United States
Environmental Protection
Agency

Water Engineering
Research Laboratory
Cincinnati OH 45268

Research and Development

EPA/600/S2-85/103 Jan. 1986

EPA

Project Summary

Chemical and Microbial Aspects of Sludge Composting and Land Application

L. J. Sikora, P. D. Millner, and W. D. Burge

A series of six studies was undertaken to study various chemical and microbial aspects of the composting and land application of sewage sludge. Ammonia, which is generated in sludge by ammonifying microorganisms, was shown to be virucidal. In the pH range of 7 to 9, NH_3, but not OH^- or NH_4^+, was effective. Temperature effects were related to a single NH_3 concentration. Sludge and sludge compost with high concentrations of heavy metals and chlorinated organic materials appeared to have no inhibitory effect on soil enzyme activity, probably because of the age or the highly stabilized nature of the sludge and sludge compost.

Sludges were applied once (100 megagrams [Mg]/ha) or annually (20 Mg/ha) for 5 years to field plots. N movement down the soil profile occurred in the sludge-amended plots, especially in all of the split plots that received additional fertilizer. Phosphorus movement occurred only down to the 60-cm depth, or four times the depth of incorporation in the sludge-amended plots.

Laboratory studies conducted to test methods for improving the efficiency of composting indicated that the most efficient system was the temperature-demand aeration system. This method resulted in twice as much drying and yielded 2.5 times as much CO_2 as constant aeration composting.

Results of studies have shown that *Aspergillus fumigatus* (AF) and thermophilic actinomycetes (TA) are present in air at very low levels in most non-agricultural sites, even when organic matter is present and temperatures are occasionally higher than ambient. Compost and moldy agricultural substrates are the biggest reservoirs and sources of AF and TA. The tolerance of AF to broad ranges of temperature, CO_2, and water content limit the benefits of modifying the composting process by these parameters to inhibit this microorganism.

This Project Summary was developed by EPA's Water Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Applying sewage sludge or sludge compost to land can affect several chemical and microbiological factors in soils. The benefits of this practice, which include the addition of nutrients, trace metals, and organic matter, can be offset by excess additions of phytotoxic metals, nitrogen, and organic chemicals. The need to differentiate between proper and excessive sludge additions to soil is imperative to evaluate properly the benefits of each sludge product. Certain sludges have excessive amounts of toxic materials and should not be applied to land. Other sludges may have elevated amounts, but they have no apparent phytotoxic consequences when added to soil at low rates. The long-term effects on soil productivity, surface water, and groundwater need to be elevated along with the short-term, first-year effects.

This report discusses the effect of NH_3 on the survival of viruses and compares NH_3 with halogens for virucidal properties. The availability of sludge N and P to plants and the movement of these nutrients through the soil profile over the long term are also discussed. Soil enzymes, the key to successful biochemical transformations in soil, were monitored to determine the effects of large or repeated sludge applications. The data presented here provide a better understanding of the long-term effects of such applications.

Composting stabilizes sewage sludges and transforms them into an easily spread and stored material. The composting process was analyzed extensively using a self-heating laboratory composter, and the effects of temperature and aeration on the efficiency of the composting process were determined. These investigations improved our understanding of the optimum composting process for producing material for soil amendments.

Composting is a thermophilic process and results in a product containing numerous thermophilic organisms that have various public health implications. This study provides data on the numbers, types, and potential health implications of thermophilic organisms produced during the composting of sewage sludge, the movement of compost and other self-heating materials, and the eventual distribution of these materials to users.

Kinetics and Thermodynamics of Viral Inactivation by Ammonia

Ammonia has been shown to be virucidal in sludge and in NH_4Cl solutions. Our studies examined the kinetics and influence of temperature on the inactivation of f2 bacteriophage and poliovirus 1 by NH_3. At pH values from 6.5 to 9.5 and NH_3 concentrations from 50 to 800 mg/L, the inactivation of both viruses was pseudo-first-order. The OH^- had no measurable effect on the viruses, and the virucidal effect of NH_4^+ was insignificant compared with that of NH_3. The bacteriophage f2 was approximately 4.5 times more resistant to the effects of NH_3 than was poliovirus.

A general rate equation was derived for virus inactivation as influenced by NH_3 concentration. Although NH_3 is a weak disinfectant, it may be a practical virucide. Temperature strongly influenced inactivation rate. Poliovirus was inactivated at a greater rate than f2, but the change in the rate of inactivation with increasing temperature in the range of approximately 10° to 40°C was greater for poliovirus. At higher temperatures, the rate of change was greater for poliovirus. Arrhenius plots of the data were biphasic, indicating that two inactivation processes were occurring at 300 mg/L NH_3—one for the low-temperature range and another for the high-temperature range (Figure 1). However, the magnitudes of the thermodynamic variables for f2 were low enough, as calculated for the low (10° to 35°C) and high (35° to 60°C) phases, that inactivation could have occurred by breakage of nucleic acid chains. For poliovirus, the sizes indicated possible involvement of nucleic acid at the low range (10° to 40°C) but some unkown mechanism for the high range (40° and 50°C). The study concluded that inactivation by NH_3 could play an important role in the destruction of viral pathogens in sludge.

Effects of Sludge and Compost on Soil Enzymatic Activity

Soil enzymes are important factors in plant nutrient mineralization. They may be temporarily or permanently impaired by soil amendments that contain excessive amounts of heavy metals or organic chemicals. A study was initiated to quantitate and compare the effects of various sewage sludges and sludge composts on important soil enzymes such as dehydrogenase, urease, and alkaline phosphatase.

A high-metal, high-organic chemical sewage sludge and its composted counterpart were tested to determine their effects on soil enzymatic activity. Dehydrogenase activity and rate of CO_2 evolution of the amended soils were closely correlated with respect to amendment type and rate, and no inhibition was apparent. Phosphatase activity of all amendments was correlated to CO_2 evolution. Net urease activity was correlated to amendment type (degree of stabilization) and rate, and it showed no apparent inhibition.

The relative level of heavy metals or organic chemicals therefore may not be a suitable indicator of the biological effects of sewage sludge and sewage sludge composts. Several studies have indicated that inorganic metal salts have inhibiting effects on enzymes, some at very low concentrations. These data indicate that, through time, metals are bound or chelated with organic matter and that organic chemicals are partially degraded or neutralized, resulting

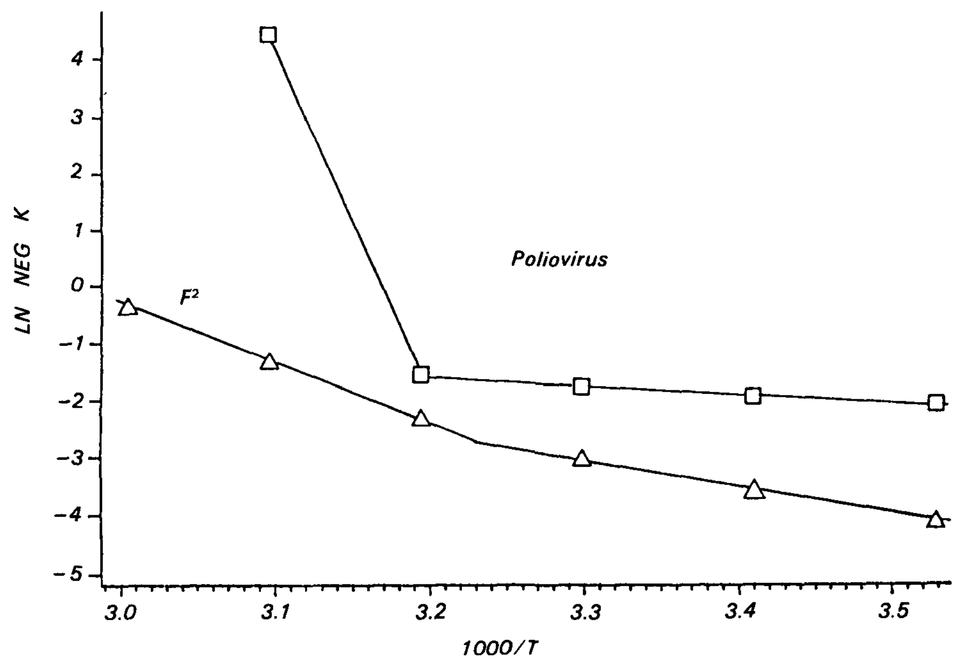

Figure 1. The relationship between the inactivation rate constant (k) and temperature (° Kelvin) for f2 and poliovirus 1 (Chat).

in little or no inhibitory effect on biological processes such as enzyme activity.

Effects of Sewage Sludge Applications on Nitrogen Mineralization and Phosphorus Mobility in Soils

Sewage sludges contain a wide range of essential plant nutrients. Recycling these nutrients on agricultural land can augment commercial fertilizer sources and thereby conserve the energy used in their production.

In 1978, the W-124 Regional Committee formulated a cooperative, 5-year research project on the land application of sewage sludge to answer the questions concerning the effects of soil type and climate on N mineralization and P mobility.

The field data collected at Beltsville, Maryland, generally indicated that a 20-Mg/ha annual application rate resulted in yields similar to those from the recommended fertilizer application rate, but that slightly more N was taken up by the plants growing on plots receiving sludge. The 20-Mg/ha annual application resulted in a greater cumulative yield and N uptake than the single 100-Mg/ha application added to the plots in 1978. The application of N on the split plots in 1981 resulted in larger, but not significant, yield increases and N uptake increases in most instances. During the first and second years, phosphorus uptake was greater in the 100-Mg/ha plots than in the 20-Mg/ha plots. The uptake for the third through the fifth years was the same for each treatment.

Soil samples were taken with depth after the harvest in 1983 and compared with soil samples taken from the plots in 1978 before sludge application. Migration of N was detected to the deepest sampling depth, which varied from 60 to 180 cm in all N^- and sludge-fertilized plots. Phosphorus migration down to 60 cm was found in plots receiving sludge application.

The movement of P does not pose a problem and may even be beneficial. The depth of P movement is within the root zone and below the level of incorporation. Plants should therefore benefit from the deeper soil horizons containing P.

Effect of Temperature and Aeration on the Composting Process

Composting is a process that is self-starting, self-heating, and in certain circumstances, self-limiting. In general, the variables that control or affect composting are the quality of the starting materials, moisture, aeration, pH, and temperature.

In the process of removing water from composts, heat is concomitantly removed. Vaporization is the dominant heat removal mechanism, removing nearly nine times more heat than convection. Evaporation can be accelerated by turning piles or by increasing the aeration rate. Thus the control of temperature is best accomplished through control of vaporization or moisture removal.

A laboratory composter that uses thermistors as temperature-sensing devices and an aeration system, which permits diffusion of air into the mass, was designed for testing parameters to improve the composting system. Raw, highly limed filter cake sludge from the Blue Plains Wastewater Treatment plant (Table 1) was mixed with woodchips in a ratio of 1:1.8 (v/v) and composted. Aeration was controlled either at preset airflow rates or according to the demand necessary to hold the temperature desired. One study limited the temperature of the insulating water bath to 55°C, thereby preventing the composting organic material from reaching 60°C. A second study aerated the sludge-woodchip mixture at 900 or 1800 m^3/h per Mg and compared temperatures, moisture, volatile solids, and CO_2 loss. A third composter study directly compared composting of a sludge-woodchip mixture under constant aeration with that of a temperature-demand system.

Carbon dioxide data indicated that the water-bath-controlled, 55°C composter produced 50% more CO_2 than the uncontrolled composter that reached 80°C, probably by having a more diverse population to degrade a greater variety of compounds in the mixture (Table 1). The data obtained from the study at two aeration rates indicated that continuous rapid aeration did reduce peak temperatures, but it also reduced the duration of the composting process. In the temperature-demand study, 2.5 times more substrate decomposed than in the constant aeration composter. The final moisture content of the compost from the temperature-demand study was 33%.

Constant, high aeration did reduce peak temperatures, but it did not result in the most efficient composting system. Increasing and decreasing the aeration rates to keep temperatures between 50° and 55°C allowed the maximum thermophilic population to remain active for extended periods.

The microbial data indicated that high temperatures (>65°C) decreased both total number and diversity of population, which resulted in a substantial decline in CO_2-C evolution or stabilization. The disappearance of fungi from the high-temperature composts and the significant difference in CO_2 evolution underlined the importance of fungi in the stabilization process and the neces-

Table 1. *Carbon, Nitrogen, and Moisture Losses During Composting of Raw, Limed Sewage Sludge and Woodchip Mixtures under Various Aeration and Temperature Conditions*

Aeration-Temperature Condition	Material Losses (%) Wet Weight	Dry Weight	Total N	CO_2-C*	Final % Moisture
Bath controlled at 55°C	32.9	6.6	2.8	6.9	38.1
versus					
900 m^3/h per Mg constant aeration	29.0	0.7†	4.6	3.1	37.7
900 m^3/h per Mg constant aeration	29.4	6.3	4.1	1.8	41.3
versus					
1800 m^3/h per Mg constant aeration	29.4	6.3	3.9	3.1	39.8
900 m^3/h per Mg constant aeration	22.1	5.3	10.6	2.4	49.3
versus					
Temperature, demand aeration	45.3	12.2	21.7	5.9	33.0

*Grams of CO_2-C lost per 100 g dry initial mixture.
†Error was due to inaccurate moisture determination.

sity of a successful compost operation for controlling temperatures as much as possible.

Nitrogen loss from organic material composting has not been studied extensively, and from the data collected in these studies, the amount of N lost was proportional to condensate loss. Thus increased aeration leads to increased loss of nitrogen, but if the N loss is accompanied by an increased loss of volatile solids (as in the temperature-demand study), the N content of the final product changes only slightly.

Nutritional and Non-Nutritional Factors in the Growth of *Aspergillus fumigatus* (AF) and Natural Sources of Airborne AF and Thermophilic Actinomycetes

The potential public health risk associated with aerosols of *Aspergillus fumigatus* (AF) that cound be inhaled at sludge-composting sites has been a concern to those who are responsible for the planning and operation of compost facilities. Information about the ambient levels of AF spores in air could be used to help evaluate the potential impact of the aerosols on the public health in adjacent areas.

The work reported here was undertaken to increase the data base on the quantitative differences in airborne levels of AF under environmental circumstances that affect the growth of the fungus. An extensive literature survey was made to determine the present knowledge of the occurrence of AF in the air. Then a series of air samples was collected from various locations (including some suspected natural sources) and analyzed for viable AF.

Studies were also made of the nutritional and non-nutritional factors in sewage sludge composting that affect the growth of AF. This part of the work aimed to determine whether or not there was a basis for managing the composting process to produce a minimum of AF growth and aerosols.

Finally, to answer concerns about the exposure of compost-site workers to farmer's lung antigens (thermophilic actinomycetes, or TA), air levels of these microbes were determined concurrently with those made for AF in the different ambient environments.

Air Sampling for Fungi and TA

Selected for study were habitats in which environmental conditions were conducive to the growth of AF and TA. Air samples were obtained by using Andersen six-stage, viable (microbial) particle samplers (Andersen 2000, Inc., Atlanta, Georgia).* Twenty-one outdoor and indoor suspected sources and three unsuspected (reference) sources were sampled.

Nutritional and Non-Nutritional Factors Affecting the Growth of AF

An investigation was made of the tolerance limits on factors that affect the germination, growth, and sporulation of AF. The object was to suggest practical modes of imposing environmental stress on the organism in the composting situation.

Natural Airspora of AF

The airspora levels of the different sampling sites during each season appear in Table 2. During winter, the airspora in outdoor locations was generally lower than that during other seasons. AF levels at the reference sites were also lower in winter than in summer, and they were never greater than 12 colony-forming units (cfu)/m^3.

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Substrate Studies

Several types of wood common to the mid-Atlantic region of the United States, as well as oak leaves, paper pellets and cubes, and peanut hulls are excellent substrates for AF growth and sporulation when sufficient moisture and temperature are provided.

Temperature Studies

All of the seven isolates grew poorly at 55°C and very slowly at 59°C. At 45°C, the growth rate was 6 to 8 times greater than that at 50°C.

Gaseous Environment and pH Studies

In chambers containing 0.5% O_2 and 23% CO_2, AF spores germinated and mycelial extension was equivalent to that observed on the control plates incu-

Table 2. *Natural Airspora of* Aspergillus fumigatus, *1979-80*

Site	*Seasonal Counts (colony-forming units/m^3)* Fall	Winter	Spring	Summer
Lawn:				
During mowing	1	5	2	0
With mulch	75	2	6	686
Under trees	3	0	5	4
Of hospital	2	0	0	0
Of park	8	4	24	2
Wood area:				
Arboretum	4	1	6	136
Nature trail	56	0	10	8
Roadside	1	5	2	3
Agricultural:				
Corn field	1	0	0	4
Barn	2,070	105	352	5,550
Barnyard	44	0	35	4
Poultry house	21	93	2,060	6
Mushroom house	88,700	740,000	580,000	67,100
Brush pile	1	1	25	5
Refuse:				
Municipal dump	6	2	0	5
Supermarket dumpster	2	0	0	12
Greenhouse:				
Potting room	868	1,350	1,070	9,810
Low humidity	NS*	11	312	1
High humidity	NS	0	152	2
Library stacks	171	0	0	0
Attic	NS	1	1,160	125
Zoo - birdhouse	5	0	42	2
Boiler room	30	38	1	1
Reference sites:				
School playground	6	1	12	9
University parking lot	7	1	12	9
Shopping center	11	1	7	3

**NS = not sampled.*

bated in air at ambient temperature. However, only a very limited number of conidiophores and spores were produced. Rapid growth and sporulation occur at pH 6, 7, and 8, but decreased growth rate and sporulation are evident at pH 9 and 10.

Osmotic Potential

Decreased growth rate occurred at all temperatures when the osmotic potential of the growth medium was less than -40×10^2 kPa.

Natural Airspora of TA

Most outdoor and indoor locations had fewer than 10 TA cfu/m^3. Exceptions included the mushroom house, barn, barnyard, and poultry house. TA from other locations belonged to the genus *Streptomyces*, and an identification scheme for the group was devised based on test results from the type species and 55 compost and 35 natural airspora strains.

Results of these studies show that AF and TA are present in air at very low levels in most nonagricultural sites, even if organic matter and occasionally higher-than-ambient temperatures are present also. Thus the natural sources for AF and TA are very limited in terms of abundant production of spores. Few spores are airborne from the natural sources, even during mechanical disturbances such as mowing. High levels of AF and TA in air are associated with heavily colonized substrates. Compost and moldy agricultural substrates are the biggest reservoirs and sources of AF and TA.

Practical alterations of the sewage-sludge composting process to reduce AF growth and dispersal from compost sites should presently focus on the use of noncellulosic bulking agents. Such agents would substantially reduce the inoculum levels entering the process. The tolerance of AF to broad ranges of temperature, CO_2, and water content limit the benefits of modifying the composting process by these parameters to inhibit this microbe.

Conclusions

Ammonia was shown to be virucidal in sludge and in NH_4C1 solutions. Temperature effects on NH_3 activity were biphasic, indicating that two inactivation processes were occurring—one for the low-temperature range and another for the high-temperature range. The f2 virus was 5.4 times more affected by NH_3 than was poliovirus 1. As a virucide, NH_3 is extremely weak compared with chlorine. Because of its high reactivity with organic material, chlorine is required in high dosages to disinfect sludge. These translate into high chloride levels in the final sludge. The use of NH_3 to disinfect wastewater treatment plant effluents is precluded by the slowness of its reaction; but in sludge, NH_3 may indeed be a practical virucide.

The effects of two types of sludges and their corresponding sludge composts on soil enzyme activities indicated that the stabilization level of the sludge correlated negatively with enzyme activity. One sludge that was stored in a lagoon for several years and contained high concentrations of heavy metals and chlorinated organic materials showed no significant inhibitory effect on soil enzyme activity. The reason was probably that the sludge and the corresponding sludge compost were highly stabilized, with the toxic components either degraded or bound to organic matter.

Soil profile data indicated that when a digested sewage sludge was applied once at 100 Mg/ha or annually at 20 Mg/ha for 5 years, mineralized N exceeding plant needs was found below the root zone. The addition of fertilizer N to split plots increased the level of mineralized N in the deep soil profile. Phosphorus in the sewage sludge also migrated down the soil profile, but not to the same depths as N. The 20-Mg/ha application rate exceeded the nutrient needs of barley.

A self-heating laboratory composter was designed, built, and used successfully in studies of test methods for improving the efficiency of composting. The most efficient composting system tested was one that adjusted aeration to hold temperatures near or below 55°C. This system produced 2.5 times more decomposition and 2 times more moisture loss from the compost than did a compost system using a constant rate of aeration. The loss of N from the compost was directly related to the efficiency of removing moisture.

AF and TA are present in air at very low levels at most nonagricultural sites, even if organic matter and occasionally higher-than-ambient temperatures are also present. Thus the natural sources for AF and TA are very limited in terms of abundant production of spores. Compost and moldy agricultural substrates are the biggest reservoirs and sources of these organisms. The tolerance of AF to broad ranges of temperature, CO_2, and water content limits the benefits of modifying the composting process by these parameters to inhibit the microbe.

Recommendations

Ammonium was shown to be virucidal to f2 bacteriophage and poliovirus 1. The effect of NH_3 on the inactivation of several human pathogens needs to be evaluated before recommendations can be made on the use of NH_3 for reducing pathogen numbers in sewage sludge.

Caution should be exercised in evaluating the effects of heavy metals and chlorinated organic materials in sewage sludge on soil biochemical properties. Factors such as age of the sludge and the sludge treatment process should be considered when evaluating the effects of chemicals whose salts are known to be toxic to biological processes.

The application of sewage sludge to agricultural land should be coordinated with the crop's fertilizer need. Nitrogen mineralization rates of the sludge and soil should be determined, and application rates should be adjusted accordingly. Application rates based on P mineralization and movement should be considered in soils such as sands that do not fix appreciable amounts of P.

A composting system should be designed to be as efficient as possible. That is, it should result in a stabilized, dry product in as short a period of time as possible. Controlling temperatures so that they do not exceed 55° to 60°C by adjusting aeration provides a highly efficient composting system. However, destruction of pathogens under such a system needs to be evaluated in laboratory and field trials.

The sewage sludge composting process should be altered to use noncellulosic bulking agents to reduce AF growth and dispersal from compost sites. Such agents would substantially reduce the inoculum levels entering the process.

The full report was submitted in fulfillment of Interagency Agreement No. AD-12-F-2-534 by the Agricultural Research Service, U.S. Department of Agriculture under the sponsorship of the U.S. Environmental Protection Agency.

☆U. S. GOVERNMENT PRINTING OFFICE: 1986/646-116/20761

L. J. Sikora, P. D. Millner, and W. D. Burge are with Agricultural Research Service, U.S. Department of Agriculture, Beltsville, MD 20705.
***Kenneth Dotson** is the EPA Project Officer (see below).*
The complete report, entitled "Chemical and Microbial Aspects of Sludge Composting and Land Application," (Order No. PB 85-243 186/AS; Cost: $16.95, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Water Engineering Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

Official Business
Penalty for Private Use $300

EPA/600/S2-85/103

0000329 PS

U S ENVIR PROTECTION AGENCY
REGION 5 LIBRARY
230 S DEARBORN STREET
CHICAGO IL 60604