EFFECTS OF COMPOSTED MUNICIPAL REFUSE ON PLANT SEED GERMINATION AND SOIL ORGANISMS

By
PATRICK GATCH HUNT

A DISSERTATION PRESENTED TO THE GRADUATE COUNCIL OF
THE UNIVERSITY OF FLORIDA
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA
1970

Dedicated to my wife

Terry Hartsell Hunt

ACKNOWLEDGMENTS

The author wishes to express sincere gratitude to Dr. C. F. Eno, Chairman of the Supervisory Committee, for his guidance, patience, and vigorous example in the development of the graduate program, pursuit of the research problem, and preparation of the dissertation.

The author expresses appreciation to Dr. C. C. Hortenstine and Dr. D. F. Rothwell for serving on the Supervisory Committee and for their authoritative guidance in the research problem.

Gratefulness is expressed to Dr. G. C. Smart, Jr., for serving on the Supervisory Committee and for the use of his laboratory facilities.

Gratitude is extended to Dr. D. S. Anthony for serving on the Supervisory Committee and for reviewing the manuscript.

Thanks are extended to Dr. J. A. Cornell for assistance in the statistical analysis and to Dr. H. L. Breland for elemental analysis of research samples.

The author expresses appreciation to the following for their technical assistance: Mr. C. M. Hinton, Mr. R. W. Patrick, and Mr. F. Sodek, III.

Gratitude is expressed to the U.S. Public Health Service for the grant that made the research possible and to the Gainesville Municipal Waste Conversion Authority for material used in the study.

The author expresses thankfulness to his parents, Matthew P. and Lucy B. Hunt, who have greatly encouraged him during his graduate study.

The author expresses deepest gratitude to his wife for continual encouragement, understanding, and patience throughout the study.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

Page

TABLE

LIST OF TABLES (Continued)

LIST OF FIGURES

Abstract of Dissertation Presented to the Graduate Council in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

EFFECTS OF COMPOSTED MUNICIPAL REFUSE ON PLANT SEED GERMINATION AND SOIL ORGANISMS

By

Patrick Gatch Hunt

March 1970

Chairman: Dr. C. F. Eno
Major Department: Soils

Disposal of solid municipal refuse has become a paramount problem in the United States with the increased size, urbanization, and opulence of the population. Land application seems to be one of the most reasonable means of disposal. Although application of organic amendments to the soil is a common agricultural practice, the effects of large amounts of compost on soils are unknown. Research has shown that application of organic amendments to soil causes extensive microbial changes, and in some cases reduces plant growth and seed germination. Therefore, this study was conducted to determine the effect of composted municipal refuse on plant seed germination and soil organisms.

The effect of compost on nematode populations in a Leon fine sand, with oat and sorghum as the test crops, over a 2-year period was investigated. Fertilizer applied as 10-10-10 at 0.9 T/ha was compared to compost applied at rates of 1, 2, 4, 8, 16, or 32 T/ha, respectively. Spiral nematodes, Helicotylenchus spp., were highest in the fertilized plots and lowest in the 8, 16, and 32 T/ha compost plots; and cephalobids and rhabditids were highest in the soil receiving 32 T/ha of compost.

The motility of sting nematodes, Belonolaimus longicaudatus, in threefold concentrated compost extract and various extract fractions was determined. The nematodes were immotile in untreated compost extract after 2.8 hours, but motile in the extract from which the organic fraction was removed.

African Giant earthworms were studied for survival in peat, compost, Arredondo fine sand, and compost-Arredondo fine sand mixtures during a 5-week period. They survived best in peat and compost; as little as 2.5% compost added to Arredondo fine sand increased earthworm survival.

Saturation extracts of compost, Arredondo fine sand, and compost-Arredondo fine sand mixtures were added to filter paper in petri dishes. The extracts did not reduce germination of corn, oat, soybean, velvet bean, turnip, and radish seeds germinated on the filter paper. Saturation extracts of pure compost, concentrated threefold by vacuum distillation, reduced radish and turnip seed germination. Turnip seed germination was improved by removal of the organic fraction or exchange of the cation with calcium and hydronium ions; however, germination of radish seeds was not as good as germination in the control after either treatment. Compost extract with a conductivity of 14 mmhos/cm greatly reduced oat, radish, and turnip seed germination.

Combinations of Penicillium patulin, compost and Arredondo fine sand extracts, and mycological broth incubated for varying times did not affect corn seed germination. Oat seed germination was highest in those combinations that either contained compost or lacked P. patulin. Radish and turnip seed germination was more sensitive to P. patulin

and other organisms than corn or oat seed germination and was only high in those combinations that lacked mycological broth as a microbial nutrient source. This indicated that neither compost nor Arredondo fine sand would be a good medium for growth of P. patulin.

Arredondo fine sand and compost extracts were mixed in 1:1 ratios with mycological broth and inoculated with Aspergillus niger. Mycelial growth was only reduced by the compost mixture. When the organic fraction of compost extract was removed and the remaining fraction mixed in a 1:1 ratio with mycological broth, there was no reduction of Aspergillus niger mycelial growth.

Compost contained large amounts of ammonium acetate extractable calcium, sodium, and potassium, but calcium was present in the highest concentration and had the greatest range. The micronutrients iron, manganese, copper, and zinc were present in sufficient amounts to be of agricultural benefit only with extremely high application of compost. However, the results of this study indicate that land disposal of composted refuse at rates as low as 45 T/ha per year would have the agricultural benefit of reducing sting and spiral nematodes and increasing earthworm survival without reducing plant seed germination.

INTRODUCTION

During recent years few problems in the United States have received more attention than the contamination of man's environment. This problem has involved the whole gamut of contaminants from radioactive nuclide fallout to DDT in the soil. The public was massively awakened to the problem by Rachel Carson (1962), an early lay writer on environmental contamination; and more recently there have been other warnings such as the imminent extinction of our national emblem, the bald eagle. A somewhat less dramatic, but possibly more important, environmental contaminant is the immense amount of solid municipal refuse. Solid refuse contains garbage, paper, lawn trimmings, and many household items. The amount of solid refuse in the United States is increased by the urbanization, continued affluence, and rapid growth of the population. However, as the amount of solid refuse is increasing, the options and areas for disposal are decreasing. If refuse is burned or buried in any manner other than under ideal conditions, the atmosphere, soil, and water may be contaminated. If solid refuse is separated, ground, and composted under aerobic conditions, contamination of the atmosphere by refuse can be eliminated. Furthermore, if properly incorporated into most soils, contamination of the ground water can be prevented. The use of soil as a disposal system for composted refuse has not been explored extensively. Pollution or enhancement of the soil might occur if large amounts of

composted refuse were applied, but beneficial effects from low application levels would be more probable.

The purpose of this study was to determine the effects of composted municipal refuse on seed germination and several soil organisms when refuse was applied to soil at low rates as an agricultural amendment or at high rates for simple disposal.

LITERATURE REVIEW

Solid Municipal Waste Disposal

McKee (1963) aptly described the solid municipal waste disposal dilemma when he stated that suitable landfill sites were rapidly vanishing from metropolitan areas and that burning of solid refuse would only increase the pollution of an overwhelmed atmosphere. He cited Los Angeles as an example of a city unaware of solid waste disposal problems even though its solid waste was four times the per capita weight of liquid waste. However, there has been a public awakening to the solid waste problem and many disposal methods are presently being investigated.

Dorer (1967) reported the beginning of a 3-year landfill project at Virginia Beach, Virginia, in which an amphitheater was being built from solid municipal refuse. The land at the site was excavated to a depth of 2.2 m. A 1.5-m layer of refuse was then placed in the excavated area, compacted, and covered with an 18-cm layer of soil. The refuse was then placed at desired contours daily and covered with 15 cm of soil. This procedure was to be continued until a height of 20.2 m was obtained. The finished "hill" was to be topped with 2.2 m of soil and planted to grass and shrubs with a picnic area at its base. However, layered soils have water flow and retention that are different from soils with relatively homogeneous pore sizes; these differences can be both beneficial and detrimental (U.S. Department of Agriculture, 1969).

Wolf (1968) gave a number of reasons for integrating rail-haul of solid waste into an overall waste disposal system. His primary points were that all solid waste disposal systems ultimately use the soil and that soil in urban areas was limited. Therefore, the cheapest method of refuse movement to disposal areas should be devised. He proposed the movement of compressed solid municipal refuse. However, the salvaging of bulk paper and metals from the material and composting it before disposal would seem desirable. In this manner composted refuse might be moved relatively economically and used in the reclamation of eroded and defaced areas. Hortenstine (Univ. of Fla., personal communication, 1969) has initiated studies on using sites of phosphate mine tailings (a sandy waste product) as disposal areas for composted municipal refuse. Central Florida contains large areas of these tailings which lack organic matter and most plant nutrients. Composted refuse as a source of organic matter increased the cation exchange capacity and water-holding capacity, but additional plant nutrients (particularly N) were required for normal plant growth in that medium.

In 1962 Tietjen stated, "We realize that since the problem of waste disposal is steadily increasing, composting can be a solution if it is possible to use composted products to improve soils and increase crop yield without financial loss to the landowner." Research is underway to delineate the potential for soil improvement and possible phytotoxic effects from repeated compost applications at high rates.

Fertility Aspects of Land Disposal of Composted Municipal Refuse

Research toward agronomic and horticultural utilization of composted municipal refuse in the United States has not been extensive. Conover and Joiner (1966) found that the addition of 33 to 50% garbage compost by volume to sand gave 3 to 5 days earlier flowering of "Yellow Delaware" chrysanthemums. They believed the decreased time to flower could have been due to increased concentrations of iron, boron, or calcium in the compost-sand mixture. Numbers of flowers were usually higher on plants grown in compost amended soils, but flower size was sometimes smaller. Hortenstine and Rothwell (1968) studied the effects of garbage compost, sewage sludge, and cow manure as soil amendments on oat and radish growth in pots. Oat seed germination in soil containing 512 T/ha of compost was normal, but it was 3 days later than treatments with lower rates of compost. Oats grown on Leon fine sand containing 2 and 8 T/ha of compost developed nitrogen deficiencies and yielded less than oats grown in soil containing larger amounts of either compost or manure. Radishes, grown after the oat crop, yielded more foliage in the 512 T/ha compost treatment than in other treatments. Yields from lower rates of compost were less than from untreated soil. Fuller, et al. (1960) planted tomatoes in soil containing various levels of garbage compost, nitrogen, and phosphorus. Two tons of compost supplied about as much phosphorus to the tomato plants as 44 kg/ha of P_2O_5; however, compost decomposition rendered the nitrogen less available. When these same soils were replanted with cotton, decomposition of the compost had proceeded to the point that nitrogen was released and 2 T/ha of compost supplied approximately 44 kg/ha of nitrogen. Stelmach

(1962b) suggested that the formation of organic complexes with iron and aluminum might be a mechanism of phosphorus release to plants upon addition of organic amendments.

Rothwell and Hortenstine (1969) evaluated the effects of high levels of composted refuse, chicken manure, cow manure, and sewage sludge on microbial activity in Arredondo fine sand. The numbers of fungi increased when composted refuse was added. An inverse relation existed between the rate of nitrification and the rates of sewage sludge or chicken manure amendments. When composted refuse was added to the soil, nitrate accumulations did not occur. Cow manure added to soil increased nitrification, but equal mixtures of cow manure and composted refuse did not increase nitrification.

Other researchers (Anderson, 1956; Block, et al., 1958; Fuller and Bosma, 1965; Fuller, et al., 1967; Pain, 1961; and Tietjen, 1962) found beneficial effects from composts such as increased water-holding capacity, increased fertility, and erosion control. However, the economical benefit of composted refuse in agriculture has not been proved. The value of an amendment that effects limited improvement in soil fertility would not increase its agricultural use, but the use of the soil as a disposal system for refuse may be quite valuable.

Decomposition of Organic Amendments in Soil

Rothwell and Hortenstine (1969) found the magnitude of CO_2 evolution from soil containing the following organic amendments ranked in the following order. sewage > chicken manure > garbage compost > cow manure. When garbage compost was mixed with sewage sludge,

chicken manure, or cow manure, no change in order of CO_2 evolution occurred. The CO_2 evolution from combination of materials was very similar to the additive evolution of all components; therefore, they concluded that combining materials had little effect on rate of decomposition. Hutchings and Martin (1934) concluded that the chemical composition of an organic material is very important in determining its rate of decomposition. The carbon-nitrogen ratio, however, only slightly affected the rate of decomposition as measured by CO_2 evolution. According to Stelmach (1962a), fats decomposed rapidly under aerobic conditions; waxes, resins, alcohols, and alkaloids were more resistant. Oat straw, cellulose, and dextrose were found by Peevy and Norman (1948) to decompose more rapidly than materials higher in lignin.

Bell (1962) reported the analysis of an average municipal refuse as follows: cellulose, sugar, and starch - 46.6%; fats, oils, and waxes - 4.5%; protein (6.25N) - 2.06%; other organics (plastics) - 1.2%; ash, metals, glass, etc. - 24.9%. Compost derived from refuse of this type should decompose rapidly with release of many intermediate compounds as well as CO_2. However, Martin, et al. (1966) found that salt and metal complexes of plant and bacterial polysaccharides decompose very differently from their pure state. The metals used in their study were iron, aluminum, zinc, and copper. Since all of these metals are abundant in compost, polysaccharides contained in compost or produced upon its decomposition may not follow pure state decomposition patterns.

Composted refuse does not decompose as rapidly as some manures. However, when large amounts of composted municipal refuse are decomposed,

there is a deluge of organic products formed. Some of these products are incorporated by soil microorganisms; others are degraded to CO_2, H_2O, and other end products. Many of these compounds have beneficial effects on soil structure, soil fertility, and maintenance of soil organic matter. However, some metabolites could be toxic or antagonistic to plants and soil organisms.

Effect of Organic Soil Amendments on Plant Parasitic Infection

Patrick and Koch (1963) reported that exposure of tobacco plants to phytotoxic solutions obtained from decomposing rye and timothy residues increased their susceptibility to black root rot caused by Thielaviopsis basicola. In a greenhouse study with sixteen varieties of tobacco ranging from susceptible to highly resistant, all varieties were severely infected by root rot. Toussoun and Patrick (1963) reported that water soluble substances obtained from barley, rye, wheat, timothy, broccoli, and broadbean residues decomposing under field conditions greatly increased the pathogenesis of Fusarium solani and Fusarium phaseoli to lettuce. The mechanism of increased pathogenesis was thought to be an effect on cell permeability. It is possible that composted refuse applied at high rates to the soil could release compounds in the proximity of the plant root that would weaken the plant cell wall enough to increase infection from certain plant pathogens.

Toxic Effects of Organic Amendments

Toxic Effects of Organic Soil Amendments Other Than Composted Refuse

Effects on plant seed germination and growth

McCalla and Duley (1948) reported that corn seeds soaked for 24 hours in a sweet clover-water mixture were inhibited significantly in germination. Sweet clover mixtures were more toxic than alfalfa-, wheat straw-, or oat straw-water mixtures. They (1949) also found in laboratory tests where mulched and bare soils were kept excessively wet that corn seed germination was reduced in wheat stubble-mulch when compared to bare soil.

Patrick and Koch (1958) stated that substances capable of markedly inhibiting germination of tobacco seeds were obtained from aqueous extracts of soil in which timothy, corn, rye, or tobacco plants had decomposed. Aqueous extracts of unamended soil or soils containing macerated plant tissue, with extracts prepared either before decomposition or after the soil had been autoclaved, gave no toxicity.

Nielsen, et al. (1960) conducted a germination study on six plant species in sand wet with aqueous extracts of alfalfa, timothy, oats, corn, and potatoes. Timothy and alfalfa extracts were the most harmful. Oat, corn, and potato extracts were only slightly harmful. Germination of timothy seeds was least affected while alfalfa seed germination was most affected. Lawrence and Kilcher (1962) conducted a similar experiment with sand wet with root extracts of crested wheatgrass, Russian wild ryegrass, intermediate wheatgrass, couchgrass, bromegrass, wild ryegrass, wild barley, poverty weed, alfalfa, sweet clover, reed canarygrass, timothy, sorghumgrass, and dandelion. Only

alfalfa, dandelion, sorghumgrass, sweet clover, poverty weed, and couchgrass extracts inhibited germination of wheat, oat, and barley seeds. Patrick, et al. (1963) found substances in decomposition residues of barley, rye, wheat, and sudangrass that were toxic to lettuce, bean, broccoli, and tobacco seed germination.

Guenzi and McCalla (1962) reported that an ethanol-soluble substance from wheat straw inhibited germination of wheat and that the inhibitory effect was highest in the strong acid fraction and lowest in the basic fraction. Patrick and Koch (1958) reported that aqueous extracts of soils in which timothy, corn, rye, and tobacco were decomposing contained substances that were toxic to tobacco seedling respiration after exposure for less than an hour. Water extracts of wheat, oat straw, soybean, sweet clover hay, corn, sorghum stalks, and bromegrass and sweet clover stems inhibited the growth of sorghum, corn, and wheat (Guenzi and McCalla, 1962). Collison (1925) described a toxic effect of aqueous extracts of wheat straw on barley seedlings in which roots were discolored, slender, and abnormally curved. The effect was not removed by addition of a balanced nutrient solution. However, boiling or filtering the extract through a porcelain filter removed the toxin. A suspension of carbon black or ferric hydroxide removed most of the toxicity, but aeration with O_2 or air did not eliminate the toxic effect. Field studies conducted by Patrick, et al. (1963) revealed that injury to the roots of lettuce and spinach seedlings was confined mainly to those parts in direct contact with or very close to decomposing plant fragments. Organisms isolated from the spot of injury were mainly nonpathogenic.

Guenzi, et al. (1967) investigated the effect of decomposition time on the toxicity of plant residues to seedling growth. Wheat and oat residues contained essentially no water soluble toxic compounds after 8 weeks of exposure as a soil mulch. Corn and sorghum residues had considerably more toxic material at harvest and required about 22 to 28 weeks of decomposition as a soil mulch before the water soluble phase was essentially nontoxic. They also found that the toxicity of wheat straw extracts to wheat seedlings differed among seedling varieties.

Routley and Sullivan (1960) tested 95 organic compounds in varying concentrations up to 1,000 ppm for phytotoxic effects on Ladino clover seedlings in sand cultures. In general, the amino acid and nucleic acid related compounds were not toxic and supplied some nitrogen to seedlings. However, the nitrogen contained in some of these compounds was not utilized by plant seedlings. On the other hand, alkaloids and some antibiotics were toxic. Guenzi and McCalla (1964) and McCalla, et al. (1964) reported that phytotoxic substances from sorghum and corn that caused root curling tended to be nonpolar, while toxic substances from oats and wheat tended to be polar.

Tenth molar sodium pyrophosphate and acetone were used to extract phytotoxic compounds from soil by Guenzi and McCalla (1966b). The acetone extract was separated on an alumina column, and most of the compounds were either ninhydrin positive or acid. Three of the phenolic acids isolated were vanillic, p-hydroxybenzoic, and protocatachuic. When they extracted with 2N sodium hydroxide, ferulic, p-courmaric, p-hydroxybenzoic, vanillic, and syringic acids were found. These five acids found in 2N sodium hydroxide extracts were also present in oat,

sorghum, and corn residues (Guenzi and McCalla, 1966a). The concentration of p-coumaric acid was approximately double the concentration of the other acids. Root and shoot growth of wheat was suppressed by concentrations of p-coumaric acid as low as 625 ppm; this concentration could possibly exist in the surface 15 cm of soil. Whitehead (1964) identified p-hydroxybenzoic, vanillic, p-coumaric, and ferulic acids with paper chromatography from calcium oxide extracts of soil. Guenzi and McCalla (1966b) found only traces of phenolic acids when soil extractions were made with 0.1M sodium pyrophosphate, calcium oxide, 2N hydrocholoric acid, or methanol. Langdale and Giddens (1967) reported that stem residues of Sericea lespedeza in soil depressed corn growth. They identified protocatechuic, vanillic, ferulic, and p-coumaric acids in the residue. Protocatechuic was present in the highest concentration, but was not as effective in inhibiting auxin activity in Avena coleoptile as the other acids.

The inhibition or suppression of plant growth in such a wide range of plants and environmental conditions indicates that the toxic effects are probably from a large number of compounds, but most are either acids or ninhydrin positive.

Toxicity to soil-borne nematodes

Mankau's (1962) statements supported the hypothesis that parasitic nematode suppression from organic amendments was partially due to large increases in nematode predators. Steer dung and green manure caused the greatest activity in predacious fungi. However, the population of Dorylaimus spp. was not greatly influenced by organic materials.

Lear (1959) found that populations of the root-knot nematode, Meloidogyne incognita, were reduced when 11 to 22 T/ha of castor bean pomace were applied to the soil. Most plants had stunted tops and roots when grown on soil containing pomace. Root-knot nematodes were controlled on tomatoes in soil amended with 1% by weight of oat straw or lespedeza hay (Johnson, 1962). Soil incubated below 20C for 10 weeks before planting the tomatoes gave the most control. Control of root-knot nematodes in unamended soil flooded for 10 weeks before tomatoes were planted was comparable to that obtained in amended soils. Sayre, et al. (1965) reported extracts of soil that contained decomposing timothy and rye residues were toxic to Meloidogyne incognita and Pratylenchus penetrans. The extracts were not toxic to saprophytic nematodes. Pure butyric acid was found to be identical, chemically and biologically, to one of the isolated compounds. However, it is questionable whether butyric acid would exist in high concentrations under aerobic conditions. Johnson, et al. (1967) stated that root-knot nematodes were controlled more by soil addition of 22 than 11 T/ha of alfalfa hay, oat straw, lespedeza hay, or flax hay. He also obtained better control from amendments after an 8-month incubation period than from shorter periods. Mankau (1968) applied 26.4 T/ha of steer manure, 19.8 T/ha castor pomace, and finally 8 T/ha castor pomace to outdoor microplots during a 4-year period. Numbers of root-knot nematode larvae in a fertilized control plot and amended plot were very similar, but nematode infectivity and survival were lower in the amended plots. These variations in the effective incubation time and type of nematode control indicated that toxic materials were present in some residues,

were formed upon decomposition of others, and were different in mode of toxicity.

Singh, et al. (1967) applied sawdust at 2.22 T/ha with supplemental N-P-K to okra and tomato plots infested with Meloidogyne javanica. Compared to the control, they found root galling to be only 1/3 to 1/4 and a yield increase of 70% in treated okra plots and 125% in treated tomato plots. Patrick, et al. (1965) showed the differential effect of extracts obtained from soil that contained decomposing rye on parasitic and saprophytic nematodes. Plant parasitic nematodes Meloidogyne incognita and Pratylenchus penetrans were rendered immotile with 380 to 440 ppm toxic extract. The saprophytic organisms, Rhabditis, Cephalobus, and Plectus, required 3,500 ppm toxic extract for immotilization. Sayre, et al. (1965) placed paper chromatogram squares containing organic toxins in vials containing 0.2M citric acid, pH 5.3, and nematodes to study this differential effect. They found that plant parasitic nematodes were more sensitive to fatty acids than were saprophytic nematodes. O'Bannon (1968) found that Tylenchulus semipenetrans infected rough lemon roots at a faster rate when peat moss was added to sandy soils. However, once the nematode population began to increase in unamended soil, the rate of increase and peak population were similar in the unamended and the amended soil. Walker, et al. (1967) reduced Pratylenchus penetrans on soybean by adding soybean meal at the rate of 1% by weight to the soil. Raspberry canes incorporated into soil for control of Longidorus elongatus reduced the population soon enough after application to eliminate increases in predacious organisms as a control factor (Taylor and

Murant, 1966). In that study, polyphenols were suggested as the active compounds.

Tomerlin (1969) applied 9 and 10 T/ha of alfalfa meal, cotton seed meal, and rice straw to an Arredondo fine sand which was infested with Belonolaimus longicaudatus; the host plant was Phaseolus vulgaris L. 'Contender.' They found a reduction in B. longicaudatus in the amended soils which he attributed to organic toxins.

Relation of organic soil amendments to production of plant growth regulators by microorganisms

Penicillium patulin produced antibiotic material quite well in partially sterilized amended soils and for 11 days in grossly contaminated soils (Grossbard, 1952). Antibiotic production was higher in soils amended with green rather than composted wheat straw or lawn clippings; however, soils amended with either green or composted wheat straw or lawn clippings produced considerably more antibiotics when 3 to 5% by weight of glucose was added to the amendment before application to soil. Behmer and McCalla (1963) conducted a laboratory experiment with crop residues and Penicillium urticae, and found that this generally reduced seedling height regardless of residue treatment. However, soils amended with alfalfa residues were strongly inhibitory to wheat seedlings when inoculated. Raper and Thom (1949) reported Penicillium patulin and P. urticae Brainier to be the same organism. Grossbard (1952) found variations in antibiotic production on different green manure amendments to soil inoculated with P. patulin. Norstadt and McCalla (1963) isolated P. urticae from subsurface tilled plots and found that it produced a phytotoxic substance with the same melting point, infrared spectrum, and ultraviolet spectrum as patulin. Shoot

growth of wheat was 50% inhibited by 75 ppm of patulin in a soil culture. Norstadt and McCalla (1968) observed that incubation of subtilled soil with wheat straw produced a phytotoxic effect. Inoculation with P. urticae B. in nonsterile, subtilled soil gave peaks of fungal numbers and patulin concentrations that corresponded with the peaks of toxicity to corn seed germination. There was a cyclic relation between populations of P. urticae and Trichoderma sp.

McCalla (1967) concluded that tillage practices such as stubble mulch increased the organisms producing phytotoxic substances. Curtis (1958) observed malformation of corn roots, stems, and petioles after treatment with filtrates from cultures of Aspergillus niger. The toxin in the filtrate, named malformin, was found by Takahashi and Curtis (1961) to be a neutral peptide containing four amino acids: valine, leucine, isoleucine, and cysteine.

Composting reduced the number of polysaccharides available for microbial consumption, thereby reducing patulin formation. Competition in soil for available polysaccharides in nonsterile media also decreased production of regulator compounds. However, production of growth inhibitors has generally been found to be increased by organic soil amendments and this production was higher in sterile than non-sterile media. Therefore, any soil amendment that adds polysaccharides to the soil might increase production of growth regulators by organisms.

Toxicity of Composted Municipal Refuse

Composted municipal refuse was shown (G. C. Smart, Jr, Univ. of Fla., personal communication, 1969) to have possible inhibitory effects on sting nematodes, Belonolaimus longicaudatus, on tomatoes. Information

on the toxic effects of composted municipal refuse on soil organisms and plants is limited, but there is sufficient evidence to conclude that many organic soil amendments are either toxic or stimulatory to the production of compounds that are toxic to plants and soil organisms. Composted refuse amendments might act in the same manner as many other organic amendments. It is, therefore, apparent that more research is needed to determine the toxic as well as beneficial potentials of land-disposed composted municipal refuse before an accurate evaluation of this disposal method can be made.

MATERIALS AND METHODS

Field Evaluation of the Effects of Composted Municipal Refuse on Nematodes

Experimental Design and Treatments

A Leon fine sand site (Smith, et al., 1967) on the University of Florida Beef Research Unit was selected for this study. The experiment contained four blocks, each consisting of eight random 2 x 3 m plots. The composted municipal refuse, hereafter referred to as compost, was obtained from the Gainesville Municipal Waste Conversion Authority, hereafter referred to as the compost plant. Sorghum was the summer and fall test crop. The winter and spring test crop was oat. Sorghum was planted on May 28 of 1968 and 1969, after a 10-10-10 (N-P-K) fertilizer and compost at rates of 0.9 and 1, 2, 4, 8, 16, and 32 T/ha, respectively, had been added to the appropriate plots. A check plot received no additives before planting. The oats were planted on October 28, 1968, after the sorghum stalks had been disced into the soil. Due to insect infestation during the spring of 1969, sorghum was replanted on June 14, 1969. After the first year, tile drains were installed in the area at a depth of 50 cm.

Soil Analysis Procedure

Approximately 25, 3-cm diameter soil cores were taken at random from the surface 15 cm of each plot and composited for each sample.

The cores were thoroughly mixed and transferred to a polyethylene bag. The bagged samples were stored at 5C until processed. Samples were taken after compost and fertilizer application during the 1st, 2nd, 3rd, 5th, 9th, 51st, and 52nd week of the first year, and during the 1st, 2nd, 3rd, 5th, and 9th week of the second year. The actual sampling dates were 20 May, 27 May, 3 June, 17 June, and 15 July of 1968 and 13 May, 20 May, 27 May, 3 June, 10 June, 24 June and 22 July of 1969.

Samples taken the first week after the first treatment were extracted with N ammonium acetate, buffered at pH 4.8, and analyzed for potassium, calcium, magnesium, and phosphorus. Potassium, magnesium, and calcium were determined by a model B or DU - flame spectrophotometer (Southern cooperative series, 1965). Phosphorus was measured by the phosphomolybdate-stannous chloride method (Jackson, 1958). The pH values were determined in 1:1 (v/w) water:soil suspensions with a Sargent model LS pH meter with glass and calomel electrodes.

Procedures for Determining Nematode Populations

Nematode population determinations were made by the sugar flotation method (Miller, 1957). In general the process was as follows: a 100-g, moist soil subsample was taken from each plot sample and processed; however, all data were expressed on an oven dry basis. The soil was suspended in approximately 4 liters of water. The debris and large soil particles were allowed to settle for 12 seconds. The soil-water suspension was poured through no. 30 and no. 325, 18-cm diameter sieves, and nematodes were collected on the no. 325 sieve. The suspending and sieving process was repeated once. The nematodes were washed from the sieve with a small stream of water through an 18-cm, 60° angle funnel

into an 11.5 x 3.5 cm cylindrical centrifuge tube. The tubes which contained suspended soil and nematodes were centrifuged at 19,000 rpm for 3.5 minutes in an International Equipment Company, model K centrifuge. The supernatant liquid was decanted, the nematodes and soil resuspended in a 1 lb.:1 liter dextrose:water solution, and the suspension centrifuged at 19,000 rpm for 3.5 minutes. Due to differential settling the nematodes remained in solution during centrifugation. The supernatant liquid was poured onto a no. 325 sieve which retained the nematodes. The nematodes were washed into U.S. Bureau of Plant Industry watch glasses (BPI glass) by a small stream of water and stored at approximately 5C until counted under a binocular dissecting microscope with low magnification, 15 x. The following nematodes were counted: Helicotylenchus spp. (spiral), Pratylenchus spp. (lesion), Criconemoides spp. (ring), cephalobids, rhabditids, and doryiaims.

Earthworm Survival Experiment

The surface 30 cm of Arredondo fine sand (Smith, et al., 1967) and compost were obtained in Gainesville, Florida, from a wooded site and a fresh (less than a week old) compost pile, respectively. The soil was passed through a 2-mm screen, and both materials were air dried, sampled for moisture, and sealed in polyethylene bags.

Earthworms were obtained from Juston's Earthworm Farm, Leesburg, Florida. The worms were not classified according to genus and species, but they are commonly referred to as African Giants. Peat and chicken-laying mash, which were used as a growth medium and a food source, respectively, for earthworms, were also obtained from the farm.

Samples of all media were oven dried for 12 hours at 105C for moisture determination. Arredondo fine sand mixed with 2.5, 5.0, 10.0, 20.0, 40.0, 60.0, and 80.0% compost by weight, compost, Arredondo fine sand, and peat comprised the 10 experimental growth media. The media were sampled for moisture determination and sealed in polyethylene bags. Moisture information on the media consisted of the percentage moisture at the sampling time and at 100 millibars pressure. Moisture percentage at 100 millibars pressure was determined by a method similar to that described by Richards (1965). The media were placed in a pressure chamber on a water-saturated ceramic plate in duplicate in 1 x 5.5 cm rubber rings and saturated with distilled water. The pressure chamber was sealed and adjusted to 100 millibars pressure. The relationships between moisture content at 100 millibars pressure and percentage compost are given in Fig. 1.

The media were placed into 0.6-liter plastic freezer containers and adjusted with distilled water to a moisture level equivalent to that at 100 millibars pressure. Ten earthworms that each weighed approximately 1 g were placed in each container. The containers were closed with plastic lids which had six small holes to allow air circulation. Treatments were replicated eight times. Chicken-laying mash was fed at a rate consistent with consumption (approximately one time per week).

The contents of each container were emptied onto a piece of brown wrapping paper on the 3rd, 7th, 14th, 21st, 28th, and 35th day after the addition of earthworms. Live worms were counted and returned with the medium to the containers; dead worms were discarded to minimize disease.

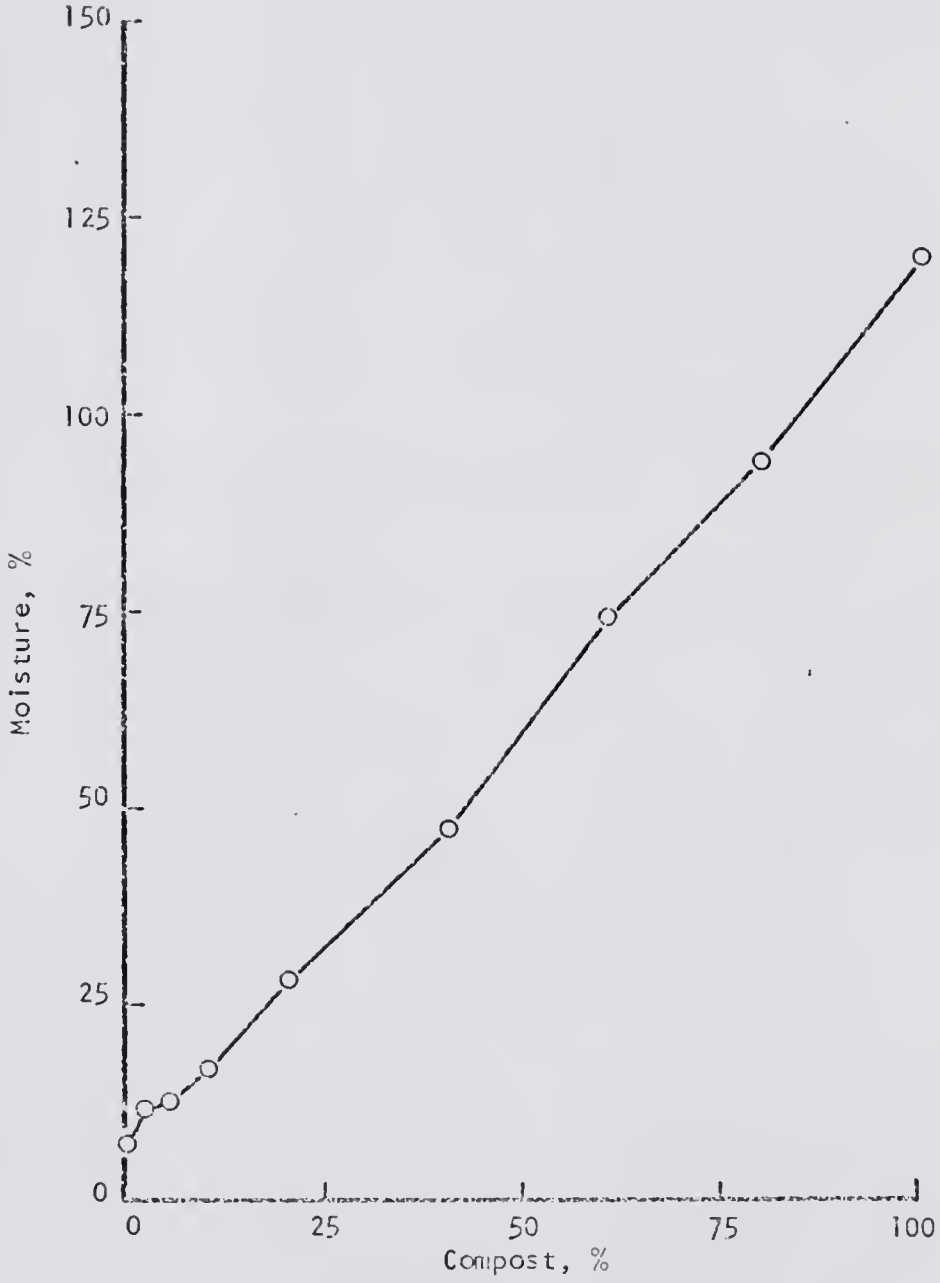


Fig. 1. Moisture content of compost-sand mixtures at 0.01 bar pressure.

After the experiment was completed, the media were air dried and measured for ammonium acetate extractable phosphorus, potassium, magnesium, and calcium and pH, as described in field evaluation of the effects of composted municipal refuse on nematodes.

Plant Seed Germination-Extract Studies

Materials and Methods for Obtaining Extracts

Compost and Arredondo fine sand were collected, mixed, and sampled for moisture as described in the earthworm experiment. The media used were 20, 40, 60, and 80% compost-Arredondo fine sand mixtures, Arredondo fine sand, and compost. Moisture was determined at 50 millibars in this experiment (Fig. 2).

The six media were placed in wide-mouth, quart Mason jars in four replications, maintained at a moisture percentage equivalent to the moisture at 50 millibars pressure, and closed with perforated aluminum foil. The experimental design was a randomized complete block with treatment combinations of six media and incubation times of 2, 4, and 6 weeks at 28C. A second series was begun 2 days later to provide sufficient extract.

After incubation, the medium in each jar was placed in three, 15-cm aluminum pie pans and saturated with distilled water. Saturation was considered to be the moisture content at which the medium glistened when touched with a spatula. The saturated media were equilibrated at 5C for 12 hours.

A suction apparatus made from six 12-cm Buchner funnels and six, 1-liter flasks attached to a vacuum line from a water aspirator was

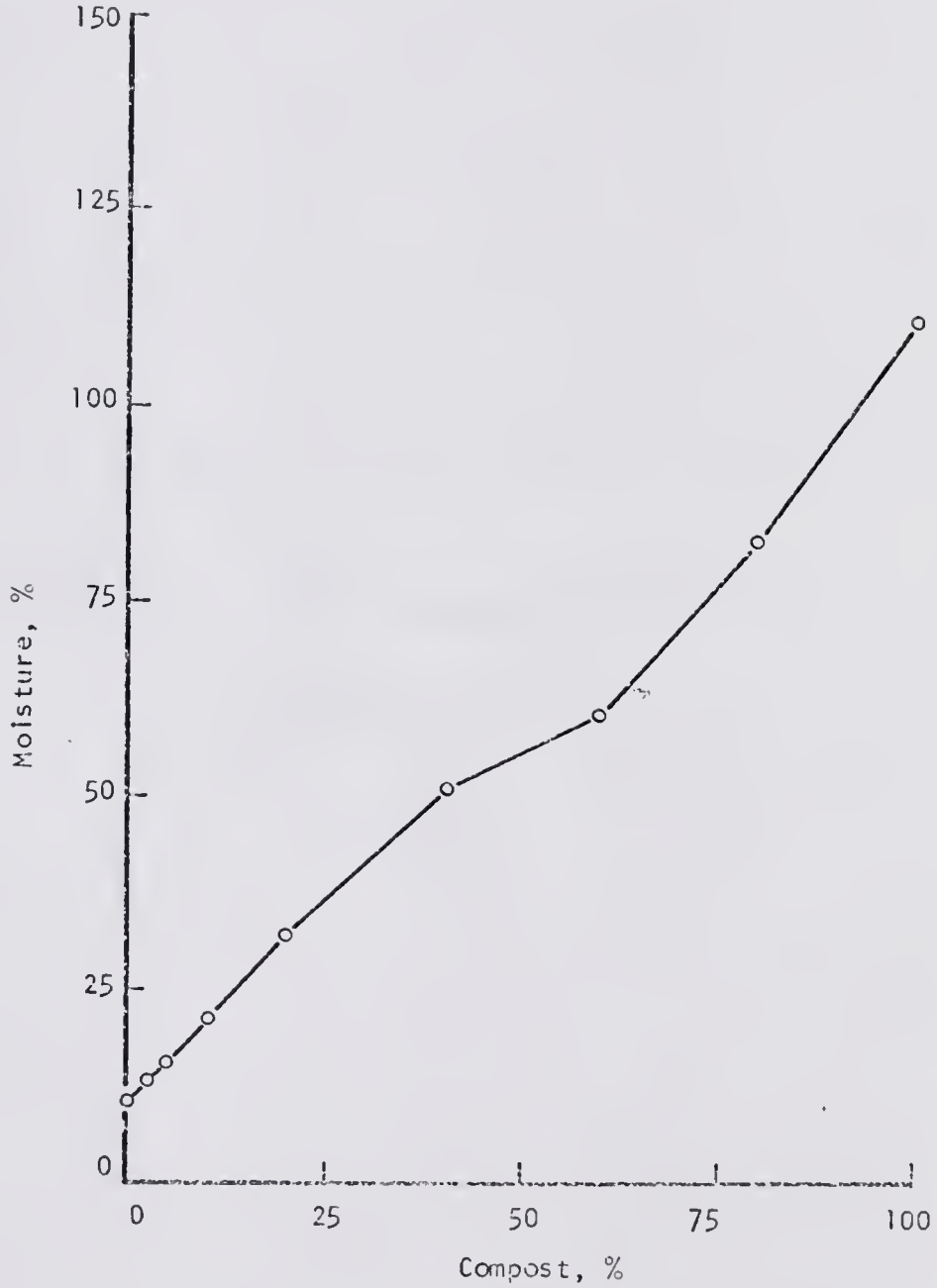


Fig. 2. Moisture content of compost-sand mixtures at 0.05 bar pressure.

used for extraction of the aqueous phase. Approximately 1 liter of each saturated medium was placed on Whatman no. 1 filter paper in a funnel and extracted under suction. Eighty-five ml of extract were needed from the medium in each jar; the filter was changed if this amount was not obtained before the extraction rate became extremely slow. The filtrates were placed in milk dilution bottles and stored at 5C until used. Conductivity measurements were made on the extract with a Beckman conductivity bridge model RC16B2. Other samples of compost were obtained and extracted by the same procedure except there was no incubation period and a Welch Scientific Company Duo Seal Vacuum Pump model no. 1397 was used for extraction.

"Penicillium"-Extract Preparations

Twenty-five ml of saturation extract were placed in 125-ml Erlenmeyer flasks in triplicate, made 0.1 M with glucose, and inoculated with 1 ml of a heavy spore suspension of 5-day-old cultures of Penicillium (urticae) patulin. The culture, no. 10120 of the American Type Culture Collection, Rockville, Maryland, was grown on Difco mycological agar.

In another experiment, compost and Arredondo fine sand extracted and concentrated threefold and P. patulin cultured as just described were used in combinations with steam sterilized mycological broth and distilled water. Two extracts were made 0.1 M with glucose and inoculated with P. patulin. The treatments used in this experiment are described in Table 1. Nine ml of a heavy spore suspension of P. patulin or distilled water were applied to 360 ml of each treatment solution. Each solution was added to nine 125-ml Erlenmeyer flasks in 40-ml increments. The flasks were capped with aluminum foil, and the extracts

Table 1. Extract-broth-*Penicillium* combinations studied for toxicity to seed germination

Treatment No.	Treatment Description
1	Compost extract + broth + *Penicillium*
2	Compost extract + water + *Penicillium*
3	Water + broth + *Penicillium*
4	Compost extract + broth + water
5	Sand extract + broth + *Penicillium*
6	Sand extract + water + *Penicillium*
7	Sand extract + broth + water
8	Compost extract + glucose + *Penicillium*
9	Sand extract + glucose + *Penicillium*

incubated on a reciprocating shaker for 1, 2, or 3 weeks at 28C. After the incubation period, all extracts except that from pure compost were filtered through Whatman no. 1 filter paper. The pure compost extracts were viscous and would not pass through the filter paper, so they were used in a nonfiltered state.

Concentration and Digestion of Extract

Saturation extracts were concentrated threefold under a vacuum of 71.0 to 72.5 cm mercury by use of a model VE50 Rinco all glass rotary evaporation apparatus. To avoid rapid changes in pressure, a Precision Scientific Company Vacuum Oven model no. 524 was connected between the evaporator and the Duo Seal Vacuum Pump. The rotary flask of the evaporator was placed in a Precision Scientific Company Water Bath model no. 6566 and kept at a temperature of 35 to 39C during concentration of the extract.

Thirty-three ml samples of the threefold concentrated extracts were digested with 30%, reagent grade hydrogen peroxide on a hot plate. The digestion was continued at a slow boil for approximately 1 hour after the solution had lost its yellowish color in order to facilitate thermal decomposition of any excess hydrogen peroxide. A volume of 33 ml or greater was maintained during digestion by addition of distilled water to prevent drying and excessive oxidation of metals. The conductivity was checked with a Beckman model RC16B2 conductivity bridge before and after digestion. In one sample the conductivity was lower, and a 1:4 distilled water-concentrated hydrochloric acid solution was added to the samples until the original conductivity was reached. Extracts from all samples were concentrated and digested in triplicate,

except the last sample that was done with 10 replicates to increase sensitivity.

Seed Germination

Five ml of the extracts or a tap water blank were added to 25 seeds of some or all of the following species on Whatman no. 1 filter paper in petri dishes: corn (Zea mays), oat (Avena sativa), soybean (Glycine max), radish (Raphanus sativus), turnip (Brassica campestris var. rapa.), and velvet bean (Stizolobium derringianum). The seeds were incubated at 28C, and the germinated seeds were counted after 4 days.

Variation in Elemental Analysis of Compost

Sampling Procedure

At the compost plant large pieces of paper, boxes, and metal were removed from the solid refuse before the first grinding. The remaining material, primarily paper, was ground twice and wet with effluent from the sewage disposal plant before composting under aerobic conditions. After 7 days of composting, the material was reground, transported by a conveyer belt to the top of a compost pile, and hauled away by truck.

The compost was sampled as it left the final grinder at random times on each Wednesday during an 8-week period. Samples were taken in two containers during a 10- to 20-minute period by periodically opening a door under the conveyer belt.

In another experiment, the compost was sampled on three randomly selected dates during a 3-week period. There were three 10- to 15-minute sampling times per day with three samples taken each time. The

sampling technique was to take approximately 10 liters of compost from the conveyer belt after the final grinding, mix it thoroughly, place a subsample in a polyethylene bag, and store the subsample at 5C.

Sample Preparation

An aliquot of all samples was used to determine the moisture; oven dry was considered to be the moisture after 12 hours at 70C. Samples taken over the 8-week period were subsampled five times in each container; 5 g of the compost from each subsample were placed into 125-ml Erlenmeyer flasks with 50 ml of N ammonium acetate, buffered at pH 4.8. Ten g of compost were removed from each 3-week-period sample and placed in a 250-ml Erlenmeyer flask with 100 ml of ammonium acetate. All of these suspensions were shaken on a reciprocating shaker for 3 hours, filtered through Whatman no. 1 filter paper, and stored at 5C.

Dry ashing the compost for total elemental concentrations was done by the procedure described by Jackson (1958), except that ash was dissolved in 2N HCl.

Elemental Analysis

Both total and extractable elemental concentrations, except boron, phosphorus, and nitrogen, were determined by use of a Perkin-Elmer atomic absorption spectrophotometer 303 under the standard conditions specified for each element by Perkin-Elmer Company (1966). Total boron was determined by the method presented by Jackson (1958).

Samples were analyzed for nitrogen concentration by the Kjeldahl method described by Jackson (1958), except, a commercial catalyst, Kelpac, was added to the acid and left overnight instead of 1 hour.

Phosphorus was determined by the phosphomolybdate-stannous chloride method (Jackson, 1958).

Experiments with a Single Compost Sample

Sample Collection and Characterization

During a 2-day period, three samples of compost each of approximately 20-liter volume were obtained during 15- to 20-minute sample periods from the conveyer belt at the final grinder of the compost plant. The three samples were mixed together for 8 hours in a cement mixer, placed in wax-lined bags, and stored at 5C.

Elemental analyses were conducted as described in the experiment on elemental variation in compost. The moisture retention of compost with increasing pressure was determined as described for the earthworm experiment. However, in this experiment pressure was adjusted upward and equilibrated for 48 hours at 0.05, 0.10, 0.20, 0.33, 0.98, 1.96, and 14.70 bar. The moisture percentages of samples equilibrated at each pressure were determined after drying for 12 hours at 70C. The relationship of compost moisture content to equilibration pressure is shown in Fig. 3.

Methods of Compost Fractionation

Extraction and concentration

Three liters of compost saturation extract were collected, concentrated as described in the plant germination studies, and randomly divided into six samples. The six sample treatment combinations are given in Table 2 and Fig. 4. Concentrations of nine elements in the treatment combinations are reported in Table 3.

Peroxide digestion

The organic fraction of the extract was destroyed by hydrogen peroxide digestion on a hot plate, as described in the seed germination

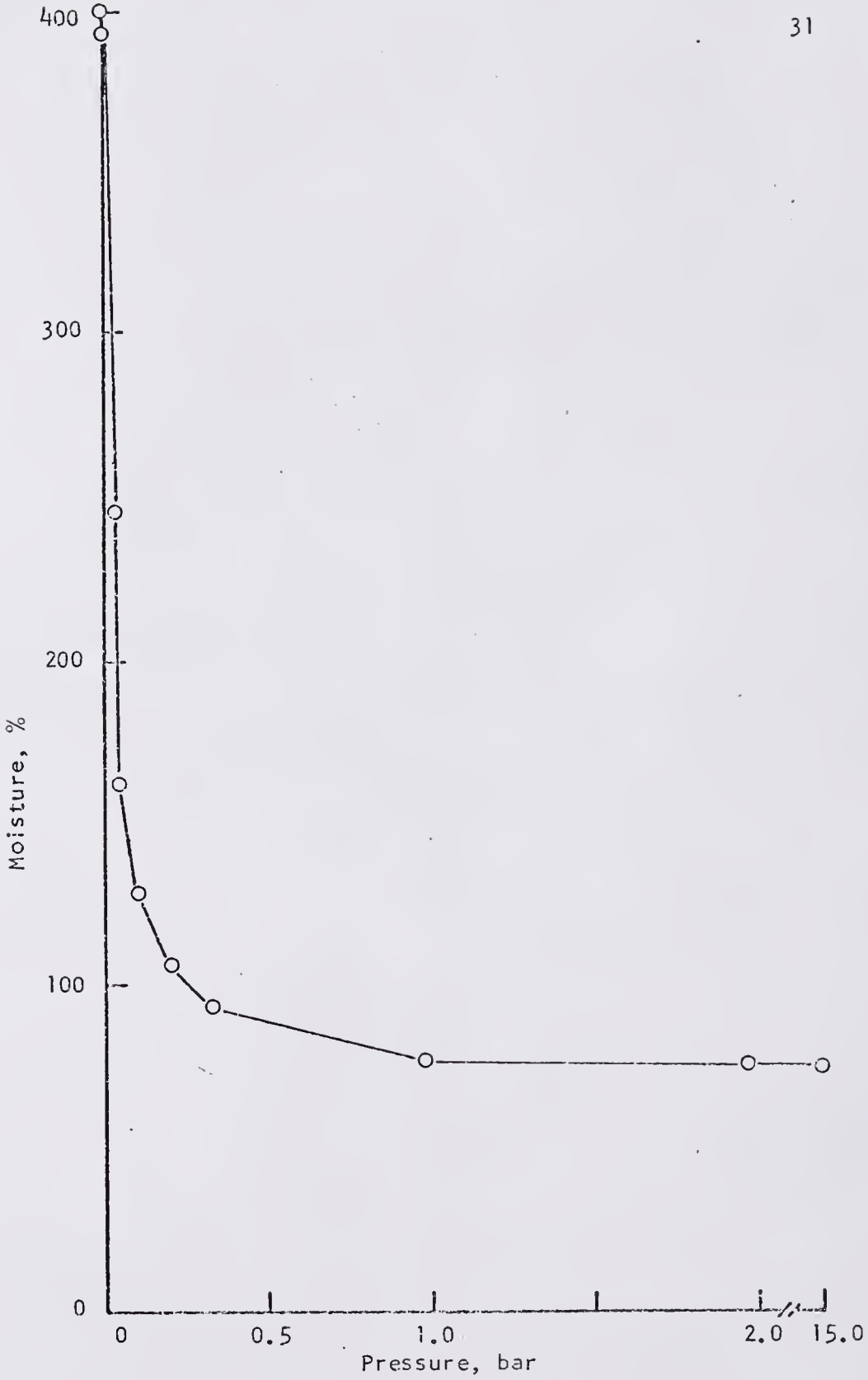


Fig. 3. Relationship of compost moisture percentage to equilibrium pressure.

Table 2. Treatment combinations of compost fractions study

Treatment No.	Treatment Combinations
1	Threefold concentration
2	Threefold concentration + cation resin
3	Threefold concentration + anion resin
4	Threefold concentration + peroxide digestion
5	Threefold concentration + peroxide digestion + cation resin
6	Threefold concentration + peroxide digestion + anion resin

Saturation Extract

Threefold concentrated by vacuum distillation

Organic matter destroyed by H_2O_2			No treatment		
No treatment	Cations exchanged	Anions exchanged	No treatment	Cations exchanged	Anions exchanged

Fig. 4. A schematic representation of the compost extract fractionation treatments.

Table 3. Concentration of certain elements in compost extract after various treatments

Treatment	Elements								
	Ca	Mg	Fe	Zn	Cu	Mn	Al	K	Na
	ppm								
Threefold concentration	540	200	15	1.1	3.0	6	18	1,120	1,400
Threefold concentration + cation exchange resin	800	150	13	0.6	3.0	3	17	810	1,180
Threefold concentration + anion exchange resin	375	130	10	0.4	1.5	2	17	960	1,300
Threefold concentration + peroxide digestion	355	170	0	0.1	1.2	1	3	1,080	1,360
Threefold concentration + peroxide digestion + cation exchange resin	520	120	2	0.3	0.9	3	7	920	1,260
Threefold concentration + peroxide digestion + anion exchange resin	220	130	0	0.1	0.1	0	5	900	1,290

study, except the volume of extract was 360 ml instead of 33 ml. All digested extracts except a fraction of one sample were filtered through Whatman no. 1 filter paper. The pH of each sample was adjusted to its original value with a 1:4 mixture of distilled water to concentrated hydrochloric acid.

Cation resin treatment

Ion exchange resin columns were used to reduce the concentrations of cations other than calcium and hydrogen in extracts. The columns were prepared as described by Rohm and Haas Company (company literature, 1964) from Amberlite ion exchange resin IRC-50(H)AR, 16 to 50 hydrated mesh size (Table 4). The column, a 250-ml burette with glass wool packed in the bottom to a height of 8 cm, had distilled water added to a height of 2 to 4 cm above the glass wool. Resin that had been soaked overnight in distilled water was poured into the column. Distilled water was passed through the bottom of the column, and an up-flow strong enough to make all the particles mobile and to remove all air pockets was maintained for several minutes. During this time particle segregation occurred with the particle size increasing from top to bottom of the column. The column was then connected at the top to a reservoir of distilled water and adjusted to a flow rate of 20 ml per minute. A Whatman no. 1 filter paper ring was placed in the top of the column, and the water level lowered to within a few cm of the resin top. The final column length and diameter were 18.7 and 3.5 cm.

To determine the rate at which a large noncharged molecule would pass through the column, 5 ml of blue dextran, a large noncharged molecule with a molecular weight of 15,000, were passed through the column.

Table 4. Ion exchange resin properties

Property	Resin type	
	Anion	Cation
Functional group	polyamine	SO_3^-
Ionic form	OH-	H+
Effective pH	0-9	5-14
CEC volume Meq/ml	2.5	3.5
CEC weight Meq/g	10	10

The dextran passed in 5.5 minutes; therefore, flow was allowed for approximately 35 minutes after samples of compost extract were applied to the column to insure that small molecules passed from the column.

The extracts were adjusted to their original pH with a saturated solution of calcium hydroxide at 28C and concentrated to their original volume using either vacuum distillation or heating on a hot plate.

Anion resin treatment

To reduce the concentration of anions other than hydroxide and chloride in compost extract, Amberlite CA-4B(OH)AR, type 1, 100 to 200 mesh anion exchange resin was used. However, this mesh size was too small to allow the column flow needed, and batch rather than column technique was used. Five g of dry resin were hydrated overnight and added to 360 ml of extract as a slurry. The resin and extract were then stirred on a magnetic stirrer for an hour, allowed to settle at 5C for approximately an hour, and decanted onto Whatman no. 1 filter paper. The extracts were reduced to their original volume by either vacuum or heat evaporation, and adjusted to their original pH values by addition of a 1:4 mixture of distilled water to concentrated hydrochloric acid.

"Aspergillus" Growth

Two experiments were conducted. In the first, compost and Arredondo fine sand extracts obtained as described in the seed germination experiment were used; in the second, compost extract and extract fractions were used.

The extracts, extract fractions, and distilled water were mixed in a 1:1 ratio with Difco mycological broth which had been steam sterilized

at 120C for 20 minutes. Each treatment solution received a heavy spore suspension of Aspergillus niger (culture no. 6275 of the American Type Culture Collection, Rockville, Maryland) which had been incubated at 28C for 5 days on Difco mycological agar. Each inoculated solution was added to 16, 125-ml Erlenmeyer flasks in 50-ml increments. The flasks were capped with aluminum foil and incubated in a static condition for 2, 3, 4, or 5 days at 28C. Growth of the fungus was measured by mycelial pad weights as described by Eno and Reuszer (1955). After incubation, mycelial pads were removed from the Erlenmeyer flasks using a glass rod and wash bottle, washed into tared aluminum cups, placed in an oven at 70C for a period of 12 to 14 hours, and transferred to another oven for 2 hours at 105C. The cup and mycelia were than removed from the oven, allowed to cool in a calcium carbonate desiccator, and weighed on a Mettler type BS chainomatic balance.

Sting Nematode Motility in Extract and Extract Fractions

Approximately 400 sting nematodes, Belonolaimus longicaudatus, were extracted from potted soil by the sugar flotation technique described by Miller (1957). Specimens were rinsed thoroughly to remove the sugar solution, washed into a Syracuse watch glass, picked into distilled water, and stored at approximately 15C.

One ml of each extract fraction, extract, and a tap water blank were placed in separate BPI glasses with five replications. Each dish received 10 motile nematodes. The nematodes were examined for motility after 2.75, 20.00, 48.00, and 96.00 hours by use of a binocular dissecting microscope at 15x power. If the nematode was not visibly motile, an attempt was made to stimulate movement by probing the nematode

with a wire pick. If motility was not observed after considerable stimulation, the nematode was recorded as immotile.

After approximately 6, 24, 48, and 144 hours in the solutions, two immotile nematodes were taken from each dish of the organic fraction, placed in distilled water, and examined for motility over a 48-hour period.

Another experiment was conducted using the same procedure, but the treatments were 1/3, 1/9, and 1/27 dilutions of concentrated extract. Filtered and nonfiltered peroxide digested extract was also tested.

Seed Germination in Compost Extract and Extract Fractions

The effect of compost extracts and extract fractions on germination of corn, oat, radish, and turnip was examined as described in the plant seed germination section.

Statistical Analyses

Analyses were done in accordance with Steel and Torrie (1960).

RESULTS AND DISCUSSION

Field Evaluation of the Effects of Compost on Nematodes

Reductions of plant parasitic nematode population by the following organic amendments: castor bean pomace, oat straw, green timothy and rye, and cotton seed meal, were reported by Lear (1959), Johnson (1962), Sayre, et al. (1965), and Tomerlin (1969), respectively. This study was conducted over a 2-year period with three soil sampling periods to investigate the effect of various compost rates on nematodes in a Leon fine sand. Reductions of sting nematode, Belonolaimus longicaudatus, on tomatoes have been found in soil and compost mixtures in greenhouse studies (G. C. Smart, Jr., Univ. of Fla., personal communication, 1969).

In this study the means within each sampling period were relatively uniform and were means of samples taken during growth of each test crop. Therefore, the data for each nematode are presented as means of each treatment during the three sampling periods (1st through 9th, 51st through 52nd, and 53rd through 61st-week periods after the first amendments) and the total time. However, means for each treatment, sampling time, and nematode are reported in Appendix Tables 35-40.

Numbers of spiral nematodes in fertilized plots were significantly higher than in any other plots during every period except the 1st through 9th week in which no significant differences occurred (Table 5). Nematodes increased in all plots during the 52 weeks after the first compost

Table 5. Spiral nematodes in Leon fine sand treated with fertilizer or various amounts of compost

Material	Rate T/ha	Time Period, weeks* 1-9[h]	51-52[i]	53-61[h]	1-61[j]
		Number/100 g			
Control	0.0	58 a	243 cd	200 bc	148 b
Fertilizer	0.9	101 a	493 a	405 a	293 a
Compost	1.0	101 a	290 bc	285 b	230 b
Compost	2.0	100 a	394 bc	287 b	227 b
Compost	4.0	116 a	411 b	263 b	227 b
Compost	8.0	36 a	270 bcd	126 c	113 c
Compost	16.0	39 a	194 d	145 c	109 c
Compost	32.0	47 a	259 cd	149 c	125 c

*Means in the same column followed by the same letter are not significantly different at the 0.05 level by Duncan's new multiple range test.

[h]Means of 20 observations on soil under sorghum.

[i]Means of 8 observations on soil under oats.

[j]Means of 48 observations.

application. Compost and fertilizer were reapplied at the same rates after 52 weeks, and the number of spiral nematodes decreased immediately in the compost plots; in contrast, the number increased in the fertilizer plots. Numbers were significantly lower in the control and the 8, 16, and 32 T/ha compost plots than in any other plots during the 53rd through 61st week. During the total period, 1st through 61st week, means of spiral nematode numbers in plots receiving the highest three rates of compost were even significantly lower than in the control plots, but among these three treatments there were no significant differences. The relationships among spiral nematode numbers, treatments, and the time are shown in Fig. 5.

The fertilized and 2 T/ha compost plots statistically had the highest numbers of ring nematodes in all periods except the 1st through 9th week, and even there the actual numbers were highest (Table 6).

Numbers of lesion nematodes in test plot soil were very low throughout the experiment (Table 7), and probably can be disregarded in interpreting results.

In this experiment C. C. Hortenstine (Univ. of Fla., unpublished data, 1969) found that crop yield was highest on the fertilized and 32 T/ha treatment plots and lowest on the control plots. Nonsignificant treatment differences during the first time period were probably due to insufficient time for large populations to develop. In the following periods the higher numbers of spiral nematodes on the fertilized plots were expected since the fertilized plants were more vigorous and the larger root systems provided more nematode feeding sites and consequently more reproduction. The relatively lower numbers of parasitic nematodes

Fig. 5. Spiral nematodes in Leon fine sand treated with fertilizer or compost.

Legend:

— — 0.9 T/ha fertilizer

-·-· 8.0 T/ha compost

———— 16.0 T/ha compost

---- 32.0 T/ha compost

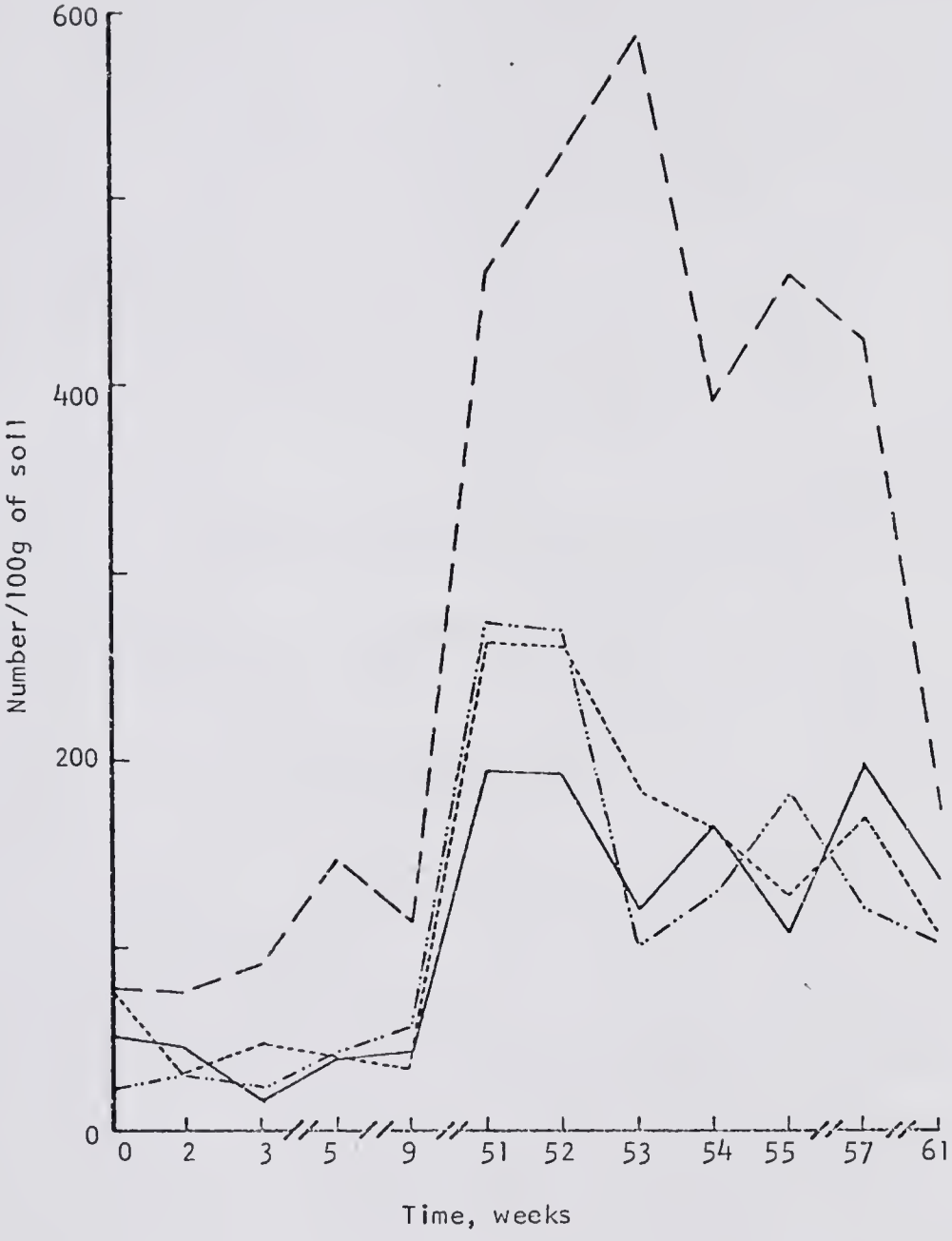

600
400
200
0
Number/100g of soil
0
2
3
5
9
51
52
53
54
55
57
61
Time, weeks

Table 6. Ring nematodes in Leon fine sand treated with fertilizer or various amounts of compost during four time periods

Material	Rate T/ha	Time Period, weeks*			
		1-9[h]	51-52[i]	53-61[h]	1-61[j]
		Number/100 g			
Control	0.0	15 b	40 bc	36 b	28 b
Fertilizer	0.9	31 a	80 a	65 a	53 a
Compost	1.0	23 b	39 bc	30 b	29 b
Compost	2.0	44 ab	59 ab	59 a	53 a
Compost	4.0	31 ab	39 bc	29 b	32 b
Compost	8.0	26 ab	40 bc	37 b	31 b
Compost	16.0	25 ab	43 b	34 b	32 b
Compost	32.0	17 b	21 c	31 b	23 b

*Means in the same column followed by the same letter are not significantly different at the 0.05 level by Duncan's new multiple range test.

[h]Means of 20 observations on soil under sorghum.

[i]Means of 8 observations on soil under oats.

[j]Means of 48 observations.

Table 7. Lesion nematodes in Leon fine sand treated with fertilizer or various amounts of compost

Material	Rate T/ha	Time Period, weeks* 1-9[h]	51-52[i]	53-61[h]	1-61[j]
		Numbers/100 g			
Control	0.0	9.1 ad	6.5 a	6.7 a	7.6 ab
Fertilizer	0.9	10.8 ab	5.6 a	5.6 a	7.7 ab
Compost	1.0	5.6 bcd	4.3 a	4.1 a	4.7 b
Compost	2.0	12.1 a	6.4 a	9.7 a	9.9 a
Compost	4.0	9.8 a	0.4 a	6.6 a	6.8 ab
Compost	8.0	7.5 ad	3.9 a	7.1 a	6.7 ab
Compost	16.0	3.9 cd	1.4 a	5.0 a	3.8 b
Compost	32.0	4.4 cd	1.3 a	4.0 a	3.6 b

*Means in the same column followed by the same letter are not significantly different at the 0.05 level by Duncan's new multiple range test.

[h]Means of 20 observations on soil under sorghum.

[i]Means of 8 observations on soil under oats.

[j]Means of 48 observations.

on the control were also expected since the unfertilized plants were less vigorous and had smaller root systems. Both lack of nutrients and nematode damage undoubtedly contributed to the lower yields on the control plots. On the fertilized plots the more vigorous plants yielded well even with nematode damage. The better crop yields and significantly lower numbers of spiral nematodes in the plots treated with the higher rates of compost undoubtedly were due to the compost. Nutrients for plant growth and toxins or antagonists against nematodes originated directly or indirectly from the compost. While it is possible that predacious fungi or other organisms might have restricted nematode populations, Tomerlin's (1969) work indicates otherwise.

Toxic compounds from the second application of compost probably caused the reduction of spiral nematode numbers between the 52nd and 53rd week in the three highest compost plots. The 2 T/ha compost plots originally contained the most ring nematodes which probably were not reduced by the low level of compost application. However, compost might have had an antagonistic effect that prevented significant increases in ring nematode numbers in all compost treated plots. It is also quite possible that neither sorghum nor oat were good hosts for ring or lesion nematodes.

Numbers of dorylaimid nematodes were not significantly different during the first 9 weeks and were only slightly changed during the second and third periods. However, during the 61-week period, the 32 T/ha compost plots contained significantly more dorylaims than the fertilized or control plots (Table 8). Numbers of cephalobids during the first 52 weeks were not significantly different among plots; but

Table 8. Dorylaims in Leon fine sand treated with fertilizer or various amounts of compost during four time periods

Material	Rate T/ha	Time Period, weeks* 1-9[h]	51-52[i]	53-61[h]	1-61[j]
		Numbers/100 g			
Control	0.0	4.8 a	11.3 d	9.2 bc	7.7 b
Fertilizer	0.9	3.9 a	12.5 cd	12.0 abc	8.7 b
Compost	1.0	5.7 a	26.6 a	11.5 abc	11.5 ab
Compost	2.0	10.0 a	13.9 bcd	7.8 c	9.5 ab
Compost	4.0	7.1 a	15.1 bcd	14.9 ab	11.6 ab
Compost	8.0	3.5 a	22.1 abc	13.3 abc	10.6 ab
Compost	16.0	5.0 a	21.9 abc	15.6 ab	12.2 ab
Compost	32.0	8.7 a	23.3 ab	17.6 a	14.8 a

*Means in the same column followed by the same letter are not significantly different at the 0.05 level by Duncan's new multiple range test.

[h]Means of 20 observations on soil under sorghum.

[i]Means of 8 observations on soil under oats.

[j]Means of 48 observations.

during the 53rd through 61st-week period plots receiving the highest level of compost contained higher numbers (Table 9). There were no significant differences in numbers of rhabditids among treatments during the first 52 weeks (Table 10). However, during the 53rd-through 61st-week period, the 32 and 16 T/ha compost treatment plots contained significantly more rhabditids than did other plots; the 32 T/ha plots also contained significantly higher numbers than did the 16 T/ha compost plots.

Rothwell and Hortenstine (1969) showed that relative numbers of bacteria and fungi increased when compost was incorporated into soil. The dorylaims are predacious, as well as herbivorous (Christie, 1959), and dorylaims probably increased in the 32 T/ha compost plots in response to the higher numbers of organisms present. Cephalobids are primarily bacterial feeders, and probably increased in response to higher bacterial populations present in the 32 T/ha compost plots. Rhabditids are saprophagous and would be expected to be highest in the plots receiving the most compost. The delayed response of rhabditids to compost was probably due to the small original populations.

The chemical properties of the plots at the beginning of the experiment are shown in Table 11. The fertility status of the plot soils was quite uniform.

Motility of Sting Nematodes

Saturation and threefold concentrated compost extract render sting nematodes immotile (P. G. Hunt and G. C. Smart, Jr., Univ. of

Table 9. Cephalobids in Leon fine sand treated with fertilizer or various amounts of compost during four time periods

Material	Rate T/ha	Time Period, weeks* 1-9[h]	51-52[i]	53-61[h]	1-61[j]
		Number/100 g			
Control	0.0	8.4 a	36.0 a	24.8 c	19.8 d
Fertilizer	0.9	11.4 a	37.4 a	43.9 c	29.7 bcd
Compost	1.0	11.0 a	31.4 a	44.1 bc	28.1 bcd
Compost	2.0	12.0 a	28.4 a	37.1 c	30.0 bcd
Compost	4.0	16.5 a	27.0 a	39.6 bc	27.5 cd
Compost	8.0	18.2 a	24.6 a	62.3 b	41.0 ab
Compost	16.0	16.0 a	32.4 a	58.2 b	36.3 bc
Compost	32.0	17.2 a	43.1 a	102.6 a	57.1 a

*Means in the same column followed by the same letter are not significantly different at the 0.05 level by Duncan's new multiple range test.

[h]Means of 28 observations on soil under sorghum.

[i]Means of 8 observations on soil under oats.

[j]Means of 48 observations.

Table 10. Rhabditids in Leon fine sand treated with fertilizer or various amounts of compost during four time periods

Material	Rate T/ha	Time Period, weeks* 1-9[h]	51-52[i]	53-61[h]	1-61[j]
		Number/100 g			
Control	0.0	2.2 a	12.4 a	30.2 c	15.6 c
Fertilizer	0.9	3.6 a	19.4 a	42.1 c	22.3 ab
Compost	1.0	3.0 a	7.9 a	36.1 c	17.6 bc
Compost	2.0	7.5 a	12.5 a	28.6 c	16.5 c
Compost	4.0	6.2 a	10.9 a	30.9 c	17.3 b
Compost	8.0	7.2 a	15.4 a	37.8 c	21.3 abc
Compost	16.0	9.5 a	16.3 a	53.0 b	28.7 a
Compost	32.0	6.3 a	11.8 a	67.1 a	32.5 a

*Means in the same column followed by the same letter are not significantly different at the 0.05 level by Duncan's new multiple range test.

[h]Means of 20 observations on soil under sorghum.

[i]Means of 8 observations on soil under oats.

[j]Means of 48 observations.

Table 11. Chemical properties of soils from plots at the start of the field study of the effects of compost on nematodes

Material	Rate T/ha	pH	Element			
			Ca	Mg	K	P
			ppm			
Compost	0.0	4.9	685	87	21	1.9
Fertilizer	0.9	4.6	810	108	49	6.3
Compost	1.0	4.9	715	80	35	2.2
Compost	2.0	4.7	809	108	30	2.1
Compost	4.0	4.8	714	80	21	1.8
Compost	8.0	4.8	805	94	25	1.7
Compost	16.0	5.1	693	82	25	2.2
Compost	32.0	5.1	736	78	41	1.8

Fla., unpublished data, 1969). In order to determine whether the organic or inorganic fraction of the compost extract caused the immotility, concentrated extract and five fractions were tested for their effect on sting nematodes. Motility of sting nematodes in the compost extract after various fractionation treatments is shown in Table 12 and Fig. 6. Sting nematodes were completely immotile in treatments 1 and 3 and 42% immotile in treatment 2 after 2.8 hours. Treatments 4, 5, and 6 had significantly better nematode motility than treatments 1, 2 and 3, but not as good as treatment 7 which was the only treatment with no organic compounds and low salt concentration. Nematodes became immotile rapidly in the organic fraction with or without negative ion exchange, but nematodes remained motile longer after positive ion exchange in the extract. Reduction of the inorganic cations did not greatly increase motility after the organic fraction was removed. Therefore, the increase in motility in the organic-cation exchanged fraction may have been due to the removal of a positively charged organic toxin; however, the toxicity was not eliminated by cation exchange, as the nematodes were immotile in this fraction after 20 hours. The cation exchange was not efficient enough to allow definite conclusions to be drawn about the charge of the organic toxin.

Immotile nematodes taken from the extract containing the organic fraction and placed in distilled water regained motility within 10 minutes, indicating that they were only anesthetized. Nematodes that were immotile for over 48 hours regained motility in distilled water within an hour. Mankau (1968) and V. G. Perry (Univ. of Fla., personal communication, 1969) observed improved plant growth after treatment

Table 12. Motility of sting nematodes during exposure to compost extract and extract fractions*

Treatment No.	Treatment Description[j]	Exposure Time, hr				
		2.8[h]	20.0[h]	48.0[h]	96.0[h]	Mean[i]
		Number Motile				
1	Extract	0.0 d	0.0 b	0.0 c	0.0 c	0.0 e
2	Extract with cations exchanged	5.8 c	0.0 b	0.0 c	0.0 c	1.5 d
3	Extract with anions exchanged	0.0 d	0.0 b	0.0 c	0.0 c	0.0 e
4	Extract with organic matter destroyed	8.4 b	7.8 a	6.8 a	1.8 b	6.2 b
5	Extract with organic matter destroyed and cations exchanged	9.4 a	8.4 a	7.8 a	3.2 a	7.2 a
6	Extract with organic matter destroyed and anions exchanged	8.8 ab	8.2 a	1.4 b	1.0 b	4.9 c
7	Tap water check	10.0	10.0	9.4	8.4	9.5

*Means in the same column followed by the same letter are not significantly different at the 0.01 level by Duncan's new multiple range test.

[h]Means of 5 observations.

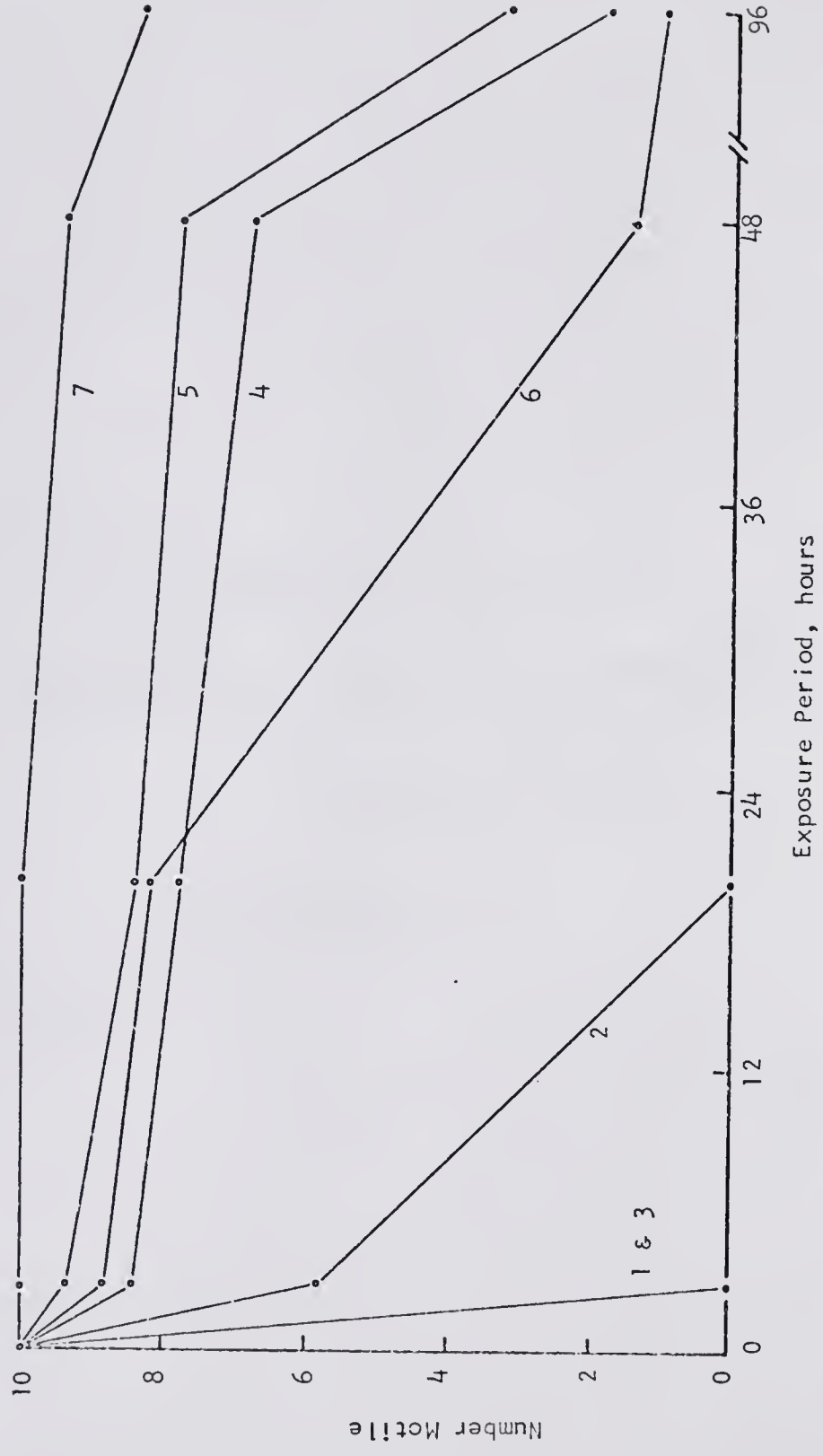
[i]Means of 20 observations.

[j]Extract was a threefold concentration of compost saturation extract.

Fig. 6. Motility of 10 sting nematodes during exposure to compost extract fractions.

Legend:

1 = Extract
2 = Extract with cations exchanged
3 = Extract with anions exchanged
4 = Extract with organic matter destroyed
5 = Extract with organic matter destroyed and cations exchanged
6 = Extract with organic matter destroyed and anions exchanged
7 = Tap water check


Number Motile
10
8
6
4
2
0
0
12
24
36
48
96
Exposure Period, hours
7
5
4
6
2
1 & 3

with nematicides and organic amendments, with no reduction in nematode numbers. It may be that certain compounds inactivate nematodes without fatal effects.

Nematode motility in dilutions of compost extract, as shown in Table 13, decreased as the concentration of compost extract increased. The relationship of compost concentration to nematode motility during a 96-hour period is presented in Fig. 7. The greatest reduction in motility was caused by 4 to 11% compost; approximately 55% of the nematodes were rendered immotile in this range. Since nematodes from the same stock colony were used in the study, genetic selection was not involved in the nonlinearity of the relationship. The variation was probably discontinuous as described for bacteria by Lamanna and Mallette (1965), with the tolerant group comprising approximately 40% of the population. The sensitive portion of the population might have exhibited quantitative variation if more points had been measured, but these data are insufficient for such information.

The antagonism and immotility of plant parasites such as sting and spiral nematodes are definitely beneficial effects, and they may occur with land disposal of compost. Sting nematode motility was only suppressed significantly by greater than 4% compost extract. However, in the soil a lower percentage of compost might be effective in reducing the parasitic effects of sting nematodes because of the close proximity of the nematodes to the source of the toxin. The spiral nematodes may be more sensitive to compost because their numbers were reduced by less than 1.5% compost in Leon fine sand. Reduction in numbers of parasitic organisms would make compost disposal in soil desirable if the compost was nontoxic to beneficial soil organisms and plants.

Table 13. Motility of 10 sting nematodes during exposure to various concentrations of compost extract in distilled water*

Medium	Exposure Time, hr				Mean
	2.8	20.0	48.0	96.0	
	Number Motile				
Saturation extract	3.2b	1.8c	1.6c	.6c	1.8d
1/3 Saturation extract	4.0b	4.2b	5.8b	3.6b	4.4c
1/9 Saturation extract	9.4a	9.4a	9.0a	7.6a	8.9a
Distilled water	10.0a	10.0a	10.0a	8.6a	9.7a

*Means in the same column followed by the same letter are not significantly different at the 0.01 level by Duncan's new multiple range test.

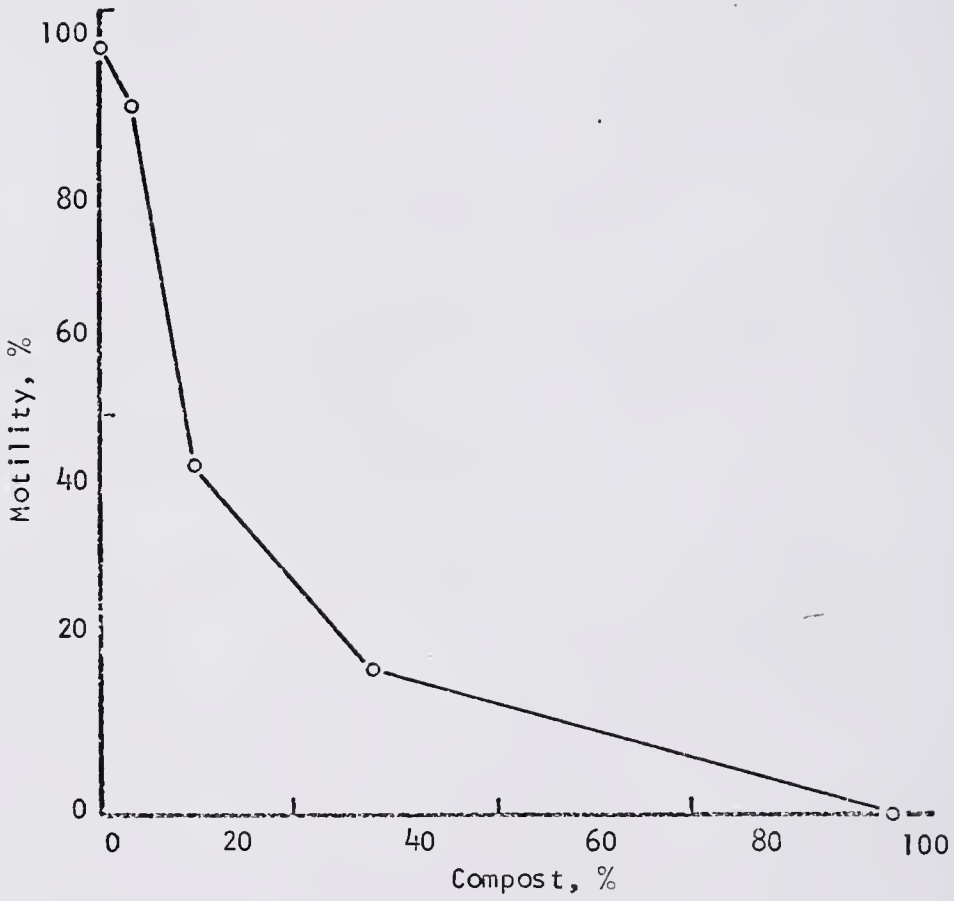


Fig. 7. Relationship of sting nematode motility to percentage of compost in distilled water.

Earthworm Survival Experiment

Earthworms are one of the beneficial organisms in the soil; they increase soil aeration and tilth by ingesting soil and organic matter, humifying the organic matter, and ejecting granular casts into the soil (Guild, 1955; Clark, 1957). In Florida earthworms are raised and sold as bait to fishermen. Therefore, this study had two objectives: to determine if application of compost to soil at low rates would increase earthworm survival and to determine if compost or compost-Arredondo fine sand mixtures in small shipping containers were comparable to peat for earthworm survival.

Earthworm survival data are presented in Appendix Table 41. A comparison of earthworm survival in sand, compost, and peat is shown in Fig. 8. Earthworms were able to survive much better in compost or peat than in Arredondo fine sand. Compost and peat were equally good media for survival until the 4th week, after which earthworm survival was better in peat than in compost. Appendix Table 41 and Fig. 9 show that compost and compost plus 20 or 40% Arredondo fine sand were similar; likewise, compost plus 60, 80, and 95% Arredondo fine sand were similar media for earthworm survival. The addition of 2.5% compost to Arredondo fine sand resulted in good survival during the 1st and 3rd week, but not during the following weeks. Chemical analyses of the media are presented in Appendix Table 42. Ammonium acetate extractable calcium, magnesium, and potassium in peat and compost were comparable, but extractable phosphorus in peat was about double the amount in compost. The pH of peat was considerably lower than the pH of compost, but apparently this acidity did not adversely affect the earthworms.

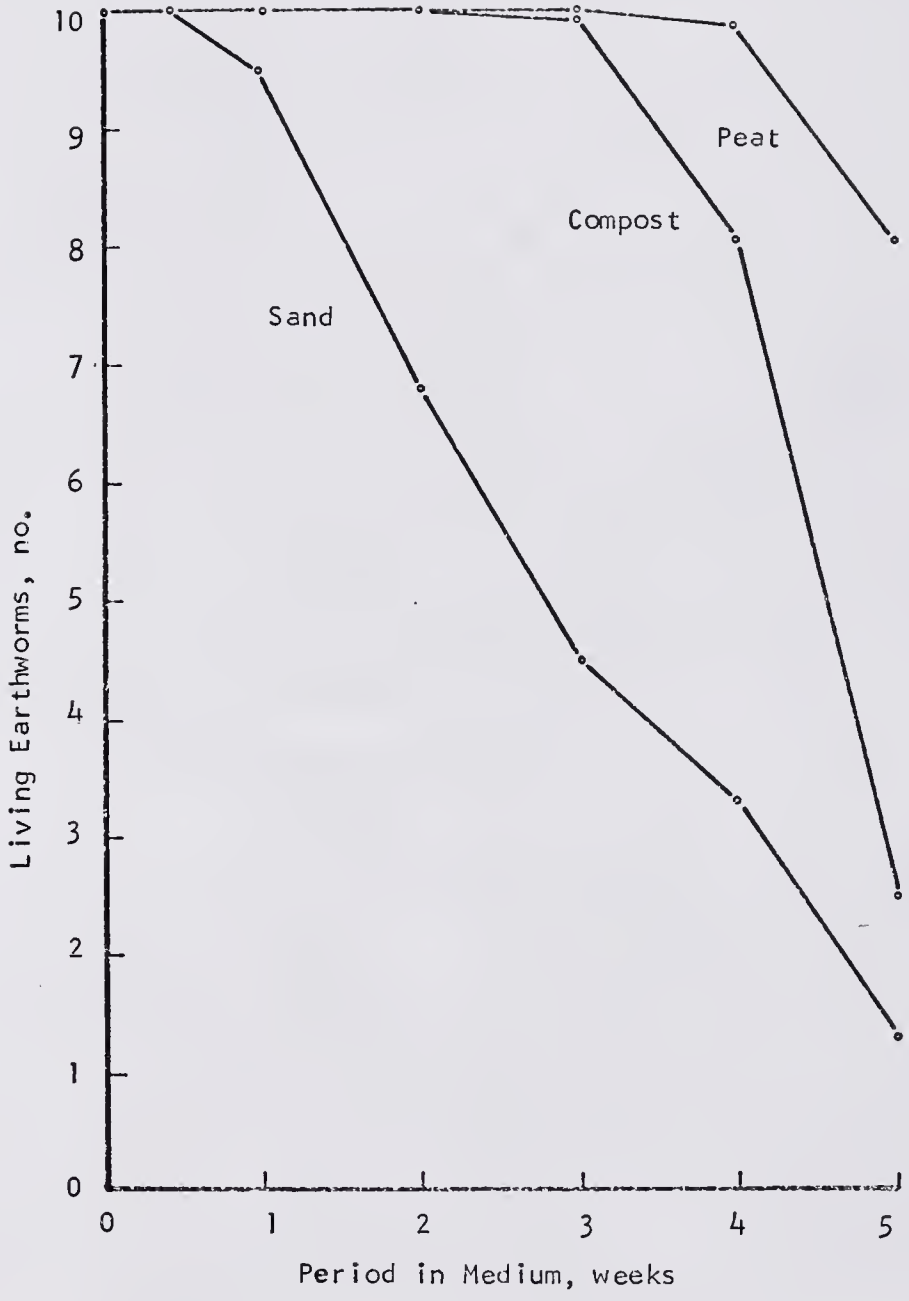


Fig. 8. Survival of 10 earthworms in Arredondo f.s., compost, and peat.

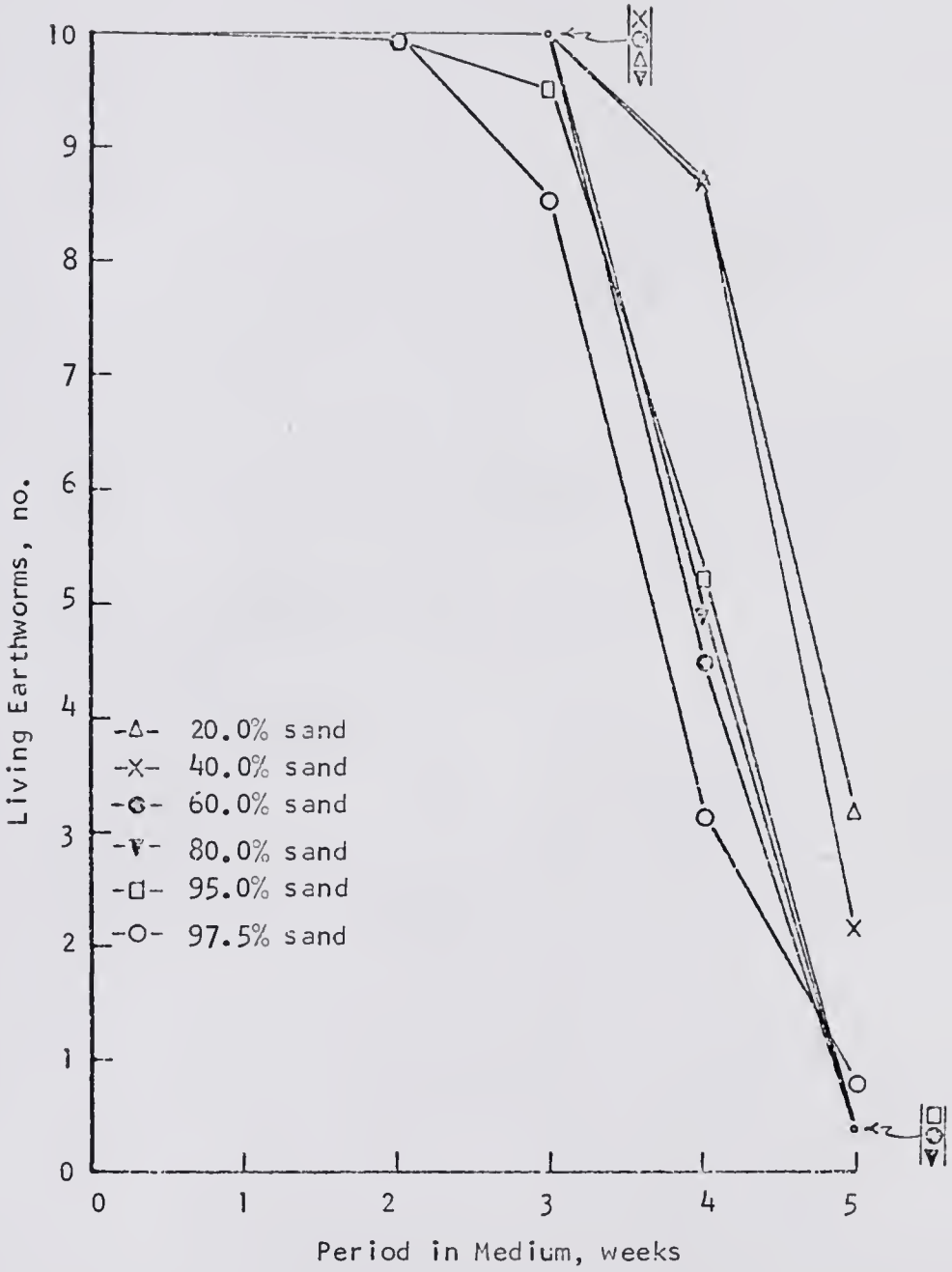


Fig. 9. Survival of 10 earthworms in compost-Arredondo f.s. mixtures.

Moisture should not have been a major factor in survival, since moisture in all media was maintained at the moisture percentage retained at 0.05 bar. The physical condition of peat was such that it could be more easily ingested by the earthworms than compost. The increased survival of earthworms in sand with only 2.5% compost, which may be of importance to agriculture, was probably the result of increased calcium and the improved physical condition of Arredondo fine sand. Increased survival between 5 to 50% and 60 to 80% compost levels was probably a response to increased nutrients and better physical condition in the Arredondo fine sand. Each range was probably a survival plateau. Thus, most any rate of compost applied to soil would not be harmful to earthworms and would probably be beneficial. However, for shipping periods longer than 3 weeks, peat would allow better earthworm survival. Compost might be a desirable medium in areas that do not have peat, but desire an earthworm shipping medium for less than 3-week periods.

Evaluation of the Effects of Extracts and Treated Extracts on Seed Germination

The land disposal of compost was shown to have some antagonistic or inhibitory effects on sting and spiral nematodes, and control of parasitic nematodes is definitely valuable to agriculture. However, McCalla and Duley (1948, 1949), McCalla and Haskins (1964), Patrick and Koch (1958), and Guenzi and McCalla (1962) reported reduction of seed germination by substances in organic soil amendments. Significant reduction in seed germination caused by compost would negate the advantages of land disposal particularly if the reduction took place at

low compost concentrations. Therefore, experiments with compost and compost-soil mixtures were conducted to investigate the possible toxic effects of compost against plant seed germination.

Data on the gemmination of corn seeds in saturation extracts are reported in Table 14. Average germination for the full 6-week period was not significantly different. However, germination was significantly lower in the 100% compost extract treatment than in any other treatment in two incubation periods. Reductions were only 4 and 8% of the control and probably were not agriculturally important.

Soybean germination in the saturated extracts taken after 2 weeks of incubation was not significantly different among treatments, but after a 4 weeks' incubation period germination was lower in extracts from compost and 60 and 80% compost mixtures (Table 15). Reduction after 4 weeks incubation may have been due to formation of toxic compounds. Oat germination was not significantly different for various extracts in two incubation periods, but was significantly different in the 20 and 60% compost extracts when all times were averaged (Table 16). The reason for lower germination in the 60% compost was not clear. Velvet bean, turnip, and radish seed germination in the various extracts was not significantly different (Table 17). Since no large reduction in seed germination was found, it was probable that any toxins that may have existed in the compost were diluted to nontoxic levels with distilled water or Arredondo fine sand. As seen in Fig. 3, page 31, there was a threefold increase in the moisture content of compost between 0.33 bar moisture content and saturation. The reduction of extract conductivity by increased percentages of Arredondo fine sand is shown in Table 18.

Table 14. Germination of 25 corn seeds in saturation extracts of materials incubated for different periods*

Extraction Material	Incubation Period, weeks 2	4	6	Mean
	Number Germinated[e]			
Arredondo f.s.	24.3bc	24.5ab	24.0a	24.5a
Arredondo f.s. + 20% Compost	24.0c	24.8ab	22.8c	23.8a
Arredondo f.s. + 40% Compost	24.8ab	24.8ab	24.0a	24.5a
Arredondo f.s. + 60% Compost	25.0a	24.3b	23.3bc	24.2a
Arredondo f.s. + 80% Compost	24.8ab	24.3b	23.5ab	24.2a
Compost	23.0d	25.0a	22.0d	23.3a
Blank	24.3	25.0	24.5	24.6a

*Means in the same column followed by the same letter are not significantly different at the 0.01 level by Duncan's new multiple range test.

[e]Values are means of 4 replicates.

Table 15. Germination of 25 soybean seeds in saturation extracts of materials incubated for different periods*

Extraction Material	Incubation Period, weeks 2	4	Mean
	Number Germinated[c]		
Arredondo f.s.	22.5a	16.5a	18.0a
Arredondo f.s. + 20% Compost	20.5a	16.5a	18.8a
Arredondo f.s. + 40% Compost	20.3a	13.0ab	16.6a
Arredondo f.s. + 60% Compost	22.0a	10.8b	16.4a
Arredondo f.s. + 80% Compost	21.5a	11.3b	16.4a
Compost	23.3a	11.8b	17.5a
Blank	23.0	18.8	20.9

*Means in the same column followed by the same letter are not significantly different at the 0.01 level by Duncan's new multiple range test.

[c]Values are means of 4 replicates.

Table 16. Germination of 25 oat seeds in saturation extracts of materials incubated for different periods*

Extraction Material	Incubation Period, weeks 2	4	Mean
	Number Germinated[c]		
Arredondo f.s.	22.0a	23.3a	22.6ab
Arredondo f.s. + 20% Compost	24.5a	24.5a	24.5a
Arredondo f.s. + 40% Compost	24.8a	23.5a	24.2ab
Arredondo f.s. + 60% Compost	22.5a	21.0a	21.8b
Arredondo f.s. + 80% Compost	24.5a	23.5a	24.0ab
Compost	22.3a	24.5a	23.4ab
Blank	23.8	24.5	24.2

*Means in the same column followed by the same letter are not significantly different at the 0.01 level by Duncan's new multiple range test.

[c]Values are means of 4 replicates.

Table 17. Germination of 25 seeds of three plant species in saturation extracts of Arredondo f.s., compost, and Arredondo f.s.-compost mixtures

Extraction Material	Seed Plant*		
	Velvet bean	Turnip	Radish
	Number Germinated[b]		
Arredondo f.s.	23.3a	23.8a	22.5a
Arredondo f.s. + 20% Compost	24.5a	23.0a	22.5a
Arredondo f.s. + 40% Compost	24.0a	22.5a	21.3a
Arredondo f.s. + 60% Compost	24.5a	22.5a	23.3a
Arredondo f.s. + 80% Compost	24.3a	22.5a	18.0a
Compost	23.8a	24.3a	21.0a
Blank	24.3	23.5	24.0

*Means in the same column followed by the same letter are not significantly different at the 0.01 level by Duncan's new multiple range test.

[b]Values are means of 4 replicates.

Table 18. Conductivity at 28C of saturation extracts of Arredondo f.s., compost, and Arredondo f.s.-compost mixtures

Extraction Material	Conductivity mmhos/cm*
Arredondo f.s.	0.581b
Arredondo f.s. + 20 % Compost	2.456a
Arredondo f.s. + 40% Compost	2.844a
Arredondo f.s. + 60% Compost	3.250a
Arredondo f.s. + 80% Compost	2.934a
Compost	3.287a

*Means in the same column followed by the same letter are not significantly different at the 0.01 level by Duncan's new multiple range test.

Pure compost was extracted and concentrated threefold by vacuum distillation to remove the dilution factor. Corn, oat, radish, and turnip seed germination data in saturation extract, threefold concentrated extract, and tap water are presented in Table 19. Corn seed germination was not significantly different in the three solutions, but tended to be lowest in the threefold concentrated extract. Oat and turnip seed germination did not differ in the saturation extract and tap water, but it was significantly lower in the concentrated extract. Germination of radish seeds in both normal and concentrated extract was significantly lower than in tap water, and germination was eliminated in the concentrated extract.

In order to determine if the toxin was organic or inorganic, the saturation extract was concentrated threefold and digested with hydrogen peroxide. Oat, radish, and turnip seed germination in extract that was saturated, concentrated, and divested of organic matter and tap water is reported in Table 20. Oat germination in the four solutions was not significantly different. There were no significant differences in radish or turnip seed germination among the saturation extract, concentrated extract with organic matter destroyed, and tap water. Germination of radish and turnip seeds was significantly lower in the concentrated extract than in all other treatments. Apparently, toxic material in the compost sample was organic in nature and was destroyed by peroxide digestion.

Another sample of compost was extracted, concentrated, and digested as previously stated; but the digested extract was divided into a high conductivity (14.8 mmhos/cm) and a lower conductivity

Table 19. Germination of 25 seeds of four plant species in varying concentrations of compost extract and tap water

Germination Medium	Seed Plant			
	Corn*	Oat*	Turnip*	Radish**
	Number Germinated[d]			
Saturation Extract	20.0a	23.3a	21.0a	11.0b
3x Saturation Concentration	16.0a	14.0b	3.3b	0.0c
Tap Water	23.6a	22.6a	22.3a	23.3a

*Means in the same column followed by the same letter are not significantly different at the 0.05 level by Duncan's new multiple range test.

**Means in the same column followed by the same letter are not significantly different at the 0.01 level by Duncan's new multiple range test.

[d]Values are means of 4 replicates.

Table 20. Germination of 25 seeds of three plant species in compost saturation extract, treated extract, and tap water

Germination Medium[h]	Seed Plant		
	Oat*	Turnip*	Radish**
	Number Germinated[i]		
Saturation extract	23.3a	24.0a	20.6a
Concentrated extract	22.5a	15.0b	6.5b
Concentrated extract - organic matter	23.5a	24.5a	22.0a
Tap water	24.6a	23.3a	24.6a

*Means in the same column followed by the same letter are not significantly different at the 0.05 level by Duncan's new multiple range test.

**Means in the same column followed by the same letter are not significantly different at the 0.01 level by Duncan's new multiple range test.

[h]Concentrated extract is a threefold concentration of saturation extract.

[i]Values are means of 4 replicates.

(10.9 mmhos/cm) group. Treatment means for this experiment are presented in Table 21. The saturation extract had a conductivity of 4.1 mmhos/cm; and the concentrated, nondigested extract had a conductivity of 10.4 mmhos/cm. The concentrated, high conductivity inorganic fraction caused the lowest oat seed germination. This reduction probably was not due to toxicity from the concentration of individual inorganic ions, since extractable and total elemental concentrations in compost were not in normally toxic ranges (Tables 31-34 and Appendix Tables 43-55). An osmotic effect may have been the mechanism of inhibition. Seatz and Peterson (1965) stated that only tolerant plants would yield normally in soil with extract conductivities greater than 8 mmhos/cm. Oat seed germination in the concentrated extract was significantly lower than in the saturation extract or tap water; however, germination in the concentrated low conductivity inorganic fraction was not significantly different from the tap water or saturation extract. This, again, indicated that toxicity was associated with an organic fraction. Radish and turnip seed germination was good in the tap water blank; but the saturation extract contained sufficient toxic material to lower seed germination of radish. When the extract was concentrated, the concentration of inorganic ions was high enough to cause a large decrease of germination even in the low conductivity inorganic fraction. Furthermore, when the concentrated extract contained both the organic and inorganic fraction, germination was essentially eliminated. This indicated an additive detrimental effect of inorganic ions and organic toxins on plant germination. However, the inorganic fraction with a conductivity of 14.8 mmhos/cm effectively eliminated seed germination, showing that high salt concentrations alone could eliminate seed

Table 21. Germination of 25 seeds of three plant species in compost saturation extract, treated extract, and tap water

Germination Medium[d]	Conductivity mmhos/cm	Seed Plant		
		Oat*	Turnip**	Radish**
		Number Germinated[e]		
Saturation extract	4.1	21.8a	18.0a	13.5b
Concentrated extract	10.4	14.5b	0.3c	0.3c
Concentrated extract, high conductivity, inorganic fraction	14.8	1.8c	0.8c	0.0c
Concentrated extract, low conductivity, inorganic fraction	10.9	20.0a	9.8b	7.8bc
Tap water	0.4	24.3a	23.0a	23.4a

*Means in the same column followed by the same letter are not significantly different at the 0.05 level by Duncan's new multiple range test.

**Means in the same column followed by the same letter are not significantly different at the 0.01 level by Duncan's new multiple range test.

[d]Concentration is a threefold concentration of saturation extract.

[e]Values are means of 4 replicates.

germination. The results of radish and turnip seed germination were in agreement with Hayward and Bernstein (1958) and Bernstein (1965) who found that radish was a salt sensitive plant and oat was a medium tolerant plant. The upper limit for good oat seed germination was 12 mmhos/cm conductivity in saturation extract. Reduction of radish germination at 10 mmhos/cm conductivity was in agreement with the report of the United States Salinity Laboratory (1954) that sensitive plants were affected at about 4 mmhos/cm conductivity. However, reduction of seed germination in saturation extract was primarily from organic toxins.

Characterization of toxic material was necessary, but the compost was extremely variable and organic characterizations were laborious. Therefore, a composite sample was obtained during a 2-day period and used for a partial characterization of the compost extract. Total boron was determined on this sample, and found to be 29 ppm. Hydrogen peroxide and ion exchange resins were used to remove specific fractions of the extract so that their contribution to the inhibition of seed germination could be determined.

Data on oat, radish, and turnip seed germination in the various threefold concentrated extract and extract fractions are presented in Table 22. Oat seed germination was not significantly different in any medium. This was consistent with other results where germination of oat seeds was not greatly reduced by threefold concentrations of compost extract. Extract with cations exchanged was not significantly different in turnip seed germination from extract with the organic matter destroyed. This was evidence in support of the hypothesis that

Table 22. Germination of 25 seeds of three plant species in compost extract and extract fractions

Germination Medium[e]	Seed Plant*		
	Oat	Radish	Turnip
	Number Germinated[f]		
Extract	23.5a	0.0a	1.8b
Extract with cations exchanged	23.5a	3.8b	16.5a
Extract with anions exchanged	23.8a	0.8a	4.0b
Extract with organic matter destroyed	23.8a	9.0c	21.5a
Extract with organic matter destroyed and cations exchanged	24.0a	13.0d	22.3a
Extract with organic matter destroyed and anions exchanged	23.3a	1.0a	17.0a

*Means in the same column followed by the same letter are not significantly different at the 0.01 level by Duncan's new multiple range test.

[e]Extract is a threefold concentration of a compost saturation extract.

[f]Values are means of 4 replications.

the toxin affecting turnip seed germination was an organic molecule with a positive charge. Radish seed germination in the extract containing the organic fraction and the extract with organic matter destroyed and anions exchanged was extremely low. The anion exchanged extracts were yellowish in color after treatment, and the resin had a polyamine functional group. Therefore, it was possible that some of the amines went into solution with the extract and reduced the germination of radish seeds. The largest increase in germination resulted from destruction of the organic fraction. However, there were still enough inorganic ions in the remaining inorganic fraction to reduce radish seed germination. This was as expected since the conductivity of the solution was approximately 6 mmhos/cm. Exchange of the cations significantly increased the radish germination; this could have resulted from a reduction in sodium concentration. According to Seatz and Peterson (1965) the conductivity of water suitable for plant growth was higher in water with a low sodium concentration than in water with a high sodium concentration.

The effect of compost on plant seed germination varied greatly among species. The effect was due to both organic and inorganic compounds and was additive. Indications are that the major organic toxin potential was in the positively charged fraction. Although some toxic potential against oat, radish, and turnip seed germination was found in both the organic and inorganic fraction of extract, it was primarily in the threefold concentrated, pure compost extract. There was very little inhibition of germination found in the saturation extract. The amount of compost that could be added to the soil without

inhibition of seed germination could not be determined from these data because of unknown factors such as the extraction efficiency and the effect of seed proximity to toxic sources in the field. However, if there was even a tenfold loss of toxicity in extraction, compost could probably be applied at rates of 10% by weight (180 T/ha) without significant reductions in oat, corn, radish, turnip, velvet bean, or soybean seed germination. As was earlier shown, sting and spiral nematodes were probably suppressed and earthworm survival enhanced by these rates of compost application. The differential effect against parasitic nematodes is a positive factor for land application of compost.

Effects of "Penicillium" Grown in Extracts on Seed Germination

Although Grossbard (1952) found that composting of lawn mowings and wheat straw reduced the antibacterial activity of *Penicillium patulin*, the effects of composted refuse on production of substances by *P. patulin* that were harmful to seed germination were yet unknown. Behmer and McCalla (1963) later found crop residues inoculated with *P. patulin* reduced seedling growth. To determine the suppression of seed germination by *P. patulin* in the presence of another organic residue, compost cultures were grown in extracts of Arredondo fine sand, compost extracts, mycological broth, and glucose.

Oat seed germination was lower in Arredondo fine sand extracts that were enriched with glucose, inoculated with *P. patulin*, and incubated for 2 or 3 weeks than in any other treatment (Table 23). Germination was not significantly different among extracts incubated for 1 week. Patulin, the antibiotic produced by *P. patulin*, may not

Table 23. Germination of 25 oat seeds in extracts enriched with glucose, inoculated with Penicillium patulin and incubated for different periods*

Extraction Material	Incubation Period, weeks 1	2	3	Mean
	Number Germinated[c]			
Arredondo f.s.	15.0b	2.5b	5.3b	7.6b
Arredondo f.s. + 20% Compost	20.0a	14.0a	17.8a	17.3a
Arredondo f.s. + 40% Compost	19.5ab	16.3a	20.5a	18.6a
Arredondo f.s. + 60% Compost	18.5ab	12.8a	17.5a	16.3a
Arredondo f.s. + 80% Compost	21.0a	15.3a	19.8a	18.7a
Compost	19.3ab	14.5a	16.0a	16.6a
Blank	23.5	23.3	23.5	23.4

*Means in the same column followed by the same letter are not significantly different at the 0.01 level by Duncan's new multiple range test.

[c]Values are means of 4 replicates.

have been very concentrated after 1 week's incubation. The growth of P. patulin and the production of patulin in extracts from compost and Arredondo fine sand-compost mixtures were probably reduced by either high concentrations of antagonistic organic and inorganic compounds or fungal competition.

Corn seed germination was not significantly different among extracts of Arredondo fine sand, compost, and Arredondo fine sand-compost mixtures that were enriched with glucose, inoculated with P. patulin, and incubated for 1, 2, and 3 weeks (Table 24). Germination of corn in extract-broth-Penicillium combination is reported in Table 25. No large differences in seed germination existed; but the best medium for development of P. patulin (water-broth-Penicillium) had the lowest germination, and the poorest medium for development of P. patulin (sand-water-Penicillium) had the highest seed germination.

Oat seed germination in the extract-broth-Penicillium combinations is presented in Table 26 and Fig. 10. Treatment 3 resulted in the lowest germination, probably because P. patulin had a good nutrient source and little competition. The toxicity decrease during the 3-week period was linear and probably due to depletion of nutrients or accumulation of toxic by-products. Treatment 9 had the next lowest germination and was significantly lower than treatment 8. Better germination in treatment 8 might have been caused by antagonistic effects of compounds in compost extract against P. patulin. The third lowest germination which also decreased in toxicity with time was produced by treatment 5, where P. patulin had broth as a nutrient

Table 24. Germination of 25 corn seeds in extracts that were enriched with glucose, inoculated with *Penicillium patulin* and incubated for different periods*

Extraction Material	Incubation time, weeks 1	2	3	Mean
	Number Germinated[b]			
Arredondo f.s.	23.3a	25.0a	24.8a	24.3a
Arredondo f.s. + 20% Compost	24.3a	25.0a	23.8a	24.3a
Arredondo f.s. + 40% Compost	22.5a	23.0a	24.5a	23.3a
Arredondo f.s. + 60% Compost	23.8a	22.8a	23.3a	23.3a
Arredondo f.s. + 80% Compost	24.5a	24.3a	20.3a	23.0a
Compost	22.8a	24.0a	23.3a	23.3a
Blank	24.5	24.5	24.8	24.6

*Means in the same column followed by the same letter are not significantly different at the 0.01 level by Duncan's new multiple range test.

[b]Values are means of 4 replicates.

Table 25. Germination of 25 corn seeds in extract-broth-*Penicillium* combinations with varying incubation times*

Treatment No.	Treatment Description	Incubation time, weeks 1	2	3	Mean
		Number germinated[d]			
1	Compost-broth-*penicillium*	22.7 ab	22.7 bc	24.0 a	23.1 abc
2	Compost-water-*penicillium*	24.7 a	22.7 bc	23.7 a	23.7 abc
3	Water-broth-*penicillium*	21.7 b	22.0 c	22.6 a	22.1 c
4	Compost-broth-water	23.3 ab	23.6 a	22.6 a	23.2 abc
5	Sand-broth-*penicillium*	22.6 ab	22.6 bc	22.3 a	22.5 bc
6	Sand-water-*penicillium*	24.6 a	25.0 a	24.0 a	24.5 a
7	Sand-broth-water	23.6 ab	20.6 c	22.6 a	22.3 bc
8	Compost-glucose-*penicillium*	24.3 a	22.3 bc	22.3 a	23.0 abc
9	Sand-glucose-*penicillium*	24.3 a	24.3 ab	24.0 a	24.2 ab

*Means in the same column followed by the same letter are not significantly different at the 0.01 level by Duncan's new multiple range test.

[d]Values are means of 4 replicates.

Table 26. Germination of 25 oat seeds in extract-broth-*Penicillium* combinations with varying incubation times*

Treatment No.	Treatment Description	Incubation time, weeks 1	2	3	Mean
		Number Germinated[e]			
1	Compost-broth-*penicillium*	20.3 abc	22.0 ab	19.3 abc	20.5 ab
2	Compost-water-*penicillium*	24.0 a	24.6 a	23.0 a	23.9 a
3	Water-broth-*penicillium*	0.3 d	7.0 c	13.3 c	6.8 d
4	Compost-broth	23.0 ab	22.3 ab	22.6 a	22.6 a
5	Sand-broth-*penicillium*	14.6 bc	18.0 ab	20.6 ab	17.7 bc
6	Sand-water-*penicillium*	24.0 a	23.6 a	23.3 a	23.6 a
7	Sand-broth	16.6 abc	20.6 ab	20.3 abc	19.2 ab
8	Compost-glucose-*penicillium*	23.0 ab	22.3 ab	22.0 a	22.4 ab
9	Sand-glucose-*penicillium*	14.0 c	14.0 bc	13.6 bc	13.9 c

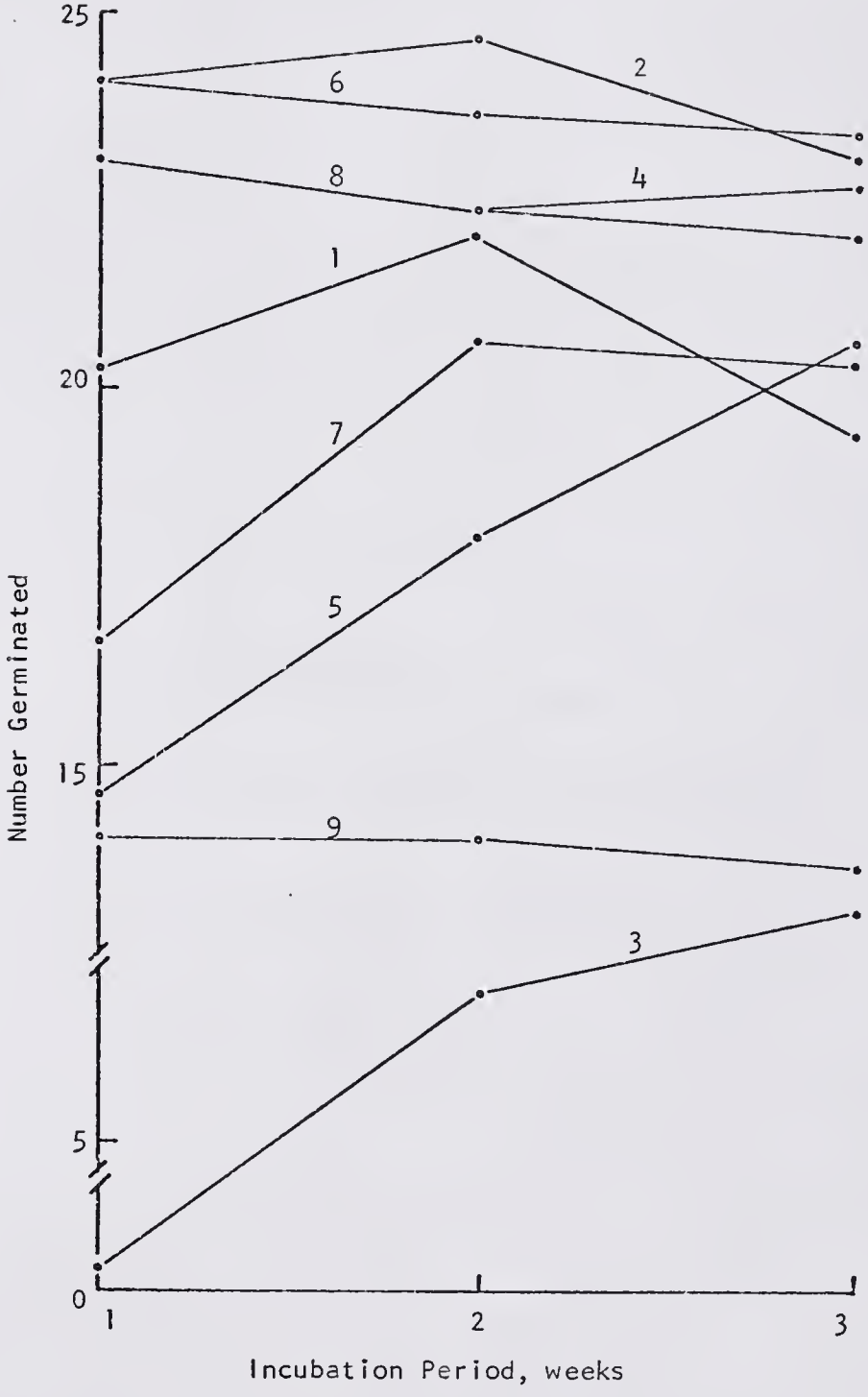
*Means in the same column followed by the same letter are not significantly different at the 0.01 level by Duncan's new multiple range test.

[e]Values are means of 4 replicates.

Fig. 10. Relationship of germination in 25 oat seeds to incubation period of extract-broth-*Penicillium* combinations.

Legend:

1 = Compost-broth-*Penicillium*
2 = Compost-water-*Penicillium*
3 = Water-broth-*Penicillium*
4 = Compost-broth-water
5 = Sand-broth-*Penicillium*
6 = Sand-water-*Penicillium*
7 = Sand-broth-water
8 = Compost-glucose-*Penicillium*
9 = Sand-glucose-*Penicillium*


25
20
15
5
0
Number Germinated
1
2
3
Incubation Period, weeks
1
2
3
4
5
6
7
8
9

source. Germination was also low in sand-broth, treatment 7, after 1 week of incubation, but increased during the following 2 weeks. An organism capable of producing a toxin might have been extracted from the sand and its toxicity decreased with the depletion of the nutrient source. In treatments 1, 2, and 8 seed germination was high. Probably P. patulin growth was limited by substances in the compost. In treatment 6 the nutrient source was Arredondo fine sand extract, and germination was high. This is in agreement with the view that the soil is a poor nutritive medium (Waksman, 1948).

Germination of turnip seeds in extract-broth-Penicillium combinations is presented in Table 27 and Fig. 11. Treatments 1, 4, and 9 had the lowest seed germination. Treatments 1 and 9 contained P. patulin and had broth and glucose, respectively, as nutrient sources. Treatment 4 contained compost extract and sterilized, mycological broth as a food source but no P. patulin inoculum. The reduction of seed germination in treatment 4 probably was not from compounds originally present in compost, because treatment 2 which contained compost but no supplemental food source had high seed germination. Therefore, organisms capable of producing inhibitory effects against turnip seed germination in the presence of a good nutrient source may have been present in the compost. As with oat, turnip seed germination in treatment 3 was initially very low, but increased with time. Treatment 6, another poor medium for growth, had high seed germination. Treatments 5 and 8 had higher seed germinations than expected in relation to the inoculum and food source; the reason for this higher germination was not clear. Treatment 7 probably did not have an

Table 27. Germination of 25 turnip seeds in extract-broth-*Penicillium* combinations with varying incubation times*

Treatment No.	Treatment Description	Incubation time, weeks 1	2	3	Mean
		Number germinated†			
1	Compost-broth-*penicillium*	0.0 c	0.3 c	4.3 d	1.5 e
2	Compost-water-*penicillium*	24.6 a	22.0 a	22.6 a	23.1 a
3	Water-broth-*penicillium*	0.0 c	7.0 bc	18.6 ab	8.5 cd
4	Compost-broth-water	0.6 c	2.0 c	5.3 d	2.6 e
5	Sand-broth-*penicillium*	5.3 bc	15.0 ab	17.3 abc	12.5 bc
6	Sand-water-*penicillium*	21.3 a	23.3 a	21.3 ab	22.0 a
7	Sand-broth-water	10.3 b	17.3 a	9.3 cd	12.3 bc
8	Compost-glucose-*penicillium*	10.6 b	15.6 a	13.6 bc	13.3 b
9	Sand-glucose-*penicillium*	5.3 bc	4.0 c	4.0 d	4.4 de

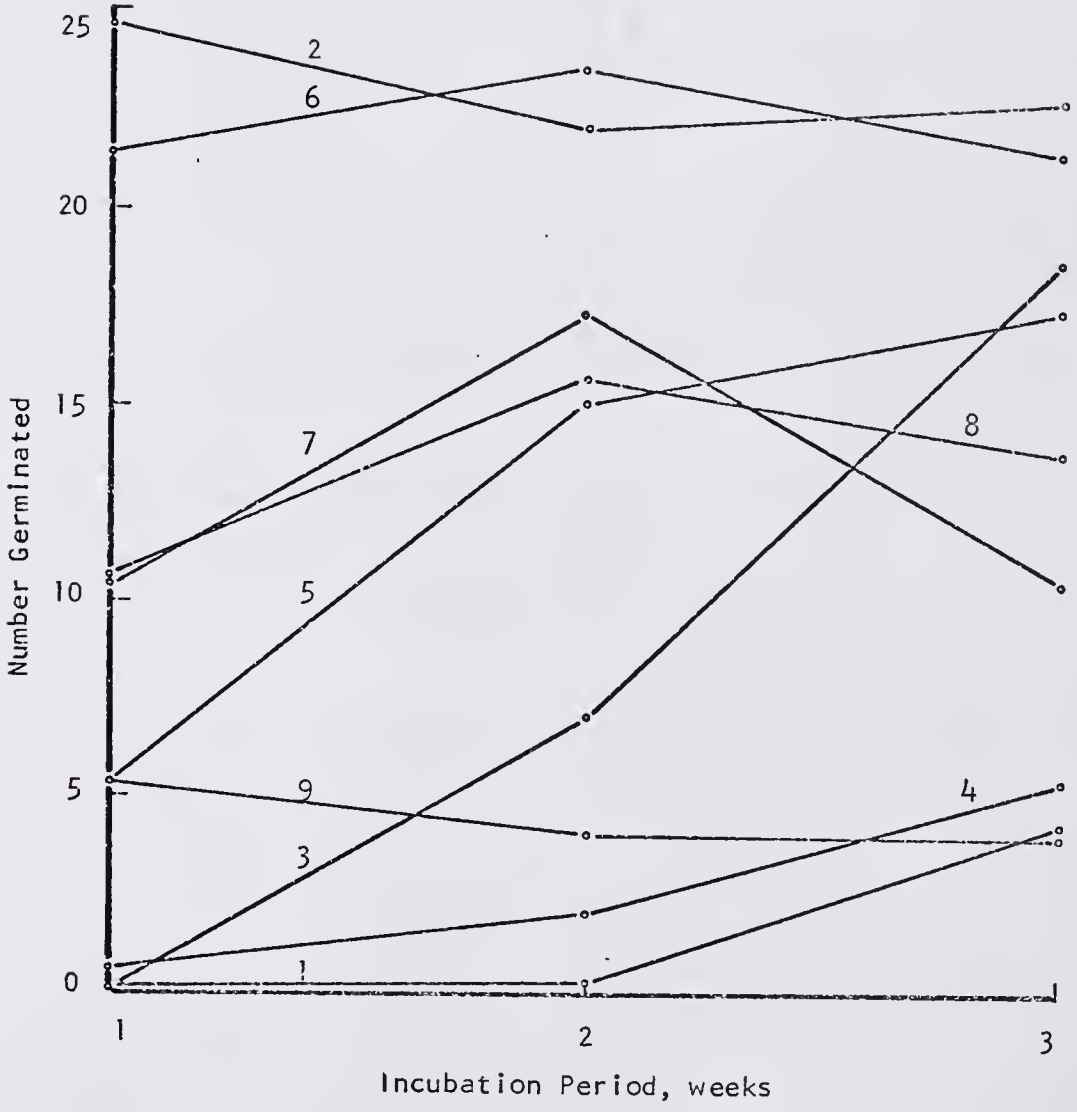
*Means in the same column followed by the same letter are not significantly different at the 0.01 level by Duncan's new multiple range test.

†Values are means of 4 replicates.

Fig. 11. Relationship of germination in 25 turnip seeds to incubation period of extract-broth-*Penicillium* combinations.

Legend:

1 = Compost-broth-*Penicillium*
2 = Compost-water-*Penicillium*
3 = Water-broth-*Penicillium*
4 = Compost-broth-water
5 = Sand-broth-*Penicillium*
6 = Sand-water-*Penicillium*
7 = Sand-broth-water
8 = Compost-glucose-*Penicillium*
9 = Sand-glucose-*Penicillium*


25
20
15
10
5
0
Number Germinated
1
2
3
Incubation Period, weeks
2
6
7
8
5
9
4
3
1

inoculum from Arredondo fine sand that was capable of producing extreme reduction in seed germination; therefore, it had intermediate germination. In general, turnip appeared to be more sensitive to toxins than oat.

Germination of radish seeds in extract-broth-*Penicillium* treatments is presented in Table 28 and Fig. 12. As with turnip seeds, treatments 2 and 6 resulted in the best germination probably because both were poor media for microbial growth. High seed germination in treatment 7 was probably due to low numbers of toxin-producing organisms in Arredondo fine sand extract. Treatments 1 and 4 had the lowest seed germination; both treatments contained compost and broth. Apparently, organisms capable of producing inhibitory effects against radish, as well as turnip, seed germination were present in the compost. Treatments 3, 5, and 9 had low germination after the 1st week's incubation, but germination after the 3rd week had increased to 17 or more seeds out of 25. This was probably due to the decrease of nutrients with time and the related decrease in toxin production. Treatment 8 had low germination after the 1st week of incubation, and only a small increase with time. Low germination in treatment 8 after 3 weeks' incubation may have been due to organisms in the compost.

Effects of *P. patulin* on corn, oat, radish, and turnip seed germination differed greatly. Corn was only slightly affected by *P. patulin*. Oat seed germination was reduced in the media with good *P. patulin* growth, but not in the other treatments. Radish and turnip seed germination was somewhat parallel; both were reduced by treatments

Table 28. Germination of 25 radish seeds in extract-broth-*Penicillium* combinations with varying incubation times*

Treatment No.	Treatment Description	Incubation time, weeks 1	2	3	Mean
		Number Germinated[g]			
1	Compost-broth-*Penicillium*	0.0d	0.7c	5.7c	2.1f
2	Compost-water-*Penicillium*	21.7a	20.0a	21.7a	21.1ab
3	Water-broth-*Penicillium*	1.0cd	7.3bc	18.7a	9.0cde
4	Compost-broth-water	0.7d	1.0c	14.0abc	5.2e
5	Sand-broth-*Penicillium*	8.7 cd	14.0ab	19.3a	14.0bc
6	Sand-water-*Penicillium*	23.3a	23.0a	22.3a	22.9a
7	Sand-broth-water	18.0ab	22.7a	16.3ab	19.0ab
8	Compost-glucose-*Penicillium*	4.0cd	9.0bc	9.0bc	7.3de
9	Sand-glucose-*Penicillium*	10.0bc	6.7bc	17.0ab	11.2cd

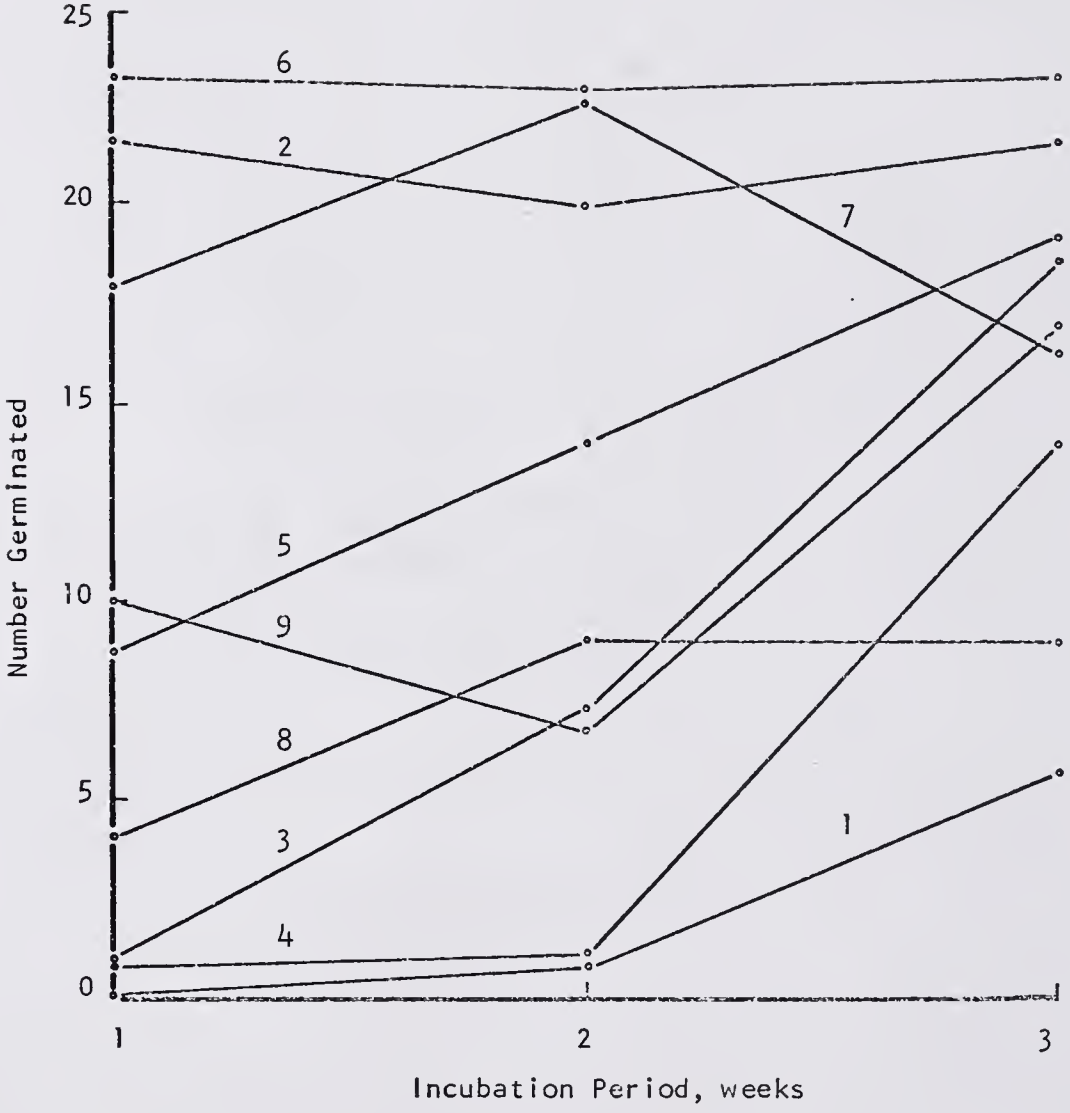
*Means in the same column followed by the same letter are not significantly different at the 0.01 level by Duncan's new multiple range test.

[g]Values are means of 4 replicates.

Fig. 12. Relationship of germination of 25 radish seeds to incubation period of extract-broth-*Penicillium* combinations.

Legend:

1 = Compost-broth-*Penicillium*
2 = Compost-water-*Penicillium*
3 = Water-broth-*Penicillium*
4 = Compost-broth-water
5 = Sand-broth-*Penicillium*
6 = Sand-water-*Penicillium*
7 = Sand-broth-water
8 = Compost-glucose-*Penicillium*
9 = Sand-glucose-*Penicillium*


25
20
15
10
5
0
Number Germinated
6
2
7
5
9
8
3
4
1
1
2
3
Incubation Period, weeks

containing P. patulin or compost when a suitable nutrient source was present. It appeared that organisms capable of producing inhibitory effects against turnip and radish, but not corn and oat, seed germination were present in compost. These differences might have been due to such things as toxin absorption rates, detoxifying enzymes, or variation of the affected compound or compounds in the different plant seeds. However, in all cases a good nutrient source was required for the production of compounds toxic to seed germination. Neither compost nor Arredondo fine sand extracts alone (treatments 2 and 6) could serve as such a nutrient source.

"Aspergillus niger" Growth in Extracts

Rothwell and Hortenstine (1969) reported increases of relative numbers of fungi in soils to which compost had been applied. Aspergillus niger, a typical soil-borne organism, is commonly used as a bioassay organism (Alexander, 1961). Therefore, A. niger was used as an indicator to test the effect of compost extract on a common soil fungus.

Saturation extracts of Arredondo fine sand, compost, and Arredondo fine sand-compost mixtures were inoculated with A. niger spores. However, no visible mycelial growth occurred. In another experiment, compost and Arredondo fine sand extracts were concentrated threefold before being mixed in equal amounts with mycological broth. An equal mixture of water and mycological broth was used as a control. A. niger mycelial weights, when grown in these mixtures, are presented in Table 29. Growth of A. niger on water- and sand-broth mixtures was not

Table 29. *Aspergillus niger* mycelial cumulative weights in compost-, sand-, and water-mycological broth mixtures*

Treatment	Incubation time, days 2	3	4	5	Mean
	mg				
Water-broth	143.8a	174.9a	196.9a	209.5a	181.3a
Compost-broth	22.4b	29.0c	38.2b	41.7b	32.8b
Sand-broth	141.2a	163.2b	186.9a	204.7a	174.2a

*Means in the same column followed by the same letter are not significantly different at the 0.01 level by Duncan's new multiple range test.

significantly different at any time, but growth on compost-broth mixture was significantly lower than the other mixtures at all times. Since the mycological broth was a complete nutrient medium, mixtures of compost extract, which probably added both inorganic and organic compounds as well as other microorganisms, would have been expected to change growth. Arredondo fine sand or water should not have contained as many organic or inorganic compounds or microorganisms; therefore, should not have changed growth as much as compost extracts.

To determine what fraction of the compost extract was reducing A. niger growth, compost extract was divided into several fractions and mixed in equal amounts with mycological broth before inoculation and growth. The mycelial weight of A. niger during a 5-day period in these media is given in Table 30 and Fig. 13. Treatments 1 and 3 had the lowest mycelial weights, and treatments 4 and 5 had the highest. Treatments 2, 6, and 7 were intermediate in mycelial weights. The means for all seven treatments were significantly different. Exchange of the cations in the organic fraction and destruction of the organic fraction removed toxicity. Treatments 4 and 5 had better growth of A. niger than the control, treatment 7, at all times. Therefore, reduction of A. niger growth was related to the organic fraction, and the primary reduction was from the positively charged component of compost extract.

Relative numbers of fungi do rise when compost is added to the soil (Rothwell and Hortenstine, 1969; and P. G. Hunt, Univ. of Fla., unpublished data, 1967). However, certain fungi such as A. niger may be suppressed. Thus, the qualitative as well as quantitative nature

Table 30. *Aspergillus niger* mycelial cumulative weights in compost extract-, extract fractions-, and distilled water-mycological broth mixtures during a five-day period*

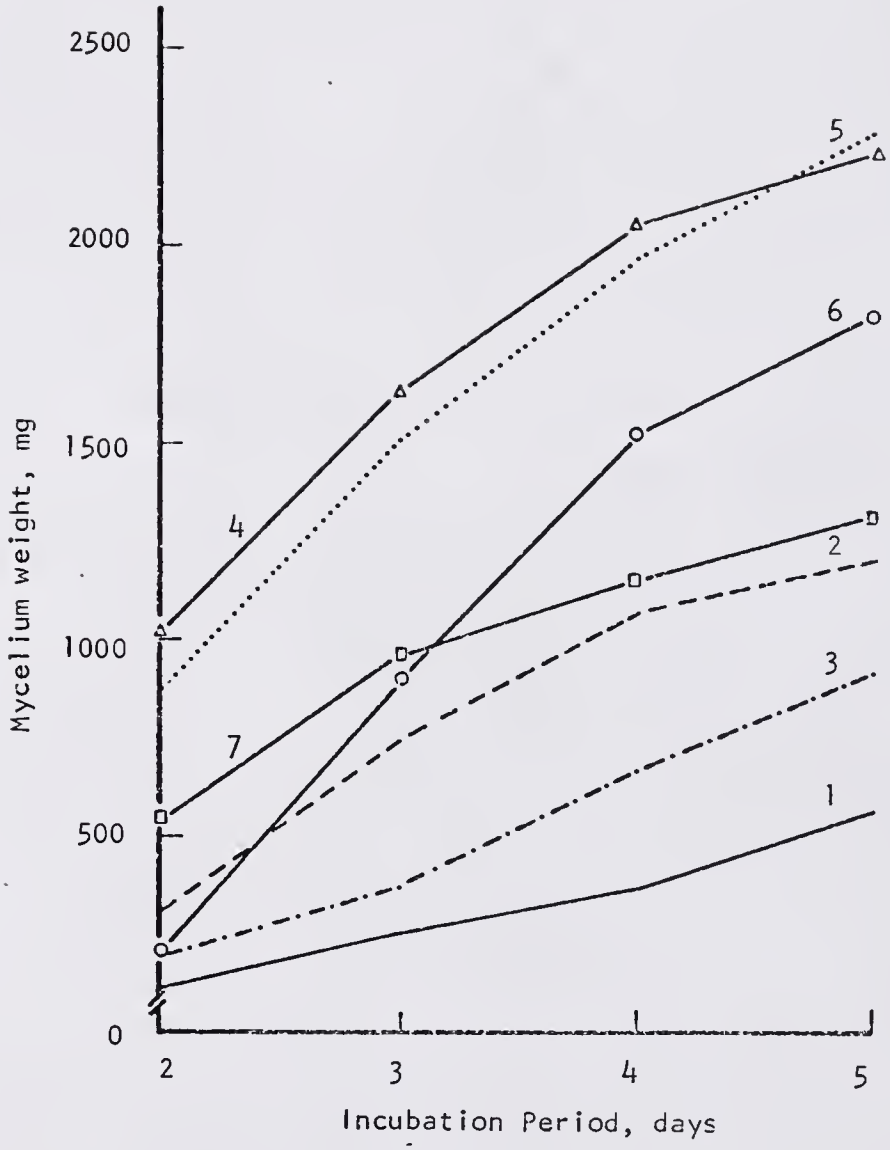
Treatment No.	Growth Medium	Incubation period, day 2	3	4	5	Mean
		mg				
1	Extract + broth	113 f	256 f	363 g	577 g	327 g
2	Extract with cations exchanged + broth	307 d	740 e	1,079 e	1,214 d	835 e
3	Extract with anions exchanged + broth	200 e	375 f	688 f	925 f	547 f
4	Extract with organic matter destroyed + broth	1,066 a	1,638 a	2,064 a	2,226 b	1,749 a
5	Extract with organic matter destroyed and cations exchanged + broth	859 b	1,507 b	1,972 b	2,302 a	1,660 b
6	Extract with organic matter destroyed and anions exchanged + broth	192 c	908 d	1,536 c	1,838 c	1,119 d
7	Distilled water + broth	551 c	968 c	1,148 d	1,321 e	1,329 c

*Means in the same column followed by the same letter are not significantly different at the 0.01 level by Duncan's new multiple range test.

Fig. 13. Relationship of Aspergillus niger mycelial cumulative weight in compost extract-, extract fractions-, and distilled water-mycological broth mixtures to incubation period.

Legend:

1 = Extract + broth
2 = Extract with cations exchanged + broth
3 = Extract with anions exchanged + broth
4 = Extract with organic matter destroyed + broth
5 = Extract with organic matter destroyed and cations exchanged + broth
6 = Extract with organic matter destroyed and anions exchanged + broth
7 = Distilled water + broth


2500
2000
1500
1000
500
0
Mycelium weight, mg
2
3
4
5
Incubation Period, days
1
2
3
4
5
6
7

of fungal populations changes upon application of compost to the soil.

Elemental Analysis of Compost

In order to determine the variation and range of the inorganic fraction of compost, samples were taken over a 15-week period and analyzed for certain elements. The variation of N ammonium acetate (pH 4.8) extractable elements in compost during an 8-week period is presented in Table 31. Iron was the only element that did not differ significantly during the 8-week period; however, this insignificance was probably due to high variance. The range of iron concentration was from 47 to 351 ppm. Calcium, potassium, magnesium, and sodium were in highest concentrations. The largest amount of these elements, especially calcium, was probably due to the addition of sewage effluent to the refuse; the effluent contained solid material from the municipal water treatment plant. Aluminum was also found in high concentrations, but probably would not cause toxicity, as soil acidity would be neutralized by the calcium in compost. The micronutrients, iron, manganese, copper, and zinc were present in concentrations that could be of some agricultural benefit, but not concentrated enough to be toxic to most agronomic crops.

The ranges of elemental means over the 8-week period are reported in Table 32. Ranges of copper, iron, aluminum, and calcium were greater than twofold; calcium was the only element in sufficient concentrations to cause gross variations in the inorganic characteristics of compost such as conductivity, pH, and SAR (sodium absorption ratio).

Table 31. Concentrations of ammonium acetate extractable elements in compost during an eight-week period

Time Period wk	Element								
	Fe n.s.	Ca*	Na*	Mn*	Cu*	Zn*	Al*	K**	Mg**
					(ppm)				
1	47	15,246	1,750	130	6.7	161	171	2,077	709
2	111	8,605	1,792	138	10.5	180	344	1,614	473
3	82	8,353	2,314	115	14.0	160	350	2,003	589
4	85	10,873	1,982	116	22.4	175	362	1,960	521
5	293	13,517	2,013	156	14.5	202	452	1,798	658
6	351	12,064	2,170	103	12.3	253	214	1,892	539
7	69	11,366	2,186	102	16.8	213	210	2,104	573
8	100	18,467	2,065	107	12.4	210	246	2,095	629
Mean	142	12,313	2,034	121	13.7	193	294	1,943	587

*There was a significant difference among time periods by the F-test at the 0.05 probability level.

**There was a significant difference among time periods by the F-test at the 0.01 probability level.

n.s. There was no significant difference among time periods by the F-test at the 0.05 probability level.

Table 32. Ranges of means of ammonium acetate extractable elements in compost during an eight-week period

Element	Range (ppm)
Cu	7-17
Fe	47-351
Mn	102-157
Zn	160-243
Al	171-452
Mg	521-709
K	1,614-2,104
Na	1,750-2,186
Ca	8,605-18,467

Means of ammonium acetate extractable elements in compost samples taken on 3 randomly selected days are presented in Table 33. Zinc and aluminum had no significant differences and iron was only significantly different for dates. Magnesium, potassium, and manganese had significant differences only for sampling periods, indicating that variation during short time intervals or for daily means was small. Since compost was taken from the composting bin in a side-to-side scooping path, one would expect to find variation of these elements in regions of the bin, and no great differences in small areas. Sodium, however, was quite variable, with significant differences among dates and sampling periods. Calcium was significantly different for dates, sampling periods, and date-sampling period interaction. Variation of calcium during daily sampling would have caused the most extreme variations in compost characteristics, such as pH, SAR and conductivity, but the most variable element was copper (Table 34) with significant variation among replicates as well as dates.

Ammonium acetate extractable phosphorus was less than 20 ppm and rather uniform among samples (Appendix Table 43), but total phosphorus ranged from 638 to 2520 ppm (Appendix Table 44). Application of high levels of compost to the soil may add sufficient phosphorus to increase soil fertility after an appropriate decomposition period; and since phosphorus in the soil has a low solubility and would be slowly released from compost, there would be little danger of water pollution from phosphorus runoff into streams or drainage into ground water.

Total concentrations of calcium, magnesium, potassium, sodium, zinc, and manganese were very similar to their ammonium acetate

Table 33. Concentration of certain ammonium acetate extractable elements in compost during three randomly selected days[a]

Date	Sampling Period	Elements							
		Mg**	Na**	K**	Mn**	Zn n.s.	Ca**	Fe n.s.	Al n.s.
		(ppm)							
I	1	495	2,110	1,421	79	619	10,064	129	276
	2	501	2,464	2,002	75	214	8,823	247	337
	3	409	2,392	1,785	101	232	11,057	100	403
	Mean	468	2,322	1,736	85	355	9,981	159	339
II	1	580	2,960	2,718	135	248	9,834	160	337
	2	487	2,879	2,461	135	264	7,285	176	433
	3	485	2,799	2,734	100	229	6,466	102	260
	Mean	518	2,879	2,638	123	247	7,862	146	343
III	1	599	2,793	2,690	145	348	7,472	93	365
	2	831	4,367	3,676	186	458	16,385	191	432
	3	624	4,080	3,191	147	305	7,824	108	416
	Mean	685	3,747	3,186	159	370	10,560	131	404

**Sampling periods were significantly different at the 0.01 level by the F-test.

n.s. Sampling periods were not significantly different at the 0.05 level by the F-test.

[a]Total analysis of variance is shown in Appendix.

Table 34. Concentration of ammonium acetate extractable copper in compost sampled during three random days[a]

Date	Replication	Sampling Period 1	2	3
		(ppm)		
I	1	15	12	12
	2	10	16	15
	3	7	19	15
	Mean	11	16	14
II	1	11	19	12
	2	10	21	8
	3	8	19	11
	Mean	10	20	10
III	1	19	18	10
	2	28	19	10
	3	13	19	11
	Mean	20	19	11

[a]Analysis of variance table is presented in Appendix.

extractable concentrations (Appendix Tables 45-50). The total copper concentrations were approximately double the extractable copper concentrations (Appendix Table 51). However, total iron and aluminum concentrations were much higher than their ammonium acetate extractable concentration (Appendix Tables 52 and 53). It is possible that aluminum might become toxic to plant growth if extremely high rates (> 450 T/ha) of compost were applied to a soil with a low pH.

Saturation extracts of the compost samples had conductivities from 2.37 to 4.78 mmhos/cm (Appendix Table 54). Thus, sensitive plants grown in compost might be adversely affected. However, except in very dry soils, a mixture with only 50% soil would probably eliminate the salt hazard to even the most sensitive plants.

Nitrogen ranged from 0.43 to 1.05%, indicating that nitrogen would be immobilized rather than released in the soil during decomposition of compost (Appendix Table 55). The amount of nitrogen that must be added to various compost-soil mixtures to allow nitrogen release instead of immobilization has been determined by D. F. Rothwell (Univ. of Fla., unpublished data, 1969).

SUMMARY

Disposal of solid refuse has become a problem of paramount importance in the United States with the increased size, urbanization, and wealth of the population. The problem is compounded because two traditional disposal methods, landfills and incendiary disposal, may pollute the water and air. Land application of compost has been considered as a possible means for disposal and land reclamation. Application of organic amendments to the soil is a common agricultural practice which generally improves soil structure and increases soil aeration (Baver, 1956) and often adds significant quantities of nutrients. In addition, plant parasitic nematode suppression from the application of such soil amendments as castor bean pomace, oat straw, green timothy and rye, and cotton seed meal have been reported by Lear, 1959; Johnson, 1962; Sayre, et al., 1965; and Tomerlin, 1969; respectively. However, some organic amendments have been shown to be detrimental to seed germination and growth of plants (McCalla and Duley, 1948; Patrick and Koch, 1958; Guenzi and McCalla, 1962; Langdale and Giddens, 1967). Since the effects of large amounts of compost on soils are unknown, this study was conducted to illustrate further the effect of compost on plant seed germination and soil organisms.

The effects of compost on nematodes in Leon fine sand during a 2-year period were investigated. Compost and fertilizer (10-10-10)

were applied to 2 x 3 m plots at rates of 1.0, 2.0, 4.0, 8.0, 16.0, and 32.0 and 0.9 T/ha, respectively, in May of 1968 and 1969. A control plot received no amendments. Sorghum was planted in the summer and fall and oats in the winter and spring. The surface-15 cm of soil was sampled during the 1st, 2nd, 3rd, 5th, 9th, 51st, and 52nd week following the first application and during the 1st, 2nd, 3rd, 5th, and 9th week after the second application. Samples were processed for nematode counts by the sugar flotation method (Miller, 1957). Treatments had no effect on spiral nematodes, Helicotylenchus spp., during the first 9 weeks; but after 52 weeks, spiral nematodes were more numerous in the fertilized plots. During the 9 weeks after application of the second amendment, soil from the control plot and the three highest compost treatments had fewer spiral nematodes than soil from other treatment plots. A 61-week average of spiral nematode numbers showed that the fertilized plots had the highest numbers and the three highest compost plots had the lowest numbers, but no significant differences in spiral nematode numbers existed among the plots with the three highest rates of compost. A 61-week average showed ring nematodes, Criconemoides spp., also were highest in the fertilized plots. Lesion nematodes, Pratylenchus spp., showed little variation with treatments, and their populations were small throughout the study. Dorylaims were higher in the 32 T/ha compost plots than in the fertilized or control plots, when averaged over the 61-week period. Neither cephalobids nor rhabditids were significantly different for any treatment during the first 52 weeks. Numbers of cephalobids in plots receiving 32 T/ha compost increased significantly

in the 9 weeks after the second application of compost. Rhabditids were significantly higher in soil from the 16 and 32 T/ha compost treated plots during the 9 weeks after the second application of compost.

The motility of sting nematodes, Belonolaimus longicaudatus, in compost extract and various extract fractions was studied in the laboratory. Motility was determined by examination of the nematode under a microscope as it was stimulated with a pick. Nematodes were immotile after 2.8 hours in the threefold concentrated compost extract. Exchange of the cations with calcium and hydronium ions prolonged motility in 58% of the nematodes from 2.8 to 20.0 hours, and removal of the organic matter in the extract by hydrogen peroxide digestion greatly increased the motility. During a 96-hour period, over 55% of sting nematodes were rendered immotile by 4 to 11% compost in distilled water. Considerably higher concentrations were required to immobilize the remaining nematodes.

Earthworms (African Giants) were studied for survival in 0.6 liter freezer cartons containing peat, compost, Arredondo fine sand, or compost-Arredondo fine sand mixtures. Peat and compost were much better media for survival than Arredondo fine sand; and, after 3 weeks, peat was better than compost. As little as 2.5% compost added to Arredondo fine sand greatly improved earthworm survival. Compost plus 20 or 40% Arredondo fine sand resulted in similar survival; so did compost plus 60, 80, and 95% Arredondo fine sand. Compost increased the aeration and calcium concentration of Arredondo fine sand.

Corn, oat, soybean, velvet bean, turnip, and radish seeds were germinated in saturation extracts taken from compost, Arredondo fine sand, and compost-Arredondo fine sand mixtures after 2, 4, and 6 weeks incubation at 28C. Seeds were germinated on filter paper in petri dishes. No agronomically significant differences in germination were found. Saturation extracts of pure compost, concentrated threefold by vacuum distillation, were found to reduce oat, turnip, and radish seed germination. In another case, threefold concentrated compost saturation extract was not inhibitory to oat seed germination; and peroxide digestion removed the inhibitory effect against radish and turnip seed germination. Extract from a third compost sample was considerably higher in conductivity than previous samples and threefold concentrated extract decreased oat, radish, and turnip seed germination. Removal of the organic matter in the extract significantly increased seed germination, but it was still lower than the control. Those extracts with 14 mmhos/cm conductivities nearly eliminated germination of oat, radish, and turnip seed. Another compost sample, with a conductivity of 2.58 mmhos/cm in the saturation extract, was concentrated; fractionated; and checked for its effect on oat, radish, and turnip seed germination. Oat seed germination was not affected. Low turnip seed germination was significantly improved by either destroying the organic matter or exchanging the cations in the extract with calcium and hydronium ions. Radish seed germination was increased by destroying the organic matter, but was increased more by destroying the organic matter and exchanging the cations in the extract.

Corn and oat seeds were germinated in extracts of compost, Arredondo fine sand, and compost-Arredondo fine sand mixtures that were enriched with glucose, inoculated with Penicillium patulin, and incubated for 1, 2, or 3 weeks. Corn seed germination was not affected, but oat seed germination in the Arredondo fine sand extract after 2 or 3 weeks of incubation was significantly lower.

Germination of corn, oat, radish, and turnip seeds in combinations of P. patulin, compost and Arredondo fine sand extract, and mycological broth after 1, 2, or 3 weeks of incubation was also studied. Corn seed germination was not significantly affected by any combination of treatments. Oat seed germination was higher in treatments that had compost or lacked P. patulin. Radish and turnip seed germination was more sensitive, and germination of these seeds was high only in combinations lacking the added nutrient source, mycological broth.

Compost-, Arredondo fine sand-, and water-mycological broth mixtures were inoculated with Aspergillus niger and incubated for 2, 3, 4, or 5 days at 28C. Mycelial weights on compost-broth mixtures were lowest, the sand- and water-broth mixtures were not significantly different. Compost extract was concentrated, fractionated, and incubated for 2, 3, 4, or 5 days at 28C in order to determine the fraction that was causing the reduction in mycelial weight. Mycelial weight was significantly increased after destruction of the extract's organic fraction with hydrogen peroxide, and a slight additional increase in mycelial weight occurred from cation exchange.

Compost sampled during an 8-week period was analyzed for selected ammonium acetate (pH 4.8) extractable elements. Calcium ranged from

8,000 to 15,000 ppm which was approximately eight times higher than the concentration of the next most concentrated element, sodium. Calcium, sodium, manganese, copper, zinc, aluminum, potassium, and magnesium varied significantly during the 8-week period. The micronutrients iron, manganese, copper, and zinc were concentrated enough to be of some agricultural benefit, but not enough to be toxic to most agronomic crops. Aluminum concentrations were high enough to cause some crop damage if extremely high rates of compost were applied to soils of pH 4.8 or less. The nitrogen percentage was less than 1.2, indicating that nitrogen would be immobilized during the decomposition of compost.

CONCLUSIONS

1. African Giant earthworm survial in small containers was better in peat than in compost; both were better media than Arredondo fine sand.
2. As little as 2.5% compost added to Arredondo fine sand improved it as a medium for earthworms.
3. Spiral nematodes, Helicotylenchus spp., in Leon fine sand on which oat or sorghum were grown, were reduced by 8, 16, or 32 T/ha of compost.
4. Two annual applications of 32 T/ha of compost in Leon fine sand increased cephalobids, rhabditids, and dorylaims.
5. Immotility of sting nematodes, Belonolaimus longicaudatus, in threefold concentrations of compost saturation extracts was primarily caused by the organic fraction. A large percentage of sting nematodes was rendered immotile by 4 to 11% compost saturation extract in distilled water.
6. Corn, oat, soybean, velvet bean, turnip, and radish seed germination was not reduced greatly by saturation extracts of compost, Arredondo fine sand, or compost-Arredondo fine sand mixtures.
7. The reduction of corn, oat, radish, and turnip seed germination in threefold concentrated compost saturation extract varied greatly. Inorganic or organic compounds caused germination reductions; however, reduction from organic compounds occurred more often.

8. According to procedures in this study, corn seed germination was not affected by compost or Arredondo fine sand extracts that were enriched with glucose or mycological broth and inoculated with Penicillium patulin.

9. Oat, radish, and turnip seed germination was reduced by solutions from enriched cultures of P. patulin. However, P. patulin culture solutions were not toxic when growth occurred in unsupplemented saturation extracts of compost or Arredondo fine sand.

10. Aspergillus niger growth in mycological broth was reduced by compost extract, but not by Arredondo fine sand extract; the reduction was due to the organic fraction of compost extract.

11. Ammonium acetate (pH 4.8), extractable calcium, sodium, magnesium, copper, zinc, aluminum, manganese, and potassium in compost varied considerably during any period of several weeks. Calcium had the greatest range of concentrations.

12. Application of compost at extremely high rates (>450 T/ha) might cause aluminum toxicity in soils with a pH of 4.8 or less.

13. The nitrogen content of compost is so low that soil nitrogen would be immobilized during the compost decomposition.

14. Indications were that compost applied to Leon or Arredondo type soils at annual rates of 45 T/ha would reduce crop damage from Helicotylenchus spp. and Belonolaimus longicaudatus and improve conditions for soil animals such as earthworms without lowering plant seed germination.

APPENDIX

Table 35. Spiral nematode numbers in Leon fine sand treated with fertilizer or various amounts of compost

Material	Rate T/ha	Time Period, weeks[a]											
		1	2	3	5	9	51	52	53	54	55	57	61
		Number/100 g											
Control	0.0	57	33	102	65	36	288	196	203	222	224	186	165
Fertilizer	0.9	79	78	91	146	113	459	523	587	388	459	423	170
Compost	1.0	118	50	145	90	106	479	480	270	293	300	408	155
Compost	2.0	71	74	75	157	102	290	490	270	331	266	377	194
Compost	4.0	119	104	91	100	168	347	475	205	253	250	287	319
Compost	8.0	23	34	23	43	57	273	268	97	126	183	120	103
Compost	16.0	51	45	17	41	42	194	193	119	166	106	198	134
Compost	32.0	84	27	48	41	34	261	258	184	163	125	169	105

[a]Time periods are weeks after applications of fertilizer or compost.

Table 36. Ring nematode numbers in Leon fine sand treated with fertilizer or various amounts of compost

Material	Rate T/ha	Time Period, weeks[a]											
		1	2	3	5	9	51	52	53	54	55	57	61
		Number/100 g											
Control	0.0	17	15	14	18	12	32	43	47	30	28	30	47
Fertilizer	0.9	17	40	24	37	38	54	106	90	50	59	93	32
Compost	1.0	22	17	38	18	21	31	48	29	24	25	40	35
Compost	2.0	22	40	43	67	46	50	68	47	53	52	84	60
Compost	4.0	25	28	32	31	41	29	49	35	17	19	25	50
Compost	8.0	16	27	20	24	45	34	95	26	27	44	38	51
Compost	16.0	26	23	18	36	46	23	63	34	29	14	48	46
Compost	32.0	23	16	22	17	5	13	29	16	60	17	38	24

[a]Time periods are weeks after application of fertilizer or compost.

Table 37. Lesion nematode numbers in Leon fine sand treated with fertilizer or various amounts of compost

Material	Rate T/ha	Time Period, weeks[a]											
		1	2	3	5	9	51	52	53	54	55	57	61
		Number/100 g											
Control	0.0	7	7	13	12	7	10	3	5	13	2	8	7
Fertilizer	0.9	8	9	9	22	6	10	1	1	5	8	8	8
Compost	1.0	3	5	6	9	7	6	3	3	7	10	0	2
Compost	2.0	6	9	18	21	6	10	1	3	15	7	4	4
Compost	4.0	10	12	5	16	7	1	0	2	8	11	6	7
Compost	8.0	2	14	8	7	9	7	1	2	7	8	10	8
Compost	16.0	2	2	4	6	7	3	0	5	7	5	5	4
Compost	32.0	3	3	8	7	1	2	1	2	4	4	8	3

[a]Time periods are weeks after application of fertilizer or compost.

Table 38. Numbers of dorylaims in Leon fine sand treated with fertilizer or various amounts of compost

Material	Rate T/ha	Time Period, weeks[a]											
		1	2	3	5	9	51	52	53	54	55	57	61
		Number/100 g											
Control	0.0	7	3	4	10	1	5	18	14	13	12	5	3
Fertilizer	0.9	5	4	4	2	5	7	19	7	16	22	15	3
Compost	1.0	6	2	8	7	6	18	35	12	8	15	19	4
Compost	2.0	12	12	9	8	10	8	20	6	8	12	14	1
Compost	4.0	10	10	5	6	4	15	16	12	27	21	13	3
Compost	8.0	1	4	3	5	5	23	22	17	15	14	18	4
Compost	16.0	4	10	3	7	1	15	29	19	24	18	16	2
Compost	32.0	15	4	8	8	9	19	28	2	19	19	33	16

[a]Time periods are weeks after application of fertilizer or compost.

Table 39. Numbers of cephalobids in Leon fine sand treated with fertilizer or various amounts of compost

Material	Rate T/ha	Time Period, weeks[a]											
		1	2	3	5	9	51	52	53	54	55	57	61
		Number/100 g											
Control	0.0	9	7	5	15	6	45	28	19	29	21	18	38
Fertilizer	0.9	8	16	10	16	14	43	33	30	48	38	51	52
Compost	1.0	7	19	19	8	2	37	26	22	49	32	34	84
Compost	2.0	4	20	13	12	12	31	23	30	37	30	39	50
Compost	4.0	8	20	24	20	12	29	20	21	44	21	23	90
Compost	8.0	8	21	27	27	10	59	31	23	43	41	62	133
Compost	16.0	15	20	15	21	9	40	25	41	40	39	63	109
Compost	32.0	15	10	15	15	23	44	42	34	60	76	104	239

[a]Time periods are weeks after application of fertilizer or compost.

Table 40. Numbers of rhabditids in Leon fine sand treated with fertilizer or various amounts of compost

Material	Rate T/ha	Time Period, weeks[a]											
		1	2	3	5	9	51	52	53	54	55	57	61
		Number/100 g											
Control	0.0	4	0	3	3	2	16	9	13	27	44	27	41
Fertilizer	0.9	2	6	1	4	5	27	12	15	48	71	35	42
Compost	1.0	2	4	3	1	3	7	9	10	32	48	50	43
Compost	2.0	2	12	8	6	3	15	10	10	14	48	29	43
Compost	4.0	1	0	10	7	13	13	9	12	36	43	29	35
Compost	8.0	0	8	18	7	3	21	10	9	15	84	31	51
Compost	16.0	2	1	22	11	13	16	16	18	27	109	51	60
Compost	32.0	0	3	8	8	13	13	11	11	23	144	62	95

[a]Time periods are weeks after application of fertilizer or compost.

Table 41. Survival of 10 earthworms in peat, Arredondo f.s., compost, and Arredondo f.s.-compost mixtures during a 35-day period[a]

Medium	Time period, days					
	3	7	14	21	28	35
	Number living					
Peat	10.0	10.0	10.0	10.0	9.9	8.1
Compost	10.0	10.0	10.0	9.9	8.1	2.5
Compost + 20% Arredondo f.s.	10.0	10.0	10.0	10.0	8.5	3.1
Compost + 40% Arredondo f.s.	10.0	10.0	10.0	10.0	8.6	2.1
Compost + 60% Arredondo f.s.	10.0	10.0	10.0	10.0	4.6	0.6
Compost + 80% Arredondo f.s.	10.0	10.0	10.0	10.0	4.9	0.5
Compost + 90% Arredondo f.s.	10.0	10.0	10.0	9.6	8.4	1.2
Compost + 95% Arredondo f.s.	10.0	10.0	9.9	9.5	5.2	0.3
Compost + 97.5% Arredondo f.s.	10.0	10.0	10.0	8.5	3.1	0.8
Arredondo f.s.	10.0	9.5	6.8	4.5	3.3	1.3

[a]Means of 8 replications.

Table 42. Chemical properties of media used in the earthworm survival study[a]

Medium	pH	Elements[b]			
		Ca 10^3ppp	Mg 10^2ppm	P ppm	K 10^2ppm
Peat	4.4	12.44	17	84	27
Compost	7.0	14.56	10	41	33
Compost + 20% Arredondo f.s.	7.0	13.19	9	38	30
Compost + 40% Arredondo f.s.	7.1	9.79	7	33	22
Compost + 60% Arredondo f.s.	7.2	8.19	5	21	14
Compost + 80% Arredondo f.s.	7.2	4.66	4	16	10
Compost + 90% Arredondo f.s.	6.5	2.51	2	9	6
Compost + 97.5% Arredondo f.s.	6.3	1.41	2	5	4
Arredondo f.s.	6.1	1.03	1	5	3

[a]Means of 8 replicates.

[b]N ammonium acetate (pH 4.8) extractable.

Table 43. Ammonium acetate extractable phosphorus in compost sampled during three randomly selected days

Day	Replicate	Period 1	Period 2	Period 3
		ppm		
I	1	17.5	17.7	6.0
	2	8.8	10.1	1.3
	3	6.2	12.7	6.1
	mean	10.8	13.5	4.5
II	1	19.3	21.9	26.3
	2	23.6	14.2	25.7
	3	15.0	18.0	25.7
	mean	19.3	18.0	25.9
III	1	12.0	6.7	17.9
	2	20.0	16.1	11.8
	3	18.3	14.1	16.5
	mean	16.8	12.3	15.4

Table 44. Total concentration of phosphorus in compost sampled during three randomly selected days

Day	Replicate	Period 1	Period 2	Period 3
		ppm		
I	1	1,000	975	845
	2	975	942	798
	3	538	1,070	868
	mean	838	996	837
II	1	1,019	1,480	1,217
	2	1,250	2,350	1,050
	3	1,400	2,170	1,100
	mean	1,223	2,000	1,122
III	1	1,670	970	870
	2	928	638	2,520
	3	1,050	1,290	1,530
	mean	1,216	966	1,640

Table 45. Total concentration of calcium in compost sampled during three randomly selected days

Day	Replicate	Period 1	Period 2	Period 3
		ppm		
I	1	13,266	9,266	13,179
	2	14,300	11,368	10,209
	3	12,177	13,068	12,300
	mean	13,248	11,234	11,896
II	1	13,755	10,656	10,275
	2	13,450	14,652	9,086
	3	14,760	12,789	23,360
	mean	13,988	12,699	14,240
III	1	17,100	12,628	17,297
	2	9,785	8,232	14,952
	3	11,937	9,256	11,775
	mean	12,941	10,039	14,675

Table 46. Total concentration of magnesium in compost sampled during three randomly selected days

Day	Replicate	Period 1	Period 2	Period 3
		ppm		
I	1	764	565	621
	2	878	742	652
	3	578	977	639
	mean	740	761	637
II	1	871	740	754
	2	920	2,368	973
	3	996	845	960
	mean	929	1,318	896
III	1	957	647	524
	2	1,387	420	1,025
	3	688	739	958
	mean	1,011	602	836

Table 47. Total concentration of potassium in compost sampled during three randomly selected days

Day	Replicate	Period 1	Period 2	Period 3
		ppm		
I	1	1,507	1,906	1,708
	2	1,609	2,219	1,794
	3	1,660	2,673	1,564
	mean	1,592	2,266	1,689
II	1	1,474	2,830	3,392
	2	2,352	2,664	3,451
	3	3,321	3,639	2,736
	mean	2,382	3,044	3,193
III	1	2,308	1,732	1,262
	2	2,565	1,134	2,268
	3	1,719	2,002	1,059
	mean	2,197	1,623	1,530

Table 48. Total concentration of sodium in compost sampled during three randomly selected days

Day	Replicate	Period 1	Period 2	Period 3
		ppm		
I	1	2,865	1,103	2,484
	2	1,852	2,362	3,262
	3	2,214	4,158	2,815
	mean	2,310	2,541	2,854
II	1	2,653	4,162	4,459
	2	2,519	4,662	5,670
	3	5,128	4,631	4,020
	mean	3,433	4,485	4,716
III	1	4,233	3,119	6,049
	2	4,131	3,780	6,048
	3	3,224	5,206	4,062
	mean	3,863	4,035	5,386

Table 49. Total concentration of zinc in compost sampled during three randomly selected days

Day	Replicate	Period 1	Period 2	Period 3
		ppm		
I	1	342	255	328
	2	310	414	319
	3	209	441	430
	mean	287	370	392
II	1	388	385	308
	2	353	650	404
	3	342	432	428
	mean	361	489	380
III	1	302	368	828
	2	361	286	561
	3	490	102	374
	mean	384	252	588

Table 50. Total concentration of manganese in compost sampled during three randomly selected days

Day	Replicate	Period 1	Period 2	Period 3
		ppm		
I	1	106	104	150
	2	95	123	183
	3	50	198	202
	mean	84	142	178
II	1	156	157	219
	2	170	216	150
	3	396	200	134
	mean	241	191	168
III	1	200	117	138
	2	190	66	215
	3	157	164	612
	mean	182	116	288

Table 51. Total concentration of copper in compost sampled during three randomly selected days

Day	Replicate	Period 1	Period 2	Period 3
		ppm		
I	1	46	45	87
	2	36	46	1,220
	3	28	46	350
	mean	37	46	552
II	1	38	47	92
	2	50	72	36
	3	65	92	54
	mean	51	70	61
III	1	58	38	107
	2	48	120	134
	3	78	59	16
	mean	61	72	86

Table 52. Total concentration of iron in compost sampled during three randomly selected days

Day	Replicate	Period 1	Period 2	Period 3
		ppm		
I	1	4,020	932	2,029
	2	2,925	1,357	1,653
	3	2,804	1,564	1,293
	mean	3,248	1,284	1,658
II	1	1,022	1,976	2,466
	2	2,220	3,345	2,584
	3	1,642	2,837	3,226
	mean	1,628	2,719	2,759
III	1	3,052	3,588	1,599
	2	1,482	1,235	2,940
	3	1,776	2,403	3,203
	mean	2,103	2,409	2,581

Table 53. Total concentration of aluminum in compost sampled during three randomly selected days

Day	Replicate	Period 1	Period 2	Period 3
		ppm		
I	1	4,422	4,378	7,038
	2	7,215	6,438	10,976
	3	3,260	4,950	6,672
	mean	4,966	5,255	8,229
II	1	6,288	6,660	7,398
	2	8,402	7,326	7,434
	3	10,516	7,276	5,952
	mean	8,402	7,087	6,928
III	1	5,899	5,205	3,646
	2	11,970	6,048	6,300
	3	4,154	4,361	35,325
	mean	7,341	5,205	15,090

Table 54. Conductivity of saturation extracts of compost sampled during three randomly selected days

Day	Replicate	Period 1	Period 2	Period 3
		mmhos/cm		
I	1	2.78	2.93	2.39
	2	2.95	2.54	3.22
	3	2.54	2.37	2.66
	mean	2.76	2.61	2.76
II	1	3.97	3.39	3.07
	2	3.90	3.30	2.94
	3	4.25	3.32	3.12
	mean	4.04	3.34	3.04
III	1	3.93	4.58	4.75
	2	3.66	4.48	3.24
	3	4.00	4.78	3.35
	mean	3.86	4.61	3.78

Table 55. Total concentration of nitrogen in compost sampled during three randomly selected days

Day	Replicate	Period 1	Period 2	Period 3
		%		
I	1	.61	.48	.80
	2	.57	.43	.51
	3	.45	.50	.73
	mean	.54	.47	.68
II	1	.92	1.04	1.05
	2	.73	.86	.68
	3	.71	.97	.77
	mean	.79	.96	.83
III	1	1.00	.46	.64
	2.	.94	.60	.54
	3	1.03	.64	.60
	mean	.99	.57	.57

Table 56. Analysis of variance for nematode numbers in Leon fine sand treated with fertilizer or various amounts of compost

Source	Degrees of freedom	Mean Squares					
		Nematode					
		Spiral	Ring	Dorylaim	Rhabditids	Lesion	Cephalobids
Time (A)	11	374,123.14**	3,403.84**	1,176.54**	16,021.96**	269.53**	19,638.22**
Block (B)	3	828,143.40**	3,308.48**	43.28**	1,685.53**	160.39**	2,865.27**
Treatment (C)	7	235,810.42**	6,163.50	236.08**	1,834.77**	222.75**	5,560.46**
A x B	33	65,065.88	1,326.57*	187.31**	754.70**	133.04**	2,041.08**
A x C	77	15,548.91	647.95	96.52	631.89*	45.61	1,500.49*
B x C	21	287,322.90**	1,962.02**	156.26*	543.09	58.01	411.29
A x B x C	231	25,101.13	715.64	66.26	279.70	58.26	433.63
Total Level (1)	362	41,924.26	829.24	88.95	413.20	62.37	805.80
Total Level (2)	382	61,176.21	1,253.36	122.52	897.44	72.09	1,467.99

*Significantly different by the F-test at the 0.05 level.

**Significantly different by the F-test at the 0.01 level.

Table 57. Analysis of variance for concentrations of certain ammonium acetate extractable elements in compost sampled during three randomly selected days

Source	Source of Freedom	Mean Squares Element Al	Fe	Zn
Time	2	12,641.926	25,279.148*	51,346.037
Treatment	2	12,356.037	1,771.259	40,974.370
A x B	4	12,985.315	2,974.037	62,765.093
Replicates	2	3,767.815	871.259	82,996.259
A x C	4	8,770.093	3,018.204	82,317.148
B x C	4	1,621.704	5,051.481	61,263.481
A x B x C	8	10,946.565	9,237.343	70,706.954
Total Level (1)	18	7,593.074	5,995.556	72,553.926
Total Level (2)	26	9,177.405	6,689.114	66,987.379

*Significantly different by the F-test at the 0.05 level.

**Significantly different by the F-test at the 0.01 level.

Table 57 (Continued)

Mean Squares					
Element					
Cu	Na	K	Mn	Ca	Mg
0.934*	931,715*	445,707	826	13,568,196**	2,274,919
0.312	4,638,844**	4,818,342*	13,187**	18,169,822**	11,584,751**
0.453*	649,773	306,458	1,581	37,936,945**	2,133,791
6.259**	35,121	76,565	240	2,531,466	419,972
0.201	34,243	222,552	729	521,477	431,542
6.037	161,131	189,229	552	551,254	425,204
9.842	237,768	189,937	816	1,238,543	1,007,691
0.109	221,480	184,430	674	1,070,123	684,914
0.241	681,802	579,756	1,788	9,018,693	1,865,875

BIBLIOGRAPHY

Alexander, M. 1961. Introduction to Soil Microbiology. John Wiley and Sons, Inc., New York. 472p.

Anderson, M. S. 1956. Compost as a means of garbage disposal. Soil and Crop Sci. Soc. of Fla. 16:134-145.

Baver, L. D. 1956. Soil Physics. John Wiley and Sons, Inc., New York. 489p.

Behmer, D. E. and T. M. McCalla. 1963. The inhibition of seedling growth by crop residues in soil inoculated with Penicillium urticae Bainer. Plant and Soil. XVIII:199-206.

Bell, I. M. 1963. Characteristics of municipal refuse. p. 28-38. In American Public Works Association special report no. 29. Amer. Pub. Works Assoc., Chicago, Illinois.

Bernstein, L. 1965. Salt tolerance of crops. U. S. Dept. Agr. Info. Bull. 283.

Block, S. S., G. Taso, and H. Lunghrwe. 1958. Production of mushrooms from sawdust. Jour. Agr. Food Chem. 6:923-927.

Carson, R. L. 1962. Silent Spring. Houghton Mifflin, Boston. 368p.

Christie, J. R. 1959. Plant nematodes their bionomics and control. The H. and W. B. Drew Company, Jacksonville, Florida. 256p.

Clark, F. E. 1957. Living organisms in the soil. p. 157-165. In Soil, the 1957 yearbook of agriculture. U. S. Dept. Agr.

Collison, R. C. 1925. The presence of certain organic compounds in plants and their relation to the growth of other plants. J. Amer. Soc. Agron. 17:58-72.

Conover, C. A. and J. N. Joiner. 1966. Garbage compost as a potential soil component in production of Chrysanthemum morifolium "Yellow Delaware" and "Oregon." Fla. Sta. Hort. Soc. Proc. 79:424-429.

Curtis, R. W. 1958. Curvature and malformation in bean plants caused by culture filtrate of Aspergillus niger. Plant Physiol. 33:17-22.

Dorer, R. E. 1967. Solid waste disposal demonstration project, section B-7. In Engineering Foundation Research Conference, University School, Milwaukee, Wisconsin.

Eno, C. F. and H. W. Reuszer. 1955. Potassium availability from biotite, muscovite, greensand, and microcline as determined by growth of Aspergillus niger. Soil. Sci. 80:199-209.

Fuller, W. H. and S. Bosma. 1965. The nitrogen requirement of some municipal composts. Compost Sci. 6(2):26-32.

_____, E. W. Carpenter, and M. F. L'Annunziata. 1967. Evaluation of municipal waste compost for greenhouse potting purposes. Compost Sci. 8(2):22-26.

_____, G. Johnson, and G. Sposito. 1960. Influence of municipal refuse compost on plant growth. Compost Sci. 1(3):16-19.

Guenzi, W. D. and T. M. McCalla. 1962. Inhibition of germination and seedling development by crop residues. Soil Sci. Soc. Amer. Proc. 26:456-458.

_____ and _____. 1964. Residue substances affect crop growth. Crops and Soils. 16(8):25.

_____ and _____. 1966a. Phenolic acids in oats, wheat, sorghum, and corn residues and their phytotoxicity. Agron. J. 58:303-304.

_____ and _____. 1966b. Phytotoxic substances extracted from soil. Soil Sci. Soc. Amer. Proc. 30:214-216.

_____, _____, , and F. A. Norstadt. 1967. Presence and persistence of phytotoxic substances in wheat, oat, corn, and sorghum residues. Agron. J. 59:163-165.

Grossbard, E. 1952. Antibiotic production by fungi on organic manures and in soil. J. Gen. Microbiol. 6:295-310.

Guild, W. J. Mc L. 1955. Earthworms and soil structure. p. 83-98. In D. K. M. Keuan (ed.), Soil Zoology. Academic Press, New York.

Hayward, H. E. and L. Bernstein. 1958. Plant-growth relationships on salt-affected soil. Bot. Rev. 24:585-635.

Hortenstine, C. C. and D. F. Rothwell. 1968. Garbage compost as a source of plant nutrients for oats and radishes. Compost Sci. 9(2):23-25.

Hutchings, I. J. and T. L. Martin. 1934. Influence of the C:N ratios of organic matter on the rate of decomposition in the soil. Jour. Amer. Soc. Agron. 26:333-341.

Jackson, M. L. 1958. Soil Chemical Analysis. Prentice-Hall, Inc., Englewood Cliffs, N. J. 498p.

Johnson, L. F. 1962. Effect of the addition of organic amendments to soil on root knot of tomatoes. II. Relation of soil temperature, moisture, and pH. Phytopathology. 52:410-413.

Johnson, L. F., A. Y. Chambers, and H. E. Reed. 1967. Reduction of root knot of tomatoes with crop residue amendments in field experiments. Plant Dis. Rep. 51:219-222.

Lamanna, C. and M. F. Mallette. 1965. Basic Bacteriology. The Williams and Wilkins Company, Baltimore. 1001p.

Langdale, G. W. and J. E. Giddens. 1967. Phytotoxic phenolic compounds in serica lespedeza residues. Agron. J. 59:581-584.

Lawrence, T. and M. R. Kilcher. 1962. The effect of fourteen root extracts upon germination and seedling length of fifteen plant species. Can. J. Plant Sci. 42:308-313.

Lear, B. 1959. Application of castor pomace and cropping of castor beans to soil to reduce nematode populations. Plant Dis. Rep. 43:459-460.

Mankau, R. 1962. The effect of some organic additives upon soil nematode population and associated natural enemies. Nematologica. 7:65-73.

_____. 1968. Reduction of root-knot disease with organic amendments under semifield conditions. Plant Dis. Rep. 52:315-319.

Martin, J. P., J. O. Ervin, and R. A. Shepherd. 1966. Decomposition of the corn, aluminum, zinc, and copper salts or complexes of some microbial and plant polysaccharides in soil. Soil Sci. Soc. Amer. Proc. 30:196-200.

McCalla, T. M. 1967. Effect of tillage on plant growth as influenced by soil organisms. p. 19-25. In conference proceedings of tillage for greater crop production. Amer. Soc. Agr. Eng., St. Joseph, Michigan.

_____ and F. L. Duley. 1948. Stubble mulch studies: Effect of sweetclover extract on corn germination. Science. 108:163.

_____ and _____. 1949. Stubble mulch studies: III. Influence of soil microorganisms and crop residue on the germination, growth, and direction of root growth of corn seedlings. Soil Sci. Soc. Amer. Proc. 14:196-199.

_____, W. D. Guenzi, and F. A. Norstadt. 1964. Phytotoxic substances in stubble mulching. Eight Intern. Congr. of Soil Sci., Bucharest, Romania. 42:933-942.

_____ and F. A. Haskins. 1964. Phytotoxic substances from soil microorganisms and crop residues. Bacteriol. Rev. 28:181-207.

McKee, J. E. 1963. Dimensions of solid waste problem. p. 1-7. In American Public Works Association special report no. 29. Amer. Pub. Works Assoc., Chicago, Illinois.

Miller, P. M. 1957. A method for the quick separation of nematodes from soil samples. Plant Dis. Rep. 41:194.

Nielsen, K. F., T. F. Cuddy, and W. B. Woods. 1960. The influence of the extract of some crops and soil residues on germination and growth. Can. J. Plant Sci. 40:188-197.

Norstadt, F. A. and T. M. McCalla. 1963. Phytotoxic substances from a species of Penicillium. Science. 140:410-411.

_____ and _____. 1968. Microbially induced phytotoxicity in stubble-mulched soil. Soil Sci. Soc. Amer. Proc. 32:241-245.

O'Bannon, J. H. 1968. The influence of an organic soil amendment on infectivity and reproduction of Tylenchulus semipenetrans on two citrus rootstocks. Phytopathology. 58:597-601.

Pain, A. K. 1961. Effect of compost (mulberry) manure on the nutrition of mulberry. Indian Soc. Soil Sci. 9:29-37.

Patrick, Z. A. and L. W. Koch. 1958. Inhibition of respiration, germination, and growth by substances arising during the decomposition of certain plant residues in the soil. Can. J. Bot. 36:621-647.

_____ and _____. 1963. The adverse influence of phytotoxic substances from decomposing plant residues on resistance of tobacco to Black Root Rot. Can. J. Bot. 41:747-758.

_____, R. M. Sayre, and H. J. Thorpe. 1965. Nematicidal substances selective for plant-parasitic nematodes in extracts of decomposing rye. Phytopathology. 55:702-704.

_____, T. A. Toussoun, and W. C. Snyder. 1963. Phytotoxic substances in arable soils associated with decomposition of plant residues. Phytopathology. 53:152-161.

Peevy, W. J., and A. G. Norman. 1948. Influence of composition of plant materials on properties of the decomposed residues. Soil Sci. 65:209-226.

Raper, K. B. and C. Thom. 1949. A manual of the Pencillia. The Williams and Wilkins Company, Baltimore.

Richards, L. A. 1965. Physical condition of water in soil. p. 128-152. In Methods of soil analysis, part 1. American Society of Agronomy, Inc., Madison, Wisconsin.

Rothwell, D. F. and C. C. Hortenstine. 1969. The effect of composted municipal refuse and other waste on carbon dioxide evolution, nitrate production, and relative numbers of fungi and bacteria in Arredondo fine sand. Agron. J. 61:837-840.

Routley, D. G. and J. T. Sullivan. 1960. Toxic and nutritional effects of organic compounds on Ladino clover seedling. Agron. J. 52:317-319.

Sayre, R. M., Z. A. Patrick, and H. J. Thorpe. 1965. Identification of a selective nematicidal component in extracts of plant residues decomposing in soil. Nematologica. 11:263-268.

Seatz, L. F. and H. B. Peterson. 1965. Acid, alkaline, saline, and sodic soils. p. 292-319. In F. E. Bear, Chemistry of the Soil, Reinhold Publ. Corp., New York.

Singh, R. S., B. Singh, and S. P. S. Beniwal. 1967. Observations on the effect of sawdust on incidence of root knot and on yield of okra and tomatoes in nematode-infested soil. Plant Dis. Rep. 51:861-863.

Smith, F. B., R. G. Leighty, R. E. Caldwell, V. W. Carlisle, L. G. Thompson, Jr., and T. C. Mathews. 1967. Principal soil areas of Florida a supplement to the general soil map. Florida Agri. Exp. Sta. Bull. 717. 64p.

Southern Cooperative Series. 1965. Procedures used by state soil-testing laboratories in the Southern Region of the United States. S-52 technical committee. Bull. 102. 49p.

Steel, R. G. D. and J. H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Company, Inc., New York. 481p.

Stelmach, Z. 1962a. Effect of organic matter on soil fertility. Part I. Compost Sci. 3(1):36-39.

_____. 1962b. Effect of organic matter on soil fertility. Part II. Compost Sci. 3(2):27-32.

Takahashi, N. and R. W. Curtis. 1961. Isolation and characterization of malformin. Plant Physiol. 36:30-36.

Taylor, C. E. and A. F. Murant. 1966. Nematicidal activity of aqueous extracts from raspberry canes and roots. Nematologia. 12:488-494.

Tietjen, C. 1963. Conservation and field testing of compost. p. 175-186. In American Public Works Association special report no. 29. Amer. Pub. Works Assoc., Chicago, Illinois.

_____. 1964. Conservation and field testing of compost. Compost Sci. 5(1):8-14.

Tomerlin, A. H., Jr. 1969. The influence of organic amendments on numbers of nematodes and other microorganisms in the soil. Ph.D. Dissertation. University of Florida, Gainesville, Florida. 49p.

Toussoun, T. A. and Z. A. Patrick. 1963. Effect of phytotoxic substances from decomposing plant residues on root rot of beans. Phytopathology. 53:265-270.

U. S. Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils. U. S. Dept. Agr. Handbook 60. 160p.

U. S. Department of Agriculture. 1969. Flow and retention of water in layered soils. Conservation research report no. 13. Agr. Res. Serv. 28p.

Waksman, S. A. 1948. Antibiotics. Biol. Rev. 23:452-487.

Walker, J. T., C. H. Specht, and S. Mavrodineau. 1967. Reduction of lesion nematodes in soybean meal and oil-amended soil. Plant Dis. Rep. 51:1021-1024.

Whitehead, D. C. 1964. Identification of p-hydroxybenzoic, vanillic, p-coumaric, and ferulic acid in soils. Nature. 202:417-418.

Wolf, K. W. 1968. The potential benefits of rail-haul as an integral part of waste disposal systems. Section A-3. In Soil Waste Research and Development. II. Engineering Foundation Research Conference. Wayland Academy, Beaver Dam, Wisconsin.

BIOGRAPHICAL SKETCH

Patrick Gatch Hunt was born in Baltimore, Maryland, on November 5, 1943. He attended secondary school in Stanly County, North Carolina. In 1961 he entered Clemson University, and, while attending Clemson, he received a National Plant Food Institute scholarship and was an officer in Alpha Sigma Gamma. In 1965 he received a Bachelor of Science degree with a major in agronomy from Clemson University.

He entered graduate school in 1965 at Clemson University and did research on land disposal of liquid peach cannery waste, under the direction of Dr. T. C. Peele. In 1966 he received a Master of Science degree from Clemson University.

In 1967 he entered graduate school at the University of Florida to work toward the degree of Doctor of Philosophy with a major in soils. He is a member of Gamma Sigma Delta and Sigma Xi.

He is married to the former Terry J. Hartsell and has a daughter, Christina Noelle.

This dissertation was prepared under the direction of the chairman of the candidate's supervisory committee and has been approved by all members of that committee. It was submitted to the Dean of the College of Agriculture and to the Graduate Council, and was approved as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

March 1970

Dean, College of Agriculture

Dean, Graduate School

Supervisory Committee:

Chairman