when the sludges were applied at the fertilizer rate, the yields did not differ significantly from the yield from LNPK fertilizer. Although more N and P were supplied with the sludges than with the LNPK fertilizer, much of the N and P are in forms unavailable to plants. Hence, no yield response from the additional N and P is observed compared to the fertilizer.

In general the composts produced significantly more fescue dry matter when incorporated in the soil than when spread on the surface. The yield of fescue was significantly greater in soil fertilized with LNPK compared to the yield from applying composts to the soil surface. Each compost gave an increase in dry matter production in comparison to that produced in unfertilized soil. The yield of fescue was increased by incorporating compost B in soil, was not affected by incorporating compost D, and was depressed by incorporating A and C,

Table 6. Yield of dry matter of fescue and quality rating of turf

Treatment[1]	Dry weight	Rating[2]
A_1	0.98 mn	1 ½
A_1+FA	2.55 fghi	3
A_2	2.30 ghijk	3 ½
A_2+FA	2.70 efgh	3 ½
B_1	1.96 ijkl	3
B_1+FA	3.46 d	3 ½
B_2	4.41 b	4
B_2+FA	2.90 efg	4
C_1	2.42 ghij	3
C_2	1.88 jkl	2
D_1	2.26hijk	2
D_2	2.99 fghi	3
Am_A	3.61 ed	3
Am_B	4.20 b	3 ½
Sn_{A1}	2.50 ghi	2 ½
Sn_{A2}	2.72 efgh	3
Sn_{B1}	4.05 bc	2
Sn_{B2}	5.33 a	5
FA_2	1.74 kl	3
BA_1	0.42 e	1
BA_1+LNPK	1.97 ijkl	1
W_1	0.35 e	2
W_1+LNPK	1.45 lm	2
LNPK	3.03 e	3
SOIL	0.52 no	2

[1] Subscripts: 1=applied surface, 2=incorporated with soil, A=fertilizer rate, B=disposal rate.

[2] 1=poor, 5=excellent

Mean separations by Duncan's New Multiple Range Test at the 1% level.

Table 7. Non-orthogonal comparisons of selected treatment means for dry weight

Comparison	t	Comparison	t
$(A_2+B_2+C_2+D_2) - (A_1+B_1+C_1+D_1)$	3.9**	$(A_{1+2}+B_{1+2}) - (C_{1+2}+D_{1+2})$	n.s.
LNPK $- (A_1+B_1+C_1+D_1)$	2.8**	$(A_{1+2}+B_{1+2})$ - LNPK	n.s.
$(A_{1+2}+B_{1+2}+C_{1+2}+D_{1+2})$ - SOIL	4.3**	$(C_{1+2}+D_{1+2})$ - LNPK	n.s.
$Am_{A+B} - (A_{1+2}+B_{1+2}+C_{1+2}+D_{1+2})$	4.6**	$(A_2+B_2+C_2+D_2)$ - LMPK	n.s.
Am_B - LNPK	2.2*	Am_A - LNPK	n.s.
Am_{A+B} - SOIL	7.3**	Sn_{A1+2} - LNPK	n.s.
Sn_{B1+2} - LNPK	3.6**		
$(Sn_{A1+2}+Sn_{B1+2})$ - SOIL	7.4**		
FA_2 - SOIL	2.3*		

compared to LNPK.

Dry weights of fescue produced by soil amendment with composts containing fly ash did not differ significantly from those produced by composts without fly ash (table 7). However, yields produced by soil amendment with composts A and B were improved when fly ash was added to these composts after the completion of the composting process. This effect was most apparent with A + FA and B + FA when they were spread on the soil surface and the yields compared to A and B that had also been applied to the surface. An explanation for this yield response may be that the fly ash contributed a substantial amount of fine particles to the composts. This would provide a better medium for seed germination and seedling establishment compared to the compost alone which, when applied to the surface, would provide a coarser medium. An improvement in performance might be observed if the composts were screened before application. The liming effect of the added fly ash may also have increased the yield over that from A and B alone.

Applying the Amherst sludge directly to the land resulted in significantly greater yield than when the sludge was composted before application. An exception to this is treatment B_2 for which no significant difference existed for yield compared to the disposal rate of sludge. Yield from B_2 exceeded that from the fertilizer rate of sludge. Sludges and composted sludge were not applied at equivalent fertilization rates.

The composting process may convert some nutrients, especially N, into forms that are less available to plants than those in the fresh sludge. In addition, composting may increase N less by volatilization. An odor of ammonia was apparent during the turning of windrows on many occasions. Because of the added carbon in the composts containing woodchips, the C:N ratio of the soil amended with composts would be wider than that of the soil amended with sludge alone. A wider C:N ratio would result in less N being available to the fescue even if equivalent amounts of N were applied as composts or sludge. Greater quantities of compost than used in the experiment would seem warranted on the basis of N availability.

Using mulches of bottom ash (BA_1) and woodchips (W_1) depressed the yield of fescue compared to soil alone. Treatments BA_1 + LNPK and W_1 + LNPK produced significantly less dry matter than LNPK without the mulches. These treatments do not seem suitable for the intended use of establishing fescue.

Adding fly ash to the soil resulted in a significant, positive yield response compared to unamended soil. This may be principally due to the liming property of the fly ash which raised the soil pH to 6.7 in the 0 to 5 cm depth and to 6.4 in the 5 to 10 cm depth.

Data for total N and NO_3^--N in the fescue clippings are shown in table 8. The highest concentrations of N and NO_3^- were accummulated by the plants grown on the two sludges at the disposal rate. These observations, as well as the fact that the highest yields were produced by the sludges at the disposal rate, indicate that N supply and N accumulation could have played a role in creating the high yields from these treatments. Total N and NO_3^--N in the tissue were found to be significantly correlated with dry weight. Values of r were 0.73** and 0.53** for NO_3- and total N, respectively.

Data for individual composts show significant differences in percent N or NO_3^- accumulated in tissue when comparisons are made between

Table 8. Total N and NO_3^-- N in harvested portion of fescue tissue

Treatment	Total N (% dry weight)	NO_3^-- N
A_1	2.3 h	0.03 d
A_2	2.4 g	0.03 d
B_1	2.2 i	0.02 d
B_2	2.5 f	0.10 c
C_1	2.8 c	0.09 c
C_2	2.6 e	0.05 cd
D_1	2.5 f	0.04 cd
D_2	2.6 e	0.05 cd
Am_A	2.7 d	0.10 c
Am_B	3.1 a	0.23 b
Sn_{A1}	2.5 f	0.09 c
Sn_{A2}	2.6 e	0.06 cd
Sn_{B1}	3.0 b	0.21 b
Sn_{B2}	2.7 d	0.42 a
LNPK	2.6 e	0.11 c
FA	2.7 d	0.06 cd
SOIL	2.3 h	0.03 d

Mean separations by Duncan's New Multiple Range Test at the 1% level the two modes of application (table 8). However, data in table 9 shows that when comparing across composts the amount of N or NO^-_3 accumulated was not significantly different whether the composts were applied to the surface or incorporated. Comparisons of effects of composts applied to the surface against those of inorganic fertilizer and of composts that were incorporated against inorganic fertilizer also show no significant difference in percent N or NO^-_3 accumulated. Those observations suggest that the composts are supplying N in amounts equivalent to the fertilizer.

The fact that no large pool of NO^-_3 was accumulated in fescue grown on soil amended with composts suggests that the NO^-_3 taken up by the plants was being assimilated approximately as rapidly as it was being taken up. It may also be that the mineralization of N in soil amended with composts is proceeding at a slower rate than in soil amended with either of the sludges. The composts and sludges were not applied on an N- equivalency basis and mineralization and nitrification were not measured. No hazardous level of NO^-_3 was found in tissue grown on any treatment. However, the concentration of 0.42% NO^-_3 found in tissue grown on Sn_{B2} is approaching the level of 0.5% that is considered to be a dangerous concentration in feed for ruminants (U.S. EPA, 1977).

Some factors contributing to the N balance in the systems amended with sludge or fertilizer are listed in table 10. The ratio of N accumulated to applied for each sludge treatment has been calculated and expressed as a percentage that can be compared to the same ratio for the fertilizer treatment. An amount equivalent to almost 70% of the N applied as 10·10·10 was recovered in the fescue. This is primarily due to the high solubility and availability of the N in the inorganic fertilizer. An average of 24% of the applied N was accumulated

Table 9. Non-orthogonal comparisons of selected treatment means of NO_3^--N and total N in fescue

Comparison	t (NO_3^--N)	t (total N)
$(A_1+B_1+C_1+D_1) - (A_2+B_2+C_2+D_2)$	n.s.	n.s.
$(A_1+B_1+C_1+D_1)$ - LNPK	n.s.	n.s.
$(A_2+B_2+C_2+D_2)$ - LNPK	n.s.	n.s.
$Am_{A+B} - (A_{1+2}+B_{1+2}+C_{1+2}+D_{1+2})$	5.9**	4.3*

Table 10. Partial N balance of treatments receiving sludge or LNPK fertilizer*

Treatment	N applied (kg/ha)	N accumulated (kg/ha)	$\frac{\text{N accumulated}}{\text{N applied}}$
Am_A	448	97	21.7
Am_B	1120	130	11.6
Sn_{A1}	448	63	14.1
Sn_{A2}	448	69	15.4
Sn_{B1}	616	121	19.6
Sn_{B2}	616	146	23.7
LNPK	112	78	69.6

*Values of N accumulated and $\frac{\text{N accumulated}}{\text{N applied}}$ are averages of four replications.

in fescue grown on treatment Sn_{B2}. One would not expect an accumulation of an equivalent percentage of applied N with sludge compared to inorganic fertilizer since it is less soluble and available and since about 4, 6, and 10 times more N was applied as sludge than as 10·10·10. Although lesser percentages of applied N were accumulated by fescue grown on soil amended with sludge compared to LNPK, the needs of the fescue for N were evidently being met since no symptoms of N deficiency were apparent. More N was accumulated by plants grown on soil amended with sludge at the disposal rate than at the fertilizer rate. A greater percentage of the N applied in the Sunderland sludge at the disposal rate was available to the fescue than with the Amherst sludge at the same rate. Incorporating the Sunderland sludge with soil instead of spreading it on the surface seemed to make available to the fescue more of the N that was applied.

Amending the soil with fly ash significantly increased the N concentration in the fescue tissue compared to the untreated soil. Possibly the organisms converting native soil N to forms available to the fescue were able to do so at a faster rate at the pH of 5.8 in the fly ash amended soil than at the pH of 4.4 in the untreated soil.

The Ca, K, and Mg concentrations accumulated by the fescue are shown in table 11. For Ca, the most apparent effect is from amending the soil with sludge. This resulted in increases in Ca concentrations in the tissue of 2.0 and 2.2 times for the fertilizer and disposal rates, respectively, compared to concentrations in tissue grown on unamended soil. Amending the soil with composts A and B also resulted in increases in foliar Ca compared to soil alone. These observations are probably due to the large amount of lime that is added to the sludge during treatment that is later supplying Ca to plants grown on soil

Table 11. Ca, K, and Mg in fescue leaves

Treatment	Ca	K	Mg
	% dry weight		
A_1	0.56 d	3.08 fg	0.20 i
A_2	0.44 fg	3.23 def	0.26 fg
B_1	0.61 c	2.97 fg	0.25 gh
B_2	0.52 e	3.64 b	0.29 cd
C_1	0.41 ghi	3.41 bcd	0.27 ef
C_2	0.36 k	3.54 bc	0.24 h
D_1	0.46 f	3.35 cde	0.28 de
D_2	0.37 jk	3.45 bcd	0.28 de
AM_A	0.82 b	2.37 h	0.28 de
AM_B	0.87 a	1.97 i	0.30 c
Sn_{A1}	0.41 ghi	3.33 cde	0.27 ef
Sn_{A2}	0.38 ijk	2.94 fg	0.25 gh
Sn_{B1}	0.42 fgh	2.87 g	0.33 b
Sn_{B2}	0.53 de	3.01 gh	0.37 a
LNPK	0.27 l	3.93 a	0.24 h
FA	0.35 k	3.18 def	0.29 cd
SOIL	0.40	2.95 fg	0.18 j

Mean separations by Duncan's New Multiple Range Test at the 1% level.

amended with the sludge. That the LNPK treatment resulted in a lower concentration of Ca in the fescue than the unfertilized soil is probably due to a dilution of Ca in the greater yield of foliage in the LNPK treatment than in the soil. The Sunderland sludge supplied Ca to the fescue yet not as much as the Amherst sludge. Again, this is a reflection of the method of treatment of the sludge since lime is not added to the sludge at the Sunderland facility. No symptoms of Ca deficiency were apparent on tissue grown on any treatment.

The greatest concentration of K occurred in fescue grown on the LNPK treatment. Plants grown on soil amended with sludge accumulated the least K. Sludge has a low concentration of K; therefore, little K fertilization resulted. The addition of the composts to the soil resulted in significantly greater concentrations of K in fescue leaves than the Amherst sludge. Possibly this K came from components of the compost such as woodchips and fly ash that are not present in the sludge.

While significant differences exist for the concentrations of Mg in the fescue leaves, the differences are rather small, and the range of values is narrow. Two observations are worthy of note. First, the unamended soil may be supplying Mg to barely meet the needs of the fescue. Second, the Sunderland sludge resulted in the greatest foliar concentration of Mg of any of the treatments.

Table 12 gives some non-orthogonal comparisons of treatment means of Ca, K, and Mg concentrations in the fescue leaves. Generally these comparisons show that the Amherst sludge is supplying more Ca to the plants than the Sunderland sludge or lime. They also show that the K fertilizer value of the sludges is less than that of inorganic

Table 12. Non-orthogonal comparisons of selected treatment means for Ca, K, and Mg in fescue leaves[1]

Comparison	t		
	Ca	K	Mg
$(A_{1+2}+B_{1+2}+C_{1+2}+D_{1+2})$ - LNPK	8.14**	n.s.	n.s.
$(A_{1+2}+B_{1+2}+C_{1+2}+D_{1+2})$ - SOIL	4.44*	n.s.	5.78*
$(A_{1+2}+B_{1+2}+C_{1+2}+D_{1+2})$ - Am	-13.38**	6.98**	n.s.
Am_{A+B} - LNPK	17.57**	-8.22**	n.s.
Am_{A+B} - SOIL	14.83**	n.s.	6.57**
$(Sn_{A1+A2}+Sn_{B1+B2})$ - LNPK	5.63*	-4.59*	4.17*
$(Sn_{A1+A2}+Sn_{B1+B2})$ - SOIL	n.s.	n.s.	8.08**
Am_{A+B} - $(Sn_{A1+A2}+Sn_{B1+B2})$	17.58**	-5.70*	n.s.

[1] A negative value of t indicates that the average of the portion of the comparison to the left of the minus sign is less than the average of the portion to the right of the minus sign.

fertilizer and not significantly different than that of the unamended soil. The addition of K fertilizer with sludges seems warranted.

The concentrations ofCd, Cu, and Zn in the fescue leaves are presented in table 13. In no case was a hazardous concentration of Cd reached either in terms of phytotoxicity or toxicity to animals that might consume the foliage (U.S. EPA, 1976). The greatest concentration of Cd resulted from amending the soil with Sunderland sludge although this sludge contained less Cd than the sludge from Amherst. The Cd applied with the Sunderland sludge may have been more available to the fescue because of the low pH of the soil receiving the sludge (tables 14 and 15). In contrast, the pH of the soil in plots amended with Amherst sludge were much higher. Thus the solubility of Cd applied with Amherst sludge would be less than with the Sunderland sludge. Significantly less Cd was accumulated by fescue grown on soil amended with fly ash than on unamended soil. This observation is again evidence of the low solubility of Cd at high pH.

It should be noted that the concentration of Cd in the fescue leaves was increased over that from soil alone only by the application of Sunderland sludge at the disposal rate. Also, the higher rate of Amherst sludge does not result in more Cd being accumulated by the fescue than with the fertilizer rate.

Concentrations of Cu and Zn in the tissue follow a pattern similar to that of Cd (for Cd and Zn $r = 0.89^{**}$). The more acidic environment in the soil amended with Sunderland sludge caused greater concentrations of Cu and Zn to be accumulated by the fescue. The concentrations of these metals found in the tissue are well below levels that would damage the crop or cause problems for consumers (U.S. EPA, 1976).

Table 13. Cd, Cu, and Zn in fescue leaves

Treatment	Cd	Cu	Zn
A_1	0.4 d	10 e	48 cd
A_2	0.6 c	18 a	50 cd
B_1	0.6 c	12 d	54 c
B_2	0.6 c	18 a	53 c
C_1	0.6 c	11 de	41 de
C_2	0.5 c	15 c	39 e
D_1	0.6 c	11 de	39 e
D_2	0.4 d	14 c	40 e
Am_A	0.5 c	14 c	43 de
Am_B	0.5 c	16 c	43 de
Sn_{A1}	0.6 c	14 c	48 cd
Sn_{A2}	0.5 c	17 b	54 c
Sn_{B1}	0.7 b	21 a	95 b
Sn_{B2}	0.9 a	22 a	140 a
LNPK	0.5 c	14 c	43 de
FA	0.4 d	10 e	27 f
SOIL	0.6 c	11 de	29 f

Mean separations by Duncan's New Multiple Range Test at the 1% level.

Data for soil pH, (tables 14 and 15), show that all of the composts and the Amherst sludge produced increases in pH when applied to the soil. The Sunderland sludge did not significantly alter the pH of the soil. Fly ash was very effective in raising the soil pH. The analysis of soil pH at different depths into the profile indicates that when the composts were rotary-tilled into the soil, they were not evenly mixed to the 15 cm depth. Values of pH for the 0 to 5 and 5 to 10 cm depths probablymore accurately represent the acidity of the root environment than the values obtained when the 0 to 15 cm samples were analyzed.

It would seem best to incorporate sludges or composts with the soil for best results in terms of dry matter production. Applying more compost or sludge to the surface, or screening it prior to application, may increase the yield of the crop compared to less compost or unscreened compost. It may be possible to apply greater quantities than the 56 t/ha of the sludges that were utilized since the large quantities of sludge applied do not adversely affect yield or dangerously increase the concentration of NO_3- in the fescue.

Fly ash appears to be an acceptable soil amendment, especially in combination with sludge, for raising the pH of the soil and for increasing dry matter production over unamended soil. Finally, some composts, notably B_2 and D_2, are as good as or better than LNPK, as applied, for the production of fescue dry matter. More research is needed to compare rates and methods of application of composts to conventional fertilization.

Table 14. Soil pH at time of seeding and at harvest[1]

Treatment	Seeding 0-15 cm*	Harvest 0-15 cm*
A_1	5.0 ef	5.1 cd
A_2	5.5 cd	5.3 cd
B_1	5.2 de	5.5 ab
B_2	5.8 bc	5.3 bc
C_1	5.5 cd	5.3 bc
C_2	6.0 b	5.2 c
D_1	5.5 cd	5.7 ab
D_2	6.0 b	5.8 a
Am_A	5.1 e	5.1 cd
Am_B	5.8 bc	5.5 ab
Sn_{A1}	4.5 gh	4.3 ef
Sn_{A2}	4.3 hi	4.3 ef
Sn_{B1}	4.5 gh	4.2 f
Sn_{B2}	4.7 fg	4.3 ef
LNPK	4.7 fg	4.6 e
FA	6.5 a	5.8 a
SOIL	4.4 h	4.4 ef

Mean separations by Duncan's New Multiple Range Test at the 5% level.

*Depth into soil profile from which sample was taken.

[1] Values of pH are means of five observations.

Table 15. Soil pH at harvest;different depths into profile[1]

Treatment	0-5 cm*	Harvest 5-10 cm*	10-15 cm*
A_1	6.5	5.4	4.8
A_2	6.0	5.8	5.6
B_1	5.8	4.6	4.4
B_2	6.4	6.4	5.6
C_1	6.6	5.7	4.6
C_2	5.6	5.0	4.7
D_1	6.8	6.0	5.0
D_2	6.4	6.5	4.7
Am_A	6.2	5.1	4.5
Am_B	6.5	6.0	5.4
Sn_{A1}	4.8	4.4	4.5
Sn_{A2}	4.5	4.2	4.3
Sn_{B1}	4.9	4.2	4.2
Sn_{B2}	4.7	4.2	4.2
LNPK	5.6	4.5	4.5
FA	6.7	6.4	6.0
SOIL	4.5	4.5	4.5

Mean separations by Duncan's New Multiple Range Test at the 5% level.

[1] Values of pH are means of two observations.

* Depth into profile from which sample was taken

CHAPTER IV

EVALUATION OF SLUDGE, COMPOSTED SLUDGE, AND FLY ASH AS SOIL AMENDMENTS FOR THE GROWTH OF TOMATOES AND MARIGOLDS IN CONTAINERS

Tomatoes

On 5 January 1979, tomato seeds (Lycopersicon esculentum Mill., cv. Heinz 1350) were sown into a 1:1 (v:v) mixture of peat and vermiculite. The seedlings were transplanted on 19 January into 10-cm peat pots containing the potting mix described in table 16. Liquid 20-20-20 fertilizer (3.9 ml/l) was applied as a drench at approximately ten-day intervals. The media described in table 16 were formulated, placed in pots, and moistened on 20 February. The seedlings were transplanted into 15-cm flower pots containing the various media on 9 March. Each treatment was replicated five times and the pots were arranged on the greenhouse bench in a randomized complete block design. An 18±3 C night temperature was maintained, and the ventilation system in the greenhouse was set to operate above 21 C.

Beginning on 9 March, a liquid 20-20-20 fertilizer was applied at approximately ten-day intervals as a 1500 ppm N solution of 100 ml. Ten applications of the fertilizer were made totalling 1500 mg each of N, P_2O_5, and K_2O. The fruit were harvested, weighed, and rinsed in deionized water on 7 June. Separate weights were recorded for the ripe and immature fruit from each plant. All ripe fruit were quartered and

Table 16. Description of soil media used in tomato and marigold studies [a]

Medium	Description
S[b]	sandy loam, pH 4.7, CEC 4.0 to 5.8 me/100g
$S+L_1$	S + 15 g CaO/pot
$S+L_2$	S + 30 g CaO/pot
SPS	S: peat: sand (7:3:2)
$SPS+L_1$	SPS + 15 g CaO/pot
$SPS+L_2$	SPS + 30 g CaO/pot
SPB[c]	S: peat: bottom ash (2:1:1)
FA_1[d]	S: fly ash: peat (10:1:4)
FA_2	S: FA: peat (8:2:4)
FA_3	S: FA: peat (9:3:4)
FA_4	S: FA: peat (8:4:4)
$S+A_1$[e]	S: compost A (1:1)
$S+A_2$	S: compost A (1:2)
A	compost A
$S+B_1$	S: compost B (1:1)
$S+B_2$	S: compost B (1:2)
B	compost B
$S+C_1$	S: compost C (1:1)
$S+C_2$	S: compost C (1:2)
C	compost C
$S+D_1$	S: compost D (1:1)
$S+D_2$	S: compost D (1:2)
D	compost D
SPS+Am	SPS + 100 g Amherst sludge/pot
POTTING MIX	fine sandy loam: peat: sand (1:1:1) + $CaCO_3$ to pH 6.5 +3.5 g superphosphate/l

[a] All ratios are on a volume basis.
[b] Soil passing 0.6 cm screen
[c] Bottom ash passing 0.6 cm screen
[d] Fly ash is a blend of fly ash: bottom ash (2:1,v:v)
[e] All composts passing 0.9 cm screen

dried to constant weight in Pyrex beakers in a forced-draft oven at 55 C. The dried tissue was then ground in a Wiley mill to pass a 20-mesh screen. The plant tops were harvested and weighed on 14 June. Recently expanded leaves were separated from the stem at the petiole, rinsed in deionized water, and dried to constant weight in a forced-draft oven at 55 C. The dried leaf blades and petioles were then ground in a Wiley mill to pass a 20-mesh screen.

The dry ashing procedure consisted of igniting 1.000-g samples of the dried and ground fruit or leaf tissue in porcelain crucibles at 450 C overnight. The ash was dissolved in concentrated HCl, evaporated to dryness and baked on a hotplate for one hour. The residue was redissolved in 2 N HNO_3, quantitatively transferred to a 25-ml volumetric flask, and brought to volume with distilled water. The Ca, K, Mg, Cd, Cu, and Zn concentrations in the ashes were determined by atomic absorption spectroscopy using deuterium arc background correction for Cd.

Soil samples were taken from each pot at 30 days and 100 days after the transplanting date. The samples were dried on the greenhouse bench and pH was determined electrometrically on a 2:1 (0.01 M $CaCl_2$:soil) supernatant after one hour of equilibration after stirring.

Results and Discussion

Table 17 shows the dry weight of shoots and the fresh weight of tomato fruit produced by each treatment. The yield data for the four lime treatments have been omitted since the plants grown on each of these treatments died due to excessively high pH. The pH of S+L_1, S+L_2, SPS+L_1, and SPS+L_2 were 7.8, 8.2, 7.8, and 8.1, respectively, 30 days after potting the tomatoes and were probably higher shortly after liming with the CaO. The yield of fruit and dry weight of shoots grown on SPS+Am are presented but no further data was collected since these plants were stunted at the onset of the experiment due to a toxic effect from the insufficiently cured sludge used to formulate this treatment. An incubation period for soil and sludge of greater than the two weeks utilized in this experiment would be necessary to eliminate the toxic effect of the fresh sludge. Experiments conducted in the winter of 1979-1980 indicate that when using sludge/soil mixtures for the culture of tomato plants in pots, a minimum incubation period of four weeks is necessary before the toxic effects abate. After four weeks of incubation, yields of tomato shoots grown in pots of soil amended with sludge were seen to equal or exceed the yield from limed and fertilized soil (table 27).

Each treatment, with the exception of SPS and Am, significantly increased the yields of dry weight and fruit weight compared to the unamended soil. In addition, each of the soil/compost mixes, with the exception of S+C_1, yielded shoot dry weight equal to or exceeding that from the potting mix. However, the yield of fruit from the potting mix was significantly greater than from any other treatment except S+B_2.

Table 17. Dry weight of tomato shoots and yield of fruit

Treatment	Shoot dry weight (g/plant)	Total Fruit (g/plant)	$\frac{\text{Ripe Fruit}}{\text{Total Fruit}}$ %
S	17.8 i	183.2 k	29.8 abcd
SPS	20.3 hi	127.2 l	19.6 cde
SPB	23.6 gh	314.6 ghi	13.8 def
FA_1	32.8 cde	337.4 ij	31.2 abcd
FA_2	35.0 bcde	291.4 ij	22.2 bcde
FA_3	33.6 bcde	357.4 cdef	6.8 ef
FA_4	38.6 abc	358.6 cdef	13.5 def
$S+A_1$	39.7 ab	381.2 cd	10.4 ef
$S+A_2$	42.2 a	354.4 def	9.7 ef
A	36.5 abcd	356.6 cdef	25.3 bcde
$S+B_1$	31.6 de	339.0 efgh	34.0 abc
$S+B_2$	33.1 cde	479.4 a	17.4 cdef
B	28.9 efg	434.6 b	33.3 abc
$S+C_1$	25.0 fgh	363.2 cde	34.2 abc
$S+C_2$	33.7 bcde	263.2 j	39.3 ab
C	34.1 bcde	306.8 hi	22.8 bcde
$S+D_1$	33.2 cde	323.4 fghi	23.6 bcde
$S+D_2$	32.1 de	346.6 defg	31.4 abcd
D	31.4 def	390.8 c	43.5 a
SPS+Am	17.3 i	29.8 m	0.1 f
POTTING MIX	32.6 cde	489.2 a	17.9 cdef

Mean separations by Duncan's New Multiple Range Test at the 5% level.

As a group the fly ash treatments did not produce significantly different quantities of dry weight compared to the potting mix but a trend of increasing dry weight with increasing amounts of fly ash added to soil was observed. The four fly ash treatments also allowed the production of more fruit weight than the unamended soil or SPS but not as much as the potting mix. Overall the compost or fly ash amendments allowed the production of shoot dry matter in a range equivalent to about 77% to 129% of that produced by the potting mix. Fruit weight produced by these treatments was equivalent to about 55% to 98% of that produced by the potting mix. These observations seem to indicate that the composts and fly ash, as used in this study, are adequate for the growth of tomato shoots but may require further refinements to produce satisfactory yields of fruit; which is, after all, the primary reason for growing tomatoes. Wooton (1977) has shown that screening composts into different size fractions and remixing the resulting fractions in specific proportions before blending with soil, results in satisfactory media for the growth of marigold (Tagetes), Petunia, and Zinnia. It may also be necessary to alter the nutritional regime to better accomodate the requirements of tomato plants.

The percentage of fruit that was ripe at harvest was negatively correlated with shoot dry weight, r= -0.45**. Apparently, if the plants produce a large amount of vegetative growth, fruit ripening may be reduced compared to plants producing lesser amounts of vegetative growth. The percent ripe fruit was not significantly correlated with the yield of fruit. Both the total yield of fruit weight and the yield of ripe fruit were significantly correlated with Ca in leaves, r= 0.70** and

0.60** respectively. Since the compost amendments are supplying more Ca to the plants than the other treatments (table 18), these observations indicate that Ca supply may be an important factor whereby the composts are increasing the yield of fruit and may be enhancing the ripening of fruit.

Approximately 25 days after transplanting the tomatoes into the media containing fly ash, chlorotic areas were noticed on the tips and margins of the lower leaves with the exception of the plants growing in the FA_1 treatment. With time the leaf tips and margins became necrotic. These symptoms were determined in earlier work to be caused by an excess of boron in the leaves of tomato plants (table 28). High B concentrations in the leaves notwithstanding, the fly ash treatments improved yield over unamended soil. The yields from these treatments equalled or exceeded that produced by the potting mix.

The Ca, K, and Mg concentrations in the leaves of the tomato plants are shown in table 18. The composts supplied more Ca to the plants than the other treatments including the limed potting mix. This reflects the large amount of lime used in the treatment of the sludge that is a constituent of the composts. The generally lower concentrations of K found in the leaves of plants grown in compost amended soil compared to the potting mix and treatments S, SPS, and SPB, reflects the low amount of K in the sludge. Although K fertilizer was applied in the form of soluble 20-20-20 throughout the experiment, the media containing the composts were excessively porous and much of the applied K could have been lost by leaching. In contrast, the S, SPS, SPB, and potting mix treatments had slower perco-

Table 18. Ca, K, and Mg in tomato leaves

Treatment	Ca	K	Mg
		(% dry weight)	
S	0.82 fg	2.87 a	0.20 ijk
SPS	0.27 h	2.89 a	0.17 k
SPB	0.52 gh	2.20 b	0.20 ijk
FA$_1$	0.60 gh	1.36 cd	.034 def
FA$_2$	0.60 gh	1.32 cd	0.51 c
FA$_3$	0.60 gh	0.95 ef	0.52 bc
FA$_4$	0.87 fg	1.04 ef	0.74 a
S+A$_1$	1.87 cd	1.12 def	0.18 jk
S+A$_2$	1.96 bc	1.02 ef	0.18 jk
A	2.05 bc	0.67 g	0.24 hijk
S+B$_1$	2.02 bc	1.04 ef	0.26 ghi
S+B$_2$	2.99 a	0.87 fg	0.33 efg
B	2.94 a	0.92 ef	0.34 def
S+C$_1$	2.11 bc	1.29 cd	0.39 de
S+C$_2$	1.77 cde	1.32 cd	0.28 fgh
C	1.86 cd	1.34 cd	0.33 efg
S+D$_1$	2.30 b	1.17 de	0.42 d
S+D$_2$	1.54 de	1.38 cd	0.33 efg
D	2.28 b	1.50 c	0.58 b
POTTING MIX	1.44 e	1.54 c	0.39 de

Mean separations by Duncan's New Multiple Range Test at the 5% level.

lation rates than the media containing composts A and B. This could account for the higher K concentrations in the leaves of the plants grown in S, SPS, and SPB. Screening the composts through a mesh finer than the 0.9-cm screen used and including a greater proportion of finer particles in the media could result in higher concentrations of K in leaves than were found in this experiment.

The concentrations of Mg in leaves indicate that fly ash, whether used alone or as a constituent of compost, was supplying Mg to the plants. Concentrations of Mg in leaves increased with increasing quantities of fly ash in the media. The supplies if Ca, K, and Mg appear to have been adequate in all treatments with the possible exception of treatment A, since the concentrations of these elements in the leaves are in the range of values normally found in tomato leaves (Lorenz and Maynard, 1980).

The Cd, Cu, and Zn concentrations in the leaves of the tomatoes are shown in table 19. The Cu concentrations are at the high end of the range of sufficiency for most crops while the Zn concentrations are at the low end (Jones, 1972). Plants grown on treatment D may have been approaching Cu toxicity. Cadmium in the leaves may have been reduced by amending the soil with either fly ash or compost. Although the composts contributed Cd, Cu, and Zn to the media, they also raised the pH (table 21); thus the solubility of these metals was reduced compared to what it would have been in unamended soil. Whether the Cd found in leaves of plants grown in unamended soil was mostly soil-derived or was from Cd added from the environment is unresolved. Possibly Cd from rubber hoses used to water the plants contributed

Table 19. Cd, Cu, and Zn in tomato leaves

Treatment	Cd	Cu (ppm dry weight)	Zn
S	1.1 a	23 bc	48 a
SPS	0.3 g	19 bcde	22 ef
SPB	0.4 fg	21 bc	19 fg
FA_1	0.4 fg	18 cdef	21 ef
FA_2	0.5 ef	14 ef	14 g
FA_3	0.3 g	13 f	19 fg
FA_4	0.4 fg	15 def	14 g
$S+A_1$	0.7 cd	23 bc	33 bc
$S+A_2$	0.8 bc	23 bc	30 cd
A	0.7 cd	20 bcd	30 cd
$S+B_1$	0.7 cd	22 bc	26 de
$S+B_2$	0.9 b	23 bc	37 b
B	0.7 cd	22 bc	23 ef
$S+C_1$	0.6 de	23 bc	23 ef
$S+C_2$	0.5 ef	20 bcd	21 ef
C	0.6 de	21 bc	20 f
$S+D_1$	0.7 cd	22 bc	22 ef
$S+D_2$	0.3 g	18 cdef	24 ef
D	0.8 bc	44 a	26 de
POTTING MIX	0.3 g	25 b	19 fg

Mean separation by Duncan's New Multiple Range Test at the 5% level.

to the Cd found in the leaves.

Table 20 shows the Cu and Zn concentrations in the tomato fruit. Cadmium was not detectable (less than 0.3 ppm) in fruit grown on any treatment. While significant differences were found to exist between the Cu and Zn concentrations in the fruit, in practical terms these differences are probably not important from the standpoint of human consumption. Other crops normally accumulate Cu and Zn in edible portions in concentrations exceeding those found in this study (Giordano and Mays, 1976).

Most of the media underwent a drop in pH over the course of the experiment (table 21). This is probably due, in part, to the use of fertilizer containing NH_4^+. Each of the composts and the fly ash raised the pH of the soil to levels that were more favorable to the growth of tomatoes compared to the unamended soil (Lorenz and Maynard, 1980). This effect alone was probably responsible for some of the increase in yield of the plants. There does not appear to be any danger of excessive accumulation of Cd, Cu, or Zn by tomato fruit grown in pots on compost prepared from Amherst sludge. Screening the composts into smaller size fractions could improve the water retention capabilities of composts A and B. This could possibly improve the growth of plants grown in these media compared to what was observed in this study. In summary, both fly ash and the sludge composts would appear to be beneficial amendments for the acidic, low-fertility soil that was used. Each of these amendments needs to be tested against limed and fertilized soil to determine the relative improvements in plant growth from compost, fly ash, and lime amendments.

Table 20. Cu and Zn in ripe tomato fruit[1]

Treatment	Cu	Zn
	(ppm dry weight)	
S	11 bcd	29 a
SPS	9 cd	27 ab
SPB	7 d	21 b
FA_1	11 bcd	20 b
FA_2	10 bcd	21 b
FA_3	11 bcd	21 b
FA_4	10 bcd	21 b
$S+A_1$	12 abc	25 ab
$S+A_2$	13 abc	27 ab
A	11 bcd	21 b
$S+B_1$	14 ab	25 ab
$S+B_2$	12 abc	22 ab
B	12 abc	23 ab
$S+C_1$	13 abc	25 ab
$S+C_2$	11 bcd	24 ab
C	16 a	24 ab
$S+D_1$	14 ab	24 ab
$S+D_2$	13 abc	24 ab
D	14 ab	25 ab
POTTING MIX	11 bcd	20 b

[1] Cd was not detectable (less than 3 ppm) in fruit samples from all treatments.

[2] Mean separations by Duncan's New Multiple Range Test at the 5% level.

Table 21. pH of media cropped to tomatoes at 30 days and 100 days

Medium	pH	
	30 days	100 days
S	4.7 gh	4.2 i
SPS	4.5 h	4.7 gh
SPB	4.8 g	4.3 i
FA_1	5.3 f	4.5 hi
FA_2	5.7 e	4.9 g
FA_3	5.9 e	5.3 f
FA_4	6.1 e	5.3 f
$S+A_1$	6.5 d	5.4 f
$S+A_2$	6.6 cd	5.9 e
A	6.6 cd	6.4 ab
$S+B_1$	6.8 abc	6.0 cde
$S+B_2$	6.8 abc	6.2 bcd
B	6.9 ab	6.3 abc
$S+C_1$	6.7 bcd	5.9 e
$S+C_2$	6.9 ab	6.0 cde
C	7.0 a	6.6 a
$S+D_1$	6.8 abc	6.2 bcd
$S+D_2$	7.0 a	6.4 ab
D	7.0 a	6.5 ab
POTTING MIX	5.9 e	5.8 e

Mean separations by Duncan's New Multiple Range Test at the 5% level.

Marigolds

On 6 February 1979, marigold seeds (*Tagetes patula*, cv. Lemon drop) were sown into a 1:1 (v:v) mixture of peat and vermiculite. The seedlings were transplanted into 15-cm azalea pots, three seedlings per pot, when the first true leaves had expanded on 16 March. The media had been moistened 24 days earlier and were as described in table 16. Each treatment was replicated five times, and the resulting 125 pots were arranged on the greenhouse bench in a randomized complete block design. Four applications of liquid 20-20-20 fertilizer were made at approximately 20-day intervals beginning on the day of transplanting. Each application consisted of 100 ml of a solution containing 125 mg each of N, P_2O_5, and K_2O for a total of 500 mg of each nutrient added per pot. Buds and blossoms were counted separately on 21 May and were classified as indicated in table 23. After the flowers were removed on 7 June, the shoots were harvested at the soil line, weighed, rinsed in deionized water, and dried to constant weight in a forced-draft oven at 55 C. The dried shoots were then ground in a Wiley mill to pass a 20-mesh screen. The ashing and elemental analyses of the tissue were performed as for the tomato plants.

Soil samples were taken from each pot at 30 days and 80 days after the transplanting date. Determinations of pH were made electrometrically on the air-dried samples on a 2:1 (0.01M $CaCl_2$:soil) supernatant after one hour of equilibration after stirring.

Results and Discussion

The shoot fresh and dry weights, numbers of buds, numbers of blossoms, and fractions of buds in bloom are given in tables 22 and 23. Data for the two lime treatments have been omitted since the plants grown on these treatments were severely stunted due to overliming. The pH of $S+L_1$, $S+L_2$, $SPS+L_1$, and $SPS+L_2$ were 7.8, 8.2, 7.8, and 8.1, respectively, 30 days after potting the marigolds and were probably higher shortly after liming with the CaO. However, unlike the tomatoes, the marigolds were not damaged in the SPS+Am treatment and the data for this treatment are reported. This observation may be due to the fact that the media used for potting the marigolds had incubated for one week longer than the media used for the tomatoes and may have been less noxious. Possibly the marigolds are more tolerant of fresh sludge-soil mixtures than are the tomatoes.

Treatments B and $S+B_2$ increased the fresh weight of plants compared to each other treatment and the most fresh weight was produced in 100% compost. Treatments $S+A_2$, A, SPS+Am, and the potting mix also increased the fresh weight compared to most of the other treatments. Amending the soil with fly ash increased the fresh weight compared to unamended soil. However, all of the compost-soil blends and treatments A, C, and D depressed the yield of the plants compared to the potting mix. Further refinement of the composts by sceening into different size fractions and possibly altering the fertilization regime may result in yields more comparable to that of the potting mix.

Table 22. Fresh and dry weights of marigold shoots

Treatment	Shoot fresh weight (g/pot)	Shoot dry weight (g/pot)
S	17.3 k	2.85 h
SPS	25.1 hij	4.84 efg
SPB	30.6 fg	5.16 def
FA_1	37.0 de	6.13 cd
FA_2	34.1 ef	5.33 def
FA_3	30.3 fg	5.32 def
FA_4	29.8 fg	5.37 def
$S+A_1$	34.7 ef	5.55 def
$S+A_2$	42.6 c	6.06 cde
A	42.6 c	7.79 b
$S+B_1$	37.3 de	5.65 de
$S+B_2$	47.5 b	6.89 bc
B	57.8 a	10.01 a
$S+C_1$	28.9 gh	4.92 def
$S+C_2$	23.7 ij	3.63 gh
C	27.9 ghi	4.32 fg
$S+D_1$	21.0 jk	2.94 h
$S+D_2$	22.7 j	3.03 h
D	22.1 j	2.81 h
SPS+Am	43.0 c	6.86 bc
POTTING MIX	40.8 cd	9.20 a

Mean separation by Duncan's New Multiple Range Test at the 5% level.

Table 23. Number of buds[1], number of blossoms[2], and fraction of buds in bloom at harvest of marigold

Treatment	Buds (number/pot)	Blossoms (number/pot)	$\frac{\text{Blossoms}}{\text{Buds}}$
S	36 hi	15 gh	0.42 cde
SPS	44 defg	18 efg	0.40 ef
SPB	51 abcd	22 bcd	0.44 bcde
FA_1	52 abc	24 b	0.46 abcd
FA_2	51 abcd	24 b	0.47 abc
FA_3	51 abcd	24 b	0.47 ab
FA_4	49 bcde	23 bc	0.47 ab
$S+A_1$	49 bcde	20 cdef	0.42 cde
$S+A_2$	52 abc	23 bc	0.44 bcde
A	46 cdef	18 efg	0.44 bcde
$S+B_1$	51 abcd	21 bcde	0.41 def
$S+B_2$	53 abc	21 bcde	0.40 ef
B	56 ab	24 b	0.43 ab
$S+C_1$	48 bcde	19 def	0.39 ef
$S+C_2$	53 efgh	19 def	0.44 bcde
C	41 fgh	18 efg	0.44 bcde
$S+D_1$	50 fgh	17 fgh	0.43 cde
$S+D_2$	58 ghi	14 h	0.36 f
D	51 i	15 gh	0.49 ab
SPS+Am	43 efgh	18 efg	0.42 cde
POTTING MIX	57 a	29 a	0.51 a

[1] Buds counted include only those with a pedicel greater than approximately 1.7 cm (3/4 in.) in length.

[2] Blossoms counted include only those open buds showing petals.

Mean separations by Duncan's New Multiple Range Test at the 5% level.

The greater the fresh weight of the plants, the more buds were produced, r= 0.76**. More of the buds were in bloom on the harvest date on plants that produced the greater amounts of fresh weight, r= 0.75**. The fraction of buds in bloom was negatively correlated with the total number of buds per pot, r= -0.70**. These observations seem to indicate that the marigolds were, in general, growing well and would have continued to produce flowers beyond the harvest date. Composts A and B and the fly ash amendments generally produced buds in amounts equvalent to the potting mix. These treatments significantly depressed the yield of blossoms compared to the potting mix. However, the number of blossoms was significantly increased by A and B compared to S and SPS. In general, composts A and B produced significantly more buds and blossoms than SPS+Am.

Data for Ca, K, and Mg in the shoots are presented in table 24. Each of the composts increased the percent Ca in shoots compared to the potting mix, S, or SPS. The fly ash treatments did not significantly affect the Ca concentration compared to S or SPS but did depress levels of Ca in shoots compared to the potting mix. SPS+Am significantly increased Ca in shoots compared to S or SPS. Fly ash and composts containing fly ash significantly increased the concentrations of K and Mg in the shoots compared to the potting mix. These treatments also significantly increased the concentrations of Mg in the shoots, but not K, compared to S or SPS. Plants grown on composts A and B and SPS+Am possibly would have benefitted from more K fertilization. Wooton (1977) has shown the need for supplemental K when marigolds are grown in soil amended with composted sludge.

Table 24. Ca, K, and Mg in marigold shoots (% dry weight)

Treatment	Ca	K	Mg
S	0.82 i	2.68 bcde	0.18 l
SPS	0.73 i	2.54 def	0.28 k
SPB	1.36 gh	2.88 bcd	0.26 k
FA	0.70 i	2.80 bcde	0.68 bc
FA	0.79 i	3.03 abc	0.82 a
FA	0.72 i	2.68 cde	0.73 ab
FA	0.93 hi	2.62 de	0.86 a
A	2.08 efg	1.88 h	0.37 j
S+B	2.41 cdef	2.52 efg	0.49 efgh
S+B	2.32 def	2.57 def	0.55 def
B	2.19 fg	2.17 gh	0.49 fghi
S+C	1.87 g	2.65 de	0.39 ij
S+C	2.21 efg	2.72 bcde	0.52 efg
C	2.21 efg	2.84 bcde	0.61 cd
S+D	2.57 cd	3.04 abc	0.58 de
S+D	2.53 cde	3.29 a	0.59 cd
D	5.08 a	3.04 abc	0.85 a
SPS+Am	2.65 cd	2.48 efg	0.63 cd
POTTING MIX	1.14 h	2.23 fgh	0.42 hij

Mean separation by Duncan's New Multiple Range Test at the 5% level.

Table 25 shows the Cd, Cu, and Zn concentrations in the shoots. These data, as well as those in table 19 for tomatoes, illustrate the differences in heavy metal accumulation by different species. Overall the marigolds accumulated greater concentrations of these elements than did the tomatoes. As with tomatoes, some of the Cd may have entered the media, and subsequently the plants, as contamination from rubber hoses used to water the plants. Although, at pH 5.9 (table 26) in the S+A_2 treatment, the marigolds accumulated 2.0 ppm Cd which is not significantly different than the 2.1 ppm accumulated by plants grown in S at pH 4.2. One would not expect equivalent concentrations of Cd to be accumulated by plants in two environments differing so widely in pH if the Cd was coming from the same source. Evidently some of the Cd is coming from the sludge. The potential for the accumulation of over 2.0 ppm Cd in the foliage of plants grown in this relatively "clean" sludge would be cause for concern if plants grown were to be eaten in large quantanties or were to constitute a large portion of the diet (U.S. EPA, 1976). Plants grown in SPS accumulated a significantly lower concentration of Cd than those grown in S. This may be due to decreased solubilization of Cd in SPS because of the higher pH of 4.5 and the inclusion of peat in this medium. Possibly some Cd was immobilized in chelation complexes arising from the peat. Treatments FA_2, FA_3, and FA_4 significantly depressed the concentration of Cd, Cu, and Zn in shoots compared to most of the media containing composts or unamended soil; although the media containing composts generally had a higher pH than the media containing fly ash. Possibly the metals are coordinated in soluble chelation complexes that arise

Table 25. Cd, Cu, and Zn in marigold shoots

Treatment	Cd	Cu	Zn
S	2.1 ab	57 bcd	230 a
SPS	1.1 fgh	50 cdefg	187 b
SPB	1.4 def	54 cde	183 b
FA_1	1.1 fgh	45 efg	108 d
FA_2	1.0 ghi	39 gh	49 h
FA_3	0.7 ijk	38 gh	38 i
FA_4	0.5 k	40 fgh	37 i
$S+A_1$	2.3 a	58 bcd	73 ef
$S+A_2$	2.0 abc	58 bcd	77 e
A	1.3 efg	50 cdefg	78 e
$S+B_1$	1.7 cd	61 bc	69 f
$S+B_2$	1.4 def	59 bcd	71 ef
B	1.9 bc	54 cde	81 e
$S+C_1$	0.9 hij	51 cdef	38 i
$S+C_2$	1.0 ghi	54 cde	59 g
C	0.7 ijk	59 bcd	52 h
$S+D_1$	1.3 efg	54 cde	59 g
$S+D_2$	1.2 efgh	68 ab	55 gh
D	1.5 de	76 a	63 fg
SPS+Am	1.7 cd	47 defg	120 c
POTTING MIX	0.6 jk	32 h	31 i

Mean separations by Duncan's New Multiple Range Test at the 5% level.

Table 26. pH of media cropped to marigolds at 30 days and 80 days

Medium	pH	
	30 days	80 days
S	4.4 h	4.2 k
SPS	4.3 h	4.5 ij
SPB	4.3 h	4.3 jk
FA_1	4.9 g	4.7 hi
FA_2	5.6 f	4.5 ij
FA_3	5.7 f	4.9 h
FA_4	6.0 e	5.3 g
$S+A_1$	6.1 e	5.3 g
$S+A_2$	6.7 cd	5.9 e
A	6.5 d	6.3 bc
$S+B_1$	6.8 c	6.0 de
$S+B_2$	6.8 c	6.1 cde
B	6.5 d	6.2 cd
$S+C_1$	6.7 cd	5.9 e
$S+C_2$	6.9 bc	6.0 de
C	7.2 a	6.7 a
$S+D_1$	6.9 bc	6.2 cd
$S+D_2$	6.9 bc	6.3 bc
D	7.1 ab	6.5 ab
POTTING MIX	5.7 f	5.6 f

Mean separations by Duncan's New Multiple Range Test at the 5% level.

from the sludge and thus, are more available for uptake by plants. The Cu and Zn concentrations in the tissue are not excessive for an edible crop (U. S. EPA, 1977).

CONCLUSION

The results of these experiments emphasize the necessity for the evaluation of the potential for heavy metal accumulation of each species to be grown on soils amended with sludge or composted sludge. In addition, they demonstrate that sludges containing low concentrations of Cd can supply substantial amounts of this element to plants and that factors in addition to pH can play a role in mediating the availability of heavy metals to plants. Yet, the ultimate use of the crop must be considered when assessing risks from heavy metal accumulation. For example, the accumulation of 2 ppm or more Cd in marigold shoots presents no hazard since this is an ornamental crop. However, this concentration of Cd might result in its accumulation in the bodies of consumers if the crop comprised a large portion of the diet.

The development of constraints on the use of sludge on land regarding the accumulation of NO_3^- or potentially toxic organic compounds by plants also necessitates an assessment of crop use before recommendations are made.

Composted sludge is easier to handle than raw or digested sludge and possesses physical properties that make its use in potting media more feasible. In addition, composting sludge before application to cropland reduces the potential for high levels of NO_3^- in plants compared to spreading raw or digested sludge. Properly composted sludge has lower pathogen numbers and lower concentrations of potentially toxic organic compounds than does uncomposted sludge. Thus, the cycling of these contaminants into the food chain is minimized by the use of composted sludge compared to digested or raw sludge.

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APPENDIX

Table 27. Dry weights[a] at harvest of tomato shoots grown in compost or greenhouse soil[b]

Composting time[c] (weeks)	Compost (g/plant)	Soil (g/plant)	Age of plant (days)	Date of harvest
1	1.80	4.19	69	20 Nov
2	3.15	5.78	70	30 Nov
3	3.51	5.75	70	7 Dec
4	2.98	3.24	69	15 Dec
5	4.07	2.57	74	6 Jan
6	5.47	6.59	88	27 Jan

[a] Means of four replications. Plants were harvested when flowers appeared.

[b] Greenhouse soil = sandy loam:peat:sand (1:1:1, v:v:v) plus limestone to pH 6.5 and 3.5 g superphosphate/l
Compost = greenhouse soil:Amherst sludge (3:1, v:v)

[c] Represents number of weeks from blending of soil and sludge to potting of tomato plants into compost

Table 28. Boron concentration in leaves of tomato plants grown in soil and soil amended with fly ash[a]

Treatment[b]	B (ppm)	Toxicity symptoms[c]
S	38.4	no
S+FA	112.2	yes
FA	173.4	yes

[a] Means of three replicates

[b] S = sandy loam:peat:sand (1:1:1, v:v:v) plus limestone to pH 6.5 plus 3.5 g superphosphate/l
FA = Brayton Point fly ash
S+FA = 2 S: 1 FA (v:v)

[c] See text p