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THE PREPARATION, CHARACTERIZATION AND AGRICULTURAL USE OF BARK-SEWAGE COMPOST

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ABSTRACT

THE PREPARATION, CHARACTERIZATION AND
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A method for the preparation of a compost produced by windrowing fresh, dry, shredded bark and residential sewage is described. Those micrometeorological, chemical, and microbiological changes monitored during composting are discussed. Microbial activity was estimated by measuring dehydrogenase concentration and for comparison by counting on agar media. Moisture, pH, oxygen tension, and temperature at positions in the windrow were measured during composting. Pathogen survival time was estimated using two bacteria, Salmonella heidleberg and Escherichia coli, and one yeast, Candida albicans, which were seeded into the compost to act as indicator organisms.

The mature compost was chemically analyzed for seventeen elements and for cation exchange capacity by standard analytical techniques. Anion exchange capacity was determined and compared to other horticultural mixes by using manoxol, sodium dioctylsulphosuccinate. The anion from this salt is differentially absorbed by humic acid and other soil compounds and the unabsorbed manoxol was estimated colorimetrically after reaction with methylene blue.

Three indicator pathogens were reduced in number from over 10^6/g dry compost to zero within thirty-six hours. No other human pathogens appeared to resist the composting condition of the windrowing. Prevalent bacteria, actinomycetes, fungi, yeasts, protozoans and algae were identified to genus level.

Pot and field experiments designed to find optimum levels of N, P, and K fertilization for plant growth are described. Nitrogen was the major nutrient deficiency while P and K and trace element content was satisfactory for six week production of sudan grass. The C/N ratio was reduced from 250/1 to 20/1 in three months time. Cation exchange capacity was 76.5 g/100 g dry compost. Anion exchange capacity was 13.3% as compared to pure humic acid, while peat and loam delivered 15.4% and 5.0% respectively. Moisture holding capacity was 40% at 31% relative humidity as compared to peat 43% and silt loam at 6%.

It was concluded that bark and raw sewage can be composted together to produce a pathogen free material which, when supplied with modest fertilizer supplementation of 2.24 lbs/yd^3 of both fast and slow acting nitrogen, 1.12 lbs/yd^3 potash (K_2O) from granite dust, 1.12 lbs/yd^3 P_2O_5 from rock phosphate and 5 lbs/yd^3 of dolomitic limestone, could be used as a horticultural soil substitute.

CHAPTER I

INTRODUCTION

New Hampshire, north of the White Mountains, is sparsely populated by small towns with low per capita incomes and poor tax bases. Many of of the farms which remain are marginally profitable and much of the land has been allowed to revert to scrub and forest.

A significant problem of this area is pollution; some towns allow their sewage to run directly into the once clean waters of the Connecticut River. While the Federal and State governments have ordered that pollution of the river and air cease, sawdust, woodchips, and pulp wastes are often dumped or burned. Governmental agencies offer no financially reasonable way of implementing pollution abatement in these small towns.

Beginning in 1966 Mr. Gregory Macdonald challenged the Environmental Protection Agency and the New Hampshire Water Supply and Pollution Commission to aid the towns of North Stratford, New Hampshire and Bloomfield and Brunswick, Vermont in the development of a composting process to recycle solid and sewage wastes from the villages using as a carrier the wood wastes from local mills. During the period 1968 - 1972 a composting plant, a transportation system, and a small corporation were operated. The townsfolk, the private investors, the Environmental Protection Agency, and the New Hampshire Water Supply and Pollution Control Commission recognized that there was the possibility that the wastes from the towns could be safely composted and the material could be worked into the depleted local soils, possibly improving crop production. In the fall of 1972, when funds allocated by Congress for the composting

project were impounded by Presidential decree, the United States Forest Service funded the research reported in this thesis.

In order to study environmental and health hazards involved in handling bark-sewage compost, meteorological, chemical, physical, and microbiological information was collected during the construction and throughout the decomposition phases of a compost windrow which was composed of hard wood bark saturated with sewage.

Once the composting and curing phases were completed the chemical, physical, and microbiological characteristics of the compost were determined. This included elemental analyses of elements involved in plant nutrition as well as, moisture, pH, and cation exchange determinations by standard methods. Using a new manoxol technique for anion exchange, the compost was compared to other agricultural media.

While the compost was curing preliminary controlled pot and field experiments were conducted to determine the major variables involved in plant nutrition. The cured compost was then utilized in rigidly controlled and replicated greenhouse and field experiments to develop fertilization recommendations for supplemental nitrogen, potassium and phosphate.

Beyond the conclusions determined experimentally these investigations make possible the development of practical guidelines for processing, analyzing, and using this and similar composts.

CHAPTER II

LITERATURE REVIEW

Angus McDonald (1966), formerly a soil conservationist for the Soil Conservation Service, USDA, wrote about our colonial agricultural heritage:

> "The felling of the first tree by colonists in the New World, though never mentioned by historians, was an act of great significance. It marked the beginning of the era of the most rapid rate of wasteful land use in the history of the world."

He briefly describes the continuous destruction of our native soils and the movement away from the depleted soils of the eastern shore across the nation to the west. "Then", states McDonald, " a few of the farms in the older sections noticed a change in the soil. At first it had been dark, in some places almost black, but now it was lighter in color. This change, imperceptible at first, meant that deterioration of the soil had set in. It was a symptom of the slow sickness that would for a long time afflict our land. It meant that much of the organic matter, attacked first by fire and then by plow, was gone."

When the colonists settled the eastern shore of the United States they found that, once the forest was cleared and burned and the soil cropped for a few years, production declined. Since the glacial period only a relatively thin topsoil had been developed on leached rocks, gravels and sands from old mountains. Soil nutrient deficiencies plagued agriculture in New England until the advent of commercial fertilizers. Issac Hill (1839) said that "...the virgin soil of every new country must be cultivated in a manner that necessarily leads to its

exhaustion; and the more fertile the soil the greater the danger that deterioration will not stop until necessity shall either force its abandonment or a change of cultivation from actual suffering." Now soils throughout the world require continual addition of commercial fertilizer for sustained production. From antiquity man has known about green manuring, contour plowing, crop rotation, and composting. This last technique was often mentioned in the Bible, and George Washington (Schatz and Schatz, 1970) mentions composting stable manure and soil on his farm in 1760. Deane, (1790) utilized many forms of organic wastes and manures in composting procedures in his New England farming experiments. Among the many techniques suggested to reduce soil destruction by the early American agronomists - Lorain (1814), Drown (1824), Hill (1840), Ruffin (1855), and Eliot (1934) - were mulching and composting. Johnson (1859) of the Connecticut Agricultural Experiment Station, described the composting techniques of New Englanders. He also mentioned what may have been the first commercial producer of compost, the Liebig Manufacturing Company of East Hartford, Connecticut. In England, Thompson (1850) and Way (1850, 1852) evaluated the absorbent power of soil recognizing what now is known as the ion exchange properties of humus-rich agricultural land.

The importance of organic matter in developing both water and nutrient holding capacity of soil was studied by Alway and Neller (1919) in their field investigations. Sprague and Marrero (1931) utilized various sources of organic matter on sandy and clay soils, measuring physical change and plant growth response. In all their experiments organic matter incorporated into sandy soils improved the soil. They were first to note the problems involved in incorporating very dry

organic matter into soil. Later Bollen and Glennie (1963) found that decay resistant lignins, fats, and waxes made desiccated bark and other composts difficult to resaturate.

Faced with great quantities of waste and exceptionally depleted soils, the British agronomists Howard and Wad (1931) began to employ composting and to publish extensive studies about 1930. J. I. Rodale, the initiator of the organic farming movement in the United States, credited Howard as the inventor of modern composting techniques. Commercial composting began in Europe with the Itano Process in 1928 (Itano and Arakawa, 1928). Today the Becarri, Bordas, Frazer, Dano, Vuil-Arvoer-Maat Schappi (VAM) processes, with modification, are used extensively in Europe (Teensma, 1961), South East Asia and Russia (Howard, 1940; Gotaas, 1956; Kupchick, 1966). In the United States, Waksman and his many collaborators (Waksman, Tenny, and Diehm, 1929), at Princeton started as early as 1926 to research extensively the nature of aerobic decomposition of plant residues and manures. The function of algae in composts and soils was considered by Bristol (1920) and further investigated by Skinner (1932). Because algae are prevalent on bark they are found abundantly in bark compost. Sewage composts were found to harbor both helminths and protozoans (Cram, 1943); their ecology was studied by Barker (1946). Recently the survival of fecal organisms in manure slurries was studied by Dazzo, Smith and Hubbell (1973). The ecology of compost fungi is described in the works of Webley (1947), Conn (1948), Eastwood (1952), Stevenson (1962), Klopotek (1962, 1963), and Chang and Hudson (1967). The complexity of microbial nitrogen metabolic pathways in composts is reviewed by Jansson, Hallam and Bartholomew (1955).

Although sewage was known to contain pathogenic bacteria, yeasts,

and protozoans it was not until recently that the threat of virus was proven (Melnick, et al., 1954). The danger from virus is well illustrated by the outbreak of enterovirus in Eastern Canada in 1960 (Ozere, Faulkner and van Rooyen, 1961). Sewage and sewage sludges are now being disposed of on agricultural land in many areas of the world (Anderson, 1955; Amrami, 1957; Reeves, 1959; Lunt, 1959; Kupchick, 1966; Sopper, 1970). Recently the use of sewage, sewage sludge, and composts of sewage and municipal and industrial solid wastes has increased; these materials have proven very useful in reclaiming denuded land, mine spoils, dumps and eroded farmlands (Sopper, 1970, Vlamis and Williams, 1972; Sutton and Vimmerstedt, 1973; Harter, 1975). Some studies have been conducted recently to determine the effect upon yield, digestibility, and both soil and plant chemical composition (Anderson, 1955; Amrami, 1957; Lunt, 1959; Reeves, 1959; Toth, 1960; King and Morris, 1972; Poincelot, 1972; Bengtson and Cornette, 1973; Norvell and Sawhney, 1973; Blackburn, 1974).

During the initial phases of decay all compostable organic matter is rich in readily available substrate which is high in carbon and low in nitrogen (Stevenson, 1962). Higher plants must compete with microbes for a dwindling amount of nitrogen which they need in the nitrate form. The ratio of carbon to nitrogen, the C/N ratio, is an important parameter in agricultural utilization of waste matter expressing numerically the maturity of compost (Tisdale and Nelson, 1966). The nature of nitrogen loss and the changes in the form of this nitrogen by decaying nitrogenous materials is reviewed by Hoyle and Mattingly (1954). In some composts low nitrogen content is corrected by use of ammonia which is readily converted to nitrate by microbial activity (Aspitarti,

1958). Bollen (1959) and Poincelot (1972) emphasized the importance of total microbial ecology to soil fertility. Biochemical and physical analyses of bark and wood wastes and their interactions with microbial flora are further considered by Dunn (1959), Gassell (1960), Berger, (1962), and Ellis (1962); they emphasized that compost must be sufficiently aged or else nitrogen must be supplied. Phosphate and potassium availability and their relationship to microbial activity have been extensively researched by Russian agronomists Korovkin (1952) and Bodrova and Ozolina (1968). The interaction of pH and temperature, oxygen tension, moisture regime and nutrient concentration has been investigated by Carnes and Lossin (1970).

In 1953 the Sanitary Engineering Research Project was begun at the University of California at Berkeley (Golueke and Gotaas, 1954). The World Health Organization commissioned Gotaas (1956, 1962) to prepare a comprehensive text on composting. Since that time the techniques for municipal composting have developed so that by 1965 evidence from Karim and Chowdbury (1958), Knoll (1959), Krige (1961), Schultze (1961), Gray and Sherman (1969), Kochtitzky, Seaman, and Wiley (1969), Mercer et al. (1962, 1968) and Nell and Krige (1971) showed conclusively that not only solid wastes, but sewage sludges, septic tank slurries, manures, and slaughter house wastes could be handled safely and effectively by composting.

Composting raw sewage with ground bark and wood at North Stratford, New Hampshire was described by Macdonald (1973). The efforts of the team which worked at North Stratford resulted in the formation of the Rural Recycle Corporation and the processing of manures, abattoir wastes, privy wastes and septic wastes with ground bark, wood chips,

leather scraps and selected rubbish. The experiments described in this thesis follow years of practical work accomplished at the composting site in North Stratford.

CHAPTER III

MATERIALS AND METHODS

Four separate and distinct problem phases were treated in the bark-sewage-compost experiment: 1) site preparation and production of compost; 2) monitoring of windrows; 3) characteristics of mature compost; and 4) nutrition studies.

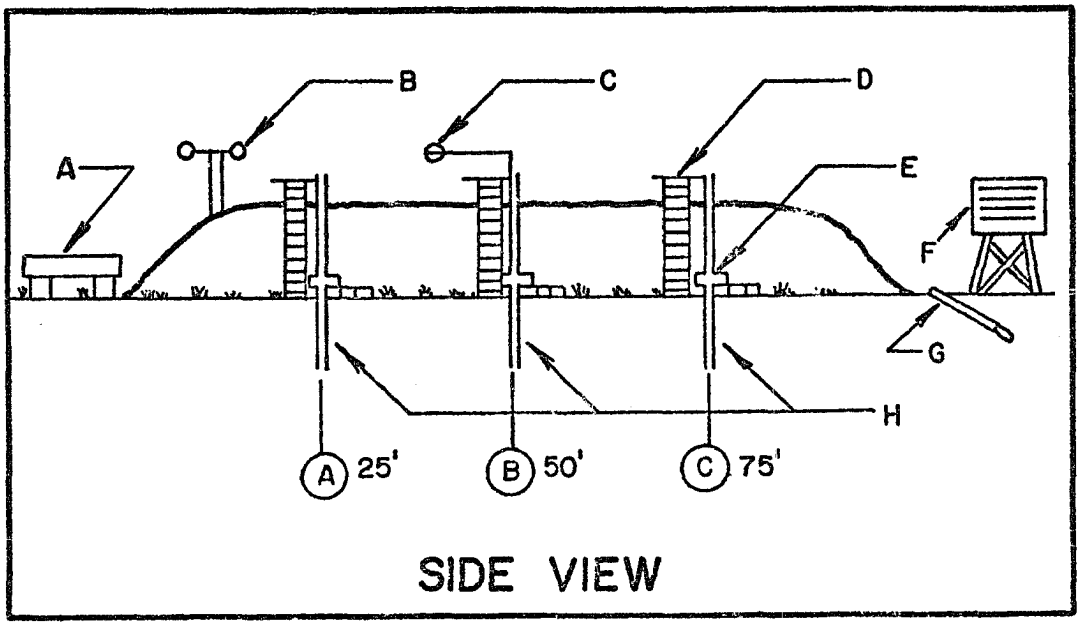
During the monitoring phase meteorological, chemical and microbiological tests were conducted over a three month period. At the end of the monitoring phase the mature compost was characterized, that is, the physical and chemical properties of the compost were determined and the microbiological inhabitants identified, usually to genus level.

Site Preparation and Production of Compost

During August, 1972, a field of approximately 1/3 acre of Hinckley sandy loam in Gonic, New Hampshire was selected as the compost site. Four ceramic-tipped lysimeter tubes were installed before the area was seeded to Balboa rye. One tube was placed slanting downward in the north-east section of the field and three along the centerline of the proposed windrow. The ceramic tips were placed two feet below ground level and the ends stoppered. Before the windrow was made, the tubes were partially evacuated to allow sampling of the leachate soon after the initiation of composting. In order to compare soil moisture in the adjacent field to that beneath the windrow using neutron activation, four one and one-half inch aluminum tubes were installed vertically; three along the centerline of the windrow at points A, B, and C

(Figures 1 and 2). One was placed in the field near the suction lysimeter at position F. The open tip ends were placed four feet below ground level. A standard white slatted weather box was installed and equipped northeast of the windrow in order to gather daily temperature and humidity data. In the center of the windrow a cedar post was driven securely into the soil to which were attached the electrical leads and plastic air line from a Fritschen net radiometer. Such leads and air line were run into a deep trench to a steel shed where auxillary test equipment was housed.

On September 15, 1972, eight truck loads of fresh, dry, ground hardwood bark, representing 100 cubic yards, were dumped at a sewage plant. On September 16, using a five cubic yard gravel truck and front-end loader, generously provided by Mr. George C. Nadeau, Public Works Department, Rochester, New Hampshire, the loading and mixing of sewage-compost was initiated. About four cubic yards of ground bark was loaded in increments by carefully dumping the bark from the uplifted bucket. Simultaneously, utilizing a mud soaker pump, sewage was pumped from the main effluent line of the Rochester Sewage System in Gonic into a truck. The bark and sewage were mixed with shovels as the solid and liquid materials were deposited into the truck. When the truck was full, the overly saturated mass was allowed to drain. After drainage the mixture contained approximately a 40/60 ratio of liquids to solids (bark) on a volume/volume basis. After drainage of excess liquid from the mixture, the truck was driven to the composting site and dumped. The front-end loader followed and the material was placed upon and around the instrumentation previously installed at the site. This procedure was repeated and the windrows dressed to shape using shovels.



A EVAPORATION PAN
B ANEMOMETER
C NET RADIOMETER
D OBSERVATION PLATFORM
E THERMOCOUPLE STATION
F WEATHER STATION
G SUCTION LYSIMETERS
H NEUTRON PROBE TUBES
J X-SECTION OF THERMOCOUPLES
K INSTRUMENT SHED

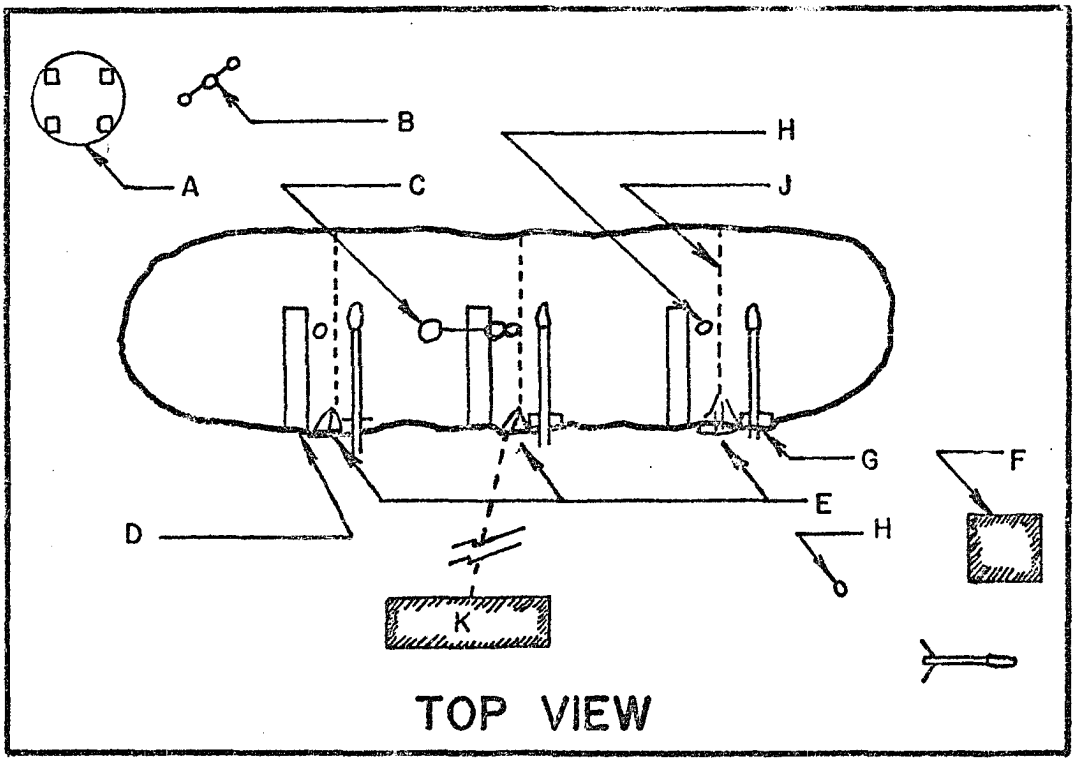


FIGURE I. SIDE AND TOP VIEWS OF WINDROW .

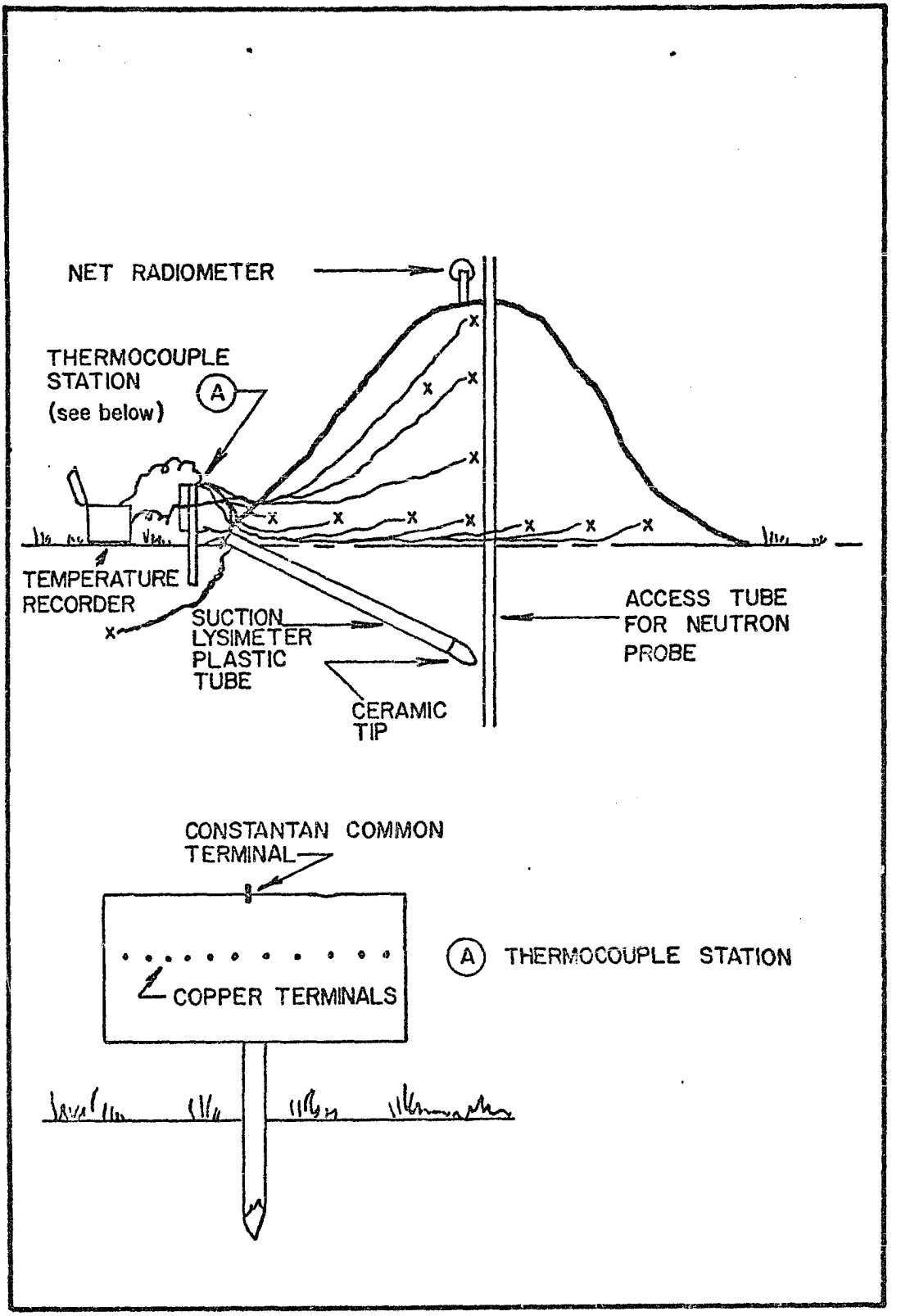


FIGURE 2. END VIEW AND DETAIL OF WINDROW

The completed windrow was 100 feet long, 7 feet wide, and 6 feet high (Figures 1, 2, and 3).

Tables 1, 2, and 3 give the microbiological population of sewage used, the physical characteristics of sewage solids, and the chemical composition of the solids respectively.

Table 1. Microbial population of sewage from Rochester, New Hampshire. Values represent the mean values found during monitoring of Rochester Oxidation Ponds (City of Rochester, N. H., 1972).

Microorganisms	Population Organisms/ml sewage
Candida forms	5-12
Salmonellaae	50-150
Coliforms	3.5×10^8
E. Coli	2.0×10^6
Fecal coliforms	2.0×10^7

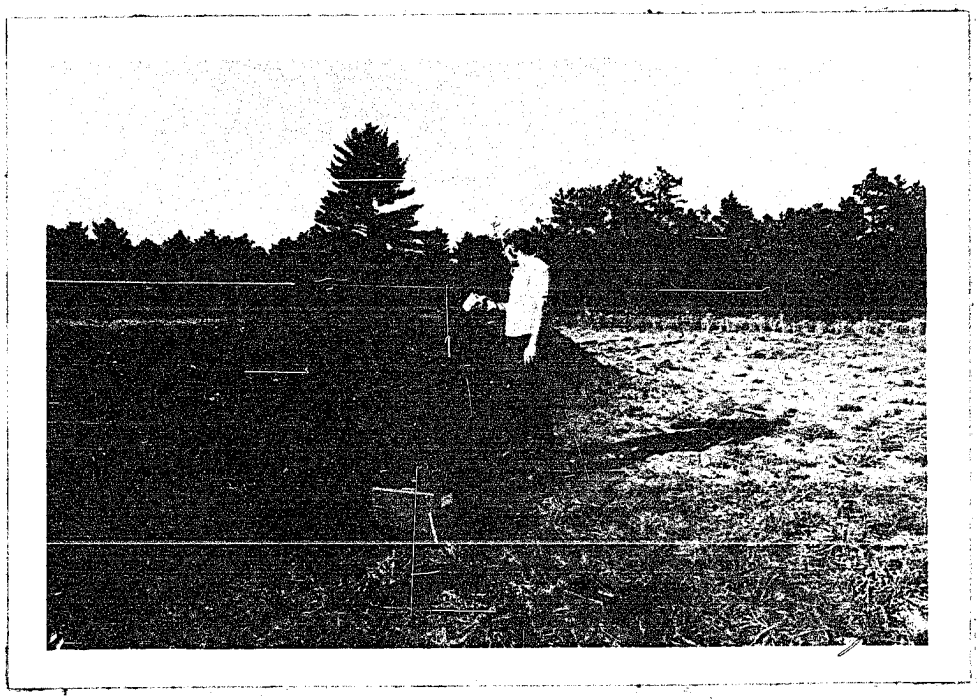
Three slots were cut in the windrow at 25, 50, and 75 feet along its length and thermocouples installed at three cross sections along radial lines (Figure 2). To the southwest of the windrow, an evaporation pan was placed on cement blocks and adjusted to level. An initial reading was taken September 17, 1972. A cup anemometer, which measured in miles per unit time, was installed atop an eight foot galvanized pipe to the west of the windrow. The net radiometer was installed on September 18 (Figure 3). In cases of equipment malfunction, some weather readings were obtained at Hobby's Weather Station, Gonic, New Hampshire.

Table 4 shows nutrient data from Kjeldahl and spectrographic analyses of the untreated bark and a bark-sewage mixture which served to characterize the compost prior to the windrow production.

Figure 3. Photographs of Composting Site in Gonic, New Hampshire.

A. Measuring the surface temperature of the windrow

B. View of anemometer, evaporation pan, neutron probe and net radiometer.



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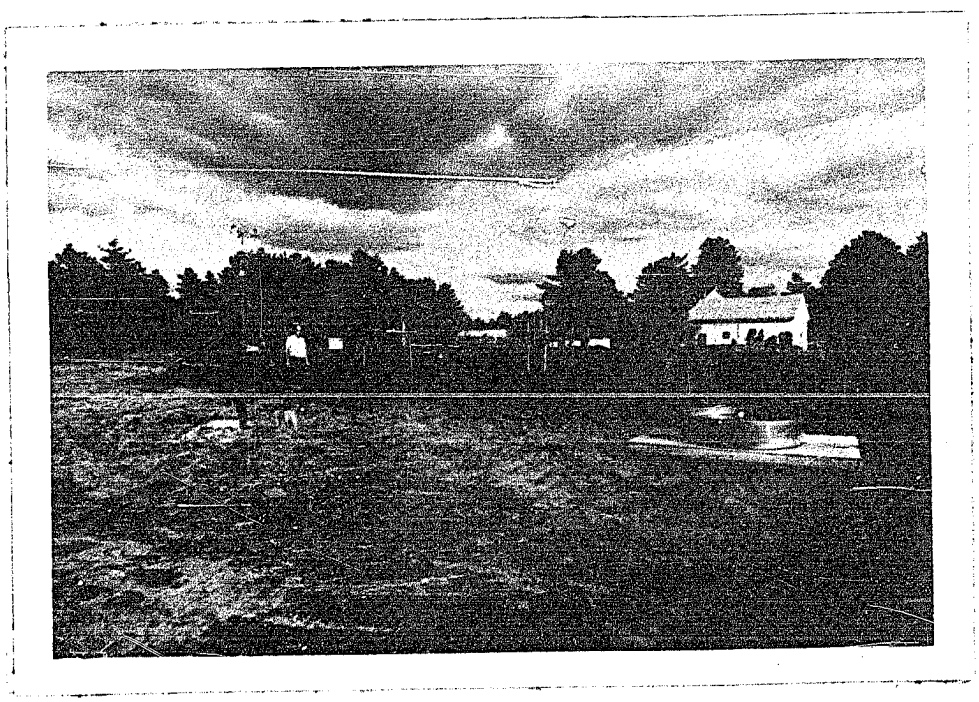

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Table 2. Physical characteristics of sewage solids from Rochester, New Hampshire. Values represent an average of two samples taken in August 1972, expressed as mg/liter.

State of Solid	Mineral[e]	Organics[f]	Total	5-Day 20°C BOD
Suspended [a]	72	126	198	96
Settleable [b]	48	94	142	42
Non-settleable [c]	24	32	56	54
Dissolved [d]	186	167	353	26

a. Suspended solids by gravimetric technique
b. Settleable solids by Imhoff cone
c. Non-settleable solids by difference: colloidal
d. Dissolved solids by evaporation of filtered samples
e. Minerals by ignition of organics
f. Organics by difference (total-mineral)

All data provided by Rochester Public Works Department, Rochester, New Hampshire.

Table 3. Chemical composition of sewage solids from Rochester, New Hampshire. Values represent mean values from Rochester Oxidation Ponds. (City of Rochester, 1972)

	%		ppm
Ash	6.4	Iron	24,200
Volatile Matter	75.2	Zinc	1,460
Organic Residue	12.1	Manganese	420
Total N	0.9	Copper	78
Protein N	0.87		
Nitrate N	0.03		
Total P	0.28		
Total S	0.22		
Calcium	2.87		
Magnesium	0.56		
Potassium	0.66		
Sodium	0.46		

Table 4. Chemical composition of untreated bark and bark-sewage mixture prior to composting.

Element	Bark			Bark + Sewage		
%	1	2	Average	1	2	Average
N	.66	.73	.70	.94	.87	.90
K	.30	.30	.30	.30	.30	.30
P	.10	.12	.11	.15	.16	.15
Ca	2.12	1.97	2.04	1.13	1.40	1.27
Mg	.10	.09	.09	.20	.22	.21
Si	.04	.11	.07	.40	.70	.55
Na	.04	.02	.03	.01	.02	.01
S	.03	.03	.03	.12	.15	.13
ppm						
Mn	398	420	409	266	292	279
Fe	213	923	568	2341	2696	2518
B	18	19	18	10	11	10
Cu	11	11	11	47	52	49
Zn	226	289	257	273	295	284
Al	71	392	231	1722	1761	1741
Sr	91	80	85	57	59	58
Mo	3.78	8.06	5.92	10.07	18.79	14.43
Ba	115	225	115	96	103	99

Monitoring of Windrows

Meteorological Monitoring

Each morning between 7:00 and 7:30 A.M. the readings on the evaporation pan and anemometer were recorded, and evaporation in inches and average wind speed were determined. The temperature and humidity drums were checked and new rolls attached if needed. Two recorders were used so that data overlapped if either recorder developed trouble. Surface temperature readings were taken using an infra-red thermometer in the morning, at noon and at dusk at three locations on each side and top as well as both ends of the compost pile (eleven readings) so that directional differences could be noted.

Neutron probe data for soil moisture profiles was taken each day at first and then less often as the experiment proceeded. When the neutron probe was used, a fifteen minute warm-up period was allowed for standardization purposes. Readings were taken at one, two, and three feet below ground level. At the field site, actual field soil samples were taken and treated along with compost moisture samples to check against the neutron probe standard curve. The net radiometer recorded day and night incoming and outgoing radiation directly above the windrow. Air for maintaining pressure within the plastic bubble of the net radiometer was dried over Drierite using a small aquarium aerator before pumping the air to the bubble via the underground plastic tubing. Samples of compost were collected periodically for chemical and microbiological tests as described later. Oxygen tension was read using a Model 210-002 IBC oxygen sensor mounted in a plastic cone attached to the end of a metal probe. A portion of the cone was filled with Silica-gel to dry the air drawn into the cone, since the compost air was saturated

with moisture and caused erratic readings if drying was not performed.

Chemical Tests

The controlling chemical parameters in composting are: moisture, pH and C/N ratio (Gainsville Municipal Waste Conversion Authority, 1969). The environmentalist is concerned with the levels of nitrate, phosphate, and potassium in leachate water. For these reasons these parameters were measured frequently during the three months of composting. The microbiologist is interested in following the interaction between microbes and the environment, the relative abundance of microbial forms, and in the survival of pathogenic organisms. For these reasons counts of bacteria, fungi, and actinomycetes were taken.

Moisture. Pre-weighed, oven-dried, glass screw-cap jars were used to determine percent moisture. The jars were filled, weighed, and stored until air dried; and then they were brought to equilibrium moisture level over phosphorus pentoxide. To avoid loss of valuable organic materials samples were not oven-dried. Samples were taken at 0.5, 1.5, and 3.0 feet in depth, at about two feet from locations A, B, and C in the pile from both north and south sides.

pH. Measurements of pH were made on the above collected samples prior to moisture determinations. An Accumet 520 Digital pH/Ion meter was used and pH was read in 0.01M calcium chloride solution as described by Peech (1965) to avoid salt interference. It must be noted that pH measured in 0.01 $CaCl_2$ is about 0.5 pH units lower than that measured in water using one part soil and two parts water.

Leachate. Leachate samples were withdrawn from the partially

evacuated lysimeter tubes every two weeks or after rains when the tubes were usually full. Twelve samples were withdrawn, three from each Field (F) and positions A, B, and C under the windrow. Chloride and iron were measured colorimetrically using a Hach color comparator; nitrate was measured with a nitrate electrode; phosphate was measured colorimetrically after development of the phospho-molybdate blue color; and potassium was analyzed by flame emission spectroscopy. Leachate nitrogen was measured as nitrate using the Model 701 Orion Meter. Prior to utilization of the meter, a standard curve using sodium nitrate, covering a range of 0 to 1000 parts per million, was established. The method of Myers and Paul (1969) was utilized. Leachate phosphate was analyzed using the methods of Greweling and Peech (1960) with special attention to a comparison of phosphate concentration between leachate of windrows and that of the field location. Leachate potassium samples were analyzed by flame emission using a Jarrel-Ash atomic absorption spectrophotometer.

Carbon-Nitrogen Ratio. The carbon-nitrogen ratio was monitored during the composting process. Carbon was analyzed by the Walkley-Black method (Allison, 1965). The compost was low in soluble Cl, Mn, and Fe and low in clay so no correction was necessary for these interferences (Allison, 1960). The compost was ground in a Wiley Mill using a brass screen so that no oxidizable iron was introduced. Nitrogen was determined by conventional Kjeldahl analysis.

Microbiological Tests

Periodically during the composting period an attempt was made to follow the population levels of bacteria, actinomycetes, and fungi. Only the center of the windrow at A, B, and C locations, 25, 50, and 75

feet along the length of the windrow was tested (Figure 1). In order to develop an easier and faster method of microbiological assay, a modification of the dehydrogenase method of Stevenson (1962) was employed to follow the production of triphenylformasan (TPF) with microbially produced dehydrogenase. TPF concentrations would be detected with a spectrophotometer and compared to microbial plate counts.

A standard curve for TPF was prepared as follows: One tenth gram of TPF was dissolved in 100 ml of 50% methanol. This 1000 ppm solution was diluted to 30 and 0.5 ppm, using a dilution media extracted from compost. The extract was produced by incubating 20 grams of compost with 5 ml of distilled water for 24 hours, then adding 10 ml of 1% TTC, 200 mg of $CaCO_3$ and, in three 25 ml extraction increments, 75 ml of methanol. The TPF transmittance curve was then developed upon a background containing the compost extract, TTC and methanol.

In order to test windrow dehydrogenase activity, 20 gram subsamples of compost (three replicates of three samples A, B, and C) were extracted from the A, B, and C samples, used in microbial count procedures. To each sample 200 mg of $CaCO_3$ and 10 ml of 1% TTC were added and the mass stirred thoroughly with a sterile glass rod. Blanks were prepared using 5 ml of distilled water rather than TTC. The twelve beakers and glass rods were covered with aluminum foil and incubated 24 hours in a 35-37°C water bath. At the end of the incubation period the blank was treated with 10 ml of TTC, and 25 ml of methanol was added to all beakers. The mixtures were stirred and filtered through Whatman No. 2 disks, using a Buchner funnel. Two other 25 ml washes of methanol were used to remove all traces of reddish color. These extracts were colorimetrically tested, using a wavelength of 650 millimicrons. Blanks

were used to zero the instrument.

During the plating process transfers were made from microbial colonies for future identification. Compost-extract agar, Bacto-Actinomycete agar, and Rose Bengal were used to screen for compost bacteria, actinomycetes, and fungi respectively.

Samples for microbial analysis were collected at the same time and location as pH and moisture samples. A hole was dug into the center of the pile with a washed spade. Autoclaved one-pound coffee cans were used to collect two samples at each of three locations. One sample was used for pH and moisture determinations, and the other for microbial counts on undisturbed compost. A dilution series was prepared on the microbial sample using 10 g of sample. The first dilution bottle contained several dozen glass beads to aid in breaking up the compost and microbial aggregates (Clark, 1965c). To allow plates to be poured without the agar solidifying, media were prepared in three, 500 ml batches. From each dilution, 1 ml portions were aseptically pipeted into five sterile plates initially from the 10^{-3} to 10^{-7} dilutions. When all 75 empty, sterile plates (25 plates/site) were inoculated, then the twelve ml of sterile medium were aseptically added, the plates swirled to thoroughly mix the sample with the medium and the mass allowed to solidify.

This procedure was repeated with a bacterial medium, an actinomycete medium and a fungi medium. When assays were made for other microbes an identical dilution technique was followed. The routine analysis involved 225 samples. All microbes were incubated at 20-22°C. Actinomycetes and fungi were counted at ten days, while bacteria were counted at four days. Two series of five plates with dilutions yielding

colony counts of 30-300 range were used in determining plate counts. These counts were adjusted to microbes/g dry weight using the moisture data obtained from the same sample site.

Once the microbial counts were completed, transmittancies were plotted against microbial count using the logarithm of transmittance versus total microbial count and/or TTC concentration (Figure 9).

Characterization of Mature Compost

Physical Properties

Anion-Exchange Capacity. The method of Lenhard, DuPlooy, and Ross (1963) was utilized to determine anion exchange capacity. Manoxol, sodium dioctylsulphonuccinate, was used to provide an anion source. For A.E.C. measurements humic acid was chosen as the standard since it represents the predominant natural component of soils with high anionic adsorption properties. Samples included two bark-sewage compost samples, Jiffy Mix, the Hinckley soil from the field site in Conic, New Hampshire, Perlite, Canadian peat, Vermiculite, coarse and fine sand, and twelve soils supplied by the Council on Soil Testing and Plant Analysis Laboratory, Athens, Georgia. The procedure used followed that of Lenhard et al. (1963) and Longwell and Maniece (1955).

Humic acid samples were weighed and transferred to 250 ml Erlenmeyer flasks. Then, 10 ml of 25 ppm manoxol, 90 ml of distilled deionized water, 5 ml of neutral methylene blue solution, and 10 ml of alkaline phosphate solution were pipetted into the flasks. After mixing for one hour, the samples were shaken with 10 ml of chloroform for one minute and transferred through a glass funnel plugged with a wad of glass wool to the first separatory funnel. The Erlenmeyer flask was

washed with two 5 ml washes of chloroform to complete the transfer. The wool was squeezed gently with a flattened glass rod and washed with two 5 ml chloroform washes. The separatory funnel was then shaken for one minute and solvents were allowed to separate.

A glass rod was used to break up the emulsion which formed on the sides of the separatory funnel. The lower layer was drawn off to a second separatory funnel. Ten ml of distilled deionized water and 5 ml of acid methylene blue were added. The separatory funnel was then shaken for one minute, allowed to separate, and the almost clear lower layer was drawn off through a cotton wad into a 50 ml volumetric flask. The separatory funnel was shaken with three 5 ml chloroform washes until the blue disappeared. Each time the lower layer was added to the 50 ml flask. Finally, the flask was brought to exactly 50 ml with chloroform, inverted several times and samples drawn for colormetric determination. For each sample run, a water blank was used to set 100% transmittance and a set of standards was run each day.

Samples were tested by the procedure used for humic acid except that samples of only 0.1, 0.5, 1.0, 2.0, 5.0, and 10.0 grams were used. When examination of the first separatory funnel showed that the samples possessed high anion adsorption, so that little was leached into the chloroform layer, smaller aliquots of wash chloroform and more washes were used so that all methylene-blue-manoxol complex was washed in the solid alkaline and acid methylene steps. Washes were adjusted so as not to exceed 50 ml in the final volumetric flask.

The adsorptive capacities were calculated as follows:

$$\frac{\text{Grams humic acid (at 90\% of maximum)}}{\text{grams test medium}} \times 100$$

Cation-Exchange Capacity. Two methods were utilized to obtain measurements of cation-exchange capacity: the ammonium saturation method and the summation method as described by Chapman (1965a, 1965b). In all procedures, the following test samples were used in triplicate: 1) Kingman Research Farm, Madbury, New Hampshire, Charlton silt loam, 2) Jiffy Mix, 3) Canadian peat, 4) six-month old compost, and 5) one-year old compost.

Water Retention. Since percent moisture had been determined at sites A, B, and C, at several depths, these values were used to represent percent moisture (Bollen and Glennie, 1963). Water-holding capacity for the same five media used in cation exchange determinations was estimated from the amount of water retained by samples placed in Gooch crucibles wetted from below by partial immersion and then allowed to drain to constant weight in a moisture saturated atmosphere. The samples were saturated by placing them in coffee cans on shelves above shallow water. Water-saturation capacity (soluration capacity) was conducted over water also but was determined from weight of the saturated material before any loss by gravitational drainage. Water retention was determined after drying saturated samples for 48 hours over hydrous calcium chloride ($CaCl_2 \cdot 6H_2O$) at 25°C (31% relative humidity). For all of these determinations, triplicate samples were used.

Chemical Properties

Selected samples of windrow material and plant tissue material were spectrographically analyzed for P, K, Ca, Mg, Na, Si, Mn, Fe, B, Cu, Zn, Al, Sr, Ba, and Mo. The services of the Spectrographic Laboratory at the Ohio Agricultural Research and Development Center, Wooster,

Ohio were used for this phase of study. Kjeldahl analyses were also conducted by conventional techniques on plant tissue and compost samples.

Microbiological Population Study

During the monitoring of the windrows for population counts of fungi, actinomycetes, and bacteria, over 100 samples had been taken of plate colonies which appeared repeatedly for later identification. Notes were taken as to date picked, colony color and morphology, and medium on which they were isolated. Later the microbe was classified as a fungus, F; yeast, Y; actinomycete, A; or bacterium, B.

Suspected fungal colonies were routinely spotted onto Czapek's (CZ); Czapek's 20% sucrose (CZS); Malt Extract (MX); potato dextrose agar (PD); potato carrot dextrose agar (PCD); and if suspected to be a yeast, Davis's yeast salt agar (DY). They were cultured at 25°C and after two days were daily examined for two weeks to check growth and purity. Most cultures were mixed and contamination was difficult to eradicate, but after several transfers pure cultures were obtained.

Yeasts and fungi were identified to genus level using methods of Gilman (1957), Lodder (1970), Menzies (1965), Toussoun and Nelson (1968), Barnett and Hunter (1972), Raper and Fennell (1965), and Raper and Thom (1949). All colonies were rated for color using the Ridgeway Color Charts (1912).

The actinomycetes collected originally on Difco Actinomycete agar and those subsequently found on Rose Bengal or soil extract agar were brought to the active state of growth on new plates of actinomycete medium (Clark, 1965a). Colonies were picked and streaked onto other selected media (Gilman, 1957) and notes taken as to rapidity of growth,

colony morphology, color and odor. Carbon and nitrogen assimilation tests were run on most of the media used for yeasts to aid in using Lodder's Keys (Lodder, 1970). The keys of Waksman and Henrici printed in Bergey's Manual (Breed, Murray and Smith, 1957) were a main source of information. Waksman's (1965), The Actinomycetes, provided methods for use with the keys.

Most bacteria recovered were from plates of bark-extract agar, although some bacterial colonies slowly developed on Rose-Bengal or actinomycete agars. These were brought to active states of growth on standard nutrient agar; gram-stained slides were made on such specimens. The main taxonomic procedures followed were those described by Smith, Gordon and Clarke (1952), Skerman (1959), Clark (1965b, 1965c), and Harrigan and McCance (1966); agars, liquid media, stains and special growth media used were described in these references.

Since the survival of pathogens in the composting process is of great concern to environmentalists, special emphasis was placed upon detection and enumeration of pathogenic organisms. Golueke and Gotaas (1954) had found the major factors which controlled pathogen survival to be temperature, oxygen tension, pH, antitoxin level, microbial competition, protozoan activity, and species characteristics.

Based upon Wiley and Westerburg's (1969) composting studies, Salmonella heidleberg, Escherichia coli, and Candida albicans were chosen as indicator organisms. A search was made for bacterial, protozoan, and metazoan pathogens in the bark-sewage compost directly after windrowing and after three to five days. Sterilized coffee cans were filled with prepared compost at the beginning of composting, seeded with the three indicator bacteria and tested at zero time, one day,

three days, and five days. They were analyzed as previously described.

For initial detection and estimation at three days, compost samples were tested by the accelerated procedure for Salmonella developed by Sperber and Deibel (1969). The slower Bacteriological Analytical Manual (1969a) procedure was utilized after five days of composting to assay for Salmonella and related species. The Bacteriological Analytical Manual (1969b) procedure for E. coli was used in conjunction with the standard coliform count procedure for recovery of fecal coliforms. The method for recovery of C. albicans was not standard, but followed Wiley and Westerburg (1969).

On the fifth day, growth in Selenite-Cystine (SC) and Tetrathionate (Tt) broth was streaked onto standard selective media. A total aerobic bacteria plate count was performed on the fifth day and colonies picked for subsequent classification. Suspected Micrococcus and Streptococcus were tubed for later study using methods from Harrigan and McCance (1966). Suspected Shigella colonies from Salmonella-Shigella agar on the fifth day of the study were subcultured to purify and then tested with Kohn's 2-tube media. Colonies picked from fungi, actinomycete, yeast, plate count agar, and the Salmonella and coliform tests were taxonomically tested until proven to be non-pathogenic. A search was made for pathogenic fungi using the methods of Hazen, Gordon, and Reed (1970). To test for metazoans, three 10 gram samples of compost were emulsified in 50 ml of physiological saline. Three 5 ml samples were concentrated using 34% zinc sulfate solution and repeated centrifugation as described by Wiley and Westerburg (1969). Another three 5 ml sample sets were incubated for twenty-one days at room temperature and concentrated by zinc sulfate flotation. Samples were examined

microscopically to view ova and viability.

Protozoans were counted using the techniques of Clark and Beard (1965) and Singh (1955) using Aerobacter aerogenes and Pseudomonas fluorescens as food. During this estimation, microscopic search was made for the human pathogen Entamoeba histolytica.

Algae were known to be present on the bark utilized in this experiment so a cursory examination using the methods of Clark and Durrell (1965) were utilized to enumerate species. No attempt was made to estimate spore survival.

Nutrition Studies

Preliminary Studies

While the 100 cubic yards of bark-sewage compost was maturing, some preliminary experiments were conducted using a less mature compost to determine the relative importance of suspected variables affecting the compost as a soil replacement.

Since the windrow was not mature, a smaller windrow was built in the storage yard at the Rochester Main Sewer Pumping Station in Gonic. Ground bark was saturated with sewage from the wet well of the station and heaped into a pile twenty feet long. The excess sewage was drained off into the wet well and was piped to the lagooning system. This material was allowed to compost only one-month (June-July 1972) but was turned at two and three weeks.

Study 1. To determine the lime requirement of the compost a series of compost samples were mixed with high-magnesium-limestone (14% Mg) and pH measured. Because the compost from previous testing had shown low magnesium and local soils were low in magnesium a

magnesium rich limestone was used.

Eight paired samples of 50 grams of moist compost were weighed. To these samples 0, 0.1, 0.3, 0.5, 1.0, 2.0, 5.0, and 10.0 grams of limestone were added. All were saturated with 100 ml of distilled deionized water, stirred with glass rods, allowed to settle and read electrometrically, using glass and saturated calomel electrodes using pH 4 and pH 7 buffers. Readings were taken at 0.5, 24, 48, and 120 hours at ambient laboratory temperature.

Study 2. The compost described above was used in a factorial design with tomato as the test plant. Three levels of nitrogen (0, 0.5, and 1.0 lbs NH_4NO_3/yd^3) and potassium, (0, 0.5, and 1.0 lbs KCl/yd^3) and two levels of phosphorus (0, and 2 lbs superphosphate/yd^3) were used. Following incorporation of fertilizer treatments, tomatoes (Lycopersicum esculatum var. Sunset) were transplanted into prepared pots. The plants were harvested after 8 weeks growth under greenhouse conditions.

Study 3. When the compost was $2\frac{1}{2}$ months old, two experiments were conducted parallel to those described above. Three levels of lime were employed at higher concentrations than in Study 1. Both experiments received rates of 0, 10, and 20 lbs lime/yd^3 of compost. Study 3 was conducted with "organic" sources of nutrients; nitrogen was supplied by Milorganite, a dried sewage sludge from Milwaukee, Wisconsin. Since Milorganite contained only 5% N compared to 35% for NH_4NO_3 more Milorganite was used than NH_4NO_3. Potassium was supplied by granite meal (Hybrotite) which was 5.7% K compared to 52.4% for KCl. A rate of 9.2 times that of KCl was used. Phosphate was supplied by rock phosphate and dried sewage sludge. A rate was calculated such that total

phosphate was the same as that supplied in the parallel experiment using superphosphate fertilization.

Study 4. In order to study the effects upon tomatoes of increments of lime, an attempt was made to overcome the poor C/N ratio and to supply N, P, and K from both organic and inorganic sources so as to supply these three essential nutrients from both readily and slowly available sources. Two pounds of N, P, and K/yd^3 were added, half of each nutrient being readily available and the other half from the slower "organic" sources mentioned in the previous experiments.

Lime was supplied at 0, 5, 10, 15, 20, 30, 40, 50, 60, and 70 lbs/yd^3 in order to show pH effects. Tomatoes were direct seeded immediately after limestone addition.

Study 5. Three parallel tomato growth experiments were conducted to determine the best source of phosphate for composts. Experiments by Bodrova and Ozolina (1968) had shown that rock phosphate could replace the more expensive superphosphates as a phosphate source when an organic-rich material was in use. Nitrogen and potassium were both supplied at rates of 2 lbs/yd^3 on the basis of N and K_2O; lime was supplied at 10 lbs/yd^3. In both compost and soil, ten levels of phosphate were supplied from two sources - rock phosphate and superphosphate.

Study 6. Three tomato growth experiments were conducted using increments of three soil additives (bentonite clay, perlite, and vermiculite) to determine if such additives increase availability of nutrients. Bentonite, a clay mineral with high cation exchange capacity, was used at ten levels with a basal application of N, P, K, and lime.

Other experiments were conducted using (1) perlite and (2) vermiculite mixed in volume/volume ratios of 0, 1/10, 2/10, 3/10, 4/10, and 5/10 additive to compost. Five replications of each of the aforementioned treatments were employed.

Osmocote NPK Study

After six months of composting, experiments were initiated in the spring of 1973 on a microbiologically safe compost using a split plot experimental design. Main plot treatments consisted of Osmocote, a controlled release 14-14-14 fertilizer, applied at rates sufficient to supply 0, 0.14, 0.28, 0.56, 1.12, and 2.24 lbs nitrogen/yd^3 of compost. Subplot treatments consisted of biweekly applications of NH_4NO_3 solution at three concentrations - 0, 100, and 200 ppm N. Subplot treatments were initiated following the first harvest and consisted of 250 ml applications of each of the above NH_4NO_3 solutions. Limestone was applied at a rate equivalent to 5 lbs/yd^3. Each treatment was replicated four times.

Osmocote, a product manufactured by Sierra Chemical Co., Newark, California, possesses a 8.4% ammoniacal nitrogen, and 5.6% nitrate nitrogen encapsulated to provide 10.5% controlled release N. The phospherus (P_2O_5) is derived from ammonium and calcium phosphates; the potassium is derived from potassium sulfate.

Eight-inch pots of 2.53 m^3 were filled with 2700 grams of moist compost, fertilizer and limestone, and the material poured onto plastic sheets and thoroughly mixed. After mixing, the pots were repacked to about one inch from the top. The compost was leveled and about 450 seeds of sudan grass (Sorghum sudanese var. Piper) were sown evenly

over the surface. The sudan grass was selected as the test plant to allow sustained harvest during the warm summer period. Following the seeding, about one-fourth inch of the treated compost was sifted over the seeds. Watering was subsequently performed to simulate 70% field capacity on a weight basis. At one month after seeding and every two weeks thereafter for 18 weeks, the grass was harvested using a cutting frame which allowed a flat surface to be cut at about one inch above the pot. Samples were placed in paper bags following harvest, dried at 80°C and weighed. Samples of the 4th, 8th, and 12th week harvest were ground to pass a 40 mesh screen and were spectrographically analyzed.

Nitrogen Study

As soon as tissue weight and general observations made interpretation of the Osmocote study possible, it was obvious that optimum nitrogen needs of the plants were not being met. To provide additional information on optimization of nitrogen, a study involving sulfur-coated urea (SCU-30) as the nitrogen source was started. A randomized complete block with four replications and ten treatments represented the experimental design. The nitrogen treatments consisted of N applied at rates equivalent to 0, 0.14, 0.28, 0.56, 1.12, 2.24, 3.36, 4.48, 6.72, 8.96, and 13.44 lbs/yd^3 from the SCU-30 source (39.1%N). All compost received basal applications of limestone, muriate of potash, and rock phosphate at rates equivalent to 0.5, 1.8, and 3.6 lbs/yd^3 respectively. As in the osmocote study, eight inch pots were used, and compost treatment and seeding were as described earlier. Harvests were made four weeks after planting and every two weeks thereafter. Kjeldahl nitrogen analyses were conducted on selected treatments and spectrographic

analysis performed on harvests made at the 6th and 16th week following seeding. Kjeldahl analyses were performed on composite samples of all replications of harvests made in the 10th, 12th, 14th, and 16th weeks following seeding due to limited yields.

Potassium Study

To assess the K requirement of plants growing in the composted sewage-bark mixture, a randomized block experiment was set up with replications and K_2O rates identical to those described under the Nitrogen Study. Basal rates of limestone, phosphorus, and nitrogen were added from high-magnesium limestone, rock phosphate, and sulfur-coated urea at rates equivalent to 5, 3.6, and 2.24 lbs/yd^3 respectively, since these represented the apparent optimum based on previous and concurrent research. Sudan grass was again used as the test plant, and pots were prepared as described previously. In this study, harvests were made as described earlier and spectrographic analysis performed on harvests made on the 6th and 16th week following planting.

Phosphate Study

To parallel the nitrogen and potassium experiments a final greenhouse randomized block study was set up varying rock phosphate rates when limestone, N, and K_2O were applied at basal rates of 5, 2.24, and 1.8 lbs/yd^3 respectively. Rock phosphate was applied at eleven rates of 0, 0.5, 0.9, 1.8, 3.6, 7.2, 11.6, 14.4, 21.6, 28.7, and 43 lbs/yd^3. Crops were planted and harvested as with previous experiments and the 6th and 12th week harvests spectrographically analyzed.

Field Nutrition Study

This study was conducted in Gonic, New Hampshire, with large volumes of compost applied to field plots. The experiment consisted of 25 plots measuring 15 x 20 feet laid out over lightly harrowed coarse sandy loam (Hinckley sandy loam). A front-end loader was used to place 150 cubic feet of compost on each plot; the compost was then raked to about 6 inches deep by hand and 80 pounds of high-magnesium limestone spread per plot. Five replications were employed with five N rates - 0, 2, 4, 8, and 16 lbs. NH_4NO_3/plot - to create a 5 x 5 Latin square design. Limestone and nitrogen were tilled into the compost with about two inches of soil being incorporated in the process. Five furrows thirty inches apart were made per rectangle, and twenty five seeds of sweet corn (Zea mays var. Sugar and Gold) were planted at eight inch intervals. Seeds were covered with two inches of compost. Although growth was poor, selected samples were analyzed.

CHAPTER IV

RESULTS AND DISCUSSION

Site Preparation and Production of Compost

In order to obtain maximum sewage holding capacity, bark and wood waste should be as fresh as possible. Microbes indigenous to bark burst into activity and drive temperatures up within a shredded or chipped mass of bark as soon as this material is heaped so that if bark is allowed to begin to compost before sewage is added some potential heat is lost. It is important to mix sewage with bark in about a 60/40 waste to liquid ratio while the carrier solid is freshly chipped and dry so that the bark is wet enough to encourage rapid microbial activity but not so wet as to allow anaerbiosis. Practical observation concerning compost handling, transport and site requirements are discussed subsequently.

Monitoring of Windrows

Meteorological Monitoring

Examination of the subsoil moisture data revealed that the upper layers of soil beneath both the windrow and field are usually more moist than the lower layers. In one several day period (after 30 days composting), the soil beneath the windrow was equally dry at depths of one, two and three feet showing that moisture had been drawn up into the windrow. At the beginning of composting there was a noticeable flux of moisture moving from the base of the windrow into the soil; the

moisture levels at one and two feet beneath the windrow were greater than that in the field at the same depth. Moisture levels at three feet remained rather constant at both the field location and the windrow location, although moisture was drawn upward beneath the windrow at some points. During one period (50-80 days) moisture again fluxed downward into the soil from the windrow but reached less than two feet. It was possible to conclude that:

1. During the initial saturated state, moisture from the windrow reaches a depth of three feet.

2. Moisture moved both upward from the subsoil toward the windrow and downward during rainy periods into the subsoil; at no time during this experiment was there a continuous flux downward from the windorw to leach nutrients from the windrow into the water table.

Suction lysimeter samples for NO_3-N, PO_4^{3-}, K^+, Cl^-, and Fe^{3+} concentrations are summarized in Table 5. The initial NO_3-N and PO_4^{3-} concentrations beneath the windrow were lower than in the field. On later dates the NO_3^- and K^+ were more concentrated beneath the windrow than in the adjacent field. Phosphate and iron in the compost mixture (contributed from the sewage to some degree) appeared to be retained in the pile, possibly due to the high cation exchange characteristics of the compost.

The compost remained moist throughout the period of maturation at all depths, leveling off at about 45% moisture during winter months when little evaporation loss apparently occurred while the pile was frozen or snow covered (Note Figure 4). At six inch depths, drying by evaporation was pronounced and moisture fluctuated moderately. At the one and one half and three foot levels, moisture fluctuations was minimal. In the fall months, the moisture again remained close to 45% equilibrium state. Moisture content at one and one half feet was only about 2% less than that at three feet even when the surface was much

Table 5. Chemical constituents of sub-soil suction lysimeter samples from selected field and windrow sites over the composting period September 9, 1973 to December 26, 1973. Values represent one field sample and an average of three windrow samples expressed as ppm of the respective elements.

	NO_3-N		PO_4^{3-}		K^+		Cl^-		Fe^{3+}	
Date	Field	Windrow	Field	Windrow	Field	Windrow	Field	Windrow	Field	Windrow
9/19	300	180	.08	.04	3	2.9	4	6	0.2	0.2
9/26	17	350	.20	.18	2.5	6.0	2	6	0.5	0.2
10/10	100	520	.18	.16	3	8.0	2	4	0.5	0.2
10/17	170	700	.15	.13	3.3	9.0	2	2	0.3	0.2
10/24	140	470	.17	.16	3.9	10.1	4	4	0.4	0.1
10/31	90	320	.18	.16	4.0	11.3	2	2	0.4	0.1
11/7	30	470	.19	.17	4.0	12.6	4	4	0.7	0.2
11/13	38	200	.20	.18	3.3	14.2	2	2	0.5	0.2
11/21	250	720	.08	.04	5.0	12.5	4	4	0.4	0.2
11/28	170	620	.17	.16	5.1	11.9	4	4	0.5	0.2
12/5	320	780	.08	.02	5.5	10.7	2	4	0.3	0.1
12/12	540	800	.02	.02	6.1	9.0	4	2	0.4	0.2
12/19	540	500	.02	.02	5.3	8.0	2	2	0.5	0.2
12/26	490	720	.08	.04	5.0	6.6	4	2	0.5	0.1
Mean	228	525	.13	.11	4.2	9.5	3	3	0.4	0.2

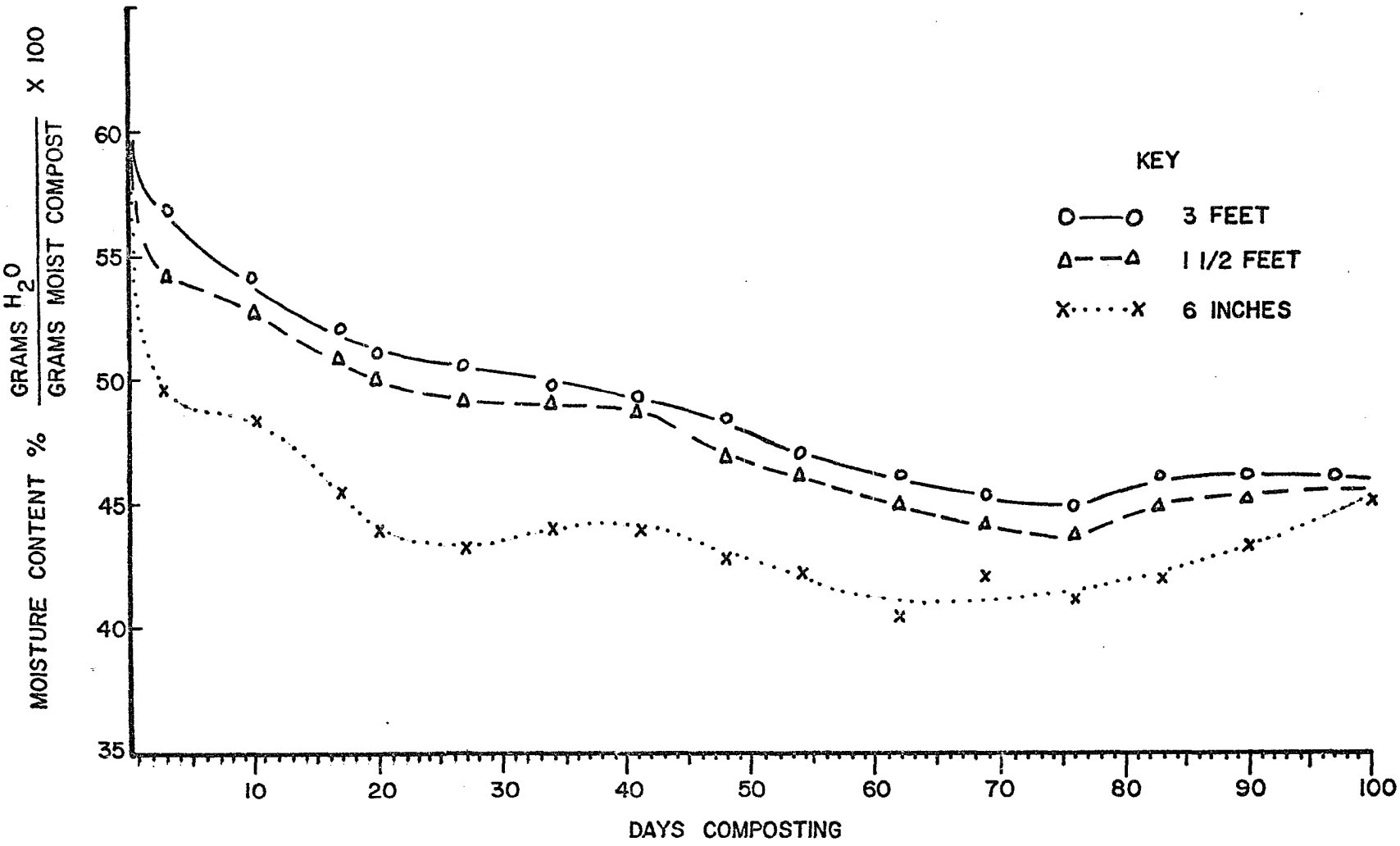


FIG. 4 MOISTURE CONTENT OF COMPOST AT THREE DEPTHS DURING COMPOST PERIOD.

more dry than the interior. A distinct moisture decrease within the windrow occurred during the first ten days of composting. Part of this moisture appeared, as noted in leachate studies, in subsurface moisture flux.

Temperature. Changes in temperature of the compost mixture during the 0 - 110 days is illustrated in Figure 5. Pasteurization temperatures were attained during the early stages of composting with subsequent temperatures never going beyond 120°F.

Chemical Tests

pH and Oxygen. Data reflecting changes in pH and oxygen tension are plotted on Figure 6. The inverse relationship between oxygen utilization and changes in hydrogen ion activity, which this plot illustrates, results from the production of organic acids by the microbes which require utilization of oxygen during their exponential phase of growth. Lowest pH occurred a few days after construction or turning of the windrow, reflecting the great increases in microbial activity. The growth of bacteria initially caused a slow decrease in oxygen tension, but as their numbers increase the oxygen tension drops, and this in turn slows their growth. The production of organic acids by the microbes decreases pH; as microbial activity decreases, the pH rises, because the organic acids are utilized by other microbes and in reactions with inorganic materials. It is noteworthy that pH changes lag behind the corresponding cause - the aeration brought about by the turning of the windrow. Furthermore, oxygen tension always remained above 90 mm pressure so that the windrow interior remained aerobic even during winter months.

At the end of the maturation process, pH and oxygen tension

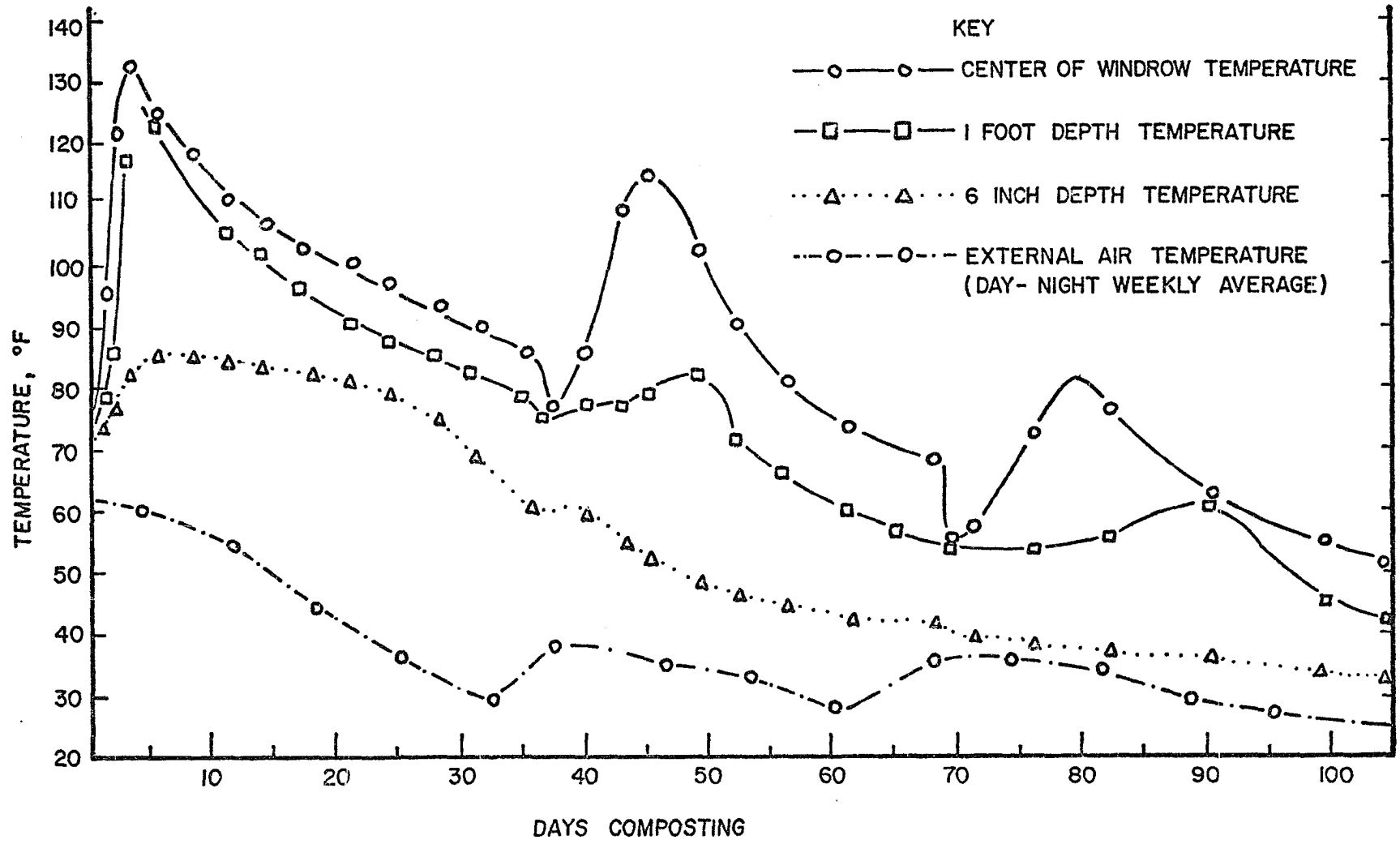


FIG. 5 CHANGES IN TEMPERATURE OF WINDROW WITH DEPTH DURING COMPOSTING.

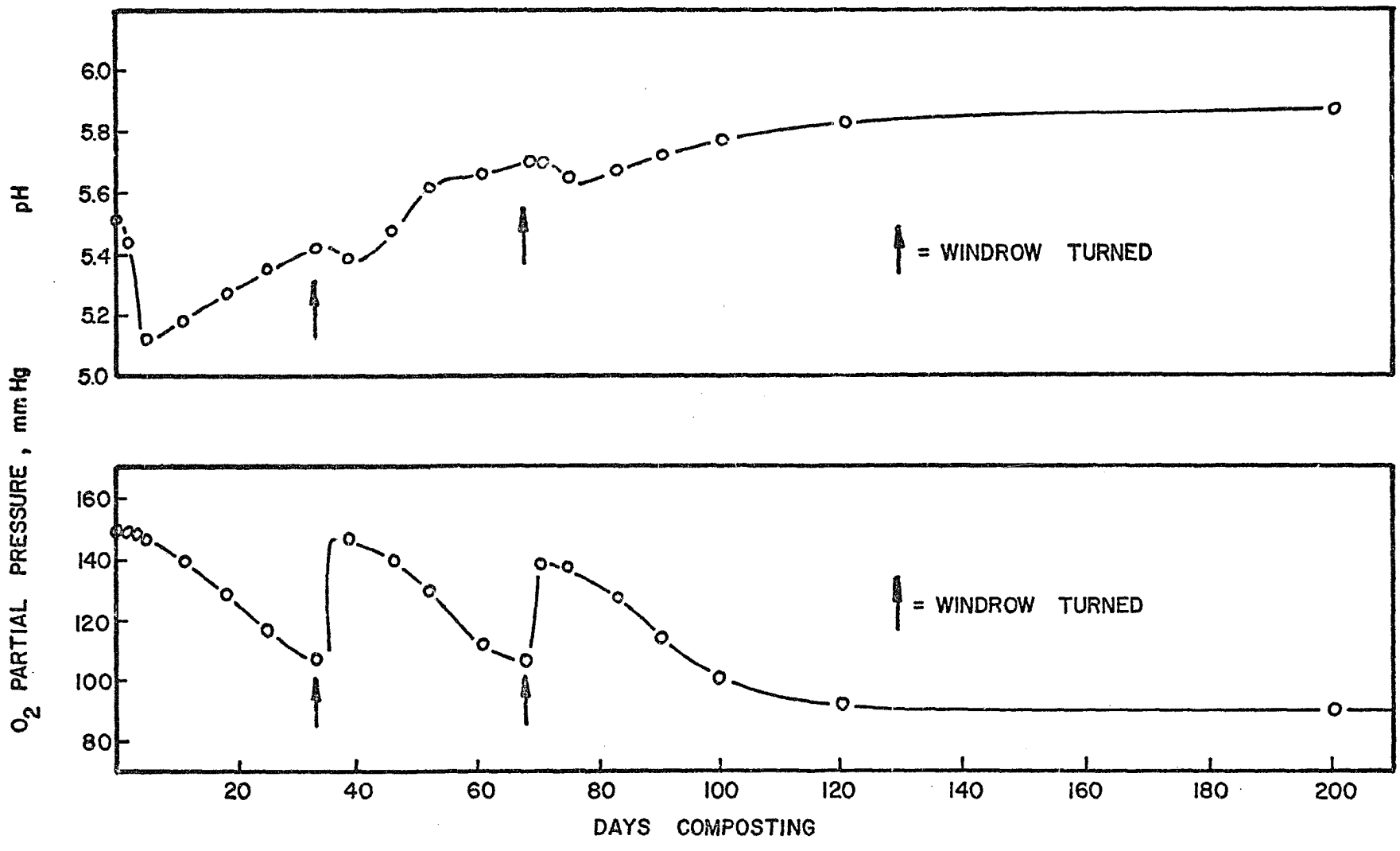


FIG. 6 pH AND OXYGEN TENSION DURING COMPOSTING.

appear to reach steady values reflecting the usage by the microbes of most of the soluble carbon sources, the attainment of a stable C/N ratio, moisture content, and the evolution of a climax microbial population of bacteria, actinomycetes and fungi.

Carbon-Nitrogen Ratio. While undecomposed fresh bark possessed C/N ratios between 200 and 350, depending upon species and time since the material left the debarkers, the first samples of bark-sewage compost, taken after three days of composting, had ratios ranging from 69 to 76. Figure 7 shows the values of samples tested over time. Final C/N ratios after fifty weeks of composting were 16.5 to 19.2. When the C/N ratio of compost is plotted against time of composting, the slope between points A and B, C and D, and E and F are steep corresponding to rapid microbial degradation. A slight reduction in carbon utilization occurred when windrows were turned, and after point F, the rate of decomposition becomes relatively stable. The change in C/N ratio from the 15th to the 50th week of composting is only about 11 units, from 30 to 19, while there is a 45 unit drop from the third day of composting until point F is reached. Thus, there are two stages of the composting process - a relatively rapid period of decomposition followed by a slower maturation point. If a C/N ratio less than 20 is to be obtained, generally considered to be necessary to prevent nitrogen deficiency, several additional months should be allowed for further maturation or the windrow turned one or two more times (Gray, Sherman, and Biddlestone, 1971). Under the conditions of this study, supplemental nitrogen is needed to avoid a nitrogen stress when such compost is used as a plant growth media. The quantitative requirement for nitrogen in plant nutrition studies is discussed in a later section

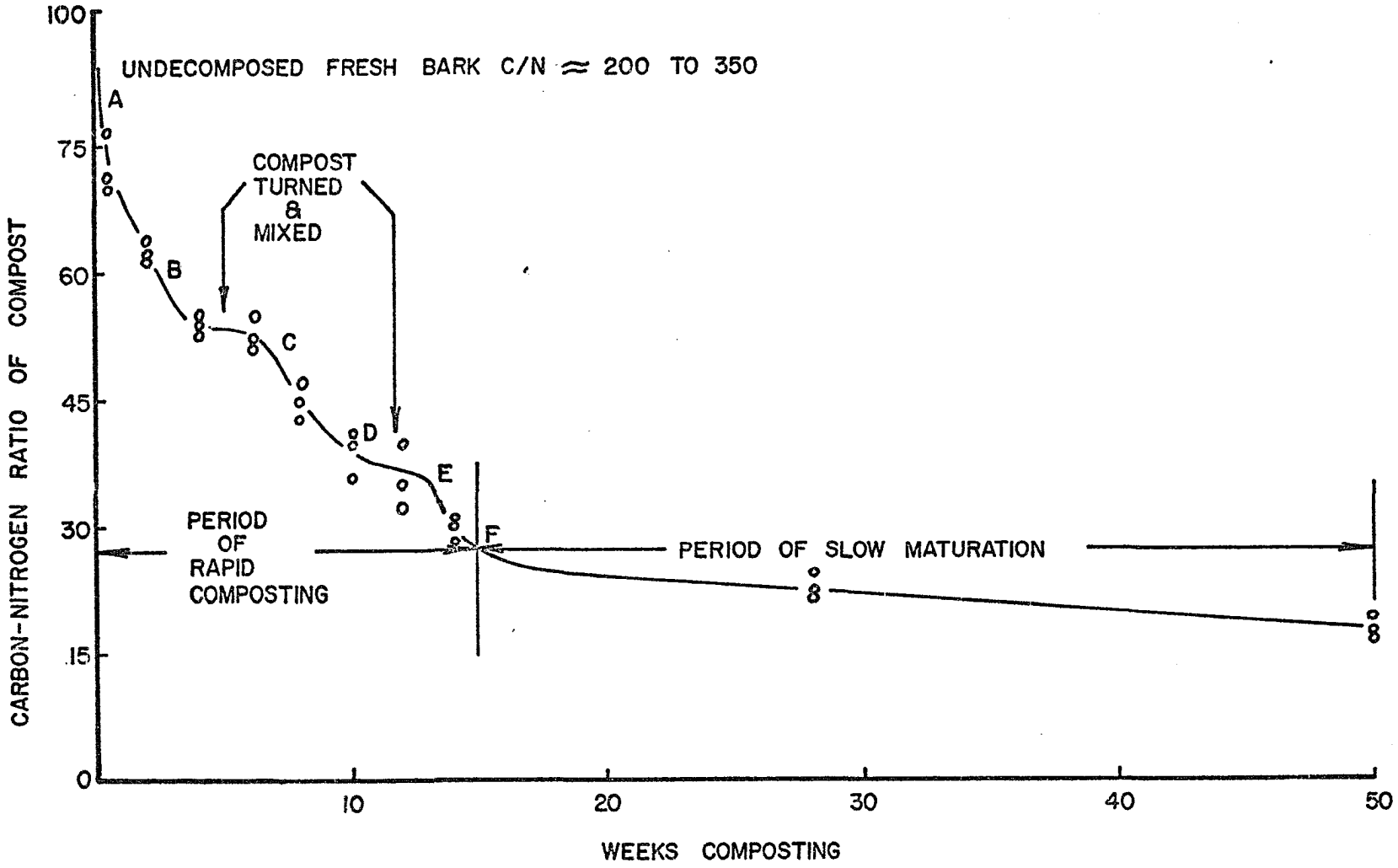


FIG. 7 CHANGE OF CARBON-NITROGEN RATIO WITHIN WINDROW COMPOST DURING COMPOSTING.

of this paper.

Microbiological Tests

Table 6 shows the microbial population of selected organisms during the composting period as well as transmittance data relating to the triphenylformazan reaction for microbial activity. Figure 8 illustrates the fluctuation of microbial population during composting. The TPF test provided a convenient index of microbial activity during the composting period.

From the microbiological data, the following general conclusions may be made:

1. During the initial stages of composting, when soluble components (sugars, alcohols, acids, and proteins) are available, bacteria dominate as the principle microbes within the compost.

2. Turning the compost encourages bacterial activity.

3. Toward the end of the composting period bacterial activity drops relative to that of actinomycetes and fungi, but numerically, the bacteria remain the dominant life form in the compost.

Of special note are the data obtained from the triphenylformazan test for microbial activity which is depicted in Figure 9. This enzyme assay, used carefully in conjunction with microbe counts to obtain standard curves, should be of significant value in assessing microbial activity within compost during the processing period. The method is faster, easier and less expensive than the plate count technique and within 24 hours will give information necessary to judge turning time or pathogen status.

Table 6. Microbial population during the composting period September 17, 1973 to December 26, 1973. Values represent the mean of five replications.

DATE	DAYS OF COMPOSTING	ORGANISM POPULATION (x 10^6/g dry compost) ACTINOMYCETES	FUNGI	BACTERIA	TOTAL
9/17	1	.19	.01	.25	.45
9/19	3	.34	.05	1.14	1.53
9/26	10	.56	.07	5.51	6.14
10/10	24	.48	.18	1.73	2.39
10/17	31	.39	.24	.35	.98
10/22	WINDROW TURNED				
10/24	38	.18	.13	2.29	2.60
10/31	45	.36	.06	1.51	1.93
11/7	52	.40	.08	1.02	1.50
11/13	58	.18	.04	.78	1.01
11/21	66	.17	.03	.45	.65
11/23	WINDROW TURNED				
11/28	73	.15	.04	1.24	1.43
12/5	80	.12	.02	.57	.71
12/12	87	.07	.02	.36	.45
12/19	94	.08	.02	.20	.30
12/26	101	.07	.03	.15	.24

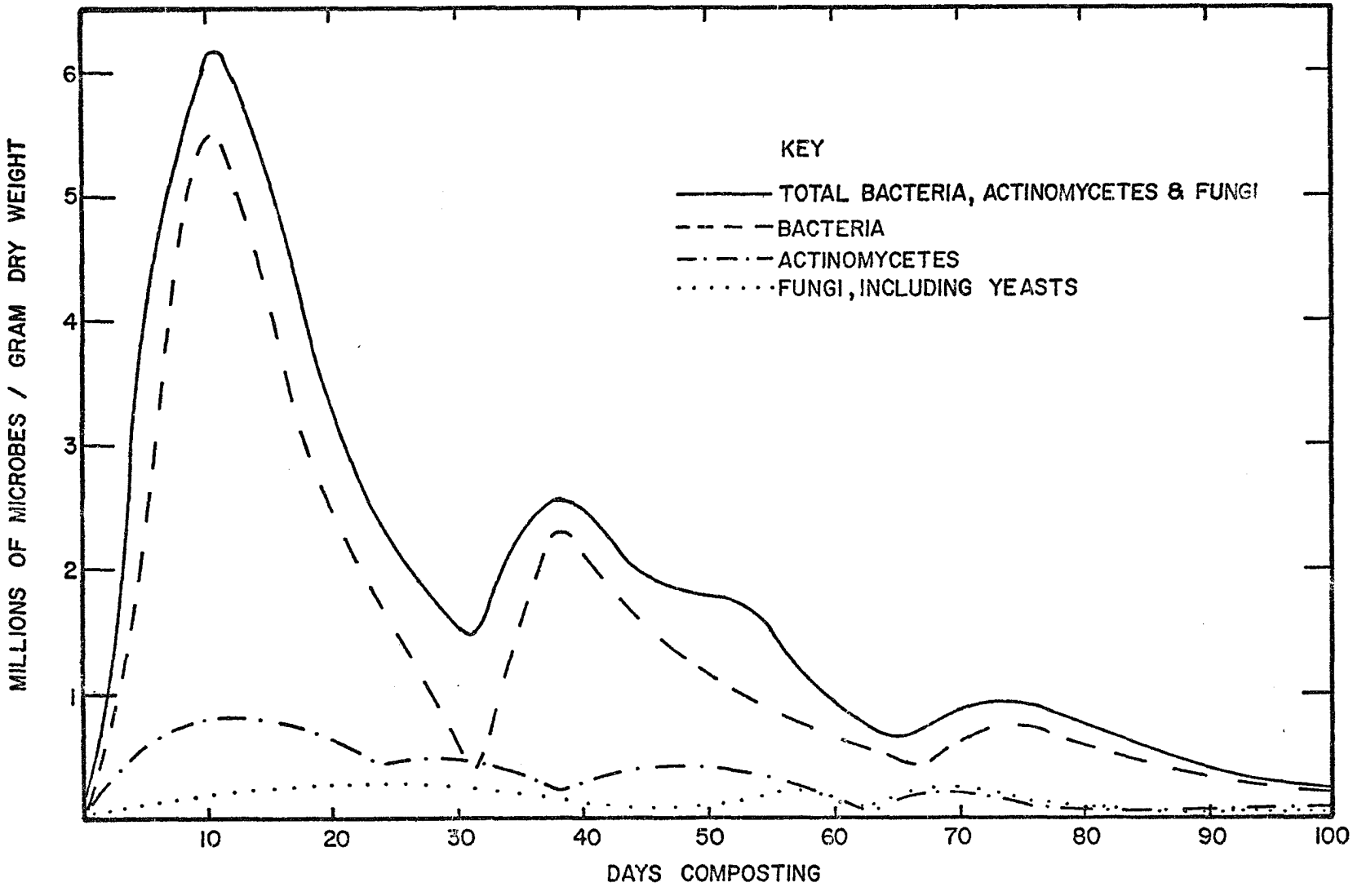


FIG. 8 FLUCTUATION OF MICROBIAL POPULATION WITHIN WINDROW DURING COMPOSTING.

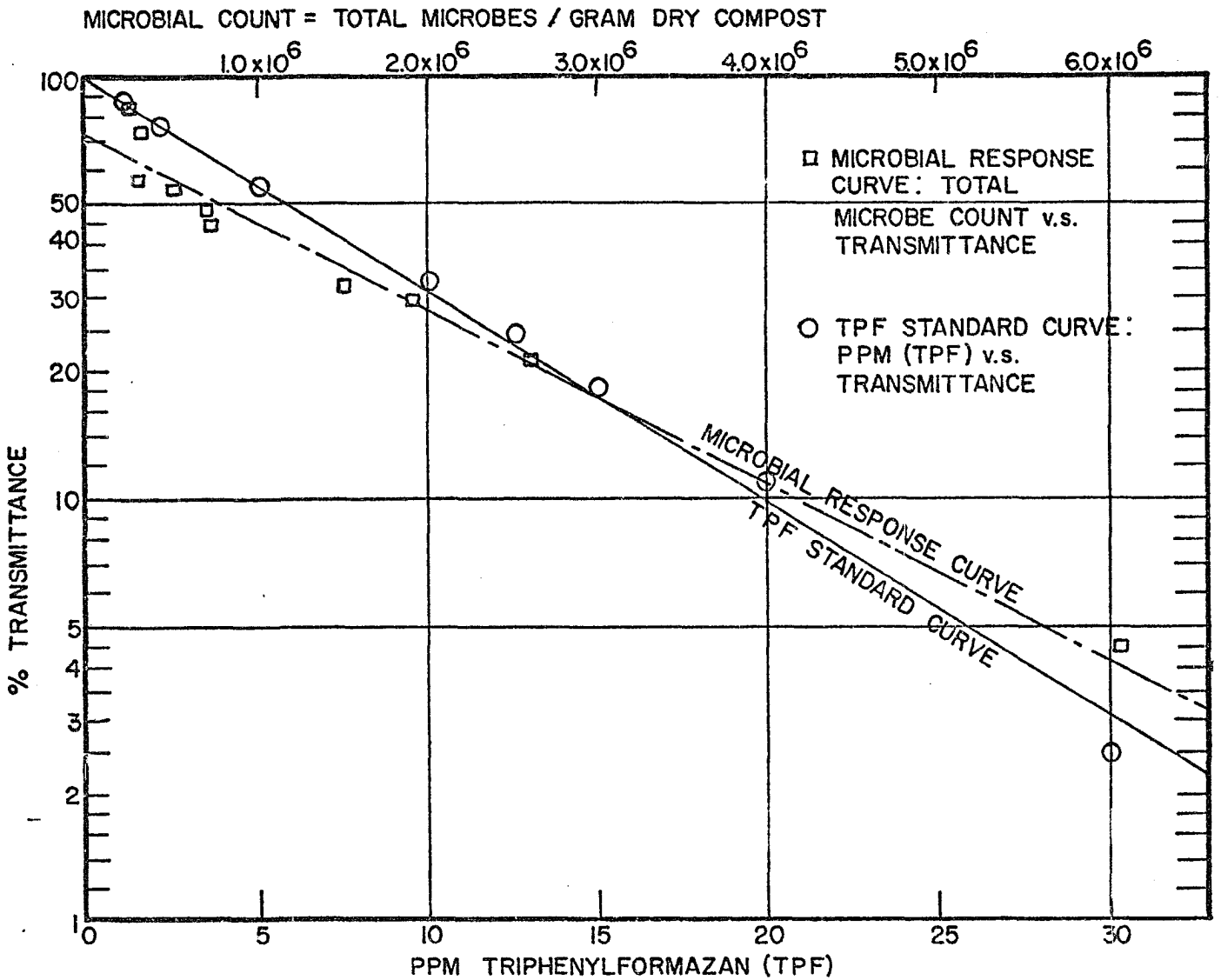


FIGURE 9. USE OF TTC TO MEASURE MICROBIAL ACTIVITY

Characterization of Mature Compost

Physical Properties

Anion Exchange Capacity(AEC). Following techniques of Lenhard et al. (1963), a plot of milligrams adsorbed manoxol versus weight of sample material was constructed for humic acid and selected soil and compost materials (Figure 10). When the 90% of maximum adsorption line for humic acid was drawn, a value of 0.225 mg adsorbed manoxol was obtained; similar curves for other media were then established from experimental data. The weight of these materials required to absorb the same amount of manoxol as humic acid at 90% of maximum adsorption was then determined. The adsorption capacities of the various test media were calculated as follows:

$$\frac{HA}{TM} \times 100 = AEC$$

where, HA = grams of humic acid which absorbed 0.225 mg manoxol, and, TM = grams of test soil medium which absorbed 0.225 mg manoxol.

A value of 0.225 mg manoxol was chosen because it was 90% of the maximum value of manoxol absorbed by the humic acid. The maximum amount of manoxol absorbed by humic acid was 0.250 mg.

For one-year old compost the AEC was calculated as follows:

$$AEC = \frac{HA}{TM}(100) = \frac{0.5}{3.75}(100) = 13.3\%$$

where, grams humic acid which absorbed 0.225 mg manoxol = 0.5, and, grams one-year old compost which absorbed 0.225 mg manoxol = 3.75.

The anion exchange capacities represent the relative absorption efficiency of a given soil medium compared to humic acid. These values are given in Table 7. The organic-rich media show markedly

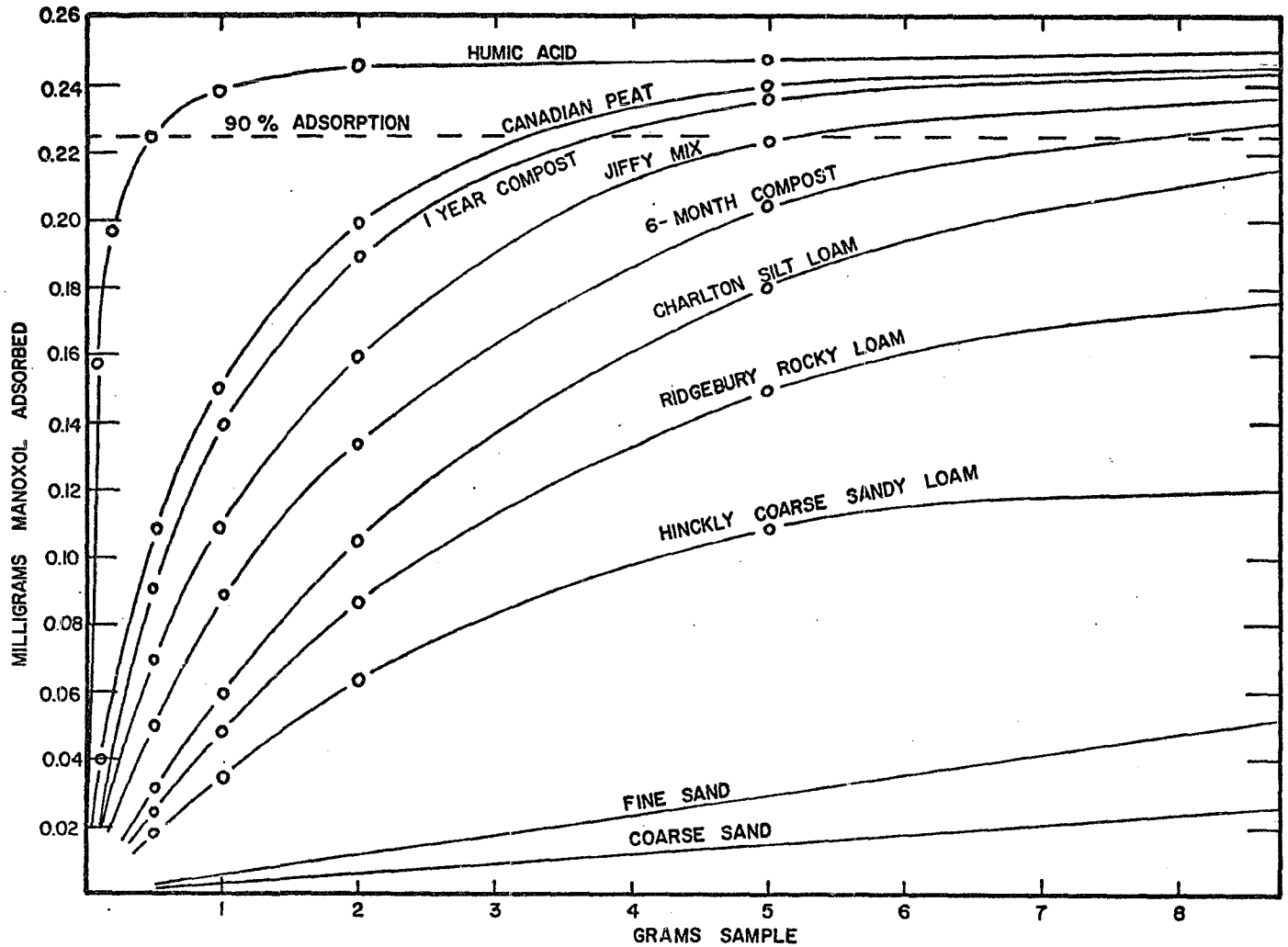


FIG. 10 MANOXOL ADSORPTION PER UNIT SAMPLE MASS FOR SELECTED AGRICULTURAL MEDIA.

Table 7. Selected chemical characteristics of some agricultural growing media. Values represent the mean of three samples.

Sample	Cation Exchange Capacity	Total Exchangeable Bases (TEA)	Exchangeable Acidity (EA)	Summation (TEA + EA)	Anion Exchange Capacity
	meg/100 grams				%
Soil (Charlton silt loam)	19.6	13.3	3.9	17.2	5.0
Jiffy-Mix	113.5	91.6	27.3	118.9	9.5
Peat	108.8	112.3	29.6	141.9	15.4
6-Month Compost	37.5	57.6	16.9	74.5	6.5
1-Year Compost	76.5	74.0	21.6	95.6	13.3

higher values in AEC than mineral rich soils; Canadian peat and one-year old compost show nearly identical anion exchange values. Jiffy-Mix, a widely used commercially available potting media showed AEC values intermediate between mineral soils and compost or peat moss. Based on these data, the high AEC of compost is noteworthy in that it favorably compares with the AEC of peat, the most widely used organic soil amendment for conditioning purposes.

Cation Exchange Capacity (CEC). Cation exchange capacity was determined by the ammonium acetate method (Chapman, 1965a) and also by summing the exchangeable bases and exchange acidity (Chapman, 1965b).

Jiffy-Mix and peat moss showed the highest cation exchange capacities; compost possessed cation exchange capacities intermediate between peat and soil.

Water Retention: Compost samples showed high values of water retention as displayed by soluration capacity, drained capacity and water retention at 31% relative humidity (Table 8). The high soluration capacity of organic material reflects the high porosity of such media. Jiffy-Mix and peat possessed noticeably higher values for the above parameters compared to compost.

Chemical Properties

Analyses for bark and bark-sewage composts are shown in Table 4. Levels of nitrogen, phosphorus and zinc were not increased (appreciably). Magnesium was increased by about 100%; this increase is desirable if the compost is used in New England where soils are generally deficient in this important element. Molybdenum content was

Table 8. Water retention characteristics of selected agricultural growing media. Values are expressed as % water content on a dry weight basis and represent the mean of three replications.

Sample	Soluration Capacity, % H_2O	Drained Capacity, % H_2O	Water Retention, @ 31 % RH
Soil (Charlton silt loam)	37	33	6
Jiffy-Mix	1189	695	41
Peat	1343	735	43
Compost-6 month	443	188	25
Compost-1 year	518	223	40

increased about 200% to a level above that expected in garden soils (Baker, 1957). Iron and copper levels increased about 400% but remained lower than the background levels in garden soil. Silicon and aluminum were increased about 800% from low values to modest values. The addition of sewage to bark did not increase levels of K, Ca, Na, Mn, B, Sr, and Ba since the bark was richer in these elements than was the sewage. In this experiment the sewage contained low levels of macro and micro nutrients and only trace amounts of Zn, Mn, and Cu. The addition of sewage improved the nutrient status of the compost, but its main function was to provide moisture and organic substrate to encourage rapid microbial activity.

Spectrographic analysis of field compost samples showed that nitrogen additions under field conditions did not significantly increase percent nitrogen in the surface six inches. Nitrogen additions up to 800 lbs. NH_4NO_3/acre increased soil nitrogen levels from 0.55 to 0.69 percent, the highest soil nitrogen level being lower than that expected in garden soil which should test 1 to 1.5% nitrogen. The percentages of P, K, and Mg were 0.13, 1.00, and 0.15, respectively, which were adequate for garden soil. Calcium analyzed 0.72%, a value less than the acceptable 1.5% level. The trace elements Mn, Fe, B, Cu, Zn, Al, and Mo, were present at ppm values of: 193.2, 1033.6, 14.6, 19.6, 69.6, 1100.6, and 30 respectively. These elements existed at concentrations consistent with average values reported by Mortvedt, Giordano, and Lindsay (1972). Both bark and compost were rich in boron. With the increased use of borates in detergents and in industry, a toxicity could result if boron accumulates in the humus of soil, as found by Hasler and Zuber (1966). Normal soil boron levels range from 7 to

80 ppm (Chapman, 1966) so that toxic effects are unlikely when the compost is tilled into soil already low in boron. No test was made for cobalt, but it is known that ferromagnetic alloy pollution wastes contribute this element to Rochester sewage. Since the agricultural lands nearby show markedly low cobalt content, (Kobota, 1954), the compost used as a plant growth medium could help to prevent cobalt deficiencies in livestock.

Microbiological Population Study

Initially 211 isolates of bacteria, actinomycetes, and fungi were obtained from the many plates made available by the population study. Those organisms which were found only at the beginning of composting or found only occasionally on plates were arbitrarily classified as transient microbes. These are tabulated in Appendix Table 1. Organisms consistently present in the compost are shown in Appendix Table 2. Bacterial representatives of the class Schizophyceae included members of only three orders: Pseudomonadales, Eubacteriales, and Actinomycetales. By far the most numerous were pseudomonads.

Nematodes were present throughout the windrowing stage and in the final compost. Time did not permit complete search and classification of those nematodes separated in the funnel technique. Those found included microbivorous species such as Rhabditis and Aerobeles and phytophagus species such as Aphelenchoides and Dorylaimus.

The results of monitoring procedures for the indicator organisms Escherichia coli, Salmonella heidleberg, and Candida albicans are displayed in Table 9. The sewage displayed a high coliform count, but most were not enteric forms, the E. coli count being less than one-tenth the coliform count. Salmonella species were found in the sewage at low

Table 9. Population of pathogenic microorganisms within seeded compost, in unseeded samples of compost, and in other selected material used in compost construction. Values are given in microbes/gram dry weight of sample (solids), or as microbes/ml (liquids).

Sample	Organism* *E. coli*	*Salmonella* sp.	*Candida albicans*	Coliforms
Ground Bark	0	0	0	0
Sewage, Rochester, N. H.	1.7×10^7	137	7 forms	3.6×10^8
Seeded Samples:				
Inoculant	3.5×10^8	3.2×10^8	2.4×10^8	2.6×10^6
Initial Compost	2.5×10^6	2.8×10^6	2.2×10^6	2.6×10^6
Compost-24 hrs.	11	130	620	72
Compost-36 hrs.	0	0	0	0
Unseeded Samples:				
Initial Compost	1.4×10^5	12	1	2.0×10^6
Compost-24 hrs.	213	3	0	1.7×10^3
Compost-36 hrs.	0	0	0	0

* Tests were negative for the genera *Shigella*, *Micrococcus*, and *Streptococcus*.

levels; Candida was also found but in smaller numbers than Salmonella bacteria. The initial compost contained over two million cells per gram dry weight of each of the inoculated species. Within 24 hours the pathogen levels were reduced 1000-fold and by the end of a 36 hour period the pathogens had been destroyed. Had sampling been more extensive, pathogens may have been found near the outside of the windrow for an extended period, but time and the overturning of the windrow must have completed their destruction since they were not found later when the mature compost was characterized microbially.

Nutrition Studies

Preliminary Studies

Study 1. The relatively high rates of high-magnesium limestone application to moist undecomposed bark causes substantial pH change (Figure 11). One gram of limestone per 50 grams of moist bark is equivalent to about 22 lbs/yd^3. Between 2.2 and 22 pounds of limestone application, the pH at 120 hours was elevated only about one unit; another ten-fold addition of limestone produced an additional two pH units of change within the 120 hour test period. While the initial pH may be increased following addition of limestone, the pH continuously decreases due to the extreme acid nature of the bark. Increase and stabilization of pH is beneficial for those crops not acclimated to the equilibrium pH value of 5.5 - 6. For liming to be effective in an acid compost it must be applied well in advance of seeding a crop. If a value of around pH 7 is needed a rate of 22 lbs/yd^3 is required, but a minimum of 5 lbs/yd^3 should be mixed into the compost both to improve pH and to add calcium and magnesium.

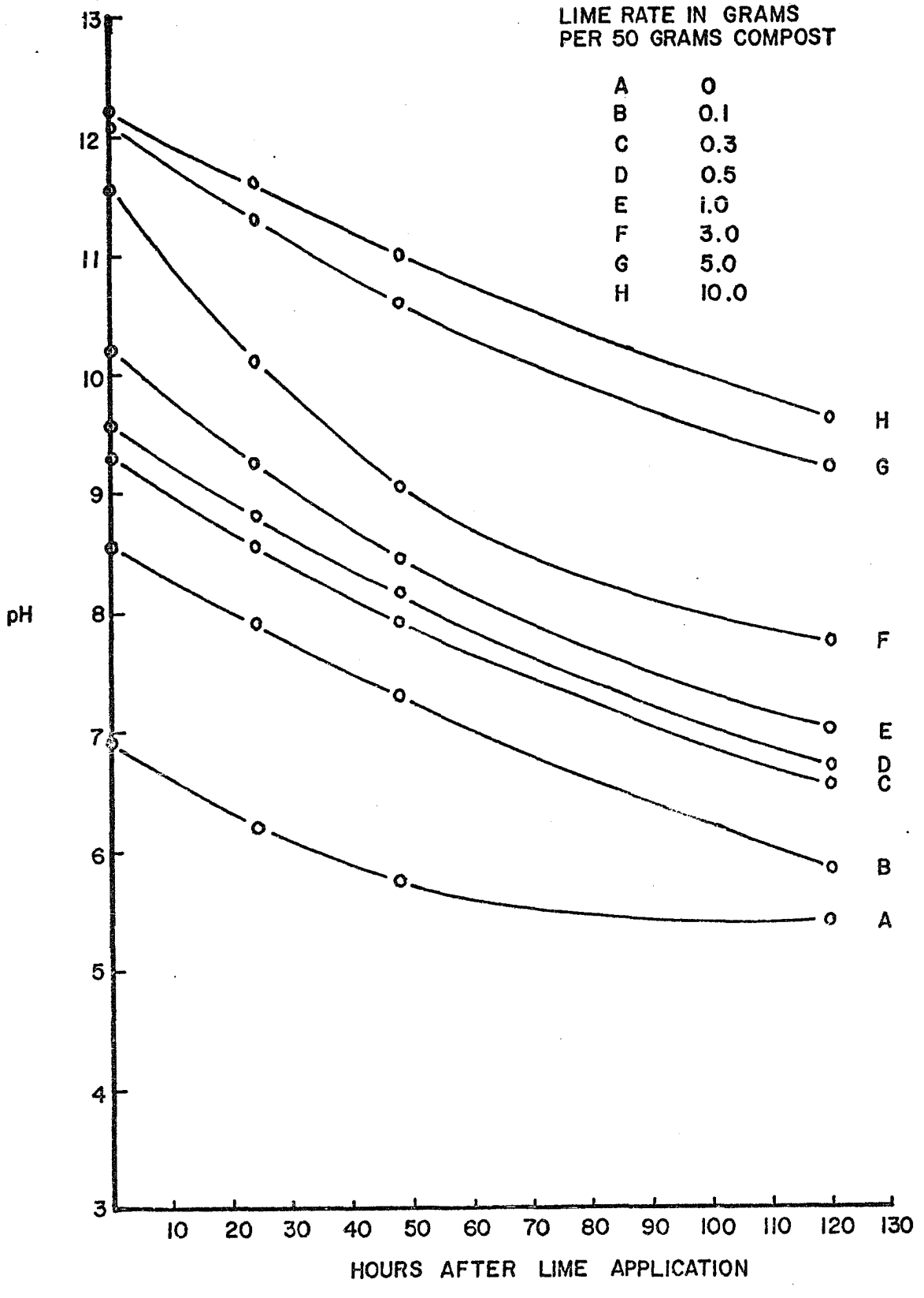


FIG. 11 INFLUENCE OF LIMESTONE APPLICATION ON IMMEDIATE pH RESPONSE IN MATURE COMPOST.

Study 2. When tomatoes were directly seeded into the above undecomposed medium, severe stunting occurred. The problem appeared directly related to extremely low pH and insufficient nitrogen.

Study 3. This study, involving a cursory study of slow-release nutrient sources; sewage sludge, granite dust, and rock phosphate, continued to produce exceedingly poor growth of tomato plants. Both low and high fertilization rates yielded poor plants and symptoms appeared related to low pH and nitrogen deficiency.

Study 4. The foliage dry weight of tomato plants as influenced by increasing increments of limestone addition to the undecomposed bark is illustrated in Figure 12. Foliage dry weight was utilized as the response in these studies because this variable directly relates to ultimate fruit yield. Tomato plant yield increased up to and including a limestone addition of 10 lbs/yd^3.

Study 5. This study was concerned with evaluation of phosphate source for growth enhancement of tomatoes when applied at varying rates to undecomposed bark-sewage mixtures. Figure 13 illustrates the distinct benefit of applied P_2O_5 up to 26.6 lbs/yd^3 from superphosphate and up to 40 lbs/yd^3 from rock phosphate sources. Plant growth diminished at rates of phosphate application beyond these above levels.

Study 6. The results of this study, relating to incremental addition of vermiculite, perlite, and bentonite clay to undecomposed bark-sewage medium are shown in Figure 14.

Tomato yields increased with addition of the above amendments up to a limit; greatest average yield occurred when either vermiculite

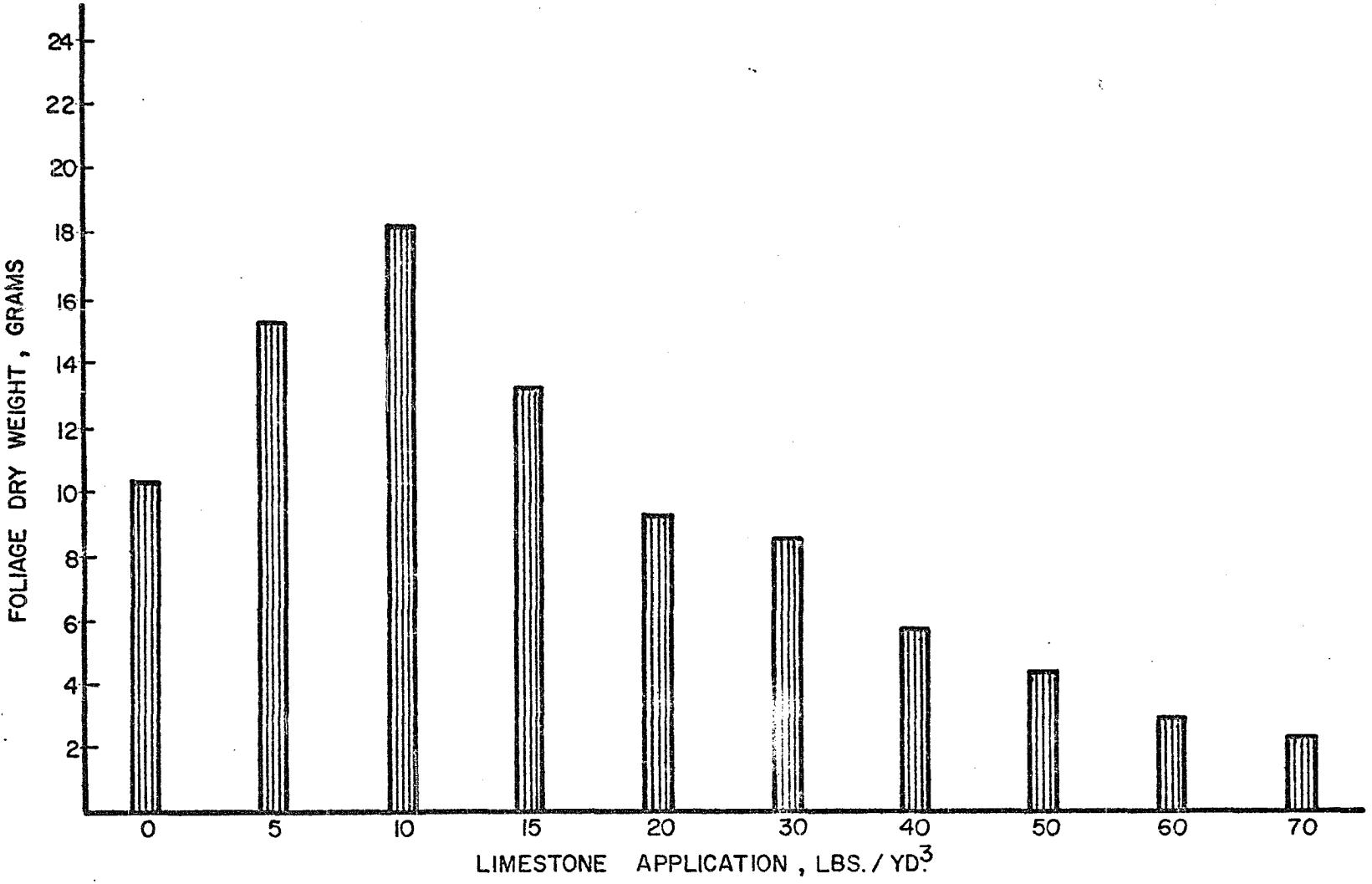


FIG. 12 FOLIAGE DRY WEIGHT OF TOMATO PLANTS AS INFLUENCED BY INCREASING INCREMENTS OF LIMESTONE

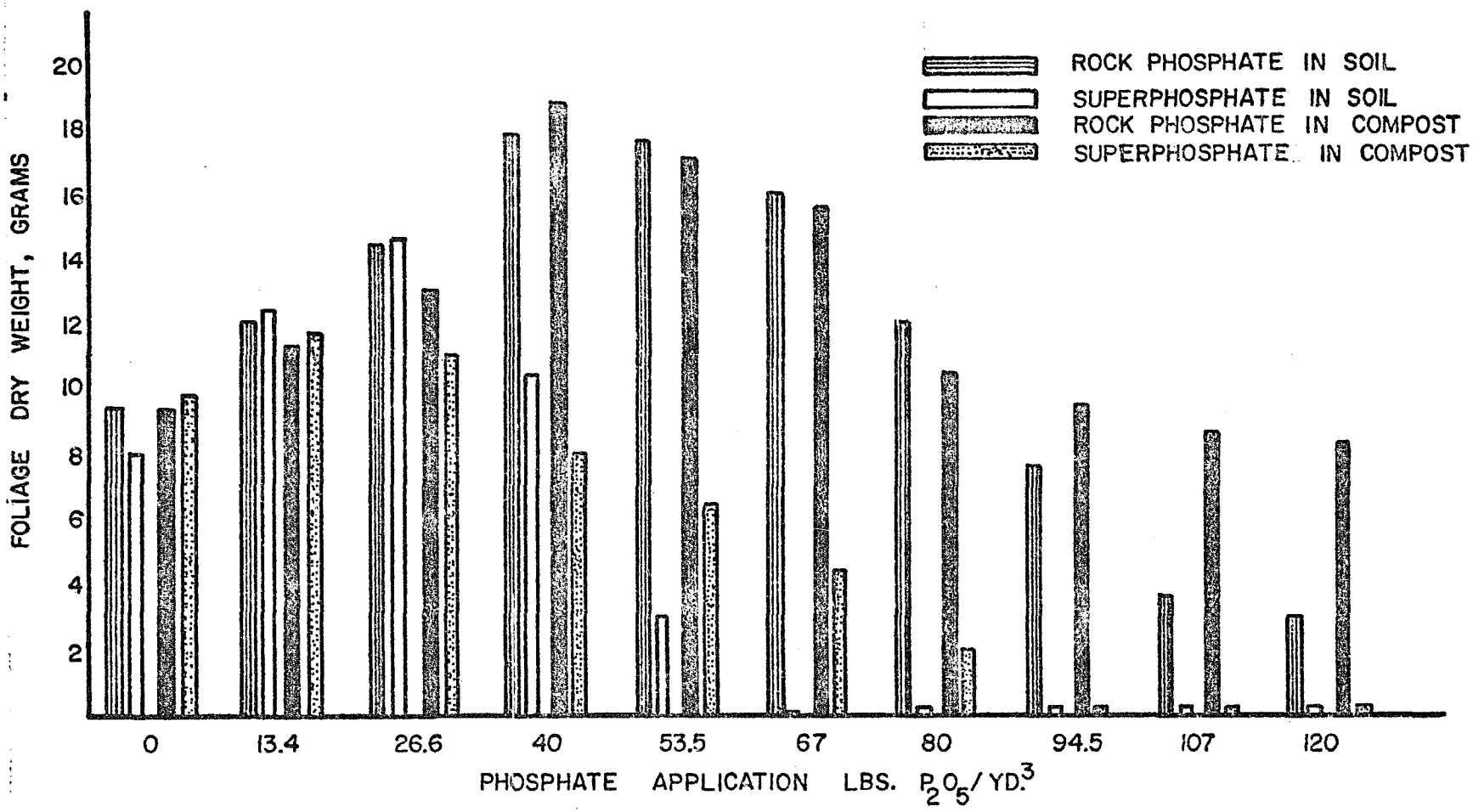


FIG. 13 FOLIAGE DRY WEIGHT OF TOMATO PLANTS AS INFLUENCED BY ADDITION OF INCREASING INCREMENTS OF PHOSPHATE USING TWO P_2O_5 SOURCES AND TWO MEDIA.

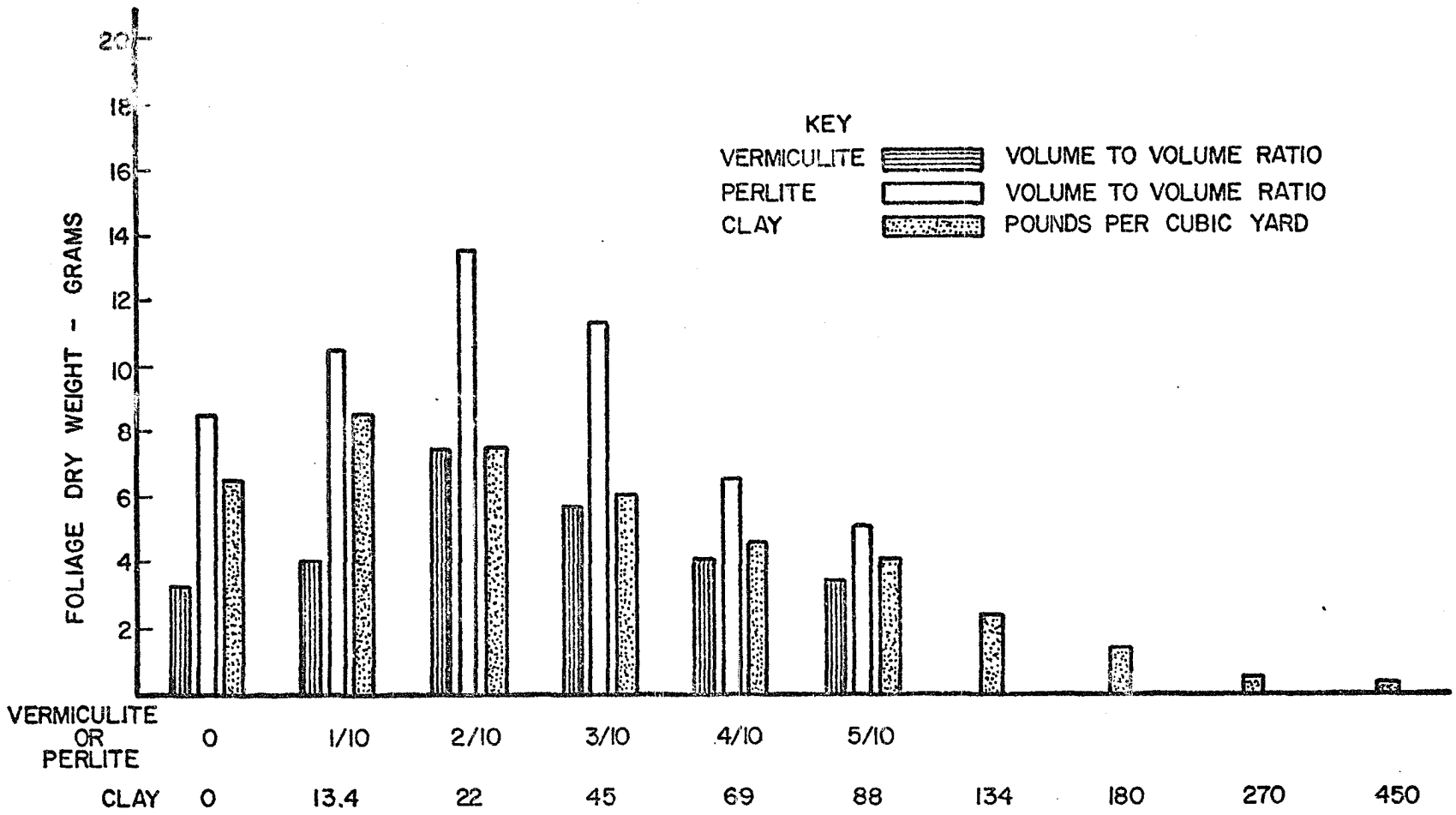


FIG.14 FOLIAGE DRY WEIGHT OF TOMATO PLANTS AS INFLUENCED BY INCREMENTAL ADDITION TO COMPOST OF THREE SOIL AMENDMENTS.

or perlite were added on the basis of 1:5 volume/volume ratio. Greatest benefit was shown with the addition of perlite compared to vermiculite and clay. Clay addition produced the lowest relative benefit compared to the other additaments. Nitrogen deficiency continued to exist in the plants; further studies are needed to determine the contribution of these additaments to a bark compost in terms of benefit/cost relationships and specific aspects of improved soil chemical behavior.

Osmocote NPK Study

The controlled-release 14-14-14 grade of Osmocote was incorporated with the composted bark-sewage prior to seeding with Sudan grass. Visually discernible effects were noted on grass growth following treatment with as little as 0.14 lbs N/yd^3 of compost from Osmocote (Appendix Table 3). The nitrogen requirement for optimum or maximum growth was not met however, even at a level of 2.24 lbs Osmocote/yd^3. The results of Osmocote treatment and subplot effects of supplemental nitrogen on crop yield are given in Appendix Table 4.

Kjeldahl analysis of the grass tissue from three harvests is summarized in Figure 15. Marked increase in percent N in plant tissue was obtained with the 1.12 and 2.24 lbs N/yd^3 compared with lower rates; however, yield data tend to show that optimum N levels still have not been achieved in the compost.

The composition of N, P, and K in the Sudan grass foliage was influenced by Osmocote treatments, data for which are given in Table 10.

No significant effects were noted from the subplot nitrogen treatments. Figure 16 shows photographic evidence of main plot Osmocote

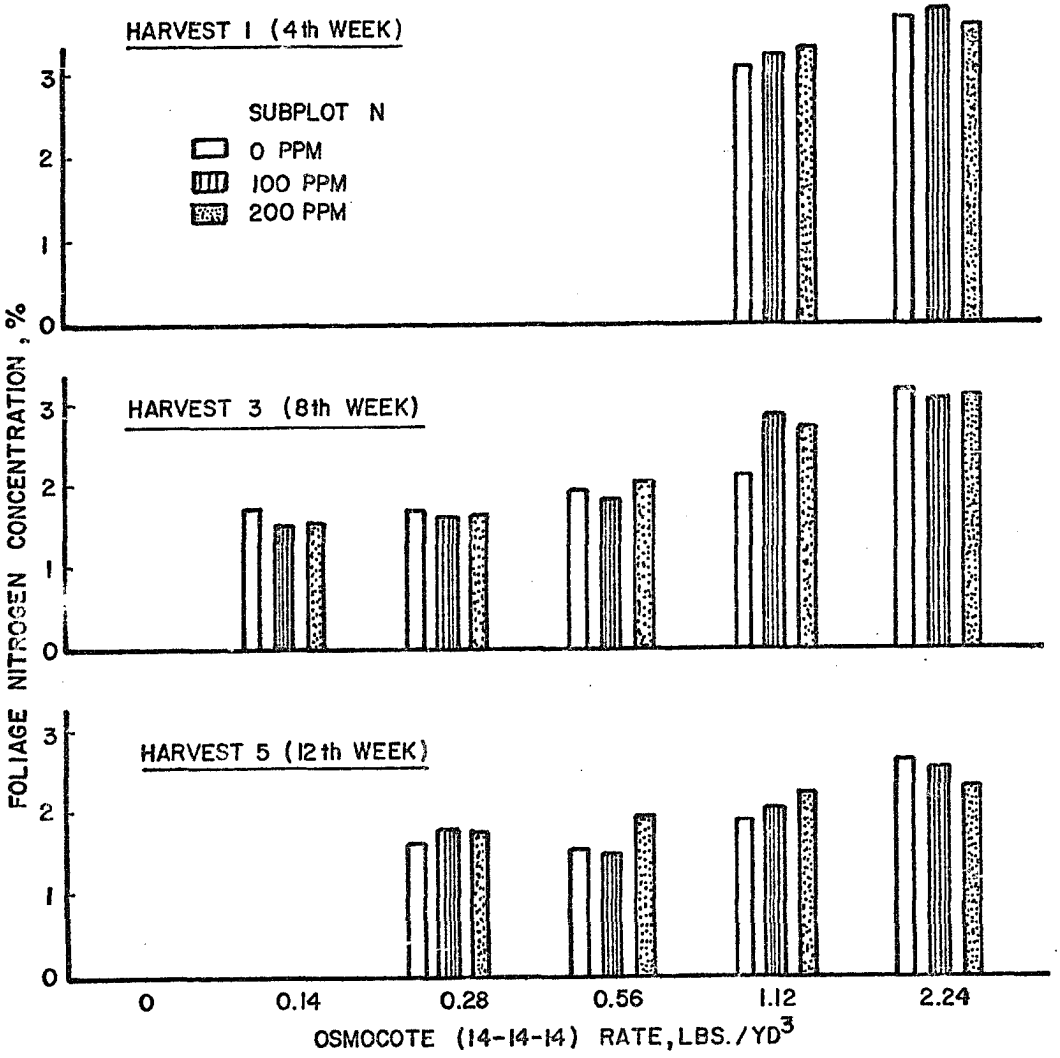


FIG. 15 Nitrogen concentration (%) of Sudan grass foliage as influenced by the addition of Osmocote (14-14-14) controlled-release fertilizer. Values represent an average of three replications. Limited sample size prevented Kjeldahl analysis of tissue from the lower Osmocote rates.

Table 10. Elemental concentrations of sudan grass foliage on the 8th week following planting as influenced by differential rates of Osmocote (14-14-14) application. Values represent the mean of three replications.

Osmocote Rate, lbs/yd^3	Elemental Concentrations, %		
	Nitrogen	Phosphorus	Potassium
0	---*	---*	---*
.14	1.64	.41	2.64
.28	1.63	.37	2.46
.56	1.93	.47	2.70
1.12	2.64	.67	3.32
2.24	3.15	.84	3.80
LSD .05	.26	.09	.32

* Limited sample size prevented Kjeldahl analysis of tissue.

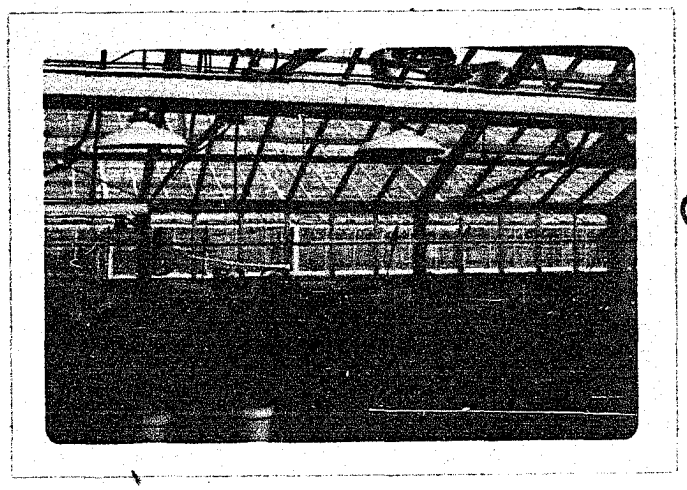
effects on Sudan grass growth. Figure 16A shows the gradient of effects if pots are arranged in order of decreasing Osmocote rate from left to right on the greenhouse bench. Figure 16B shows the growth rate of the control, 0.28 lbs N/yd^3, and 1.12 lbs N/yd^3 treatments. Figure 16C shows the entire spectrum of growth of Sudan grass in compost supplied with increasing amounts of Osmocote supplying nitrogen from 0 - 2.24 lbs/yd^3.

Nitrogen Study

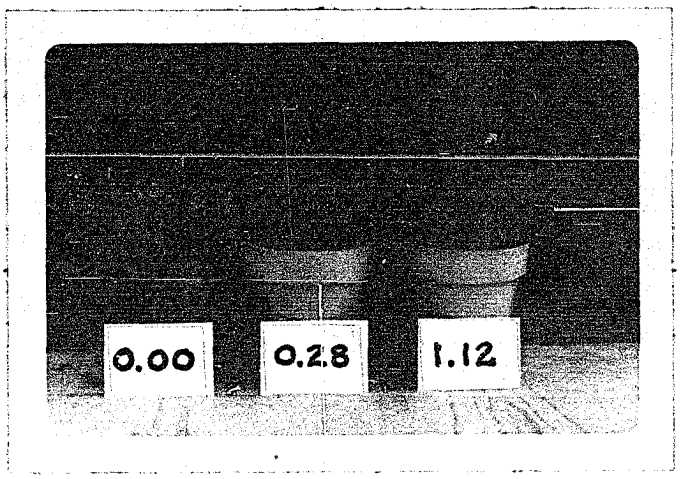
Yield data showing the influence of sulfur-coated urea on dry weight of Sudan grass at nine harvest dates are shown in Appendix Tables 5 and 6. Figure 17 displays graphically the influence of sulfur-coated urea on Sudan grass harvests. In all cases growth rate beyond the sixth week drops off rapidly.

Relatively rapid nitrogen depletion of the medium apparently occurred in successive harvests at the lower rates of applied nitrogen. Highest yield at the 6th week after planting occurred with the 3.36 lb. rate of applied N; highest yields of grass were maintained for about two months with the sulfur-coated urea; less soluble N materials are warranted for use with this compost for long-term planting.

The tissue levels of N in Sudan grass foliage for selected harvests are given in Appendix Table 4. Appendix Table 7 shows tissue levels of other elements. Using nitrogen levels between 1.5 and 2.5% (Table 11) as reasonable intermediate values for sudan grass tissue, it is apparent that the three lower levels of nitrogen treatment do not maintain adequate nitrogen for the twenty week growth period. However the highest treatment produced inordinately high tissue nitrogen levels.



(A)



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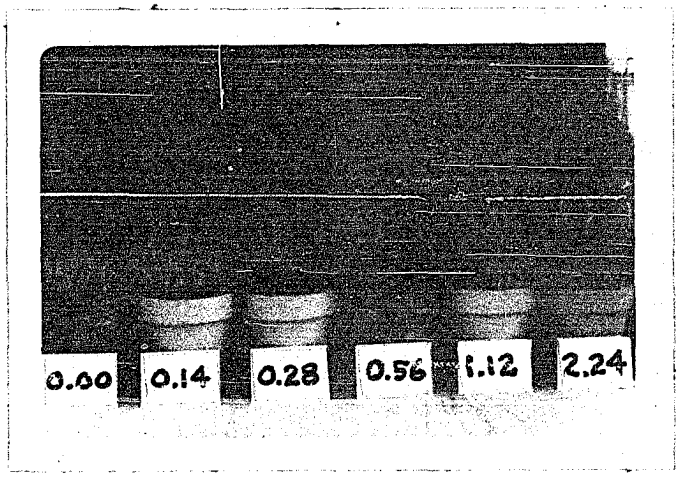

(C)

Figure 16. Photographs showing the influence of incremental addition to the compost of Osmocote controlled-release fertilizer upon growth of Sudan grass. Values shown represent nitrogen level incorporated with bark-sewage compost on the basis of lbs N/yd^3.

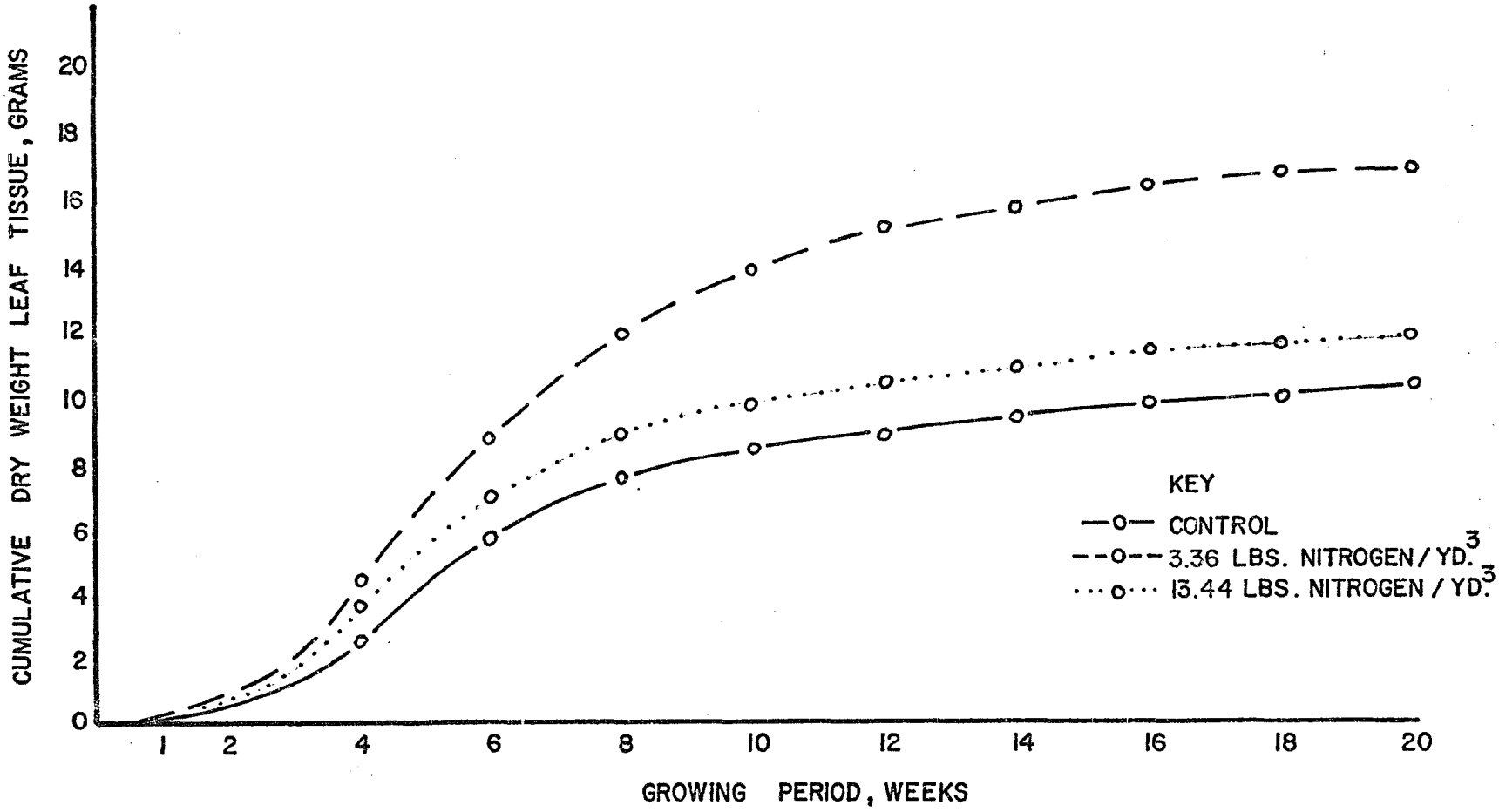

FIG. 17 INFLUENCE OF SULFUR-COATED UREA ON SUDAN GRASS YIELD.

Table 11. Comparisons of tissue, compost, and soil nutrient levels of sixteen selected elements.

Element	Tissue Deficiency Level[a]	Tissue Intermediate Level[a]	Tissue Toxic Level[a]	Sudan Tissue[b]	Municipal Compost & Sludge[c]	Bark-Sewage Compost[d]	Garden Soil[e]
			%				
Nitrogen (total)	1.5	1.5-2.5	4.0	1.43	.94	.5-.7	1-1.5
Potassium	0.25-1.5	1.5-3.0	5.0	2.38	.28	.5-.7	1-1.5
Phosphorus	0.05-0.15	0.25-0.35	0.6	.44	.28	.1-.15	0.1-0.2
Calcium	0.15-0.30	0.3-0.5	5.0	.58	1.41	.3-.8	1.5
Magnesium	0.10-0.25	0.25-0.75	1.0	.36	1.56	.1-.25	.1
Sodium	not req'd	--10% NaCl solution toxic--		.05	.42	.01	.01
Silicon	not req'd	---	---	.18	---	.9-1.5	30-90 variable
			ppm				
Manganese	2-20	50-400	500-1000	81	300	140-220	20-50
Iron	20-60	60-200	500	495	10,700	100-1050	100
Boron	5-20	30-150	100-1000	26	5	12-15	50
Copper	2-3	5-20	50-100	27	500	15-30	10
Zinc	5-15	20-150	200-500	52	50	50-75	30
Aluminum (exch)	not req'd	500	1000	542	11,900	1100-1200	100
Strontium	not req'd	5-50	400	34	---	20-40	5
Molybdenum	0.01-0.15	0.25-1.5	5	1.77	---	<30	.2
Barium	not req'd	5-40	100	26	---	30-60	5

a. Composite from Sauchelli (1965), Kilmer, Younts and Brady (1968), and Mortvedt et al. (1972), Chapman, (1966), and Gauch (1972)

b. Nitrogen study; control

c. Johnson City Municipal refuse, Kupchick, (1966)

d. Table 4, this report

e. Composite from Baker, (1957), Gauch, (1972), and Macdonald, (1973).

Table 12 displays the tissue analysis data in three parts, elements supplied at correct levels, elements supplied at low levels, and elements supplied at possibly dangerous levels. Magnesium tissue levels were at six weeks below a reasonable intermediate value of 0.26%, but not quite at deficiency level of 0.18%; additional magnesium should be applied to the compost. This situation, again, emphasizes the need for dolomitic rather than calcitic lime and reflects the interaction between Ca and Mg cations at low pH values (Tisdale and Nelson, 1966). Iron and aluminum were found at high tissue levels as a result of their solubility at low pH. Aluminum was found at close to toxic levels in some tissue, and its effect as a root poison should not be overlooked. High aluminum uptake is common in healthy plants (Chapman, 1966) and is to be expected at low pH. Minimum aluminum solubility is found between pH 5.8 and 7.0 so that adequate liming should minimize the effects of aluminum. Values of iron in tissue are abnormally high, but not so high as to suspect a toxic reaction. Chapman (1966) discusses the possibility of dust contamination of samples and points out that iron concentration in leaf tissue is 10^{-2} to 10^{-4} times that of the soil in which the plant grows. Since the compost displayed values of between 100 and 1050 ppm iron the values obtained in this study appear to be higher than expected. Molybdenum was found at higher than normal concentration in leaf tissue but not at toxic levels. Chapman (1966) reports tissue values of 372 ppm Mo after foliage application of fertilizer without noticeable effect. Values of 100 to 2000 ppm Mo are evidently required to cause toxicity symptoms.

Examination of the statistical data displayed in Appendix Table 7 shows that P, Na, Si, Cu, and Mo levels in the tissue were not

Table 12. A comparison of the concentrations of twelve elements found in Sudan grass tissue to those levels found in normal Sudan grass. Values are from Chapman (1966), a; Gauch (1972), b; and Mortvedt et al. (1972), c; for percent or ppm on dry weight basis. Where Sudan grass values were not available corn values were utilized. I, supplied at correct levels; II, supplied at low levels; and III, supplied at possibly dangerous levels.

Element		Supply Level	Normal Tissue	Source	Sudan Grass Tissue
N	%	I	1.5-2.5	a,b	2.18-3.86
P	%	I	0.13-0.48	a	0.30-0.46
K	%	I	1.50-3.00	a,b	2.18-3.29
Ca	%	I	0.38-0.80	a,b	0.44-1.07
B	ppm	I	30-150	a,c	30-61
Mn	ppm	I	20-500	a,c	91-185
Zn	ppm	I	16-150	a,c	66-93
Cu	ppm	I	5 -20	a,c	11-14.5
Mg	%	II	0.26-0.75	a	0.16-0.49
Fe	ppm	III	50-200	a,c	323-946
Mo	ppm	III	0.1-0.5	a,c	0.87-4.73
Al	ppm	III	1000	c	98-918

significantly changed by increasing nitrogen application rate. Potassium, magnesium, zinc, and to some extent copper concentrations in the tissue were found to be highest when nitrogen rates were also high. Manganese and iron tissue levels were depressed by the high nitrogen concentrations throughout the study; calcium was at first depressed and then as nitrogen was utilized calcium uptake increased. Boron, aluminum, strontium, and barium were slightly depressed when soil nitrogen levels were high.

Potassium Study

Yield data showing the influence of increasing increments of applied potassium on dry weight of sudan grass at nine harvest dates appear in Appendix Table 5 and are graphically presented in Figure 18. The highest sustained yields occurred at the 1.12 lb/yd^3 rate of applied K_2O. After 18 weeks, all yields were low, indicating depletion of nutrients. Of primary significance, however, is the lack of difference between levels of applied K_2O during the early stages of the experiment. The data from the previous nitrogen study and this data would tend to show that the compost is amply supplying potassium to the plants and supplemental K is of questionable value except for long-term cropping. Tissue analysis data for the 6th and 14th weekly harvest period are given in Appendix Table 8. At low potassium rates no K deficiency nor toxicity is shown; the nutritional needs of the sudan grass for K were met. Plant growth was likely inhibited, however, by the relatively short days experienced during the fall period.

At a rate higher than 1.12 lbs/yd^3 of K_2O the data tend to show evidence of salt stress (Tisdale and Nelson, 1966). Conductivity tests

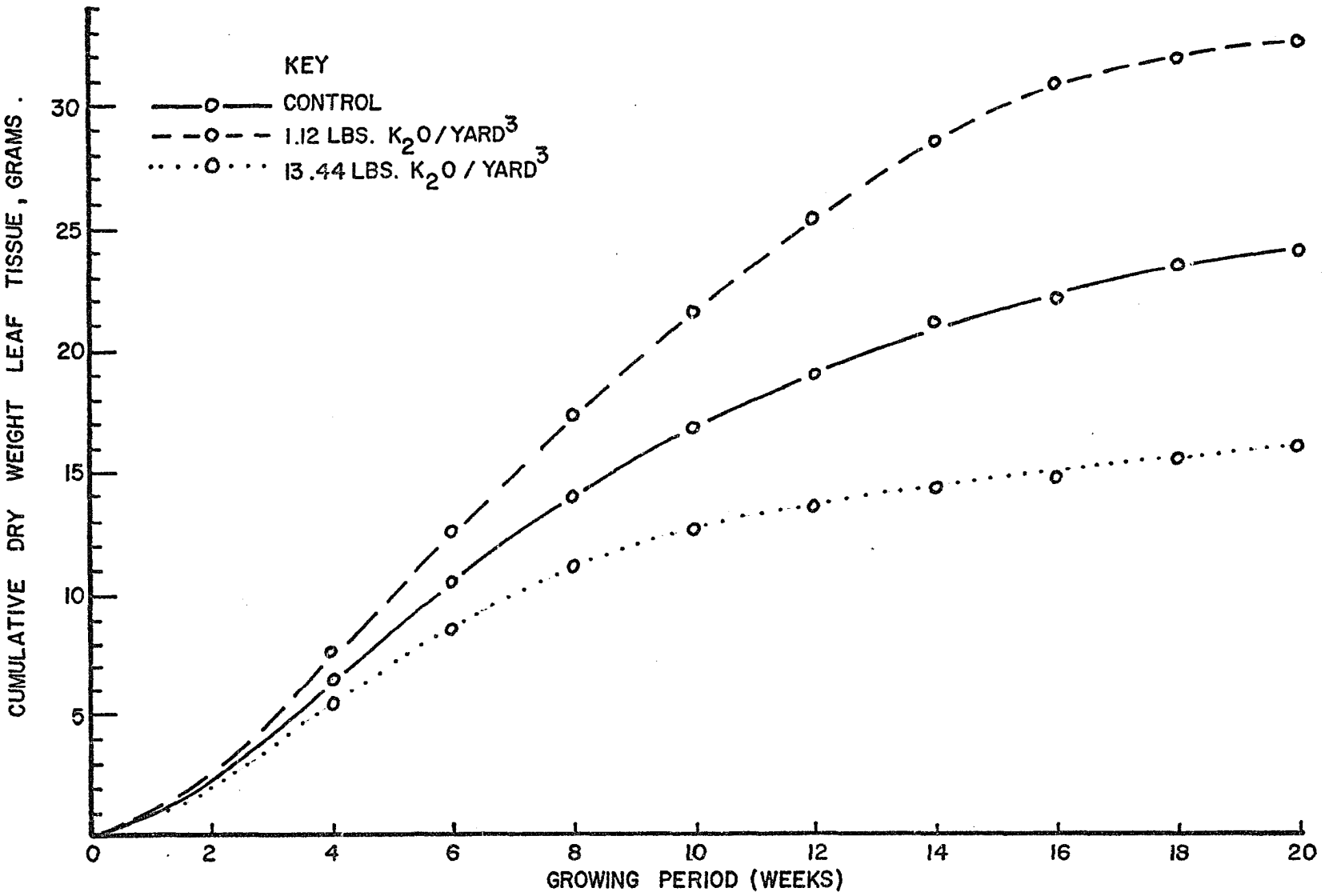

FIG. 18 INFLUENCE OF INCREMENTAL POTASSIUM CHLORIDE ADDITIONS UPON SUDAN GRASS YIELD.

were made on samples receiving 0, 0.14, 1.12, 2.24, and 13.44 lbs K_2O/yd^3 and showed values (1 x 10^{-5} mhos) of 9, 15, 156, 310, and 520 respectively. Such readings are strong evidence that the highest potassium rate is creating severe salt stress on the plants from the applied KCl even if the medium is a highly buffered system.

Duncan's Test was utilized to determine which treatment produced significantly different elemental tissue level analyses. High potassium fertilization rates often cause depression of both calcium and magnesium in tissue (Kilmer, Younts, and Brady, 1968). The expected depression of magnesium was found, but calcium levels were erratic. Manganese tissue concentration increased significantly with increasing potassium application.

Maas, Moore, and Mason (1969) found that calcium and magnesium levles affect uptake of manganese. Increasing Mg decreased absorption of Mn, but Ca by itself had no effect upon Mn uptake by excised barley roots. The increased Mn found at high concentration of K may be the result of depression of Mg, which in this study resulted in higher Mn levels.

Phosphate Study

The influence of increasing increments of phophorus applied to compost from rock phosphate on the dry weight of sudan grass foliage is graphically displayed in Figure 19, and the numerical data are tabulated in Appendix Table 6. Data from this study indicate that P_2O_5 rates of 1.12 and 2.24 lbs/yd^3 produced the highest plant yields although no sharp demarcation exists between low and high phosphorus application rates. Phosphorus applications greater than 2.24 lbs/yd^3

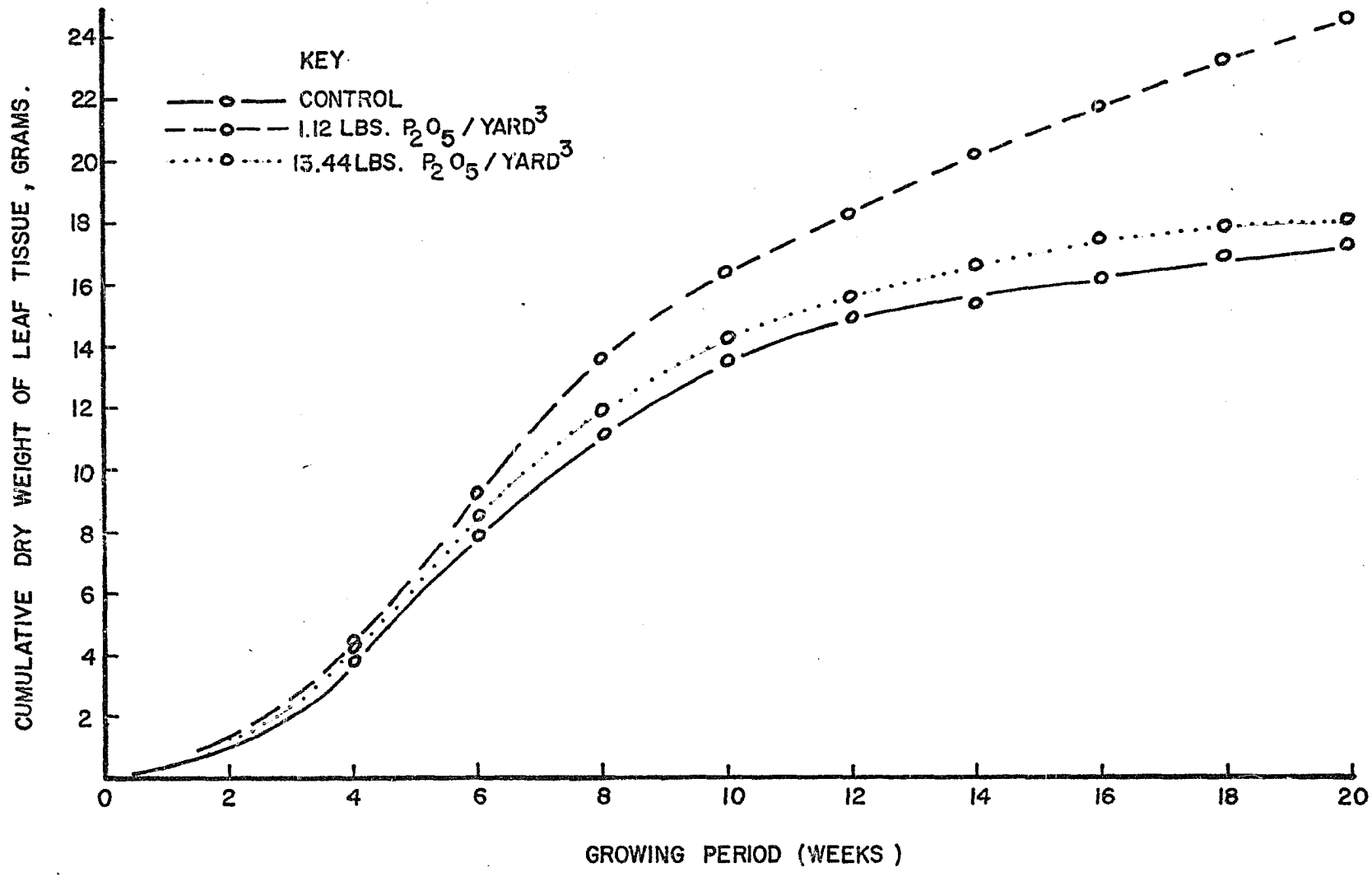

FIG. 19 INFLUENCE OF INCREMENTAL ROCK PHOSPHATE ADDITIONS UPON SUDAN GRASS YIELD.

caused very slight depression in yields relative to the pronounced effects noted with the highest levels of nitrogen and potassium. Tissue analysis data for the 6th and 12th weekly harvest period are given in Appendix Table 9. Percent P in grass tissue was not significantly increased at the highest levels of applied P indicating that the compost was furnishing the plants with adequate amounts of this element for sustained production. It is conjectured that microbial metabolic action produced organic acids which transformed the relatively insoluble rock phosphate to a slow acting but reliable phosphate source. Similar results were found in Russian composting studies (Bodrova and Ozolina, 1968). No nutrient deficiencies nor toxicities were found at moderate P_2O_5 application rates. Iron and molybdenum were found at higher than expected levels in tissue which reflects their increased availability under the microbiologically active condition existent in this medium.

In both the potassium and the phosphorus studies a molybdenum-phosphorus interaction may exist. Molybdenum uptake is enhanced by high phosphorus levels (Greenwood and Hallsworth, 1960). Molybdenum absorption and its subsequent release from root cells into the translocation system is stimulated by phosphorus because, as noted by Mortvedt et al. (1972), the phosphomolybdate anion is readily absorbed by the plant roots.

Iron and molybdenum interact by mechanisms which can have either beneficial or detrimental effects. With adequate molybdenum, the reduction of iron necessary for translocation is accomplished, but at very high molybdenum concentrations, iron-molybdate complexes may precipitate and iron chlorosis may result (Gerloff, Stout, and Jones, 1959). The compost apparently supplied both iron and molybdenum at

modest levels since iron chlorosis did not occur. Evidently the compost supplied adequate molybdenum, but not so much as to cause toxic effects.

Field Nutrition Study

Field studies with corn grown on compost with increasing increments of nitrogen from ammonium nitrate (Table 13) indicate that maximum production was obtained at a nitrogen rate of 400 lbs N/acre. It is interesting that leaf nitrogen levels were within the intermediate range for levels of 200 -800 lbs/acre yet growth was poor. Since the greenhouse pot experiments indicated that P and K as well as micronutrient requirements should have been met by the blanket applications of KCl, superphosphate, and dolomitic lime, only one possible reason remains to explain the generally poor growth, inadequate liming. Apparently after composting the bark-sewage medium remains potentially acid. The ammonium nitrate utilized in the field experiment apparently caused the pH to drop below the already low 5.4 level of the soil-compost plow layer (Andrews, 1956; Raney, 1960). The high aluminum level of both soil and compost also increased the acidity level.

Table 13. Influence of nitrogen incorporated with compost prior to planting on the yield and nitrogen level in corn tissue. Values represent one replication and are not treated statistically.

Treatment lbs N/acre	Nitrogen Concentration of Leaf Tissue, %	No. Ears/ Plot	Fresh Weight 3 plants, lbs
0	1.29	34	6
100	1.44	36	8
200	1.57	42	12
400	1.83	44	14
800	1.80	39	13

CHAPTER V

GENERAL CONCLUSIONS AND MANAGEMENT CONSIDERATIONS

Processing Bark-Sewage Wastes

Although this study utilized hardwood bark as the absorbant base material for composting, work of Knoll (1959), Karim and Chowdbury (1958), Gray, Sherman and Biddlestone (1971), and many others has shown that any dry, shredded, non-toxic, organic material will produce good compost.

This study has shown that bark, having an initially high C/N ratio requires a long maturation period and requires N supplementation under conditions where it will be used as a plant growth medium. Bark represents an excellent material for composting since it contains some N, significant amounts of P and K, and most of the essential trace elements important in promoting plant growth. Furthermore, it lacks toxic substances and is easy to handle with a wide variety of equipment from shovels to front-end loaders. Physical consistency and chemical characteristics of the finished product are excellent as a growth medium for plants. Composting should be recognized as a feasible technique of reducing the C/N ratio of products such as bark. The wettability of composted bark-sewage is a feature important to greenhouse managers, since poor wetting and water retention often characterizes dry, unshredded bark. Under the best conditions, a three month period of composting would appear to represent the minimum time requirement for preparation of the finished product.

Despite the cost involved it is advisable to utilize one of the several reactor systems to mix and provide containerization during the first three days of composting. One approach would be a slowly revolving drum (Schulze, 1961); another would be utilization of bins which could be emptied with a front-end loader or bins built on a slope to provide gravity flow of liquids from the mixture. In the above systems, dry solids could be saturated with liquid wastes and any excess drawn off and recycled to the compost. At the end of the third day, the compost will no longer drain by gravity and loss of microbes and nutrients to the surrounding area will be negligible.

The reactor should be insulated sufficiently so that heat loss is minimized. Air ducts are required to provide sufficient oxygen to keep the mixture aerobic. Too much air may cool the reacting mass and prevent the attainment of pasteurizing temperature. An oxygen probe, thermocouples, and six-hour interval dehydrogenase (TTC test) testing could provide an index of the condition of the mixture within the reactor.

When the tests show that pasteurizing conditions have been met, the mixture can be moved to the field. The windrow may be built daily for an extended period of time to provide about 1000 yd^3 of material but constructed in such a way that the cross-sectional area will allow aeration; the interior should not be permitted to go anaerobic (Webley, 1947). Sealing of the pile with a topping of one foot of finished compost is needed in order to develop high temperature and to retain moisture in the interior where the composting is occurring. When testing shows that temperature and oxygen levels are low in the interior, resulting from a gradual temperature decline, turning is required to

allow the dry outside layers to be recycled. Many devices exist for turning such as a front-end loader, plow, and road grader (Kupchick, 1966). Considerable space is necessary for ease in managing large scale windrows. Two turnings of compost at monthly intervals followed by a three month maturation period provides a composted product of excellent physical consistency with a manageable C/N ratio which may be used as a plant growth media; pH and nutrient requirements can easily be met.

As in the reactor phase, windrows should be monitored, using such equipment as thermocouples, an oxygen probe, and the dehydrogenase (TTC) test. When the mature compost is 3 - 6 months old, test plants also provide a useful index of N status within a few days growth (Jann, Howard, and Salle, 1960; Keller, 1961).

Although all the methods available to characterize the finished compost were not used in this project, the following examinations are suggested to provide means of comparing composts, peat mixes, and other organic-rich soil media.

1. Water-holding capacity
2. Adsorption/Exchange capacity - anions & cations
3. Physical consistency (pore volume, texture, structure)
4. C/N ratio

After 90 days of composting, microbial populations of bacteria, actinomycetes, and fungi are significantly reduced in the bark-sewage mixture (Figure 6). During the composting process, a marked change occurs in the type and number of organisms present. In the initial stages, the abundance of energy rich organic material causes a dramatic increase in bacterial population. Changes in population levels of

actinomycetes and fungi were ten to twenty-fold during composting, but remained much lower than bacterial population levels. Pasteurization temperatures were achieved during the early stages of the composting process below one foot after which time temperature levels failed to reach temperatures beyond 54°C. Microbial levels declined steadily during the composting and no evidence of plant pathogenic organisms appeared when the composted bark-sewage mixture was used in plant studies. When compost was purposely seeded with the indicator organisms Escherichia coli, Salmonella heidleberg, and Candida albicans, none of these organisms were evident in the compost 36 hours after exposure to composting temperatures (Table 9). Pathogens near the surface of the windrow will persist unless a covering of previously pasteurized composts is used to hold heat and moisture within a kill zone at depths beneath one foot. Windrow turnings after the first heating should then assure pathogen destruction (Wiley, 1962; Lenhard, 1963).

Utilizing Bark-Sewage Compost

The cation and anion exchange capacities of bark-sewage compost lie intermediate between that of peat and soil. In this respect, adsorption capabilities for nutrients are highly favorable if this material were to be used as a plant growth medium. Water retention characteristics are likewise favorable for this product.

The C/N ratio of fresh bark was between 200 -350; while well composted mature compost reached an acceptably low level of about 25/1. A distinct need for supplemental nitrogen exists if the finished product is used to support plant growth. This N requirement can satisfactorily be met for a six week period by addition of 2.24 lbs N/yd^3 to mature compost. Because some sources of nitrogen also increase acidity the

choice of N-source is important. Calcium or magnesium nitrate, sodium nitrate, potassium nitrate, cyanamid, and natural sources of nitrogen such as tankage, guano, fish scrap, or dried sewage sludge require less lime for neutralization and are preferred as N-sources. Beyond six weeks, further nitrogen must be administered or a higher level of N supplied initially using a slow release N source. The needs of P and K are not as great as for N and basal rates of 1.12 lbs K_2O and P_2O_5/yd^3 should prove satisfactory with composted bark products. The contribution of nutrients from the sewage which was initially added to the bark must be considered insignificant based on the results of this study.

When bark or sawdust is used as the absorbant medium in composting, the final pH after a years maturation remains distinctly acid. It would be a fundamental error to correct this low pH prior to or during composting by addition of lime, but it would also be a mistake not to mix heavy applications of lime long before a crop was planted. Magnesium-rich limestone, finely ground and mixed with organic rich soil reacts slowly so that crops requiring neutral pH may suffer in bark-compost-soil mixtures unless limed heavily. The carboxyls, phenols, and other alcoholic hydroxyls which cause the low pH of organic level soils persisted after long composting in bark compost (Tisdale and Nelson, 1966). Organic acids produced by microbial activity may have solubilized the low calcium and magnesium sources in the soil and hasten their removal by leaching (Bodrova and Ozolina, 1968). Liming of the compost-soil mixture will also assure that the molybdenum which is less available in acid soil will remain available and that manganese which could reach toxicity levels will remain depressed. One of the easiest methods of increasing nitrogen in this compost-soil mixture

would be to encourage growth of a leguminous crop. Unfortunately legumes require soil with high pH; it may be necessary to grow buckwheat or annual rye grass upon a limed compost soil to allow time for pH adjustment prior to growing a legume crop (King and Morris, 1973).

Composted bark products appear entirely satisfactory for use as replacement media for peat mixtures now available commercially for greenhouse operations. Consistency of material and standardization of quality control of finished product represent significant but manageable needs. Nitrogen addition and pH adjustment are major requirements for the compost to serve as a plant growth medium.

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APPENDICES

Appendix Table 1. Transient Fungi and yeasts which existed within the compost. Species marked by asterisk were identified to genus but insufficient data was obtained to determine species. Species enclosed in parentheses resemble very closely the strain described by others in the literature so that the taxonomy was brought to species level.

Rhizopus nigricans	Absidia orchidis
Rhizoctonia sp.*	Rhizopus arrhizus
Geotrichum candidum	Candida (parapsilosis)
Mucor pusillus	Cladosporium herbarum
Penicillium digitatum	Rhodotorula rubra
Mucor racemosus	Aspergillus tamarii
Torulopsis sp.*	Zygorhynchus vuilleminii
Aspergillus flavus	Trichosporon cutaneum
Absidia (ramosa)	Verticillium sp.*
Saccharomyces sp.*	Syncephalastrum sp.*
Pullularia sp.*	Pichia sp.*
Pythium sp.*	Cylindrocarpon sp.*
Hanisenula sp.*	Chaetomium (thermophile)
Trichoderma koningi	Lipomyces sp.*
Talaromyces (Penicillium) duponti	Sporotrichium thermophile
Stysanus stemonitis	Fusarium moniliforme
Gliobotrys (alboviridis)	Humicola insolens
Humicola griseus var. thermoideus	

Appendix Table 2. Organisms consistently present in the compost during the composting process. Species marked by asterisk were identified to genus but insufficient data was obtained to determine species. Species enclosed in parentheses resemble very closely the strain described by others in the literature so that the taxonomy was brought to species level.

INDIGENOUS FUNGI

Aspergillus fumigatus	Fusidium sp.*
A. terreus	Penicillium citrinum
A. amstelodami	P. ochrochloron
A. repens	P. 5 species*
A. nidulans	Humicola (lanuginosa)
A. candidus	Thermomyces lanuginosus
A. versicolor	Hormodendron viride
A. spinulosus	H. resinae
A. proliferans	Cladosporium lignicolum
Scopulariopsis murina	Cl. (herbarum)
Oospora variables	Memnoriella sp.*
Cylindrophora sp.*	Alternaria tenuis
Verticillium effusum	A. humicola
Monilia humicola	A. fasciculata
M. geophila	Mycelia sterilia

INDIGENOUS YEAST FUNGI

Rhodotorula glutinis	Debaromyces sp.*
Candida (salmonticensis)	Schizoblastosporon sp.*
C. (quilliermondi)	Torula thermophile
C. (membranefacieus)	

Appendix Table 2. (cont.)

BACTERIA	ACTINOMYCETES
Aerobacter (aerogenes)	Nocardia brasiliensis
Bacillus megatherium	Thermomonospora viridis
B. stearothermophilus	T. curvata
B. cereus	Micromonospora parva
B. mycoides	Thermoactinomyces vulgaris
Pseudomonad sp.* (seven isolates one of which appears to be P. fluorescens.. also member of Acidovorans and Alcaligenes group)	Actinoplanes sp.*
	Thermopolyspora polyspora
Flavobacterium sp.* (3 isolates; species unknown)	Streptomyces sp.* (5 species)
	S. violaceoruber
Micrococcus sp.*	ALGAE
Sarcina sp.*	Hormidium (nitens)
PROTOZOANS	Vaucheria (terrestris)
Chilomonas (paramecium)	Euglena mutabilis
Cyathomonas (truncata)	Protococcus vulgaris
Lycogala epidendrum	Dactylococcus (bicandatus)
Cercomonas (crassicanda)	Chlorococcum humicola
	Microcoleus vaginatus
	Porphyridium (cruentum)
	Kentrosphaera sp.*
	Diatoms (numerous unidentified)

Appendix Table 3. Osmocote Study. Dry weight of sudan grass tissue from eight harvests taken at two week intervals beginning four weeks after planting. Values given are means of four replications in grams taken for each of six nitrogen treatment levels. For a given harvest, means followed by the same letter are not significantly different according to Duncan's Test at the 5% level.

Treatment lbs N/yd^3	Harvest Week 4	6	8	10	12	14	16	18
0.00	.44a	.60a	.42a	.29a	.23a	.88a	.13a	.07a
0.14	.70a	1.98b	3.04b	2.74b	2.52b	1.98b	2.10b	1.48b
0.28	1.13b	2.99c	4.52c	3.43c	3.28c	2.98c	2.67c	2.28c
0.56	1.95c	6.52c	7.08d	4.91d	4.72d	6.52d	3.12d	2.45c
1.12	3.08d	11.98e	7.79e	6.96e	6.51e	11.98e	4.21e	3.63d
2.24	5.87e	17.48f	9.51f	8.94f	7.89f	17.48f	4.36e	3.93d

Appendix Table 4. Nitrogen Study. Dry weight of sudan grass tissue from nine harvest dates taken at two week intervals beginning four weeks after planting. Values are means of four replications in grams taken from each of eleven nitrogen treatment levels. For a given harvest, means followed by the same letter are not significantly different by Duncan's Test at the 5% level.

Treatment lbs N/yd^3	Harvest Week 4	6	8	10	12
0.00	2.55a	3.15a	1.80ag	0.85a	0.53a
0.14	2.95b	3.48bi	2.03abf-h	1.03abi	0.63abgi
0.28	3.05b	3.63bch	2.00abf-h	0.90ab	0.68abgi
0.56	3.28c	3.95d-g	2.43c	1.43cgh	0.93cd
1.12	3.48cd	3.80ce	2.53cd	1.53cdgh	0.93d
2.24	3.68dei	4.10df	2.68cd	1.63de	1.13c-e
3.36	4.23g	4.35g	3.23e	1.95f	1.18d-f
4.48	3.98fh	3.95e-h	3.23e	1.75d-f	1.18d-f
6.72	4.05fg	3.83ceh	2.00afg	1.33gh	0.63agi
8.96	3.80ehi	3.53bhi	1.75g	1.28h	0.65abg-i
13.44	3.58di	3.35i	1.85agh	0.93abi	0.63ai

Harvest 14 through 20 were uniformly low and were not significantly different between treatments.

Appendix Table 5. Potassium Study. Dry weight of sudan grass tissue from nine harvest dates taken at two week intervals beginning four weeks after planting. Values are means of four replications in grams taken for each of eleven potassium treatment levels. For a given harvest, means followed by the same letter are not significantly different by Duncan's Test at the 5% level.

Treatment lbs K_2O/yd^3	Harvest Week							
	4	6	8	10	12	14	16	18
0.00	6.35af	4.20ae-h	3.35ag	2.78a	2.43agh	1.98a	1.38ah	1.13a
0.14	6.93be	4.43abe-g	3.50ab	3.08ab	2.78abfg	2.45bc	1.43abh	0.68bdgi
0.28	7.45c	4.53bc	3.65ef	3.55cef	3.13bcf	2.68b	2.00cf	0.53bcfhi
0.56	7.60cd	4.63cd	4.43c	4.25d	3.78d	2.85c	2.05cdf	0.80ceg
1.12	7.68cd	4.98d	4.65c	4.28d	3.75de	3.18d	2.43de	0.95ae
2.24	6.58abef	4.55cd	4.05d	3.63cef	3.40ce	3.05cd	2.28c-e	1.05ae
3.36	6.55aef	4.15e-h	3.65bef	3.30bef	2.70afg	2.35e	1.78abfg	0.65bfgij
4.48	6.18f	4.08f-h	3.53abe	3.25bf	2.33gh	1.58f	1.58abgh	0.93adeg
6.72	5.70gh	3.95gh	3.15fg	2.28g	2.08h	1.15gh	1.18hi	0.65bfj
8.96	5.58gh	3.93h	2.73h	1.95g	1.25i	1.05g	0.90ij	0.75dgij
13.44	5.38h	3.30j	2.43i	1.55h	0.55j	1.13gh	0.53j	0.80defj

Harvest 20 showed only slight difference in dry weight between check and highest treatment level.

Appendix Table 6. Phosphate Study. Dry weight of sudan grass tissue from eight harvests taken at two week intervals beginning four weeks after planting. Values are means of four replications in grams taken for each of eleven levels of rock phosphate. For a given harvest, means followed by the same letter are not significantly different by Duncan's Test at the 5% level.

Treatment lbs P_2O_5/yd^3	Harvest Week								
	4	6	8	10	12	14	16	18	20
0.00	3.80a	4.05a	3.30a	2.40a	1.43abj	1.35ag-j	0.83a	0.70ai	0.50ahi
0.14	3.95ab	4.08ab	3.40a	2.45ab	1.35bj	1.68bcef	1.20bfh	0.90bh	0.80bg
0.28	4.15bc	4.38c-h	3.85bhi	2.58a-cg	1.58a-cg-j	1.68cf	1.50c	1.28cf	1.00cf
0.56	4.17b-dhj	4.50c-eg	3.95ceg	2.90deh	1.85d-f	1.80b-e	1.78de	1.60de	1.35d
1.12	4.40degij	4.78d	4.38d	2.78cdf-j	1.95d-f	1.85b-e	1.60c-e	1.48c-e	1.35e
2.24	4.48e-gi	4.38d-h	3.90ceg	2.82d-fh	1.73ce-h	1.68cf	1.60ce	1.38e	1.15cd
3.36	4.45e-gi	4.38e-h	3.85e-g	2.68cfgij	1.73cf-h	1.45aeg	1.30bf-h	1.13fg	0.95bf
4.48	4.30cdg-j	4.30fhi	3.73bfhi	2.58abg	1.50abgij	1.23f-j	1.10fi	1.00bg	0.75g
6.72	4.15bh	4.38gh	3.80bf-h	2.78cf-j	1.55abg-j	1.18hj	1.10fgi	0.78ah	0.48hi
8.96	4.25cdh-j	4.28hi	3.65hi	2.60a-cgi	1.45abij	1.20h-j	1.20f-h	0.50ij	0.38ij
13.44	4.18bchj	4.15abi	3.60i	2.60a-cgj	1.35j	1.03j	0.90ai	0.43j	0.23j

Appendix Table 7. Nitrogen Study. Tissue concentrations of five elements from selected harvests. Values are the mean of four replications in percentage taken from six sulfur-coated urea treatments applied to compost prior to planting. For a given harvest, means followed by the same letter are not significantly different by Duncan's Test at the 5% level.

Treatment lbs N/yd^3	Nitrogen %			Phosphorous %		Potassium %		Calcium %		Magnesium %	
	Harvest Week										
	4	5	6	6	16	6	16	6	16	6	16
0.00	1.85a	1.45a	1.30a	.36a	.30a	2.67a	2.18a	.69a-c	.79ab	.17a	.20a
0.28	1.90ab	1.58a	1.59a	.34a	.40bc	2.72ab	2.74b	.68b-e	.77b	.16a	.30b
1.12	2.33ab	2.28b	2.18b	.35a	.46bde	2.88a-c	3.44cd	.79bc	.79bc	.22b	.38c
3.36	3.10c	3.19c	2.69c	.31a	.38c	3.13cd	3.29cd	.50ce	.71d	.22c	.39c
6.72	3.86d	3.64d	3.22d	.29a	.43b-e	3.17c-e	3.11bde	.49de	.82ab	.27d	.45d
13.44	4.09d	4.22e	4.00e	.28b	.41bce	3.13ce	2.75be	.44e	1.07a-c	.26d	.49d

Appendix Table 7. (cont.)

Treatment lbs N/yd^3	Zinc ppm		Aluminum ppm		Strontium ppm		Molybdenum ppm	
	Harvest Week							
	6	16	6	16	6	16	6	16
0.00	67.5a	73.8a	663.3a	959.3a	36.3a	42.5a	1.21a	4.73a
0.28	66.3a	75.5b	738.8b	918.8b	37.3a	42.5a	1.12a	4.11b
1.12	84.0b	93.8c	434.8c	830.0c	35.3a	45.8b	1.11a	2.50c
3.36	90.5c	93.0c	349.8d	686.0d	31.8b	42.3a	.87b	2.99d
6.72	91.0c	92.8c	195.8e	525.3e	32.8b	47.3b	.93b	2.30c
13.44	92.0c	93.8c	98.3f	872.5c	31.0b	52.5c	.89b	3.52d

Appendix Table 7 (cont.)

Treatment lbs N/yd^3	Manganese ppm		Iron ppm		Boron ppm		Copper ppm	
	Harvest Week							
	6	16	6	16	6	16	6	16
0.00	152.5a	185.3a	648.0a	946.3a	61.8a	35.8a	13.3a	11.3a
0.28	149.3a	142.8b	670.8b	853.5b	46.0b	32.8b	14.5b	11.0a
1.12	113.5b	125.5c	561.8c	768.8c	39.8c	28.5c	11.0c	12.0b
3.36	105.3c	95.8d	462.3d	664.5d	40.5c	31.3b	11.0c	12.3b
6.72	102.8c	109.8e	374.5e	614.0e	38.0c	30.8b	12.8a	13.3c
13.44	91.8d	130.5c	323.3f	669.5d	34.0d	32.5b	12.3a	13.8c

Appendix Table 8. Potassium Study. Tissue level analyses of eleven selected elements from harvests 6 and 14. Values are means of four replications taken from six treatments applied to compost prior to planting. For a given harvest, means followed by the same letter are not significantly different by Duncan's Test at the 5% level.

Treatment lbs K_2O/yd^3	Potassium %		Phosphorus %		Calcium %		Magnesium %	
	Harvest Week							
	6	14	6	14	6	14	6	14
0.00	2.76a	1.86a	.38a-f	.33a-f	.72a-f	1.19a-f	.43a	.67a
0.28	2.77ab	2.27b	.44a-d	.36a-d	.64a-f	1.07a-f	.39a-d	.55b
1.12	3.05a-c	2.63c-e	.41a-df	.40ce	.63a-f	.90a-f	.36b-d	.58abd
3.36	3.18a-d	2.59bd-f	.38a-f	.30d	.62a-f	1.34a-e	.35b-d	.51bd
6.72	3.49cd	2.79cd-f	.30ad-f	.38ce	.68a-f	.79a-f	.23e	.42de
13.44	4.67cd	2.75cd-f	.32acd-f	.34a-f	.75a-f	.70a-cef	.28e	.37e

Appendix Table 8. (cont.)

Treatment lbs K_2O/yd^3	Manganese ppm		Iron ppm		Boron ppm		Copper ppm	
	Harvest Week							
	6	14	6	14	6	14	6	14
0.00	105.0a	129.8a	642.5a-e	869.5abef	22.5a-f	27.3a-df	12.8a-f	13.0a-f
0.28	113.8ab	153.3a-c	481.0a-e	883.8abef	22.8a-df	29.3a-f	14.0a-e	12.0a-f
1.12	136.0a-c	113.8ab	701.8a-d	460.0cd	22.0a-f	30.3a-f	13.5a-e	13.0a-f
3.36	171.0b-d	135.0a-c	585.5a-d	577.3cd	23.0a-df	30.8a-f	14.8a-d	11.8a-f
6.72	213.3d	138.3a-c	982.3ace	793.3bd-f	20.0acef	31.8b-f	12.5a-cef	12.8a-f
13.44	219.3d	159.3ac	756.3a-e	847.8bef	21.0a-f	30.0a-f	11.0aef	13.3a-f

Appendix Table 8 (cont.)

Treatment lbs K_2O/yd^3	Zinc ppm		Molybdenum ppm		Aluminum ppm	
	Harvest Week					
	6	14	6	14	6	14
0.00	93.5a-f	92.75a-f	3.01a-f	9.18a	712.3a-f	135.8abef
0.28	93.0a-f	92.25a-f	3.35a-f	8.90ab	362.0a-df	865.3abef
1.12	93.0a-f	92.75a-f	3.72a-f	5.60c-f	687.8a-f	491.5c-f
3.36	92.0a-f	93.00a-f	5.01a-f	4.96c-f	532.5a-f	520.5c-f
6.72	92.0a-f	92.75a-f	4.03a-f	4.94c-f	948.0acd-f	819.8a-f
13.44	89.0a-f	92.50a-f	4.75a-f	4.47cd	834.0a-f	467.8a-f

Appendix Table 9. Phosphorus Study. Tissue level analyses of seven selected elements, harvest week 6 and 12. Values are means of four replications taken from six treatments applied to compost prior to planting. For a given harvest, means followed by the same letter are not significantly different by Duncan's Test at the 5% level.

Treatment lbs P_2O_5/yd^3	Phosphorus %		Potassium %		Calcium %		Magnesium %	
	Harvest Week							
	6	12	6	12	6	12	6	12
0.00	.403a-d	.323a-e	3.04ade	2.37a-e	.593a-c	.883ab	.410a-c	.520acd
0.28	.385bc	.288b-d	3.14a-ce	1.94b-d	.550bc	.863b	.388acd	.418abe
1.12	.385c	.283cd	3.04c-e	1.80c	.528c	.985ac-e	.398a-c	.370b
3.36	.395b-d	.280d	3.14a-ce	1.85cd	.588b-d	1.035c-e	.383c-e	.430a-ce
6.72	.420a-e	.360ae	2.57d	2.47a-e	.665ade	.938abde	.318de	.433a-e
13.44	.448a-e	.318c-e	2.94de	2.10b-e	.703ade	.910abe	.313e	.390bc

Appendix Table 9. (cont).

Treatment lbs P_2O_5/yd^3	Manganese ppm		Iron ppm		Molybdenum ppm	
	Harvest Week					
	6	12	6	12	6	12
0.00	122.75ac	153.75a	386.00a-c	809.00a	1.33a-d	5.12ad
0.28	141.00a-d	228.25a-d	290.75bc	912.00a-c	1.14bc	6.85a-e
1.12	104.50c	214.00ac	233.50c	894.00ac	0.99c	5.44cd
3.36	130.25acd	266.50b-e	529.00a-d	950.00b-d	1.29b-d	8.69b-e
6.72	163.75abde	223.25ad	694.75abde	956.00b-e	2.49abde	3.29d
13.44	147.75a-e	251.00b-e	642.25abde	958.00b-e	2.56abde	5.63ac-e

BIOGRAPHICAL DATA

Name in Full: Raymond Henry Walke

Date of Birth: August 8, 1933

Place of Birth: Salem, Massachusetts

Secondary Education: Classical High School, Springfield, Massachusetts
Wilbraham Academy, Wilbraham, Massachusetts

Collegiate Institutions Attended:

Lehigh Univeristy	1952-1960 B.S.
East Carolina College	1958-1959
Wesleyan University	1962-1967 M.A.
Adelphi College	1961-1962
C. W. Post College	1962-1963
Nathaniel Hawthorne College	1969-1970
University of New Hampshire	1967-

Honors or Awards:

Physics Award, 1952
Sigma Cum Laude, 1952
Phi Sigma, 1972
NSF Faculty Fellowship, 1970

Positions Held:

Mining Engineer, Eagle Mine, New Jersey Zinc Co., Gilman, Colorado	1960-1961
Instructorships:	
Suffolk County Community College, Selden, New York	1961-1962
Canaan College, Canaan, New Hampshire	1963-1965
Franklin Pierce College, Rindge, New Hampshire	1967-1968
New England College, Henniker, New Hampshire	1969-1970
Nathaniel Hawthorne College, Antrim, New Hampshire	1967-1970
New Hampshire Vocational-Technical College at Berlin, Berlin, New Hampshire	1974-