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WINDROW MANAGEMENT METHODS FOR COMPOSTING STRAW AMENDED DAIRY MANURE

By

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ABSTRACT

WINDROW MANAGEMENT METHODS OF COMPOSTING STRAW AMENDED DAIRY MANURE

By

Michael C. Kenny

On-Farm windrow composting methods of dairy manure needed to be studied to determine an optimal method of management. Temperature, carbon dioxide and time were used to determine an optimum method of windrow management during the composting of five straw amended dairy manure windrows. It was concluded using carbon dioxide as an indicator to time windrow turnings while having a minimum number of turns in a given time period is optimal.

ACKNOWLEGMENTS

I would like to thank my major professor Dr. Ted Loudon for taking a chance on me and for his guidance and patience during my research and writing of this thesis. I would also like to thank Dr. Cynthia Fridgen and Dr. Howard Person for serving on my committee. Dr. Cynthia Fridgen helped me understand the large scope of waste management issues and brought a non-engineer flavor to my committee. Dr. Howard Person provided his insight to compost engineering.

I would like to thank the many individuals associated with the Manure Management Demonstration Project for their time and effort in helping me understand the value composting brings to agriculture. Christopher Lufkin, who managed the project, deserves credit for giving me direction and guidance in my composting studies. Jim Scott and Keith Meyers helped with equipment needs and provided their valuable time to the project.

Finally, I would like to thank my parents and my future wife Liz. My parents have guided me positively through life and patiently helped teach me to never give up. Liz helped keep my spirits up and pushed me towards my goals.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

Introduction

Waste management in agriculture is an increasing problem for the farmer has populations expand into agricultural areas. Some of the problems encountered by the animal farmer are the availability of land for manure application, odors, flies and negative perceptions by the general public of manure waste management.

Composting of the manure is one option that the farmer has for waste management on the farm. Composting of manure reduces flies, odors and volume of the manure when properly performed. Prior composting research has focused on the many aspects of waste management from industrial sludge to garbage and animal agriculture. Many experiments have been facilitated by bench scale methods and do not generally take into account larger scale manure management operations such as a farm.

Rynk et al (1992) gives a good overview of the composting process and how to manage composting farm operations, however, more in depth research for on-farm practices is needed to help bring the use of composting into common practice. Recently, Lopez-Real and Baptista (1996) have compared three different composting systems of windrow, minimal intervention and forced aeration methods of composting dairy manure. Based on common on-farm manure handling practices, it was decided that the windrow system of composting is more suitable with the manure handling capabilities and machinery on a farm, so it was chosen for study.

The research presented here focuses on the effect different management techniques have on the process parameters during the windrow composting of dairy manure. There was not an attempt to conduct a replicated research analysis. The research was part of a demonstration project to demonstrate and compare different windrow management schemes. The methods used to evaluate the compost were based on the composting process being used as a manure management tool for on-farm applications.

Chapter 2

Objectives

The objectives of this research are; (1) to study the effect that turning windrows based on different process parameters has on the composting of dairy manure; (2) to develop better understanding of the windrow composting process and how it can be utilized in animal waste management; (3) to develop dairy manure windrow composting techniques based on experimental results and observations of the process parameters during composting.

Chapter 3

Literature Review

3.1. Compost Definition

Composting is defined in many ways. Bell (1973) wrote that composting is a self-heating, thermophilic, aerobic decomposition process, which occurs naturally in accumulations of biodegradable solid organic matter. Haug (1980) states it is the biological decomposition and stabilization of organic substrates under conditions that allow development of thermophilic temperatures as a result of biologically produced heat, with a final product sufficiently stable for storage and application to land without adverse environmental effects. Haug (1993) then added to the above statement that the resulting compost must be free of pathogens and weed seeds. Mathur (1991) describes composting as a biological conversion of organic wastes, under controlled conditions, into hygienic, humus rich, relatively biostable product that improves land and fertilizes plants.

Hoitink et al (1991) divides the composting process into three phases. In the first phase the temperatures rise to 40-50 C and the easily degradable substances are destroyed. In the second phase the temperatures range from 45-65 C and less degradable substrates of cellulose are destroyed while lignins are slowly broken down. In the third phase, known as the curing phase, humic substances accumulate and mesophilic organisms recolonize the compost.

3.2. Compost Systems

Reactor and nonreactor are the two main classifications of compost systems (Haug 1980). Reactor systems are also referred to as in-vessel or mechanically operated. Reactor systems include vertical flow, horizontal, inclined flow and nonflow processes. Within these systems are the rotating drum, agitated bin and static bed bins. Nonreactor systems are referred to as open systems or those in which the compost materials are not placed into a reactor (Haug 1980).

3.2.1. Reactor

The vertical flow systems are divided into classifications by agitation. If the solids are agitated while they move down the reactor then it is considered a moving agitated bed reactor. If the substrates are mixed before placement into the reactor and are not agitated through the process then it is considered a moving packed bed system (Haug 1993).

3.2.1.1 Horizontal Flow and Inclined Flow Processes

Rotating drum reactors operate by rotating the composting material inside of a drum mechanism. The drum is usually inclined so that the materials will move down the incline as the drum is rotated. The process can be a continuous movement down the incline or the drum can have cells and the composting material is moved from one cell to the next as the process proceeds down the drum.

3.2.1.2. Agitated Bins

Agitated bins are another form of the Horizontal flow composting process. Bins of varying shapes and sizes are used in this process. The material is placed into the bins and during the composting process the material can be agitated using shaking, augers, or other agitation devices depending on the design of the system. Air maybe forced through the bins during the process to satisfy the aeration requirements of the active organisms.

3.2.1.3. Static Bins

Static bed bins are similar to the agitated bins except that the composting material is not agitated within the bins. Air is forced through the bins and the material is moved from one stage to the next by conveyor, hydraulic pushing or through the use of a walking floor.

3.2.2. Nonreactor

Nonreactor systems include static, agitated solids bed, and pile or windrow processes. The majority of on-farm composting operations use the nonreactor compost systems (Rynk 1994).

3.2.2.1. Static Solids Bed

In the static pile process there is no mechanical or other type of agitation after the pile formation. The aeration requirement is maintained through forced or natural ventilation. Mathur (1991) used perforated pipe placed across the bottom of the windrow to facilitate air movement by convection through the windrow due to the temperature stratification within the windrow. This became known as the passively aerated windrow system.

3.2.2.2 Agitated Solids Bed

Windrow composting is considered the main form of the agitated solids bed process (Haug 1993). In the windrow process the substrates are formed into the shape of a windrow and turned or agitated periodically. Various forms of equipment can do the turning or agitation. Forced or natural ventilation processes are used in the process.

Typically on-farm manures are composted using the windrow process. Voghtmann and Besson (1978) stated windrow processes were used in Europe to compost manures. Fabian et al. (1992) describes the use of agitated windrows for farms from small to large in size. LaCross and Graves (1992) indicate that windrow composting for farmers is the most common system used.

Windrow processes are used on the farm because it is a relatively low technology method that can utilize existing machinery found on most farms. Bell (1973) describes the use of a front-end loader to turn windrows as a method of composting. Rynk (1992) includes farm machinery, such as a manure spreader and front-end loader to agitate the windrow for compost windrow management.

The disadvantage of using existing farm machinery is the time it takes to turn the windrows (Rynk 1992 and Fabian et al 1992). Specialized equipment has been developed to accelerate the windrow agitation. There are self-propelled and power-assisted windrow turners available. Included in the power-assisted compost turners are those which are pulled and mechanically driven with a tractor. This type of compost turner is often used on farms where composting is done. Rynk (1992) gives a good overview of the specialized composting equipment that can be used on the farm. Fabian et al (1992) indicate the advantages a windrow compost turner can provide in particle size reduction, mixing and reduction in time it takes to turn the windrows.

3.3 Biological Fundamentals of Compost

3.3.1 Microbe Types

There are many different types of organisms that can be found in the composting environment. Factors that will influence the types and quantities of microbes found are temperature, moisture, pH, aeration, and feed sources for the microbes. Bacteria, actiomycetes and fungi are the primary organisms in compost systems, however, there are groups such as algae, protozoas and viruses which are less significant. There has been confusion in classifying actiomycetes because they have characteristic of both bacteria and fungi. Haug (1980) includes actiomycetes in the bacteria group for ease.

3.3.1.1 Bacteria

Bacteria are the smallest living organisms known to man. They can be unicellular or multicellular. Reproduction of bacteria mainly occurs by binary fission. During the composting process bacteria are generally divided into thermophilic and mesophilic categories. *Bacillus stearothermophilus, thermomonospora, and clostridium thermocellum* are prominent bacteria during the thermophilic composting process (Atlas and Bartha 1981).

Cysts, microcysts and endospores are capable of producing dormant forms of cells, which are more resistant to heat, radiation and chemical disinfection. Endospores are considered the most stable of the three under adverse conditions and become significant when heat inactivation is considered (Haug 1980).

3.3.1.2 Actinomycetes

Actinomycetes comprise a group of branching unicellular microorganisms. They form a mycelium which may be of a single kind, designated as substrate or vegetative, or of two kinds, substrate and aerial. They reproduce by fission or by means of special spores or conidia. Actinomycetes are found in virtually every natural substrate and live and multiply most abundantly in various depths of soil. Waksman et al (1934) shows that actinomycetes are abundant in high temperature composts of manure and plant residues.

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Thermoactinomyces and other thermophilic genera grow abundantly in stable manure and in high temperature composts (Waksman 1967).

3.3.1.3 Fungi

Fungi are eukaryotic heterotrophic spore-bearing organisms, which lack chlorophyll. Fungi can be split into two groups: Slime molds and true fungi (Atlas and Bartha 1981). The molds are aerobic while the true fungi can be both aerobic and anaerobic. The fungi molds have an advantage over bacteria in low moisture and nitrogen environments (Haug 1980).

Geotrichum candidum, aspergillus fumigatus, mucor pusillus, chaetomium thermophile, thermoascus auranticus and torula thermophila are prominent fungi during the thermophilic phase of the composting process (Atlas and Bartha 1981).

3.3.2 Microbial Growth

The rate of microbial growth depends on the concentration of substrates if no other factors are limiting. Equation 3.1 developed by Monad in 1942 and given in Haug (1980) describes the effect of substrate concentration on the rate of substrate use by a microbe. Equation 3.2 describes the growth rate of microbes with regard to the utilization of substrate.

$$\frac{dS}{dt} = -\frac{k_m SX}{K_s + S} \qquad (3.1)$$

Where

dS / dt = rate of substrate utilization, mass/volume - time
X = concentration of microbes, mass/volume
k_m = maximum utilization coefficient, maximum rate of substrate utilization at high substrate concentration, mass substrate/mass microbes – day
K_s = half – velocity coefficient, also reffered to as the Michaelis – Menton coefficient, mass/volume
S = concentration of the rate limiting substrate, mass/volume

$$\frac{dX}{dt} = Y_m \frac{k_m SX}{K_s + S} - k_e X \qquad (3.2)$$

Where

dX / dt = net growth rate of microbes, mass / volume - time
Y_m = groth yield coefficient, mass of microbes / mass of substrate
k_e = endogenous respiration coefficient, time^{-1} or mass of microbes respired / mass of microbes - time

Values for $Y_m, k_{m,} K_s$ *and* k_e must be known for the particular substrate and microbe under consideration. The coefficient values have been determined for various substrates under both aerobic and anaerobic conditions.

3.3.3 Microbial Destruction

3.3.3.1 Heat Inactivation

One of the goals of composting is to produce a sanitized product that is beneficial to plant growth (Zucconi and Bertoldi 1987). Strauch (1987), after an extensive literature review, states the requirements needed to disinfect sludge for the windrow process as the composting must be operated for at least three to four weeks with the temperature of the windrow exceeding 65° C for at least one of the weeks. Haug (1980) states that heat inactivation of microbes are a function of time and temperature.

3.3.3.1.1 Exponential Decay of Microbes

Heat inactivation of certain microbes can result in straight-line first order decay as described by Equation 3.3.

$$\frac{dn}{dt} = -k_d n \qquad (3.3)$$

Where

$$n = \text{viable cell population}$$
$$k_d = \text{thermal inactivation coefficient}$$

The thermal inactivation coefficient is a function of temperature and can be described by Equation 3.4.

$$k_d = Ce^{-E_d / RT_k} \qquad (3.4)$$

Where

$$T_k = \text{Temperature, °K}$$
$$E_d = \text{inactivation energy, kcal/mole}$$
$$C = \text{Constant}$$
$$\text{R} = \text{universal gas constant} = 1.99 \text{ cal/deg - mol}$$

The constant C and inactivation energy E_d is determined by plotting the logarithm of k_d versus $1/T_k$.

During composting there are phases of heating, holding and cooling, therefore, k_d will not be constant. Haug (1980) in Equation 3.5 describes this effect.

$$\ln \frac{n_o}{n_f} = \int_o^{t_f} Ce^{-\left[E_d / RT_k(t)\right]} dt \qquad (3.5)$$

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$n = n_o$ at $t = 0$, to final conditions, $n = n_f$ at $t = t_f$.

3.3.3.1.2 Nonexponential Decay of Microbes

In certain situations during composting there may be a lag then an exponential decay or an exponential decay followed by a retardant die away of microbes. Wei and Chang (1975) propose that clumping of organisms is a major factor for nonexponential decay of microbes. Lag decay results from a large percentage of the microbe population existing in clumps while the asymptotic decay results from a large percentage of microbes existing as discrete particles along with a number of clumps of unusual size. Large particles that have formed during composting may not receive adequate oxygen and would significantly reduce heat buildup within the particle itself.

3.3.3.2 Microbe Destruction Limitations

Particle size can limit microbe destruction as described earlier. Haug (1980) analyzed the effect of particle size on heating and concluded clumps larger than 20 cm in radius cou

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could effect heating potential and may limit the destruction of microbes.

Temperatures in the outer zones of the composting mass may cause no microbial destruction. Turning of the compost redistributes the compost mass, submitting more of the mass into the higher temperature zones. Haug (1980) describes the effect of turning on the inactivation of microbes in Equation 3.6.

$$n_t = n_o\left(f_1 + f_h e^{-k_d \Delta t}\right)^N \qquad (3.6)$$

Where

n_t = number of organisms surviving
n_0 = intial number of organisms present
f_1 = fraction of composting material in the sublethal temp. zone
f_h = fraction of composting material in the lethal temp. zone
Δt = time interval between turnings
k_d = thermal death coefficient
N = number of turnings

Bacterial growth after the compost temperatures have reduced to sub-lethal temperatures is another factor that limits thermal inactivation. Satriana (1974) presented data compiled by Dr. William Gaby that shows temperatures of 49° to 55° C reduce coliform levels to numbers under the minimum level of detection. However, coliforms reestablished themselves in the latter stages of the compost process of refuse and sewage sludge. Also in the study, *Fecal streptococci* maintained populations even when temperatures reached 55° C to 60° C.

3.4 Empirical Studies of the Compost Process

3.4.1 Temperature

Schulze (1962b) studied the effect of controlling temperature by restricting the air supply to an enclosed mass of decomposing material. It was found that at the beginning of the thermophilic phase long periods of airflow were needed to increase the temperature to the preset maximum. Snell (1960) states there were three objectives of high temperature composting, (1) destroy pathogenic organisms, (2) destroy weed seeds and (3) destroy fly eggs and larvae. Lynch and Cherry (1996) studied the effect of cold ambient temperatures in Ontario Canada on the composting process and concluded it was possible to compost through the winter months.

Wiley (1957) indicates the optimal temperature for maximum decomposition is in the 54° to 63° C range. Snell (1960) observed that in the initial phase of composting garbage the optimal temperature for oxygen uptake was 35° C, but later in the thermophilic range, the optimal temperature was 45° C. Finstein (1980) concluded that 55° C was the optimum temperature for thermophilic microbial activity.

3.4.2 Oxygen and Carbon Dioxide

Lambert and Davis (1934) indicates the sum of the carbon dioxide and oxygen content percentages in mushroom compost heaps approximately equals twenty-one. Schulze (1960) along with Lambert and Davis (1934) concluded the respiratory quotient (RQ) of compost could be figured by Equation 3.7.

$$RQ = \frac{Volume\,of\,CO_2\,produced}{Volume\,of\,O_2\,consumed} = 1 \tag{3.7}$$

Oxygen consumption rates varied directly with temperature. Equation 8 defines the relation between temperature and the oxidation reaction rate and is usually expressed as the temperature coefficient (Schulze, 1960).

$$Q_{10} = \frac{K_t}{K_{t-10}} \qquad (3.8)$$

Where:

Q_{10} = temperature Coefficient
K_t = the oxidation reaction rate at temperature t
K_{t-10} = the oxidation reaction rate at temperature t - 10 (10° C. lower)

Lambert and Davis (1934) found oxygen content within compost heaps was greater towards the outside of the heaps while the carbon dioxide content increased as sampling moved toward the lower center of the heap. Miller et al (1996) found oxygen content decreased while carbon dioxide content increased as measurements approached the lower center in Phase 1 composting stacks. Miller et al (1996) and Michel et al (1996) reported that turning frequency had no significant affect on windrow oxygen concentrations.

3.4.3 Aeration

3.4.3.1 Aeration Types

3.4.3.1.1 Forced Aeration

Forced aeration uses mechanical devices to supply the aeration requirement of the composting substrates. Aeration can be continuous or intermittent depending on the parameter used. Schulze (1962), Hansen et al (1989), Fernandes and Sartaj (1997) and Emerton et al (1988) used temperature as an indictor for aeration. Schultze (1960) used the oxygen content of compost exhaust air as an indicator for aeration. Bell (1970) used continuous aeration while comparing two different aeration rates to determine optimum aeration requirements in the composting of poultry manure and ground corncobs.

3.4.3.1.2 Natural Aeration

Naturally aerated composting does not include mechanical means for air delivery, rather it relies on diffusion and convection has the means of aeration. Emerton et al (1988) compared natural versus forced aeration methods on dairy manure solids and concluded that under natural aeration the static compost piles achieved temperatures high enough for optimum composting. Fernandes and Sartaj (1997) found that naturally aerated composting is slower than forced or passive, however, it was still feasible for composting poultry manure slurry amended with sphagnum peat.

3.4.3.2 Aeration Mechanisms

Michel et al (1996) indicates primarily turning the windrow does not do oxygenation of windrow composting but rather convection and diffusion appear to be the primary aeration mechanism.

3.4.3.2.1 Convection

The density difference between the warm moist air within the interior of the windrow and the colder, less moist ambient air outside the windrow produces an upward buoyant force that induces natural ventilation of the windrow (Haug 1993). Natural convection is not easily measured due to the non-homogeneity, spatial variability and the difficulty measuring small air velocities (Miller et al 1989).

Lambert and Davis (1934) concludes the convex shaped temperature contours from a cross sectional area of a compost heap are the result of convection currents. Tietjen (1961) indicated that the structure of the compost piles have an effect on the movement of gases within the air pores.

Mathur et al (1986) and Lynch and Cherry (1996) used perforated pipes at the bottom of the compost piles to aid the convection currents in increasing the oxygen concentration near the bottom of the piles.

3.4.3.2.2 Diffusion

Another aeration mechanism for composting is molecular diffusion. Molecular diffusion results from constant and random collisions between molecules of a fluid. The molecules have a tendency to move from a zone of high concentration to low concentration (Haug 1993). Oxygen diffusion through smaller pores and into the aqueous film surrounding compost particles is essential to maintaining aerobic conditions for the active microorganisms (Richard 1996). Diffusion rates will vary with stack porosity, which is affected by location within the stack, compaction, m

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mixing, moisture content and the extent of decomposition (Miller et al 1989).

3.4.3.3 Heat Transfer

Conduction, convection and radiation are the three mechanisms of heat transfer. Convection is the process in which heat energy is carried from place to place by the bulk movement of fluid (Cutnel and Johnson 1989). Movement of air within a bed of composting particles such as the evaporation of water from the composting particles is an example of convective and latent heat transfer (Haug 1993).

Heat transfer from contact between particles is an example of conduction. Fourier's law (Equation 3.9) explains the quantitative law of heat conduction.

$$\frac{dQ}{dt} = \frac{-kdAdT}{dx} \tag{3.9}$$

Where

$$dQ = amount\ of\ heat$$
$$dA = plane\ of\ area$$
$$dt = amount\ of\ time$$
$$\frac{dT}{dx} = temperature\ gradient$$
$$k = thermal\ conductivity$$

Air movement across the compost produces convective heat loss resulting in a temperature difference. Heat is then conducted from the interior of the compost to the outer layers to compensate for the loss of heat. Equation 3.10 describes this heat transfer within the compost piles.

$$q = UA(T_1 - T_2) \tag{3.10}$$

Where

q = rate of heat transfer
U = overall heat transfer coefficient, which includes both conductive and convective heat transfers, $cal/h \cdot cm^2 \cdot °C$
A = area perpidecular to direction of heat transfer, cm^2
T_1, T_2 *= temperatures at position 1 and position 2,* $°C$

When a warm compost surface is exposed to cooler ambient air, such as after turning a windrow or pile, a rapid surface temperature drop should result from radiative and convective losses with the outside ambient air (Haug 1993). Stefan-Boltzmann law given in Equation 3.11 describes radiant heat transfer between two bodies.

$$q = \sigma A\left(T_a^4 - T_b^4\right)F_a F_e \tag{3.11}$$

Where

$\sigma = Stefan - Boltzmann\ consant, 4.87 \times 10^{-8}\ kcal/\left(h \cdot m^2 \cdot {}^\circ K^4\right)$
$F_a = configurational\ factor\ to\ account\ for\ the\ relative\ position\ and\ geometry\ of\ the\ bodies$
$F_e = emissivity\ factor\ to\ account\ for\ non - black\ body\ radiation$
$T_a, T_b = absolute\ temperature\ of\ bodies\ A\ and\ B, {}^\circ K$

3.4.3.4 Moisture Vapor

Haug and Haug (1978) describes the two major energy fluxes of the composting processes are heats released as a result of organic decomposition and energy required for latent heat moisture evaporation. Finstein (1980) concludes that microbial generated heat is removed by evaporative cooling of the compost.

Haug and Haug (1978) estimates a value of ten grams of water per gram of degradable organic can be used as a rule of thumb to judge the thermodynamics of the composting process. Below ten grams there should be sufficient energy available for temperature elevation and water evaporation. If the water ratio is above ten then other factors, such as surface drying, will be needed to provide sufficient energy for the composting process.

The amount of water that can be carried by air increases exponentially with increases in air temperature, as shown in Figure 3.1.

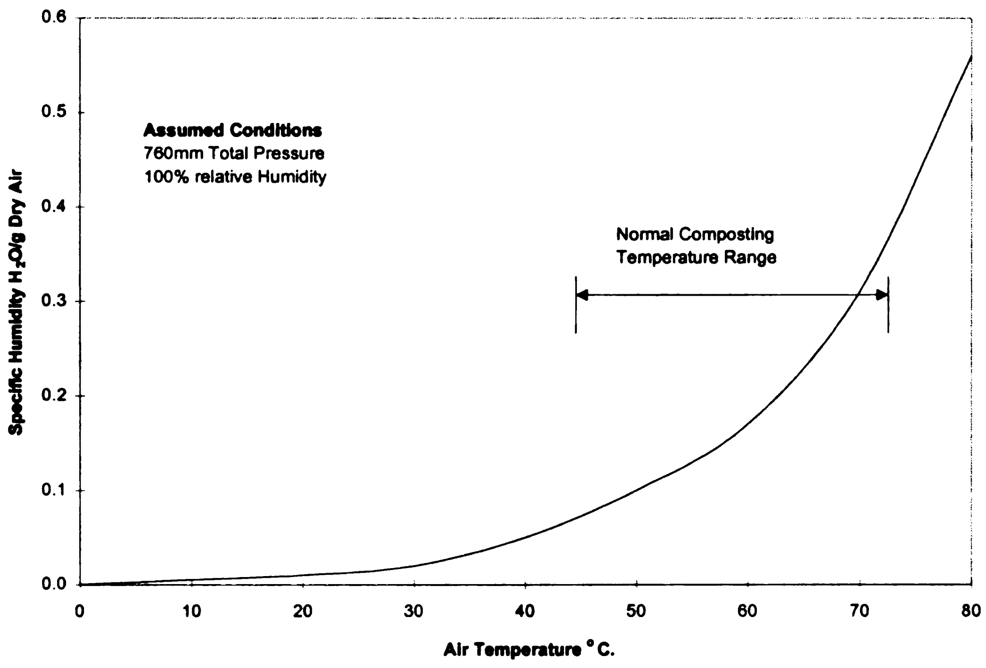

Figure 3.1 : Specific Humidity as a Function of Air Temperature (Haug 1993)

3.5 Physical Properties

3.5.1 Windrow Size

Windrow size is an important factor of the windrow composting process. An oversized windrow retains too much heat and could compress, thereby, reducing the aeration rates. A windrow too small can cool too readily and inhibit the heating process of composting, while a windrow too large inhibits the oxygen content (Strom et al 1980). Windrow sizing effects and their remedies are listed in Table 3.1.

Table 3.1: Effect of windrow size on temperature and oxygen content, (Strom et al 1980)

	Windrow Size		
	Too Large	Too Small	Acceptable
Temperature (°C)	>60	<20	20 to 60
Oxygen Content (%v/v)	<5	>5	>5
Remedy	Both the temperature and O_2 requirements call for a smaller windrow	Temperature requirements call for a larger windrow, possibly conflicting with the O_2 requirement	

Strom et al (1980) concluded that windrows of composting leaves should have a height of four feet with a width of seven feet. With this windrow size oxygen diffusion is favored in the early stages of the process. Combining windrows during the later stages of composting can insulate the windrows from cooling too quickly. Diaz et al (1993) states an ideal composting windrow is six to seven feet high with a width of eight to thirteen feet, depending on equipment used.

Loaf shaped windrows tending toward a flattened top are appropriate in dry windy conditions due to the ratio of exposed surface to overall volume. A conical shape with a less flattened top would be conducive in wetter conditions because it would be more likely to shed water. The overall volume of the hot zone is greater in triangle or conical shaped windrows, (Diaz et al 1993).

3.5.2 Particle Size

The significance of particle size is in the amount of the surface area of the composting process exposed to microbial attack (Diaz et al 1993). Michel et al (1996) found particle size decreases with increasing turning frequency and piles handled by a tractor loader compared to windrows of composted yard trimmings had higher levels of larger particles. Figure 3.2 shows the effect of turning frequency on particle size. Windrows 1A-1E were turned seven times every four weeks, windrows 2A-2E were turned once every four weeks and piles 3A-3E were turned once every four weeks.

Particle size distribution of compost defines the use of the compost. Uniform distribution of particle size would be used in the nursery industry, while less uniform compost would be used as a soil amendment (Diaz et al 1993).). Particle size affects the moisture requirements of the composting process (Jeris and Regan 1973).

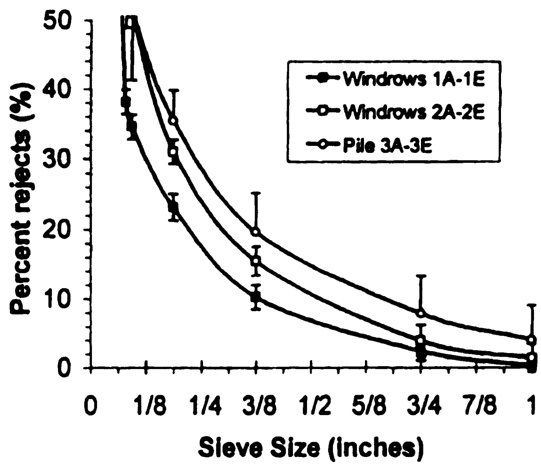

Figure 3.2: Sieve Analysis of Composted Yard Trimmings (Michel, et al 1996)

3.5.3 Free Air Space

Free airspace is important in the composting mixture in determining quantity of oxygen available and movement of air through the mixture (Haug 1993). Free air space is determined primarily by moisture content and bulk density (Schulze 1962a). Schulze (1962a) concluded that a minimum of thirty- percent free air space should be maintained during the composting of garbage refuse. Jeris and Regan (1973a) found that oxygen consumption rates were optimal between twenty-eight and thirty-two percent free air space. Free air space can be determined from Equation 3.12 if bulk weight and specific gravity from Equation 3.13 are known (Schultze 1962a).

$$Free\ air\ space, \% = 1 - \left(\frac{bw \times dm}{sg}\right) \times dm \qquad (3.12)$$

Where

$bw = bulkweight, g/cm^3$
$dm = dry\ matter\ in\ percent$
$sg = specific\ gravity, g/cm^3$

$$S_s = \frac{100 s_f s_v}{100 s_v + p_v\left(s_f - s_v\right)} \qquad (3.13)$$

Where

S_s = *specific gravity of raw material*
s_v = *specific gravity of volatile matter*
s_f = *specific gravity of fixed solids or ash*
p_v = *% volatile matter in raw material*

3.5.3.1 Bulk Density

Bulk density, which is inversely related to compost volume and particle size, was the characteristic most affected by windrow turning frequency (Michel et al 1996). Bulk densities primarily increase in the composting process as shown by Singley et al (1973), Lopez-Real and Baptista (1996), Michel et al (1996) and Jackson and Line (1997). Lopez-Real and Baptista (1996) found there was no significant difference in the percent of bulk density change when comparing the windrow and the static pile composting methods.

3.5.3.2 Moisture

Moisture levels during the composting process must be high enough to sustain microbial activity but not so high as to limit free air space and reduce the rate of oxygen transfer. The optimum moisture content is a tradeoff between the moisture and oxygen requirements of the microbes within the composting process (Haug 1993).

Snell (1960) indicates moisture content should be maintained from fifty to sixty- percent throughout the composting process. Jeris and Regan (1973a) found sixty-five to seventy percent moisture content of composting garbage refuse maximized the oxygen consumption rate.

3.5.4 Volume Reduction

Jackson and Line (1997) concluded volume reduction was closely related to the increase in bulk density and reduction of gravimetric water content during the composting of paper mill sludge while using a front-end loader to perform the turning. Lopez-Real and Baptista

(1996) concluded the biggest volume reduction of cattle manure compost occurred in the windrow system when compared to the forced and passive aeration systems.

3.6 Chemical Properties

3.6.1 C/N Ratio

Organic carbon is oxidized to CO_2 by dry or wet combustion and measured as CO_2. Compost nitrogen is usually determined by the Kjeldahl method. The C/N serves as an index of the decomposability of the material (Keller 1961). Livshutz (1962) when discussing improving windrow composting methods, describes the optimum starting C/N ratio should be around 30:1. Mathur (1991) concludes the optimum C/N ratio for mature compost is about 10.

Schulze (1962b) used Equation 3.14 to figure the carbon content of the C/N ratio. Total nitrogen was figured using the Kjeldahl method.

$$\%C = \frac{(100 - \%ash)}{1.8} \tag{3.14}$$

Lopez-Real and Baptista (1996) compared three different manure composting systems and concluded the C/N ratio for each fell from an initial value of approximately 30 to an ending value of approximately 14. Michel et al (1996) used different feedstock mixtures during the composting of yard trimmings and concluded the C/N ratios decreased from around 25 at the start to between 12 and 19 in the finished compost.

3.6.1.1 Carbon

Carbon accounts for approximately 50% of the dry mass of most organisms and is needed to synthesize the variety of organic molecules used in the structure and machinery of the cell. Two sources of carbon are available: carbon in the form of organic molecules, used by heterotrophs, and the carbon present in carbon dioxide, used by autotrophs (Haug 1993). The carbon content for the C/N ratio should be figured from the biodegradable fraction of the organic substrate (Kayhanian and Tchobanogous 1992).

3.6.1.2 Nitrogen

Sufficient nitrogen is needed to supply the microorganisms with a feed source while composting. During composting the organisms use about 15-30 parts of carbon for each part of nitrogen (Haug 1980). Part of the nitrogen in organic compounds is released on breakdown as NH_3. Depending on circumstances, the greater part of NH_3 is either assimilated by organisms to NO_2 or NO_3 or it escapes to outside air (Keller 1961). A low C/N ratio and an alkaline pH in the decomposing stage combined with a high temperature has lead to nitrogen volatilization as ammonia (Zucconi and Bertoldi 1987). Hansen et al (1989) concluded that the C/N ratio, stirring frequency and particle size had the biggest impact on nitrogen retention. During the composting of poultry manure Vanstaen et al (1980) found that the addition of straw helped immobilized the nitrogen. Lopez-Real and Baptisa (1996) found the percent nitrogen content of the compost generally increased through the process due to the loss of volatile solids during composting, regardless of composting system.

3.6.1.3 Substrate Biodegradability

The degradability of the substrates determines the quantity of available heat, mass balance and the stoichiometeric oxygen demand of the composting process. Substrate biodegradability can be predicted from Equation 3.15 (Chandler et al 1980).

$$B = 0.830 - (0.028)X \tag{3.15}$$

Where:

B = biodegradable fraction of the volatile soilds
X = lignin content, % of VS

3.6.3 pH

Jann, Howard and Salle (1960) found that the completion of the composting process can be determined if the compost stays alkaline while the organic matter is held at 55° C four 24 hours. Jeris and Regan (1973) obtained maximum thermophilic composting rates in a pH range of 7.5 to 8.5.

3.7 Properties of Finished Compost

3.7.1 Curing Phase

The curing phase of the composting process follows the active composting stage. During the curing phase the rate of oxygen consumption decreases and the composting slows to a rate where the compost can be piled without further aeration (Rynk 1992). Haug (1980) describes the curing phase as compost stabilization. Haug states stabilization of compost occurs when the rate of oxygen consumption is reduced to the point where the compost can be stored without odors or anaerobic conditions.

After mature compost has gone through the stabilization period, maturity can be measured in a variety of ways. Jann, Howard and Salle (1960) state pH stabilization can be used to measure stability while Keller (1961) summarizes that maturity can be measured by physical, chemical, biological characteristics or temperature. Mathur (1993) conducted a literature review on the numerous tests for biomaturity of composts. The tests include:

1. C/N Ratio of Compost
2. Organic C/N Ratio in Water Extract of Compost
3. Nitrogen Ratio in Water Extracts

4. Circular Chromatography Test of Alkali Extracts
5. Humification Indicators
6. Microbial Activity
7. CEC
8. Water Extracts of Compost
9. Reheating
10. Direct Phytotoxicity

Mathur concluded that there was no one best way for measuring maturity and no one test is adequate by it's self. Which test is used and the degree of compost maturity needs to be decided by the use of the compost.

3.7.2 Humus Development

Humification of the compost can be described as the ratio between total humic like substances and the total organic matter (Zuccini and Bertoldi 1987). The three main groups of humic substances include Fulvic acids, Humic acids and Humus carbons (Keller 1961). Humic acids have the highest cation exchange capacity and aids in the availability of nutrients for plant uptake when applied to soil (Steffen 1979). Lenhard (1963) describes humus as having an indirect effect on crop production by stabilizing clays and cations and increasing the soil water holding capacity.

3.7.3 Disease Suppression Characteristics

Hoitink et al (1976) investigated differences between composted and non-composted hardwood bark and the survival of certain plant pathogens that were buried in those piles. Selected pathogens of *Phytophthora cinnamomi, Pythium irregulare, Rhizictonia solani, Botrytis cinerea, and Erwinia carotovara* var. *chrysanthemi* could not be found recovered in the composted piles. However, *P. cinnamoni, P. irregulare* and *R. solani* were found in the non-composted piles. Hoitink et al (1977) concluded that hardwood bark compost is suppressive of *Phytopthora cinnamomi.* In another studied by Chef et al (1983) composted hardwood bark was found to be suppressive of Fusarium wilt of flax and chrysanthemum.

Chen et al (1987) studied which factors affect the suppression of *Pythium ultimum* damping-off in container media amended with compost. Compost was taken from different temperature zones of the compost piles and used in a bioassay test to determine damping-off. It was determined that compost samples taken from the low temperature outer edges of the compost piles suppressed while the samples taken from the high temperature (60 C) zones were conductive of *Pythium ultimum*. It was concluded those compost samples taken from the high temperature zones had reduced microflora activity after incubation at low temperatures which caused a biological vacuum where *P. ultimum* could thrive. The low temperature compost samples had the highest microflora activity after incubation, therefore, it was concluded the microflora suppressed the *P. ultimum* by actively taking up the nutrients the *P. ultimum* needed to survive. The effects of other factors such as the carbon sources and the level of organic matter decomposition have been investigated (Chung et al 1988 and Mandelbaum and Hadar 1990).

Vogtmann et al (1978) studied the effect composting has on the concentration of the antibiotic Zn-Bacitracin in poultry manure. The results of the study showed that the concentration of Zn-Bacitracin was 150 ppm in the fresh poultry manure while the composted manure had concentration levels less than 30 ppm.

Chapter 4

Methods

4.1 Composting Site

The composting was conducted on a compost pad at a landfill in Belding, Michigan. The compost pad was constructed based on recommendations in Rynk (1992) with a three-percent slope in the direction of the windrows and no cross slope. The pad was approximately 122 meters in length with the high point centered perpendicular to the length of the pad. The base of the pad consisted of fine sand fill that existed at the site and capped with approximately 20 cm. of road gravel (Michigan Spec. 23A).

4.2 Manure Origin

The manure used to form the windrows came from the same milking herd and from milking cows that were fed the same rations. This was done to ensure the manure would be as consistent as possible from one windrow to the next. The dairyman used sawdust in the alleys of the barn to absorb liquids; therefore, the manure used had a small percentage of sawdust in it.

4.3 Windrow Management

Five windrows (CDA, CDL, TMP, WTL, WCT) were built and managed for the experiment. The windrows were managed according to time, carbon dioxide or temperature, depending on the windrow (Table 4.1). All the windrows were built to approximately the same specification except for windrow CDA, which had a high clay content soil added.

Windrows CDA and CDL were managed according to the carbon dioxide level of the windrow. If mean carbon dioxide level exceeded 10% the windrow was turned with a compost turner. Clay soil was added at approximately 10% by volume to windrow CDA to determine if an addition of a clay soil helps to retain nutrients through the process. Windrows CDA and CDL were never turned more than once every two days.

Windrow TMP was managed according to the mean temperature level of the windrow. The windrow was turned with the compost turner when the windrow temperature exceeded 65° C., but never more than once every two days.

Windrow WCT and WTL were turned on a time schedule of once every week. The compost turner was used for windrow WCT and a tractor loader turned windrow WTL.

Table 4.1: Windrow treatments

Treatment	Turning Mechanism	Turning Threshold	Frequency
CDA	Compost Turner	10 % Carbon Dioxide Levels	Never more than once every 2 days
WCT	Compost Turner	Time	Weekly
WTL	Tractor Loader	Time	Weekly
CDL	Compost Turner	10 % Carbon Dioxide Levels	Never more than once every 2 days
TMP	Compost Turner	65° Celsius	Never more than once every 2 days

4.4 Windrow Turning Mechanism

The windrows were mixed using either a farm scale compost turner or a tractor loader depending on the windrow. The compost turner used to mix and aerate the windrows was a single-drum, tractor-drawn turner developed in Austria and sold under the trade name Sandberger. Production of this turner had been licensed to Midwest Bio-systems in Tampico, IL. This unit has a capacity of up to 1150 cubic meters per hour. The turner was advanced slowly (less than 0.8 km/h) along the windrow. This requires the use of a hydrostatic-drive tractor. The tractor used was an International Harvester Hydro 84. A loader attachment having a capacity of 0.8 cubic meters was used on this tractor to turn the loader turned windrow.

4.5 Windrow Design

The windrows were sized to the specifications of the compost turner that was used. This required a maximum height of 1.5 meters and a maximum width of 3.0 meters in a parabolically shaped windrow.

The building of each windrow consisted of laying down 15 bales of straw end to end and then placing another 15 in the same manner along side. This produced a windrow approximately 15.2 meters in length. The compost turner was then run through the bales to break them up leaving bedding on which the manure was placed. A volume of 13.8m^3 of manure, which was lightly bedded with sawdust, was placed on top of the straw with a tractor loader. For the windrow containing clay, 2.3 cubic meters of clay was evenly distributed across the windrow on top of the manure. Each windrow was mixed with two passes of the compost turner to start the process on October 3 1994.

The windrows were covered with a geosynthetic fabric made from polypropylene. The cover is sold under the trade name Top Tex™. It is 4 meters wide and is adequate to cover a windrow 3 meters at the base and 1.5 meters high. This "fleece blanket" sheds water while still allowing for gaseous exchange through the material. It was used to avoid excessive moisture in the windrows from rainfall. Lynch and Cherry (1996) used a similar cover to prevent material loss due to wind and provide insulation against cold temperatures and excessive moisture during winter composting.

4.6 Temperature Measurement

The temperature of each windrow was measured using a Reotemp FRK probe with a 7001K-thermocouple thermometer. The probe was placed approximately 30 centimeters into the windrow from top center. Lambert and Davis (1934) described this area to have the highest temperatures in compost heaps. A temperature measurement was recorded at 5 equally spaced intervals along the length of each windrow. The means of the five values are presented in the results section. Each windrow was monitored Monday, Wednesday and Friday for temperature.

4.7 Carbon Dioxide Measurement

Carbon dioxide measurements were taken in each windrow using a Bachrach Inc. fyrite volume expansion gas analyzer. This instrument uses potassium hydroxide to react with the carbon dioxide. A known volume of potassium hydroxide is sealed into a fixed volume container. The air sample is pumped into the container and the potassium hydroxide depletes the carbon dioxide in the air sample, which creates a vacuum that allows the fluid level to rise up the graduated column for measurement.

Previous research by Lambert and Davis (1934) showed the highest carbon dioxide levels of composts occur near the lower center of the pile. Carbon dioxide measurements were taken approximately 30 centimeters from the bottom center of the windrow. Previous cross sectional carbon dioxide profiles of windrows showed this area usually had the highest percent of carbon dioxide in the pore spaces of the compost.

Windrows that were managed by carbon dioxide levels were measured at five equally spaced locations along the windrow. Windrows that were not turned based on carbon dioxide concentrations were checked at four equally spaced locations along the windrow to save the expense of frequently replacing the fluid in the expansion gas analyzer.

4.8 Moisture Content

Moisture was determined for each subsample by drying approximately 100 grams of the material in an oven at 50^0 C for 48 hours. Weight of the sample was recorded before and after drying to obtain moisture content. The sampling procedure used is described in section 4.11. As recommended by Rynk (1992) a low drying temperature was used so that no organic material was burned off during the process.

4.9 Cross Sectional Area Measurement

Cross sectional area was measured throughout the composting process by recording the height at top center of the windrow and the width across the base of the windrow. Height was measured with a slender probe placed down into the windrow from the top center until the tip of the probe touched the hard surface of the ground.

Cross sectional area measurements for the windrows using the compost turner were figured by a formula given by Rynk (1992) for windrows which have a base (b) at least twice the height (h) (Equation 4.1). Area was measured three times in each windrow and then averaged.

$$\text{Area} = h * (b-h) \tag{4.1}$$

Cross sectional area measurements for the windrows using the tractor loader were figured by a formula given by Rynk (1992) for windrows which are turned using a bucket loader (Equation 4.2). Measurements were replicated three times and averaged.

$$\text{Area} = 2/3 \times b \times h \tag{4.2}$$

4.10 Bulk Density

Bulk density was measured as the windrow was being reformed behind the turner. A pan 41.91cm in diameter and 8.89cm deep was placed in the windrow behind the turner so that the top of the pan was at the same height as the drum of the compost turner. The compost turner drum was then brought to 200 rpm and the turner moved forward into the compost. This formed the windrow behind the turner and over the pan. After the windrow was formed, the pan was carefully removed and the compost was leveled off to the top of the pan. It was weighed and corrected for moisture. This was repeated three times in each windrow and the values were then averaged. Bulk density measurements were taken at the beginning and end of the process.

A different method had to be used for the windrow WTL, which was turned with the tractor loader. Using a pitchfork, the material from the windrow was dumped into the pan. An up swing motion with the pitchfork and then a quick release from under the material was used to mimic the action of the loader, as it would dump the material into a windrow. The material would dump into the pan and this would be repeated until the material was at a height equal to the windrow over the pan. After the windrow was formed on top of the pan it was carefully removed and the compost was leveled off to the top of the pan. It was weighed and corrected for moisture. Lynch and Cherry (1996) used a similar method to figure bulk density with loader turned windrows.

4.11 Windrow Sampling Technique

Samples for laboratory analysis were taken from the windrows at various times throughout the process. The sampling technique consisted of taking samples by hand at various depths from the surface of the windrow at ten locations down each side of the windrow and ten from the top middle. Hand sampling was used because the straw particles could then be extracted along with the manure in a

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a consistent manner each time a sample was taken. When applicable this was performed after a turning. These 30 samples were then mixed together and a subsample was taken. This was repeated three times to get 3 subsamples from each windrow. Lopez-Real and Baptista (1996) adopted similar sampling methods of cattle manure mixed with straw.

Samples were sent to the Research-Extension Analytical Laboratory at the Ohio Agricultural Research and Development Center, Ohio State University. The samples were analyzed for pH, Nitrate-N, TKN, Ammonia-N, C/N ratios and total carbon.

4.12 Germination Test

Germination tests were performed using watercress seed (Mathur et al. 1986) in finished compost. Germination in distilled water and commercial topsoil was used for a comparison. A 20ml compost, water or topsoil sample was placed in a 60ml petri dish. A Whatman #42 filter disk was then placed on top of the sample. Distilled water was added until a film of water formed on top of the filter paper. Twenty seeds were than added to the petri dish. The petri dishes were covered and placed in a dark room at 20^{0} C for

96 hours. The numbers of seeds germinated were counted and a percent germination value was calculated. Five replications for each windrow were completed.

4.13 Sieve Analysis

A sieve analysis was performed to determine particle size distribution at the end of the process using an approximately 100-gram sample of finished compost. The compost sample was placed onto the sieve with a catch pan underneath. The sieve was shaken with a back and fourth action for a specific amount of time for each sieve size starting with the largest sieve opening and successively moving to a smaller sieve opening. The shake times were determined from prior experience to eliminate excess shaking and particle deterioration for each sieve size. To keep the particles from breaking apart no vertical motion was used. The sieves size and shake times used are listed in Table 4.1.

Table 4.2 : Sieve size and shake times. A # indicates the standard U.S. Sieve number.

Sieve Size	Shake Time	Sieve Size	Shake Time
(0.952cm)	15s.	# 12 (0.170cm)	50s
(0.792cm)	15s.	# 14 (0.140cm)	60s
# 4 (0.475cm)	20s.	# 16 (0.118cm)	60s
# 6 (0.335cm)	30s.	# 20 (0.085cm)	75s
# 7 (0.280cm)	30s.	# 30 (0.060cm)	90s
# 8 (0.236cm)	40s.	# 50 (0.030cm)	120s

Chapter 5

Results and Discussion

5.1 Windrow Turning

Windrows managed by carbon dioxide were turned the most often. Windrow CDA was turned 24 times while windrow CDL was turned 20 times. Both the WTL and WCT windrows were turned 12 times. The temperature-managed windrow was turned the least with 11 turnings. The TMP windrow was turned frequently early in the process but it cooled to below 65° C after day 26 due to increased wind speeds at the composting site and never reheated enough to reach the turning temperature threshold.

As the windrows were turned repeatedly the substrates of the windrows became homogenous as the composting process progressed. Windrows CDL and CDA were turned more often which relocated a higher percentage of the substrates into the active composting areas of the windrows.

The TMP windrow was turned with sufficient frequency early in the process. However, once the temperature of the windrow declined below the preset turning level of 65° C the windrow did not receive another turning. Since the windrow was not turned after day 26 the TMP windrow had the highest carbon and C/N ratio levels at the end of the monitoring process.

Michel et al (1996) concluded turning frequency has little effect on windrow temperatures, however, the lack of turning after day 26 for windrow TMP shows that turning can provide greater substrate utilization and sustain higher temperature levels longer into the process.

5.2 Windrow Temperature

Figure 5.1 gives the mean of the temperatures taken along the windrow through the sampling period for all the windrows. Temperatures in all the windrows reached thermophilic levels within three days. Each windrow achieved a temperature of at least 65° C. Windrows WCT, CDL, and TMP achieved 65° C on day four, windrow CDA on day eight and windrow WTL day 12. Temperatures were similar in all the windrows until day 38.

Temperatures within TMP started to decline at day 29 and by day 38 had declined enough to separate itself from the other windrow temperature measurements. Windrow WCT temperatures abruptly declined from a value of 58° C on day 47 to 27° C on day 50 and steadily declined to ambient as the days progressed.

Temperatures within windrows CDA and CDL, which were turned according to carbon dioxide levels, closely resembled each other until day 49 when windrow CDL temperatures started to decline more rapidly.

Weekly turned windrows resulted in the most variable temperatures with temperatures staying at higher levels longer into the process. Temperatures would peak after turning and would then decline through the week until the next turning. Temperatures in Windrow WTL, which was turned with a tractor loader, declined the slowest and had not reached ambient by day 78.

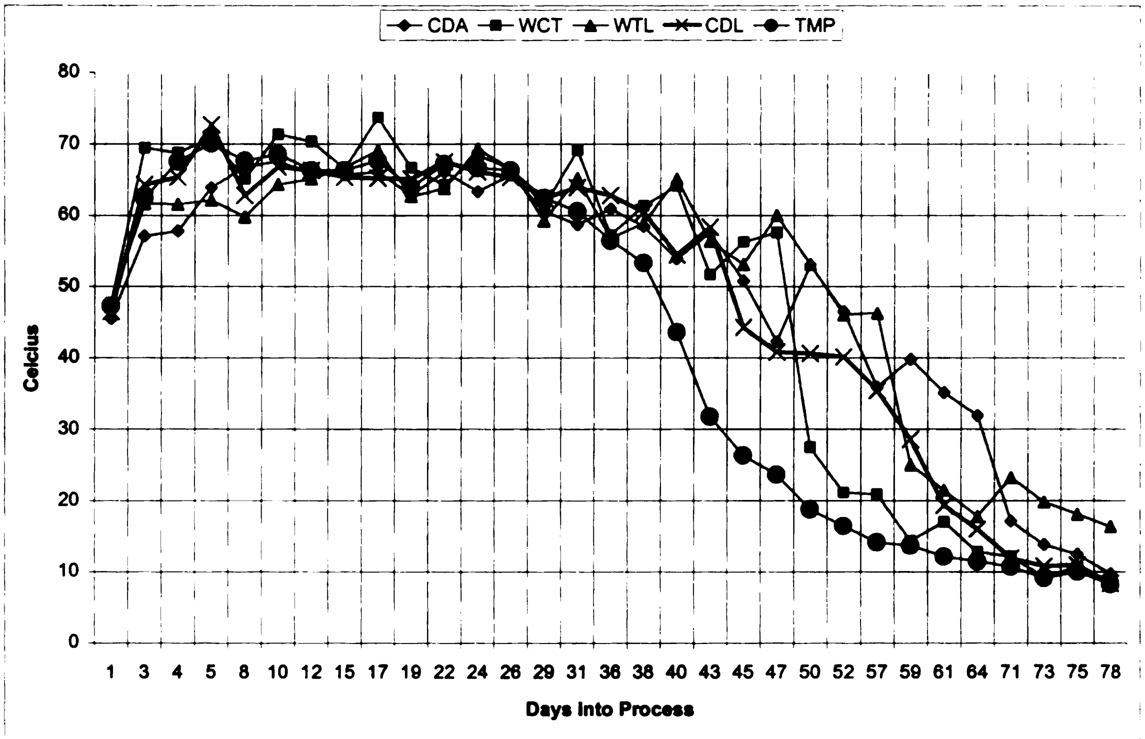

Figure 5.1: Mean Temperature Values for all the Windrows.

Temperatures in all the windrows stayed above 60° C for the first three weeks of the process providing enough time to kill unwanted weed seeds and pathogens. From day 10 through day 17 all the windrows had temperatures above 65° C providing for a sanitized product as described by Strauch (1987).

The weekly turned windrows WCT and WTL had more pronounced peaks and valleys in their temperature profiles when compared to windrows TMP, CDA and CDL. This may be attributed to thermal inactivation of microbes, which according to Haug (1980) can be reduced by more frequent turnings of the windrow. The more consistent temperatures in windrows TMP, CDL and CDA may be attributable to this effect. Equation 3.6 describes the relationship between turnings and thermal inactivation. No organism counts were taken to determine whether organism populations in the windrows followed the thermal inactivation curve.

The TMP windrow cooled earlier in the process due to a lack of turning after day 26. It can be concluded that without additional turnings after day 26 there was less substrate utilization in the outer regions of the windrow as compared to the other windrows. As a result the TMP windrow had the lowest carbon reduction percentage. A windrow management scheme that contributes to a minimum number of turns over a period of time would have resulted in better substrate utilization. The TMP temperature profile would have been expected to more closely follow the other windrows in the latter stages of the composting process if a minimum number of turns was defined.

Figure 5.1 shows temperature differences in management schemes became more apparent after temperatures declined to less than 60° C. There were no apparent differences in the temperature profiles between the windrow CDA and CDL. The addition of a high clay soil did not seem to affect temperature.

5.3 Windrow Carbon Dioxide

Figure 5.2 shows that each windrow had reached a twenty-percent carbon dioxide level by day three. The measurements were at or near twenty percent in all windrows until day 22 when they all decreased followed by a rebound on day 26 and then a greater decrease on day 29. Measurements of carbon dioxide on day 29 were significantly lower than on day 26 in all windrows. After day 29 there were significant variations between windrows.

Figure 5.3 shows from day 22 until day 64 Windrows WCT and WTL, which were turned weekly, had higher carbon dioxide levels following a turning of the windrow and then declined until the windrow was turned again. Windrow TMP had carbon dioxide levels above fifteen percent until day 29 and stayed at ten or below after day 31.

The carbon dioxide measurements for Windrows CDA and CDL closely followed each other until day 52. After day 52 until day 59 windrow CDA stayed above ten percent while windrow CDL stayed below five percent. After day 59 both windrows CDA and CDL were below five percent.

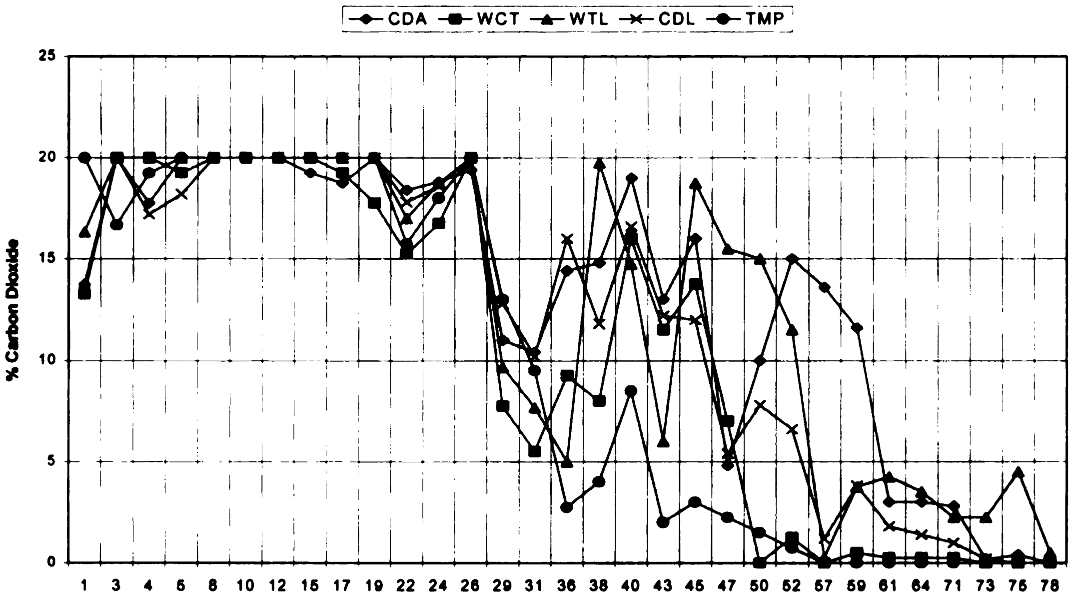

Figure 5.2: Changes in windrow carbon dioxide levels during composting.

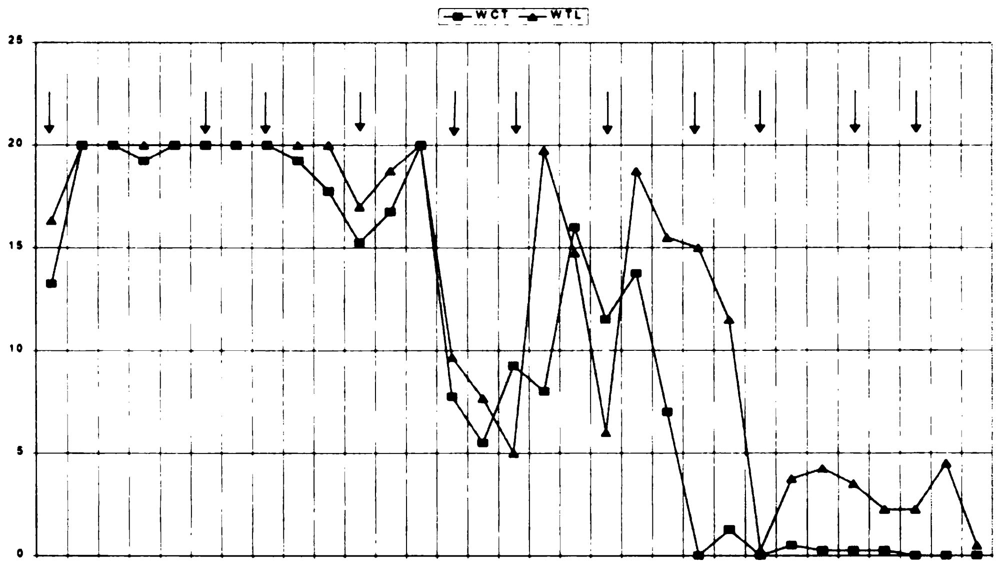

Figure 5.3: Changes in windrow carbon dioxide levels for the weekly turned windrows. Arrows indicate a turning event.

Carbon dioxide levels quickly reached the 20% level in all the windrows indicating rapid microbial growth and carbon degradation resulting in high levels of carbon dioxide evolution. After day 26 Figure 5.2 shows a sharp decrease in carbon dioxide levels. This decrease is a result of high winds at the composting site, which increased the convection currents and caused more air movement through the pile reducing carbon dioxide levels.

Figure 5.2 shows windrows WCT and WTL had more pronounced variations in carbon dioxide content than the other windrows. The carbon dioxide levels of the weekly turned windrows increased after the windrows were turned and slowly declined until the next turning (Figure 5.3). This rise and fall trend can be seen in the other windrows but not with as much amplitude. Michel et al (1996) reports similar results of rising oxygen concentrations after turning with a decline in the concentrations within hours.

Figure 5.3 also shows a difference in carbon dioxide levels between turning weekly with a loader and weekly with a compost turner. There was more carbon dioxide content variation with the loader turned windrow. Carbon dioxide l

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levels in WCT declined to fewer than 5% approximately ten days before those of WTL. Visually, the windrow WTL had clumps of substrate and larger particle sizes when compared to WCT. Therefore, later in the composting process the tractor loader turned windrow was still degrading readily available carbon sources that a compost turner would have exposed to areas of increased microbial degradation earlier in the process.

Figure 5.2 shows that the TMP windrow carbon dioxide levels did not rise above 13% after the winds between days 26 and 29. This resulted from either better rates of aeration or decreased microbial activity. Since other windrows showed increased carbon dioxide levels after the winds subsided it can be concluded there was a decrease in microbial activity.

5.4 Windrow Moisture Content

Windrow moisture content data given as % wet basis are presented in Figure 5.4. Samples taken at the beginning of the composting process showed initial moisture contents ranging from 64-70%. Windrow CDA had the lowest moisture content at 64% and windrows CDL and TMP had the highest at

70%. Ending moisture contents ranged from 46% to 54%. Windrow CDA had the lowest moisture content while the other four windrows were between 50 and 54%.

Windrow CDA lost 39% of its initial water content during the composting process. The other four windrows had reductions of 29% for windrow WCT, 30% for CDL and 32% for windrows WTL and TMP.

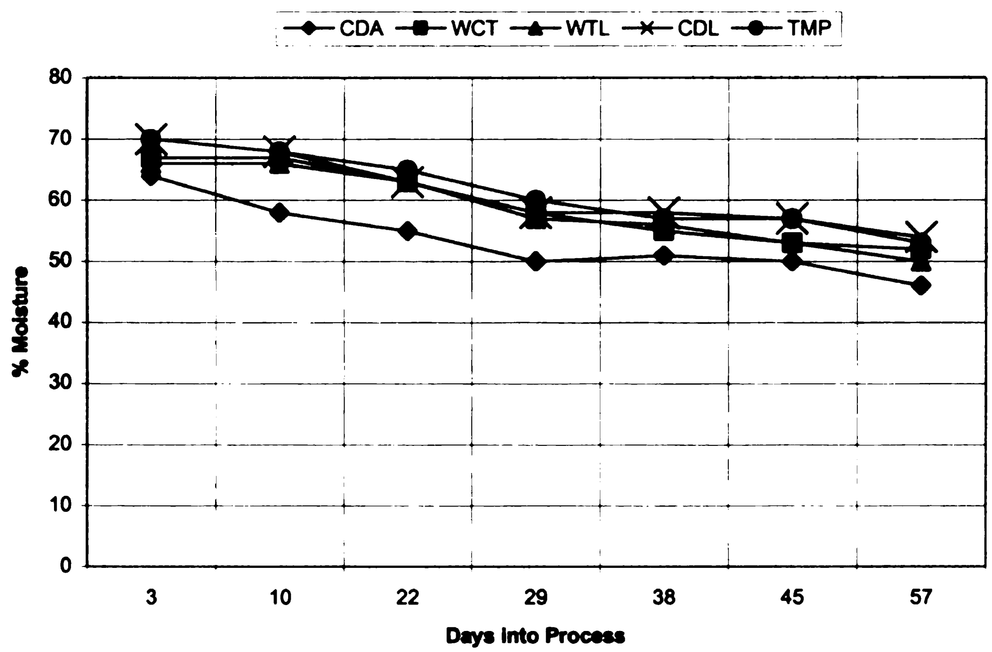

Figure 5.4: Changes in windrow moisture content during composting.

Ending moisture content values were in the acceptable range of 40% to 65% as given by Rynk (1993). The addition of a high clay soil had a significant effect (P=0.025) on windrow moisture level reduction. The lower moisture levels for windrow CDA can be attributed to the addition of the high clay soil that was dryer than the compost when added to the windrow.

Using the Top Tex™ cover controlled windrow moisture by limiting evaporative moisture loss and also reduced the amount of moisture soaking into the windrows during rain and snow events. Generally, it would be expected that the windrows would have had higher moisture losses during the summer months due to higher ambient temperatures and less likelihood of a rain event.

5.5 Windrow Cross Sectional Area

Windrow cross section change can be used as an indicator of volumetric change as long as the windrow length remains constant. The initial cross-sectional area measurements ranged from 0.95m^2 for windrow TMP to 1.05 m^2 for windrow WTL (Figure 5.5). All windrow cross-sectional areas decreased steadily during composting. Final measurements indicated the values decreased to 0.62 m^2 for windrow CDA, 0.51 m^2 for windrow WCT, 0.76 m^2 for windrow WTL, 0.59 m^2 for windrow CDL and 0.62 m^2 for windrow TMP.

Windrow WTL had the lowest reduction percentage at 27.62% during the composting process. Windrow WCT had the highest reduction value of 46.88%. Windrows CDA, CDL, and TMP, which were turned has needed using the compost turner, had reductions of 30.0%, 38.74% and 38.54% in cross-sectional area.

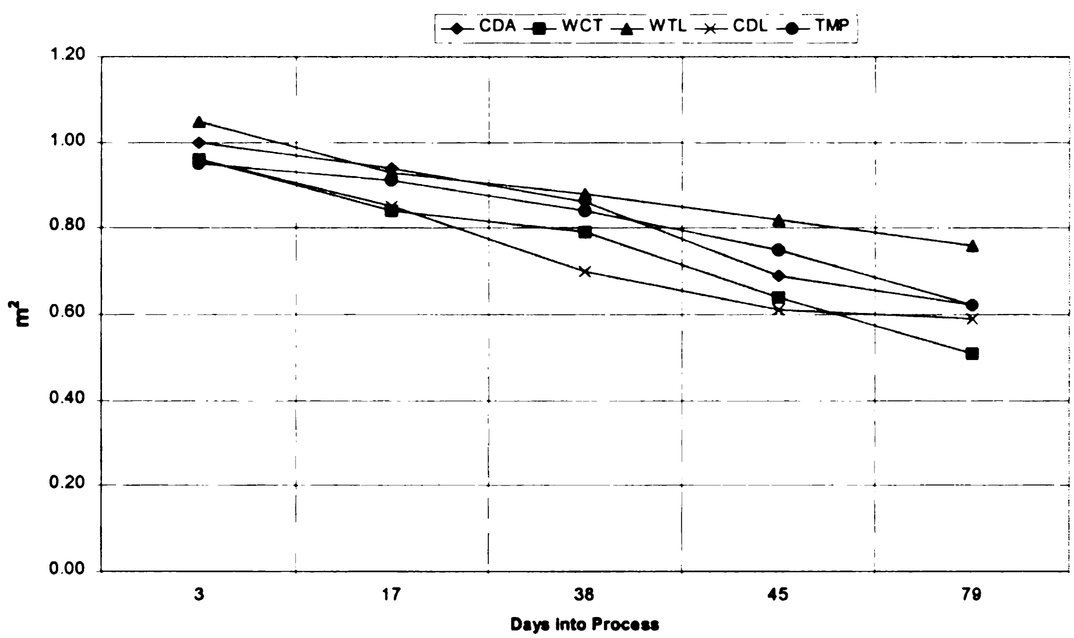

Figure 5.5: Changes in windrow cross sectional area during composting.

Cross Sectional area measurements decreased as the composting process progressed, as expected. Differences in turning mechanisms became quite evident after investigating the physical properties of windrow composting.

The compost turner produced smaller particles with better uniformity. The loader turned windrow had much larger clumps of substrate and did not condense in size has readily as the other windrows. The WTL had the smallest reduction in cross sectional area as a result of the tractor loader's inability to break down the clumps of substrate into more readily degradable particles like those produced by the compost turner.

Another factor that caused a smaller cross sectional area reduction in WTL was that is was easier to keep the length of the windrow from increasing using the loader. The rotating drum action of the compost turner had a tendency to increase the length of the windrow, thereby, reducing the height.

The WCT windrow had the largest reduction in cross sectional area. This may be explained by a combination of compaction and mass degradation. The windrow was only turned on a weekly basis and had more time to settle and compact before a measurement was taken. This settling is evident early in the process because the weekly turned windrows WTL and WCT had steeper reduction lines than the other windrows which were turned more often during the initial two weeks of monitoring.

5.6 Bulk Density

The initial dry bulk density values were highest in windrow CDA at 224 kg/m^3. The other windrows had values ranging from 156 kg/m^3 for windrow TMP to 170 kg/m^3 for windrow WCT (Figure 5.6). All windrows increased in dry bulk density values from the initial to final measurements.

Windrows WCT and TMP had an 8% increase in bulk density. Windrow CDL increased 11% while windrow CDA increased 15%. Windrow WTL had the largest increase with a 75% increase in bulk density.

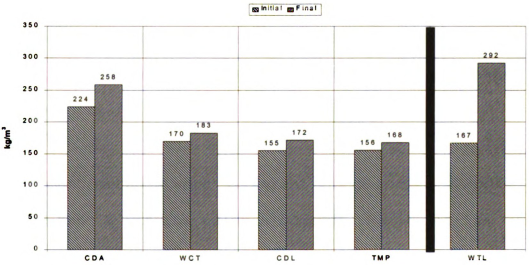

Figure 5.6: Windrow bulk density (dry) measurements at the beginning and end of the compost process.

There were no bulk density measurement techniques reported in the literature that could be utilized and adapted to an open windrow method of composting. Previously bulk density measurements have been taken either by core sampling (Tietjen and Banse 1961) or were taken by simulating compaction by packing a graduated cylinder with compost and dropping it from a known height with repeating action (Jackson and Line (1997). Neither of these techniques are sufficient in comparing the effects of using different turning mechanisms.

As expected, the windrow with the addition of a high clay soil initially had the highest level of bulk density. Bulk density increased in all the windrows with WCT and TMP increasing 8% while CDL and CDA increased 11% and 15%. The WTL windrow had an increase of 75% in bulk density. This large increase is not normal when compared to the other windrows.

Measurement methods were different for a loader turned windrow then a windrow using a compost turner and the results may not be comparable. A factor to consider is that the loader dropped larger particle sizes and increased compaction into the catch container upon impact.

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The likely reason for the outlying value is some of the composting pad made from gravel had been mixed into the compost windrow during turning with the tractor loader. Michel et al (1996) had similar problems with rocks introduced into compost samples from the turning mechanism.

If the final density measurement of WTL was not skewed due to debris in the density sample then it could be assumed the free air space of the windrow was quite small and there that would have caused a significant difference in moisture reduction from the other windrows. This did not seem to be the case. Therefore, it can be concluded the bulk density value was skewed by debris.

5.7 Windrow Total Dry Mass Change

Figure 5.7 shows mass reductions for the windrows turned with a compost turner ranged from 44.8% for CDA to 45.9% for TMP. Windrows WCT and CDL had reductions of 45.7% and 45.8% respectively. WTL had an increase in mass of 23.4%.

The increase in mass by the WTL windrow was a result of the increased final dry bulk density measurement of the windrow. The total mass was figured by multiplying the volume of the windrow by the bulk density. The skewed bulk density value lead to a skewed total mass value.

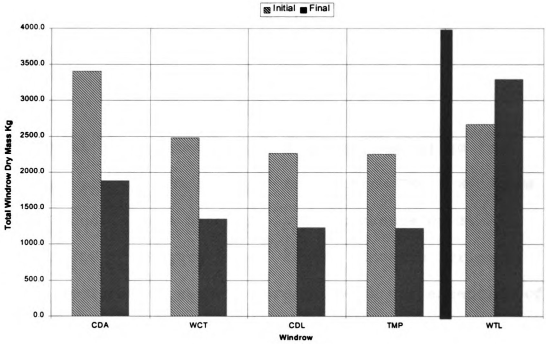

Figure 5.7: Total dry mass change during composting.

5.8 Chemical Tests

Sample variances in the chemical property results from within the same windrows were relatively high. Three sub-samples per windrow may not be enough to accurately characterize the material. The sub-samples were acquired from extensive sampling, however the amount of material that is used for the chemical tests does not always rep

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represent actual results of the windrow. The composting process is too dynamic for a full understanding from small quantities of materials used for the testing.

5.8.1 Windrow Carbon Content

The initial carbon contents of the windrows varied from 22.7% for windrow CDA to 37.9% for windrow TMP. Windrows WCT, WTL and CDL had starting carbon contents of 34.9%, 28.4% and 35.3% (Figure 5.8). Carbon contents for each windrow declined at each measurement with the exception of measurements taken on day 40 during which windrows CDA, WTL and CDL had slightly increasing values over the prior measurements.

All the windrows showed a reduction from the initial values to the ending measurements. Weekly turned windrows WCT and WTL had carbon content reductions of 46% and 48% during the composting process. Windrow CDL had a 35% reduction while windrow CDA and TMP had reduction values of 22% and 18%.

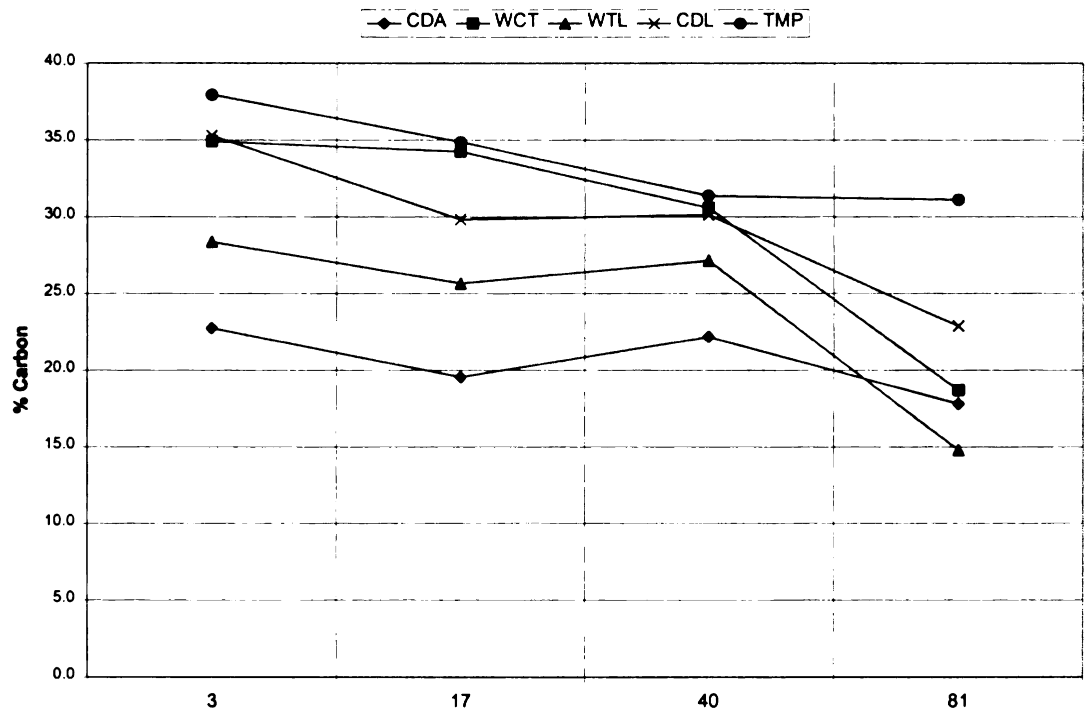

Figure 5.8: Changes in windrow carbon percentage during composting.

Carbon data showed considerable variations between windrows. This may be explained by the difficulty in getting a representative sample of the windrow in the early stages off the process due to the nature of the manure and straw mix. The sample size of 1 to 2 grams used by the lab may not represent the kilogram sub-sample taken in the field and an extra particle off sand or straw in the lab sample could hinder the results.

Windrow carbon reductions were greater during the final 40 days when comparing the mean reduction values for all the windrows. The mean carbon reductions during the initial 40 days were 10% while the final carbon reductions for the last 40 days was 25%. This may be explained by the temperature data presented in Figure 5.1.

During the initial 40 days the windrow temperatures were almost exclusively above 60° C. Wiley (1958), Snell (1960) and Finstein (1980) describe the optimal temperature range for maximum decomposition to be from 45° C to 55° C, depending on the author. After the windrow temperatures decreased below the 55° C it would be expected that more carbon is decomposed, which corresponds to the temperature range after day 40 in the data presented here.

The C/N ratios decreased more rapidly during the initial stages of the composting process while the carbon percentages decreased more rapidly during the final 40 days of the process. This indicates nitrogen retention occurred more prevalently during the early stages.

5.8.2 Windrow Nitrogen Content (TKN)

Windrow nitrogen content is expressed on a % dry matter basis, measured by the Total Kjehdal test. This test includes nitrogen in the organic and ammonia forms but does not include nitrate. The initial nitrogen content values ranged from 0.84% for CDA to 1.34% for windrow WCT. Windrows WTL, CDL and TMP had values of 0.93%, 1.15%, and 1.23% (Figure 5.9). The percent TKN increased through the first three measurements for all the windrows as the dry matter decreased. The last measurements, which were taken on December 81, showed a decrease in percent TKN from the previous values taken on day 40 for all the windrows with the exception of, windrow CDA.

Windrows CDA and CDL, which were turned according to the carbon dioxide level, increased in percent TKN by 48% and 52%. Windrows WTL and TMP increased by 31% and 33% while windrow WCT had only an increase of 10%.

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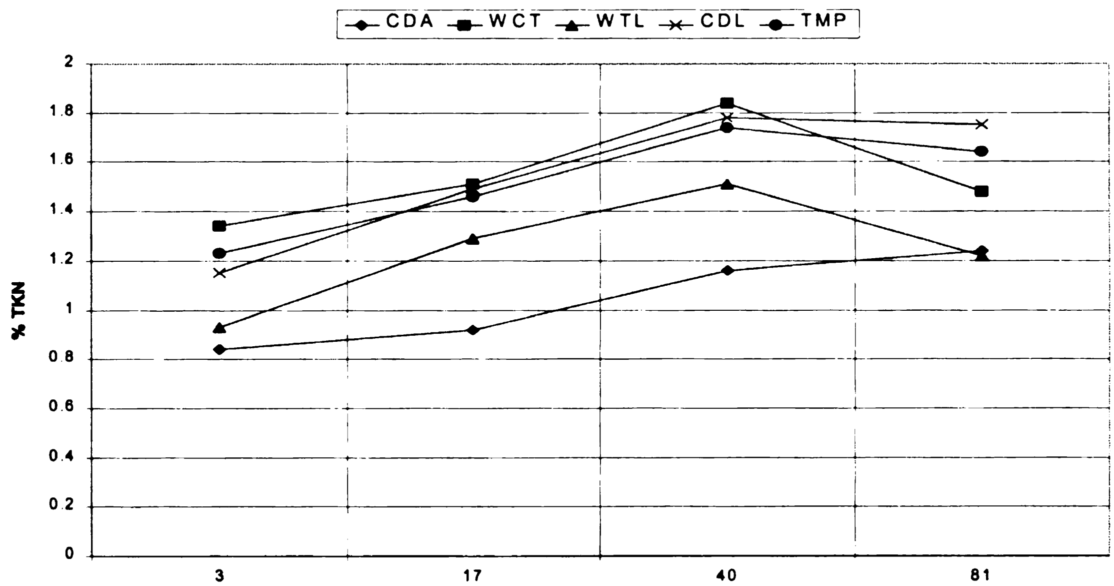

Figure 5.9: Changes in percent of Total Keldajl Nitrogen (TKN) in the compost windrows.

Figure 5.10 shows that except for windrow WTL, there was an overall reduction in the mass of nitrogen per windrow based on the TKN method from the start of the process to the end. Since the bulk density for the WTL windrow was quite high, the calculations for the mass of the windrow gave an increased value of dry mass; therefore, the percent of TKN nitrogen was skewed high. The nitrogen value for the WTL windrow would have approached that of the WCT windrow if the bulk density measurements were similar.

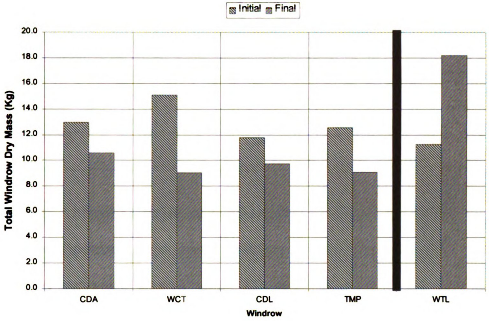

Figure 5.10: Windrow Dry Mass Nitrogen Totals based on % TKN

Hansen et al (1989) used the Taguchi method of data analysis on eight controllable composting factors and concluded that stirring frequency impacts nitrogen retention during the bench scale composting of poultry manure. Comparing the windrows turned with a compost turner Table 5.1 suggests that increased turning frequency in the early stages of composting resulted in less nitrogen loss based on dry mass calculation of % TKN. The CDL, CDA and TMP windrows required a greater number of turns in the early stages of the process when compared to WCT.

Table 5.1: Comparison of windrow turns and % TKN nitrogen loss on a dry mass basis.

Treatment	# of Turns	Nitrogen Loss
CDL	20	17.5%
CDA	24	18.5%
TMP	11	27.9%
WCT	12	40.0%

Nitrate nitrogen could not be added to the dry mass equations because the lab conducted the tests on a saturated extract basis with no way to correlate the results into a mass balance equation.

5.8.3 C/N Ratio

C/N ratio data is presented in Figure 5.11. At the start of the composting process the C/N ratios ranged from a value of 26.7 for windrow WCT to 31.0 for windrow TMP. The initial C/N ratios for all the windrows are generally within the range recommended for starting windrows subjected to intensive management.

Windrows WCT, WTL, and CDL had a final C/N ratio value at or near 13.0 and these windrows had similar C/N ratio reduction from 52% for windrow WCT to 57% and 58% for windrows WTL and CDL respectively. Windrow CDA had an ending value of 15 with a C/N ratio reduction of 44%. Windrow TMP had the highest ending value of 19.7, which corresponded to the lowest reduction in the C/N ratio of 37%.

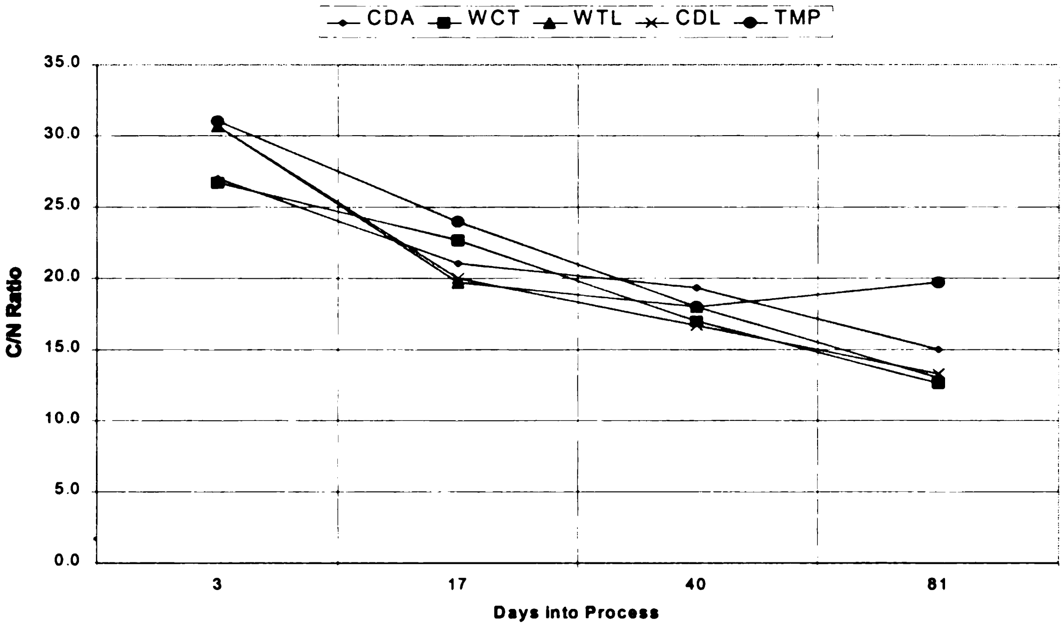

Figure 5.11: Changes in windrow C/N ratios during composting.

The initial C/N ratios for all the windrows were within the optimal range and were not significantly different (α=0.05) which indicates the ratio of manure and straw were equal between the windrows. The final C/N ratios also were not significantly different between the windrows.

The C/N ratios are the result of dividing the TKN values into the total carbon values. C/N ratio reductions were highest during the first two weeks of the composting process except for the WCT windrow. This rapid reduction indicates there is rapid biodegradation of carbon occurring, however, increasing nitrogen values were as important as the reduction in carbon values. For example, the WCT windrow had a C/N ratio reduction of 15% during the first two weeks but the carbon reduction was only 2% during the same time frame.

The TMP windrow had the highest ending C/N ratio and the lowest overall C/N ratio reduction. The low reduction is a result from the windrow not being mixed after the windrow temperature decreased below 65° C. If the windrow would have been turned after the temperature fell below 65° C the C/N ratio would have more closely matched the other windrows.

C/N ratio reductions ranged from 37% for TMP to 58% for CDL. These values correspond to values Lopez-Real and Baptisa (1996) found of 52% to 59% reduction during the composting of dairy manure and straw.

5.8.4 pH

pH values for the windrows were initially measured at 8.4 for windrow CDA, 8.6 for windrow WCT, 8.7 for windrow WTL, 8.4 for windrow CDL and 8.7 for windrow TMP (Figure 5.12). Fourteen days after the initial measurements were taken all the windrows except windrow CDA showed a decrease in the pH value. At the time of the third measurement on day 40 windrows WCT, WTL and CDL showed an increase in pH while windrow TMP stayed the same. Windrow CDA had a decrease in pH during this same time.

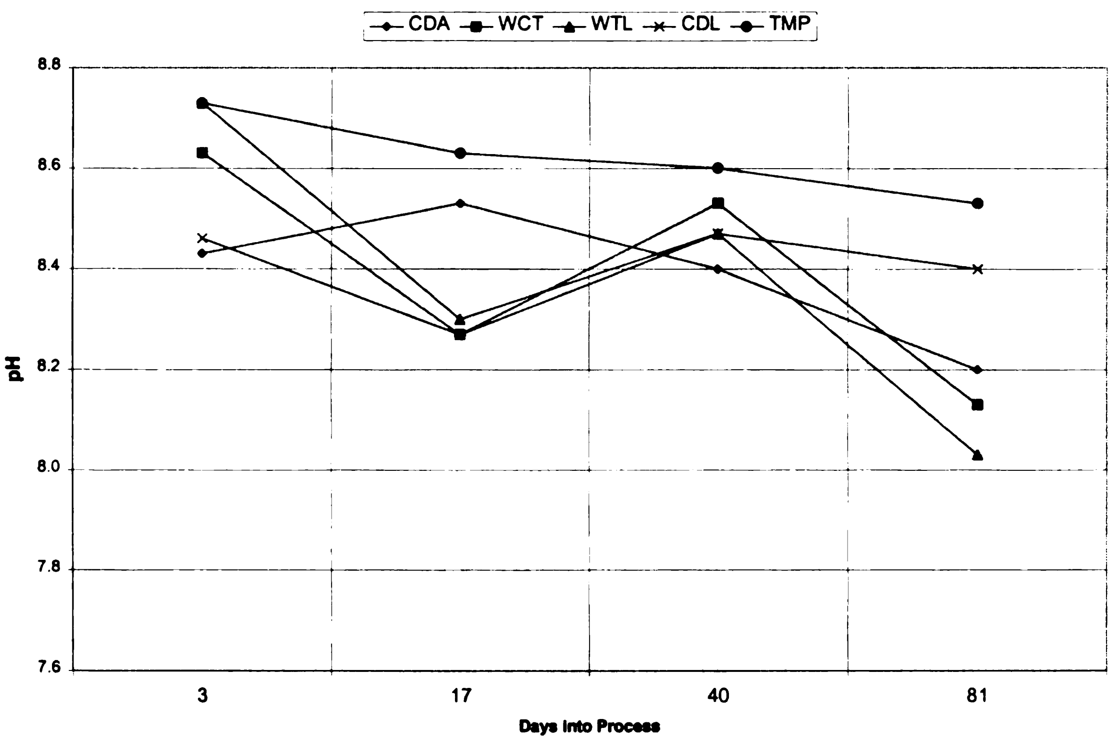

Figure 5.12: Changes to windrow pH during composting.

Final pH values taken on day 81 showed that all the windrows had decreased in pH from the initial value to the final values. Windrow CDA had a final pH of 8.2 while windrows WCT, WTL, CDL, and TMP had pH values of 8.1, 8.0, 8.4 and 8.5.

The pH mean values stayed close to the optimal range of 7.5 to 8.5 for maximum thermophilic composting as described by Jeris and Regan (1973). Each windrow had a decrease in pH by the end of the process with increased reduction occurring in the final 40 days of the process.

A decreasing pH indicates a production of organic acids (Miller et al 1991). The production of organic acids results from the humification of the compost. During the last 40 days there was a decrease in the pH values resulting from the build up of humus and indicates the compost became more stable.

The CDA windrow was the only windrow to have an increasing pH during the first two weeks of composting. A rise in pH could indicate ammonification, however, the pH only increased 0.1. Therefore, and it can not be said that the increase in pH is a definite result of ammonification. The addition of the clay soil may have caused the difference in pH but there are too many other factors at work to make a definite conclusion.

5.9 Germination Tests

Table 5.2 gives the results of the cress seed germination test. Distilled water was used as the control. Windrow WTL had the lowest germination at 56% of the control. Windrows CDL and TMP had germination values of 75% of control while windrows CDA and WCT had values of 89% and 84% respectively.

Table 5.2: Cress Seed Germination as a % of Control

Sample	% of Control
Windrow CDA	89
Windrow WCT	84
Windrow WTL	56
Windrow CDL	75
Windrow TMP	75
Bagged Top Soil	66

The germination test using sensitive watercress seeds is a measure of the phytotoxicity of the composts. The WTL windrow was the only windrow below the germination percentage of the bagged topsoil. The low germination percentage of the WTL windrow can not be explained from the chemical tests. The WTL windrow had the nearest neutral pH of all the windrows and the C/N ratio was not out of range from the other windrows, which had greater germination percentages.

The large clumps of substrate in the WTL windrow could cause poor germination. The clumps of substrate were not completely composted and could hinder germination of the watercress seeds. Additional tests would need to be performed to describe further the difference in phytotoxictity levels between the windrows.

5.10 Sieve Analysis

Cured compost samples were passed through a series of sieves with the percent rejections by weight of particles given in Figure 5.13. The WTL windrow had 20% rejects by weight at the 9.5mm sieve opening while the other windrows were fewer than 2%. The WTL windrow had 50% rejection at

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1.7mm while the other four windrows reached the 50% rejection level between 0.85mm and 0.60mm. Using a compost turner gave similar results of particle size rejection regardless of the windrow management scheme.

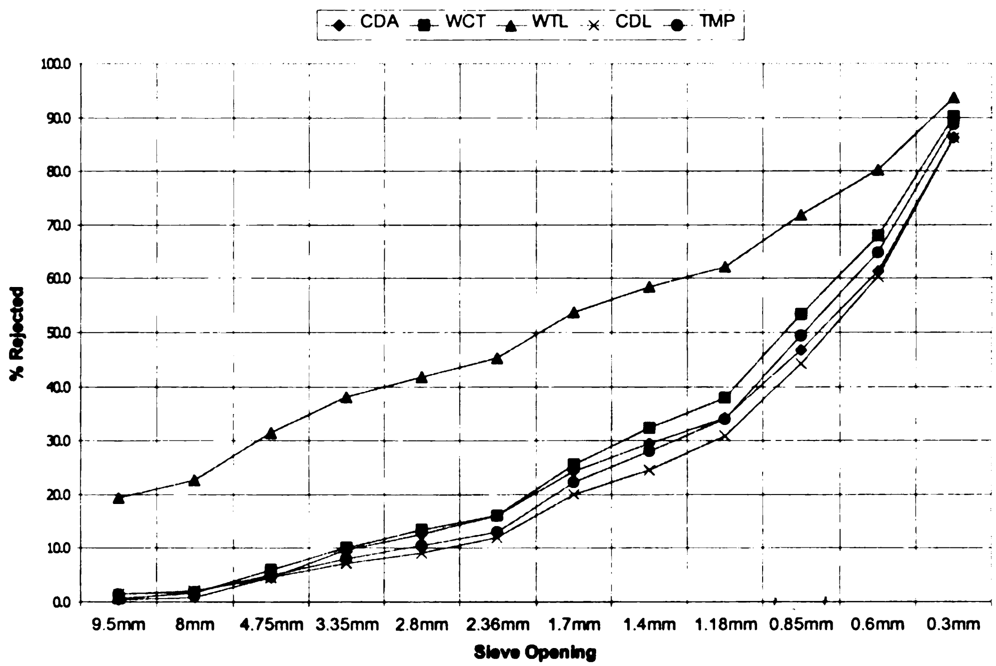

Figure 5.13: Percent Rejects from Sieving Cured Compost. Values are means of two samples per windrow.

The sieve analysis shows a distinct difference between managing a compost windrow with a compost turner and a tractor loader. The compost turner produced similar particle sizes regardless of whether the windrow was turned weekly or by temperature and carbon dioxide levels.

Even though the WTL windrow had greater percentages of larger particles, the compost would have been sufficient for a farm application however it may not have been suitable for use in a greenhouse or nursery container media.

The compost turner produced compost with suitable particle size for most applications. A compost turner is necessary if a consistent compost product is desirable.

5.11 Data Summary

Table 5.3 presents a summary of the results taken from the data presented. Values given have been rounded to the nearest whole number for ease in presentation. The asterisks in the WTL data indicate a different bulk density measurement method was used for the windrow, which affected the noted values.

Table 5.3: Data Summary

	CDA	WCT	WTL	CDL	TMP
Number of turns based on treatment indicator	24	12	12	20	11
Moisture Reduction	39%	29%	32%	30%	32%
Cross Sectional Area Reduction	30%	47%	27%	39%	35%
Bulk Density Change	+15%	+8%	*+75%	+11%	+8%
Total Dry Mass Change	-45%	-46%	*+23%	-46%	-45%
% Carbon Reduction	22%	46%	48%	35%	18%
Nitrogen change based on % TKN of Dry Mass	-19%	-40%	*+62%	-18%	-28%
C/N Ratio Reduction	44%	52%	58%	58%	37%
Watercress seed germination in finished compost (% of Distilled Water, used as control)	89%	84%	56%	75%	75%
50 % Rejection Level of Particle Size in millimeters	0.83	0.87	2.03	0.81	0.85

* May not be directly comparable because it is based on a different bulk density measurement technique.

Chapter 6

Conclusions

1. Dairy manure amended with straw can be successfully composted on a farm scale using various methods of management.

2. The addition of a high clay content soil showed a benefit in the germination study and also, based on carbon dioxide evolution and temperature levels in the latter stages of the process, kept the composting process more active.

3. Using carbon dioxide levels of 10% compared to using 65° C as the temperature threshold to initiate the turning of dairy manure compost windrows maintained higher temperature and carbon dioxide levels over a longer period of time and produced a product with greater nitrogen retention and lower phytotoxicity.

4. A compost turner produces smaller more uniform particle size and greater mass reduction of the windrow.

5. Regular turning of the compost windrows produced the best end product. Turning based on carbon dioxide produced the greatest nitrogen retention.

6. Using carbon dioxide as an indicator to time windrow turnings while having a minimum number of turns in a given time period is optimal.

Chapter 7

Further Research

1. A standard method to measure bulk density in compost windrows needs to be developed.

2. An optimal composting method needs to be developed to maximize nitrogen retention in animal manure composting.

3. Further research is needed to quantify variations in compost windrow sampling in relation to test lab methods so that a representative sample can be achieved.

4. Additional research using a high clay content amendment to dairy manure compost needs to be examined further to validate the beneficial results shown in this research.

5. Finding an optimum number of turns based on substrate utilization for a given time period during windrow composting dairy manure is needed.

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