EPA-600/8-80-022
May 1980

MANUAL FOR COMPOSTING SEWAGE SLUDGE BY THE BELTSVILLE AERATED-PILE METHOD

by

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This study was conducted in cooperation with
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FOREWORD

The U. S. Environmental Protection Agency was created because of increasing public and governmental concern about the dangers of pollution of air, water, and land to the health and welfare of the American people. Its personnel are charged with the responsibility of alleviating, correcting, and when possible preventing problems of that nature.

The U. S. Department of Agriculture is broadly concerned with all aspects of U. S. agriculture. Its personnel endeavor to facilitate the efforts of the U. S. farmer to supply food and fiber to populations at home and abroad, but always with the minimum practical hazard to the environment.

The work here reported was aimed at the furtherance of the purposes of both agencies. It originated from an urgent need of both large and small municipalities for better methods to dispose of ever-increasing amounts of sewage sludge. Composting offers a double-barreled solution to that problem. It not only disposes of sludge but also converts it into a product which is more aesthetically acceptable, safer from a health standpoint, and useful in many important practical applications as a soil amendment beneficial to the growth of plants. The present manual discloses details of the Beltsville Aerated Pile Method of Composting sewage sludge. Research conducted at Beltsville by USDA in cooperation with the Maryland Environmental Service with the support of EPA, has shown that composting is a cost-effective and environmentally acceptable alternative to such ultimate disposal methods as incineration, ocean dumping, and landfilling.

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PREFACE

In the early 1970's, the Blue Plains Wastewater Treatment Plant in Washington, D.C., serving seven jurisdictions, was producing about 300 wet tons (23% solids) of digested sludge per day. Construction for advanced wastewater treatment facilities displaced existing sludge storage. Disposing of the sludge by discharging it into the Potomac River or barging it for off-shore dumping into the Atlantic Ocean were both rejected as environmentally unacceptable. The consulting firm of Metcalf and Eddy, Inc. recommended sludge incineration as the best disposal system for Blue Plains. Until the incinerators could be constructed, the Maryland Environmental Service (MES), assumed the responsibility for disposing of the sludge by land application.

In 1971, the Biological Waste Management Laboratory at the U.S. Department of Agriculture's Beltsville Agricultural Research Center initiated research on land application of sludge in cooperation with MES and the Metropolitan Washington Council of Governments. Several methods were investigated, including trenching and landspreading. In 1972, at the request of MES and the Blue Plains participants, this Laboratory began research on composting of sewage sludge. By early 1973, a successful windrow method utilizing woodchips as a bulking and moisture-absorbing agent had been developed for composting digested sludge. During 1973 and 1974, the Beltsville facility windrow composted in excess of 50 wet tons of digested sludge each day (Figure 1).

By 1975, the Blue Plains Wastewater Treatment Plant had increased its capability for removal of solids from the wastewater. This resulted in the production of an additional 200 wet tons of undigested or raw sludge (a mixture of primary and activated secondary sludges), for a total output of about 500 wet tons of sludge per day. Meanwhile, digestion capacity remained at 300 tons per day.

Difficulties were encountered when the windrow method was applied to raw sludge, because of the greater level of malodors associated with this type of sludge. Moreover, raw sludge generally contains a higher level of pathogens and there was concern that some of these organisms might survive in the outer layers of the windrow, where temperatures would be lower. The need for disposal of the raw sludge resulted in the development of the composting process now referred to as the Beltsville Aerated Pile Composting Method described in this manual.

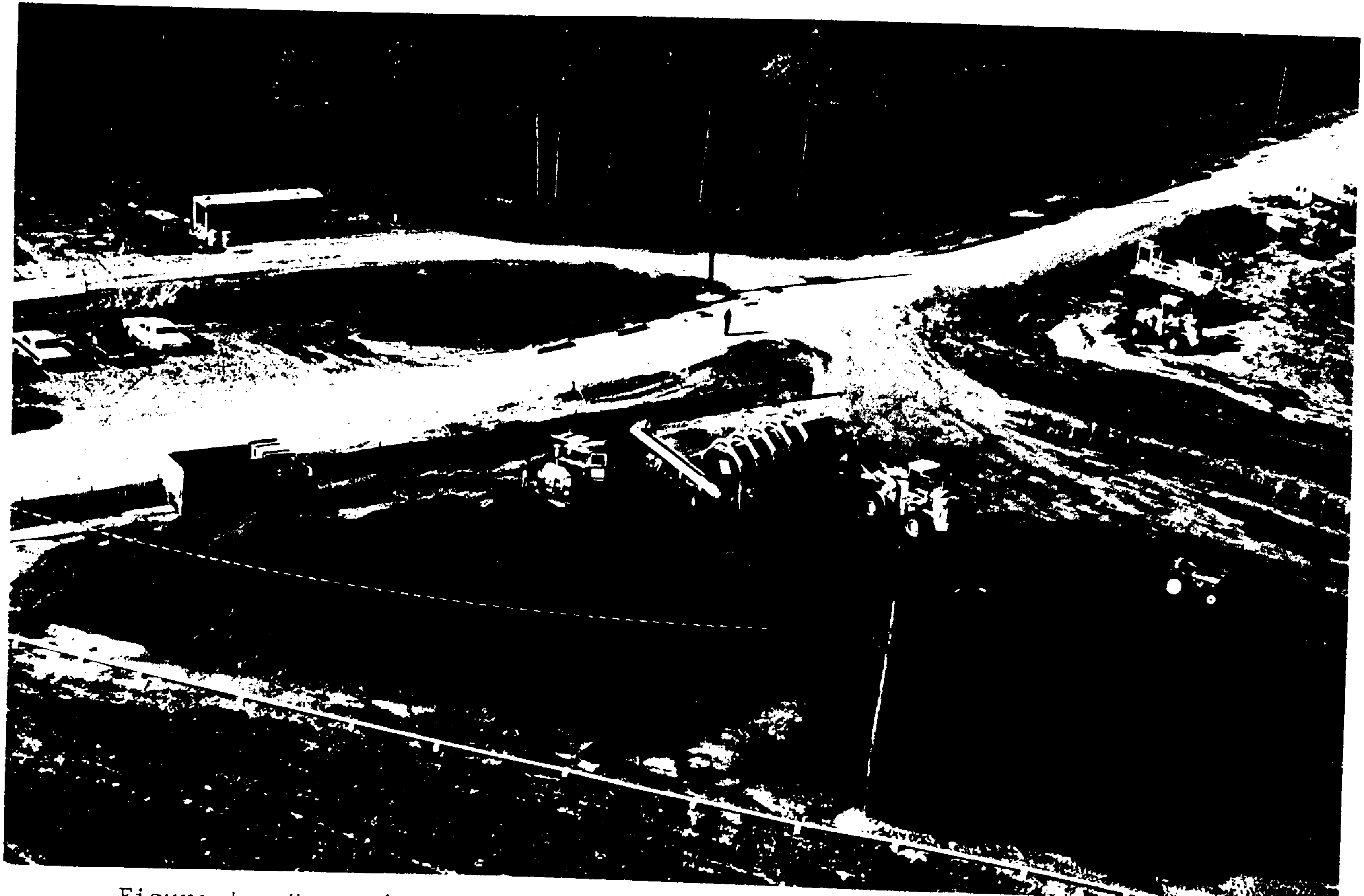


Figure 1. Screening woodchips from sewage sludge compost for recycling, Beltsville, 1973. Stock pile of screened compost in left foreground. Air-dried compost before screening in right foreground.

The Environmental Protection Agency has issued a deadline of 1981 or sooner to cities that are presently ocean dumping their sludge to cease using that method of disposal. This manual was developed for the assistance of those sewage authorities that must find acceptable new outlets for their sludge on short notice. The manual has been written during the early stages of research; improvements can be expected as development continues and communities adopt the process.

ABSTRACT

In producing clean water from sewage, wastewater treatment plants also produce sludge. Most of the commonly used methods to dispose of this material are now considered to be either environmentally unacceptable, wasteful of energy, or very expensive. To ease this situation, a relatively simple, rapid, and inexpensive sludge composting process has been developed at Beltsville. The method makes possible the conversion of undigested sludge into a composted product that is aesthetically acceptable and meets environmental standards. The material has demonstrated usefulness as a soil amendment stimulative to plant growth. If relatively simple control procedures are followed, the compost appears to be free of primary human pathogens because of the lethal effect of heat generated during the composting process on such organisms.

The new Beltsville composting procedure, detailed here in respect to both principles and practice, represents a major advance over previously known composting methods. It is adaptable to practical use in municipalities of widely varying size. In many situations its short startup time will allow its use as an emergency interim solution for sludge management. Key information is presented on the economics of the process, and on the marketing and use of the product as a soil conditioner to improve plant growth.

This report was submitted in partial fulfillment of Grant No. S803468 by the Maryland Environmental Service under sponsorship of the U.S. Environmental Protection Agency. Work was done under subcontract by the U.S. Department of Agriculture. This report covers the period July 1975 to December 1977, and work was completed as of June 1978.

CONTENTS

CONTENTS (continued)

CONTENTS (continued)

FIGURES

FIGURES (continued)

TABLES

CONVERSION FACTORS

Length	
1 inch	= 2.54 centimeters
1 foot	= 30.48 centimeters
Area	
1 square inch	= 6.45 square centimeters
1 square foot	= 0.0929 square meters
1 acre	= 0.405 hectares
Volume	
1 cubic inch	= 16.39 cubic centimeters
1 cubic foot	= 0.0283 cubic meters
1 cubic yard	= 0.765 cubic meters
1 gallon	= 3.79 liters
Weight	
1 pound	= 454 grams
1 ton	= 0.907 metric ton
Application rate	
1 pound per 1000 square feet	= 4.89 grams per square meter
1 ton per acre	= 2.24 metric tons per hectare
1 pound per acre	= 1.12 kilograms per hectare
Temperature	
F^{o}	$= 9/5\ C^{o} + 32$

ACKNOWLEDGEMENTS

We wish to acknowledge financial support from the Metropolitan Washington Council of Governments (COG), The Blue Plains Participants, and the Maryland Environmental Service (MES) throughout our research and development of sewage sludge composting at Beltsville.

The U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, Ohio, provided a 2-year grant (effective July 1, 1975) for research and development of process technology for composting municipal sewage sludges, and for investigating the use of sludge composts on land.

The U.S. Environmental Protection Agency, Region III, Philadelphia, Pennsylvania, provided a 2-year grant (effective December 1, 1975) for construction, improvements, and operations at the Beltsville Composting Facility.

We also acknowledge grants from the USEPA, Office of Research and Development, Cincinnati, Ohio, which have enabled ARS and MES to continue research on the effects of sludge entrenchment on soil chemical, physical, and biological properties.

Grants from the Food and Drug Administration, Department of Health, Education, and Welfare, the USEPA Office of Solid Waste Management Programs, Washington, D.C., and the Washington Suburban Sanitary Commission (WSSC) provided further support for research on the toxicity of sludge-borne heavy metals to plants, and their uptake and accumulation by plants when sludges and sludge composts were applied to soils.

SECTION 1

INTRODUCTION

Many municipalities are looking for solutions to their problems of disposal of sewage sludge. As energy costs continue to increase and as wastewater treatment plants across the nation produce larger amounts of sludge, composting will be considered as an alternative to land-fill, ocean dumping, and incineration. Moreover, as abatement and pretreatment measures are implemented, many municipalities now producing sludges with an undesirable content of heavy metals and industrial chemicals will produce sludges that are environmentally safe and acceptable for land application.

Composting of sewage sludge is now being conducted successfully by an increasing number of municipalities throughout the country, while others are seriously considering the practice. This has resulted in an urgent need for a state-of-the-art document on the various aspects of sludge composting and compost utilization.

This manual attempts to fulfill the above-mentioned need. It was written with three principal objectives in mind: 1) to provide municipal planners and decision-makers with information which would assist them in deciding whether composting would be adaptable and economically practical in their local situation, 2) once having made a decision to compost, to provide design information on a rapid aerobic, thermophilic composting method of demonstrated reliability, moderate cost and high environmental acceptability, and 3) to present information on the beneficial use of the compost product as a soil conditioner and source of nutrients for plant growth.

SECTION 2

DEFINITION OF THE PROBLEM AND KEY FACTS ON COMPOSTING AS A SOLUTION

THE PROBLEM

Efforts to reduce the pollution of rivers, lakes, and oceans by treating sewage are generating a rapidly growing amount of sludge, solid material that is removed from a wastewater to produce a clean effluent. Present national production of 5 million dry tons of sludge annually is expected to double by 1985. The increase will be largely due to implementation of Federal legislation that prohibits disposal of sewage into fresh waters (Water Pollution Control Act Amendments of 1972) and oceans (Marine Protection Research, and Sanctuaries Act of 1972). Implementation of these laws will require progressively better treatment through 1985.

Table 1 shows the USEPA estimates of the percentages of 1975 sludge production disposed of by various methods. The U.S. Environmental Protection Agency has ordered that municipalities shall cease all dumping of sewage into the oceans by 1981. As ocean dumping is phased out, use of other methods must increase. Air pollution, which may result during incineration, is subject to stringent regulations imposed by the Air Quality Act of 1967. These restrictions, together with rapidly increasing costs and decreasing supply of petroleum products, reduce the cost-effectiveness of incineration and other thermal methods of sludge processing, and will probably reduce the number of communities that will convert from ocean dumping to this disposal action. To make matters even more difficult, land costs for landfill sites are increasing rapidly and new sites are difficult to obtain.

Since the choice of acceptable management alternatives is decreasing at the same time that sludge production is increasing, the use of land application systems will probably increase substantially. The conversion of sludge to composts is expected to accelerate this trend, especially in large metropolitan areas surrounded by extensive suburbs.

BENEFITS OF COMPOSTING

Sludge composting is the microbial conversion of this material in the presence of suitable amounts of air and moisture

TABLE 1. PERCENTAGE ESTIMATES OF USE OF DIFFERENT MANAGEMENT METHODS FOR MUNICIPAL WASTEWATER SLUDGES IN THE U.S. IN 1975.

Disposal method	Use in % of total
Landfill	35
Landspreading	20
Ocean dumping	20
Incineration	25
Pyrolysis	0
Composting	<1
Thermal dehydration	<1

into a product with the general appearance and many of the other characteristics of a fertile soil. The sludge is conditioned for composting by the use of a bulking material (e.g., woodchips, leaves, refuse) to make it permeable to air. As the aerobic microorganisms biologically oxidize the sludge, they release heat and the sludge temperature increases. In the Beltsville Aerated Pile Composting Method, the mixture is placed over a system of perforated pipes connected to a blower that draws air down through the mass. Exhaust gases are scrubbed through a pile of finished compost to remove odor before their release to the atmosphere. A blanket of compost over the composting sludge prevents odor escape from the surface and insulates the pile so that all of the sludge is exposed to elevated temperatures.

Composting sewage sludge offers several advantages:

1. Microbial decomposition oxidizes the organic material to a fairly stable state resistant to odor production.

2. Heat produced during decomposition destroys many of the human pathogens.

3. The compost is a valuable product when used as a soil conditioner and a source of macro and micronutrients favorable to plant growth.

4. Unlike sludge, the compost can be stored conveniently.

5. Composting uses very little external energy.

Advantages of the Beltsville Aerated Pile Composting Method over the windrow method previously developed are the following:

(1) Satisfactory processing of raw sewage sludge, thereby eliminating the need for expensive digesters or other means of sludge stabilization.

(2) Greater flexibility in scale of operation.

(3) Lower capital costs.

(4) Greater reduction of pathogenic organisms.

(5) Greater flexibility in the ratio of labor to capital.

Aerated pile composting can be used as a permanent sludge management method, or it can be used as a temporary method while a permanent solution to sludge management is being developed. A composting operation may be started on very short notice if a site is available. In many areas, sites could be found that would need little or no preparation. No permanent facilities are required for the process. The only essential major equipment--a front-end loader--can readily be rented. Other equipment, such as the blowers, are stock items. If electricity is not available, portable generators can be rented until service is provided. On a moderate scale and a temporary basis, operations could be commenced on an acceptable undeveloped site within hours. Usually, however, some grading, runoff control, and paving would significantly increase the dependability of the operation.

The relative effects of different wastewater treatment processes on the destruction of pathogens and stabilization of sludge were compared by Farrell and Stern (Table 2). Processes such as pasteurization, ionizing radiation, and heat treatment can eliminate pathogens; however, they leave sludges that are unstabilized and subject to putrefaction when applied to land. Anaerobic and aerobic digestion stabilize sludge, as does composting. However, composting is the only process that provides both good pathogen control and stabilization. Additionally, the compost can be handled and stored easily.

SLUDGE COMPOSITION

The suitability of sewage sludges for processing into compost depends on the characteristics of the wastewater and on the treatment process. The composition of the sludge depends on the type of wastewater treatment (primary, secondary, digestion, etc.), chemical used for flocculation, and sludge source (industrial or domestic). The composting process is not particularly sensitive to the added chemicals, so both digested and undigested or raw sludges can be composted satisfactorily within the pH range of 5

TABLE 2. RELATIVE EFFECTS OF VARIOUS WASTEWATER TREATMENT PROCESSES ON DESTRUCTION OF PATHOGENS AND STABILIZATION OF SEWAGE SLUDGES (ADAPTED FROM FARRELL AND STERN, 1975)

Processes	Pathogen reduction	Putrefaction potential	Odor abatement
Anaerobic digestion	Fair	Low	Good
Aerobic digestion	Fair	Low	Good
Chlorination, heavy	Good	Medium	Good
Lime treatment	Good	Medium	Good
Pasteurization (70°C)	Excellent	High	Fair
Ionizing radiation	Excellent	High	Poor
Heat treatment (195°C)	Excellent	High	Poor
Composting (60°C)	Good	Low	Good
Long-term lagooning of digested sludge	Good	--	--

to 11. Digested sludge, however, has less energy available for raising the temperature to the thermophilic range. Moisture content appears to be the most important characteristic of the sludge for composting. The drier the sludge, the less material there will be to handle in the composting operation and the less it will cost.

Heavy metals content of sludges will vary with the level of industrial contribution. However, we have not found the metal content to affect the composting process. Bulking materials will to some extent dilute the heavy metals content of the sludge.

Under certain conditions heavy metals (zinc, copper, nickel) can kill plants and cadmium can be taken up by plants in concentrations that may be harmful in the human diet. Even domestic wastewater may yield sludges containing enough metals to warrant limiting continuous application. It is apparent therefore, that heavy metal analyses are needed to assess the marketability of the compost to be produced. If levels are high, a source control program may need to be developed in conjunction with the composting program. Analyses and monitoring can be pursued (Appendix) to estimate safe application rates. Table 3 shows the properties of raw and digested sludge compost. The sludges were obtained from the Washington, D.C. Blue Plains Wastewater Treatment Plant and composted with woodchips. Because these sludges are mostly from domestic sources, the derived compost is relatively low in heavy metals and pesticides and, therefore, suitable for land application.

TABLE 3. COMPOSITION OF RAW AND DIGESTED SLUDGES FROM WASHINGTON, D.C., BLUE PLAINS WASTEWATER TREATMENT PLANT AND THEIR RESPECTIVE COMPOSTS PROCESSED AT THE USDA COMPOSTING FACILITY, BELTSVILLE, MD

Component	Raw sludge	Raw sludge compost	Digested sludge	Digested sludge compost
pH	9.5	6.8	6.5	6.8
Water, %	78	35	76	35
Organic carbon, %	31	23	24	13
Total N, %	3.8	1.6	2.3	0.9
NH_4^+-N, ppm	1540	235	1210	190
P, %	1.5	1.0	2.2	1.0
K, %	0.2	0.2	0.2	0.1
Ca, %	1.4	1.4	2.0	2.0
Zn, ppm	980	770	1760	1000
Cu, ppm	420	300	725	250
Cd, ppm	10	8	19	9
Ni, ppm	85	55	-	-
Pb, ppm	425	290	575	320
PCBs1/, ppm	0.24	0.17	0.24	0.25
BHC2/, ppm	1.22	0.10	0.13	0.05
DDE3/	0.01	<0.01	-	0.008
DDT, ppm	0.06	0.02	-	0.06

1/ Polychlorinated biphenyls as Arochlor 1254.
2/ The gamma isomer of benzene hexachloride is also called lindane.
3/ DDE results from the dehydrochlorination of DDT.

ECONOMIC FEASIBILITY OF COMPOSTING

To evaluate the economic desirability of composting for a municipality, one must first evaluate the costs of converting raw sludge into compost and then the benefits the compost will furnish to the community. Benefits will partially offset costs and the net cost of composting may then be compared with the cost of other forms of sludge management.

The cost of composting will vary among projects. Much of the variation will result from differences in physical inputs (i.e., equipment and site preparation) in response to (1) the amount of sludge composted, (2) the topography of the composting site, (3) state and local restrictions, (4) local institutional constraints, and (5) amounts of already existing public works equipment available for the composting. The unit prices of the physical inputs will also differ among localities, adding another cost variable.

Table 4 compares costs of various sludge disposal methods. The wet sludge actually composted contained 23% solids. The dry ton figures presented may be converted to approximate wet tons by dividing by 4.

TABLE 4. APPROXIMATE COMPARATIVE COSTS FOR VARIOUS SLUDGE DISPOSAL PROCESSES, 1976.

Process	Range of costs in dollars per dry ton 3/ 4/
Digested sludges by:	
Ocean outfall	10 to 35
Liquid landspreading	20 to 54
Digested and dewatered sludges by:	
Ocean barging	31 to 44
Landfilling	23 to 53
Landspreading	26 to 96
Dewatered sludges:	
Trenching 1/	116 to 134
Incineration 2/	57 to 93
Heat drying 2/	62 to 115
Composting 2/	35 to 50

1/ Costs exclude transportation of sludge to disposal site.

Table 4 (continued)

2/ Costs exclude cost of removal of residues from the site and benefits from resource recovery.
3/ Cost comparisons require careful interpretation. For example, the cost of digestion should be included in the cost of land-spreading. However, digestion reduces mass of sludge solids by about one-half so there is less sludge to process.
4/ 1 dry ton = 0.908 metric ton (or tonne).

Composting compares favorably in cost with other sludge disposal processes. Landfilling and ocean-dumping may be cheaper in some instances, but they offer no benefits and have serious disadvantages. Incineration is likely to be more expensive than composting and offers benefits only if heat is recovered. Composted and heat-dried sludge will improve the soil. Heat-drying, however involves a large use of energy. Both heat-drying and composting produce a product that is more easily handled and less offensive than digested sludge for use on land. The optimal sludge management system will differ between municipalities due to the variability of the relative environmental, social, and economic ramifications of the alternatives.

Composting dewatered sludge is estimated to cost between \$35 and \$50 per ton of dry sludge. The higher cost is based on an operation that processes 10 dry tons per day, the lower one on 50 dry tons per day. Economies of size in equipment and labor use decrease the unit cost as the size of the operation increases. These calculations include all on-site expenditures but exclude costs of (1) dewatering the sludge to 20% solids, (2) transporting the sludge to the composting site, (3) treating the runoff from the site, and (4) transporting the compost to the location of its use.

Operating costs account for about 80% of the composting cost per dry ton, with labor accounting for about half of these operating costs and the bulking agent for about a quarter.

The capital costs of composting are not large in relation to such costs in other sludge management options. Capital costs of composting are estimated to be \$30,000 to \$40,000 per dry ton of daily capacity, although this figure may vary considerably between sites. If these capital costs were increased 10 percent, it would increase the unit cost of composting by less than \$1.00 per dry ton.

A cost function for aerated pile composting as practiced at Beltsville, Maryland is presented in Figure 2. It is apparent that operating costs are subject to economies of size which are attained by facilities that compost over 70 dry tons per day.

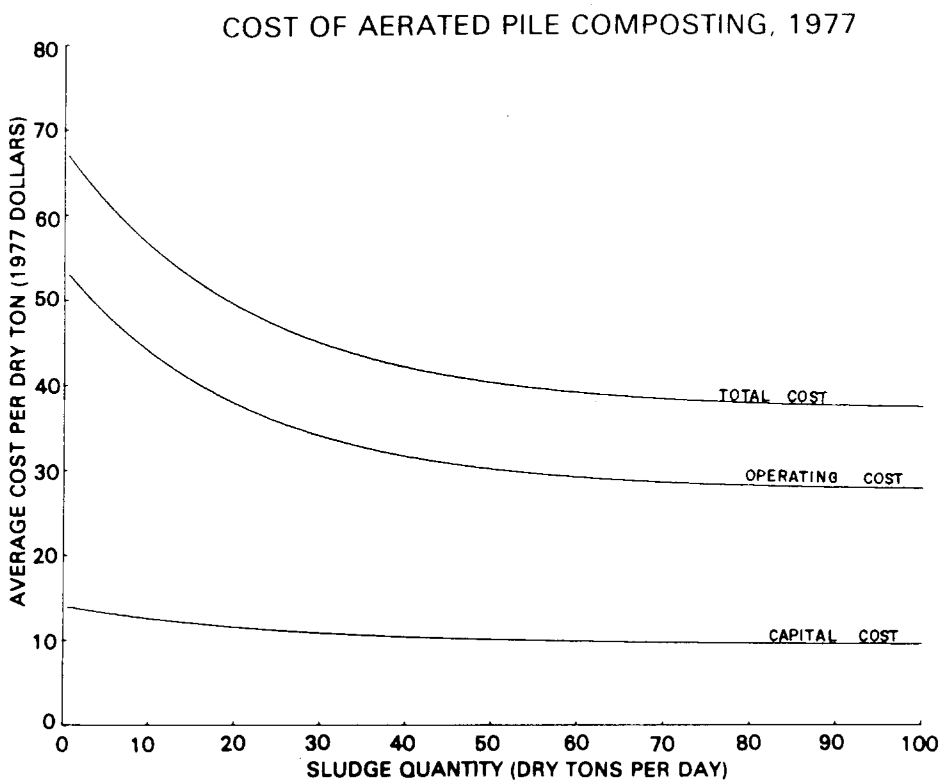


Figure 2. Cost of composting with the Beltsville Aerated Pile Method, 1977.

There will be beneficial uses for all sludge compost that might be produced by including the use of compost for fertilizer on farm land. Compost contains small amounts of nutrients, so the Beltsville compost has a value of about $4 per cubic yard in terms of 1977 prices in Maryland for nitrogen and phosphate. A market study is necessary to determine the net benefits or cost to a community from the distribution of the sludge compost. Some refuse composting operations have closed because of the lack of a developed market for compost in their area and because they expected to show a profit on the production and distribution of the compost. Composting will benefit the sewage authority economically if the net cost of production and distribution is less than that of any other environmentally acceptable disposal system. A well-planned and -managed marketing program is essential to derive a profit over distribution costs, as is the case in Los Angeles County. If the sludge compost is used for its fertilizer value alone, there could be a net cost of distribution, depending on the hauling distance.

Compost may be used in place of peatmoss or topsoil in certain horticultural applications. During preparation for the National Bicentennial, the National Park Service used Beltsville sludge compost to construct Constitution Gardens in the Mall area of Washington, D.C. The Park Service saved over $200,000 by making an artifical topsoil with the compost instead of buying topsoil, which was selling at about $5 per cubic yard undelivered in 1976. The yield of compost is about 5 cubic yards per ton of dry sludge solids, so the net profit or loss on distribution per yard must be multiplied by 5 to obtain the effect per ton of sludge solids.

Composting may be a cost-effective alternative for some municipal sludge management problems. The net cost of composting will vary among municipalities because the production costs and the utilization benefits will also vary. Therefore, a feasibility study of sludge composting must include not only a cost analysis of the process but also a comprehensive analysis of the potential market for the product.

SECTION 3

THE COMPOSTING PROCESS

Composting is an ancient practice used by farmers to convert organic wastes into soil amendments that supply available nutrients to crops and replenish depleted soil organic matter. The practice remained more of an art than a science until about 40 years ago when Sir Albert Howard, a British agronomist in India, developed the Indore Process for composting. Named after the state in India where Howard developed it, the method utilizes a 5- to 6-foot layered pile of various organic wastes such as leaves, night soil, animal manure, sewage sludge, straw, and garbage. The pile is turned after 2, 4, and 8 weeks, and composting is complete in about 3 to 4 months. The method is essentially a combination of aerobic and anaerobic composting. Howard demonstrated that composting is a beneficial alternative to the burning and dumping of refuse and sewage sludge.

The Beltsville Aerated Pile Composting Method stimulates a natural biological process. Complex organic molecules are decomposed into simpler compounds through the growth and activity of bacteria, actinomycetes, and fungi. While these organisms utilize a portion of the carbon and nitrogen fraction in the composting biomass for synthesis of cellular materials, they also convert chemical energy into heat through respiration. This heat raises the temperature of the biomass, evaporates moisture, and raises the temperature of air passing through the biomass. Heat is also lost at the pile surface by radiation, conduction, and convection. A flow diagram for the process, explained at a later point in detail, is presented in Figure 3.

FACTORS AFFECTING THE COMPOSTING PROCESS

A number of factors influence the rate at which composting can proceed and the quality of the finished product.

Temperature Temperature profoundly affects the growth and activity of microorganisms and, consequently, determines the rate at which organic materials are composted. Most of the microorganisms in sewage sludge are mesophilic; that is, they grow best in the temperature range of 20 to 35^{o}C. However, as temperatures increase during composting, a specialized group of microorganisms becomes predominant. These are thermophilic aerobic organisms that develop only at higher temperatures and grow

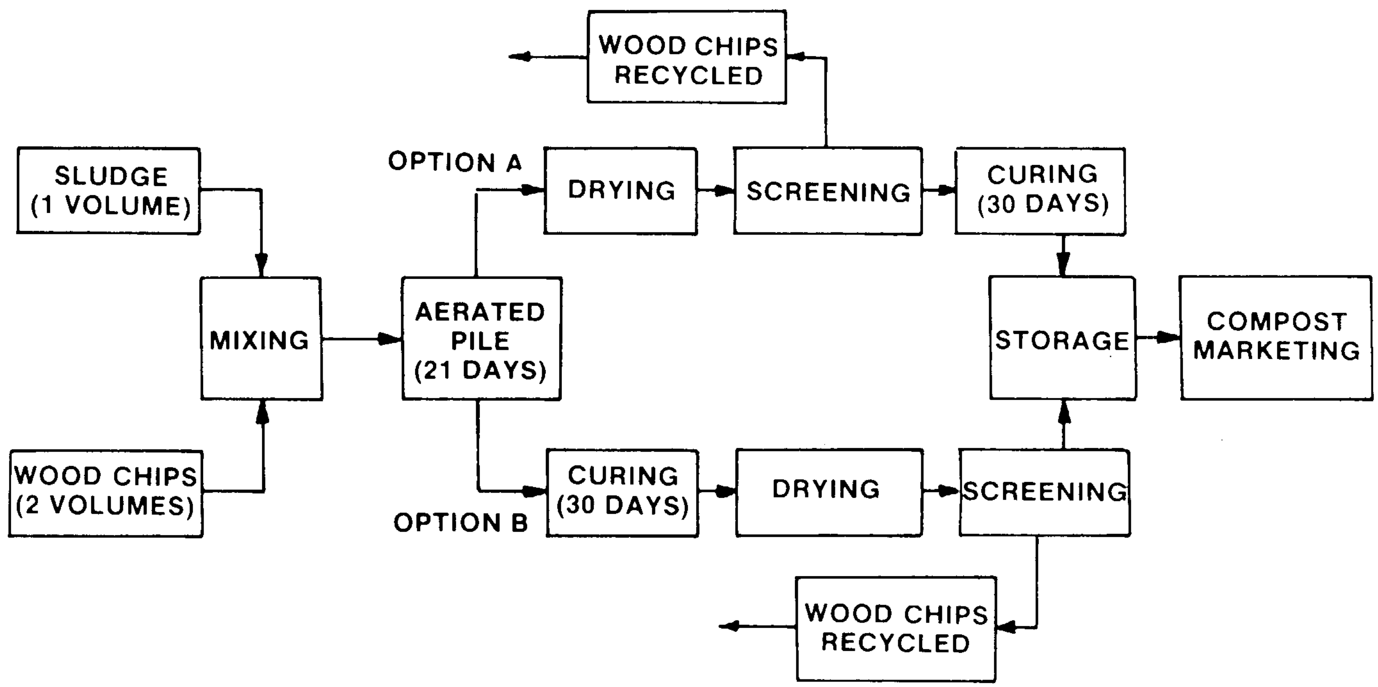


Figure 3. Flow diagram for composting operation.

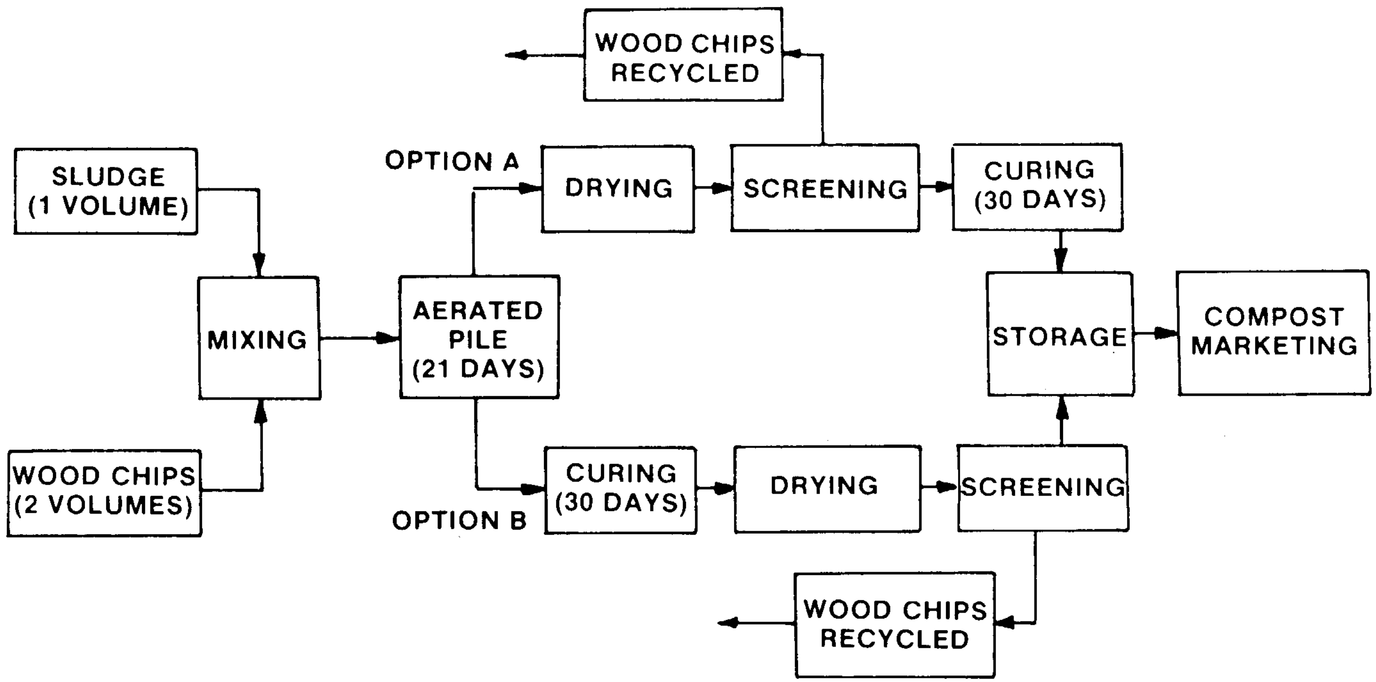
fastest at 45 to 65°C. They generate sufficiently high temperatures to destroy human pathogens.

Carbon:Nitrogen Ratio The C/N ratio is an important parameter in composting because it provides a useful indication of the probable rate of organic matter decomposition. Microorganisms use about 30 parts of carbon for each part of nitrogen. Thus, an initial C/N ratio of 20 to 35 would be most favorable for rapid conversion of organic wastes into compost. Sewage sludges usually have C/N ratios of less than 15. Although decomposition will be rapid at this ratio, nitrogen may be lost as ammonia. In the process described here, the addition of woodchips or other organic bulking materials raises the C/N ratio, ensuring the conversion of available nitrogen into organic constituents of the biomass. The subsequent removal of the woodchips for reuse then lowers the C/N ratio, allowing N to mineralize.

Moisture Content Sewage sludges can be composted aerobically over a wide range of moisture contents, 30% and higher, if aeration is adequate. However, excessively high moisture contents should be avoided in most aerobic composting systems, because water displaces air from the pore spaces and can quickly lead to anaerobic conditions. On the other hand, if the moisture content is too low (less than 40%) stabilization will be slowed because water is essential for microbial growth. The most favorable moisture content for composting sludge (22% solids) with woodchips by the aerated pile method is from 55 to 65% in the sludge-chip mixture.

Aeration and Oxygen Supply In composting sewage sludge, aeration is essential for the development of thermophilic microorganisms to ensure rapid decomposition, odor abatement, and stabilization of the residual organic fraction which remains as compost. Aeration also provides for lowering the moisture content of composting materials that may have initially been too high. The forced aeration system used with the Aerated Pile Composting Method provides for internal oxygen levels of from 5 to 15%. Within this range, maximum temperatures are attained to ensure pathogen destruction and rapid stabilization. Proper control of the aeration rate is essential because too high a rate can lead to excessive heat loss, cooling of the pile, and incomplete stabilization.

Use of Inocula Wherever composting has been practiced, there has been considerable debate as to whether special strains of microorganisms, or other biological factors such as chemical activators, enzymes, and hormones, are necessary to ensure successful composting. A number of these products are commercially available, the contents of which are known only to the manufacturers. However, most organic wastes and residues are already colonized with large numbers of indigenous microorganisms (bacteria, actinomycetes, and fungi) with a wide range of physiological



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Aeration and Oxygen Supply In composting sewage sludge, aeration is essential for the development of thermophilic microorganisms to ensure rapid decomposition, odor abatement, and stabilization of the residual organic fraction which remains as compost. Aeration also provides for lowering the moisture content of composting materials that may have initially been too high. The forced aeration system used with the Aerated Pile Composting Method provides for internal oxygen levels of from 5 to 15%. Within this range, maximum temperatures are attained to ensure pathogen destruction and rapid stabilization. Proper control of the aeration rate is essential because too high a rate can lead to excessive heat loss, cooling of the pile, and incomplete stabilization.

Use of Inocula Wherever composting has been practiced, there has been considerable debate as to whether special strains of microorganisms, or other biological factors such as chemical activators, enzymes, and hormones, are necessary to ensure successful composting. A number of these products are commercially available, the contents of which are known only to the manufacturers. However, most organic wastes and residues are already colonized with large numbers of indigenous microorganisms (bacteria, actinomycetes, and fungi) with a wide range of physiological capabilities, and most composting studies indicate that inoculants and other additives to accelerate or activate the composting process are ineffective and unnecessary.

pH of the Sludge Sewage sludges can be composted over a pH range of from pH 5 to 10. The most favorable pH range for rapid aerobic composting of sludge would be from 6 to 8, because most microorganisms exhibit maximum growth and activity in that range. Nevertheless, initial pH values as extreme as 5 or 11 do not seem to retard microbiological activity for more than 1 or 2 days. Generally, as composting proceeds the pH shifts toward neutrality.

SITE SELECTION AND DESIGN CRITERIA

Locating the composting site near the wastewater treatment plant results in lower costs for hauling and transportation of sludge, bulking materials, and equipment; a possible reduction of manpower requirements; and more effective utilization of the space allocated for the composting operation. Adverse public reaction to sludge haulage through residential areas may also be avoided.

A sludge-composting facility should comprise the following areas: (a) receiving and mixing, (b) composting pad, (c) drying and screening, (d) curing, (e) compost storage, (f) storage of woodchips or other bulking materials, (g) administrative and maintenance buildings, and (h) driveways. These facilities can be provided for a 10-dry-ton-per-day production rate on a 3.5-acre site.

The sludge and bulking material can be mixed directly on the composting pad with a front-end loader. This mixing procedure is quite satisfactory for small municipalities and requires only a small area for handling materials and maneuvering the equipment. Larger amounts of sludge, i.e., more than 15 dry tons per day, would best be mixed in a stationary mixer (drum mixer or pugmill) located near the filtering equipment. This will substantially decrease the area required for mixing, and also minimize potential problems.

The composting pad should be large enough to accommodate 4 weeks of sludge production by the treatment plant. This will provide for the usual 21-day composting period and the necessary space for operating the equipment. It also will provide a safety margin to allow for extending the composting period beyond 3 weeks if necessary due to low temperatures, excessive precipitation, or equipment malfunction. The odor filter pile will occupy a space equivalent to about 10% of the pile area.

$$\text{Pad area} = \frac{(1.1)(\text{vol. of 4 wks. sludge production})(R+1)}{\text{Av. ht. of sludge layer}}$$

$$\text{where} \quad R = \frac{\text{volume of bulking agent}}{\text{volume of sludge}}$$

The size of the processing area for drying and screening depends on climatic factors, the bulking material used, and the potential use of the product. A considerably smaller area will suffice in hot, dry climates, where the material is relatively dry after composting, than in cool, humid climates. If fine, granular bulking materials are used, the compost may not require screening. For a climate similar to Washington, D.C.,

Processing area = pad area

The curing area should accommodate 30 days of compost production. In regions where compost application is restricted to spring, summer, and fall, the compost must be stored during winter. Thus, the area required for compost storage would be considerably larger in the Northern than in the Southern United States. For Washington, D.C., where compost was stored during the winter,

Curing and storage area = 2 x pad area

In addition to the areas specified earlier, access roads, turnaround space, and a truck-wash area are needed. If the composting site is not near the treatment plant, or if runoff from the site cannot be drained into a sewer system, a runoff collection pond must be provided. Figure 4 shows most of the ARS-MES sludge-composting facility at Beltsville, Maryland, which can compost 20 dry tons of sludge per day.

A buffer zone around the compost site is desirable. Although the Beltsville Aerated Pile Composting Method effectively contains most of the sludge odor, a faint earthy or musty odor of compost remains. Under most weather conditions, this odor dissipates in a very short distance. A screen of trees and shrubbery around the site may reduce the likelihood of odor complaints.

BULKING MATERIALS TO CONDITION THE SLUDGE FOR COMPOSTING

To ensure rapid aerobic composting, the sludge must be mixed with a suitable bulking material to provide the necessary structure, texture, and porosity for mechanical aeration. The bulking material, which is usually organic, can also function as a carbon carrier to provide extra energy for the microorganisms during composting. While some decomposable carbon in the bulking material is desirable, it is not essential to the composting process.

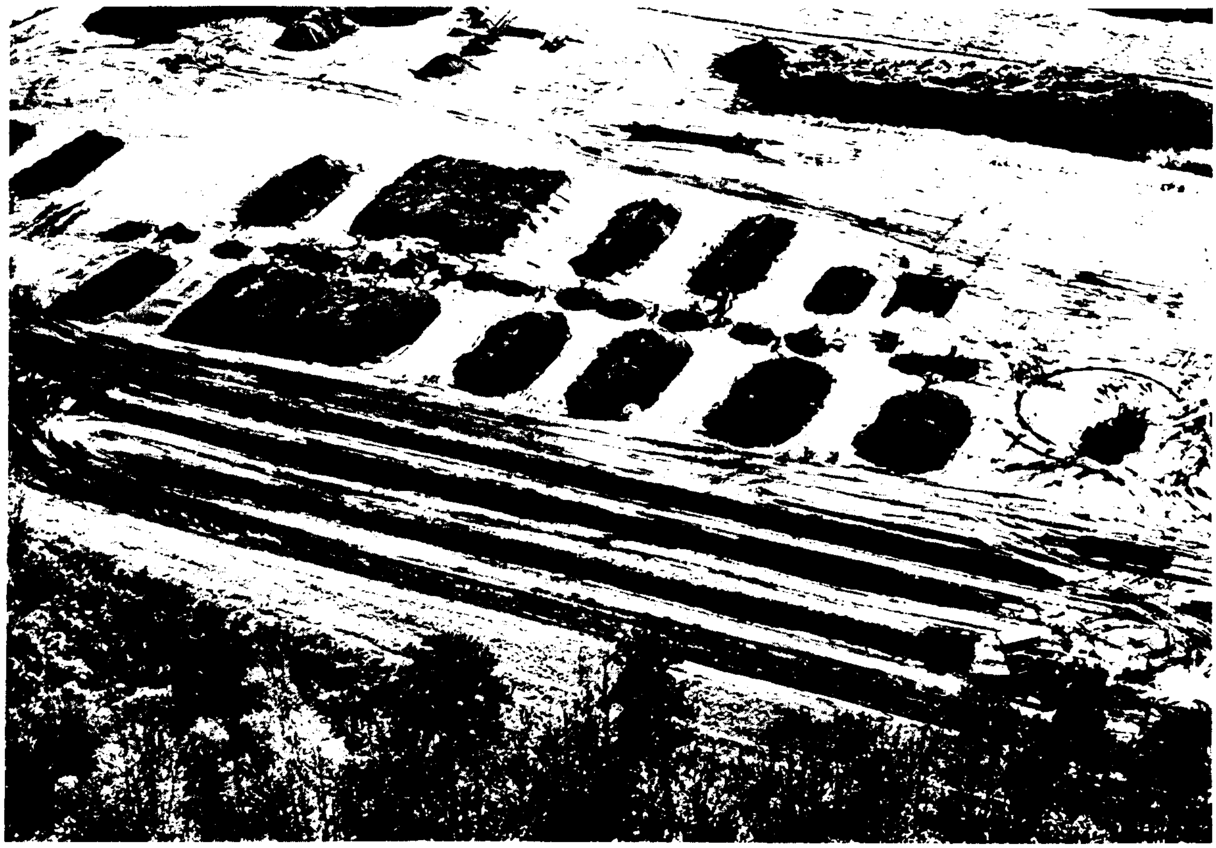


Figure 4. Aerial view of sludge-composting research site. Windrows in foreground are being used to dry compost prior to screening. Extended pile adjacent to windrows contains as much sludge as five of the individual aerated piles. Piles in upper portion of picture are stored compost. Weather has caused no interruptions in the processing rate of 60 T/day, 5 days per week during the 4 years that aerated pile composting has been the major mode of operation.

The amount of bulking material needed is related to moisture content of the sludge. For example, liquid sludge at 6 to 8% solids would require about 5 to 7 times as much of a given bulking material as partially dewatered sludge at 22 to 24% solids. Bulking materials should have sufficient wet strength to allow the necessary porosity for air movement when mixed with the sludge and placed in the pile. These materials also should have sufficient moisture absorptive capacity to induce crumbling of the sludge. Because most of the decomposition during composting occurs at exposed surfaces, crumbling speeds stabilization by increasing the surface-to-volume ratio. The upper limit for good crumbling of sludge is at a moisture content of about 60%.

Many materials frequently considered wastes have the properties of a suitable bulking agent in some degree, e.g. woodchips, wood shavings, sawdust, peanut hulls, corncobs, leaves, refuse (garbage), cotton gin trash, sugarcane bagasse, pelleted refuse-derived fuel (RDF), rice hulls, cereal straws, shredded bark, and various air-classified fractions (mainly paper) from solid waste recovery plants.

Landfill operators may have valuable information on sources and amounts of waste materials that might be used as bulking materials for the composting of sewage sludge. The amount of bulking material needed will vary with the material selected and the sludge. For a partially dewatered sludge of 20% solids, the most effective bulking material-to-sludge ratio has ranged between 1:1 and 4:1 on a loose volume basis. The mixture should be porous and contain no free liquid. Some bulking materials can be recovered by screening and used several times; others might need to be screened out and landfilled; some might become a part of the compost. The influence of the bulking material on the value of the compost should not be overlooked.

Woodchips have been the most commonly used bulking material for composting sewage sludges at USDA's Composting Research Facility at Beltsville, Md., because of their low cost and guaranteed availability.

THE MIXING OPERATION

The sludge and bulking material must be thoroughly mixed so that lumps of sludge are no larger than 3 inches (7.5 cm) in diameter. If sludge aggregates are larger than this, a slow rate of decomposition and suboptimal temperatures may result.

A number of different machines (Figures 5-8) can be used to achieve this desired degree of mixing, for example, a front-end loader. Another method is to spread the bulking material and sludge in layers, and then to mix with a rototiller. Windrow turning machines can also be used effectively, but their cost

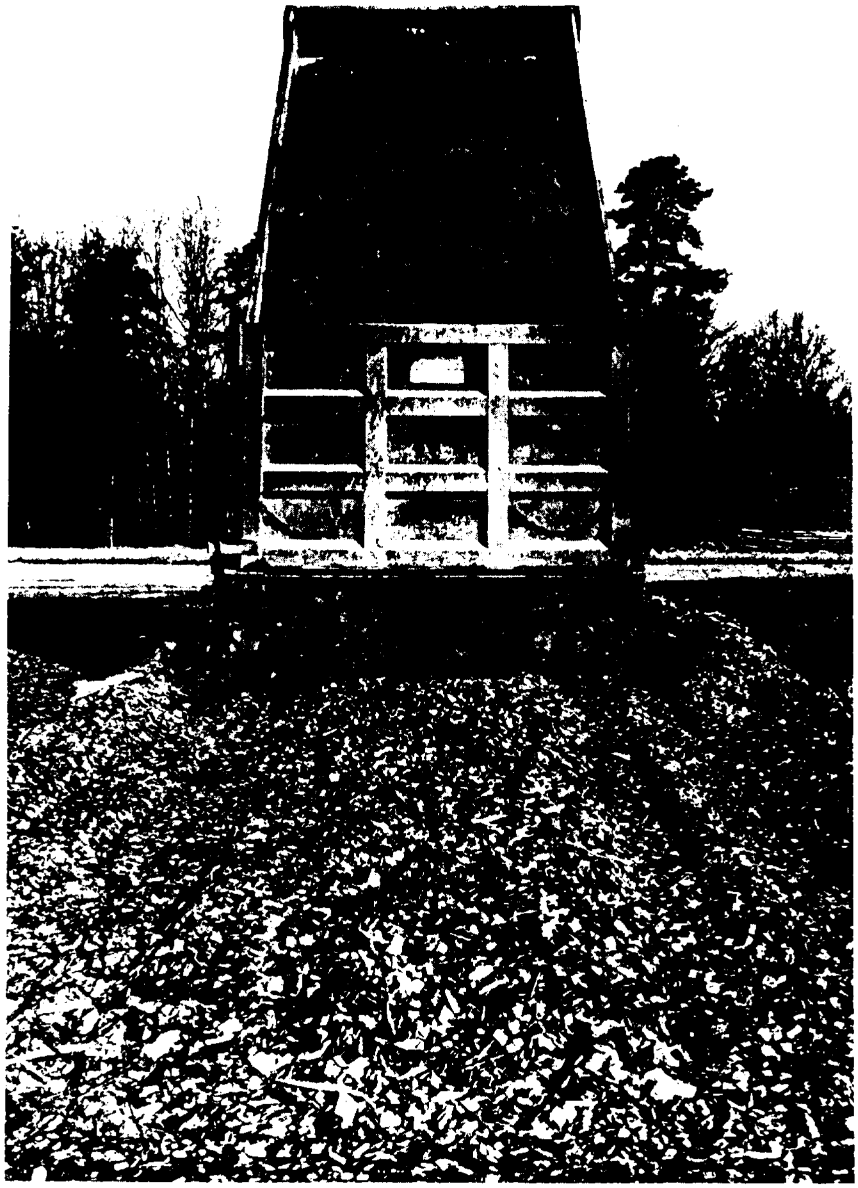


Figure 5. Dump truck load of vacuum filter cake sludge from the Blue Plains Waste Water Treatment Plant being unloaded onto a bed of woodchips with which it will be mixed.

Figure 6. Front-end loader distributing sludge uniformly over bed of woodchips prior to mixing. The loader may also be used for the entire mixing operation.

Figure 7. Terex-Cobey windrow composter mixing sludge with woodchips. This method of mixing might be suitable for treatment plants producing 100 dry tons of sludge daily.

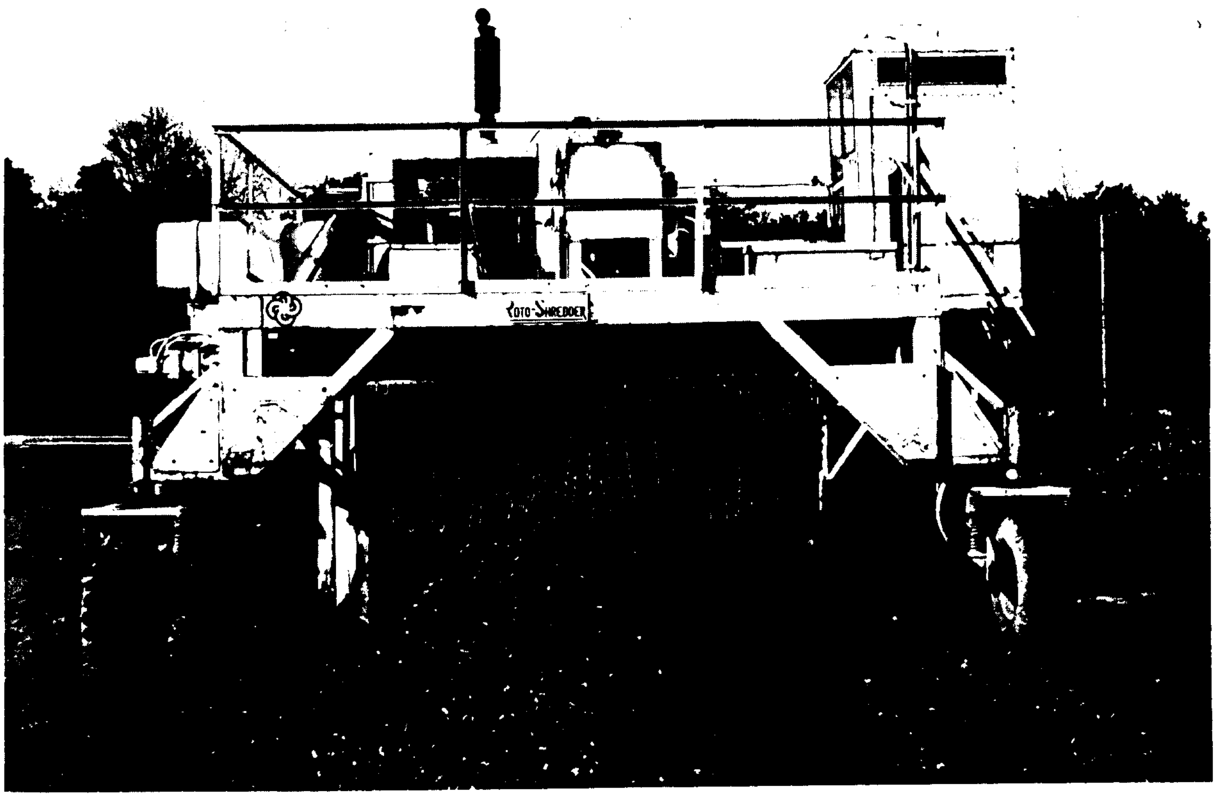


Figure 8. Roto-shredder, another windrow composting machine, mixing sludge with woodchips.

makes their use more applicable to operations that handle several hundred tons of sludge (22% solids) per day.

Drum mixers and pugmills may also be used in the mixing operation. However, the stickiness of the sludge and the flow characteristics of the bulking material are important considerations in designing systems that can successfully feed and unload them. With such mechanization it may be necessary to increase the bulking material:sludge ratio to compensate for variations in proportioning.

THE AERATED PILE

A three-dimensional schematic diagram of the Beltsville Aerated Pile Method for composting sewage sludge is shown in Figure 9. In their simplest form, the individual aerated piles are constructed as follows:

1. A loop of 4-inch-diameter (10-cm) perforated plastic pipe is placed on the composting pad lengthwise and directly under what will become the ridge of the pile (Figure 10). The perforated pipe should not extend under the end slopes of the pile because too much air may be pulled through the sides, causing localized "cold spots" that do not reach the thermophilic range.

2. A 6- to 8-inch (15- to 20-cm) layer of woodchips or other bulking material is placed over the pipe and the area to be occupied by the pile. This layer comprises the pile base and facilitates the movement and distribution of air during composting. The base material also absorbs excess moisture that may condense and leach from the pile.

3. The mixture of sludge and woodchips is then placed loosely upon the prepared base with a front-end loader or conveyor system (Figures 11 and 12) to form a pile with a triangular cross section 15 feet wide (5 m) and 7.5 feet high (2.5 m).

4. Excess woodchips are removed from around the base and the pile is completely covered with a 12-inch (30-cm) layer (often referred to as the "blanket") of cured, screened compost or an 18-inch (45-cm) layer of cured, unscreened compost to provide insulation and prevent the escape of malodorous gases during composting. If finished compost is not available, as would be the case for the first piles of a new operation, the bulking material can be used. However, the blanket thickness may have to be increased to achieve the same degree of insulation and odor control as obtained with cured compost.

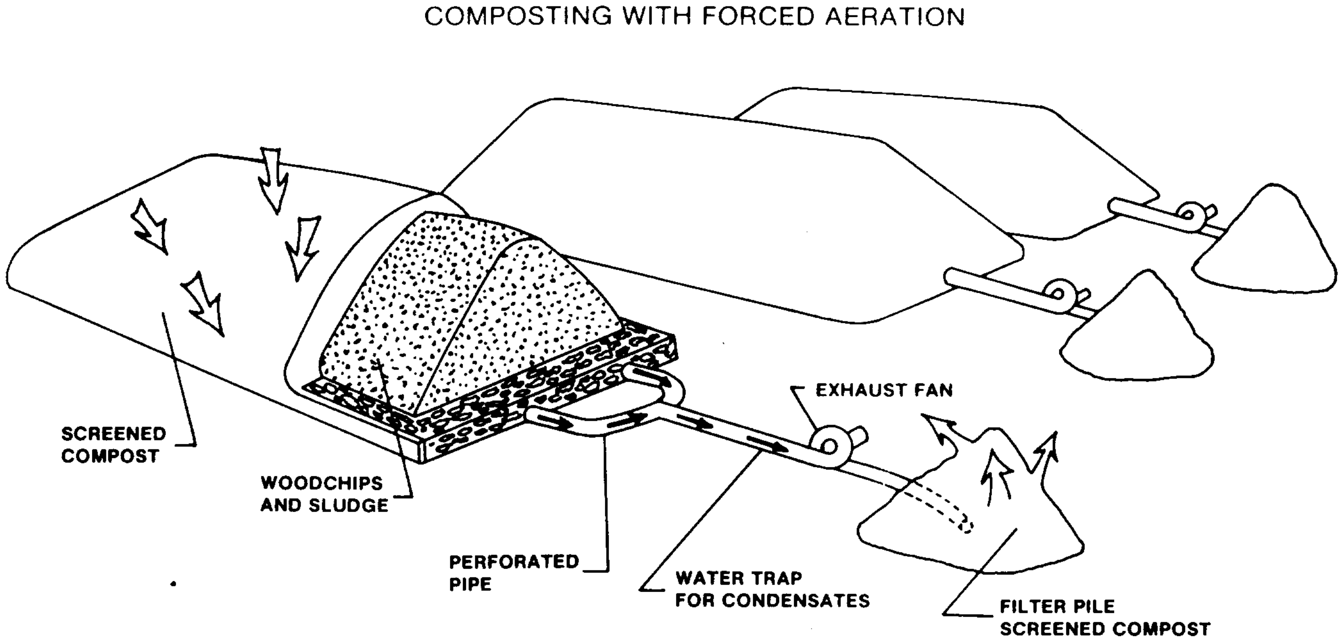


Figure 9. Schematic diagram of an aerated pile, showing location of aeration pipe. The piping under the pile is perforated for air distribution.

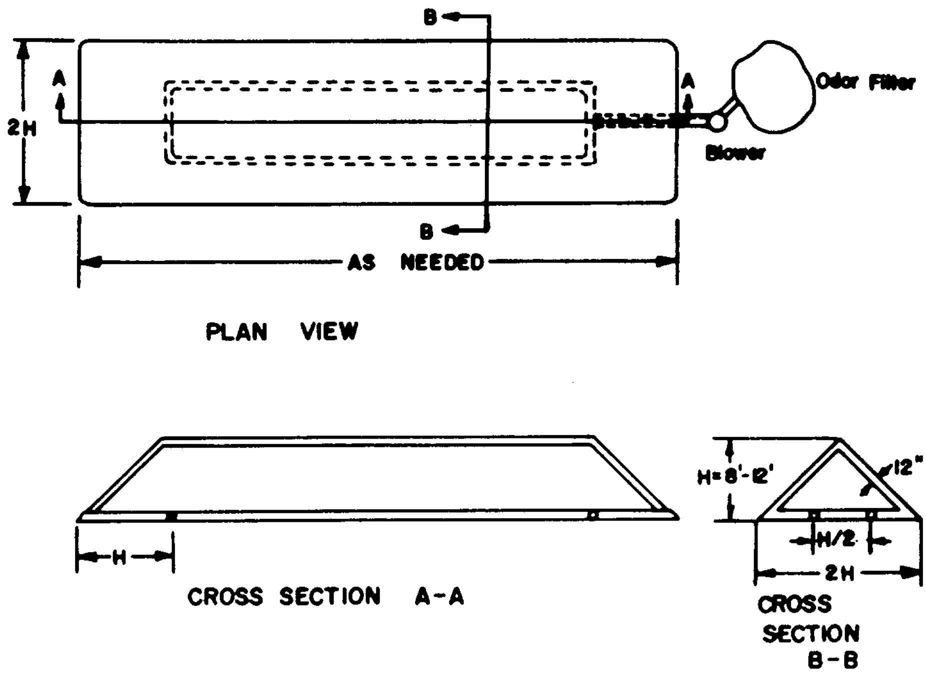
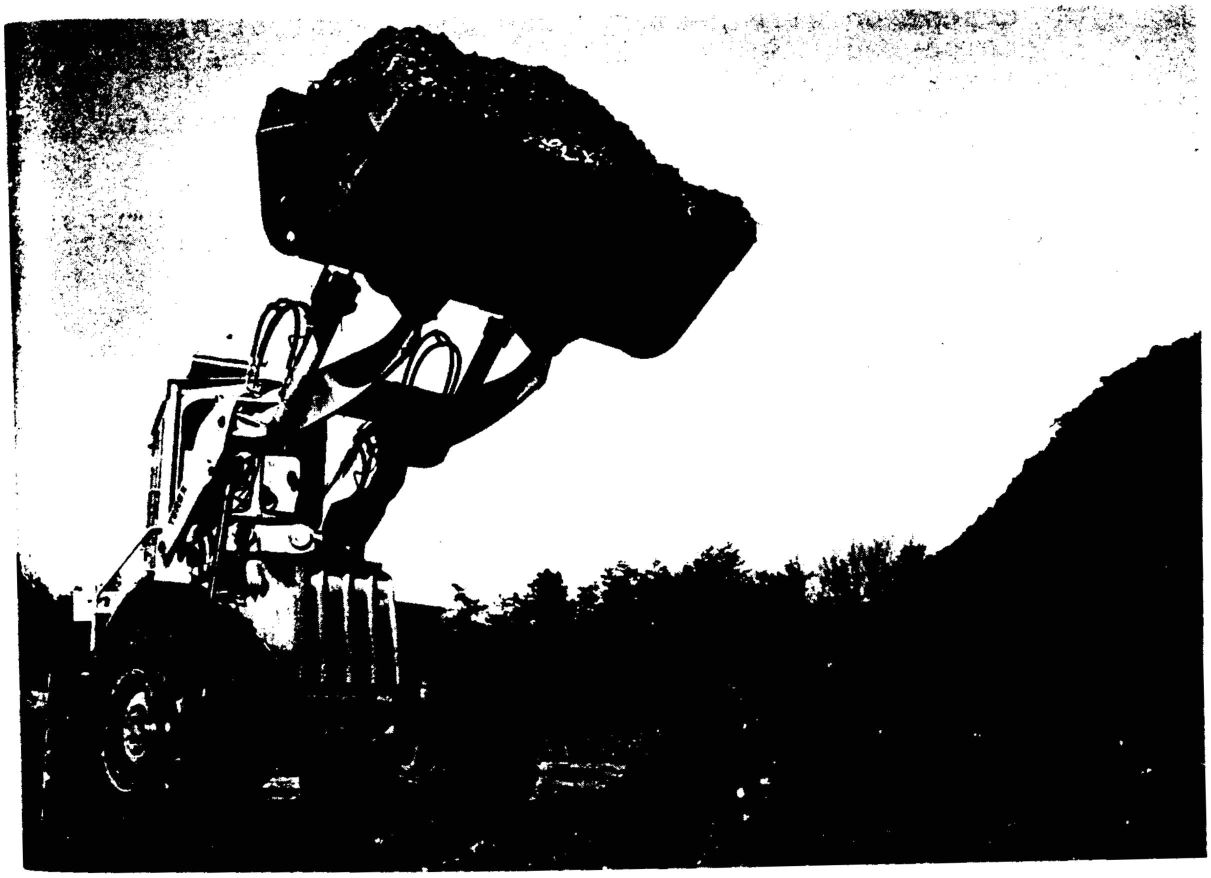


Figure 10. Orientation of aeration pipe in pile, indicating recommended edge distances and spacing for extended piles.

Figure 11. Front-end loader placing sludge-woodchips mixture on aerated pile. Note air conditioner on top of cab which enables operator to work in relatively dust-free environment.



igure 12. Front-end loader about to place sludge-woodchips ixture on aerated pile. Loader wheels ride up on the woodchip ase but not on the mixture since they would compact it, thus locking air movement.

5. During construction of the pile base, the perforated pipe is connected to a section of solid plastic pipe extending beyond the pile base. The solid pipe is connected to a blower rated at 160 cfm with 5" water head powered by a 1/3 - hp motor and controlled by a timer (Figure 13). The actual air resistance of this entire system has been less than 5" so that the actual air delivery has been 200 to 250 cfm. Aerobic composting conditions are maintained by drawing air through the pile intermittently. The exact aeration schedule will depend on pile geometry and the amount of sludge to be composted. For a pile with the dimensions described (20 m x 5 m x 2.5 m), the timing sequence for the blower is 4 minutes on and 16 minutes off. The composting begins when the blower is turned on.

6. The effluent air stream discharged from the compost pile blower is conducted into a small cone-shaped pile of cured, screened compost approximately 4 feet high (1.3 m) and 8 feet in diameter (2.7 m), where malodorous gases are absorbed. These are commonly referred to as odor filter piles. The moisture content of compost in the filter pile should not exceed 50% because the odor retention capacity tends to decrease at higher contents. A 6-inch (15-cm) base layer of woodchips or other bulking material around the perforated pipe will minimize back pressures, which could cause leakage of malodorous gases around the blower shaft. The odor filter pile should contain about 1 cubic yard of screened compost for each 10 wet tons of sludge being composted.

   With new operations, where screened compost is not yet available, some bulking material or soil (or a mixture thereof) could be used in the filter piles.

Variations in pile shape and size can adapt the process to differences in the rate of sludge production by most treatment plants. The individual pile method described here is suitable for operations ranging from as little as 5 tons of sludge (20% solids) from a single weekly dewatering operation in a cone shaped pile to more than 100 tons per week.

THE EXTENDED AERATED PILE

Another version of the aerated pile is the aerated extended pile illustrated in Figure 14. Each day's sludge production is mixed with a bulking material and added against the slope of the previous day's pile, thus forming a continuous or extended pile. The extended pile offers certain advantages for larger municipalities on a daily sludge production schedule. For example, the area of the composting pad can be reduced about 50% as compared

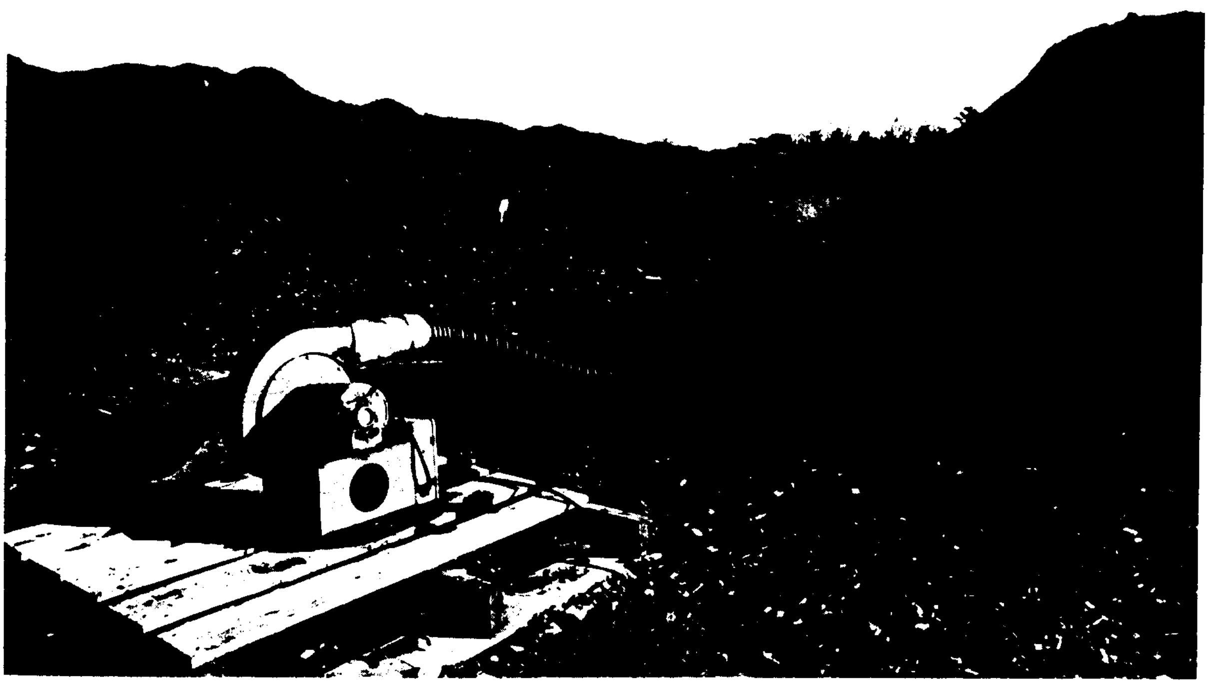


Figure 13. Axial vane centrifugal fan powered by a 1/3 horsepower electric motor. Steam is escaping from the odor filter pile on the right. Fan is controlled to operate intermittently by a time clock. Typically, the time clock is set to operate motor for 4 minutes out of 20 when serving 50 tons of vacuum filter cake.

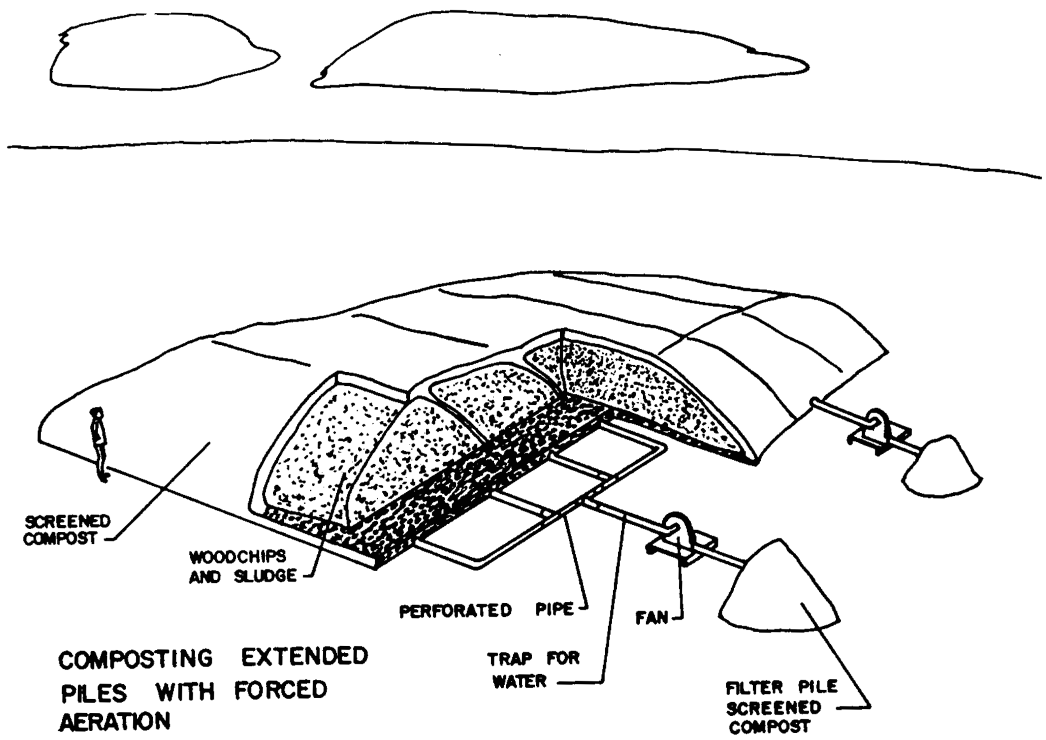


Figure 14. Schematic diagram of extended aerated pile showing construction of pile and the arrangement of aeration pipe.

with that required to accommodate an equal amount of material in individual piles. Moreover, the amount of screened compost blanket material needed for insulation and odor control and the amount of bulking material for the pile base are decreased 50%.

In constructing an extended pile, the first day's sludge production is placed in an individual pile with triangular cross section as described earlier, but only one side and the ends are blanketed. The remaining side is dusted with about an inch (2.5 cm) of screened compost for overnight odor control. On the second day, additional aeration pipe is placed on the pad surface parallel to the dusted side, the pile base is extended, and the sludge-woodchips mixture is placed in such a manner as to form an extended pile with a trapezoidal cross section as shown in Figure 15. Also on the second day, the flat top and ends are blanketed with screened compost and the remaining side receives a thin layer of compost as before. The pile is extended in this fashion each day for 28 days. However, after 21 days the first day's section is removed for either drying and screening or placing in a curing pile. After the removal of seven sections in chronological sequence, sufficient space is freed for operating the equipment so that a new extended pile can be started where the old one had been. Thereafter, a section is removed each day from the old pile and a section is added to the new one.

TEMPERATURES ATTAINED DURING COMPOSTING

The transformation of sludge into compost is essentially complete after 3 weeks in the aerated pile. Microbial decomposition of the volatile organic fraction of the sludge in an aerobic atmosphere soon raises the temperature throughout the pile to above 140°F (60°C), which effectively destroys pathogenic organisms that might cause disease in humans. Typical temperatures recorded during the composting of raw sludge by the Beltsville Aerated Pile Method are shown in Figure 16. Temperatures in the pile increase rapidly into the thermophilic range of 176°F (80°C) or higher. Temperatures begin to decrease after about 16 to 18 days, indicating that the microflora have used the more decomposible organic constituents and that the residual sludge has been stabilized and transformed into compost. Figure 16 also indicates that if piles are constructed properly, neither excessive rainfall nor low ambient temperatures affect the composting process.

AERATION AND OXYGEN SUPPLY

Centrifugal fans with axial blades are usually the most efficient mechanism for developing the necessary pressure to move air through the compost piles and into the odor filter piles. About 5 inches (12.5 cm) of water pressure across the fan has

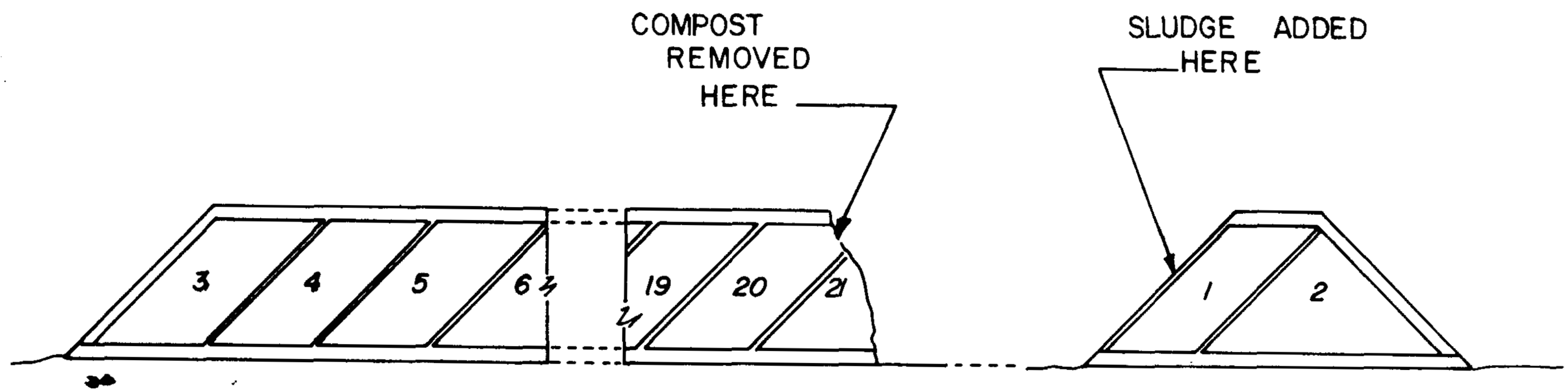


Figure 15. Cross section of an extended pile showing a typical sequence of sludge additions to the pile. Numbers indicate the age of the compost in days.

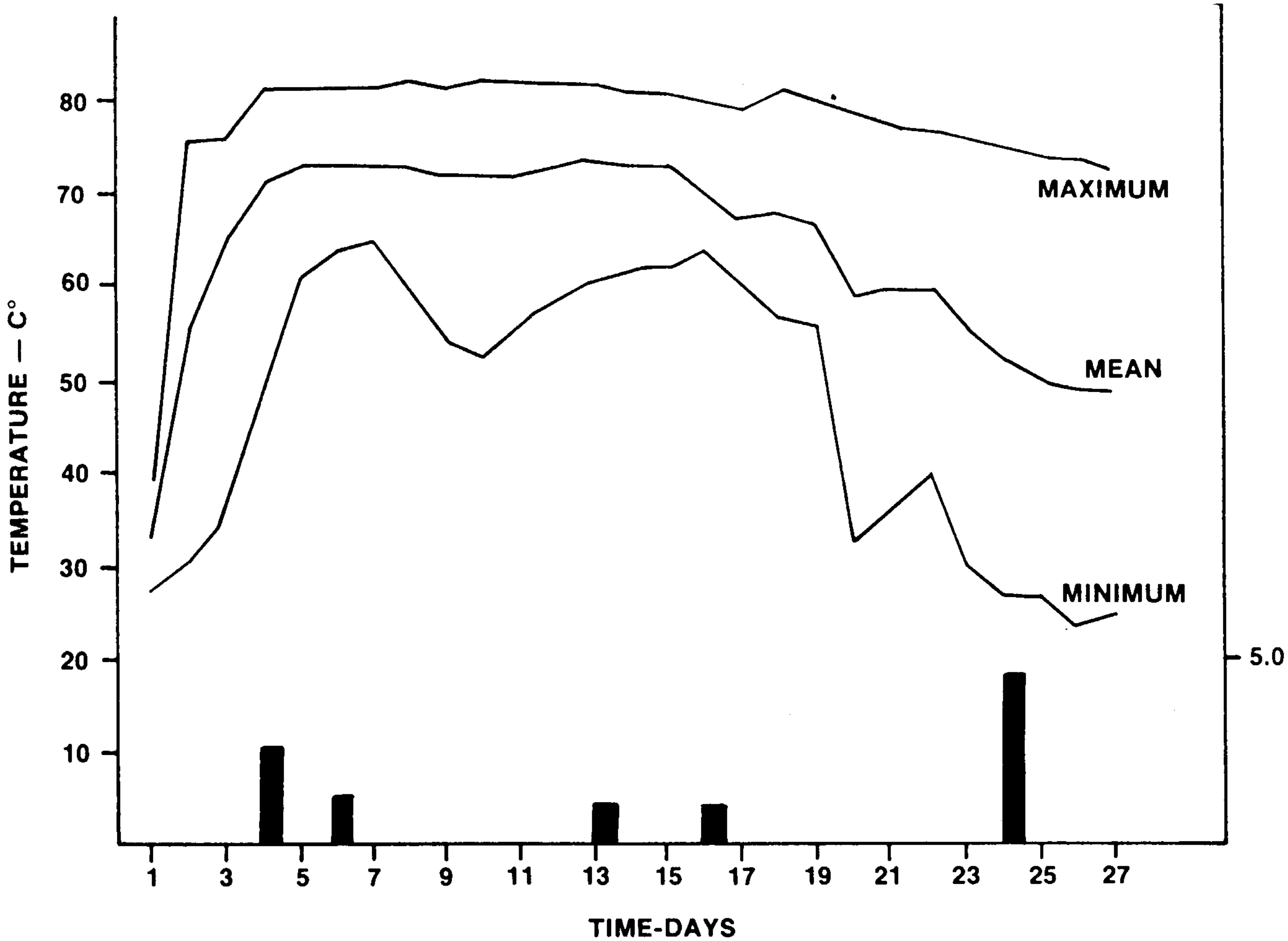


Figure 16 operation. Temperatures recorded during the composting Bars at bottom indicate rainfall events.

been adequate when woodchips are used as the bulking material. However, when finer textured materials such as sawdust are used for composting sludge, a substantial increase in pressure may be needed.

An aeration rate of about 500 cubic feet ($14m^3$) per hour per ton of sludge (dry weight basis) should maintain the oxygen level in the pile between 5 and 15% and provide for rapid decomposition of the sludge and extended thermophilic activity. Continuous aeration results in rather large temperature gradients within the pile. Cycles of 20 to 30 minutes, with the fan operating 1/10 to 1/2 of the cycle, have given more uniform temperature distribution.

The air under the compost piles is collected and delivered to the odor filter piles by 4-inch (10-cm) flexible plastic drain pipe. The pipe is damaged beyond reuse when the piles are taken down, but since it is relatively inexpensive it is considered expendable. Rigid steel pipe has also been used and can be pulled lengthwise out of the pile without damage for reuse. Pipe spacing for the extended piles should not exceed the pile height. The pipe should be large enough so that the air velocity does not exceed 2,000 ft. per minute to prevent excessive pressure variation. Manifolding the outer ends of the pipe will equalize pressure should the pipe be damaged.

CONDENSATE AND LEACHATE CONTROL

As air moves down through the composting sludge, it is warmed and picks up moisture. However, as a result of heat loss to the ground, temperatures near the base of the pile are slightly cooler. As the air reaches this area, it is cooled slightly, causing moisture to condense. When enough condensate collects, it will drain from the pile, leaching some sludge with it. Condensate will also collect in the aeration pipes and, if not drained, can accumulate and block the air flow. Leachates and condensate combined may amount to as much as 5 gallons per day per ton of dry sludge. If the bulking material is sufficiently dry when mixed, however, no leachate will drain from the pile. Since the leachate contains sludge, it can be a source of odor if allowed to accumulate in puddles, so it should be collected and handled in the same manner as runoff water from the site.

SEQUENCE OF OPERATIONS FOR COMPOSTING SLUDGE

A flow diagram for the Beltsville Aerated Pile Method for composting sewage sludge is shown in Figure 3. After 21 days of composting, there are two options which provide considerable flexibility for the process. If weather and climatic conditions are favorable and labor and equipment are available, option A is usually followed, whereby windrow drying and screening are performed before a 30-day curing period is imposed. The compost and woodchip mixture is usually dried to about 40 to 45 percent moisture to facilitate clean separation of compost from chips by screening. The recovered woodchips are recycled with new batches of sludge. If the weather is inclement or labor and equipment are not available, option B can be followed, whereby the composted biomass is taken directly from the aerated pile and placed in a curing pile for 30 days before drying and screening. Not only does this provide processing flexibility but it offers the choice of two kinds of compost - users of compost for land reclamation and erosion control often prefer the unscreened compost containing woodchips.

The curing and any subsequent storage can be considered as an extension of the composting process and are associated with elevated temperatures, though somewhat lower than the mean temperatures attained during the initial composting. Curing ensures total dissipation of phytotoxic gases and offensive odors, and allows for total destruction of any remaining pathogens.

<u>Drying</u> The moisture content of the compost can substantially influence its handling characteristics. When the moisture content is 45% or less, the compost will flow freely and can be handled or screened without difficulty. Good handling characteristics are also advantageous for the users of the product. The moisture content should not be below 35%, since dusting becomes a problem at lower moisture contents.

Two methods of mechanically assisted drying have been used at Beltsville. In the first method, the compost is spread out in a 12-inch layer and harrowed frequently with a spring tooth harrow mounted on a small farm tractor. In the second method, the compost is placed in a windrow 3 feet high and turned frequently. Generally, 1 to 2 days of drying by either method is adequate if the compost is worked hourly. Regularly updated weather forecasts are essential when drying the compost by either of these methods. When precipitation is predicted, the compost should be piled to minimize the surface exposed. Heavy precipitation will increase moisture only slightly in storage piles more than 10 feet (3 m) high. The same methods can be used for drying wet bulking material when necessary.

<u>Screening</u> Depending on the bulking agent used, operators may find it desirable to screen the compost to improve its marketability or to remove the bulking material for reuse (Figures 17 and 18). These choices are largely governed by economics. When a coarse bulking agent is used, some screened compost is desirable for blanket material. Both rotary screens (trommels) and vibrating screens have been used satisfactorily. The rotary screens, however, have been less susceptible to clogging when screening compost at higher moisture contents. A 1/4 to 1/2-inch screen opening will produce a product that is attractive for most

Figure 17. Rotary drum (trommel) screen separating woodchips from composted sludge. Conveyor in foreground is delivering compost. Moisture content of compost must be less than 50% to prevent bridging in feed hopper.

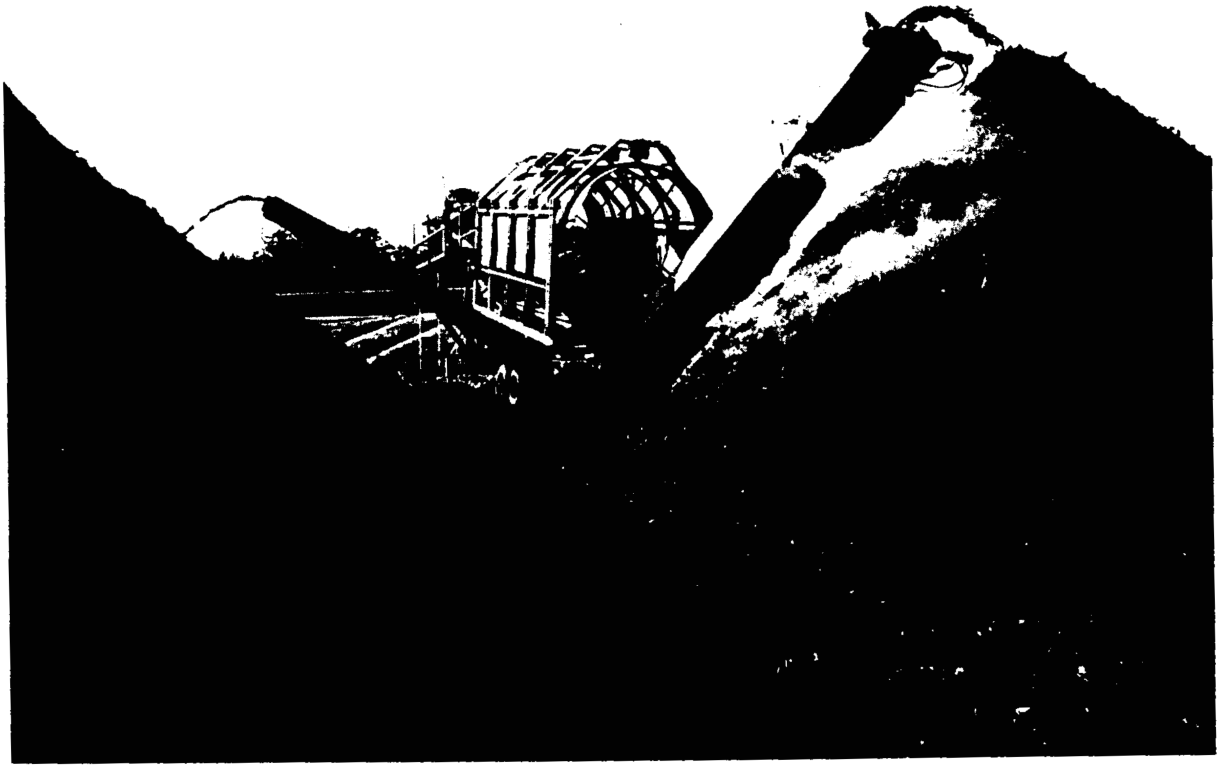


Figure 18. Still-warm woodchips steaming in foreground. Reclaimed woodchips are reused as bulking material until they decompose and become part of the compost after about 4 to 5 uses.

soil conditioning uses.

Curing and Storage After the compost has been cured for about 30 days (screened or unscreened), it may have to be kept in a storage pile. Use of the compost will be somewhat seasonal, i.e., most of it will be applied either in the spring or fall. Thus, a storage capacity to accommodate 3 to 6 months' production will be needed.

During storage, the compost will continue to decompose slowly. Usually, this does not present any problem because by this time the compost is well stabilized. Decomposition in storage can be largely curtailed by drying the compost to a moisture content of about 15%. If it is stored in large piles at a moisture content of, say 45%, temperatures will increase to the thermophilic range, and additional composting will occur. The compost can be stored without cover and may be piled as high as is convenient with the equipment available. The tops of the storage piles should be rounded so that wet pockets do not develop.

MONITORING OPERATIONS

The aerated pile composting process is relatively insensitive to changes in operating conditions and materials. However, to achieve economy of operation, produce a product of adequate quality, and reduce potential for pollution, control and monitoring of operating parameters is necessary. Since microbiological activity during composting is mainly influenced by temperature, oxygen, and moisture content, these parameters should be monitored so that improper composting conditions can be corrected. Composting as described here is a batch process, making it important to collect some data on each pile or each section of an extended pile.

The most common cause of difficulties is excessive moisture in the composting mixture. The maximum moisture content for consistently good composting activity will be about 60% wet basis of the sludge-bulking agent mixture. A skilled operator will soon learn to identify this limit by appearance, as well as by the moisture content of the bulking material needed to produce a compostable mix.

Temperature will reveal more about the process than any other single measurement. Temperatures should be measured at several locations in the pile. Continuous measurement is not needed, but remote recording of temperature from several thermocouple or thermistor probes may be more cost-effective than periodically sending out an operator to take measurements.

Most of the compost pile should reach 130°F (55°C) within 2 to 4 days, indicating satisfactory conditions with respect to moisture content, bulking material ratio, mixing, and pH. If substantial portions of the pile exceed 175°F (80°C), the aeration rate can be increased to remove additional moisture from the pile. Temperature also is an excellent indicator of the probable extent of pathogen destruction or survival. Pathogens die off rapidly when temperatures are 130°F (55°C) or higher for several days. Some temperature measurements should be taken just inside the blanket, where cold spots are most likely to occur. Cold spots may result from a thin place in the blanket, from the placement of an aeration pipe too close to the edge of the pile, from excessive pad material not covered by the blanket, or from incomplete mixing. If the average temperature in the pile is below 140°F (<60°C) after 5 to 7 days, the cause should be determined and corrected. If, as is most likely, the moisture content is too high, additional dry bulking material can be mixed in and the pile rebuilt. Two other possible causes of low temperatures are an excessive aeration rate (also indicated by high oxygen levels) and high sludge pH (>11.0). Equipment recommended for monitoring temperatures is listed in the appendix.

Oxygen analysis of gas samples drawn from the center of the piles is useful for locating problems and optimizing the aeration system. The oxygen level should be in the range of 5% to 15% the first week. Scattered readings below 5% indicate poor distribution or movement of air, probably due to excessive moisture or incomplete mixing. If a gas sample cannot be obtained, there are no voids for oxygen movement and the sampling location is probably anaerobic. If all readings are low, the aeration rate should be increased. High aeration rates to maximize drying will increase the oxygen level to as much as 20% during the third week of composting. Equipment recommended for monitoring oxygen levels during composting is listed in the appendix.

The maximum allowable level of pathogens or heavy metals in the compost may eventually be set by federal or state regulations, in which case the sampling procedures and frequency will be prescribed by the regulatory agency. However, a record of operating temperatures showing that the temperature of the coldest part of the pile had exceeded 60°C would indicate that most pathogens were killed.

Site operators should pay particular attention to odors. Whenever unpleasant odors are noted, the source should be located and corrected. Exposed sludge, ponding around compost piles, and partially composted sludge are potential odor sources. Improperly constructed odor filter piles or leaky pipes between the blower and the filter pile can also contribute odors. Over time, the odor filter piles tend to collect condensate, which lowers their capacity to absorb and retain odors. When the moisture content of the odor filter piles becomes excessive (i.e., 75 to 80%), they should be removed and rebuilt with dry (50% moisture content or less) compost. The used filter pile compost can be placed in a curing pile for reconditioning. A recommended procedure for measuring the moisture content of compost or bulking materials is described in the appendix.

The blowers should be checked daily to see that they are operating. Whenever the bulking agent or the air distribution system is changed, the air delivery rate should be checked.

Table 5 lists parameters that should be monitored during the composting operation, and the suggested frequency of measurement in accordance with the size of operation.

Table 5. Suggested parameters and time sequences for monitoring

Parameter	Size of operation in tons per week (dry solids)		
.	<25	25 to 250	>250
Moisture content[1]	monthly	weekly	daily
Temperature	daily	daily	daily
Oxygen	optional	weekly	daily
Pathogen survival	as required by local regulations		
Heavy metals	as required by local regulations		
Process odors	daily	daily	daily
Blower operations	daily	daily	daily
pH of sludge[2]	monthly	monthly	monthly

1 Qualitative "by eye" estimation of moisture of the compost mix should be done daily. Moisture content of sludge should be obtained from sewage plant operator.

2 Good communications should be maintained with sewage plant operators, so that the compost plant operator is informed of any process change or condition that will effect the quality of the sludge.

ODOR CONTROL

Although sewage sludge can emit a strong unpleasant odor, this odor gradually disappears as the sludge is stabilized by composting. All odor cannot be eliminated during composting, however. Even well-cured sludge composts have an earthy odor that fortunately is pleasant to most people.

Each of the unit operations can be a potential source of odors. Some of the odors are emitted intermittently and others continuously. Odor potential increases considerably during and immediately after heavy precipitation. To minimize the odor potential throughout the composting process, one must manage each operation as follows:

1. <u>The mixing operation</u> -- Prompt mixing of sludge and bulking material and placement of the mixture in the aerated pile reduces the time for odor generation. Lime added to the as a conditioner for dewatering or added with the bulking material will help to lower the odor intensity. An enclosed mechanical mixer could eliminate the release of odors during this operation.

2. <u>Aerated pile surface</u> -- This will not be a source of strong odors if the blanket of compost is adequate for insulation. Thin spots or holes in the blanket will be a potential source of odors. The effectiveness of the blanket for odor control decreases when its moisture content exceeds 60%.

3. <u>Air leakage between the blower and odor filter pile</u> -- Since air leakage can occur at this point, all pipe joints should be sealed. Back pressure from the odor filter pile should be minimized to prevent gaseous losses around the blower shaft. A layer of woodchips over the perforated pipe will minimize back pressures.

4. <u>Odor filter piles</u> -- Odor filter piles should be cone-shaped and symmetrical, and should contain about 1 cubic yard of dry (50% moisture or less) screened compost per 10 wet tons of sludge being composted. A small cone of woodchips over the pipe outlet will reduce pressure through the pile.

5. <u>Condensate and leachate</u> -- As these liquids drain from the compost pile, they should be collected into a sump and conveyed in a pipe to the sewer system or runoff pond.

6. <u>Removal of compost from the aerated pile to the curing pile</u> -- Excessive odor during this operation can probably be attributed to inadequate stabilization of the compost due to too high a moisture content of the bulking material. The situation is prevented by using drier materials in the initial mixing operation. See item 7 (below) for overcoming the problem if it occurs.

7. Curing piles -- These also can be a source of odors if the material removed from the aerated pile has not been completely stabilized. Blanketing the curing pile with dry cured compost will help to contain any odors. If sludge is incompletely composted after 21 days because of excess moisture, low temperatures, improperly constructed piles, or improperly treated sludge, it should not be put on a regular curing pile. Instead it should be mixed with additional bulking material and composted another 21 days with aeration, or put into a separate isolated pile, heavily blanketed with screened compost, and allowed to compost anaerobically for 6 to 8 months.

8. Storage piles -- Piles should not be constructed with excessively wet compost (above about 55% moisture. The compost should be dried by the procedures outlined above (see "Sequence of Operations - Drying") before piling for storage.

9. Aggregates or clumps of sludge -- When aggregates of sludge, even though small, are allowed to remain on the compost pad after mixing and processing, they soon emit unpleasant odors. All sludge aggregates should be carefully removed from the mixing areas as soon as possible.

10. Ponding of rainwater -- When rainwater is allowed to pond on the site, anaerobic decomposition can result and cause unpleasant odors. Therefore, the site must be graded and compost piles located so that no ponding will occur.

HEALTH ASPECTS OF SLUDGE COMPOSTING

Workers at sludge composting facilities encounter disease risks: (a) from the pathogens normally present in sewage sludges, and (b) from fungi and actinomycetes that grow during composting. The former are often referred to as primary pathogens because they can initiate an infection in an apparently healthy individual. The latter are referred to as secondary pathogens because they usually infect only people weakened by a primary infection or by some other trauma such as lung surgery. Densities of secondary pathogens generally are increased by composting. The growth of secondary pathogens is not peculiar to composting sewage sludge but occurs also in many farm and garden operations, such as during the composting of leaves or other materials. Examples of primary and secondary pathogens, along with the diseases they cause, are presented in Table 6.

Studies to define the risk of infection by primary pathogens to people working with sewage wastes are not as extensive as able 6. Examples of pathogens found in or generated during omposting of sewage sludge, together with human diseases ssociated with these pathogens.

RIMARY PATHOGENS

GROUP	EXAMPLE	DISEASE
Bacteria	Salmonella enteritidis	Salmonellosis (food poisoning)
Protozoa	Entamoeba histolytica	Amoebic dysentery (Bloody diarrhea)
Helminths	Ascaris lumbricoides	Ascariasis (worms infecting the intestines)
Viruses	Hepatitis virus	Infectious hepatitis (jaundice)
ECONDARY PATHOGENS		
Fungi	Aspergillus fumigatus	Aspergillosis (growth in lungs and other organs)
Actinomycetes	Micromonospora spp	Farmer's lung (Allergic response in lung tissue)

ight be desired, but available data indicate that the risk is robably low. The predominant route of infection from the waste aterial is through the mouth. Prevention of infection involves uch precautions as thorough washing of the hands before eating o prevent ingestion of the pathogens. The exposure of workers o primary pathogens in a composting operation is limited to the ile building operation because the temperatures reached in the ext processing step (composting) reduce primary pathogen densities to insignificant levels. The mixing operation presents little hazard, because the high moisture levels prevent dust formation.

Medical difficulty from secondary pathogens may result from inhalation of air containing a high density of spores. The probability that individuals in good health will be infected by secondary pathogens encountered in composting is very small. However, people who are predisposed because of such conditions as diabetes, asthma, emphysema, or tuberculosis, or who may be taking such medication as corticosteroids, broad-spectrum antibiotics, or immunosuppressive drugs may be more susceptible to infection.

The help of local medical authorities should be obtained in compiling a medical history questionnaire for work applicants so that predisposed people are screened out. Individuals who are "atopic," i.e., prone to severe allergies, should also be excluded from employment at composting facilities. Moreover, a complete physical examination is recommended, plus inoculations for typhoid, tetanus, and polio.

The following recommendations and provisions are advisable to ensure the health and safety of employees:

1. Rules pertaining to personal cleanliness should be posted in appropriate areas. For example, the following items should be emphasized:

   a. Wash hands before eating, drinking, and smoking.

   b. Wash hands before returning home after work.

   c. Never store food in close proximity to sludge or compost samples taken for analysis.

   d. If accidentally contaminated with sewage sludge or effluent, immediately take a hot shower, and put on clean clothing.

2. Showers and lockers should be provided at the composting facility.

3. The municipality should provide protective clothing, e.g., coveralls and safety shoes for all workers.

4. Workers should change from protective clothing to street clothes at the end of each day. Protective clothing should not be worn home.

5. As necessary, protective clothing should be cleaned and/or sterilized.

6. During periods of dry weather, the area should be sprinkled periodically to ensure that workers do not inhale the dust. During such weather, workers should be encouraged to wear face masks or respirators.

SECTION 4

UTILIZATION OF COMPOST

POTENTIAL MARKETS

The success of a composting operation will depend greatly on the market developed for the product. It is important to appraise the value of the compost for its potential uses; both beneficial and detrimental characteristics should be considered. A realistic evaluation of the potential market relative to the amount of compost produced is especially important. Some municipalities may find it advantageous to distribute compost to consumers at no cost, since this may be a least-cost option to the municipality.

Livestock manures and their composts, peat, topsoil, and chemical fertilizers already hold significant portions of the potential market. There are, however, possibilities for increasing the market by developing new uses.

The potential market can be classified into three broad categories: (1) a very high-profit, but usually small, market for intensive plant culture practices (luxury garden market); (2) a market for restoration of disturbed lands by mixing compost into the unproductive soil of strip mines, gravel pits, road construction sites and areas of urban or suburban development, and (3) a market for use as a fertilizer-soil conditioner for farm crops.

Some promotional effort will be necessary to distribute a steady volume of compost in any of the above markets. Since the cost of composting is very competitive with the cost of alternative disposal practices even with no credit for value of the compost, it will rarely be essential to show a profit on marketing. However, it will be necessary to develop a market sufficient to handle the planned production.

BENEFICIAL EFFECTS AS A FERTILIZER AND SOIL CONDITIONER

Sludge compost applied at a rate to supply the nitrogen requirements of the crop will supply most of the plant nutrients except potassium, thus it may be necessary to apply supplemental potash. However, it is unlikely that sewage sludge composts will be used to supply the total nutrient requirements of agronomic crops because of the large amounts that would have to be applied.

The maximum value is realized when they are employed in combination with inorganic fertilizers; they partly meet the crop's nutrient requirements and also serve as a valuable organic soil conditioner for maintaining soil productivity.

Nearly all of the nitrogen in sewage sludge compost is in the organic form and must be mineralized to inorganic ammonium or nitrate before it is available for crops. Research indicates the compost from the Beltsville Aerated Pile Method mineralizes only about 10% of the organic nitrogen (N) during the first cropping period after the compost is applied. Thus, sludge compost can indeed be considered as a slow-release N fertilizer.

The application of sludge compost alone, at fertilizer rates (i.e., the N requirement of the crop), to marginal soils can produce significantly higher yields than commercial fertilizers applied alone at the same N level. The higher yields are attributed to an improvement in soil physical properties by the compost. Sludge compost is known to improve soil physical properties, as evidenced by enhanced aggregation, increased soil aeration, lower bulk density, less surface crusting, and increased water infiltration, water content, and water retention. Sludge compost added to sandy soils will increase the moisture available to the plant and reduce need for irrigation. In heavy textured clay soils, the added organic matter will increase permeability to water and air, and increase water infiltration into the profile, thereby minimizing surface runoff. The soils also will have a greater water storage capacity. Addition of sludge compost to clay soils has also been shown to reduce compaction (i.e., lower the bulk density) and increase root development and depth.

Large quantities of the sludge compost produced at Beltsville have been mixed with subsoil and used successfully as a topsoil substitute. A number of public agencies, including the National Capital Park Service and the Maryland State Park Service, have used the compost for land reclamation and development research at Beltsville indicates that sewage sludge compost can be used to great advantage in the commercial production and establishment of turfgrasses (Figure 19), trees (Figures 20 and 21), and ornamental plants. Plants and turfgrasses produced with sludge compost were of better quality, had developed more extensive root systems, were transplanted with lower mortality, and were marketable earlier than those grown with inorganic fertilizer alone. It is likely that large amounts of sludge compost will eventually be used on golf courses and cemeteries, and for landscaping the grounds of public buildings.

In addition to the above uses, sludge compost has a major potential for use in the revegetation and reclamation of lands disturbed by surface mining, by removal of topsoil, and by

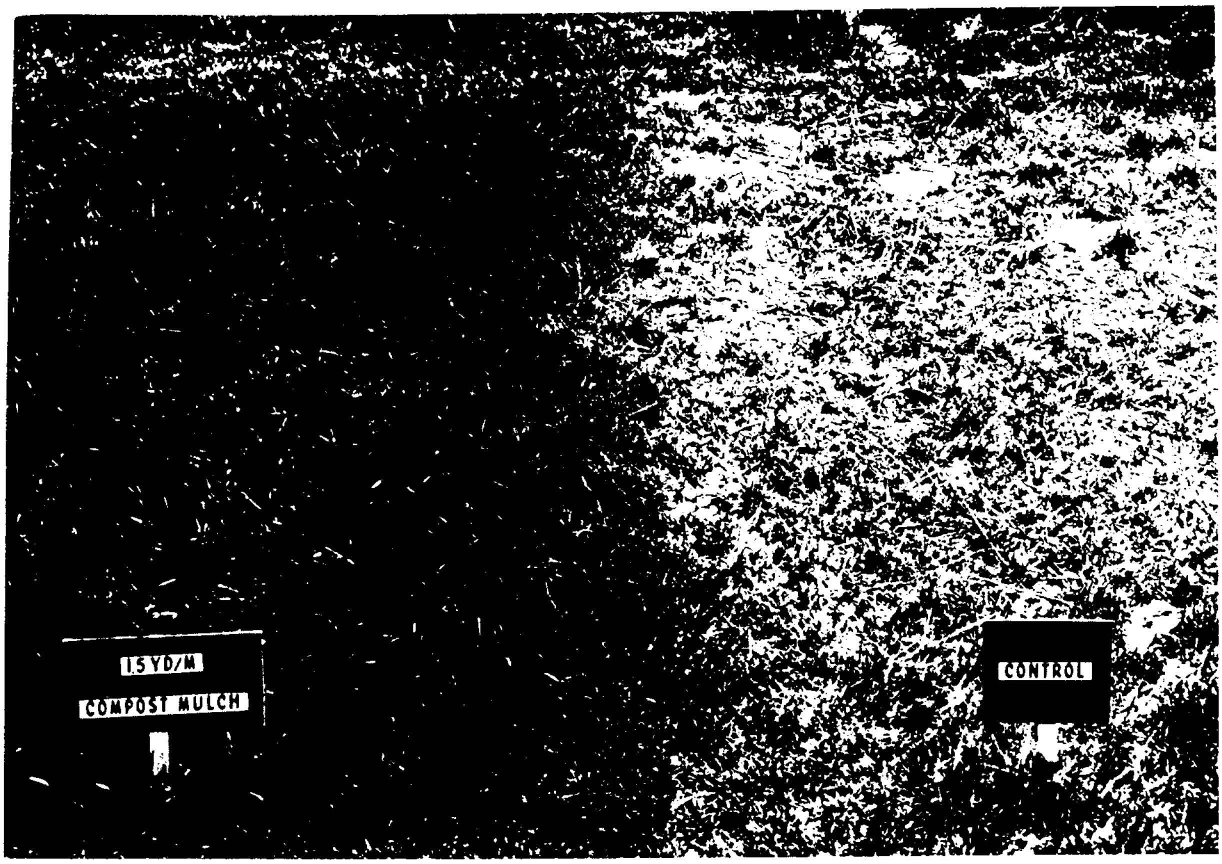


Figure 19. Effect of sludge compost amendment to an infertile soil with clay subsoil on growth of Kentucky bluegrass. Control plot on right received 2 t/1000 sq. ft. of lime, 240 lb/1000 sq. ft. of phosphate, and straw mulch, treated plot on left received 1.5 cu. yd. compost/1000 sq. ft. in addition. Courtesy Dr. Jack Murray, ARS-USDA, Beltsville, Maryland.

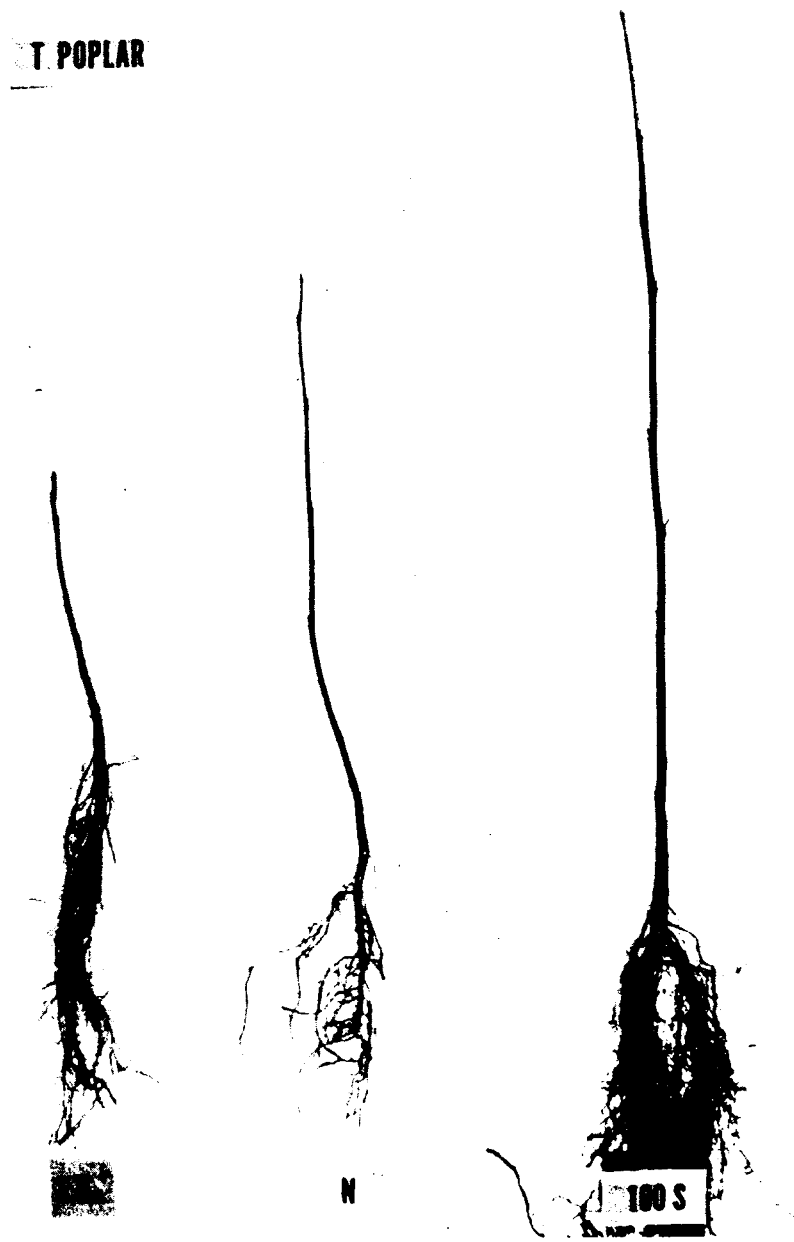


Figure 20. Tulip poplar seedlings showing effects of (N) commercial nursery fertilization; (0) unfertilized control (100 S) 100 T/A screened sludge compost amendment. Courtesty of Frank Gouin, University of Maryland. (See Hort. Sci. 12 (1): 45-47. 1977, for details).

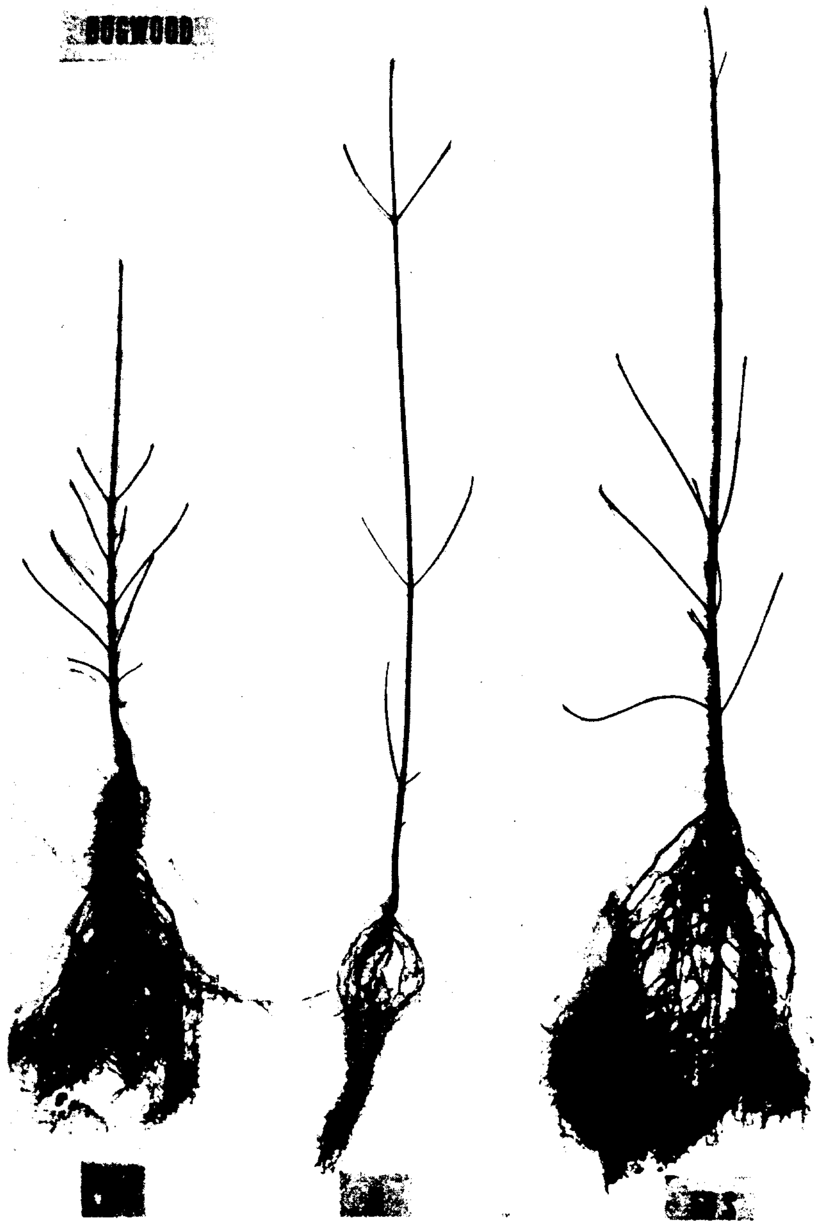


Figure 21. Dogwood seedlings showing effects of (N) commercial nursery fertilization; (0) unfertilized control; (50 S) 50 T/acre sludge compost amendment. Courtesy of Dr. Frank Gouin, University of Maryland. (See Hort. Sci. 12 (1): 45-47. 1977 for details).

excavation of gravel deposits. Eastern stripmined lands are among the most hostile environments for the establishment and growth of plants because of (a) extremely low pH (often below 3.0), (b) extreme droughtiness from lack of organic matter, (c) very high surface temperatures, (d) lack of nutrients, and (e) very poor physical conditions. Research by USDA has shown that through the proper use of sewage sludge compost and dolomitic limestone, a wide variety of agronomic and horticultural crops can be grown on such lands (Figures 22 and 23). With proper management, such disturbed lands can be reclaimed in a surprisingly short time and restored to a high production level.

Recommended compost application rates for various uses to achieve fertilizer benefits and soil improvement are shown in Table 7. In the disturbed soils, higher application rates than listed may be warranted if groundwater contamination is not considered the major factor. For example, if the watershed has little other N inputs and the resulting contamination would be small and/or temporary. Thus, a heavy single application of compost could supply the fertilizer requirements for several seasons. Heavy application rates might also be desirable for disposal purposes during the market development phase of a project.

The fertilizer benefit to the crop from nitrogen contained in the compost may be approximated by appropriate calculations. Several facts must be established to make such calulations:

1. The crop requirement for nitrogen should be estimated. County Agricultural Extension Agents can usually provide nitrogen requirements for crops grown in their particular area, taking into account soil fertility and predicted yield levels.

2. The amount of nitrogen available to the crops during the initial growing season from the applied compost can be estimated as follows:

$$\% \text{ available N} = 0.1 \times \% \text{ organic N}$$

The inorganic N in the compost immediately available to the plant is accounted for in the 10% mineralization rate prediction. Alternatively, the percent mineralizable nitrogen may be determined more accurately by an incubation technique, using the specific soil to which the compost will be added.

3. The amount of nitrogen supplied from the soil (including previously applied compost, crop residues, manures, and chemical fertilizers) should be estimated.

Mineralization of organic N from earlier compost applications will supply a considerable portion of the N requirement along with that which is available from the current application. The second year mineralization of sludge compost is about 5% of

TABLE 7. VARIOUS USES AND APPLICATION RATES OF SEWAGE SLUDGE COMPOST TO ACHIEVE FERTILIZER BENEFITS AND SOIL IMPROVEMENT (ADAPTED FROM HORNICK ET AL 1979)

Use	Compost per 1,000 square feet[1/]	Remarks
	Pounds	
Turfgrasses:		
Establishment:		
Soil incorporated	2,000-6,000	Incorporate with top 4-6 inches of soil. Use lower rate on relatively fertile soil and higher rate on infertile soil.
Surface mulch	600-700	Broadcast uniformly on surface before seeding small seeded species (bluegrass)or after seeding large seeded species (fescues).
Maintenance	400-800	Broadcast uniformly on surface On cool-season grasses apply higher rate in fall or lower rate in fall and again in early spring.
Sod production:		
Incorporated	3,000-6,000	Incorporate with top 4-6 inches of soil.
Unincorporated	6,000-18,000	Apply uniformly to surface. Irrigate for germination and establishment.
Vegetable crops:[2/]		
Establishment	1,000-3,000	Rototill into surface 1-2 weeks weeks before planting or in previous fall. Do not exceed recommended crop nitrogen rate.
Maintenance	1,000	Rate is for years after initial garden establishment. Rototill into surface 1-2 weeks before planting or in previous fall.
Field crops:[2/]		
Barley, oats, rye wheat	1,000-1,300	Incorporate into soil 1-2 weeks before planting or in previous fall.

TABLE 7 (continued)

Corn	3,000-3,800	Incorporate into soil 1-2 weeks before planting. Supplemental potash may be required depending on soil test.
Legumes[3]	---	Legumes can be grown in rotation with corn, oats, or other nitrogen-requiring crops.
Forage grasses:		
Establishment	4,000-7,000	Incorporate with top 4-6 inches of soil. Use lower rate on relatively fertile soil and higher rate on infertile soil. Supplement during first year's growth with 1/2 pound per 1,000 square feet (25 pounds per acre) of soluble nitrogen fertilizer when needed.
Maintenance	1,000-1,300	Broadcast uniformly on surface in fall or early spring 1 year after incorporated application.
Nursery crops and ornamentals (shrubs and trees):		
Establishment	1,900-7,000	Incorporate with top 6-8 inches of soil. Do not use where acid-soil plants (azalea, rhododendron, etc.) are to be grown.
Maintenance	200-500	Broadcast uniformly on surface soil. Can be worked into soil or used as a mulch.
Potting mixes	Equal ratio of material[4]	Thoroughly water and drain mixes several times before planting to prevent salt injury to plants.
Reclamation:		
Conservation planting	Up to 9,200	Incorporate with top 6 inches of soil. Use maximum rate only where excessive growth for several months following establishment is desirable. For each inch beyond 6 inches of incorporation, add 1,000 pounds per 1,000 square feet on soils

TABLE 7 (continued)

		where ground-water nitrogen will not be increased.
Mulch---------------	300-700	Broadcast screened or unscreened compost uniformly on surface after seeding; unscreened is more effective.

1/ 1,500 pounds per 1,000 square feet is equal to 1/2 inch of compost per 1,000 square feet or 33 wet tons per acre based on 40 percent moisture content and 1/2 inch mesh-screened material.

2/ When food crops are grown, careful consideration must be given to the "constraints on uses" described on pages 55 to 59.

3/ Legumes, such as alfalfa and soybeans, do not need all the nitrogen fertilizer supplied by the compost. Maximum benefit of compost as fertilizer can be realized by growing legumes in rotation.

4/ Effective potting mixes have been prepared using equal volumes of sludge compost + peatmoss + vermiculite, compost + peat + sand, or compost + infertile loamy subsoil. After several months' growth, supplemental nitrogen fertilizer may be required.

Figure 22 Response of weeping lovegrass to increasing amounts of sewage sludge compost added to an infertile acid strip-mine spoil.

Figure 23. Scientists examining heavy yield of mixed grasses and legumes grown on infertile acid strip-mine spoil amended with 50 tons per acre of sewage sludge compost.

TABLE 8. AVAILABLE N IN KG FROM A SINGLE APPLICATION OF SLUDGE COMPOST AT INDICATED RATES.*

Sludge Application dry metric tons/ha	Total N Applied (kg)	Available N (kg) 1st yr	2nd yr	Subsequent yrs
20	200	20	9	3
40	400	40	18	7
100	1000	100	45	17
200	2000	200	89	34

* Mineralization rates are 10%, 5%, and 2% for the first, second, and subsequent years, respectively.

the remaining organic N and it is estimated that 2% of the remaining organic N will mineralize per year after the second year. Table 8 contains the available N levels for a designated application of compost containing 1.0% organic N. If a user were to use compost only as the N source for his crop and the crop required 100 kg N/ha, he would apply 100 metric tons/ha the first year, about 60 metric tons/ha the second, third and fourth years, and 30 metric tons/ha thereafter until a mineralization equilibrium would be established; at that time, the amount of available N would equal the total N applied. The number of years of successive compost applications required to reach equilibrium has not yet been established by research. The user might also consider supplementing nitrogen needs with fertilizer, depending on availability and cost. The user should be aware that, in addition to N availability, heavy metal and salt accumulation will also be factors in the determination of a beneficial cumulative loading rate for sludge compost.

In potting soil mixes, sludge compost can supply organic matter, the macronutrients nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and iron (Fe), and the micronutrients copper (Cu), zinc (Zn), manganese (Mn), molybdenum (Mo), and boron (B). In such mixes, it can be used in various combinations with peat-vermiculite, peat-sand, and mixed with infertile subsoil. To ensure optimum plant growth, some inorganic N fertilizer and potassium may have to be applied.

Use of high rates (>50% by volume) is wasteful of the nutrients in the sludge compost, and can cause salt toxicity. Leaching of the mix during watering, a normal horticultural practice, removes excessive soluble salts. A very successful potting mix developed at Beltsville consists of equal parts by volume of compost, peat, and vermiculite. With this mix, no salt problems occurred during the growth of several crops (watered to achieve leaching). However, some additional nitrogen was needed after 4 weeks of growth.

CONSTRAINTS ON USES

Pathogens Because of its origin, compost made from sewage sludge may not be readily accepted by the public from the standpoint of esthetic or health aspects. Esthetic reservations will generally be dispelled upon direct examination of the compost itself, which the observer will perceive as being free from offensive odors and having the appearance of a highly fertile soil. Reassurance on health safety may depend more on an explanation of the composting process and the high temperature disinfection involved, reinforced perhaps by approval from local health authorities. If composting is properly done, as described in this manual, it destroys or reduces to insignificant levels all primary pathogens present in sewage sludges. Once destroyed, viruses, helminths, protozoans, and most bacteria will not repopulate the compost, since they cannot grow external to their hosts. Salmonella, one of the most common organisms causing food poisoning, can regrow to a limited extent in the finished compost, but it does not compete well with other microorganisms present.

Salmonella bacteria are frequently found in the environment. They are often present in fecal material of wild and domestic birds and animals, including pets, and have been isolated from streams and vegetation of mountainous areas remote from human population centers. No significant hazard should be associated with their presence in compost so long as the compost does not come into contact with food.

Heavy metals Many sewage sludges contain large amounts of heavy metals which may reduce the value as a fertilizer for either direct application to land or for composting. Excessive amounts of these metals are often found in sludges where industrial effluent is discharged into the sanitary sewers without pretreatment. Application of high metal sludges on land results in soil enrichment in heavy metals. Experiments on sludge application have shown that soil enrichment by zinc, copper, and nickel can cause direct phytotoxic effects manifested as decreased growth and yield, especially where soil pH is low (pH 5.5) and rates of application are high. Heavy metals may also accumulate in plant tissues and enter the food chain through direct ingestion by humans or indirectly through animals.

The element of greatest concern to human health where sewage sludges and sludge composts are applied to land is cadmium (Cd), since it is readily absorbed by most crops and is not generally phytotoxic at the concentrations normally encountered. Therefore, Cd can accumulate in plants and enter the food chain more readily than, for example, lead (Pb) or mercury (Hg), which are not readily absorbed and translocated to the edible portion of crops. However, since Hg is accumulated by mushrooms, sludge compost should not be used for mushroom culture. Most human exposure to Cd comes from food (principally grain products, vegetables, and fruits) and results in an accumulation of the element in the liver and kidneys. Approximately 3 to 5 percent of dietary Cd is retained by humans. If dietary Cd is substantially increased over long periods of time, Cd can accumulate to levels that might be expected to cause kidney injury. Among the sources that contribute to the level of Cd in food are (a) soils and surface waters contaminated by disposal of wastes, (b) soils inherently high in Cd because of geochemical factors, (c) industrial fallout, and (d) phosphatic fertilizers containing Cd, and (e) industrial contamination of soil and/or food.

The World Health Organization (WHO) has recommended that the maximum level of dietary Cd should not exceed 70 µg/person/day. Workers in the U.S. Food and Drug Administration (FDA) advance the view that any further increase in dietary intake of Cd seems undesirable. However, the extent of the hazard is debated because current data are incomplete about human exposure to Cd and risk through their lifetime. Thus, in order to limit this risk, the utilization of organic wastes on land is restricted by regulatory agencies to control the level of Cd in food chain crops.

Plant species, as well as varieties, have been found to differ markedly in their ability to absorb and translocate heavy metals, to accumulate them within edible organs of the plant, and to resist their phytotoxic effects. Leafy vegetables are usually sensitive to the toxic effects of metals and accumulate them; cereal grains, corn, and soybeans are less sensitive; and grasses are relatively tolerant. Uptake studies with corn, soybean, and cereal grains have shown that heavy metals accumulate less in the edible grain than in the leaves; similar results are found for edible roots, as radish, turnip, carrot, and potato, and fruits, as tomato, squash, etc.

The availability to and uptake of heavy metals by plants are influenced by certain chemical and physical properties of soil, especially pH, organic matter content, cation exchange capacity (CEC), and texture (i.e., the proportions of sand, silt, and clay). Phytotoxicity and plant availability of sludge-borne metals are higher in acid soils than in those with neutral or alkaline pH. Maintaining soil pH in the range of 6.5 or above by liming reduces the availability of heavy metals to plants. Application of organic amendments such as manures and crop residues can also decrease the availability of heavy metals to plants. The CEC is a measure of the soil's capacity to retain cations; higher CEC is usually associated with higher clay and organic matter contents. Heavy metals are generally less available to plants in soils of high CEC (e.g., organic matter rich soils or clay loams) compared with soils of low CEC (e.g., loamy sands). Recent research at Beltsville suggests that, on a total metal basis, heavy metals are less available to plants in composted sewage sludges than in uncomposted raw and digested sludges, although the reason for this is not yet known.

The metal contents of digested sewage sludge in terms of the range of observed levels, the maximum levels recommended for landspreading and the median levels found in several surveys are presented in Table 9. The levels of heavy metals for raw or undigested sewage sludges would be approximately one-half of those shown in the table, since anaerobic digestion reduces the volatile solids and thus tends to increase the metal content. In the view of the present writers, the Cd/Zn ratio of sludges used on cropland should not exceed 0.015; that is, the Cd content of sewage sludge should not exceed 1.5 percent of the zinc content. The reasons for this are as follows: a) if Zn levels in the soil are much higher than Cd, plant Zn will accumulate to phytotoxic levels before sufficient Cd can be absorbed to endanger the food chain, b) Zn reduces absorption of Cd in animal intestines, and c) Zn inhibits uptake of Cd by dicotyledonous plants at low Cd/Zn ratios. Limited experimental evidence has shown a low Cd/Zn ratio reduces potential impact of soil Cd when soil pH drops below the recommended limits, while cumulative Cd application limits control Cd effects at pH 6.5 or above. At present, regulation of Cd/Zn ratio is not universally accepted, but no other method has been proposed which limits impact of Cd in acid soils.

Median sludge Cd was 13 or 16 ppm, and Cd/Zn $\geq$ 1%. Metal contents indicated in Table 9 as "Typical Domestic Level" are achieved by many large cities in the United States, e.g. Washington, D.C., Baltimore, MD, Denver, CO, and Philadelphia, PA. Sludge metal contents in cities with higher levels could be reduced by industrial pretreatment. It has not yet been shown that pretreatment will produce acceptable sludge metal levels at all locations, although most evidence supports pretreatment.

To limit the buildup of heavy metals on agricultural land resulting from the landspreading of either sewage sludges or sludge composts, USDA proposed certain recommendations in 1976. Two categories of land were delineated: (1) privately owned land and (2) publicly owned or leased land dedicated to sludge application. (Copies of the draft document are available from the Office of Environmental Quality Activities, USDA, Washington, D.C.). Such recommendations hopefully will encourage the use of sludges of low heavy metal content for composting and direct land application on privately owned land. The recommendations were based on the best information available at the time from scientists at a number of state universities and agricultural experiment stations, as well as from USDA sources.

TABLE 9. METAL CONTENT OF SEWAGE SLUDGE BASED ON SEVERAL SURVEYS.

Element	Maximum[1] Domestic	NC-118[2] Median	NC-118[2] Mean	NC-118[2] Range	Northeast[3] Median	Northeast[3] Mean	Northeast[3] Range
Cd, ppm	25	16	110	3- 3410	13	72	0.6 - 970
Zn, ppm	2500	1740	2790	101-27800	1430	2010	228 -6430
Cd/Zn, %	1.0	1.0	4.8	0.1-100	0.84	3.64	0.26- 78
Cu, ppm	1000	850	1210	84-10400	790	1080	240 -3490
Ni, ppm	200	82	320	2- 3520	42	129	10 -1260
Pb, ppm	1000	500	1360	13-19700	500	735	52 -4900

1/ Digested sludge, Chaney and Giordano, 1977.

2/ 169-208 sludges, Sommers, L. E. 1977. Chemical composition of sewage sludges and analysis of their potential use as fertilizers. J. Environ. Qual. 6(2):225-232.

3/ 43 treatment plants, (digested sludge), Chaney, R. L., S. B. Hornick, and P. W. Simon. 1977. Heavy metal relationships during land utilization of sewage sludge in the Northeast. p. 283-314. In R. C. Loehr. (Ed.). Land as a waste management alternative. Ann Arbor Science Publishers, Inc., Ann Arbor, Mi.

Table 10 shows the recommended maximum cumulative sludge metal loadings for privately owned agricultural land according to the soil cation exchange capacity (USDA recommendations). Soils in the 0 to 5 CEC range are characteristically sands through sandy loams; the 5 to 15 range includes sandy loams, loams, silt loams; and > 15 includes silty clay loams and clays. Higher metal loadings would be considered reasonably allowable on heavier textured soils. Cadmium loadings on land should not exceed 2 kg/ha/year for dewatered sludge or sludge compost and should not exceed the total cumulative loadings shown in Table 10. When sludges are applied, the soil should be limed to pH 6.5 and maintained at 6.2 or higher. Sludges and sludge composts should not be applied to land used to grow tobacco as this crop allows high transfer of Cd to humans; sludges and composts used on land used to grow leafy vegetables should be low in Cd and Cd/Zn ratio to minimize any effects on humans.

On publicly controlled land, a maximum of up to 5 times the amount of sludge-borne metals listed in Table 10 seems to represent a reasonable limit if the sludge is incorporated into the soil to a depth of 15 cm. With deeper incorporation, total metal applications may be proportionally higher. These metal loadings are permissible only when the pH is maintained at pH $\geq$ 6.5; cropping with Cd-excluding grains (e.g. corn) minimizes the impact of this practice.

TABLE 10. RECOMMENDED MAXIMUM CUMULATIVE METAL LOADINGS FROM SLUDGE OR SLUDGE COMPOST APPLICATIONS TO PRIVATELY OWNED LAND.

Metal	Soil cation exchange capacity (meq/100g)[1/]		
	0 - 5	5 - 15	>15
	(Maximum metal addition, kg/ha)		
Zn	250	500	1000
Cu	125	250	500
Ni	50	100	200
Cd	5	10	20
Pb	500	1000	2000

1/ CEC determined prior to sludge application using 1 N neutral ammonium acetate and is expressed here as a weighted average for a depth of 50 cm.

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APPENDIX

ANALYTICAL METHODS

A compendium of analytical methods for sewage sludges and sludge composts has not yet been published. Nevertheless, a number of references are available which will be helpful in the chemical and microbiological analyses of these materials. These are listed as follows:

a. A Manual of Methods for Chemical Analysis of Water and Wastes. 1974. (EPA-625-16-74-003).

b. Standard Methods for the Examination of Water and Wastewater--Including Bottom Sediments and Sludges. 1975. 14th edition, published jointly by the American Public Health Association, the American Water Works Association, and the Water Pollution Control Federation. Available from the American Public Health Association, 1790 Broadway, New York, N.Y.

c. Sampling and Analysis of Soils, Plants, Wastewaters, and Sludge: Suggested Standardization and Methodology. 1976. North Central Regional Publ. No. 230. Available from Kansas State University Agricultural Experiment Station, Manhattan, Kansas. 20 p.

d. Methods of Soil Analysis. 1965. Part I: Physical and Mineralogical Properties, including Statistics of Measurements and Sampling. Agronomy J. No. 9, American Society of Agronomy, Inc., Madison, Wisconsin. 768 p.

e. Methods of Soil Analysis. 1965. Part II: Chemical and Microbiological Properties. Agronomy J. No. 9, American Society of Agronomy, Inc., Madison, Wisconsin. p. 768-1569.

f. Recommended Procedure for the Isolation of Salmonella Organisms from Animal Feeds and Feed Ingredients. Agricultural Research Service, U.S. Department of Agriculture. ARS 91-68-1, July 1971. 15 p.

Methods generally accepted for analyzing components needed in calculating compost application rates are: total N by Kjeldahl;

NH_4-N by analysis of NH_4 in the filtrate of an extract of 1 g of sludge or compost with 50 ml of 2N KCl for 60 minutes; total P, K, Ca, Mg, Zn, Cu, Ni, Cd, Pb, and Fe in a dry-ashed or wet-ashed sample using colorimetric or atomic absorption analysis (atomic absorption is the preferred method, especially for important elements like Cd, but background correction is required for analysis of Cd, Ni, and Pb by this method). If Hg, Se, or As analyses are needed, only wet ashing is acceptable; for Hg analyses, a wet sample should be used, as heat drying (105°C oven) causes volatilization of Hg. $CaCO_3$ is measured by consumption of acid using a pH meter titration method; soluble salts are measured as conductivity of the saturated extract.

A plant germination and early growth test in which a mix of compost soil is used at a typical loading rate ($\leq$ 50 T/ha) and compared to a control will demonstrate whether improper composting, or the salts, introduced with the compost could interfere with planned uses. Customarily, seeds of several species (corn, bean, cucumber) are sown; percent germination and growth patterns are observed.

MONITORING EQUIPMENT

Note: All equipment with exception of pH meter should be portable and rugged.

Temperature reading devices: Must have temperature range of at least 0°C to 100°C. Probe should be 1.5 meters long for insertion into compost pile. Some typical equipment is listed below:

1. Thermistemp Tele-thermometers--Yellow Springs Instruments, Model 42. (Available through Fisher Scientific or Curtis-Matheson Scientific). General purpose, with three overlapping scales to continuously monitor temperature in range from -40°C to 150°C. Probe to be used with this instrument listed below.

2. Thermistor probe. Atkins Technical Inc., Model PK-35. To be used with above Tele-thermometers. General purpose and moderately heavy duty.

3. Compact, portable, temperature-calibrated potentiometer. James G. Biddle Co., Cat. Nos. 606115 and 604116, Leeds and Northrup. Suited for making accurate temperature measurements from thermocouples, checking and measuring thermocouples, as well as checking other thermocouple pyrometers, recorders, and controllers.

4. Insulated thermocouple wire--Fisher Scientific, Leeds and Northrup Co. 16-gauge wire capable of handling

temperatures up to 195°F (90°C) used.

Oxygen reading devices

1. Portable oxygen analyzer--Teledyne Analytical Instruments Model 320 B/RC, Taylor Servomex Type OA 250. Used in field or laboratory situation for instant O_2 determination in air medium. A probe for collecting gas samples for analysis may be made from 0.6-cm steel tubing. The tube is capped or pinched off and small holes are drilled near the tip.

Moisture content determination devices

1. Moisture determination balance--Ohaus Model Nos. 6109, Mettler Model LP 11. Combination balance and heat lamp for taking original weight, drying out sample, and taking final weight. The instrument is calibrated to read in percent moisture content.

Air velocity determination devices

1. Thermo-anemometer and probe -- Alnor Instrument Co., Type D 500 K. For use in determining air flow velocity in pipe. Range from 10 to 2000 feet per minute. Portable, for field use.

Pressure determination device

1. Magnehelic pressure gauges--Dwyer Instruments Inc. Portable, for measuring pressure in pipe flow in field or laboratory. Can be obtained to cover various ranges and pressures.

pH determination devices

Compost is prepared for analysis by making a slurry with distilled water (1:1) and allowing slurry to stand for 30 minutes before the determination. Many suitable pH meters are available, two are listed below:

1. Laboratory expanded scale research pH meter--Fisher "Accumet" Model 320, Corning Model 110 (Digital) Scientific. For use in laboratory situation. Models vary in type of readout and precision.

2. pH meter, pocket size, analytical--VWR Scientific. For on the spot readings in the field. Completely self-contained in waterproof carrying case.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/8-80-022	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE MANUAL FOR COMPOSTING SEWAGE SLUDGE BY THE BELTSVILLE AERATED-PILE METHOD		5. REPORT DATE May 1980 (Issuing Date) 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) G. B. Willson, J. F. Parr, E. Epstein, P. B. Marsh, R. L. Chaney, D. Colacicco, W. D. Burge, L. J. Sikora, C. F. Tester, S. Hornick		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Department of Agriculture Beltsville, Maryland 20705		10. PROGRAM ELEMENT NO. C36B1C 11. CONTRACT/GRANT NO. S803468
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory-Cin., OH Office of Research and Development U. S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES

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16. ABSTRACT

In producing clean water from sewage, wastewater treatment plants also produce sludge. Most of the commonly used methods to dispose of this material are now considered to be either environmentally unacceptable, wasteful of energy, or very expensive. To ease this situation, a relatively simple, rapid, and inexpensive sludge composting process has been developed at Beltsville. The method makes possible the conversion of undigested sludge into a composted product that is aesthetically acceptable and meets environmental standards. The material has demonstrated usefulness as a soil amendment stimulative to plant growth. If relatively simple control procedures are followed, the compost appears to be free of primary human pathogens because of the lethal effect of heat generated during the composting process on such organisms.

The new Beltsville composting procedure, detailed here in respect to both prinples and practice, represents a major advance over previously known composting methods It is adaptable to practical use in municipalities of widely varying size. In many situations its short startup time will allow its use as an emergency interim solution for sludge management. Key information is presented on the economics of the process, and on the marketing and use of the product as a soil conditioner to improve plant growth.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Aerobic processes Sewage disposal Composts	Beltsville static-pile composting Agronomic utilization of sewage compost	13B 6D 2A

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 81
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)

☆ U S GOVERNMENT PRINTING OFFICE 1980-657-146/5649