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# Animal Waste Composting with Carbonaceous Material

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# ANIMAL WASTE COMPOSTING WITH CARBONACEOUS MATERIAL

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## FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and user community.

This report covers research conducted in the combining of selected organic waste materials in a manner that eliminates the formation of secondary pollutants and produces a safe, aesthetically pleasing, and effective soil amendment. The materials used are of agricultural origin but have municipal and industrial analogs. Consequently, the information contained in this report should be of interest to anyone concerned with the disposal of organic solid wastes.

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## ABSTRACT

High-rate thermophilic composting of animal wastes and added carbonaceous waste followed by land application has considerable potential for the treatment and useful final disposal of organic wastes. The process described in this report involves a mechanically mixed, thoroughly aerated, thermophilic first stage in which the readily available carbonaceous materials are utilized by bacteria during the stabilization of the nitrogenous wastes. This is followed by a curing period in which the hollocellulose is partially decomposed, principally by fungi. The compost may then be added to soil.

During the thermophilic stage, the composting material must be continuously mixed at a slow rate to ensure that oxygen reaches all parts of the mass. Additionally, forced aeration must be used otherwise the oxygen supplied is used up in less than 2 minutes. Under forced aeration, nitrogen losses are minimized. The completion of this stage is recognized, in batch operation, by a decrease in both temperature and oxygen usage.

Continuous runs were carried out in which up to 60-80 percent of the mass could be replaced daily. For the material removed during both batch and continuous runs the undersirable characteristics contributed by animal waste had disappeared.

Placed in storage after the initial thermophilic phase, the compost again heated as filamentous fungi spread through the material. During this second stage (about 4 weeks), the hollocellulose content decreased and the cation-exchange-capacity increased.

Testing the compost's effect on plant growth was done in three phases. The first phase involved spreading the compost over grass as a top-dressing; the second was a greenhouse study using tomatoes, wheat, millet, and beans; and the third was a field test on tomato crops.

In all three tests, the compost exhibited significant beneficial effects. The mulching experiment yielded increases in the dry weights of grasses of up to 57 percent over the control. The greenhouse experiments (terminated after 90 days) showed increases in dry weights of up to 400 percent for tomatoes and wheat over the control (no compost or inorganic fertilizer added).

Field studies using tomato plants were carried out at six compost application rates ranging from 5.6 to 488 tonnes/ha. Although the plots having lower treatments yielded fruit approximately 1 to 2 weeks earlier than those with the higher treatments, both the tomato size and total yield over the growing season increased with increasing compost application. The tomato size

increased from an average of 92 g for the control to 119 g for the maximum treatment whereas the maximum yield increased from less than 50 to an estimated 167 tonnes/ha.

This report was submitted in fulfillment of Contract No. 00270 by North Carolina State University under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period June 1, 1967, to May 31, 1970, and work was completed September 30, 1975.

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## SECTION 1

## CONCLUSIONS AND RECOMMENDATIONS

The following conclusions resulted from the data and experience obtained during the fulfillment of Grant Number EC 00270.

1. The practicality of aerobic thermophilic composting of animal wastes with carbonaceous material has been demonstrated. A wide range of types of both materials are suitable for use in the process.
2. The process is a two-stage fermentation. The first stage occurs under conditions of forced aeration, mechanical mixing and very high temperature, and may be accomplished in batches or as a continuous process. In this stage bacteria are the principal active agents and the soluble components of the mixture are stabilized. The second stage occurs as actinomycetes and themophilic and thermotolerant fungi oxidize the cellulosic and related materials.
3. The end product is characterized by a high cation-exchange capacity, a narrow carbon-to-nitrogen ratio, elimination of offensive odors, and a balanced mixture of nutrient elements suitable for use as a soil amendment.
4. The end product stimulates plant growth either when incorporated into the soil prior to planting the crop or when applied as a surface dressing to establishing sod.
5. Growth stimulation occurs over a very wide range of application, up to and including using pure compost as the rooting medium.
6. Because of the very wide range of useful application rates, the end product can be used economically at low rates to provide nutrients and improve soil physical properties or it may be used at very high rates where it is desirable to use the soil as a sink in a waste disposal system.
7. The total yield, fruit size, flavor, and nutritional quality of tomatoes grown with the compost are all excellent; both in the greenhouse and in the field. Fruit ripening may be delayed by a few days where compost is employed.
8. The process appears to be economically attractive to investors. It definitely offers an excellent means of waste control and disposal to animal growers. This would be especially true where there are concentrations of animal populations such as occur in poultry or pork production facilities.
9. The entire process involves the production and use of a valuable material from two potential environmental pollutants and does not result in the transformation of one form of pollutant into another form of pollutant. When employed properly it is environmentally safe.

The following recommendations have been made in light of experience gained during the research and evaluation phases of the grant.

1. It would usually be preferable to locate a composting facility as

described herein at or quite near the site of origin of the animal waste since it is easier, cheaper, and more sanitary to transport the much drier, and virtually odorless carbonaceous material.

2. Mechanical mixing and forced aeration are required during the first phase of the process. The exit gasses should be monitored for oxygen content which should not be allowed to drop below 5 percent concentration.

3. The moisture content of the mixture placed in the composter drum should be approximately 50 percent for optimum fermentation conditions.

4. When the compost is incorporated in soil at very high rates, the moisture infiltration rate may be excessive for a few days. Thus irrigation may be needed until the plant roots become established. At moderate or low rates of application this is not a problem.

5. A very satisfactory compost can be made using shredded paper as the carbonaceous material. Some paper contains a large amount of clay sizing. If such paper is used and high rates of soil application are employed, early cultivation may be recommended to prevent the formation of a thin crust at the surface of the soil. Again this is not a problem at moderate or low rates of application.

6. An economic analysis is recommended before a commercial composting operation is begun. An adequate, continuous supply of animal waste and carbonaceous materials must be assured. Adequate land area for the entire process must be available. A satisfactory packaging, transporting, advertising, and marketing system must be available. Finally, an adequately-sized market for the end-product must exist within an economical hauling distance of the production facility.

# SECTION 2

# INTRODUCTION AND LITERATURE REVIEW

## THE EXTENSIVE SOLID WASTE PROBLEM

### Amounted Generated

According to Can We Conquer the Solid Waste Mountain? (Anon., 1968), the per capita production of municipal refuse in the United States grew from 1.25 kg per day in 1920 to 2.04 kg per day in 1965. Presently, the refuse production per capita is believed to be increasing at about four per cent per year. The 150 million tonnes of solid wastes which were discarded nationally in 1966 will, therefore, reach 236 million tonnes by 1976. The disposable container, disposable tissue, disposable garment, and the many "durable" items combine to compound the nation-wide disposal problem.

Unfortunately, municipal refuse is only a part of the solid waste problem. Industrial and agricultural wastes also contribute greatly. Animal wastes have become a particularly serious problem since the confinement of many animals on a small area has become common. It is now quite common in the hog industry to find confinement units which market 3000 to 10,000 hogs per year and poultry ranches which house up to one million birds at one time. In 1970 the population of farm animals was estimated to be in excess of 3.1 billion animals including 189 million cattle, sheep and swine; 310 million hens; and 2.8 billion fryers (U.S. Department of Agriculture, 1970).

The volume of waste produced by these animals is equally large. Poultry manure alone totals about 36 million tonnes annually. Cattle produce approximately 64 kg of manure per day per tonne of live weight, and hogs average 7 kg per 100 kg of live weight. Farm animal wastes total about ten times the current human wastes in the U.S.

### Ultimate Goal of Recycling Waste

Whatever the treatment method employed, it must be realized that the ultimate answer to the solid waste problem will involve the recycling of all organic solid waste to the soil in a safe, hygienic manner. Ultimately, more attention must be given to the realization of this ideal. It is quite impossible for the human species to continue present rates of population increase and per capita consumption of goods and simultaneously maintain an environment in which waste products do not become inhibitory to life. Therefore, consideration must be given to a treatment method for total recycling of all materials consumed and subsequently discharged.

Composting is one such method for handling solid organic wastes. It not only provides a means of disposing putrescible wastes, but the final product may also be utilized as a valuable soil amendment.

Keller (1961) stated that the following effects should be attained through the use of compost as a soil additive:

1. Improvement in soil structure with greater friability and pore volume which results in improved moisture distribution and gas exchange;
2. Increased retention of plant-available moisture;
3. Increased retention of plant nutrients due to chelation and ion-exchange properties of humus;
4. Prevention of erosion because of improved soil structure; and
5. Promotion of plant growth by providing slowly available nutrients and increased activity of the micro- and macro-fauna in the soil.

Depletion of soil organic matter in certain regions of high-intensity agriculture is approaching a critical stage (Schatz, 1966). A low level of organic matter causes low productivity in many soils. Chemical fertilizers offer no solution to this problem. The solution is to replace the organic matter in the soil.

Although addition of raw waste into the soil results in rapid decomposition, humus in the soil is also decomposed. The total soil humus content is thus raised only a little or not at all. The high biological activity may also result in the fixing of plant nutrients and a depletion of oxygen. On the other hand, properly treated compost increases soil humus content and provides plant nutrients in a slowly available form.

The potential markets for compost may be divided into two categories: farm markets and specialty markets. Specialty markets include home gardens and lawns, parks, golf courses, plant nurseries, flower and vegetable production areas, etc. Partridge (1969) indicated that sales to farmers should involve large volumes at low unit cost, while specialty market sale units should be smaller and the unit price higher.

## COMPOSTING

### Engineering and Biological Aspects of High-rate Composting

Purpose of Mechanized Composting--

The purpose of mechanized composting is to accelerate the rate of solid waste decomposition--by means of aerobic, thermophilic composting--so that large amounts of waste may quickly be treated and disposed (Wylie, 1960). This is accomplished through a high degree of environmental control. By optimizing control variables such as nutrient supply, moisture content, temperature, aeration rate, and acidity (pH), high rate composting can be accomplished.

Characterization and Routine Control Testing--

For rapid composting and stabilization of solid organic waste, it is

necessary that the following three conditions exist during the composting operation (Eckenfelder and McCabe, 1963):

1. The waste contains all the nutrient elements required for biological growth, and in the proper amounts;
2. The environment is completely aerobic, so that there is always an excess of oxygen in the system; and
3. The environment is optimum with respect to temperature and acidity at all times.

Characterization (analysis) of raw waste material and routine control tests provide the information needed to ensure that all the above conditions are attained, and the system is operating at the peak of its efficiency. By this means, the biological population may be kept in the phase of maximum growth (Figure 1). The maximum rate of organic matter stabilization will thus be accomplished.

Batch Composting--

Schulze (1962) confirmed that batch composting -- which is treatment of a single collection of waste--proceeds through a series of four distinct phases: 1) fermentation; 2) acid formation; 3) thermophilic activity; and 4) temperature decline. During the fermentation phase, complex organic molecules (proteins, polysaccharides, fats, etc.) are hydrolyzed by extra-cellular enzymes to more simple compounds. These compounds are then further degraded to simple organic acids, such as lactic acid, acetic acid, and other organic and inorganic compounds (Eckenfelder and McCabe, 1963). Snell (1960) found that 35°C is optimum for these two phases of aerobic decomposition by mesophilic organisms. However, when the temperature exceeds 45°C, thermophilic microorganisms develop and replace the mesophiles in decomposing the waste material. The temperature range for thermophilic microorganisms is usually reported as 45 to 70°C. As mentioned earlier, thermophilic microorganisms are very effective for rapid decomposition. Finally, as available nutrients are deplenished and the temperature subsides, actinomycetes and fungi become actively involved in the decomposition of cellulose and other resistent carbon compounds.

Batch composting studies are quite useful in establishing the optimum operating parameters for efficient and rapid decomposition. Gotaas (1956) reported that the time required for composting depends upon several factors:

1. The initial carbon to nitrogen ratio;
2. The degree of mixing and particle size;
3. The moisture content; and
4. The maintenance of aerobic conditions.

In addition, efficient composting requires control of temperature, pH, and recycle of seed compost. The following sections are devoted to a thorough look at these operating parameters.

Carbon to nitrogen ratio--Microorganisms utilize 30 parts of carbon for each part of nitrogen (Gotaas, 1956). Therefore, an initial C:N of 30 would seem most favorable for rapid composting. However, many forms of carbon are not readily available for decomposition; carbon contained in cellulose and

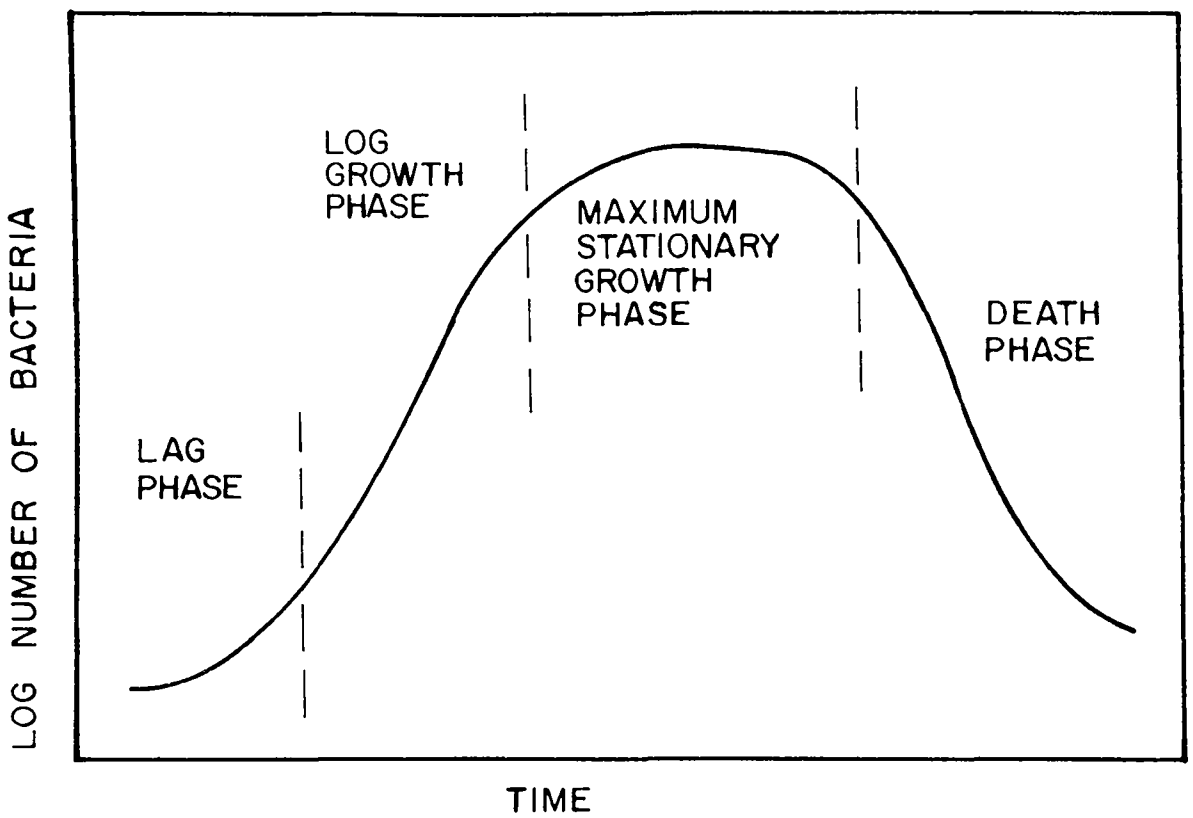


Figure 1. Growth phases in biological processes

lignin, for example, is resistant to degradation. A C:N of greater than 30 might therefore be expected to be optimal. Initial ratios reported as optimum generally range from 25 to 50.

Nitrogen loss in the form of ammonia is also affected by the C:N ratio. Since conservation of nitrogen is an important objective of aerobic composting, the C:N ratio should be adjusted for maximum nitrogen conservation. According to Gotaas (1956), there are three alternative phases in the relation of nitrogen supply and conservation to available carbon in biological decomposition:

1. When the initial C:N ratio is low, nitrogen is lost as ammonia;
2. When the required amount of carbon to nitrogen for microbial utilization is present, decomposition proceeds without much loss of nitrogen; and
3. When the initial C:N is high, nitrogen is conserved, but the rate of decomposition is lowered.

When adding mature compost to soil, a C:N ratio of 20 is generally mentioned as the upper limit at which there is no danger of robbing the soil of nitrogen. Therefore, the higher the initial C:N ratio, the greater is the work required by the microorganisms to reach the ratio of 20. Therefore, when other conditions are optimum, the rate of compost production is determined by the initial ratio of carbon to nitrogen. In addition, it must be remembered that the total carbon and nitrogen in a material or mixture is not the only important factor. The form and availability of these nutrients are also very important to the rate of composting and nitrogen conservation.

Moisture content--The moisture or water content of a compost material is important because of the essential role of water in the metabolism of microorganisms and indirectly in the supply of oxygen. The optimum moisture content for aerobic composting of municipal refuse lies in the range of 40 to 60 percent.

Schulze (1961) determined the relation between moisture content of municipal refuse and activity of the microorganisms involved in composting. He measured the biological activity in terms of the rate of oxygen consumption (Figure 2). At 10 percent moisture, no measurable oxygen uptake was found. Even at 20 percent moisture, the consumption was practically negligible. However, from this point the rate of oxygen consumption increased rapidly with moisture to a maximum at a moisture content of 60 percent.

The results of Schulze clearly indicate two extremes:

1. Too little moisture deprives the microorganisms of water needed for metabolism; and
2. Too much moisture displaces air by filling free pore space, thereby inducing anaerobic decomposition.

Moisture content affects nitrogen consumption, but to a much less extent than the C:N ratio or acidity (pH). Ammonia escape increases as the moisture decreases to below 40 percent (Gotaas, 1956).

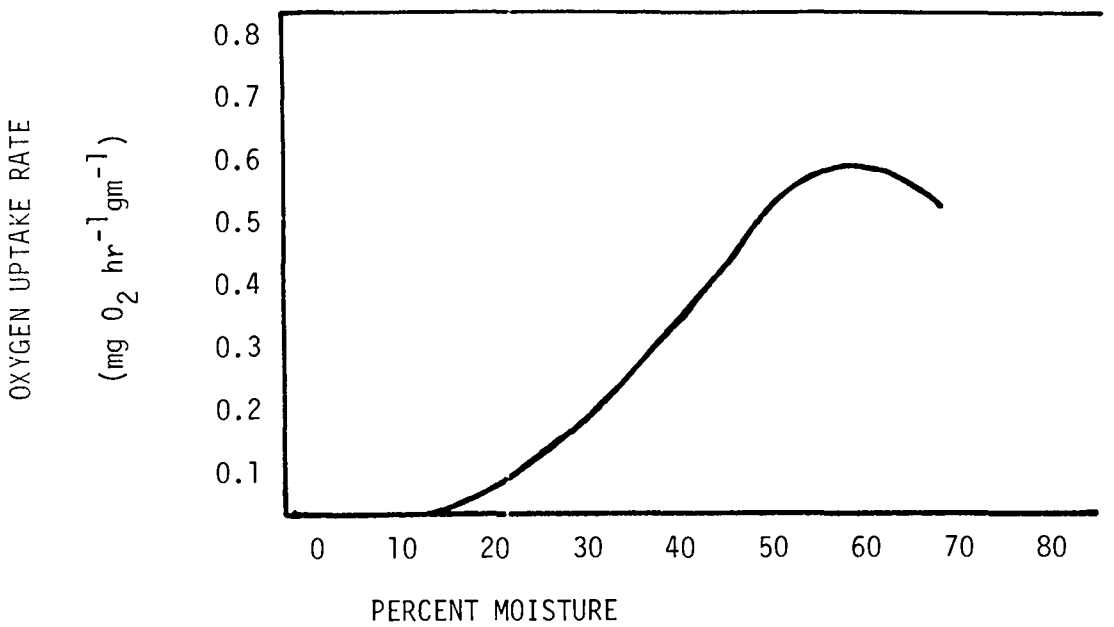


Figure 2. Relation between moisture and oxygen uptake rates (Schulze, 1961)

Aeration--Aerobic organisms require free oxygen just as they require moisture and food. Oxygen is normally provided by either, or a combination of, forced aeration and mechanical stirring. Schulze (1962) found that with thermophilic composting a continuous air supply of 0.30-0.71 $m^3$ per day per kg of volatile solids was needed. Insufficient air caused the temperature to decrease sharply. At the other extreme, continuous mixing and over-aeration also decreased temperature and tended to reduce moisture by increased evaporation. Partridge (1969) found that the maximum air requirement for optimum composting is 2.6 $m^3$ per day per kg of volatile solids.

In studies conducted by Schulze (1960), the actual oxygen consumption rate varied from one to five mg $O_2$ per g initial volatile solids per hour for a temperature range of 35 to 65°C. Translated into aeration requirements, 0.39 $m^3$ of air per kg of volatile solids per day would be needed during the period of peak demand. Obviously, in order to maintain highly aerobic conditions, considerably more oxygen must be provided than is consumed. Adequately aerobic conditions have been reported at oxygen concentrations ranging from 10 percent to as low as 2 percent (Grub et al., 1970; Willson, 1971). The 2 percent figure has been challenged (Willson, 1971).

Aeration and stirring adversely affect nitrogen conservation. However, if the initial C:N ratio is sufficiently high and the pH value sufficiently low, the nitrogen losses should be small.

Temperature--The response of temperature during the four phases of batch composting has been mentioned earlier. The high temperature during the thermophilic phase of composting represents energy in excess of that required by the microbes for maintaining metabolic reactions. Gotaas (1956)

showed that under aerobic conditions as much as 674 kcal of heat may be released per gram-mole of glucose decomposed. It is important, therefore, to maintain an aerobic condition and its accompanying high release of energy which promotes rapid decomposition of solid waste.

There is a strong linear relation between temperature and oxygen consumption rate (Schulze, 1960, 1962). The higher the temperature, the greater is the oxygen uptake (Figure 3). An increase of 10°C between 35 and 65°C produced a doubling of the oxygen consumption rate (i.e., $Q_{10} = 2$). The results leave no doubt that at temperatures in the thermophilic range, oxygen consumption rates are considerably higher than at temperatures in the mesophilic range. The general concept that thermophilic temperatures are connected with a higher rate of compost stabilization is therefore correct.

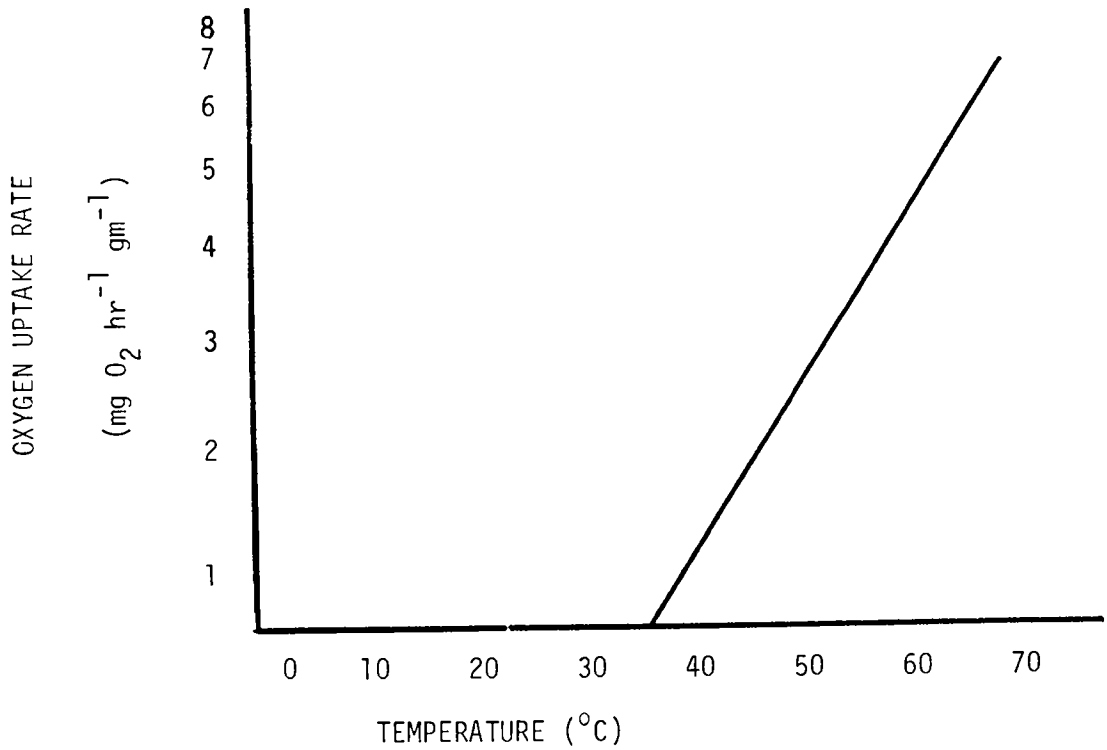


Figure 3. Relation between temperature and oxygen uptake rates (Schulze, 1962)

However, at very high temperatures (above 70°C), the rate of oxygen consumption begins to decrease because of the thermal inactivation of microorganisms. An effort should be made to maintain the temperature between 55 and 65°C.

The maintenance of thermophilic temperature for several hours should render the final compost free of all pathogenic microorganisms as a result of thermal kill alone (Gotaas, 1956). Aside from temperature, however, it is probable that biological antagonisms in the composting material also aid

the destruction of pathogenic organisms and parasites. Evidence indicates that high temperatures are most important and that where thermophilic temperatures are maintained, pest destruction is complete.

High temperature increases volatilization and escape of ammonia (Hashimoto and Ludington, 1971). However, little can be done to prevent this except to avoid temperatures above 70°C, where bacterial activity is retarded and ammonia accumulates. If other factors conducive to nitrogen conservation are maintained and the temperature is below 70°C, the nitrogen loss will be small.

Acidity--The optimum acidity for microorganisms involved in high-rate composting generally lies between pH 6.5 and 7.5. Unless the compost material is buffered, however, the acidity will normally vary as shown in Figure 4. In general, the compost material should never be allowed to exceed the acidity range of pH 4.5 to 9.5.

Conservation of nitrogen is very much pH-dependent. The pH effect on the potential for nitrogen loss as $NH_3$ is considerable. The $NH_4^+$-$NH_3$ equilibrium shifts as follows:

| pH | Equilibrium Percent $NH_3$ |
|---|---|
| 6 | 0.1 |
| 7 | 1 |
| 8 | 10 |
| 9 | 50 |

Toward the end of the thermophilic period, when the compost is near pH 9.0, the potential for the loss of nitrogen as ammonia becomes appreciable. However, in the latter (cooler) stages of composting, most of the remaining inorganic nitrogen should be in either nitrite or nitrate form. There should not be an excessive amount of nitrogen present as ammonia.

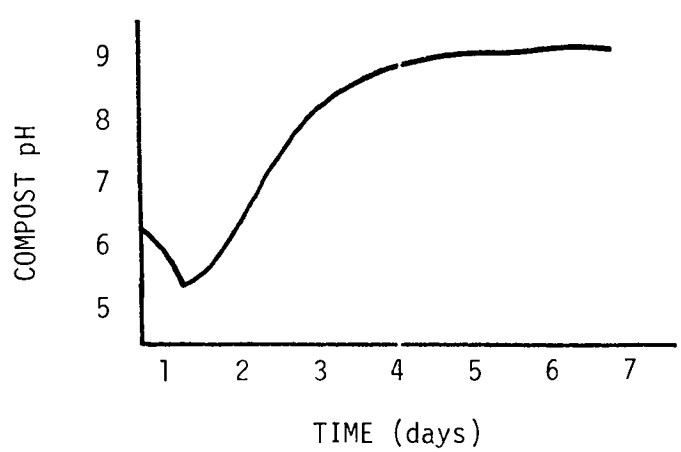


Figure 4. pH variations in batch composting

Recycle of seed compost--Experience has shown that recycling relatively small amounts of active compost material appreciably reduced lag periods associated with batch composting. This is accomplished by the placement of aclimatized microbes in the raw waste, thus reducing the time required for the correct organisms to develop. Recycling of one to ten percent of seed compost is normally sufficient. It has been found (Bell, 1969), however, that even 10 percent of old compost in the mix does not appreciably reduce the lag period. The material must be active.

Continuous Composting--

Schulze (1962) demonstrated that under properly controlled conditions it is possible to operate a composting process continuously in the thermophilic phase. His procedure of operation eliminated the lag period associated with the two initial phases of batch operation and provided rapid decomposition of the waste. After the initial charge of waste material reached the thermophilic phase, he maintained the thermophilic process by the daily addition of raw material and daily removal of decomposing material. He stated that under equilibrium conditions, the weight of material removed should range between 65 and 80 percent of the weight of raw waste added.

Degree of Compost Maturity--

If conditions favor decomposition (nutrients, pH, $O_2$, etc.) the presence of much available carbon (large supply of energy) results in an intensive decomposition during which resistant carbon in the form of cellulose and lignin is also attacked to some extent. When the supply of readily available carbon is exhausted, the energy supply, and therefore the decomposition intensity, is reduced. At this point, a degree of stabilization has been reached in which the compost is designated as being mature (Davey, 1954; Spohn, 1969). According to Keller (1961), determination of "degree of maturity" is accomplished by visual observation, by the course of decomposition, or most accurately by chemical analysis.

Raw organic waste material undergoes extensive changes in physical appearance during decomposition. The color and structure of the initial material generally disappear. Mature compost has a brown-black color and a friable texture. In addition, the rancid or putrid odor or raw organic waste disappears during composting, and the mature compost smells much like forest humus. From the standpoint of determining compost maturity, however, it should be mentioned that there is danger of erroneous interpretation. Compost which has undergone only a brief period of decomposition often looks much like a mature compost although it is still far from ripe (Spohn, 1969).

Provided favorable conditions exist, raw waste passes through characteristic stages when composted. Among the variables which may be monitored to follow these stages are temperature, pH, and oxygen consumption. Temperature is the best single indicator of the progress of batch composting. A temperature decline which has followed the typical normal steep rise and sustained high plateau is a good practical criterion for judging when a compost is mature enough for use, although some additional curing may take place at lower temperatures (Bell, 1969). In addition, oxygen consumption values which have decreased from the peak values of the thermophilic phase are also good indicators of batch compost maturity. Schulze (1961) found, for example, that

the oxygen consumption is five to ten times greater in the intensive, as compared to the mature, stage. Finally each type of compost has a characteristic pattern of changes in pH values which will indicate to some extent its stage of maturity.

Chemical analysis is the primary method of determining compost maturity in continuous operations. The most important parameters are the ratio of carbon to nitrogen (C:N ratio), chemical oxygen demand (COD), total volatile solids, percentage ash, nitrite/nitrate nitrogen, percentage cellulose and lignin, and cation-exchange capacity.

1. The C:N ratio has been discussed in a previous section of this report. At that time it was mentioned that initial ratios reported as optimum range from 25 to 50. The C:N ratio also serves as an index of maturity for a compost material from the standpoint that a mature compost has C:N ratio values between 10 and 20. However, the C:N ratio value is only an indication of degree of maturity when the carbon and nitrogen contents exist in available form in which they can be assimilated by microorganisms.
2. The COD determination provides a measure of the oxygen equivalent of that portion of the organic matter in a sample that is susceptible to oxidation by a strong chemical oxident. An 85 percent reduction in COD from raw waste to finished compost gives good reliability for determining compost maturity.
3. Total volatile solids and percentage ash are determined upon combustion of a sample in a muffle furnace at 600°C. Reduction in volatile solids from a raw waste to mature compost ranged from 37 to 45 percent (Schulze, 1962). The average percentage ash in matured compost was about 1.5 times greater than that in the raw waste. The actual loss figure would vary with the nature of the residue being composted.
4. Nitrogen in organic compounds is released upon microbial decomposition as ammonia ($NH_3$). The majority of $NH_3$ is either assimilated by organisms or oxidized to $NO_2^-$ and then $NO_3^-$. Accumulation of nitrate nitrogen is, therefore, an indication of maturity.
5. Determinations of the cellulose content and its percentage of the total organic matter at various degrees of composting give a good index for intensity of decomposition and degree of maturity (Davey, 1955; Keller, 1961).
6. An increase in lignin content and a decrease in the methoxyl content of the lignin also give estimates of the stage of decomposition (Davey, 1955).
7. Cation-exchange capacity (CEC) increases during decomposition. It is an important characteristic when compost is used in soil. In compost which contains only small amounts of soil or other mineral matter, the CEC should approximately double as the compost matures.

## PRODUCT EVALUATION

### The Soil as an Animal Waste Disposal Medium

Regardless of the uniqueness of the solution to animal waste management-

disposal problems, one factor is common to most solutions--the soil is the ultimate disposal medium (Loehr, 1972). The function of integrating the soil with animal waste disposal is two-fold: (1) Animal wastes are applied to the soil for nutrient utilization for crop production at optimum-use-efficiency; and (2) To apply animal waste at such rates that the practice becomes primarily one of disposal without contributing to pollution (Webber and Lane, 1969). Animal wastes are organic in nature and serve as carbon, energy, and nutrient sources and waste pre-treatment products for the biological fraction of the soil. The biological fraction of the soil is composed of very large populations and varieties of microorganisms. These microorganisms stabalize animal waste by converting the waste to a higher oxidation level; for example, reduced carbonaceous materials such as cellulose would be converted into $CO_2$ and other nutrients are converted into microbial tissue. Except for nitrogenous materials, the higher the oxidation level the lower the pollution potential for animal waste. The biological fraction of the soil combined with the large area of reactive surfaces and other physical and chemical properties of the soil give it a tremendous capacity to assimilate organic waste materials (Bohn and Cauthorn, 1972). However, there are several factors that must be considered if the soil is to be effectively utilized as the ultimate disposal medium for animal waste.

There are two basic alternatives. One is to employ the soil strictly as a sink (Loehr, 1972). The primary objective of this alternative is to add waste materials to the soil until an equilibrium is established between the degradation capacity of the soil and waste application that is below the threshold of environmental contamination by the wastes. This alternative may be important where land areas are limited for waste disposal (Loehr, 1972).

Employing animal waste as an amendment to increase the productivity of the soil is the major objective of the second alternative. This alternative includes the addition of animal waste to the soil only to the point that physical and chemical properties are modified or enhanced to obtain a more optimum growth medium for plants.

Either of these alternatives will require intensive management to reduce the potential for environmental contamination from animal waste. The second alternative may be more practical for long term applications of animal wastes to the soil. This alternative utilizes plants as a sink for the removal of the products derived from the degradation of animal wastes such as inorganic nutrients. The first alternative allows these degradation products to accumulate and remain in the soil. Long term, repeated applications under such a system might reduce the effectiveness of utilizing the soil as a disposal medium without environmental contamination.

Another factor to be considered in utilizing the soil as a disposal medium is to distinguish between "the soil" and a specific soil type. Variability is a major characteristic of individual soil types. This variation will influence the applicability of utilizing specific soils for animal waste disposal. "The soil" may be defined as a biochemically weathered upper portion of the earth's crust. "A soil" is a subdivision of the soil with well-defined physical, chemical, and biological properties (Buckman and Brady,

1969). The physical, chemical, and biological parameters of a soil will determine the applicability of utilizing it for animal waste disposal. Environmental factors including rainfall, drainage, vegetation, temperature, and topography will also exert a modifying influence on utilizing a soil for animal waste disposal.

Soils in North Carolina range from poorly drained organic soils to excessively drained deep sands to clay. Topography ranges from relatively flat areas to steep mountain slopes. Both mesic and thermic soil temperature regimes exist. Rainfall varies from 112 cm to 203 cm with a statewide average of approximately 127 cm per year (Lee, 1955). These factors will exert a modifying influence on the degradation of animal waste by land disposal. For example, Wilkes County is a major poultry producing county in North Carolina and, consequently, generates large quantities of poultry waste. Part of Wilkes County is in the mesic temperature region and the cool climate will reduce microbial activity, thereby, reducing the assimilation of poultry waste into the soil. The topography is generally rolling to mountainous which reduces the land available for poultry waste disposal. By contrast, Duplin County, which generates approximately the same amount of poultry waste, is in the thermic region which will allow more rapid degradation of poultry waste added to the soil and is relatively flat. On a percentage basis more land is available in Duplin County for poultry waste disposal when topography is considered. It is obvious that if guidelines are established for land disposal of animal waste, that all these complexities must be considered.

## Integrating Plants into a Composting-Soil Disposal System

Animal wastes contain many nutrients essential for plant growth. However, due to potential water contamination and the ensuing health hazards associated with $NO_3$-N, effective management of the nitrogen fraction is of primary concern with respect to land disposal of animal wastes. The nitrogen contained in animal waste and its removal from soil by plant uptake is basic to all land disposal-plant growth systems.

Poultry manure has the highest concentration of nitrogen and other plant nutrients among animal wastes (Taiganides, 1964). This indicates that both the potential for environmental contamination and plant response per unit of waste is greatest for poultry manure. The nutrients contained in animal manures can be and are utilized effectively by crop plants. Use of these nutrients constitutes a valid link in the recycling process of animal wastes (Heald and Loehr, 1971). The opportunities to recycle and use waste are enormous and society will increasingly demand the adequate utilization of these wastes since they are a valuable part of our national resource (Murphy et al., 1972). Composting, land spreading, and crop plant production offer a set of sequential steps that are compatible with the ideals of conserving and ultimately recycling animal wastes. Composting results in the conservation of plant nutrients in animal waste. Land spreading of composted materials enhances the soil as a growth medium for plants. Crop plants can be integrated into this system to remove nitrogen and other nutrients with pollution potential and simultaneously produce a marketable or useful product.

Selection of plants to be integrated into animal waste disposal systems is largely dependent upon site selection, the use and value of the harvested crop, labor requirements for crop management, and the amounts and patterns of nutrient utilization by the crop. From a nutrient recycling point of view the last criterion is of major importance (Reed, 1972; Webber and Lane, 1969).

Many different field crops have been successfully used in land disposal of wastes and recycling systems. Reed (1972) listed eleven crops that can be integrated into animal wastes--forage operations. Papanose and Brown (1950) indicated that many vegetable crops can be adequately grown with poultry manure as a fertilizer. Although positive crop responses have been produced with properly composted solid waste employed as a soil amendment (Davey, 1953, 1954; Gray, 1970; Hart, 1970; MacDonald and Dunn, 1953; Tacquin, 1965; Wolfe and Dunn, 1953), little information is available concerning agronomic crop response to composts integrated into animal waste disposal-plant systems. Previous investigations indicate that field crop response to composts will vary according to the nature of the compost, rates of application, and characteristics of the crop and soil. These parameters must be considered before composts can be effectively incorporated into a system that is consistent with the two-fold objective suggested by Webber and Lane (1969)--maximum application of waste materials for disposal and efficient nutrient uptake by plants without secondary environmental contamination.

The most efficient method of removing nutrients is to select a plant that has a high nutrient absorption and a large part of the plant is removed from the site after the growing season. The amounts of nutrients removed through plant uptake are the amounts removed through harvesting of at least a part of the plant. The quantity of element removed per hectare depends not only on the content of the nutrient in the part of the crop that is harvested but also on the total amount of dry matter removed. Nutrients accumulated in plant parts not removed by harvest will remain on the disposal site. Plant composition and yield vary widely; therefore, different amounts of nutrients are removed by different plant species. Many investigators suggest that corn or a forage crop be employed for nutrient removal (Reed, 1972; Webber and Lane, 1969). This is largely due to the ease with which these crops can be worked into a livestock feeding program. Corn will generally require 180-190 kg of nitrogen per hectare (Barber and Olson, 1968; Chandler, 1960). Approximately 60 percent of this nitrogen will be removed from the soil when the grain is harvested leaving 40 percent to be returned to the soil in vegetative residue. Other grain crops take up less nitrogen, thus decreasing the amounts removed from the disposal site (Reed, 1972). Coastal bermudagrass utilized for lawns or as forage and hay crops in North Carolina, can remove up to 640 kg of nitrogen per hectare per year at yields of 22.4 tonnes per hectare (Wagner and Jones, 1968). A large portion of the crop would be removed from the disposal site by harvesting. Vegetable crops are an alternative for removing nutrients from amended soil. Vegetable crops include many species that have exceedingly high rates of nutrient absorption. Celery, Producing 168 tonnes fresh weight per hectare, may utilize up to 336 kg of nitrogen of which 90 percent is removed from the disposal site in the process of harvesting. In the leafy vegetable crops practically all the nutrients are removed from the land. Tomatoes, producing 67 tonnes of fruit per

hectare, will utilize 280 kg of nitrogen. Approximately 70 percent of the nitrogen will be removed leaving 30 percent to be returned to the disposal site (Lorenz and Bartz, 1968). It would appear that vegetable crops would result in a greater potential for removal of nutrients from animal waste from soil than corn or small grains and most forages.

In order to successfully utilize crops with high rates of nutrient uptake, a compost-soil medium must be able to supply large amounts of nutrients at the times of nutrient stress and in a form available for plant uptake. Composts are low analysis organic fertilizers. Toth and Gold (1971) suggest that an ideal compost contains approximately 2.5-3.5 percent total nitrogen, 0.4-0.7 percent phosphorus, and 0.8-1.2 percent potassium. Not only do composts have low nutrient content but the forms of nutrients in compost are not generally readily available for plant uptake. A major portion of the nutrients in composts are in an organic form. Plants take up nutrients primarily in their inorganic forms (Tisdale and Nelson, 1976); therefore compost nutrients must be mineralized (converted from organic to inorganic forms) to become available for plant growth. Composts are considered to be slow-release fertilizers due to this characteristic. Mineralization is affected by the microbial population of the soil, the physical and chemical properties of the soil, and the climate. The rate of mineralization will be a major factor in nutrient availability from compost amendments.

Because of the nature of composts (low analysis, organic, and slow release fertilizer), high rates of application have to be employed to supply nutrients needed by high yielding crops. Yet, a balance between crop selection and rate of application of compost must be maintained. Nutrients, in excess of crop requirements, even though initially in the organic form, may become subject to leaching after mineralization has occurred (Webber and Lane, 1969). Rate of application of compost and the rate of mineralization will determine the supply of nutrients to field crops. From 34-112 tonnes of compost per hectare per year are necessary for crop production (Hart, 1970). Some crops with exceedingly high rates of nutrient uptake may require even higher rates of compost applications.

Perennial crops will require nutrients to be available every day of their growth cycle to assure that nutrients will not be limiting (Wagner and Jones, 1968) whereas, crops such as celery, corn, and tomatoes exhibit short periods of extremely high nutrient demands (Lorenz and Bartz, 1968). In the case of celery which has a growth period of 150 days from seeding to harvest, it has been found that approximately 2 percent of the growth and nutrient uptake occurred during the first half of the growing period and more than half of the nutrients were taken up during the last three weeks of growth. A similar pattern occurs with corn and tomatoes during grain and fruit formation and maturation (Chandler, 1960; Lorenz and Bartz, 1968; Ward, 1964). This situation of nutrient uptake may be described as periods of low and high uptake. Composted amendments must be able to adequately supply these nutrient demands for optimum plant growth. The rate of compost application will largely determine the success of this.

Little research has been focused on high rates of compost application to agricultural crops for waste disposal purposes. Integrating compost materials into the production of crops with high market value which are heavy nutrient feeders should include an adequate evaluation of a composting-land disposal-plant system as a means of animal waste disposal. If composts are able to produce adequate yields of high market value crops with no secondary environmental contamination, then such a system becomes more feasible as a solution to animal waste disposal problems. Until the present, this systems approach remained an untested, hypothetical solution to most animal waste disposal problems.

## SECTION 3

## THERMOPHILIC COMPOSTING

The primary steps in the investigations being reported are summarized below:

1. Sawdust and poultry manure were collected separately; analyses of each were performed to determine their moisture, pH, ash, and nutrient contents;
2. The wastes were weighed, combined, and mixed to a uniform mass by hammer mill;
3. The mixture was subjected to an aerobic, thermophilic composting process;
4. The batchwise decomposition was followed by measuring temperature, oxygen uptake, pH, moisture content, ash, and loss of nitrogen;
5. After the thermophilic phase, the total amount of decomposition was determined on a weight basis;
6. Holocellulose content and cation-exchange capacity were evaluated to determine what effect, if any, a secondary curing stage might have on final compost maturity; and
7. After completion of the batch studies, the composter was fed daily and the process studied in continuous operation.

### EXPERIMENTAL ARRANGEMENT

The central unit of equipment in the investigation was a 1.22 $m^3$ capacity composter, which was custom-fabricated by Aeroglide Corporation, Raleigh, North Carolina. The composter consisted of a rotating drum reactor which was mounted on a central shaft with a frame support (Figure 5). The reactor has a chain-sprocket drive powered by an electric motor. An electric timer and relay switch provided intermittent rotation. Other than entrance and exit air ports the drum reaction chamber was a closed system with respect to mass transfer. Heat losses were minimized by a 2.5 cm layer of styrofoam insulation which was taped over the ends and sides of the drum. Two doors located on the side of the drum were provided for addition and removal of material. During operation, these doors were closed by a hinged cover with a fitted rubber gasket.

Accessory equipment included an air compressor capable of delivering 1.2 l/s continuously, an airflow meter having a capacity of 1.9 l/s, thermister probes and temperature recorder, and galvanic cell oxygen analyzer for residual oxygen analysis. An acid trap was added to absorb evolved ammonia for nitrogen-loss determinations.

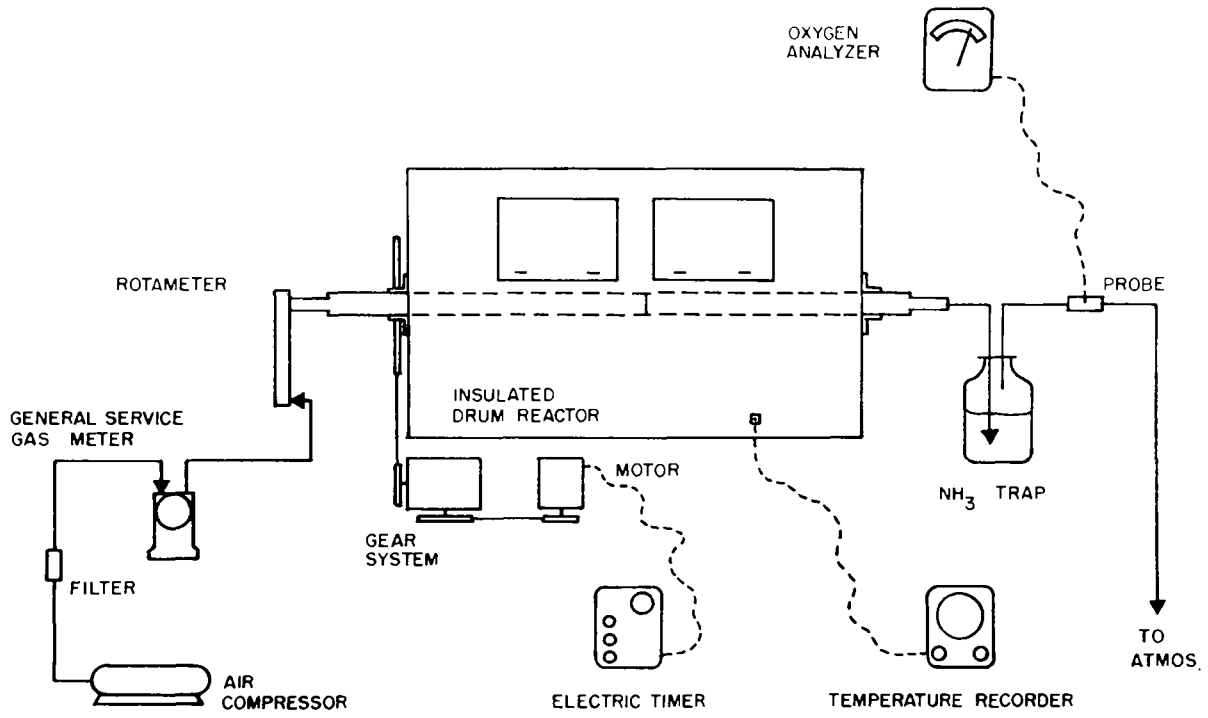


Figure 5. Diagram of the composting system

Analytical work was centered in the Sanitary Chemistry and Biology Laboratory of the Civil Engineering Department at North Carolina State University.

## EXPERIMENTAL PROCEDURE

### Waste Preparation and Analytical Methods

Sawdust for this investigation was several years old and included mostly southern pine species; 75 percent or more of which was loblolly pine (*Pinus taeda* L.). This sawdust was stored at the compost site until needed. Poultry manure was donated by the Poultry Science Department at North Carolina State University, and was collected in a fresh state as needed.

In preparation for each experimental run, the sawdust was partly air-dried. By this means moisture contents of 55 to 60 percent were obtained for initial combined waste mixtures. Schulze (1961) reported an optimum moisture content of 60 percent for the composting process. The sawdust and poultry manure then were weighed, samples for analysis were taken from each, and then were mixed to a reasonably uniform condition by passage through a hammer mill. A range of initial C:N ratio values from 20 to 45 was studied during the batch runs.

Characterization tests were conducted for each batch and continuous run to establish that all nutrient elements were present in adequate amounts for composting. The testing methods were:

1. Carbon was determined by absorption with the semi-automatic Coleman 33 Carbon-Hydrogen Analyzer;
2. Nitrogen was determined with the semi-automatic Coleman 29A Nitrogen Analyzer;
3. Phosphorus was determined colorimetrically by the stannous chloride method (Standard Methods, 1965, p. 234);
4. Potassium was determined by flame spectrophotometry according to the procedure in Standard Methods (1965); and
5. Calcium and magnesium were determined by atomic absorption spectrophotometry.

In addition, moisture content, ash, volatile solids, and pH were included in the characterization work. An electric drying oven at 75°C, muffle furnace at 600°C, and pH meter were used in these determinations.

### Batch Reaction Study

Except where otherwise specified, each experimental run was standardized according to the following conditions:

1. The reaction chamber was filled to about two-thirds capacity;
2. Microbial seeding of each batch was accomplished by recycling 2 percent (by weight) of "seed compost" (material from the just completed batch). The seed compost should contain a wide variety of microorganisms specially adapted to the aerobic, thermophilic

conditions;

3. Oxygen consumption and compost temperature were measured four times daily throughout the run;
4. Decomposing waste was sampled twice daily and tested for moisture content, ash, volatile solids, and pH;
5. Evolved ammonia was absorbed in a phosphoric acid trap located in the effluent gas line for nitrogen-loss determinations;
6. The runs were terminated when oxygen uptake and temperature indicated a sustained decrease in microbial activity; and
7. Finally, the compost product was weighed for determination of total percentage decomposition.

In addition, the agitation rate (composter drum rotation) was adjusted to 1 rpm. Intermittent agitation of 2 min/4 hr was applied to runs 1 through 10; whereas, the interval was 2 min/15 min for runs 11 and 12. Continuous agitation was applied to runs 13 through 16.

The oxygen consumption rate, which is an accurate indicator of process activity was used to follow the decomposition process. It was determined by measuring the residual oxygen content of the effluent gases at constant air input. For example, a concentration of 5 percent oxygen in the exhaust indicated that 16 percent (by volume) of incoming air had been consumed as oxygen.

Continuous Operation

After completion of the batch studies, a series of continuous-run operations was undertaken. The materials used during this phase of the program included poultry manure, swine manure, sawdust, and shredded paper. The equipment was the same as that used during the batch studies. The primary steps in the operation of the process are summarized below:

1. Sawdust, poultry manure, swine manure, and waste paper were collected separately when needed and periodic analyses of each were performed to determine their moisture and ash content and acidity (pH);
2. The wastes were weighed, combined (manure-sawdust or manure-shredded paper), and mixed to a uniform mass;
3. The mixture was subjected to an aerobic, thermophilic composting process with periodic removal of part of the material and addition of fresh mixture;
4. The continuous process was monitired by measuring oxygen use, temperature, pH, moisture content, and ash content; and
5. The output from the drum was stored in a pile and monitored for further biological activity.

The sawdust was partly air-dried before each run. The waste paper was shredded and sprayed with water to increase its moisture content as well as the weight-to-volume ratio. Neither the poultry waste nor swine waste needed any pre-treatment. The raw materials were then mixed as evenly as possible with shovels and then run through a hammer mill to distribute the animal waste more evenly through the sawdust. In the case of shredded paper the mixture tended to choke the hammer mill and thus additional shovel mixing

was done.

The waste mixture was fed into the composter drum and the doors were closed tightly. The drum was rotated continuously at 1 rpm. Air was supplied at an average rate of 0.9 l/s. The exhaust air was passed through the phosphoric acid trap where any ammonia in the exhaust was removed. The temperature was measured at two ports in the drum. Samples were taken at varying frequency and tested for acidity (pH), bulk weight, percent moisture, percent volatile solids, and percent ash. The oxygen concentration in the exhaust gas was also monitored.

When the temperature started to decline, a portion of the compost was removed and fresh mix was added. The neutralized phosphoric acid was added to the compost pile so as to return the nitrogen lost during active degradation and to supplement the phosphorus content of the compost.

### Secondary Curing

After discharge from the reactor, the compost was placed in storage. Periodically, the compost was turned and remoistened. It was presumed that the major breakdown of cellulose occurs during this immediate post-thermophilic stage. However, no data were found in the literature to substantiate this. Therefore, holocellulose content and cation-exchange capacity of the initial sawdust, compost before storage, and compost after storage were evaluated to determine what effect, if any, a secondary curing stage might have on final compost maturity.

## RESULTS

### Nutrient Studies

The most widely used parameter for assessing composting is the carbon-to-nitrogen (C:N) ratio. It has been suggested that the optimum C:N ratio ranges from 30 to 50. However, other nutrient elements are necessary for proper organism metabolism. Sawyer (1956) reported that the nitrogen-to-phosphorus ratio should be 5:1. Thus, the combined carbon-to-nitrogen-to-phosphorus (C:N:P) ratio should be 30 to 50:1:0.2. Trace amounts of other elements also are required for proper nutrition.

Table 1 lists the analyses of sawdust and poultry manure used in each batch run. The average C:N:P ratio for the sawdust was found to be 290:1.0: trace, while for the manure, it was 5.2:1.0:0.18. The C:N:P ratio for the waste mixtures used in the batch runs ranged from 21:1.0:0.19 to 43:1.0:0.15. The amounts of calcium, magnesium, and potassium were regarded as adequate.

### Batch Composting

Aeration and Agitation Requirements--

Oxygen utilization determinations were made for each run except runs 3, 4, and 10 and the air supply rate was adjusted so that the exhaust gases

TABLE 1

ESSENTIAL NUTRIENT CONTENTS OF SAWDUST AND POULTRY MANURE*

| | | Carbon | | Nitrogen | | Phosphorus | | Potassium | | Calcium | | Magnesium | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Run | Date | S.D.† | P.M.† | S.D. | P.M. | S.D. | P.M. | S.D. | P.M. | S.D. | P.M. | S.D. | P.M. |
| 1 | 4/10 | 47.7 | 34.8 | 0.135 | 6.83 | <0.001 | 1.47 | 0.050 | 0.85 | 0.075 | 2.50 | 0.025 | 0.750 |
| 2 | 4/18 | | | | | | | | | | | | |
| 3 | 4/24 | 48.5 | 35.8 | 0.103 | 6.44 | | | | | | | | |
| 4 | 5/1 | | | | | | | | | | | | |
| 5 | 5/14 | 48.9 | 37.1 | 0.130 | 6.95 | t† | 1.23 | 0.046 | 1.41 | 0.058 | 2.12 | 0.061 | 0.645 |
| 6 | 6/4 | 48.3 | 36.3 | 0.143 | 6.64 | | | | | | | | |
| 7 | 6/16 | 48.5 | 35.2 | 0.115 | 6.81 | | | | | | | | |
| 8 | 6/27 | | | | | | | | | | | | |
| 9 | 7/11 | 48.5 | 35.5 | 0.132 | 7.20 | t | 1.11 | 0.024 | 1.58 | 0.048 | 2.03 | 0.048 | 0.723 |
| 10 | 7/28 | 47.1 | 37.2 | 0.150 | 7.12 | | | | | | | | |
| 11 | 8/8 | 48.5 | 38.0 | 0.110 | 7.68 | | | | | | | | |
| 12 | 8/18 | 49.3 | 37.5 | 0.122 | 7.50 | | | | | | | | |
| 13 | 8/22 | 47.8 | 38.0 | 0.111 | 7.28 | t | 1.21 | 0.057 | 1.33 | 0.063 | 1.74 | 0.055 | 0.734 |
| 14 | 8/28 | 50.4 | 36.0 | | | | | | | | | | |
| 15 | 9/3 | 49.9 | 37.4 | | | | | | | | | | |
| 16 | 9/11 | 48.7 | 36.3 | 0.116 | 7.54 | | | | | | | | |
| Average | | 48.5 | 36.6 | 0.124 | 7.09 | t | 1.25 | 0.044 | 1.29 | 0.061 | 2.10 | 0.047 | 0.713 |

* All values are presented as percent oven-dry weight.

† S. D. (sawdust); P. M. (poultry manure); t (trace).

contained at least 5 percent residual oxygen, by volume. The drum agitation also was varied as previously indicated.

During run 10, it was determined that while the composter drum was not being agitated (i.e. turning) the oxygen being supplied could not penetrate to all parts of the composting mass. During runs 11 and 12, it was determined that in the first 2 min following the end of the agitation period, all oxygen had been used up in the region of the reactor near the bottom.

The oxygen uptake for runs 5 and 15, which had similar C:N ratios may be compared by reference to Figure 6. Run 15 had a substantially higher peak oxygen uptake rate than did run 5. This peak also was reached much sooner. Both batches were removed from the composter when their temperatures had dropped to 42°C. Batch 15 required 139 hr while batch 5 required 210 hr for the temperature to reach this point. The areas under the two curves are almost equal, thus indicating that the oxygen requirement was substantially the same for both batches; however, the biological activity rate, as shown by the oxygen utilization rate curve, was much greater in run 15 (Figure 6).

Changes in Acidity (pH)--

Acidity determinations (pH) were made twice daily during the course of each batch run. The results of a typical run are presented in Figure 7. The initial readings of the mixtures used ranged from pH 5.4 to 7.2. After an initial lag period, all batches rose to a range of pH 8.5 to 9.0.

Those batches having the lower initial pH values required more time to reach the thermophilic temperature range (above 45°C) than those having higher initial pH values. The length of the initial lag period did not affect the total length of time required for composting as did the need for proper aeration.

Temperature--

Figure 8 presents a typical temperature curve for a batch process. The temperature remained in the mesophilic range (25 to 45°C) until the pH value exceeded 7.0. The temperature then climbed rapidly to between 60 and 70°C, where it remained for up to 30 hr. The temperature then began to decline slowly until the composting batch again was out of the thermophilic range. The length of time that the composting batch remained at this high temperature level depended on proper aeration as well as the amount of readily available carbon, rather than the C:N ratio *per se*.

Carbon:Nitrogen Ratio--

Batches having an initial C:N ratio ranging from 21:1 to 43:1 were composted. Figures 9 and 10 show the oxygen uptake rate and the cumulative oxygen usage for runs having a low C:N (25:1) and a high C:N (40:1) ratio. The results indicate that the batches having the lower C:N ratio had a higher oxygen usage which extended over a longer period. These batches also had the higher manure-to-sawdust ratios.

The relationships between the volatile solids reduction, percentage of manure in the composting batch, and the initial C:N ratio are shown in

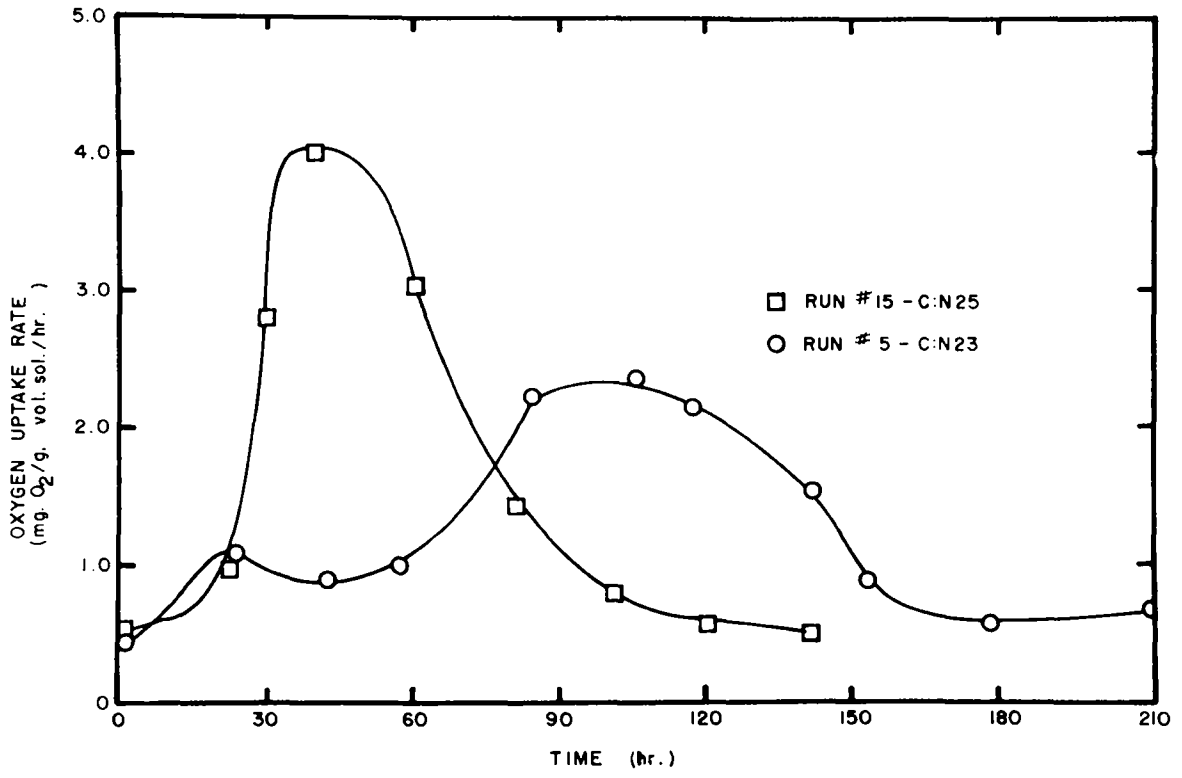


Figure 6. Comparisons of decomposition rate for completely aerobic and partly anaerobic systems

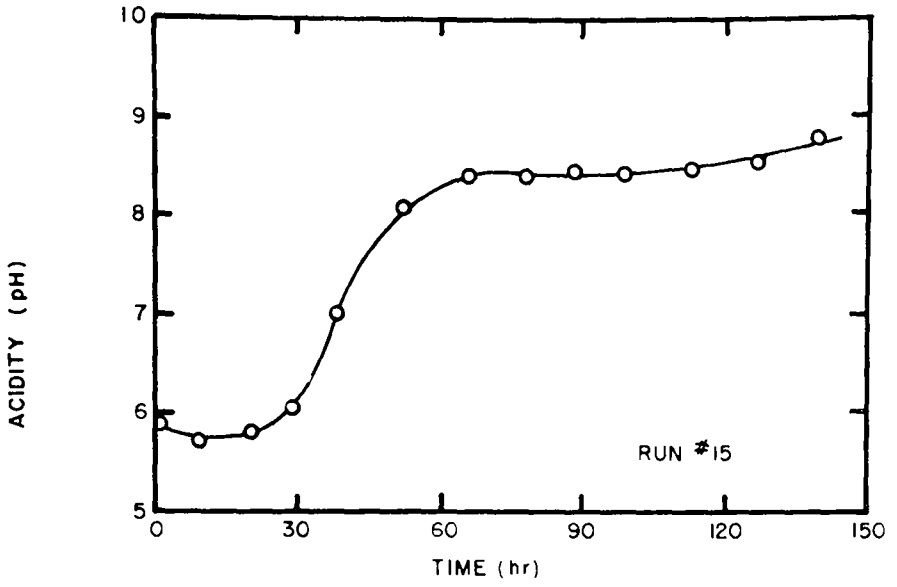


Figure 7. Phases of batch composting as evidenced by changes in acidity

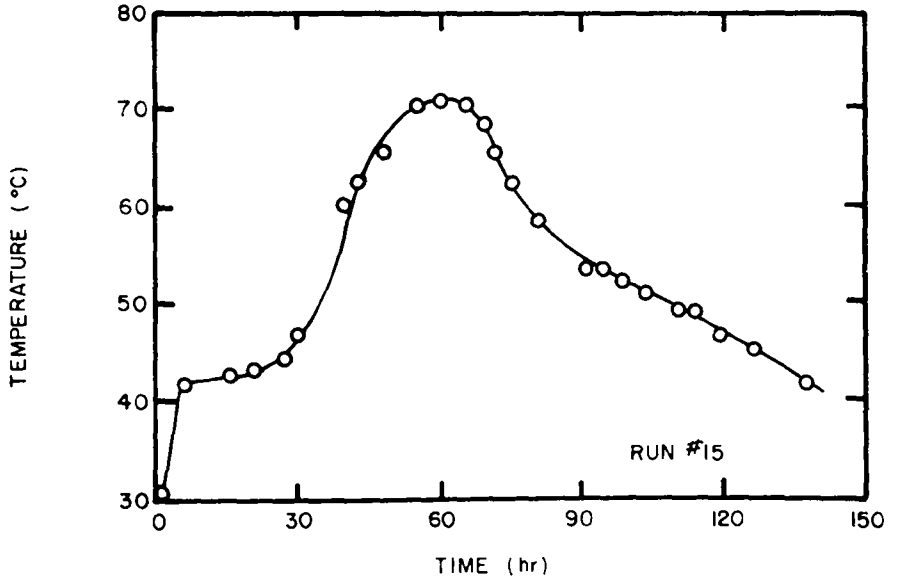


Figure 8. Phases of batch composting as evidenced by temperature

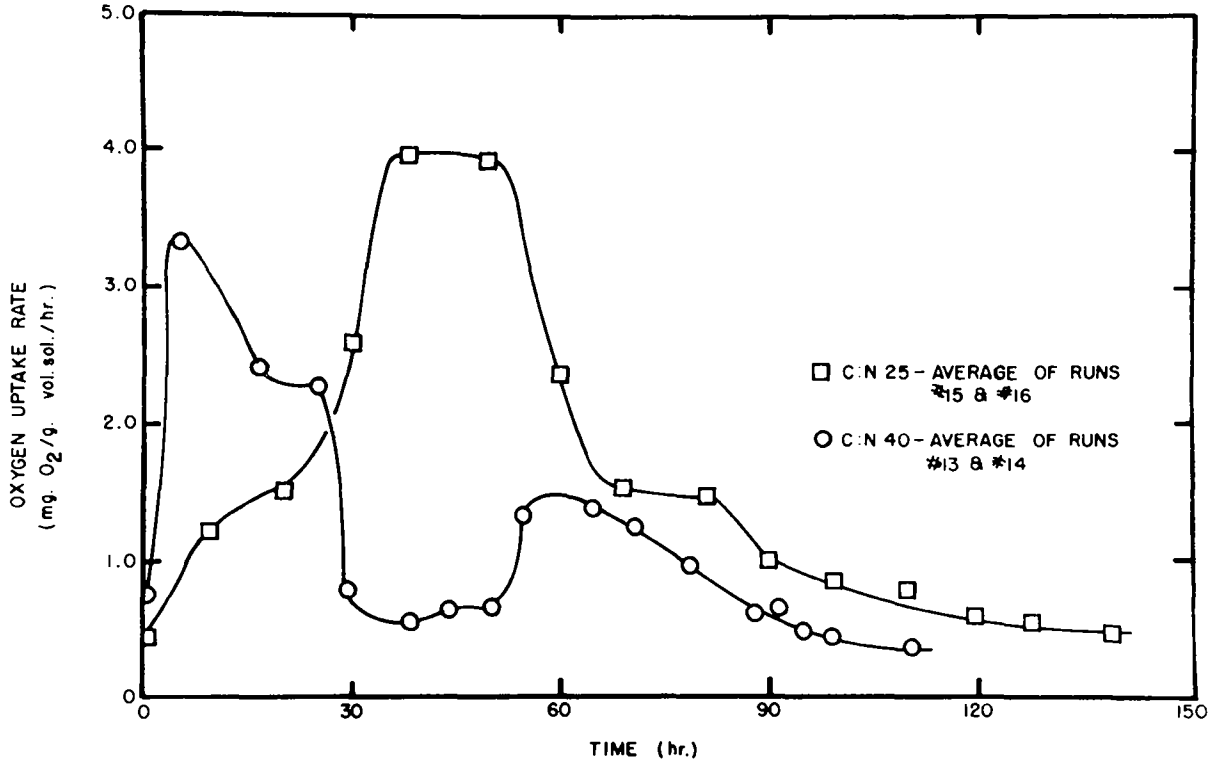


Figure 9. Oxygen uptake rates during the course of decomposition of C:N 25 and C:N 40 batch mixtures

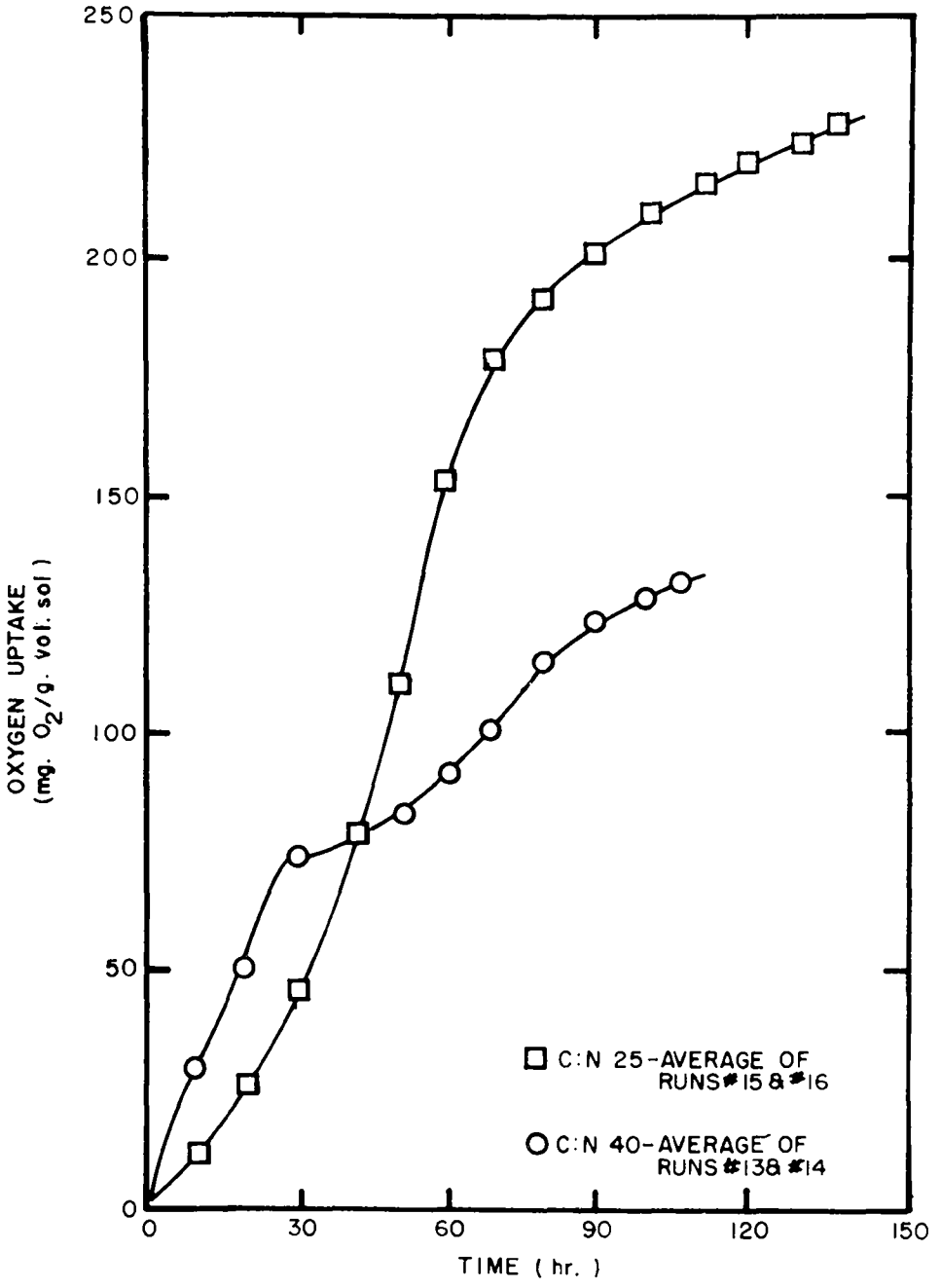


Figure 10. Total oxygen uptake as a function of composting time

Figure 11. The volatile solids reduction is seen to parallel closely the percentage of manure. Two curves are presented for volatile solids reduction. The upper curve is for early runs using relatively fresh sawdust; the lower curve is for runs using sawdust that had been in storage at least 2.5 months longer than that used in the earlier runs.

The above data indicate that the majority of the carbon used as an energy source during this portion of the process is derived from the manure. If the carbon in the sawdust had contributed substantially to the available carbon, the volatile solids reduction would not have paralleled the percentage of manure curve in Figure 11 as closely as it did, but should have been much closer to horizontal. The sawdust appears to be resistant to the microbial action in the composter (see section on organisms associated with thermophilic composting).

Moisture Content--

Quantitative determinations for optimum moisture content were not made. The moisture contents of the initial batches ranged from 50.8 percent to 63.6 percent wet weight. It was noted that as the moisture levels increased above 60 percent, there was a tendency to form small balls. During the course of a run, the moisture level did not vary by more than 1.2 percent. Apparently volatilized moisture which was lost with the exhaust gasses was balanced by the production of respiratory moisture.

Nitrogen Conservation--

Nitrogen losses ranged from 2.69 to 7.90 percent (Table 2). The results indicate that the C:N ratio had little effect on the percentage N lost. The losses were greatest in runs 6 through 9, where the agitation was least and the aeration poorest. Runs 13 through 16 had continuous agitation and the best aeration. It is thus concluded that the nitrogen conservation depends more on the rate of biological activity than the C:N ratio in the range studied.

TABLE 2

NITROGEN LOSSES DURING THE COURSE OF DECOMPOSITION OF SAWDUST AND POULTRY MANURE MIXTURES

| Batch | Initial C:N Ratio | Final Acidity (pH) | N Loss (%) |
|---|---|---|---|
| 6 | 42:1 | 8.85 | 4.52 |
| 7 | 31:1 | 8.90 | 7.90 |
| 8 | 35:1 | 8.45 | 5.90 |
| 9 | 28:1 | 8.90 | 7.17 |
| 12 | 38:1 | 8.90 | 3.84 |
| 13 | 43:1 | 8.80 | 2.69 |
| 15 | 25:1 | 8.75 | 3.83 |
| 16 | 27:1 | 8.80 | 3.35 |

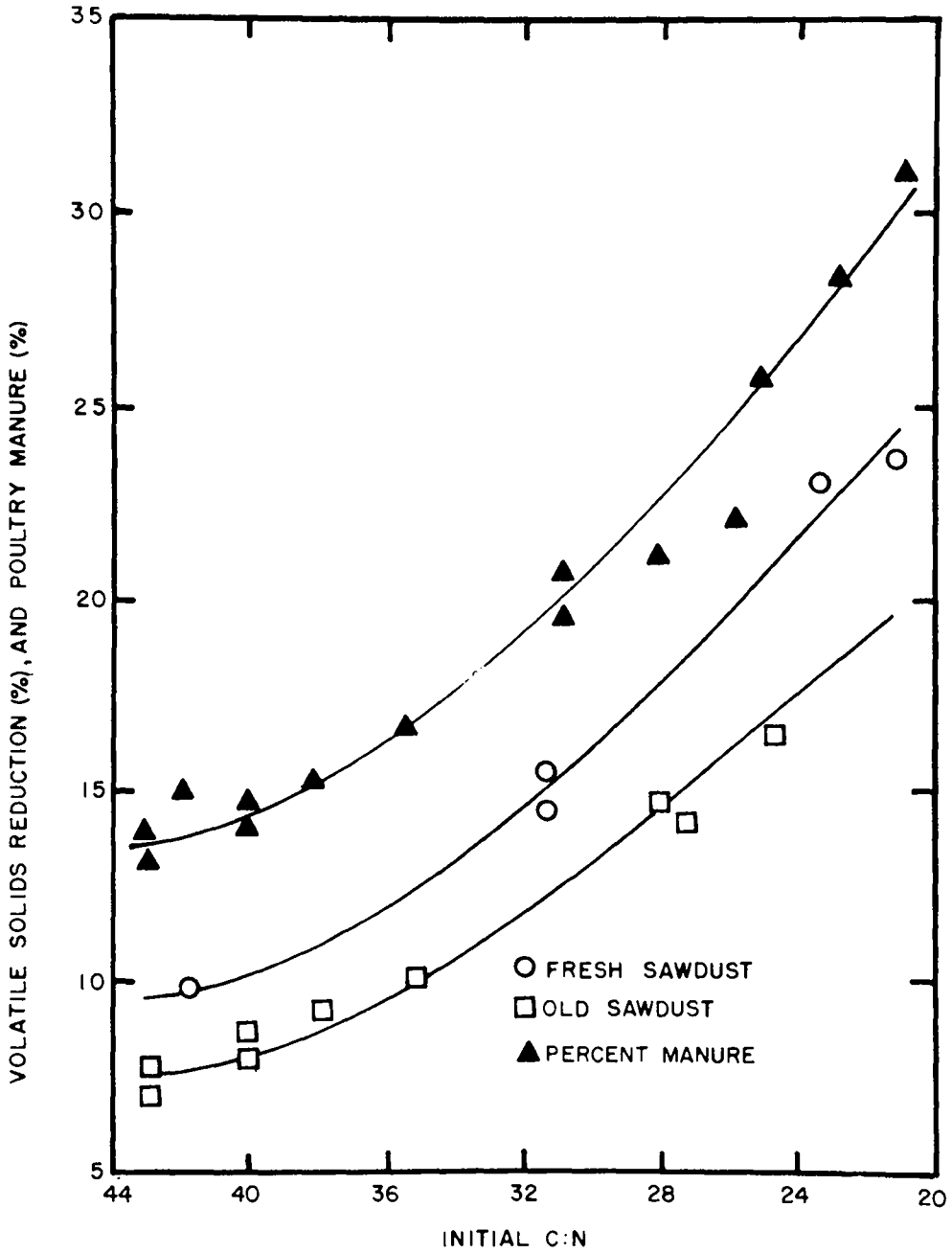


Figure 11. Relationships between volatile solids reduction, percentage manure, and initial C:N for batch composting of sawdust and poultry manure mixtures

Cellulose Degredation--

Results derived from the high-rate composter studies give evidence that the holocellulose and lignin are resistant to microbial attack during this phase. As the runs were completed, the compost was placed into storage. During the storage period, fungi developed rapidly and began decomposing the cellulose in the compost. The cellulose content did decrease during the storage phase (Figure 12).

As the cellulose content decreased, the cation-exchange capacity (CEC) of the compost increased (Figure 13). The final CEC of the compost was 67 meq/100 g. This is well within the range of a desirable soil additive.

Continuous Operation

In continuous composting, the lag phase found in the batch process was not observed. The input-output frequency and the amount of exchange are important factors in the operation of the process.

The initial continuous run was started using sawdust and poultry waste. However, the run was stopped after 10 days due to difficulties experienced in obtaining sufficient poultry waste of known composition.

A continuous run was started using sawdust and swine waste. After the thermophilic temperature was attained, a part of the composted material was taken out every day and fresh mix was fed into the composter. The input-output ratio was changed to find the maximum value that would maintain the thermophilic stage without reverting to the initial lag phase. After 12 days, due to the use of high input-output ratio continuously, the composter was nearly full and free air-sapce became limiting. Consequently, the temperature dropped below the thermophilic range. No fresh mix was fed for 2 days. On the 15th and 16th days, the feeding-removal process was repeated but the temperature did not go above the lower thermophilic range. The composter was emptied after a total of 475 hours of operation. The process was repeated twice more.

For the sixth run, poultry manure was used with shredded paper instead of sawdust. The paper was a mixture of newsprint and glossy paper used in magazines, mostly printed in black ink. It is assumed that the paper used had the same average composition as the paper content in domestic refuse, thus its chemical composition is assumed to be very close to that given for "other combustibles" in Table 3.

Two batch runs were carried out with the shredded paper-poultry waste mix. Each time, the initial mix had to be sprayed with some water in order to bring the moisture content up to the level of at least 50 percent. The continuous run was then started. Thermophilic temperatures were observed except briefly, after each feeding. The drum was stopped and emptied after a time of 1,245 hours had elapsed; an obviously successful continuous operation.

The different variables affecting thermophilic aerobic composting were investigated during the batch studies and have been dealt with in detail in

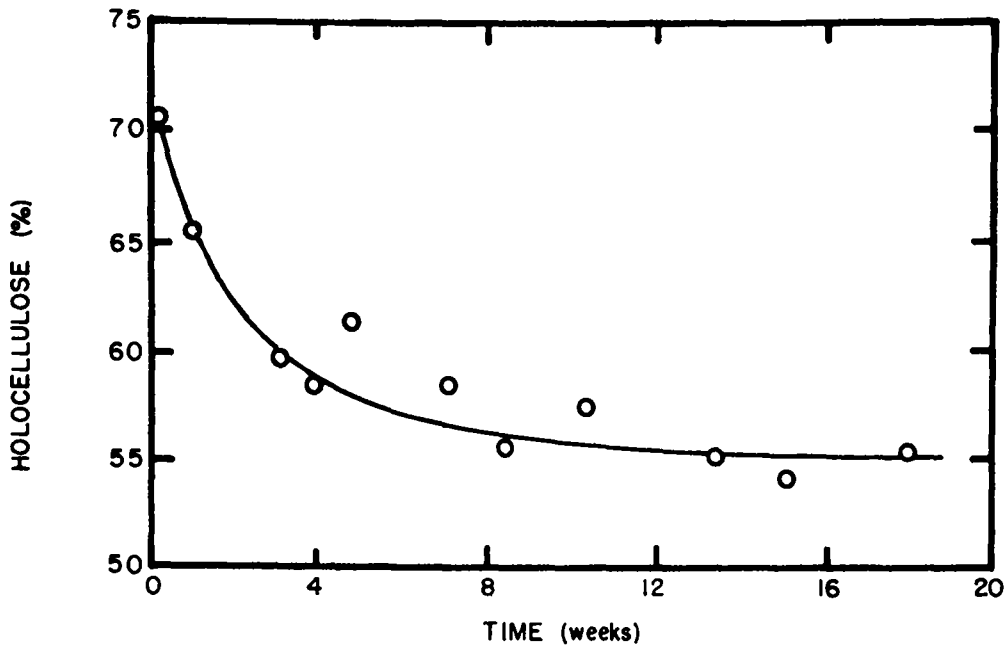


Figure 12. Effect of storage upon compost maturity as evidenced by holocellulose content

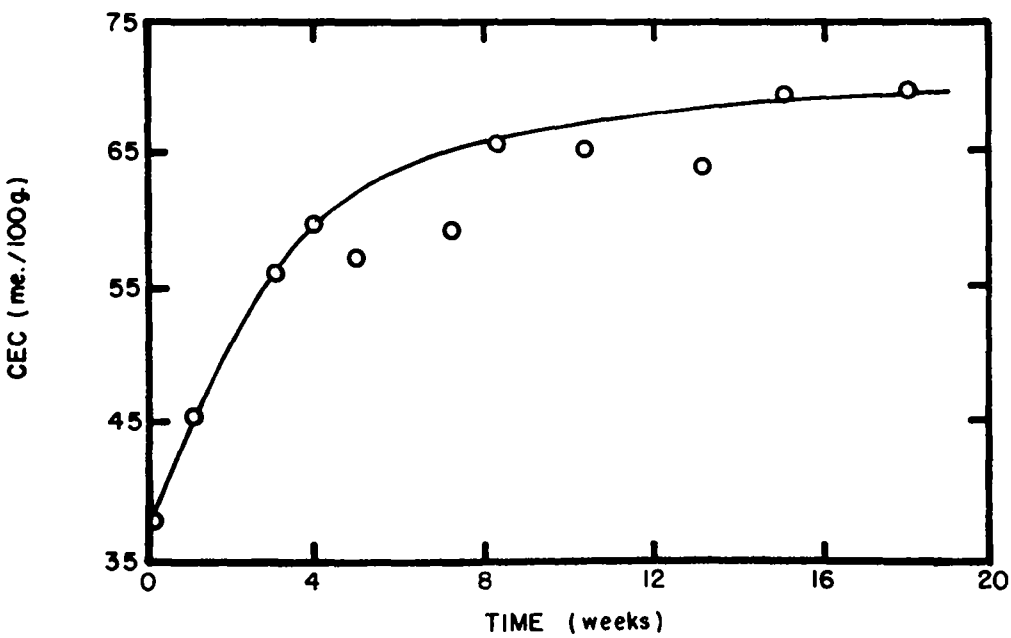


Figure 13. Effect of storage upon compost maturity as evidenced by cation-exchange capacity

TABLE 3

MEAN, STANDARD DEVIATION, AND STANDARD ERROR OF THE MEAN FOR THE CHEMICAL COMPOSITION OF DOMESTIC REFUSE IN RALEIGH, NORTH CAROLINA *†

| Component | Food wastes | | | Other combustibles | | |
|---|---|---|---|---|---|---|
| | Mean | Standard deviation | Standard error of mean | Mean | Standard deviation | Standard error of mean |
| Moisture | 69.25 | 14.20 | 8.20 | 19.60 | 8.35 | 4.82 |
| Acidity (pH) | 5.70 | 0.17 | 0.10 | | | |
| Ash | 11.74 | 3.60 | 2.08 | 4.11 | 0.91 | 0.52 |
| Volatile solids | 88.26 | 3.60 | 2.08 | 95.89 | 0.91 | 0.52 |
| Protein | 12.10 | 2.88 | 1.66 | 1.15 | 0.17 | 0.09 |
| Lipids | 11.20 | 3.48 | 2.07 | 5.33 | 1.92 | 1.12 |
| Crude fiber | 13.03 | 8.00 | 4.78 | 56.83 | 5.15 | 2.98 |
| Liquids | 75.70 | 11.60 | 6.70 | 25.61 | 9.16 | 5.30 |
| Calorific value ‡ | 853 | 12.58 | 7.21 | 901 | 2.23 | 1.29 |
| Sulfur | 0.16 | 0.01 | 0.01 | 1.06 | 0.05 | 0.02 |
| Carbon | 29.23 | 1.55 | 0.90 | 33.02 | 2.20 | 1.27 |
| Nitrogen | 1.92 | 0.28 | 0.16 | 0.20 | 0.03 | 0.02 |
| Potassium | 0.92 | 0.10 | 0.05 | 0.18 | | |
| Phosphorus | 0.28 | 0.38 | 0.02 | 0.12 | 0.02 | 0.01 |
| C:N | 15.40 | 3.36 | 1.94 | 178 | 8.10 | 4.67 |

* All values are in terms of percentage dry weight except percentage moisture and percentage liquid, which are based on wet weight of the raw material, and pH and calorific values.

† From Partridge, 1969.

‡ Kcal/kg dry weight.

the earlier portions of this report. The trend of the variables in continuous composting are discussed below.

Temperature--

Temperature readings were taken frequently during the continuous composting study. The rise and fall of temperature is directly related to the oxygen uptake rates. In a typical continuous run using sawdust and swine waste, it was noted that after the initial lag phase the temperature increased to the thermophilic range (45 to 70$^{o}$C) and stayed there most of the time (Figure 14). The arrows in Figure 14 indicate the times at which compost was removed and fresh mix was added. At these times, there was a rapid drop in temperature followed by a return to the thermophilic range beginning fifteen minutes after the feeding. It is presumed that if the system were devised so that the feeding and emptying were done continuously at opposite ends of a drum, the fluctuation in temperature would be minimized. The temperature variations were recorded in continuous runs using sawdust and poultry waste (Figure 15 and 16) and in a run using shredded paper and poultry waste (Figure 17). Due to difficulties caused by ball-forming and with moisture control and turn-over-rate, the temperature in this run was comparatively lower even though the overall trend was the same as in the other runs.

Moisture--

Moisture content is a very significant factor in the functioning of the composting process. According to Schulze (1962), the oxygen uptake rate increases directly with the moisture content from a minimum of zero at moisture contents below 20 percent to a maximum at a moisture content of 60 percent. Above 60 percent moisture, there is a tendency to form small balls and the composting rate decreases. During the continuous operation study, the moisture content of the input mix ranged from 53.5 to 64.5 percent (Table 4). It is noted that the moisture lost in exhaust gas is almost balanced by the moisture produced by the biological process of respiration and thus the net moisture content of the compost remained practically the same during the entire run. The variation of moisture in the input mix and output compost in a typical continuous run is shown in Figure 18.

Ash Content--

The percent fixed solids at any particular time is determined in part by the rate of biological oxidation. In order to determine ash content, a weighed sample is dried overnight at 105$^{o}$C. After the dry weight is obtained, the sample is placed in a muffle furnace at 600$^{o}$C for 3 hours. The weight of fixed solids or ash is determined and the ash content is expressed as percent of dry weight. The successive change of ash content in the input mix and output compost in a typical continuous run with sawdust and poultry waste is shown in Figure 19.

Acidity--

The input mix ranged from pH 5.4 to 9.05 and the output compost varied from pH 5.95 to 9.3. The lower pH values corresponded to the use of animal waste which was collected more than 24 hours prior to its use. After a lag phase at the start of each run, most runs increased to be between pH 8 and 9. It was also observed that whenever the input mix had a low pH value, it took

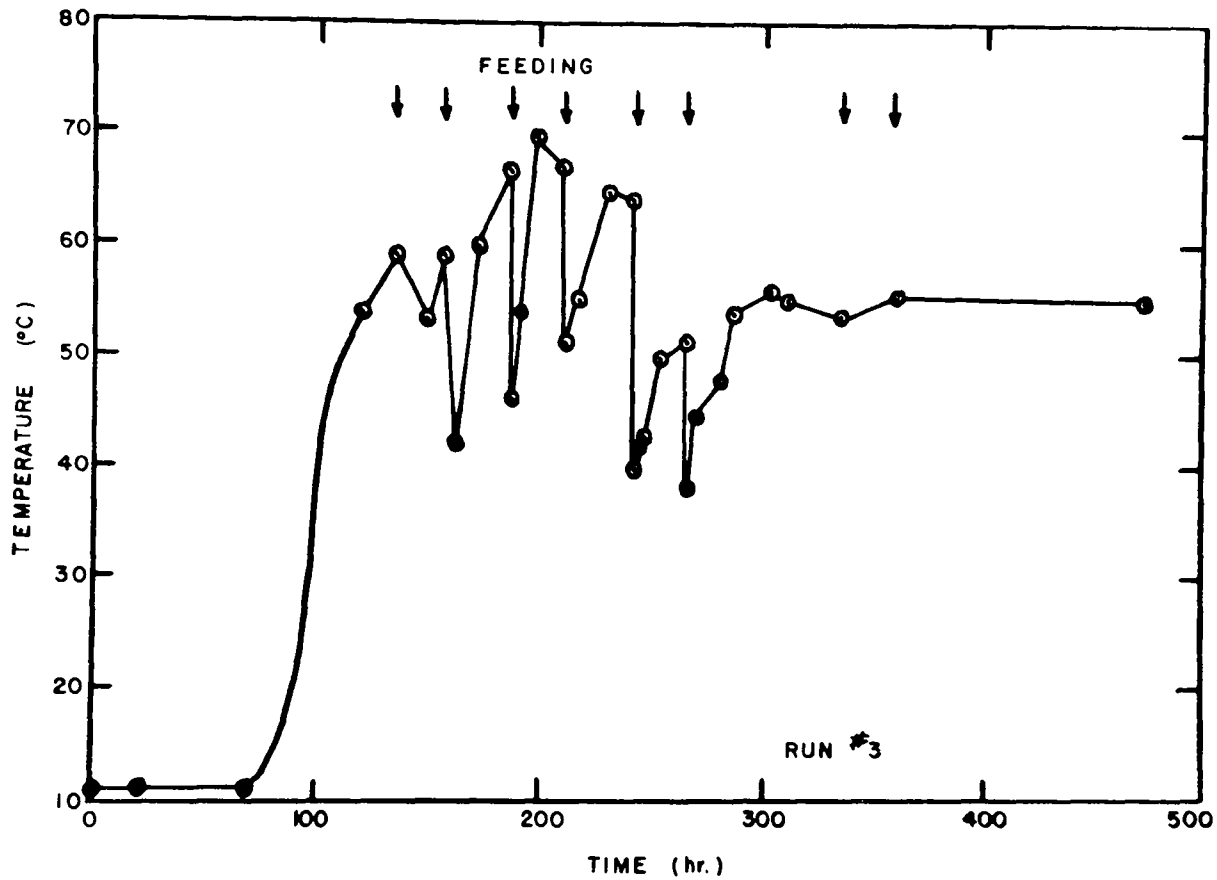


Figure 14. Temperature variation during continuous composting with sawdust and swine waste

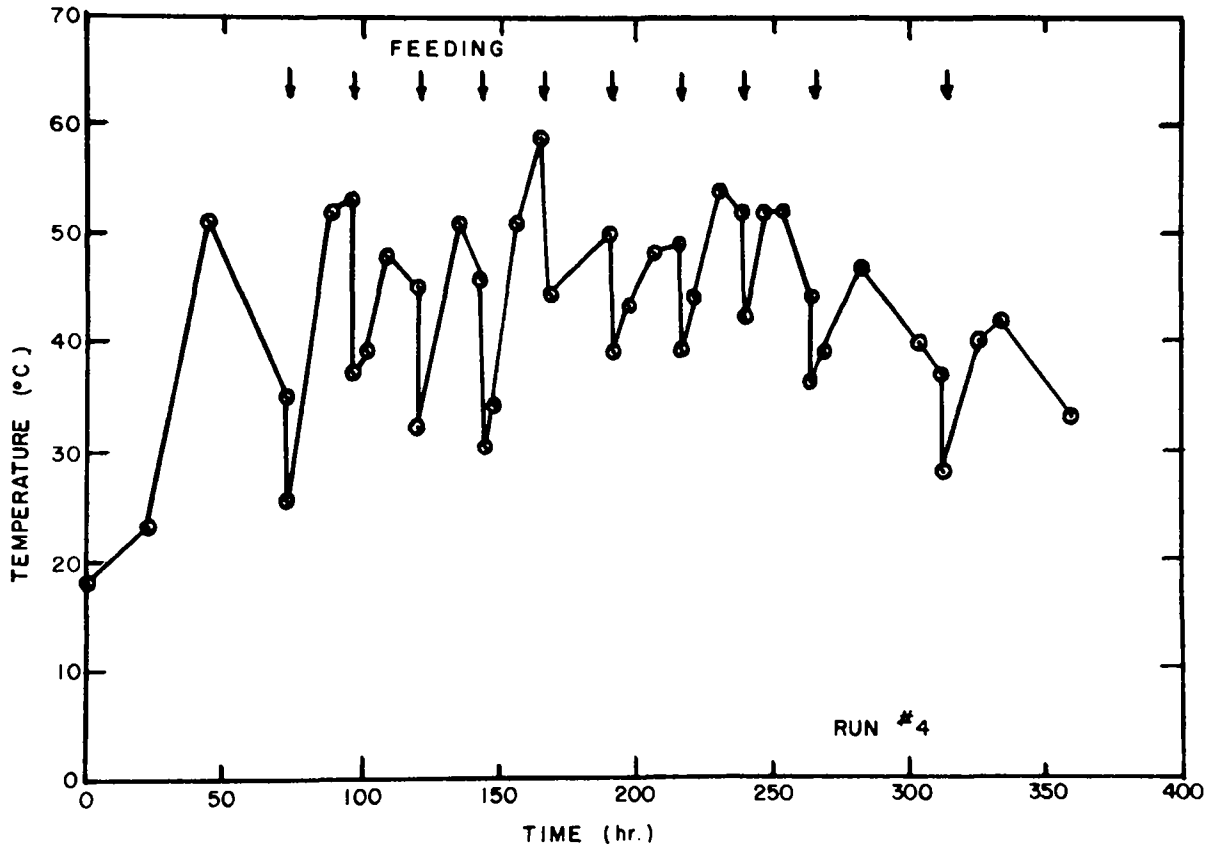


Figure 15. Temperature variation during continuous composting with sawdust and poultry waste

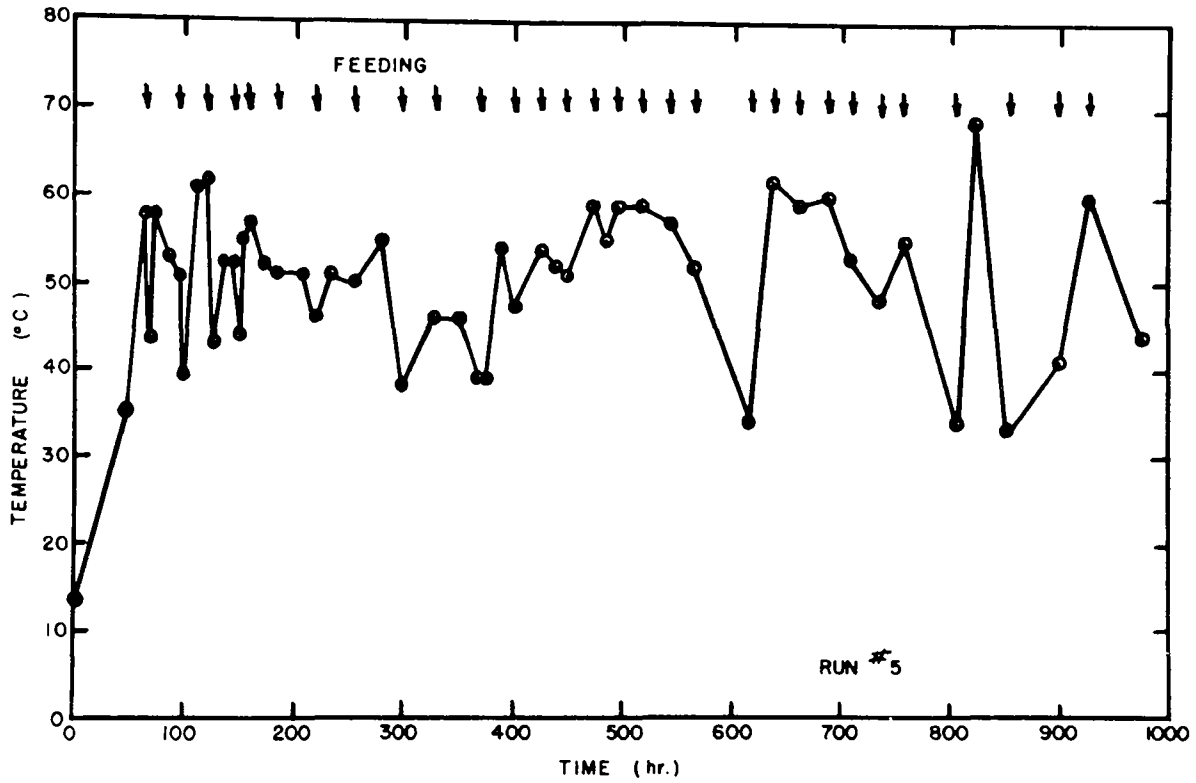


Figure 16. Temperature variation during continuous composting with sawdust and poultry waste

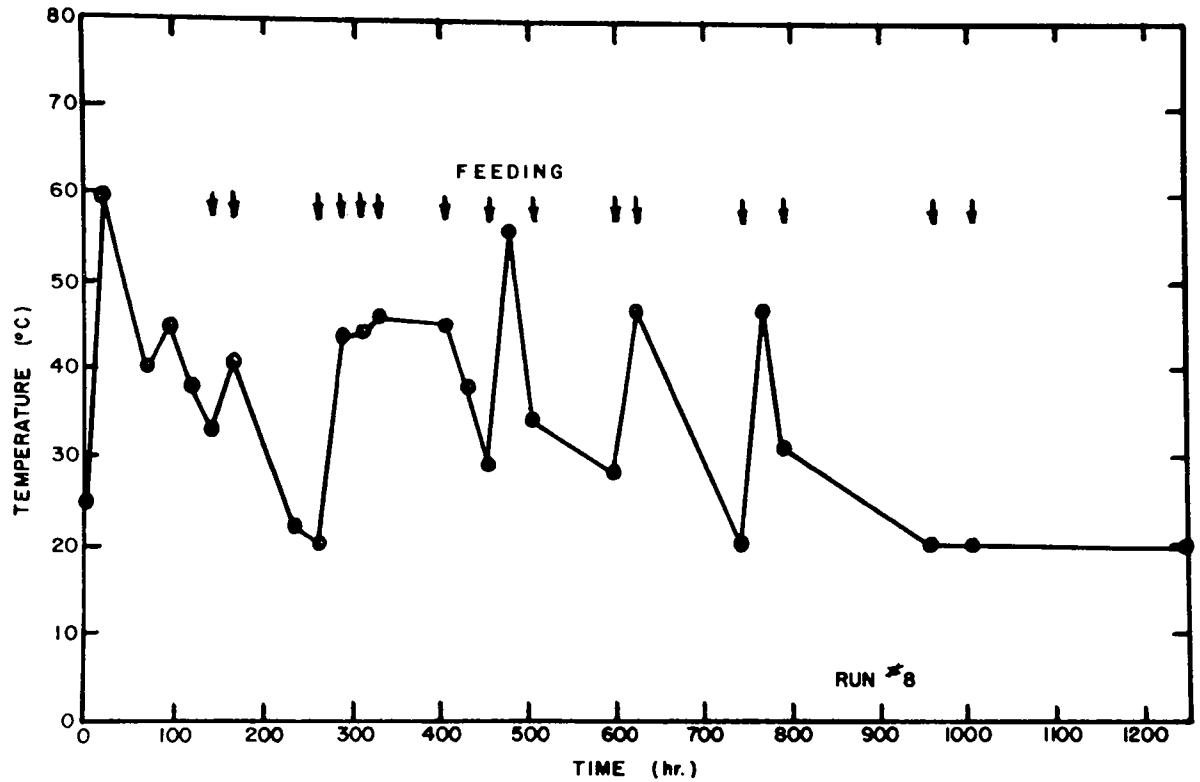


Figure 17. Temperature variation during continuous composting with shredded paper and poultry waste

TABLE 4

VARIATION OF AVERAGE MOISTURE, ASH, AND VOLATILE SOLIDS CONTENT IN INPUT MIX AND OUTPUT COMPOST IN DIFFERENT CONTINUOUS RUNS

| Run No. | Raw Materials | Percent Mositure | | Percent Ash | | Percent Volatile Solids | |
|---|---|---|---|---|---|---|---|
| | | I.M. | O.C. | I.M. | O.C. | I.M. | O.C. |
| 1 | S.D. & P.W.* | 53.5 | 56.7 | 3.80 | 4.90 | 96.20 | 95.10 |
| 3 | S.D. & S.W. | 55.6 | 56.8 | 4.06 | 4.97 | 95.94 | 95.03 |
| 4 | S.D. & P.W. | 56.9 | 55.3 | 4.26 | 5.11 | 95.74 | 94.89 |
| 5 | S.D. & P.W. | 55.1 | 55.2 | 4.48 | | 95.52 | |
| 8 | S.P. & P.W. | 64.5 | 45.2 | 21.13 | 25.52 | 78.87 | 74.48 |

* S.D. = Sawdust, S.P. = Shredded Paper, P.W. = Poultry waste, S.W. = Swine waste, I.M. = Input mix, O.C. = Output compost.

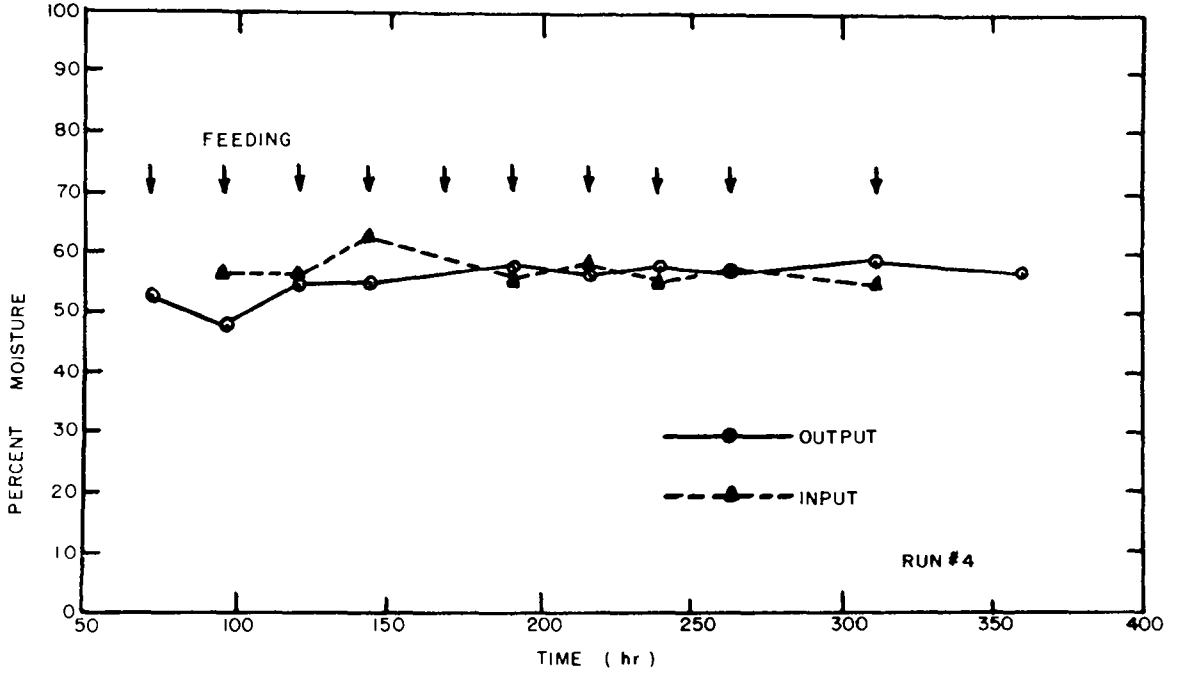


Figure 18. Moisture content variation during continuous composting with sawdust and poultry waste

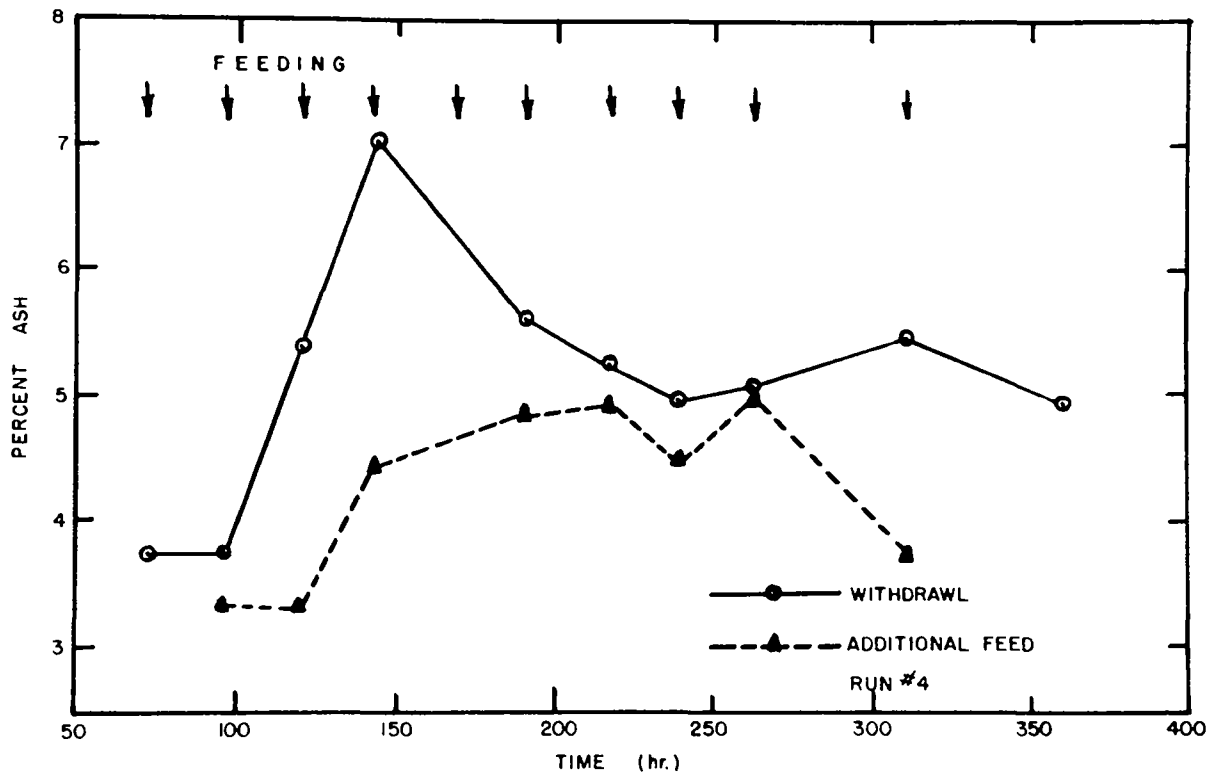


Figure 19. Ash content variation during continuous composting with sawdust and poultry waste

more time to reach thermophilic temperatures than when the value was high. Whenever the pH value exceeded 9, there appeared to be increased loss of nitrogen as ammonia. The variation of pH values during a typical continuous run is given in Figure 20.

Nitrogen Conservation--

The nitrogen losses from the composter are mostly a function of the biological activity. During the decomposition process, any ammonia that escaped in the exhaust gas was captured in the phosphoric acid trap. The nitrogen losses for the continuous runs are presented in Table 5. The percent nitrogen lost in the runs with sawdust and animal wastes ranged from 1.88 to 8.35 percent. The percent of nitrogen lost in the run with shredded paper and poultry waste was calculated to be 20.2 percent which is strikingly high, probably due to high total nitrogen content compared to total carbon content resulting in high pH and escape of extra nitrogen as ammonia. Better control of moisture (and thus physical condition of the mix) and turnover rate might have helped. While calculating the nitrogen losses presented above, average analysis of raw materials was assumed (Table 6).

Turnover Rate--

The turnover rate is defined here as the ratio of the output compost to the total compost in the drum. Initially, only about one-third of the total volume was replaced. However, in later studies, as much as two-thirds of the composting mass was replaced satisfactorily. The weight of the output was generally kept in the range of 60 to 80 percent of the weight of input mix in order to allow for the oxidation of volatile matter. A high turnover rate is significant in the sense that it tells us the minimum residence time necessary for proper decomposition of materials in the composter.

Bulkweight--

The bulkweight is generally represented as weight per unit volume; the units being kilograms per cubic meter ($kg/m^3$). According to Schulze (1962), the moisture and free air-space considerations necessitate that the bulkweight of the raw feed material be kept between 400 and 480 $kg/m^3$. During the composting process, the volatile matter is oxidized and bulkweight of the material generally increases. During the composting of animal wastes mixed with sawdust, the analyzed samples showed that the bulkweight of input mix ranged from 370 to 493 $kg/m^3$ with an average value of 448 $kg/m^3$. The bulkweight of the output compost, ranged from 456 to 564 $kg/m^3$ with an average at 509 $kg/m^3$. The variation in bulkweight of the input mix and output compost during a typical continuous run is given in Figure 21.

Aeration--

The aeration rate in the composter varied from 0.6 to 1.2 l/s with a value of 0.9 l/s used most of the time. Based upon earlier studies, it was believed that this rate would meet the oxygen requirements of the composting mass satisfactorily. There were some very small leakages in the system, but overall the losses were minor and can be safely neglected.

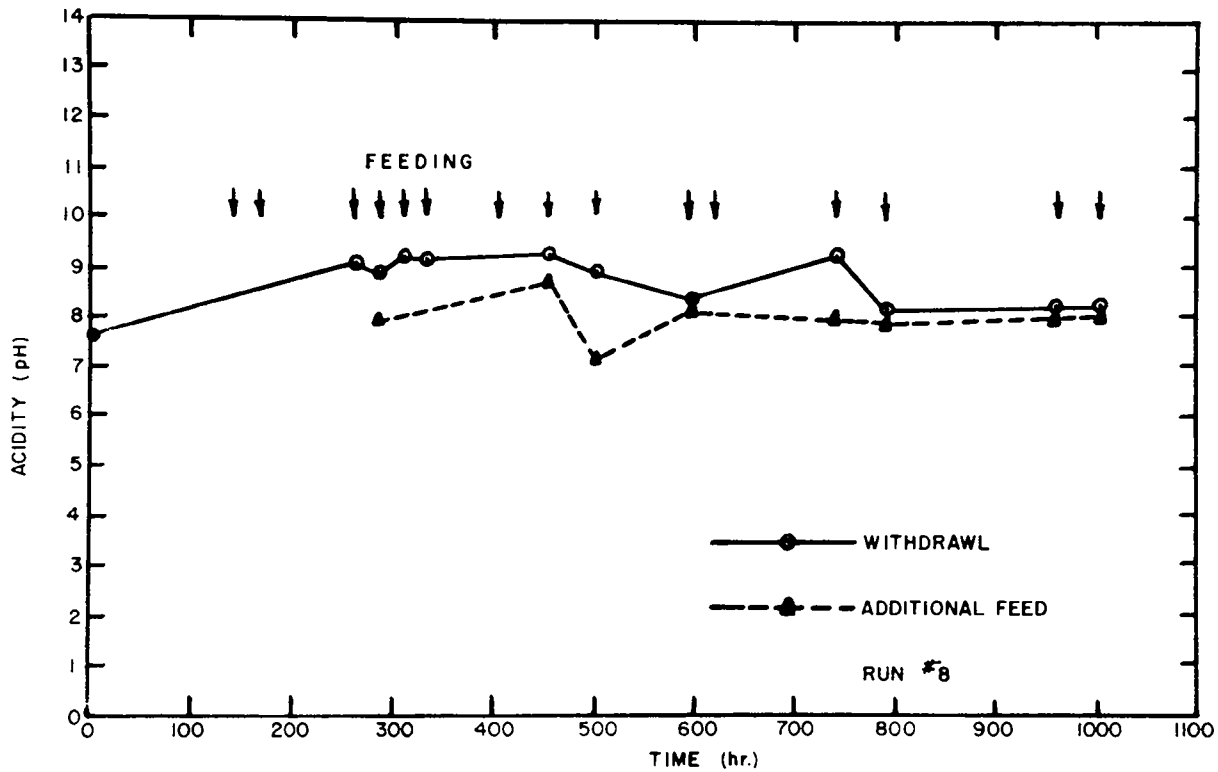


Figure 20. Acidity variation during continuous composting with shredded paper and poultry waste

TABLE 5

NITROGEN LOSS IN DIFFERENT CONTINUOUS RUNS

| Run No. | Raw Materials | Total Carbon (kg) | Total Nitrogen (kg) | Average Acidity (pH)† I.M. | Average Acidity (pH)† O.C. | Nitrogen Lost* (%) |
|---|---|---|---|---|---|---|
| 1 | S.D. & P.W.† | 70.8 | 1.76 | 8.78 | 8.57 | 5.21 |
| 3 | S.D. & S.W. | 306.6 | 7.13 | 6.41 | 7.83 | 3.10 |
| 4 | S.D. & P.W. | 346.9 | 10.43 | 8.27 | 8.82 | 1.88 |
| 5 | S.D. & P.W. | 1091.6 | 38.14 | 7.15 | | 8.35 |
| 8 | S.P. & P.W. | 212.3 | 15.17 | 7.95 | 8.76 | 20.20 |

* Lost from the compost in the drum but captured in the phosphoric acid trap.

† S.D. = Sawdust, S.P. = Shredded Paper, P.W. = Poultry Waste, S.W. = Swine Waste, I.M. = Input Mix, and O.C. = Output Compost.

TABLE 6

ESSENTIAL NUTRIENTS AND MOISTURE IN RAW MATERIALS

| Raw material | C | N | P | K | Ca | Mg | Percent Moisture |
|---|---|---|---|---|---|---|---|
| | Percent (oven-dry basis) | | | | | | (wet weight basis) |
| Poultry Manure | | | | | | | |
| Lowest Value | 34.8 | 6.44 | 1.11 | 0.85 | 1.74 | 0.645 | |
| Highest Value | 38.0 | 7.68 | 1.47 | 1.58 | 2.50 | 0.750 | |
| Average* | 36.6 | 7.09 | 1.25 | 1.29 | 2.10 | 0.713 | 75.9 |
| Swine Manure | | | | | | | |
| Average † | | 3.75 | | | | | 72.7 |
| Sawdust | | | | | | | |
| Lowest Value | 47.1 | 0.103 | Trace | 0.024 | 0.048 | 0.025 | |
| Highest Value | 50.4 | 0.150 | <<0.001 | 0.057 | 0.075 | 0.061 | |
| Average | 48.5 | 0.124 | Trace | 0.044 | 0.061 | 0.047 | 42.3 |
| Shredded Paper ‡ | | | | | | | |
| Mean | 33.02 | 0.20 | 0.12 | 0.18 | | | |
| Standard Deviation | 2.20 | 0.03 | 0.02 | | | | |
| Standard Error of Mean | 1.27 | 0.02 | 0.01 | | | | 19.6 |

* After Walter N. Reed (1969).
† After Harold B. Gotaas (1956).
‡ After Lawrence J. Partridge (1969). Assuming that the "Other Combustibles" part of domestic refuse is mostly paper.

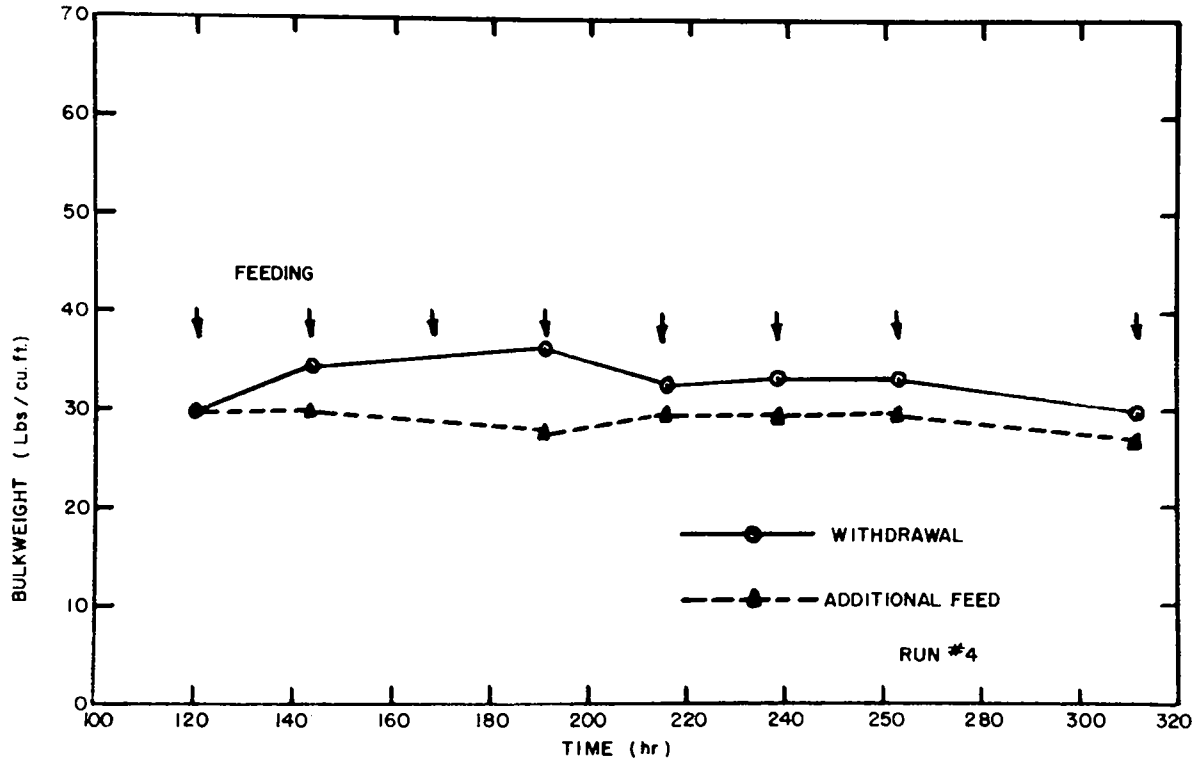


Figure 21. Bulkweight variation during continuous composting with sawdust and poultry waste

## Storage Effects on Compost Maturity

The finished compost was taken out of the composter and placed in heaps in a storage room. The outer surface of the piles reached ambient temperature and lost moisture quickly. However, after approximately one day, the temperature began to rise again at depths of 15 cm or more below the surface. A light spray of water over the pile appeared to benefit the biological activity causing further rise in temperature. For example, the temperature of the batch compost composed of shredded paper and poultry waste was 30°C when removed from the composter. It was stored in a pile and was sprayed lightly with water. After 71 hours, the temperature reached 66°C. This typical "heating phenomenon" is shown in Figure 22. It was noted that very high temperatures, representing the upper range of thermophilic activity were obtained. A heavy growth of actinomycetes and fungi was observed in the pile. After the temperature subsided, it would rise again temporarily when the pile was turned and sprayed with water. However, the renewed biological activity was not maintained. During the storage phase, there was no smell of ammonia in the piles. On the average, after four weeks, the compost was "matured" in the sense that, the biological activity had subsided and the compost had obtained a dark color with an odor like that of forest humus.

## Organisms Associated With Thermophilic Composting

The objective of the microbiological phase of this project was to characterize the organisms involved in the composting process -- both in the thermophilic and in the mesophilic stages. The organisms involved may include bacteria, actinomycetes, or fungi, and the predominance of each group may change rapidly as composting proceeds. Few quantitative studies on the organisms involved in composting have been done due to the lack of suitable methods and assay media (Cross, 1968). Attempts were made therefore to evaluate media which might be useful in quantifying changes in the microflora. This report summarizes the methods attempted, problems encountered, and results obtained.

### Bacteria and Actinomycetes--

The method initially tested for the isolation and enumeration of bacteria and actinomycetes was the widely used dilution-plate technique. A sample of freshly collected compost was dispersed in sterile water in a Waring blender. Further dilutions were prepared from this suspension and one-half milliliter aliquots of the appropriate dilutions were spread on nutrient agar plates which had been poured two days previously. The plates were incubated at 47°C.

After several attempts using this technique, it became apparent that the presence of motile bacteria frequently prevented the development of distinct, countable colonies. These bacteria (*Bacillus* spp.) covered the entire surface of the agar in 12-24 hours. Thus, other media or techniques were sought which would permit accurate counting.

A low concentration of aureomycin inhibits bacteria, thus permitting the growth of actinomycetes (Fergus, 1964). Also, Cross (1968) found Novobiocin

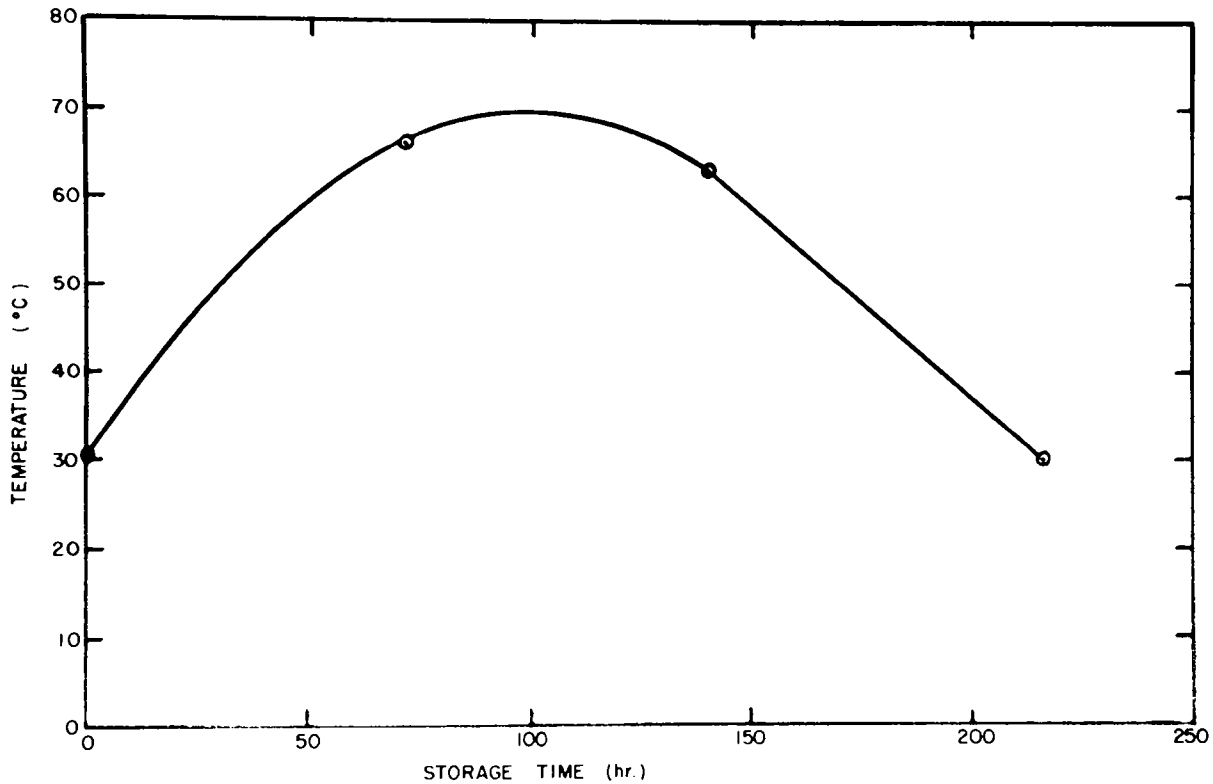


Figure 22. Typical "heating phenomenon" evidenced by composted shredded paper and poultry waste undergoing storage

very useful in isolating Themoactinomyces. Therefore a spectrum of antibiotics was tested for their ability to restrict spreading colonies of bacteria and to inhibit either all bacteria or all actinomycetes so that each group could be counted separately. The antibiotics tested and the concentrations used are given in Table 7.

In general, none of the antibiotics tested were appropriate for general use in an isolation medium. Polymyxin B was the most potent antibiotic used; 10 ppm eliminated all bacteria and actinomycetes. The only antibiotic tested that appeared to be useful was Erythromycin. When used at a concentration of 1 ppm, it resulted in increased numbers of colonies of a blue actinomycete, which has not been identified, but is readily differentiated from all other actinomycetes seen due to the production of blue spores and a blue pigment which diffuses into the agar. However, this actinomycete appears to be of minor importance as compared to a much more numerous white actinomycete and the bacteria.

TABLE 7

ANTIBIOTICS TESTED FOR USE IN ISOLATION MEDIA

| Antibiotic | Concentrations Used (ppm) |
|---|---|
| Streptomycin | 50, 100 |
| Aureomycin | 50 |
| Neomycin | 10, 100 |
| Chloramphenical | 10 |
| Polymyxin B | 10 |
| Erythromycin | 1, 10 |
| Novobiocin | 10, 100 |
| Penicillin | 2, 50, 100 |

Since motile bacteria prevented counting on agar plates, the dilution tube technique was tried (Alexander, 1964). Population estimates were made during several stages of the composting process, using dilution tubes, but two methodological problems prevented clear interpretation of the data. First, nutrient broth (pH 8) was used as the detection medium and both bacteria and actinomycetes grow in it. While total numbers could be estimated, the simultaneous development of bacteria and actinomycetes precluded accurate estimates of either group. Second, the bacterium active during the thermophilic phase of composting is a Bacillus species which forms resting spores. Thus, total counts of Bacillus sp. represent both inactive propagules (spores) and vegetative cells. However, if this technique is coupled with a treatment that eliminates vegetative cells (e.g., heating compost suspensions to 80$^{o}$C), it may be possible to determine the principal organisms active as composting progresses. Preliminary tests on estimating spore populations indicated further problems.

Two methods were used to eliminate vegetative cells; heating a compost suspension to 80°C for 10 min (Clark, 1964) and exposing a suspension to 70 percent ethanol for 30 min as recommended by Jurgensen (1967). When assayed by the dilution tube method, heating gave a spore population about three times larger than the ethanol treatment. Further, the spore density indicated by dilution tubes was only about 1/20 that indicated by dilution plates. Clearly, more critical evaluation of these techniques needs to be done if quantitative estimates of active bacteria and actinomycetes are to be obtained.

Fungi--

Fungi are much more readily detected and isolated than the bacteria or actinomycetes. The isolation media used include yeast-glucose agar and yeast-starch agar (Cooney and Emerson, 1964). Contrary to the opinion of some earlier investigators (Apinis, 1963; Cooney and Emerson, 1964; Fergus, 1964), the inclusion of several antibiotics in the isolation media was found to be necessary. The combinations of antibiotics used included 1) Streptomycin (50 ppm)-Penicillin (40 ppm), 2) Streptomycin (100 ppm)-Neomycin (100 ppm)-Penicillin (100 ppm), 3) Streptomycin (50 ppm)-Chloramphenicol (40 ppm), and 4) Streptomycin (50 ppm). Although the effectiveness of the antibiotic combinations change as the compost matures, the best combination during the thermophilic stage was found to be Streptomycin-Penicillin-Neomycin. As the compost matures and bacteria and actinomycetes become less dominant, the Streptomycin-Chloramphenicol mixture yields plates completely free of bacteria and actinomycetes.

The plates were inoculated by either sprinkling small pieces of compost directly on the surface of the agar or utilizing a multipoint replicator (Stotzky, 1965). The plates then were incubated at 25, 39, and 47°C.

Organisms Prevalent during Composting--

During the thermophilic phase of composting, a Bacillus sp. was consistently observed to be virtually the only organism present in large numbers. However, due to the variety of conditions imposed on the various batches of compost, it is difficult to generalize further on the organisms that predominate during the different stages of the composting process. For example, when a batch process was used with chicken manure, actinomycetes colonized the material following removal from the composter to the extent that the compost acquired a whitish cast. Also, the fungus Coprinus frequently was observed fruiting on the piles. However, when a continuous process with hog manure was used, the material was heavily colonized by a species of Paecilomyces and no Coprinus mushrooms were observed. Also, in the latter material, huge populations of nematodes and mites developed which were not observed in the batch-processed material. The nematodes and mites were determined to have been contaminants brought in after the compost was removed from the composter.

The lack of Coprinus in the continuous-process material may be an indication of an incomplete initial fermentation that left some readily available carbohydrates in the material removed from the composter. In pure culture on autoclaved compost, high levels of dextrose slowed both vegetative growth and

basidiocarp formation of Coprinus. When 10 g of dextrose were added to 150 g of compost, fruiting occured extensively in several flushes in from 11-43 days of incubation. However, when 30 g of dextrose were added, no mushrooms were formed until 53 days of incubation. Similarly, Coprinus readily fruits on yeast-gluclose agar but not on potato-dextrose agar which contains much higher levels of carbohydrates.

Only one true thermophilic fungus, Thermoascus aurantiacus Miehe, was isolated from the compost. This fungus was isolated only sporadically and is thus thought to be of minor importance in the composting process. The results of temperature studies of this and other organisms isolated from the compost are given in Table 8.

In contrast to Thermoascus, the thermotolerant basidiomycete Coprinus frequently was observed fruiting and appears to be one of the major organisms active in the compost as it matures. Coprinus usually became abundant early in the mesophilic phase and could be isolated from virtually every particle of material that has been composted for six months.

As mentioned earlier, Paecilomyces sp. is also a very important secondary colonizer of the compost. Although this fungus grows very slowly in culture, it seems well adapted to growing on the natural compost in that it can be observed fruiting on much of the older compost. Part of this success may be due to the fact that Paecilomyces apparently is well adapted to alkaline conditions, growing best on media of about pH 8. The response of Coprinus sp. to acidity (pH) is quite similar. Thus, secondary colonization of the compost may be determined by tolerance to alkaline conditions much as primary colonization is determined largely by temperature.

TABLE 8

CARDINAL TEMPERATURES OF ORGANISMS ISOLATED FROM POULTRY MANURE-SAWDUST COMPOST

| Organisms | Vegetative growth Temperature°C | | | Sporocarp formation Temperature°C | | |
|---|---|---|---|---|---|---|
| | Min. | Opt. | Max. | Min. | Opt. | Max. |
| Coprinus sp. * | 20 | 38 | 46.5 | 20 | 32 | 32 † |
| Thermoascus aurantiacus * | 29 | 47 | 58 | 29 | 36-42 | 47 |
| Blue actinomycete ‡ | 29 | 44-51 | 57 | | | |
| White actinomycete ‡ | 27 | 42-49 | 55 | | | |
| Bacillus sp. ‡ | | | 66 | | | |

* Linear growth on yeast-glucose agar.
† 32°C maximum for full development; abortive basidiocarps formed between 33 and 38°C (i.e. stipe and cap partly developed but no basidiospores formed).
‡ Growth estimated on nutrient agar.

## SECTION 4

## ECONOMIC FEASIBILITY

High rate thermophilic composting of animal wastes with other carbonaceous materials can be accomplished either in batch processing or by using a continuous system. However, in order for the process to be commerically attractive, it must be economically feasible. Thus, this section of the report deals with cost estimates based on a poultry production unit of 100,000 birds.

The costs reported in this section reflect the economic situation at the time this part of the study was conducted (1971). It preceded the several years of field evaluation of the end products. Most figures remain in relative proportion to one another and thus a similar survey would be revealing at any point in time. It is interesting to note that this survey resulted in an estimated cost of finished compost of $18 per tonne. In September, 1976, we were informed that essentially this same process was being used in a commercial operation in the U.S. and that the actual present cost was $17 per tonne (personnel communication, Harold E. Schlichting, Jr., BioControl Company, Port Sanilac, Michigan).

### LEVEL OF PRODUCTION

The initial size of the composting plant is determined by the needs of waste-disposal for a poultry ranch having 100,000 birds. The average manure production for poultry is assumed to be 0.19 l/bird/day, including both solid and liquid wastes. Weight of manure to be disposed daily = (100,000 birds) x (0.19 l) x (1 kg/l) = 19,000 kg = 19 tonnes.

A sawdust-to-manure ratio of about 3:1 is used. Therefore, weight of sawdust needed daily = 19 x 3 = 57 tonnes. The sawdust may have to be partly dried so that the mix-moisture remains in the optimum range. Sometimes, the manure may also have to be dried. Weight of the mix = 19 + 57 = 76 tonnes/day.

Assuming that only 80 percent of the mass is left after the thermophilic reaction and 60 percent of the original mass is left after 4 weeks of curing, the ultimate weight of the product due to one day's operation would be 45.6 tonnes.

## COSTS OF PRODUCTION

### Raw Materials per Tonne of Compost

One tonne of finished compost requires:

1.4 tonnes of raw mix

weight of sawdust = 1.4 x 3/4 = 1.05 tonnes

weight of poultry manure = 0.35 tonnes

Green sawdust can be available for about $2.20/tonne[1]

The poultry waste needs to be disposed of. Thus, there is little or no cost attached to it. Instead, there will be potential savings of the expenses incurred for safe disposal of poultry manure by any other methods. These savings depend upon the alternative method of disposal and are not included in this study.

Phosphoric acid will be used to trap any escaping ammonia from the reactor. The neutralized acid will be sprinkled on the compost piles in the curing stage to retain the nitrogen and supplement the phosphorus content of the compost. The amount of phosphoric acid needed is a function of nitrogen loss, which should be kept to its minimum. From the experience gained during the continuous composting, it was found that 10 liters of solution containing 1 liter of commercial grade (85 percent pure) $H_3PO_4$ was neutralized by about 450 kg of raw-mix while under thermophilic decomposition. Therefore, the amount of commercial grade $H_3PO_4$ for a mix of 1.4 tonnes is 1.4 ÷ 0.45 = 3.1 l. The specific gravity of $H_3PO_4$ is 1.884. The weight of $H_3PO_4$ needed for 1 tonne of finished compost = 3.1 l x 1.884 kg/l = 5.84 kg. Commercial grade (85 percent pure) $H_3PO_4$ costs about $196/tonne[2]. Therefore, cost of 5.84 kg of $H_3PO_4$ = 196/1000 x 5.84 = $1.14. Total cost of raw materials per ton of finished compost is:

| | |
|---|---|
| sawdust | $2.31 |
| Poultry manure | $0.00 |
| $H_3PO_4$ | $1.14 |

Total cost per tonne of compost = $3.45

[1] Personal contact with Mr. R. H. Hogan, Evans Products Corporation, Moncure, N. C. June, 1971.

[2] Personal contact with Mr. J. H. Collie, Southchem Inc. Durham, N. C. June, 1971.

Real Estate Requirements

A sizeable area of land will be required for the curing of the thermophilically reacted compost for 4 weeks. About 76 x 0.80 = 60.8 tonnes of such compost will be produced per day. Assuming that it takes one more week for the cured compost to be packed and hauled for sale, the amount of compost continuously on hand = 60.8 x 7 x 5 = 2128 tonnes.

The bulk weight of the compost is about 480 kg/$m^3$. Thus a rectangular-shaped pile 1 m deep and 2 m wide at the base will contain about 2 $m^3$ per running meter, or 960 kg per running meter. Therefore, one tonne of compost would need 1000/960 ≃ 1 running meter. There are 10,000 square meters per hectare (ha), 10,000/2 = 5,000 running meters (2 m wide) to a hectare.

5000/1 = 5000 tonnes per hectare.

Thus, approximately one half hectare will be enough for the compost curing. Sawdust will be stored in piles on the ground, maintaining a seven day stock pile. Poultry waste will be obtained from the ranch daily. Land will be required for the construction of a composting plant, packaging plant, offices, parking of heavy and light machinery, storage ground, etc. Approximately 4 hectares should be sufficient for the entire operation. Cost of industrial land around Raleigh, N. C. is about $740 - $1250 per hectare.[3]

cost of land = 4 x 1250 = $5000

The land should be fairly level, clean, with an ample water supply and on or near a railroad siding.

The estimated construction cost (1972) of plant buildings, offices, etc. is about $30,000 and of the railroad spur is about $10,000.

Total real estate cost = $45,000. Let the life of the plant be 30 years after which the land could be sold at least at par. Then at an interest rate of 10 percent, the annual cost of capital recovery is given by:

$$CR = (45{,}000 - 5000) \times \left[\frac{0.10\ (1 + 0.10)^{30}}{(1 + 0.10)^{30} - 1}\right] + (5000) \times (0.10)$$

$$= (40{,}000) \times (0.10608) + 500$$

$$= 4243 + 500 = \$4743$$

Let the annual maintenance expenses for the real estate items be 1 percent of the total cost = (45,000 x 1)/100 = $450.

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[3]Personal contact with Mr. C. F. Gaddy, Gaddy Real Estate Company, Raleigh, N. C. June, 1971.

The property tax will be charged on half the actual value of total property, i.e., $22,500. The rate of tax, including a reasonable fire charge, is about $1.98 per $100.[4]

yearly tax expense = 1.98 x 22,500/100 = $456

total annual expense due to real estate property = $5649.

Annual production of compost = 45.4 x 365 = 16,556 tonnes

annual cost of real estate/ton = $5,649/16,556

= $0.34/tonne

Heavy Machinery[5]

Bulk Feed Body Trucks--
These will be used to bring sawdust and to transport final compost. Three trucks will be needed.

Initial investment per truck = $25,000

Total investment = $75,000

Truck-Mounted Rotary Plows--
These will be used as spreader, loader and unloader for sawdust as well as compost.

| | |
|---|---|
| One double rotary snow-go plow equipped with drive unit | = $5,000 |
| One six-wheel drive truck | = 15,000 |
| One single rotary snow-flye plow with power unit | = 2,500 |
| Loading chute and mechanical cab controlled chute rotation | = 500 |
| Tractor with power loader attachment | = 8,000 |

Railroad Car Loaders--
These will be used to load the railroad cars with the finished compost. Two units needed. Two forge blower drive units @ $1500 = $3000.

The total value of the heavy machinery as outlined above is $109,000. Considering an average life period of ten years with a salvage value of 10 percent of the initial investment and an interest rate of 10 percent we have the

[4]Personal contact with Wake County Tax Department, Raleigh, N. C., 1971.

[5]All cost figures for heavy machinery were obtained by personal contact with Mr. George Jones, General Machinery Company, Raleigh, N. C., June 1971.

annual capital recovery as:

$$CR = (109{,}000 - 10{,}900) \times (0.16275) + (10{,}900) \times (0.10)$$

$$= (98{,}100) \times (0.16275) + (10{,}900) \times (0.10)$$

$$= 15{,}980 + 1{,}090$$

$$= \$17{,}070$$

If the yearly operation and maintenance costs are assumed to be 1 percent of the initial cost, then total yearly expense = 17,070 + 1,090 = $18,160.

Cost per tonne of compost = $18,160/16,556 = $1.10/tonne

## Other Equipment

Compost Drums--

Three 4.6 m diameter by 9.2 m long drums with about 150 $m^3$ capacity will be fed with raw mix at one end and with processed compost coming out the other end. The drums will be rotated at 1 RPM by an electric motor and gear system. The cost per drum is $70,000. Cost of fabricating three drums[6] = $210,000.

Electric Motor--

Three 40 hp electric motors @ $3000 = $9000[7]

Air Compressor and Flow Rater--

These should be capable of supplying as much as 470 l/s of air at atmospheric pressure to the three drums. The cost is estimated to be $10,000.[8]

Mixing Mechanism--

A blending mill to mix the sawdust and poultry manure homogeneously before it is fed into the drum is estimated to cost $5,000.[8]

Packaging Plant--

Packaging plant is to make 25 kg, 50 kg, and 250 kg packets of finished compost. The cost is estimated to be $10,000.[8]

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[6]Personal contact with Mr. Edward Wood and Mr. Charles Stanley, Aeroglide Corporation, Raleigh, N. C., June 1971.

[7]Personal contact with Mr. E. D. Reams, Electrical Equipment Company, Raleigh, N. C., June 1971.

[8]Personal estimate, D. S. Airan, 1971.

Phosphoric Acid Tank--

The tank should be stainless steel, on piers, and have a capacity of 29 $m^3$. The cost of the tank and installation as given by Schmaedick (1958) is assumed to hold good as: Total cost = $20,000.

Water Tank--

A lined steel tank of 436 $m^3$ capacity equipped with centrifugal pumps to deliver 19 l/s is required. Cost of tank, pump and installation as given by Schmaedick (1958) is assumed = $30,000. Total cost of above equipment = $294,000.

Considering this equipment for 30 years (the life of the plant) with a salvage value of 5 percent of initial investment and an interest rate of 10 percent, we have the annual capital recovery as:

$$CR = (294,000 - 14,700) \times (0.10608) + (14,700) \times (0.10)$$

$$= (279,300) \times (0.10608) + 1470$$

$$= 29,625 + 1470$$

$$= \$31,095$$

Assuming that yearly operation and maintenance costs are 1 percent of the initial cost, total yearly expenses are 31, 095 + 2940 = $34,035.

$$\text{Cost per tonne of compost} = \$34,035/16,556$$

$$= \$2.06/\text{tonne}$$

Miscellaneous Yearly Expenses

Miscellaneous Equipment--

This equipment consists of shovels, moisture testing equipment, pH meter, chemical analysis apparatus, tools for general maintenance, office furnishings, locker room furnishings, first aid kits, conveyor belts, etc. for raw materials or finished compost. Overall expenses estimated to be = $5000.[8]

Electric Power Requirements--

Yearly consumption of electric power is estimated to cost $2000.[8]

Water Requirements--

Yearly consumption of water is estimated to cost $1000.[8]

Communications--

Telephone, stationary, and postage - $2500.[8]

Bags for Packaging Finished Compost--
$1500[8] (including printing of brand name on the bags).

Advertising and Publicity--
Initial investment is expected to be higher than later routine expenses. The product can be put on trial basis first in local area, then statewide, and finally slowly expanding its scope in other states. A figure of $25,000 is estimated.[9] Total miscellaneous expenses = $37,000 per year.

cost/tonne of compost = $37,000/16,556 = $2.23/tonne

Labor Requirements

The yearly expenses for labor will be roughly as follows:

| Persons | No. | Yearly Rate[8] | Annual Cost |
|---|---|---|---|
| Plant Superintendent | 1 | $20,000 | $20,000 |
| Truck Drivers | 3 | 8,000 | 24,000 |
| Rotary Plow Drivers | 2 | 8,000 | 16,000 |
| Railroad Car Loader | 1 | 8,000 | 8,000 |
| Composter Drums Operators | 2 | 7,000 | 14,000 |
| Mixing Plant Operator | 1 | 7,000 | 7,000 |
| Packaging Plant Operator | 1 | 7,000 | 7,000 |
| Laboratory Supervisor | 1 | 10,000 | 10,000 |
| General Laborers | 2 | 6,000 | 12,000 |
| Secretaries for Office | 2 | 8,000 | 16,000 |
| Bookkeeper | 1 | 8,000 | 8,000 |
| Mechanic | 1 | 8,000 | 8,000 |
| Total cost of labor/yr. | | = | $150,000 |

Yearly expense per tonne of compost = $150,000/16,556

= $9.06/tonne

[9]Personal contact with Mr. W. M. Merrell, J. T. Howard Advertising Agency, Raleigh, N. C., June 1971.

Total Cost per Tonne

The following is a summation of the total production cost.

| | |
|---|---|
| Raw materials | $3.45 |
| Real estate | 0.34 |
| Heavy machinery | 1.10 |
| Other Equipment | 2.06 |
| Miscellaneous expenses | 2.23 |
| Labor expenses | 9.06 |
| Total cost/tonne | $18.24 |

Thus, at a production level of 45.4 tonnes/day, the unit cost of production for the finished compost will be $18.24 or approxiamtely $18/tonne.

SALE OF COMPOST

The finished compost is a sanitary, non-offensive material which smells like forest humus when wetted. It can be used in greenhouses, nurseries, home gardens, farms, cemeteries, golf courses, athletic fields, and city parks. The product can also be used on heavily worked soils as a soil conditioner to help retain moisture.

The possible competitors to this product in the market are peat moss, old sawdust, dehydrated cow manure and other such organic materials. Dehydrated cow manure retails for $11/100 kg and produces offensive odor when wetted. The compost produced will definitely be competitive in terms of quality and in order to introduce it in the market, a wholesale price of $2.20/100 kg FOB plant will be established. Thus the retail price should not need to exceed $4-6/100 kg which should be very attractive to the customers.[10] Thus the compost can wholesale for $22/tonne which will give an annual profit, P, of:

$$P = (\$22.00 - \$18.24) \times (16{,}556) = \$3.76 \times 16{,}556$$

$$= \$62{,}251$$

MINIMUM PRODUCTION LEVEL

The enterprise can sustain at a minimum production level where the condition of TOTAL INCOME = TOTAL COST is satisfied. It can be seen from Table 9 and Figure 23 that as the level of production is raised, the unit cost of production falls. If the sale price of compost is fixed at $22/tonne, then the break-even level of production will be about 36 tonnes/day. This means

[10] Personal contact with Mrs. R. A. Fowler, Fowler's Nurseries, Raleigh, N. C., June, 1971.

TABLE 9

UNIT PRODUCTION COST AT DIFFERENT LEVELS OF PRODUCTION*

| Level of Production | | Cost per Tonne | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Per Day, Tonnes | Per Year, Tonnes | Raw Materials $ | Real Estate $ | Heavy Machinery $ | Other Equipment $ | Miscellaneous Expenses $ | Labor Expenses $ | Total Cost/Tonne $ |
| 18 | 6,623 | 3.45 | 0.97 | 2.75 | 5.16 | 5.60 | 22.65 | 40.58 |
| 27 | 9,934 | 3.45 | 0.65 | 1.84 | 3.44 | 3.74 | 15.10 | 28.22 |
| 36 | 13,245 | 3.45 | 0.49 | 1.38 | 2.58 | 2.80 | 11.33 | 22.03 |
| 45.4 | 16,556 | 3.45 | 0.34 | 1.10 | 2.06 | 2.23 | 9.06 | 18.24 |
| 54 | 19,867 | 3.45 | 0.33 | 0.93 | 1.72 | 1.87 | 7.55 | 15.85 |

*The calculations are based upon the assumption that the real estate property, machinery and equipment, and labor remain at the same level at various production levels. In practice, it will not actually hold. However, for the purposes of illustration here, it was assumed to be satisfactory.

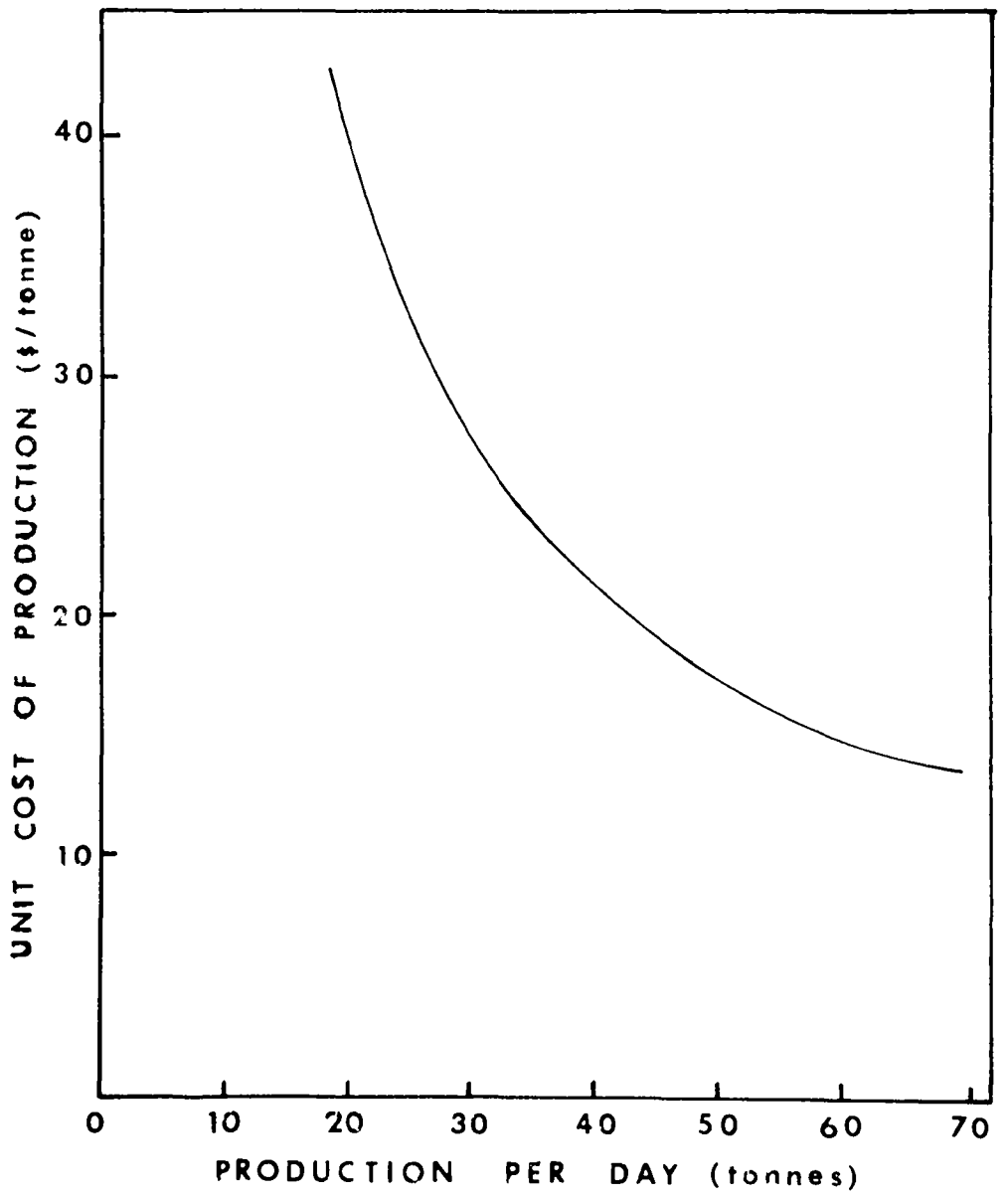


Figure 23. Compost cost-return curve

a yearly production of 13,140 tonnes of finished compost.

This process might be attractive to some poultrymen even at a loss if the loss were less than their current cost of waste disposal. Also the amount of land required is much less than would be needed for waste disposal via land spreading and the process is less offensive than lagooning of wastes.

## SECTION 5

## PRODUCT EVALUATION

As indicated in the Introduction section of this report, the efficient method of preparation of compost from animal waste and carbonaceous material would be mostly of academic interest unless there were a beneficial use for the end-products. This section includes the results of both greenhouse and field evaluations of different end-product and presents solid data indicating that the material does have beneficial properties from the standpoint of both soil improvement and increased food production. A very wide range of rates of application were tested since it was of interest to determine both the minimum amount capable of producing a significant yield increase and the maximum amount usable without causing either crop or environmental damage. In the former case the compost is serving as a fertilizer substitute while in the latter case the soil is serving as a sink in a waste disposal and nutrient recycling system.

### MATERIALS AND METHODS

#### Sawdust-Poultry Manure Compost Mulching Experiment on an Established Lawn

Sawdust-poultry waste compost was applied as a surface mulch to an established lawn. Grasses in the lawn were largely coastal bermudagrass with small amounts of fescue. A 15 m x 2.5 m plot was separated into twenty-three plots of 16.3 $m^2$ each. Compost was applied as a mulch on top of the grasses at three levels; 1.1 tonnes/ha, 2.3 tonnes/ha, and 4.5 tonnes/ha. These were completely randomized by treatment and replication. Each treated plot was separated from other treated plots by a control plot. There were three replications each of the 1.1 tonnes/ha and the 4.5 tonnes/ha treatments, six replications of the 2.3 tonnes/ha treatment, and eleven replications of the control treatment. The plots were established in May, and harvested with a lawn mower and grass catcher device approximately every thirty days for three harvests. Each plot was clipped to a 1.3 cm level at each harvest. Dry weight was determined after drying in a forced-air oven at 70°C for 48 hrs. A subsample was obtained, dried, ground in a Wiley mill to pass a 20 mesh sieve, and analyzed for total nitrogen content in a nitrogen analyzer.

#### Sawdust-Poultry Manure Compost Applications to Wheat, Millet, and Tomatoes in the Greenhouse

Cultivar GAHI-1 Pearl Millet, a summer cereal grain, and Knox winter wheat were the field crops employed. Compost was applied at nine rates to a sandy soil from the Norfolk soil series in 4.5 l plastic containers. The compost was thoroughly mixed with the soil and the pots were filled to

capacity. Treatments were a control, consisting of soil only, 100 percent compost, and the following rates of compost application to the soil (tonnes/ha equivalent): 1.12, 2.24, 5.6, 11.2, 22.4, 112, 224, and 448. Each treatment was replicated three times. A completely randomized design was used. Randomization was by treatment and replication with each crop. The grain seeds were germinated prior to planting to insure viability and equal plant population per pot. The pots were watered to maintain approximate field capacity. Initial plant population was fifty plants per pot. The plants were harvested after ninety days of growth. A 25 percent sub-sample was dried at 70°C, ground in a Wiley mill to pass a 20 mesh sieve, and analyzed for N, P, K, Ca, and Mg. Methods of nutrient analysis were Kjeldahl for N; vanadate-molybdate for P on a spectrophotomer; flame photometry for K; and atomic absorption spectrophotometry for Ca and Mg. The experiment was established in August and terminated in November.

The same experimental design and procedures were used for the tomato greenhouse experiment as were used for the grains with the exception of plant population per pot. There was one Marion tomato plant per pot. Tomato seeds were planted in a sterilized coarse sand seed bed, and the resulting seedlings were transplanted to the pots at a uniform height of ten centimeters.

Soil samples were obtained with a core sampler. Five cores per pot were composited and analyzed by the Agronomic Division of the North Carolina Department of Agriculture.

Sawdust-Poultry Manure Compost Applied to Tomatoes in the Field

Sawdust-poultry manure compost was applied at six rates to a Chesterfield sandy loam soil located on the North Carolina State University Central Crops Research Station at Clayton, North Carolina. The compost was thoroughly incorporated in the surface fifteen centimeters of the soil by spading and disc harrowing. Treatments consisted of a control treatment (no compost) and 5.6, 11.2, 22.4, 44.6, 336, and 448 tonnes/ha of compost. There were three replications of each treatment, and a completely randomized design was used. Twenty-one plots, measuring 1.8 x 1.8 m, were arranged in a 15.2 x 15.2 m block. Each plot was isolated by a 60 cm border area.

Marion tomato plants, 20 cm in height, were transplanted to the plots in April. Each plot had a plant density of nine plants in three rows. The spacing was 60 cm between rows and between plants in the rows. The border areas were planted with the same plant density as the plots. Three border rows were planted around the exterior of the entire block. Fresh fruit weight and number of friut were determined from each plant in all treatments. Mature fruit was harvested 12 times. The initial harvest was June 29, and terminal harvest was August 18. A random sample of fruits from all treatment replications from each harvest was dried at 70°C, ground, and analyzed for N, P, K, Ca, Mg, and Mn.

Six plant tops were randomly selected from each plot, dried at 70°C, ground, and analyzed for the same nutrients. The plants were harvested on August 18. Methods of analysis were the same as those reported for the

greenhouse study. In addition, Mn was determined by atomic absorption spectrophotometry. Soil samples for chemical analysis were obtained with a bucket auger in the immediate root zone of each plant to a depth of 15 cm. Soil chemical analyses were conducted by the Agronomic Division of the North Carolina Department of Agriculture. undisturbed soil samples for physical analysis were obtained with a Lutz soil sampler. A tension table and pressure membrane apparatus were utilized to determine soil moisture characteristics.

Two irrigations each of 55 mm of water, were applied to the tomatoes during the growth period. Weed control was by hand-hoe cultivation. No pesticides were used nor were any needed during this study.

Paper-Poultry Manure Compost Applied to Tomatoes in the Field

Paper-poultry waste compost was applied at four rates to Marion tomatoes on a Chesterfield sandy loam soil. Treatments consisted of a control treatment (no compost), 2.2, 11.2, 22.4, and 112 tonnes/ha of compost. There were three replications of each treatment. A completely randomized design (randomization by treatment and replication) was employed.

Row width was 1.5 m and spacing between plants was 45 cm. The plots consisted of fifteen-2.3 m rows. Border plants were planted on the ends of each row, and one row of border plants surrounded the entire plot area.

Compost was applied in a one meter wide band in the center of each row and incorporated into the soil with a rotary tiller to a depth of 15 cm. The compost was applied May 26, and 20-cm-tall Marion tomato seedlings were transplanted to the plots on May 27.

Tomato fruit was harvested eight times, and fruits from each plant were weighed and counted. A random sample of fruit from each plant was oven-dried at 70$^{o}$C for nutrient analysis. Final fruit harvest and plant tissue harvest was September 9. Plant tops were dried at 70$^{o}$C for tissue analysis. Tissue was analyzed for N, P, K, Ca, Mg, and Mn. Soil samples were also taken September 9, and analyzed by the Agronomic Division of the North Carolina Department of Agriculture.

Both the sawdust-poultry waste and paper-poultry waste composts were analyzed for nutrient content and other characteristics (Table 10).

RESULTS AND DISCUSSION

Sawdust-Poultry Manure Compost Mulching Experiment on an Established Lawn

Surface mulches of properly composted materials may have value as an amendment for home lawns, gardens, golf courses, cemetaries, nurseries, and commercial crops requiring infrequent or no cultivation. Sawdust, leaves, straw, and other litter have been effectively used as mulches to reduce soil loss and weed growth and to conserve moisture. Composts provide these benefits and supply nutrients for plant growth. Home owners, a potential market for compost used as surface mulch, could utilize composts in the maintenance

TABLE 10

PHYSICAL AND CHEMICAL CHARACTERISTICS
OF COMPOSTS UTILIZED IN THIS STUDY

| Type of Compost | Physical and Chemical Properties | | | | | |
|---|---|---|---|---|---|---|
| | Nutrient Content | | | | | |
| | .....(Percent dry weight)..... | | | | | (ppm) |
| | N | P | K | Ca | Mg | Mn |
| Sawdust Poultry Manure Compost | 0.86 | 0.65 | 0.61 | 1.42 | 0.16 | 159 |
| Paper-Poultry Manure Compost | 1.46 | 1.35 | 1.32 | 2.20 | 0.16 | 153 |

| | Particle Size Distribution (Percent) | | | | |
|---|---|---|---|---|---|
| | >10 mm | 10-2.0 mm | 2.0-1.0 mm | 1.0-.25 mm | <0.25 mm |
| Sawdust-Poultry Manure Compost | 7.0 | 52 | 18 | 18 | 5 |
| Paper-Poultry Manure Compost | 1.0 | 38 | 39 | 20 | 27 |

| | Other Characteristics | | | | |
|---|---|---|---|---|---|
| | Acidity (pH) | Bulk Density (g/cc) | CEC (meq/100g ) | Water Holding Capacity (ml/g) | C:N ratio |
| Sawdust-Poultry Manure Compost | 8-9 | 0.280 | 67 | 3.71 | 18-40:1 |
| Paper-Poultry Manure Compost | 8-9 | 0.310 | 52 | 3.32 | ND* |

*Not determined

of established lawns and flower beds. Compost could be used to increase grass growth on lawns, and, at high applications around ornamental shrubs and in flower beds could reduce weed growth. Sawdust-poultry manure compost was applied to established lawn grasses to determine its effect as a surface mulch with respect to dry weight production, N uptake, and regrowth of the grass after clipping. All compost treatments increased total dry weight production (Table 11), N concentration, and total N yield (Table 12) when compared to the control plots. The 1.1, 2.3, and 4.5 tonnes/ha treatments increased total dry weight production 45, 57, and 25 percent respectively and total N accumulation by 81, 103, and 68 percent respectively. Dry matter yield of the 2.3 tonnes/ ha compost treatment was 9.1 percent greater than the 1.1 tonnes/ha treatment and 26 percent greater than the 4.5 tonnes/ha treatment. The total N yield of the 2.3 tonnes/ha treatment was also 12 and 21 percent greater than the total N yield from the 1.1 and the 4.5 tonnes/ha treatments, respectively. Recovery and regrowth after harvest were also increased by compost treatments.

Although all compost treatments increased grass yields, there were only small differences among yields of the treated plots at the first harvest. Subsequent harvests indicated that regrowth patterns differed with compost treatment. The highest compost level demonstrated the poorest regrowth of the treated plots and was only 16 percent greater than the control plots at the final harvest. The second harvest indicated that the 2.3 tonnes/ha treatment promoted more rapid growth than the 1.1 tonnes/ha treatment. The 2.3 tonnes/ha treatment sustained a high rate of growth until the third harvest while the 1.1 tonnes/ha required thirty days longer to promote the same yield. The final harvest for the two lower compost treatments were essentially equal (Table 11).

The N concentration in the 4.5 tonnes/ha treatment indicated that some factor other than nutrient supply and uptake may have been reducing yields. The low bulk density (0.28 g/cm$^3$) of sawdust-poultry manure compost requires thick layers of compost at high application rates. Short bladed grasses, growing close to the surface of the soil, such as burmudagrass, would have to grow through the compost layer for optimum photosynthesis to occur. Compost depth and frequent close clipping appear to reduce burmudagrass growth. The effect of sawdust-poultry manure compost surface application on established burmudagrass lawns is a function of the rate of application. A maximum threshold of application exists for promoting growth (2.3 tonnes/ha), and a minimum threshold exists for reducing growth (4.5 tonnes/ha) under the conditions of this experiment (Table 12). These thresholds should vary with the variety of grass, type of compost, and frequency of harvest.

Sawdust-Pountry Manure Compost Applications to Wheat, Millet, and Tomatoes in the Greenhouse

An ideal solution to animal waste disposal is one which utilizes the wastes generated as a nutrient source to grow the feed necessary for a subsequent animal production operation. A continuous re-cycling of nutrients may be established with a minimum potential for adverse environmental effects. Wheat and millet, two grasses employed in the greenhouse study, can be utilised as forage or feed in an integrated animal production-land-waste

TABLE 11

DRY WEIGHT PRODUCTION OF THREE HARVESTS OF LAWN GRASSES AT VARIOUS RATES OF SAWDUST-POULTRY MANURE COMPOST APPLIED AS A SURFACE MULCH

| Compost Treatment (Tonnes/ha) | Harvest 1 (Mean Dry Wt. Grams/Plot) | 2 | 3 | Total Dry Wt. (Grams/Plot) |
|---|---|---|---|---|
| 0 | 97 | 137 | 165 | 399 |
| 1.1 | 152 | 188 | 239 | 579 |
| 2.3 | 144 | 236 | 246 | 626 |
| 4.5 | 141 | 166 | 191 | 498 |

TABLE 12

NITROGEN UPTAKE BY LAWN GRASSES AT VARIOUS RATES OF SAWDUST-POULTRY MANURE COMPOST APPLIED AS A SURFACE MULCH

| Compost Treatment (Tonnes/ha) | Mean Nitrogen Concentration (% Dry Wt.) | Total Nitrogen Uptake (mg N/plot) |
|---|---|---|
| 0 | 2.0 | 8.0 |
| 1.1 | 2.5 | 14.5 |
| 2.3 | 2.6 | 16.3 |
| 4.5 | 2.7 | 13.4 |

disposal system.

Tomatoes were selected as an alternative to this integrated system. The waste generated could be used to grow a crop which will not be recycled through the animal but will effectively remove nutrients from the waste and produce a crop of high market value. The returns from the sale of the crop could be used to support an animal production operation or the returns could cover the cost of waste disposal by composting.

All three crops employed in the greenhouse study are grown in the Southeast and are intended as model crops for demonstrating the feasibility of land disposal of animal waste. The greenhouse phase was initiated to indicate suitable rates of compost application to soil and crops to be utilized for field evaluation of the compost. Decisions such as the amounts of compost needed for field experiments and field plot designs were determined from the greenhouse study.

Certain conditions existing in the greenhouse limited the degree of applicability of the greenhouse study to field conditions. They included: (1) pot size (4.5 l) limited the amount of total nutrients for a given treatment and also limited the soil volume for root exploitation; (2) the experiment was conducted from mid-August to mid-November, a time of reduced radiant energy, hence reduced photosynthesis; and (3) a short term experiment (90 days) decreased the potential for maximum growth. All of these restrictions tend to reduce the potential for maximum plant growth.

Dry weight response patterns were similar for the three crops (Figure 24). The general pattern consists of increasing dry weight production with increasing compost levels up to 112 or 224 tonnes of compost per hectare with a decrease beyond these levels. The magnitude of the dry weight response is related to differences in plant population per pot and individual growth characteristics of the crop plants. Millet and wheat plant populations were 50 plants per pot while the tomato population was one plant per pot.

Both grasses exhibited greater response at lower compost levels when compared to the tomatoes (the slope of the curve is greater for these two crops at the lower levels). This indicates that the grasses may be more efficient at lower compost or lower nutrient levels than are the tomatoes. The wheat and millet had equal plant populations per pot yet the millet produced a much greater dry weight. The growth characteristics of these two grasses were different. During the 90 day growth period, the millet proceeded through sequential stages of growth from germination to grain initiation. The wheat did not follow this sequence but rather produced only vegetative growth. This growth consisted of large numbers of branches and massive tillering and appeared very succulent and had a low degree of turgidity. The wheat growth response may have resulted from the fact that it was a winter wheat but was planted similar to a spring wheat. Without the cold treatment to which it would normally be subjected, the wheat exhibited this forage-type growth pattern.

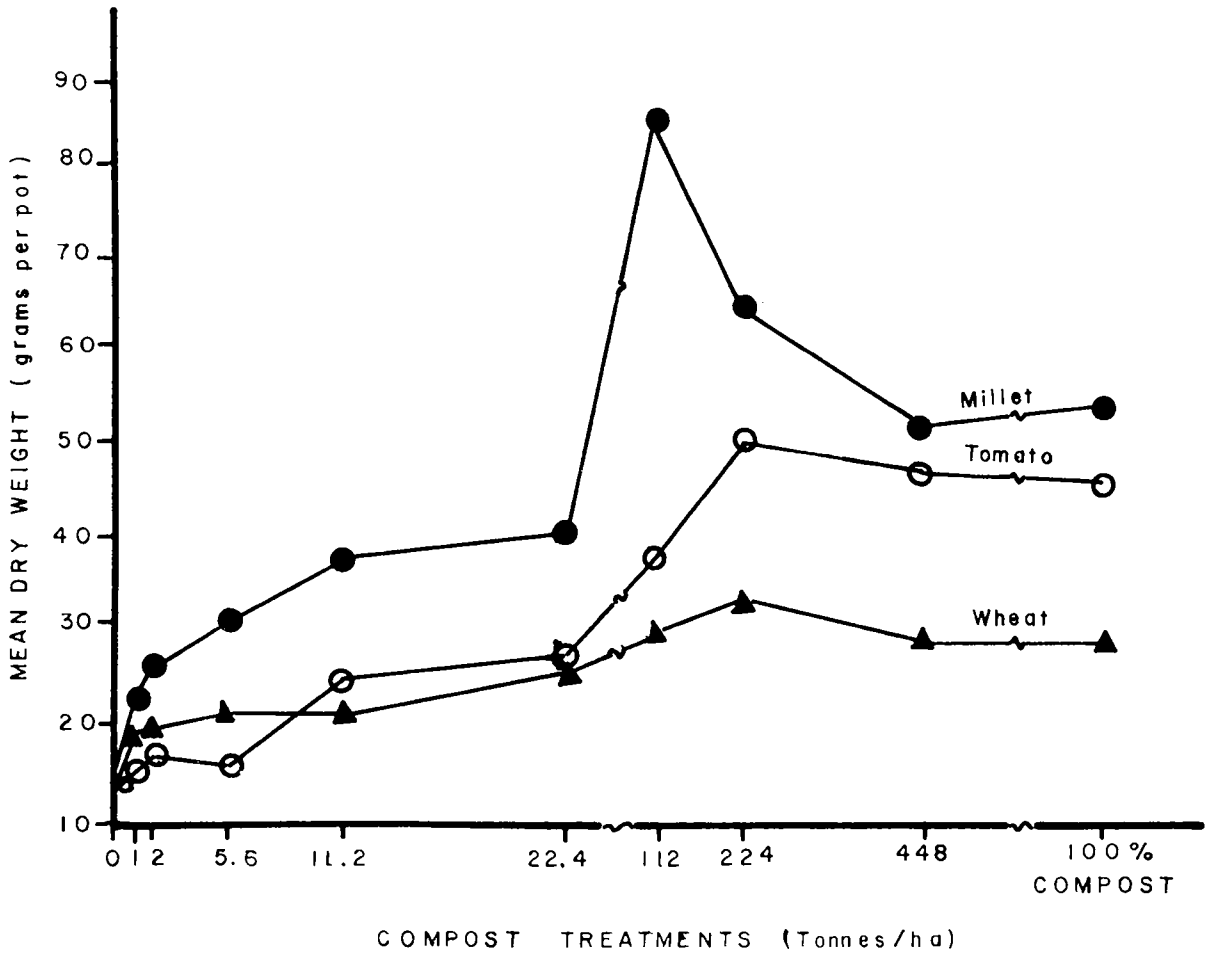


Figure 24. Dry weight yields of millet, tomato, and wheat tops in response to sawdust-poultry manure compost and soil mixtures

Although 112 to 224 tonnes/ha of compost produced maximum dry weight production, there was a decrease beyond these levels. Both the 448 tonnes/ha and the 100 percent compost treatments exhibited a significant decrease in dry weight production; at the 5 percent level of significance for all crops. The following measurements were taken from the tomato crop to determine the causes for the reduction in dry weight yield at compost levels beyond 112 and 224 tonnes/ha: (1) concentration of nutrients in plant tissue; (2) total nutrient uptake (Table 13); and soil chemical test levels (Tables 14 and 15).

At the higher compost levels the K uptake increased and Ca uptake leveled (Table 13). This is probably due to complementary ion effect and is well documented in the literature. However, this factor is not limiting since the Ca content is within the range for adequate growth (Friis-Nielsen, 1969; Ward, 1964). The Ca content increased with increasing compost and was equal in the 224 and 448 tonnes/ha treatment and the 100 percent compost treatments. None of the cations were deficient or toxic to tomato growth. Total uptake of N and P exhibited no significant differences among the three highest compost levels (Table 13). Therefore, it can be concluded that nutrients were not limiting nor present in toxic amounts within the plants.

The residual soil test levels (soil test levels at the end of the growth period) were examined for possible limiting factors in the tomato dry weight production. There was no significant difference in soil acidity (pH) among the three highest compost treatments. However, the pH value of these treatments was significantly higher than the 112 tonnes/ha treatment. This would indicate that nutrient availability was higher in the highest treatments. This should cause an increase rather than a decrease in dry weight production of tomatoes. It can be concluded that the pH effect did not cause a decrease in dry weight production.

There was no significant difference in the residual soil test levels for $NO_3$, $NH_4$, P, or Mn between the two highest compost treatments and the 112 tonnes/ha treatment. Most of these nutrients increased with increasing compost level and would tend to increase rather than decrease dry weight production of the tomatoes. Both the Ca and Mg soil tests for the two highest treatments were significantly greater than the 112 tonnes/ha compost treatment. All of the soil nutrient test levels indicate that increasing compost treatments increase the total amount of nutrients available for growth and are not present in toxic quantities.

The cation exchange capacity was high in both the highest levels of compost. This factor also suggests that greater tomato growth should have occurred at the highest levels of compost.

The soluble salt content was high and about equal in both the highest treatments. Soluble salts can induce deterimental water relationships for plant growth. If the soluble salt content is sufficiently high root "burning" or desiccation may result from water movement out of the roots in response to the high osmotic gradient. Plant species differ in their tolerance to salt content in the soil. Tomatoes are moderately tolerant. A conductivity reading of 80-100 mmhos per cm is considered moderate. The conductivity measurements in the residual soil tests were within this range

TABLE 13

TOTAL NUTRIENT UPTAKE BY TOMATOES IN THE GREENHOUSE

| Compost Treatment (Tonnes/ha) | Dry Weight (g) | Weight/plant (mg) | | | | |
|---|---|---|---|---|---|---|
| | | N | P | K | Ca | Mg |
| 0 | 12.6 | 96 | 38 | 24 | 40 | 14 |
| 1.12 | 14.1 | 109 | 48 | 28 | 49 | 17 |
| 2.24 | 15.9 | 111 | 58 | 36 | 53 | 18 |
| 5.6 | 14.6 | 103 | 63 | 34 | 47 | 18 |
| 11.2 | 24.6 | 177 | 110 | 69 | 81 | 27 |
| 22.4 | 26.5 | 274 | 126 | 71 | 91 | 31 |
| 112 | 37.5 | 333 | 259 | 149 | 167 | 42 |
| 224 | 49.4 | 475 | 336 | 256 | 219 | 42 |
| 448 | 46.3 | 475 | 339 | 262 | 208 | 27 |
| 100 Percent* | 45.4 | 477 | 369 | 343 | 208 | 31 |
| LSD .05 | 3.1 | 59 | 31 | 267 | 68 | 24 |
| LSD .01 | 4.2 | 80 | 54 | 350 | 93 | 32 |

*All compost; no soil.

TABLE 14

SOIL TEST LEVELS PRIOR TO SAWDUST-POULTRY MANURE COMPOST ADDITION

| Acidity (pH) | $NO_3$ | $NH_4$ | P | K | Ca | Mg | Mn | CEC | O.M. | SS* |
|---|---|---|---|---|---|---|---|---|---|---|
| | (kg/ha) | | | | | | | (meq/100g) | (%) | (mmho/cm) |
| 5.2 | 7.8 | 2.9 | 83 | 42 | 280 | 20 | 9 | 0.9 | 0.7 | 4.8 |

*SS = Soluble salts

TABLE 15

RESIDUAL SOIL TEST: SOIL TEST LEVELS AFTER SAWDUST-POULTRY MANURE COMPOST ADDITIONS AND GROWING TOMATOES FOR 90 DAYS

| Treatment (Tonnes of Compost/ha) | Acidity (pH) | $NO_3$ | $NH_4$ | P | K | Ca | Mg | Mn | CEC (meq/100g) | SS* (mmho/cm) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | (kg/ha) | | | | | |
| 0 | 5.4 | 0.00 | 12.3 | 107 | 13.1 | 233 | 14.3 | 12.0 | 1.8 | 8.0 |
| 1.12 | 5.5 | 0.37 | 7.8 | 118 | 11.2 | 227 | 40.3 | 19.0 | 1.7 | 9.3 |
| 2.24 | 5.6 | 0.37 | 10.1 | 93 | 14.2 | 215 | 13.8 | 19.8 | 1.6 | 10.0 |
| 5.6 | 5.5 | 0.37 | 7.5 | 94 | 17.9 | 209 | 13.4 | 19.8 | 1.7 | 10.3 |
| 11.2 | 5.7 | 0.75 | 10.9 | 110 | 22.7 | 257 | 18.8 | 22.1 | 1.6 | 11.0 |
| 22.4 | 5.9 | 0.37 | 9.0 | 110 | 36.6 | 281 | 22.4 | 20.2 | 1.7 | 14.0 |
| 112 | 6.3 | 0.37 | 5.4 | 120 | 156.9 | 526 | 60.5 | 28.0 | 2.9 | 31.7 |
| 224 | 6.7 | 0.75 | 1.5 | 120 | 322.7 | 992 | 118.8 | 28.0 | 4.8 | 55.0 |
| 448 | 6.7 | 0.75 | 5.4 | 120 | 322.7 | 1363 | 156.8 | 29.9 | 7.3 | 88.3 |
| 100% Compost | 6.8 | 1.87 | 2.7 | 120 | 322.7 | 1793 | 268.9 | 29.1 | 38.4 | 88.3 |
| LSD .05 | 0.13 | 1.21 | 14.1 | 2.9 | 10.1 | 171 | 27.9 | 5.45 | 2.0 | 4.90 |
| LSD .01 | 0.18 | 1.65 | 19.3 | 31.2 | 13.7 | 234 | 38.1 | 7.44 | 2.8 | 6.68 |

*SS - Soluble salts.

for the two highest treatments and are significantly greater (p=0.01) than the 224 tonnes/ha treatment. In greenhouse pots the soluble salt effect is more pronounced due to the restricted soil volume. The soluble salt remains in the immediate root zone and could affect root growth, nutrient uptake, and total dry weight production.

Another possible cause for the decreased growth could be the large pore space in the soil at the high compost rates. During the initial planting of the tomatoes, it was difficult to saturate the soil at the high compost levels. When water was applied, it percolated through the soil very rapidly and the soil retained little moisture in the upper portion of the pots where the young tomato roots were located. It was difficult to establish an adequate supply of water in this upper portion of the pots. However, once the compost was saturated with water and the roots grew enough to reach a zone of adequate moisture, excellent growth occurred. This delay in initial growth caused by moisture stress may have been the limiting factor in the higher compost treatments.

An approximation of the range of crop responses to sawdust-poultry manure compost was determined in the greenhouse study. These rates consisted of approximately 11.2 tonnes of compost per hectare for a minimum significant dry weight response and 224 tonnes for a maximum dry weight response for tomatoes. No detrimental buildup of nutrient levels was experienced and availability appeared adequate for tomato production. It was concluded that irrigation of the field plots might be necessary to establish an adequate plant stand at high compost levels.

Sawdust-Poultry Manure Compost Applied to Tomatoes in the Field

Field conditions offer a natural set of environmental conditions and should provide an accurate measure of the acceptability of utilizing sawdust-poultry manure compost as a soil amendment and, therefore, as a means of land disposal of animal waste. The objectives of this phase of the study were to determine the minimum and maximum tomato response to sawdust-poultry manure compost and to measure the effects of the compost on the chemical and physical properties of the soil.

A total of 68 mm of rainfall was recorded during the month of April until the day of transplanting the tomato seedlings. The rainfall was insufficient to provide adequate soil moisture. Therefore, daily watering of approximately one liter per plant was necessary to establish 100 percent plant stands. Moisture stress, as indicated by loss of plant turgidity, was most apparent in the two highest compost levels.

After the plants became established rainfall was not adequate to promote optimum plant growth. During this drought period two irrigations of 64 mm of water each were applied to prevent moisture stress. It became evident, with rainfall and subsequent irrigation, that once the compost-treated plots were saturated to field capacity, a reduction of visual symptoms of moisture stress occurred. Increasing compost levels indicated a higher degree of plant turgidity when compared to the control plants. Both the field and greenhouse studies indicated that more water is required to establish optimum

water conditions with increasing compost applications. However, once the compost is saturated there is an increase in the length of time before moisture stress symptoms are exhibited in tomato plants.

Crowding of the tomato plants within the plots occurred with the 0.37 $m^2$ per plant density. This high density effectively shaded out grass and weed competitors but caused difficulty in the harvesting of the tomato fruit. Current methods of cultivation employed in the production of indeterminate tomato varieties suggest 1.5 m row widths with 0.3-0.4 m spacing between plants. It is also suggested that indeterminate tomato plants be either pruned to one stem and/or staked or trellised (Banadyga, 1970). This row width and spacing would give approximately one-half the plant population employed in this study. Also, no staking, trellising, or pruning practices were employed. The high plant density was intentionally used both to maximize yields and to measure nutrient supply from the compost in a high yield situation.

Application of large amounts of fertilizer, especially nitrogenous fertilizer, tends to delay maturity in some crop species. Although the first harvest of tomatoes occurred 64 days after transplanting, it was not until July 6 (71 days after transplanting) that all plants were producing mature fruit. The harvest of July 18 was the initial heavy harvest, and each subsequent harvest also produced large amounts of fruit. The time between transplanting and initial heavy tomato production was 83 days. The normal length of growth from seedling to maturity for Marion tomatoes is 82 days (Banadyga, 1970); therefore, no delay in maturity was apparent. However, the first few harvests indicated that the controls and lower compost levels produced a light yield of fruit, approximately one to two weeks prior to the higher compost levels (45, 336, 448 tonnes/ha). Since this was only a light yield and not consistent, it is felt that it is not significant in terms of a delay in maturity. The mean fresh weight of the tomatoes ranged from 92 g per tomato for the control treatment to 119 g for the 448 tonnes/ha treatment. No attempt was made to separate the tomato fruit into different grades or to determine marketable tomatoes. Only total yield data were collected.

The total fresh weight yield and yield per ton of compost are given in Figure 25. Total tomato yield increased with increasing increments of compost to a maximum of 166.8 tonnes of fruit per hectare at the 448 tonnes/ha compost level. As expected, the lower compost treatments exhibited a greater increase in yield per tonne of compost; however, the yield per tonne of compost was low. At the 448 tonnes/ha compost level the response was still positive. There was no change in the return per tonne of compost between the 22.4 and 44.8 tonnes/ha level (1.4 tonnes yield per tonne compost). The difference between yields at the two highest compost levels was 30.9 tonnes/ha, and there was a 112 tonne difference in amounts of compost applied. An economic decision could be made at these levels of compost application to determine if the value of the total yield increase is sufficient to cover the cost of the additional compost inputs.

Using the least significant differences (LSD) method, minimum significant differences at the 5 percent probability level occurred at the 11.2 tonnes/ha compost treatment. The 22.4 tonnes/ha compost treatment was

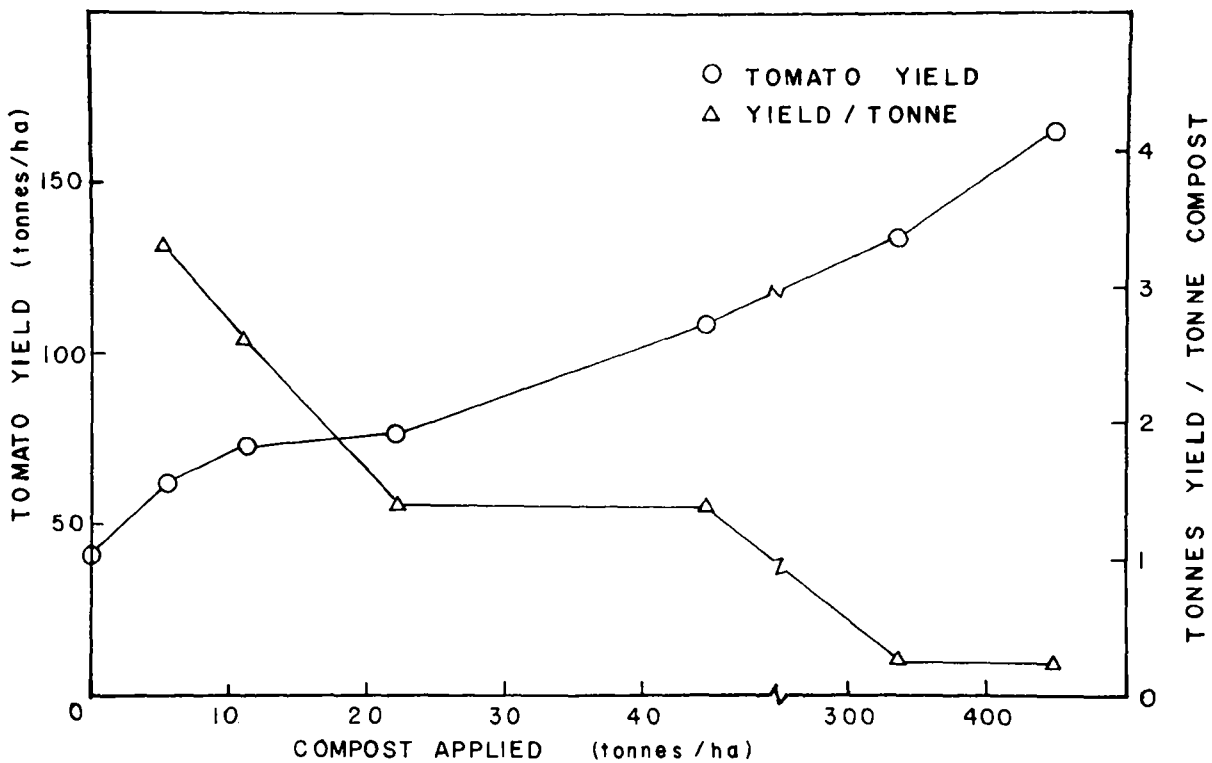


Figure 25. Total tomato fresh weight yield and yield per tonne of sawdust-poultry manure compost in the field

significantly different from the control at the 1 percent probability level. Therefore, minimum significant response of Marion tomato yield to sawdust-poultry manure compost occurred at the 11.2 and 22.4 tonnes/ha compost treatments (P = 0.05 and 0.01, respectively). Maximum tomato yield occurred at the maximum compost treatment (448 tonnes of compost per hectare).

The compost nutrients are present in complex organic forms, and plants take up nutrients primarily in inorganic forms. Mineralization of the compost nutrients to simpler inorganic forms must occur before the compost nutrients are readily available for plant growth. The tomato yields indicate that mineralization and, hence, nutrient availability was not a limiting factor for tomato growth in the highest compost treatment. Examining the initial and residual soil test levels (Tables 16 and 17), and total nutrient uptake (Table 18), one can see an indication as to the amount of nutrients available during the growth period. Total available nutrients increased with increasing compost levels. As previously mentioned, there was little or no delay in the maturing of the tomato fruit. This is an indirect indication that the rate of nutrient mineralization was adequate for tomato growth. It can concluded that, in the highest compost treatment, the rate of nutrient mineralization was adequate to supply both the amounts of nutrients required and at the time required for adequate tomato growth. The yields were lower at lower levels of compost, indicating that total amount of nutrients may have been at least somewhat growth-limiting.

The sum of the total nutrient uptake (Table 18) and the residual soil test level for available nutrients (Table 17) are a measure of total nutrient availability. It can be seen from the control plots that these sums are greater (except for P and Mn) than the initial soil test levels. These soil test levels represent only available nutrients and not total amounts of nutrients present. Data from the control plots indicate that mineralization of nutrients and/or transfer from unavailable to available forms from the total nutrient pool in the soil has to occur in order that the sum of nutrient uptake and residual soil nutrient levels be greater than the initial soil nutrient levels. The initial soil test for N indicate 7.5 and 38 kg/ha of available $NO_3$ and $NH_4$, respectively, yet 204.4 kg of N was available (sum of uptake and residual available nutrients). This N was available due to the mineralization of the organic nitrogen.

The area utilized in the field study had been fallow the four preceding years. The residual organic matter of the soil was 2 percent. At 2 percent organic matter, the surface 15 cm of the soil will contain approximately 45,000 kg of organic matter per hectare. Assuming an organic matter to N ratio of 20:1, the total N level in the control plots would be approximately 2250 kg/ha. Only 46 kg of this total N pool were initially available. The total available N (204 kg) is the sum of total N uptake and residual available soil N levels. The initial available N substracted from the total available N represents the amount of N mineralized during the tomato growth period, and this is about 8 percent of the total.

The amount of total N in the 448 tonnes/ha compost level was approximately 3800 kg. The available N in the control treatments represent available N from sources other than the compost. An approximate mineralization of

TABLE 16

INITIAL SOIL TEST: SOIL TEST PRIOR TO ADDING SAWDUST-POULTRY MANURE COMPOST

| | Acidity (pH) | O.M. (%) | Available Nutrients (kg/ha) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $NO_3$ | $NH_4$ | P | K | Ca | Mg | Mn |
| Mean of 25 samples | 5.3 | 2.0 | 7.5 | 38 | 34 | 95 | 716 | 97 | 29 |

TABLE 17

RESIDUAL SOIL TEST: SOIL TEST AFTER ADDING SAWDUST-POULTRY MANURE COMPOST

| Compost Treatment (Tonnes/ha) | Acidity (pH) | Available Nutrients (kg/ha) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | $NO_3$ | $NH_4$ | P | K | Ca | Mg | Mn |
| 0 | 5.8 | 2.3 | 106 | 24 | 114 | 1023 | 146 | 25 |
| 5.6 | 5.8 | 4.1 | 52 | 99 | 116 | 1190 | 145 | 37 |
| 11.2 | 6.2 | 2.7 | 180 | 84 | 129 | 1209 | 188 | 30 |
| 22.4 | 6.1 | 3.2 | 120 | 97 | 148 | 1330 | 165 | 40 |
| 44.8 | 6.3 | 3.6 | 206 | 244 | 247 | 1307 | 359 | 35 |
| 336 | 6.3 | 8.5 | 50 | 613 | 385 | 2160 | 400 | 52 |
| 448 | 6.4 | 8.6 | 111 | 736 | 586 | 3360 | 428 | 55 |
| LSD .05 | 0.6 | 4.3 | 176 | 21 | 169 | 893 | 758 | 12 |
| LSD .01 | 0.8 | 5.9 | 246 | 30 | 236 | 1252 | 222 | 17 |

TABLE 18

TOTAL NUTRIENT UPTAKE AND DRY WEIGHT PRODUCTION IN THE FIELD OF MARION TOMATOES IN RESPONSE TO SAWDUST-POULTRY MANURE COMPOST

| Compost Treatment (Tonnes/ha) | Dry Wt. | N | P | K | Ca | Mg | Mn |
|---|---|---|---|---|---|---|---|
| | (kg/ha) | | | | | | |
| 0 | 4093 | 95 | 8 | 102 | 44 | 13 | 0.30 |
| 5.6 | 6357 | 149 | 18 | 165 | 89 | 25 | 0.52 |
| 11.2 | 7003 | 167 | 22 | 203 | 75 | 24 | 0.45 |
| 22.4 | 7546 | 180 | 41 | 197 | 102 | 32 | 0.59 |
| 44.8 | 9818 | 241 | 61 | 355 | 104 | 31 | 0.45 |
| 336 | 11822 | 308 | 80 | 436 | 91 | 36 | 0.97 |
| 448 | 14466 | 399 | 103 | 601 | 128 | 44 | 0.81 |

compost N in the 488 tonnes/ha compost treatment can be calculated by subtracting the available N in the control treatment from the available N at the 448 tonnes of compost per hectare treatment. This determination in the 448 tonnes/ha compost treatment is 312 kg of available N from the compost which represents mineralization of 8.2 percent of the total N present in the compost. Similar arguments can be made for other nutrients.

Generally, increasing levels of compost increased residual soil test levels (Table 17). The $NH_4$ levels did not follow this trend. The $NH_4$ levels were maximum in the 44.8 tonnes/ha compost treatment and decreased beyond this maximum. This was not expected. The high LSD indicates a large error term, and this error probably is due to soil sampling and processing technique. The within-treatment range of $NH_4$ values for the 448 tonnes/ha treatment was 22 kg/ha to 269 kg/ha. This wide variation is probably due to microsite effect or that the soil samples were sieved through a 2 mm sieve prior to analysis. Of the compost particles, 59 percent were larger than 2.0 mm in diameter. Exclusion of compost from the sample analysis may have induced this variation. The higher compost levels would have indicated a disproportionate decrease over the lower compost rates.

The acidity decreased with increasing compost levels and was significantly different from the control at the 448 tonnes/ha treatment. The decrease in acidity was associated with nutrient availability and microbial activity. The N, Ca, Mg, P, and K availability and microbial activity were enhanced while the availability of Mn changed only slightly as probably did the other metallic micronutrients except Mo. Total Mn uptake and residual soil test levels increased with additions of compost. The amount of Mn present masked the pH-effect on Mn availability.

The $NO_3$ level at the two highest compost treatments was highly significantly different from the control plots. However, both these treatments had a $NO_3$ level of less than 4 ppm. This is much lower than the maximum standards set forth by the U. S. Public Health Service of 10 ppm $NO_3$-N for drinking water. The low residual levels of $NO_3$ indicate that there is no immediate danger of $NO_3$ pollution of the ground water from the compost.

High levels of compost apparently can be applied to a soil to enhance productivity. Increased nutrient availability, nutrient uptake, and moisture holding-capacity resulting from employing sawdust-poultry waste compost as a soil amendment markedly increase tomato yields. Potential pollution due to excess levels of $NO_3$ were not indicated from high compost applications.

If composting is utilized as a means of animal waste disposal, two other factors must be considered: (1) nutrient capital distribution - that removed by crop harvest and that returned to the soil as vegetative residue; and (2) long term build-up of nutrient levels as a potential source of nutrient pollution of the ground water.

Tomato growth was separated into vegetative and reproductive parts (Tables 19, 20, and 21). While the major portion of growth was reporductive and would be removed from the soil as the crop, the vegetative plant parts

TABLE 19

TOTAL DRY WEIGHT PRODUCTION OF TOMATOES IN THE FIELD IN RESPONSE TO SAWDUST-POULTRY WASTE COMPOST

| Compost Treatment (Tonnes/ha) | Mean Dry Weight Production of Tomato Plants (kg/ha) | Mean Dry Weight Production of Tomato Fruit (kg/ha) | Dry Weight Production of Plants and Fruit (kg/ha) |
|---|---|---|---|
| 0 | 1448 | 2645 | 4093 |
| 5.6 | 2599 | 3759 | 6357 |
| 11.2 | 2648 | 4356 | 7003 |
| 22.4 | 3006 | 4542 | 7546 |
| 44.8 | 3236 | 6580 | 9818 |
| 336 | 3684 | 8138 | 11822 |
| 448 | 4463 | 10003 | 14466 |

TABLE 20

NITROGEN REMOVAL FROM SOIL BY TOMATO PLANTS AND FRUIT IN THE FIELD IN RESPONSE TO SAWDUST-POULTRY WASTE COMPOST

| Compost Treatment (Tonnes/ha) | Plant N Uptake (kg/ha) | Fruit N Uptake (kg/ha) | Total N Uptake (kg/ha) | Fruit N: Total N ratio |
|---|---|---|---|---|
| 0 | 27 | 69 | 96 | 0.72 |
| 5.6 | 48 | 101 | 149 | 0.68 |
| 11.2 | 47 | 119 | 166 | 0.72 |
| 22.4 | 57 | 123 | 180 | 0.68 |
| 44.8 | 63 | 179 | 242 | 0.74 |
| 336 | 72 | 236 | 308 | 0.77 |
| 448 | 95 | 304 | 399 | 0.76 |

TABLE 21

PER PLANT DRY WEIGHT PRODUCTION OF TOMATOES IN THE FIELD IN RESPONSE TO SAWDUST-POULTRY WASTE COMPOST

| Compost Treatment (Tonnes/ha) | Dry Wt. of Vegetative Plant (g/Plant) | Dry Wt. Production of Fruit (g/Plant) | Total Dry Wt. Production (g/Plant) | Fruit Portion of Total Wt. (Percent) |
|---|---|---|---|---|
| 0 | 54 | 98 | 152 | 64 |
| 5.6 | 98 | 140 | 238 | 58 |
| 11.2 | 97 | 162 | 260 | 62 |
| 22.4 | 112 | 169 | 280 | 60 |
| 44.8 | 120 | 245 | 365 | 67 |
| 336 | 137 | 303 | 440 | 69 |
| 448 | 166 | 372 | 538 | 69 |
| LSD .05 | 33 | 46 | | |
| LSD .01 | 46 | 64 | | |

would be returned to the soil as residue. Any decision as to the amount of nutrient removal at a given rate of compost application for a given crop must take into consideration the amounts of nutrients recycled by returning plant residue to the soil.

The uptake of N, P, and four cations are considered in various ways (Tables 22 and 23). The uptake of both N and P increased with increasing compost applications but the change in N:P ratio indicates clearly that the P uptake increased more rapidly than did the N (Table 22). The cations exhibited generally an increase in their concentration (expressed as milli-equivalents per gram of plant plus fruit) from the control to the 22.4 tonne level and then a decrease, indicating some carbohydrate dilution at the highest compost levels (Table 23). This is another indication that there were no problems with high salt levels in the soil.

The total water-holding capacity of the sawdust-poultry manure compost was 3.2 ml per gram of compost. This characteristic increased the total water-holding capacity of the soil-compost system. Figure 26 indicates moisture content of the control treatment and the 448 tonnes/ha treatment. Although the 448 tonnes/ha treatment increased total-water-holding capacity by 54 percent, available water was increased by only 10.2 percent (available water is considered to be the amount of water lost between 0.05 bars and 15 bars tension). There is a five-fold difference between total water-holding capacity and available water. This results from a portion of the water being retained by the compost at 15 bars tension. The compost imparts a large water-holding capacity to the soil and also holds more water at high tensions than the soil used in this study. Therefore, only a portion of the additional water will be available. A 10.2 percent increase in available water, however, is a tremendous asset to most mineral soils. Not only will this decrease the droughtiness of excessively drained soils but will also reduce leaching loss from these soils.

The slope of the curve from 0 to 50 cm tension indicates a rapid water loss. This is a result of the large pore space in the soil-compost mixture (Figure 26). This large pore space allows rapid infiltration and permeability and thus would decrease the potential for soil erosion. After harvesting the tomato plants, it was noted that fine sand had adhered to the above-ground portions of the tomato plants but much less so at the high compost treatments than at the lower levels.

Paper-Poultry Manure Compost Applied to Tomatoes in the Field

Paper was utilized as an alternative carbonaceous material in the composting process. Field plots were established to investigate fresh weight yield of tomato plants and fruit, nutrient uptake by tomatoes, and soil chemical properties resulting from the addition of paper-poultry manure compost to the soil. Differences in chemical and physical properties between the sawdust-poultry manure compost and the paper-poultry manure compost resulted in different soil and plant responses.

Rainfall was adequate for tomato growth, and no supplemental irrigation was necessary. Immediately after transplanting tomato seedlings to the field,

TABLE 22

N AND P CONTENT OF TOMATOES: TOTAL UPTAKE FROM SAWDUST-POULTRY MANURE COMPOST

| Compost (Tonnes/ha) | Total Dry Wt. Production/plant (g) | N Total Uptake (g) | P Total Uptake (g) | N:P ratio Total N: Total P |
|---|---|---|---|---|
| 0 | 152 | 3.55 | 0.30 | 11.83 |
| 5.6 | 236 | 5.53 | 0.68 | 8.13 |
| 11.2 | 260 | 6.17 | 0.85 | 7.26 |
| 22.4 | 280 | 6.70 | 1.53 | 4.38 |
| 44.8 | 365 | 8.98 | 2.26 | 3.97 |
| 336 | 440 | 11.43 | 2.96 | 3.86 |
| 448 | 538 | 14.83 | 3.84 | 3.86 |

TABLE 23

CATION CONTENT OF FIELD-GROWN TOMATOES IN MILLIEQUIVALENTS PER GRAM OF DRY WEIGHT

| Compost (Tonnes/ha) | Total Dry Wt. Production/plant (g) | Cation Content | | | |
|---|---|---|---|---|---|
| | | K | Ca | Mg | Mn |
| | | (meq/g) | | | |
| 0 | 152 | 0.63 | 0.53 | 0.27 | 0.27 |
| 5.6 | 236 | 0.66 | 0.69 | 0.33 | 0.29 |
| 11.2 | 260 | 0.74 | 0.54 | 0.30 | 0.23 |
| 22.4 | 280 | 0.67 | 0.67 | 0.35 | 0.23 |
| 44.8 | 365 | 0.93 | 0.53 | 0.27 | 0.16 |
| 336 | 440 | 0.95 | 0.38 | 0.25 | 0.29 |
| 448 | 538 | 1.03 | 0.44 | 0.25 | 0.20 |

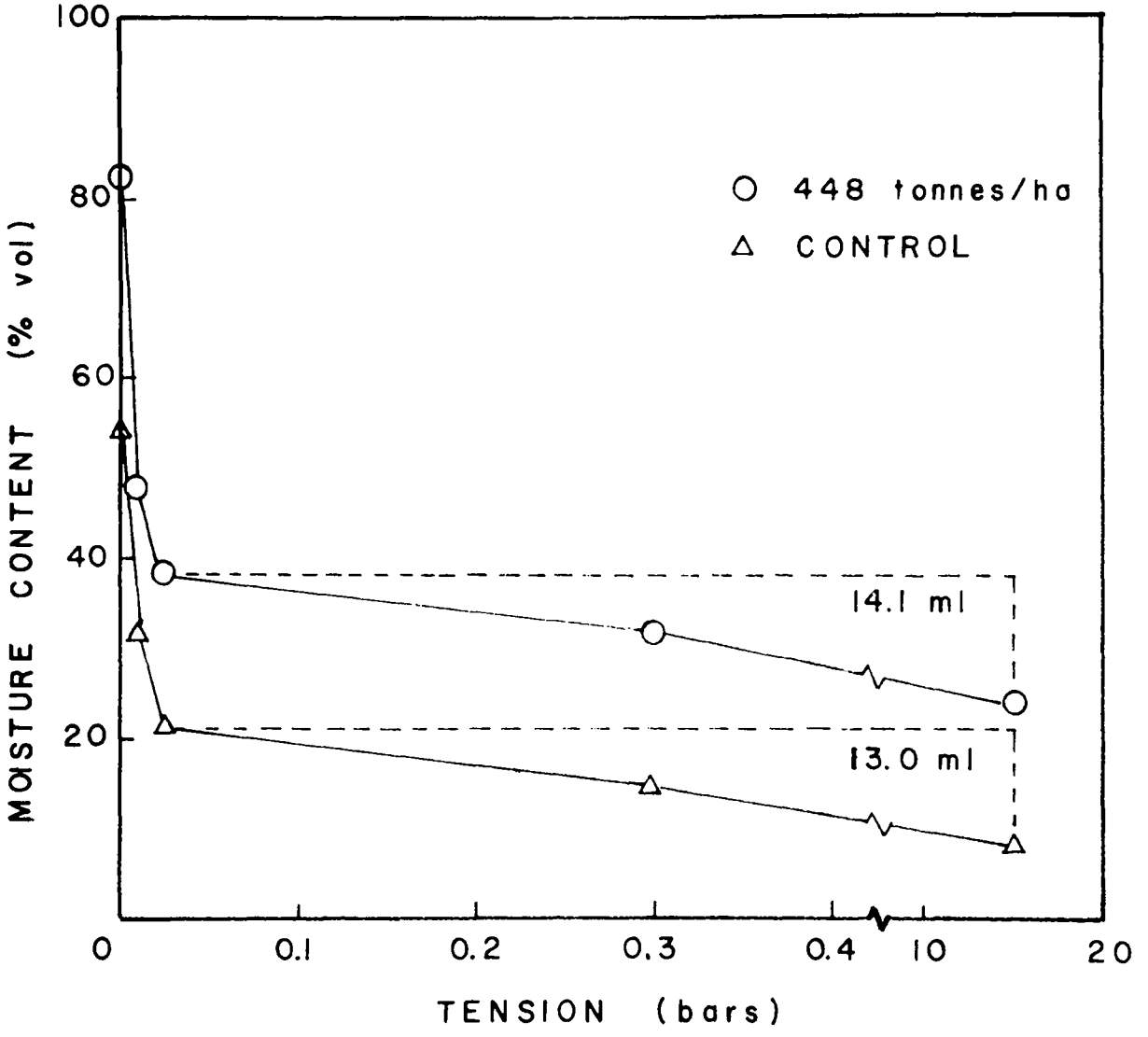


Figure 26. Water holding capacity of soil and soil-compost mixture over a range of tensions from 0 to 15 bars

the plots received an intense rainfall 4.57 cm. This rainfall caused a surface crust to be formed on the 112 tonnes/ha compost treatment. No crust was observed on any other treatment. At two weeks of growth the plants on the 112 tonnes/ha treatments were noticeably smaller than the border plants surrounding this treatment. This reduced growth was apparent until approximately 60 days after transplanting. At approximately 60 days the surface crust was no longer evident. The surface crust probably resulted from the intense rainfall and the shape of the compost particles. Rain drop impact may have arranged the plate-like paper compost particles in an overlapping configuration which effectively sealed the soil surface, resulting in decreased aeration and water infiltration. This would decrease aerobic microbiological activity, creating a detrimental effect on mineralization of compost nutrients and, hence, the availability of nutrients required to maintain adequate tomato growth.

Total fresh weight yield of tomato fruit and the tonnes of fresh weight yield per tonne of compost are given in Figure 27. Increasing compost levels increased fresh weight yield per hectare to a maximum in the 22.4 tonnes compost level. The 112 tonnes/ha treatment yield was slightly less than the 22.4 tonnes/ha treatment. Fresh weight yields of 18, 29, 38, 47, and 43 tonnes/ha were realized at the 0, 2.2, 11.2, 22.4, and 112 tonnes of compost per hectare, respectively. Minimum significant response ($p=0.05$) occurred at the 11.2 tonne compost level when compared to the control treatment. Maximum fresh weight yield was highly significantly different from the control treatment but was not significantly different from the other compost treatments. The decrease in fresh weight yield at the 112 tonne compost treatment was not significant when compared to the other compost treatments.

The tonnes of fresh weight yield per tonne of compost applied indicated, as expected, that the efficiency of the compost for increasing tomato yield decreased with additional increments of compost. The low tonnes of fresh weight yield per tonne of compost applied at the high rate indicates that very little yield increase could be expected from higher compost levels. Additionally, the data indicate that a further reduction in yield may have occurred at higher compost levels. Fresh weight yield was reduced due to the experimental conditions under which the tomatoes were grown. The tomatoes were transplanted to the field one month later than the normal planting time. A short harvesting period and an early terminal harvest also decreased the potential for maximum tomato production. Tomatoes were harvested 8 times as they matured. The 112 tonnes/ha compost treatment had a range of 30-45 percent immature fruit at the terminal harvest. This indicates that the maturation of the high compost treatment was delayed. All treatments would have had a higher yield if the harvesting period has been extended. The average size of the tomato fruit was 69 g per fruit in the control treatment and 106 g in the 22.4 tonnes/ha treatment.

The same soil type was utilized in both field studies. The sawdust compost and the paper compost plots were located adjacent to each other. The initial soil test levels are given in Table 16. Nutrient availability can be measured in terms of total uptake and by examining the residual soil fertility levels. Table 24 gives the total nutrient uptake by tomato tops and fruit

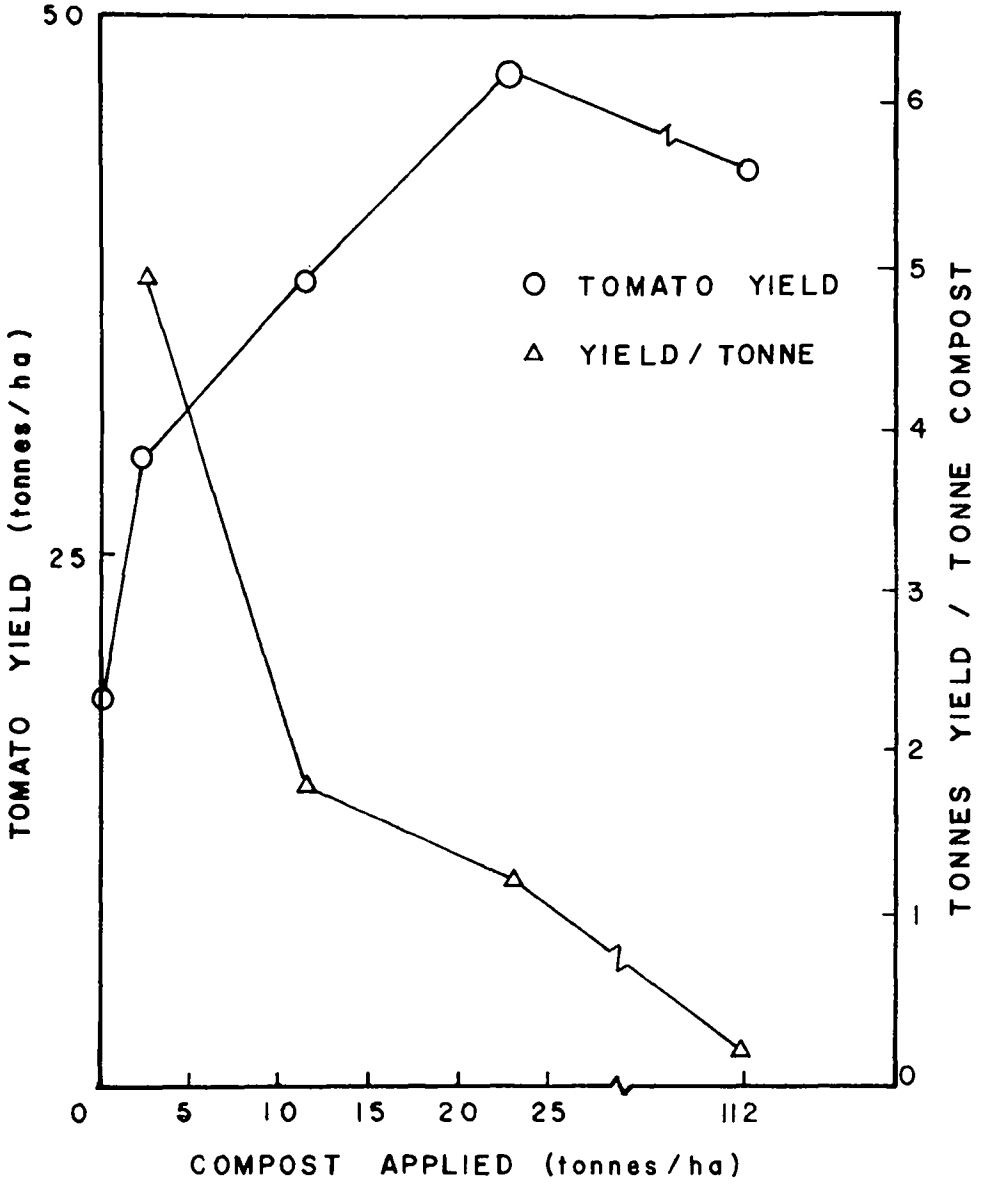


Figure 27. Total tomato fresh weight yield and yield per tonne of paper-poultry manure compost in the field

TABLE 24

NUTRIENT UPTAKE BY TOMATOES IN THE FIELD AT VARIOUS LEVELS OF PAPER-POULTRY MANURE COMPOST

A. UPTAKE BY TOMATO PLANT TOPS

| Compost Treatment (Tonnes/ha) | N | P | K | Ca | Mg | Mn |
|---|---|---|---|---|---|---|
| | | | (kg/ha) | | | |
| 0 | 19 | 1.7 | 27 | 18 | 6.2 | 0.07 |
| 2.2 | 31 | 3.2 | 63 | 34 | 9.2 | 0.96 |
| 11.2 | 27 | 2.9 | 58 | 36 | 8.7 | 0.78 |
| 22.4 | 38 | 6.5 | 92 | 45 | 11.4 | 0.77 |
| 112 | 62 | 13.3 | 138 | 50 | 13.0 | 1.22 |

B. UPTAKE BY TOMATO FRUITS

| Compost Treatment (Tonnes/ha) | N | P | K | Ca | Mg | Mn |
|---|---|---|---|---|---|---|
| | | | (kg/ha) | | | |
| 0 | 34 | 4.5 | 45 | 9 | 2.0 | 0.02 |
| 2.2 | 45 | 7.2 | 71 | 15 | 2.9 | 0.02 |
| 11.2 | 91 | 11.5 | 108 | 18 | 4.4 | 0.03 |
| 22.4 | 91 | 12.0 | 126 | 47 | 5.6 | 0.08 |
| 112 | 101 | 13.1 | 140 | 21 | 4.9 | 0.04 |

C. TOTAL NUTRIENT UPTAKE BY TOMATO TOPS AND FRUIT

| Compost Treatment (Tonnes/ha) | N | P | K | Ca | Mg | Mn |
|---|---|---|---|---|---|---|
| | | | (kg/ha) | | | |
| 0 | 54 | 6.2 | 72 | 27 | 8.2 | 0.09 |
| 2.2 | 76 | 10.4 | 133 | 48 | 12.1 | 0.99 |
| 11.2 | 100 | 14.6 | 166 | 54 | 13.1 | 0.82 |
| 22.4 | 129 | 18.5 | 217 | 92 | 17.0 | 0.85 |
| 112 | 162 | 26.4 | 278 | 72 | 17.9 | 1.27 |

at the various compost levels. Nutrient uptake generally increased with increasing compost levels. Total nutrient uptake was maximized at the 112 tonnes/ha compost level except for Ca which decreased slightly at this level. Maximum yields did not correspond with maximum nutrient uptake. This factor combined with the number of immature fruit at the terminal harvest for this treatment indicates that these plants were in a stage of vegetative rather than reproductive growth. Nutrient availability was not a limiting factor in the tomato growth. Time of availability of the nutrients may not have corresponded with the maximum nutritional requirements of the plants and, hence, could have been limiting.

Nutrient uptake by tomato fruit was greater than by the tomato tops for N, P, and K (Table 24). However, Ca and especially Mg and Mn uptake was greater in the tomato tops. The nutrients taken up by the tomato tops will be returned to the soil as plant residue. The amount of nutrients removed by the tomato fruit is the amount of nutrients permanently removed from the site. This is the most important consideration in terms of nutrient removal from the applied animal waste compost. Since N is the chief source of potential pollution from animal waste, the treatment which removes the most N would result in the maximum decrease in this pollution potential. Thirty five kilograms of N per hectare were removed in the tomato fruit in the control treatment while 101 kg were removed in the 112 tonnes/ha treatment. The net difference of 66 kg of N per hectare can be attributed to the effect of the compost. It is not possible to state that the additional N actually came from the compost since some additional mineralization of soil N may have occurred under the influence of the extra available carbon and energy of the compost.

Residual soil test levels represent the changes in soil chemistry resulting from soil-compost-plant interactions. They represent the amounts of nutrients that are present in available form but which were not taken up by the plants during the growth period.

The acidity decreased with increasing compost levels (Table 25). The pH value at the 11.2 tonnes/ha level was significantly higher ($p = 0.05$) than the control treatment. The 22.4 and 112 tonne treatments were even less acidic and their differences from the control were highly significant. This rise in pH value in the compost treatments would increase the availability of all the nutrients analysed except Mn. Since Mn values also increased, it is evident that the amounts of Mn present overcame the pH effect on its availability. The activity of bacteria, fungi, and actinomycetes would also be enhanced by the decreasing acidity. By examining the nutrient levels at the 112 tonne/ha treatment, it can be concluded that the amount of available nutrients would not be limiting to tomato growth. The high residual fertility levels indicate a very high rate of mineralization.

In conclusion, paper-poultry manure compost, at high levels of application to soil, under intensive rain fall, may form a surface crust and reduce plant growth. Some excess available C may be present which would result in some temporary nutrient immobilization. With a longer and more optimum growing period more mineralization of compost nutrients would have occurred, more nutrients would have been absorbed, and higher yields would have been

TABLE 25

INITIAL AND RESIDUAL SOIL TEST: SOIL TEST VALUES BEFORE AND AFTER ADDING PAPER-POULTRY WASTE COMPOST AND GROWING TOMATO CROP

A. INITIAL SOIL TEST VALUES

| | Acidity (pH) | $NO_3$ | $NH_4$ | P | K | Ca | Mg | Mn |
|---|---|---|---|---|---|---|---|---|
| | | (kg/ha) | | | | | | |
| Mean of 45 samples | 5.8 | 2.1 | 40 | 48 | 162 | 1157 | 146 | 26 |

B. RESIDUAL SOIL TEST VALUES

| Compost Treatment (Tonnes/ha) | Acidity (pH) | $NO_3$ | $NH_4$ | P | K | Ca | Mg | Mn |
|---|---|---|---|---|---|---|---|---|
| | | (kg/ha) | | | | | | |
| 0 | 5.7 | 6.7 | 35 | 60 | 144 | 1003 | 128 | 20 |
| 2.2 | 5.8 | 10.4 | 38 | 84 | 297 | 1290 | 137 | 25 |
| 11.2 | 6.1 | 5.9 | 44 | 159 | 485 | 1971 | 178 | 21 |
| 22.4 | 6.3 | 8.2 | 53 | 299 | 699 | 2598 | 224 | 30 |
| 112 | 6.8 | 2.2 | 85 | 968 | 2187 | 6003 | 547 | 38 |
| LSD .05 | 0.4 | 5.3 | 15 | 26 | 271 | 675 | 39 | 13 |
| LSD .01 | 0.6 | 7.6 | 21 | 38 | 394 | 982 | 57 | 19 |

obtained. The higher rates of compost application had a residual nitrate level of less than 4 ppm which would not be a hazzard either on site or as a contributor to ground water pollution.

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16. ABSTRACT

High rate thermophilic composting of animal wastes with added carbonaceous waste materials followed by land application has considerable potential as a means of treatment and useful final disposal of these wastes. The process described in this report utilizes a mechanically mixed, thoroughly aerated, thermophilic first stage in which the readily available carbonaceous materials are utilized by bacteria during the stabilization of the nitrogenous wastes. This is followed by a curing period in which the hollocellulose is partially decomposed principally by fungi. The compost may then be added to soil.

The testing of the compost's effect of plant growth was done in three phases. The first phase involved spreading the compost over grass as a top-dressing; the second was a greenhouse study using tomatoes, wheat, millet, and beans; while the third was a field test on tomato crops. In all three tests, the compost exhibited significant beneficial effects. The mulching experiment yielded increases in the dry weights of grasses of up to 57 percent over the control. The greenhouse experiments showed increases in dry weights of up to 400 percent for tomatoes and wheat over the control. Field studies, indicated that, both the tomato size and total yield over the growing season incresed with increasing compost application.

17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|
| Agricultural Wastes | Aerobic composting | 2C |
| Composts | Animal wastes | 6M |
| Field Tests | Plant response | 13B |
| Organic Wastes | Solid wastes | |
| | Themophilic composting | |

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