DEVELOPMENT OF A COMPOSTING RECIPE FOR SWINE

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A Project Completed
for the
United States Department of Agriculture
Soil Conservation Service
Northeast NTC

INTRODUCTION

This project examined the use of aerobic composting as a method of biological treatment of swine manure. Golueke (1977) defines composting as "a method of solid waste management whereby the organic component of the solid waste stream is biologically decomposed under controlled conditions to a state in which it can be handled, stored, and/or applied to the land without adversely affecting the environment." Aerobic composting occurs when the decomposition takes place in the presence of oxygen, whereas anaerobic composting occurs in the absence of oxygen. Most of the previous research with swine manure looked at anaerobic decomposition and biogas production. Polprasert (1989) lists typical biogas composition as 5565% Methane, 35-45% Carbon dioxide, and the rest small amounts of nitrogen, hydrogen, and hydrogen sulfide. Many poorer countries depend on biogas as an alternative energy source to imported petroleum. This author also states, "The biogas can be used in small family units for cooking, heating, and lighting, and in large institutions for heating or power generation." Llabres-Luengo and Mata-Alvarez (1988) looked at the advantages of the mixture of swine manure and straw for higher methane yields.

Some research has been done with aerobic composting of swine manure, but with different objectives than this research project. Ginnivan looked at the effects of temperature (Ginnivan, Aerobic, 1983) and chemical pretreatment (Ginnivan, Effect, 1983) on the aerobic digestion of piggery wastes. Lau and Wu (1987) examined the usage of swine compost in landscaping, tree planting and market gardening application. Gonzalez (1989) looked at conservation of nitrogen and nitrogen compounds. Biddlestone (1986) researched composting of manure slurries with entire square bales of straw. These papers provide a look at a particular part of the composting process, and not an overall view.

Effective composting recipes and operational requirements are needed to promote broad acceptance of animal waste composting. The purpose of this study was to develop and document recipes and associated operational requirements for composting wastes from swine operations.

PROJECT OBJECTIVES

The project was undertaken with the following objectives:

1. To develop a compost recipe for swine waste on both a unit weight and volume basis. Recipes will be developed for raw waste production scraped from a solid finishing floor.

2. To determine initial swine waste characteristics and final compost characteristics.
3. To develop a technical document to include instructions on how to operate a swine waste composting system using the recipe(s) developed in Objective 1.

PROJECT METHODS

The project was undertaken as a laboratory, bench-scale study. Sufficient raw waste was not available, nor were sufficient funds available to support a prototype field study. Furthermore, it was necessary to conduct a number of preliminary tests to gain experience with how to best blend the waste materials, and at what mixtures they should be blended before conducting the main study.

Bench-scale Composters

Laboratory composters were developed from six-gallon plastic buckets with lids that could be fitted tightly or left loose (to allow air exchange with the outside environment). The sides and bottom of each bucket were covered with a layer of fiberglass insulation (R= 11). Composters were then placed on the building floor, separated from the floor with a sheet of 3/4-inch thick extruded polystyrene. When compost temperatures were not being measured, the tops of the composters were also covered with a layer of the fiberglass insulation. Because of the relatively small volume of the composters, the insulation was used to prevent excessive heat exchange with the outside environment, and to maintain heating of the compost due to biological activity. This approach allowed the relatively small mass of test material to be used (usually 3 to 5 gallons) to simulated conditions that might occur in the hot core of a typical composting windrow or pile.

Raw Materials for Composting

<u>Manure</u>

Fresh swine manure was obtained from production floors at the Virginia Tech Swine Center, and brought directly to the composting building for preparation. The swine manure, with its high moisture and nitrogen content, and its tendency to become quickly anaerobic, expanded quickly if stored overnight. Therefore, manure was collected immediately before mixtures were prepared for placement in the composters.

Because of the above problems, it was not possible to obtain manure analyses before composting mixtures were prepared. Therefore, preparation was based on swine manure values listed in Table 1.

<u>Carbon:Nitrogen Ratio</u>

The carbon:nitrogen ratio (C/N ratio) of raw swine manure is very low (Table 1). Studies and experience with composting have shown the typical optimum C/N ratio for aerobic composting to be in the range of 20:1 to 30:1. Therefore, it was necessary to select a source of carbon to combine with the raw swine manure to develop an optimum recipe.

Many sources of carbon might be considered for a farm scale composting operation. Sawdust or wood shavings could be mixed relatively easily. However, these materials are costly, and in short supply. Newspaper is receiving interest as a bedding material, but involves a handling and processing cost, and might tend to compact and hinder natural aeration. Straw is available on many farms as a by-product of small grain production, and might be more readily available than other carbon sources to a majority of farms. Therefore, straw was chosen as the carbon source in this study.

Table 1. Swine (Finisher) Fresh Manure Summary (1990)*

Moisture % (wb)	88.0
Volatile Solids % (db)	79.0
Fixed Solids % (db)	21.0
NH_3 % (db)	3.05
NO_3 % (db)	0.0145
TKN % (db)	5.00
P_2O_5 % (db)	4.17
K_2O % (db)	3.25
C % (db)	32.2
pH	7.5
C/N Ratio	6.45
E. Coli cols/100 grams	le7

*Based on data from Department of Biological and Agricultural Engineering, N. C. State University, Raleigh, N C.

Properties of Straw

Llabres-Luengo (1988) reported values of some properties of straw (Table 2). These data provided an estimate for initial composting mixtures.

Table 2. Properties of Wheat Straw

Moisture % (wb)	8.30
Volatile Solids % (db)	83.9
Fixed Solids % (db)	16.1
NH3 % (db)	-
NO3 % (db)	-
TKN % (db)	0.234
P % (db)	-
K % (db)	-
C % (db)	53.3
pH	1
C/N Ratio	227.9

Table 3. Values of Analysis for Straw Used in Study*

	Mean	Min.	Max.	Std. Dev.
Moisture % (wb)	9.86	9.09	11.3	0.905
Volatile Solids % (db)	95.3	94.2	96.2	0.730
Fixed Solids % (db)	4.72	3.77	5.78	0.730
NH_3 % (db)	0.0594	0.0430	0.0798	0.0115
NO_3 % (db)	0.00209	0.000719	0.00465	0.00138
TKN % (db)	1.04	0.735	1.38	0.223
P % (db)	0.467	0.384	0.585	0.0700
K % (db)	1.43	1.23	1.75	0.177
C % (db)	52.9	52.3	53.5	0.406
pH	6.77	5.40	8.00	0.883
C/N Ratio	53.1	38.0	72	11.7

*Plant species for source of straw could not be determined, but is probably oat straw

The straw used in this study was purchased in standard square bales from a local landscaping nursery. Due to the high moisture content of the manure, an effort was made to select bales which were as dry as possible (lighter weight than other bales and stored under cover). An effort was also made to select bales which had "cured" for a sufficient time to have a yellow, rather than a green color. Laboratory measurements showed that the greener the bale, the higher the nitrogen content thus causing more straw to be required to achieve a desired C/N ratio.

Properties of the straw were found to be more uniform than those of manure, so several samples were analyzed and a representative average was used for preparing all compost mixtures for a particular trial run. Table 3 shows the values determined in the laboratory for straw. Since small initial samples were used for each run (usually three samples were analyzed and averaged for each run). the table was compiled using straw values from all runs.

Comparisons of Straw Values

Figure 1 shows the difference between the straw properties reported in the literature and those found for the straw used in this project. The largest difference in properties is the TKN levels. The value found in straw used in this project was over 4 times as high as that found in the literature. Golueke (1977) lists the C/N value of wheat straw as 128-150 with 0.3-0.5 % nitrogen, while oat straw was reported to have a C/N ratio of 48 with 1.1 % nitrogen. These values tend to suggest that the straw used in this project was oat, rather than wheat straw. The amount of nitrogen in the straw is very important since it may radically influence the final C/N ratio of the compost mixture. Therefore, tests should be run on straw being used for developing a mix, or one must have knowledge of the type straw used.

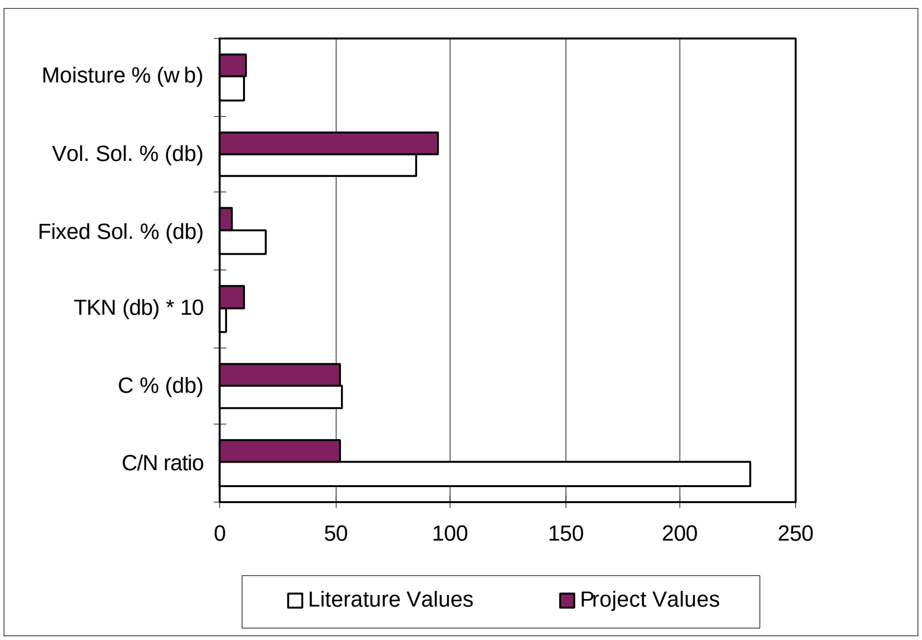

Figure 1. Physical and chemical properties of straw used in tests.

Compost Mixture Preparation

Field scale composting operations usually involve windrowing using machines or turning with front-end loaders, or static piles with forced aeration by pipes and blowers. Because of the small size of the laboratory scale composters, and the relatively small amount of manure used in each, it was deemed important to mix the straw and manure as well as possible to establish biological activity. At the same time, it was viewed as more practical in a field situation, especially on the farm, to build compost piles by layering straw and manure. Therefore, it was attempted to use both approaches with the bench-scale composters.

In spite of attempts to gain uniform mixing of manure-and straw, raw swine manure is characteristically sticky, and tended to form "balls" of straw and manure. Composters which were classified as "mixed" had this characteristic, but were only somewhat more uniform than those that were "layered".

Determination of Manure-Straw Mixtures

Initial target C/N ratios selected for test were 10:1, 15:1, 20:1, 25:1, and 30:1. Estimated values for manure and straw mentioned earlier were used to prepare compost mixtures.

Once the manure had been gathered in buckets from the swine facilities, it was mixed and stirred to uniform consistency. Larger feces were broken down into smaller pieces to allow better mixing with straw.

The straw was passed through and shredded three times with a 5 horsepower mulching and bagging chipper-shredder to break the longer pieces apart. The break-down of the straw into smaller pieces provided more surface area, and probably induced better composting action in the small bench-scale composters. Shredding also fluffed the straw, allowing better aeration and aerobic decomposition to occur. However, in a larger farm scale operation, shredding probably would not be necessary.

Sufficient straw was selected, without packing, to loosely fill the composter to approximately 2/3 full. The straw was weighed, and, based on Table 2, the amount of C and N it contained was calculated. Using the target C/N ratio, and the estimated manure C and N values from Table 1, the amount of manure needed for the target C/N ratio was calculated.

Samples of manure and straw were taken at the time of mixing for laboratory analysis. The analyses results from these samples were later used to re-check the C/N ratio for each composter. This explains the reason for why the C/N ratios shown in the test results do not correspond to those targeted. Although an idealized C/N ratio may be targeted, it will be unlikely to be obtained on a practical basis. On a farm scale basis, large quantities of manure and straw (or another carbon source) will be mixed together. Inherent variability due to manure and straw differences, density, moisture, and other factors will make the achievement of an exact C/N ratio very difficult.

Mixing of Composter Batches

Two methods were used to mix the manure and straw. One method was to minimize mixing, and to substitute layering of the straw and manure. Layers were placed as follows:

1) A bottom layer of half the straw
2) A second layer of half the manure
3) A third layer of half the straw
4) A top layer of half the manure

In field practice, more layers might be used. However, because of the relatively small amount of manure used in the bench-scale composters, it was not practical to separate the components into more layers in this study.

The second method attempted to provide more homogeneous mixing than the layering method. Targeted portions of straw and manure were placed in the composter, and hand mixed using a three-pronged hand gardening fork until a "homogeneous" mixture was obtained. This effort was not totally successful, and turned out to be fairly difficult. As mentioned earlier, swine manure tends to be sticky and forms "balls" when mixed with straw. Some of the batches mixed well (those with relatively large amounts of manure) while others balled up quickly (those with relatively low quantities of manure).

Water was added during the mixing process using a garden sprayer. Target moisture content was 55 to 70 percent. Mixtures with low C/N ratios were difficult to mix to specifications because a greater percentage of the total mix was manure, which contained considerable water. The manure tended to cause the total mixture to be too moist. Because the straw was very dry, some additional water was needed to wet the straw, and to encourage better incorporation with the manure.

In large scale composting, practical mixing with machinery will likely be somewhere between these levels of mixing. When straw and manure are initially mixed, they will tend be layered. As the windrows or piles are successively turned, re-aerated, and composted, the various components will become better mixed. Also the straw will become physically weaker as composting proceeds, partially eliminating the balling problem. More thorough mixing in preparation of the composting operation will probably aid the process to start more rapidly.

Preliminary Test Runs

Using the above procedures, preliminary test runs were conducted to become familiar with the composting process using the bench scale composters. The C/N ratios targeted were 10:1, 15:1, 20:1, 25:1, and 30:1. Based upon the test runs, the following observations were made, and were used in formulating the subsequent experimental runs:

1. The 10/1 mixture was too moist and non-responsive, showing no promise for aerobic composting. Therefore, this target C/N ratio was dropped from the experimental protocol.

2. Use of one pound of straw resulted in higher compost temperatures than those using a half pound of straw. Chandler (1990) stated that a minimum "critical mass" needed for maximum compost heating is a 3 ft.3 cube of compost". With the insulation around the composters, the preliminary tests indicated this critical mass will be less when an outer layer of compost is not needed to insulated the pile.

3. Water additions during the compost process did not result in higher compost temperatures. Since the composters were plastic, much of the moisture evaporated from the compost condensed on the lid of the composter and drained back into the compost. A field size unit would, no doubt, require additional water added at intervals as the generated heat will drive off moisture.

4. A simple moisture meter would have been helpful in monitoring compost pile water content. However, those meters found were not designed for conditions in this project. Hay and straw moisture meters are designed for much lower moisture content, and soil moisture meters are designed for materials with much higher bulk densities, rather than fluffed-up straw and manure mixtures.

5. The small amount of straw and manure composted took approximately 2 weeks until no significant temperature rise occurred upon turning and re-aeration.

6. Composters had similar composting temperatures regardless of whether they used tightly fitted or loosely fitted lids. Sufficient aeration was provided between turnings even when covered. This was important given the relatively small mass of the composting material, which made heat and moisture conservation very important for these tests.

7. Beef cattle manure was tested briefly to compare procedures using a manure that has received wider acceptance for composting. Swine manure responded better than the beef cattle manure when composted at similar C/N ratios in bench-scale composters.

8. Turning frequency was found to have a large impact on the heating curve of a given composter.

The above information developed in the preliminary test runs was used in planning the three experimental runs.

Experimental Test Runs

Laboratory analyses of manure and straw did not occur until after a compost test run was prepared and underway. It was necessary to initially rely on average literature values to calculate the C/N ratio and prepare composter mixes. Therefore, when actual C/N ratios were calculated after receiving laboratory results, the actual ratio in each composter varied slightly from the target. This point suggests the importance of remembering that the C/N ratio is only a target to attempt optimizing the combination of straw and manure. On a field scale, many gallons of manure and bales of straw would be mixed together. It is inevitably that variation of input materials will occur, and it will be difficult to accomplish an exact C/N ratio with each individual operation.

Since the 10/1 C/N ratio was unresponsive in the preliminary tests, only 15/1, 20/1, 25/1, and 30/1 targets were used in Experimental Run 1, with preparations based on the tabular values for straw and manure in Tables 1 and 2. Three replicates were prepared for each C/N ratio, and for both mixing methods (layered and hand-mixed). This resulted in 24 composters being used for the first experimental run.

Experimental Run 1 was allowed to compost until all 24 composters failed to return to the thermophilic zone (above 110 F°) after turning. This occurred on the 16th day. A 16 day test run was then adopted for the remaining Runs 2 and 3 to keep all trials on a comparable basis. Tables 6, 7, and 8 show the physical and chemical properties of the final product for each compost mixture.

Using the benefit of laboratory analyses from Experimental Run 1, C/N ratios and mixtures in Experimental Runs 2 and 3 were adjusted to reflect those laboratory values. In order that Runs 2 and 3 could be compared to Run 1, the target C/N ratios were also adjusted to 14/1, 16/1, 18/1, and 20/1. These ratios replaced the previous targets of 15/1, 20/1, 25/1, and 30/1. This departure was justified on the basis of falling performance of the higher C/N ratio, and the extreme difficulty of mixing the straw and manure in compostable mixtures at the higher C/N ratios. This might not be a problem in a large scale field composting operation. However, it was a major problem with the small volume composters of this study.

Tables 3, 4, and 5 show the mean values for each of the treatments for all three experimental runs. These values were compiled from the laboratory analyses for the straw and manure used in preparing the raw compost mixtures.

Table 3. Components of raw compost mixture, Run 1.

	Target C/N Ratio			
	15/1	15/1	20/1	20/1
Method of preparation	Layered	Mixed	Layered	Mixed
Moisture % (wb)	74.8	74.1	67.1	69.7
Volatile Solids % (db)	83.8	85.1	81.4	84.6
Fixed Solids % (db)	16.2	14.9	18.6	15.4
NH3 % (db)	1.14	1.29	0.727	0.948
NO3 % (db)	0.00181	0.00206	0.00123	0.00146
TKN % (db)	3.39	3.64	2.79	2.68
P % (db)	4.13	3.94	3.97	3.49
K % (db)	1.51	1.52	1.20	1.34
C % (db)	46.6	47.3	45.2	47.0
pH	6.66	6.66	6.47	6.58
Actual C/N Ratio	13.8	13.0	16.2	16.5
Weight (lbs)	9.88	9.88	6.50	6.50

	Target C/N Ratio			
	25/1	25/1	30/1	30/1
Method of preparation	Layered	Mixed	Layered	Mixed
Moisture % (wb)	65.0	66.1	62.8	61.2
Volatile Solids % (db)	84.4	86.1	87.5	87.1
Fixed Solids % (db)	15.6	13.9	12.5	12.9
NH_3 % (db)	0.704	0.761	0.652	0.629
NO_3 % (db)	0.00101	0.00113	0.00118	0.00103
TKN % (db)	2.67	2.75	2.65	2.40
P % (db)	3.35	3.74	3.15	3.12
K % (db)	1.28	1.33	1.25	1.25
C % (db)	46.9	47.8	48.6	48.4
pH	6.41	6.41	6.45	6.35
Actual C/N Ratio	17 5	17 5	18.4	20.2
Weight (lbs)	4.94	4.94	4.00	4.00

Table 4. Components of raw compost mixture, Run 2.

	Target C/N Ratio			
	14/1	14/1	16/1	16/1
Method of preparation	Layered	Mixed	Layered	Mixed
Moisture % (wb)	67.9	67.5	65.5	64.1
Volatile Solids % (db)	79.6	79.1	83.2	81.7
Fixed Solids % (db)	20.4	20.9	16.8	18.3
NH3 % (db)	0.601	0.642	0.738	0.536
NO3 % (db)	0.00109	0.000990	0.00119	0.00127
TKN % (db)	3.05	3.38	3.06	3.16
p % (db)	6.08	6.18	4.99	4.79
K % (db)	1.75	1.71	1.57	1.73
C % (db)	44.2	43.9	46.2	45.4
pH	6.69	6.59	6.66	6.66
Actual C/N Ratio	14.9	13.1	15.1	14.4
Weight (lbs)	8.56	8.56	6.13	6.13

	Target C/N Ratio			
	18/1	18/1	20/1	20/1
Method of preparation	Layered	Mixed	Layered	Mixed
Moisture % (wb)	62.2	62.4	58.9	59.5
Volatile Solids % (db)	84.7	84.1	85.7	85.4
Fixed Solids % (db)	15.3	15.9	14.3	14.6
NH_3 % (db)	0.580	0.572	0.498	0.492
NO_3 % (db)	0.00132	0.00120	0.00144	0.00122
TKN % (db)	2.67	2.69	2.63	2.45
P % (db)	4.59	4.70	3.97	4.07
K % (db)	1.55	1.58	1.40	1.56
C % (db)	47.1	46.8	47.6	47.4
pH	6.73	6.73	6.81	6.81
Actual C/N Ratio	17.7	17.4	18.2	19.4
Weight (lbs)	4.81	4.81	3.94	3.94

Table 5. Components of raw compost mixture, Run 3.

	Target C/N Ratio			
	14/1	14/1	16/1	16/1
Method of preparation	Layered	Mixed	Layered	Mixed
Moisture % (wb)	74.4	73.7	70.6	71.1
Volatile Solids % (db)	81.9	81.3	83.7	82.3
Fixed Solids % (db)	18.1	18.7	16.3	17.7
NH_3 % (db)	0.799	0.694	0.580	0.503
NO_3 % (db)	0.00277	0.00217	0.00273	0.00285
TKN % (db)	3.36	3.39	2.93	3.13
P % (db)	4.70	4.68	4.32	4.01
K % (db)	2.55	2.32	2.18	2.16
C % (db)	45.5	45.2	46.5	45.7
pH	6.75	6.75	6.73	6.73
Actual C/N Ratio	13.9	13.3	16.3	14.6
Weight (lbs)	8 56	8.56	6.13	6.13

	Target C/N Ratio			
	18/1	18/1	20/1	20/1
Method of preparation	Layered	Mixed	Layered	Mixed
Moisture % (wb)	67.9	67.0	63.9	63.9
Volatile Solids % (db)	85.5	85.3	87.0	86.9
Fixed Solids % (db)	14.5	14.7	13.0	13.1
NH_3 % (db)	0.492	0.419	0.415	0.395
NO_3 % (db)	0.00266	0.00261	0.00260	0.00259
TKN % (db)	2.63	2.63	2.57	2.57
P % (db)	3.53	3.58	3.18	3.21
K % (db)	2.29	1.89	1.93	1.79
C % (db)	47.5	47.4	48.3	48.3
pH	6.72	6.72	6.70	6.70
Actual C/N Ratio	18.5	18.0	18.9	19.0
Weight (lbs)	4.81	4 81	3.94	3.94

Composter Turning Frequency

Since mechanical aeration was not provided to the composters, it was necessary to turn the compost mass to provide aeration and restore compost activity. It had been planned to turn the composters when a significant decrease in pile temperature occurred. This was the approach taken in the first experimental run. However, during Run 1, it became evident that each composter, including those with the same C/N ratio and mixture, exhibited a variable behavior. Because of this variability, it became difficult to manage and make comparisons between all 24 composters. Furthermore, the layered composters did not initially heat as quickly as the mixed units. If composters were turned too early, their ability to heat to optimum levels was impaired. Differences in day to day ambient temperature also confounded comparisons; even though the insulation around the composters should have negated this effect, it was a concern. Therefore, different turning regimes were adopted for Runs 2 and 3.

Since experience with Run 1 showed that the best composting mixtures required turning on the fourth and fifth days, a four-day turning frequency was adopted for Run 2. This frequency allowed the composting mass to recover from the heat lost during the turning process.

Turning frequency was stretched even further with Run 3- It may be preferable in actual field operations to conduct specific operations, such as turning, only once a week. Therefore, composters in Run 3 were turned after seven days.

Temperature Measurements

Compost pile temperatures were taken daily throughout all test runs. Temperature is one of the best indications of compost biological activity. Golueke (1977) listed two temperature ranges where certain type organisms function. The optimum temperatures for mesophilic organisms is from about 50 degrees F up to 110 degrees F. Thermophilic organisms have optimum temperatures of 110 degrees F and higher. The importance of these two ranges is that all aerobic compost processes will migrate toward the thermophilic range if environmental conditions permit. This was one reason why preliminary test runs compared the initial base amount of straw at 0.5 and 1 pound. The half pound compost piles heated, but rarely got into the thermophilic region, whereas the one pound compost piles did heat into the thermophilic range.

Temperatures in each composter were measured daily with a digital thermometer, equipped with a 1 ft thermocouple probe. The probe was initially placed close to the bottom of the compost pile. Once the reading had stabilized, the probe was moved slowly higher in the pile. When the temperature began to decrease, the probe was left at the hottest position until the temperature stabilized. Usually this position was three to four inches from the top of the compost, and in the center of the composting material. This region of the compost mass probably had better aeration than lower regions, and enough material above to insulate and maintain high temperatures.

Daily temperatures where recorded for each individual composter as well as for ambient air temperature. While the composters were well insulated, this insulation did more to buffer the composting materials from day/night extremes than to totally negate effects of the surrounding air temperature. Figure 2 compares the temperature curve of three similar compost mixture, from the three experimental runs, and the corresponding ambient temperatures during those runs. Notice that the ambient air temperatures for Run 2 were higher than the other runs, but the compost temperatures for Run 2 were about the same as the others. Also notice the initial temperature peak and the smaller peaks afterward. These smaller peaks can be attributed to the characteristic temperature increases after compost turning.

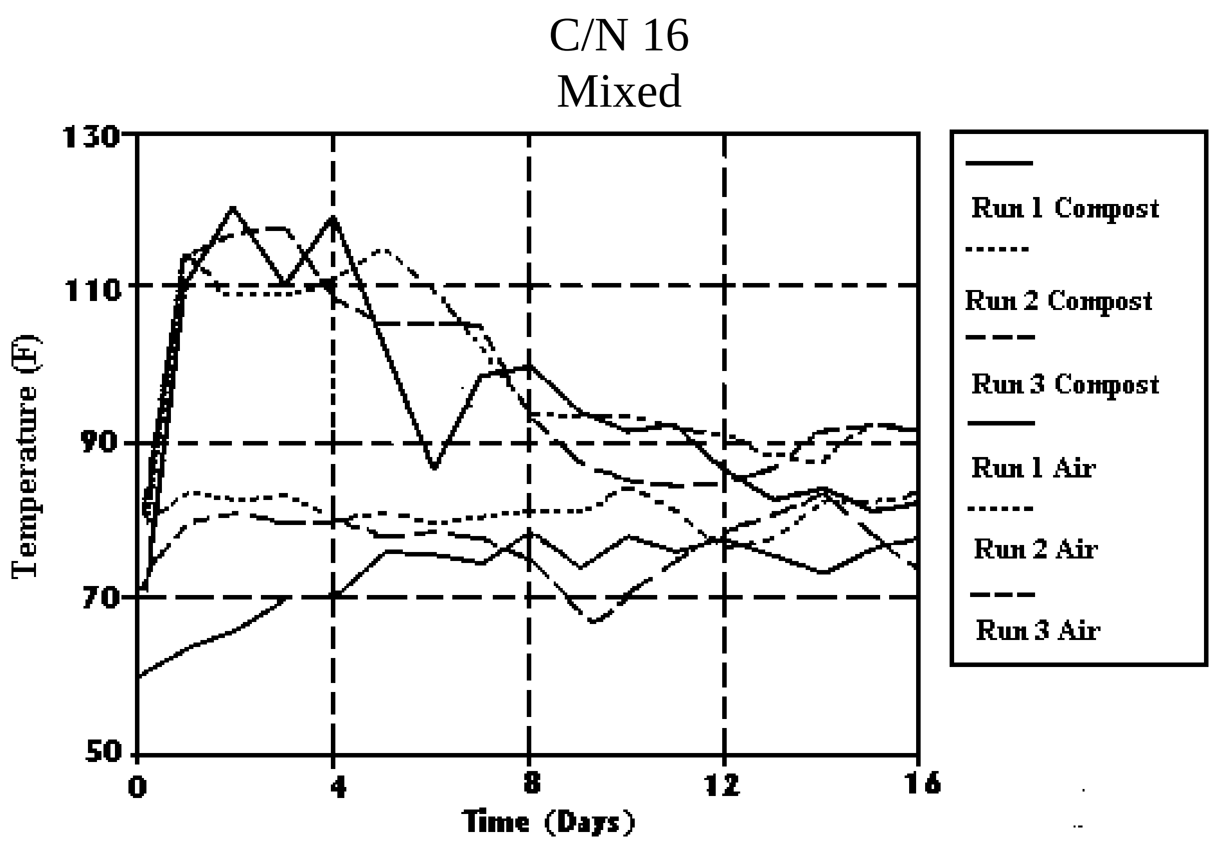

Figure 2 Mean ambient air and compost temperatures for experimental runs

Measurement of Methane Gas

The presence of methane in the composting mass is an indication of some degree of anaerobic activity within the compost pile. Experimental Run 3 was selected for measurement of methane levels, and to gain an appreciation for how well the composters approached the aerobic phase. In this project, methane was measured during the first temperature peak (day 3). By comparing methane amounts with air samples and the other composters, a “relative” amount of anaerobic composting can be determined. Those processes with lowest methane amounts were considered to be more aerobic and, thus, more desirable.

Gas samples were taken using a laboratory syringe attached to a thin rubber hose which was attached to a metal rod having several small holes at the end. The rod and hose were pushed into the compost pile, and the syringe plunger pulled out to gather the sample. The gas sample was then transferred through a hypodermic needle into an evacuated, rubber-capped test tube for pre-analysis storage. Analysis of the gas was made using gas chromatographic methods.

Laboratory Analysis of Manure, Straw, and Compost

All laboratory analyses, except as otherwise noted, were conducted according to Standard Methods (American Public Health Association). All laboratory tests listed below performed at the Virginia Tech Biological Systems Engineering Waste and Water Quality Laboratory except where noted.

Moisture Content

The moisture content was determined by comparing the weight of a sample before and after drying at 105 degrees C for 24 hours.

Volatile Solids and Fixed Solids

The sample dried above was then ashed at 550 degrees C until no significant weight loss occurred between successive ashing of a sample. The difference in weight before and after ashing is considered to be the weight of volatile solids (VS). The remaining material is defined as fixed solids (FS), or ash.

Carbon Content

The sample used for moisture content, volatile solids, and fixed solids determination was also used to estimate carbon content. Gotaas (1956) provided the following equation which is said to be accurate within 2-10 %:

$$\% \text{ Carbon} = (100 - \% \text{ ash}) / 1.8$$

The percent ash used in the equation is the same as the percent fixed solids on a dry basis. Use of more accurate methods for carbon determination was more costly, and a more accurate determination for carbon content was not available for the study.

Carbon/Nitrogen ratio was calculated after knowing the amount of carbon and total nitrogen in both the manure and straw being mixed.

Major Nutrients

NH_3, NO_3, and TKN were determined through extraction techniques. Total P and K were determined using perchloric acid digestion, followed by elemental analysis using an autoanalyzer at the Virginia Tech Soil Testing Laboratory. Determination of pH was done with pH sensitive paper to within a precision of 0.2 pH. When a sample did not have enough moisture to allow the paper to register a pH, an equal amount (volume basis) of deionized water was added to allow pH determination.

Pathogens

The pathogen indicator tested for in this study was E. Coli. Due to financial and time limitations, only Experimental Run 3 was tested for pathogens.

The technique used for pathogen analysis was the Nalgene Nutrient Pad Kit, Catalog No. 703-0001, for identifying E. Coli. This is a colorimetric technique through which colonies are identified by a characteristic green sheen.

Since the N.C. State literature (Table 1) indicated E. Coli concentrations around le7 colonies/100 g, this value was used as a target to establish the procedures for testing for E. Coli. Normally between 0-100 colonies are desired per petri dish. A problem encountered was the very high levels of colonies present in the raw manure and compost which made it impossible to read the colorimetric test. Therefore, the material being tested, whether raw manure or compost, was diluted so the number of colonies was reduced and relative value readings could be made. The following testing procedure was used:

1. 1 gram of material to be tested (manure or compost) was added to 100 ml of dilution water. This dilution water had been distilled and autoclaved to ensure no biological content.

2. The solution was agitated for fifteen minutes to uniformly mix the material through the dilution water.

3. 1 ml of this solution was diluted 20,000 times.

4. The final diluted solution was filtered and placed on the growth media.

5. After a day of growth, the number of colonies were counted.

Table 6. Run 1 Compost Analysis after 16-Day Processing.

	Target C/N Ratio			
	15/1	15/1	20/1	20/1
Method of preparation	Layered	Mixed	Layered	Mixed
Moisture % (wb)	74.8	75.0	67.3	72.3
Volatile Solids % (db)	76.9	79.9	80.3	79.5
Fixed Solids % (db)	23.1	20.1	19.7	20.5
NH_3 % (db)	1.28	1.56	0.997	1.22
NO_3 % (db)	0.00182	0.00158	0.000926	0.00111
TKN % (db)	4.42	5.00	3.51	4.25
P % (db)	5.41	5.67	5.05	5.50
K % (db)	1.99	1.98	1.77	2.02
C % (db)	42.7	44.4	44.6	44.1
pH	7.60	7.67	7.33	7.33
Ending C/N Ratio	9.86	9.04	12.8	10.59
Weight (lbs)	8.71	8.46	5.71	5.48

	Target C/N Ratio			
	25/1	25/1	30/1	30/1
Method of preparation	Layered	Mixed	Layered	Mixed
Moisture % (wb)	65.3	65.8	64.2	66.1
Volatile Solids % (db)	86.9	82.2	83.9	84.6
Fixed Solids % (db)	13.1	17.8	16.1	15.4
NH_3 % (db)	0.909	0.901	0.561	0.598
NO_3 % (db)	0.000851	0.000854	0.000689	0.00104
TKN % (db)	3.33	3.26	3.32	3.47
P % (db)	4.18	5.95	2.37	2.84
K % (db)	1.68	1.67	1.71	2.24
C % (db)	48.3	45.7	46.6	47.0
pH	7.13	7.13	7.20	7.13
Ending C/N Ratio	14.5	14.6	14.0	13.7
Weight (Ibs)	4.23	4.17	3.33	3.50

Table 7. Run 2 Compost Analysis after 16-Day Processing.

	Target C/N Ratio			
	14/1	14/1	16/1	16/1
Method of preparation	Layered	Mixed	Layered	Mixed
Moisture % (wb)	67.0	62.5	68.3	62.5
Volatile Solids % (db)	87.9	75.1	90.9	84.5
Fixed Solids % (db)	12.1	24.9	9.11	15.5
NH_3 % (db)	0.530	0.546	0.399	0.547
NO_3 % (db)	0.000984	0.000744	0.000549	0.0.000817
TKN % (db)	2.96	3.71	3.12	3.00
P % (db)	2.95	5.12	2.83	4.71
K % (db)	1.62	1.97	1.96	1.80
C % (db)	48.9	41.7	50.5	46.9
pH	7.33	7.33	7.20	7.40
Ending C/N Ratio	16.7	11.3	17.1	15.9
Weight (lbs)	7.29	6.96	5.15	5.06

	Target C/N Ratio			
	18/1	18/1	20/1	20/1
Method of preparation	Layered	Mixed	Layered	Mixed
Moisture % (wb)	71.8	56.9	51.3	43.3
Volatile Solids % (db)	91.3	80.2	87.9	87.0
Fixed Solids % (db)	8.72	19.8	12.1	13.0
NH_3 % (db)	0.255	0.169	0.194	0.0902
NO_3 % (db)	0.000734	0.000789	0.000887	0.00112
TKN % (db)	2.66	3.46	2.51	3.23
P % (db)	1.71	3.86	2.55	3.08
K % (db)	2.67	2.06	1.98	1.57
C % (db)	50 7	44.6	48.9	48.3
pH	7.73	7.40	7.13	7.20
Ending C/N Ratio	19.9	13.0	19.9	15.1
Weight (lbs)	3.92	3.50	3.02	2.88

Table 8. Run 3 Compost Analysis after 16-Day Processing[1]

	Target C/N Ratio			
	14/1	14/1	16/1	16/1
Method of preparation	Layered	Mixed	Layered	Mixed
Moisture % (wb)	76.0	74.8	71.5	72.7
Volatile Solids % (db)	80.7	75.3	82.5	80.3
Fixed Solids % (db)	19.4	24.7	17.5	19.7
NH_3 % (db)	0.398	0.369	0.399	0.315
NO_3 % (db)	0.00207	0.00213	0.00224	0.00226
TKN % (db)	4.29	3.69	4.22	3.54
P % (db)	5.88	5.21	5.68	5.68
K % (db)	1.06	1.33	1.46	1.67
C % (db)	44.8	41.8	45.8	44.6
pH	7.73	7.87	7.87	7.87
Final C/N Ratio	10.5	11.4	11.0	12.6
Weight (lbs)	7.73	7.40	5.35	5.15
E. Coli cols/100 grams	5.33e7	2.40e7	2.80e7	1.87e7

	Target C/N Ratio			
	18/1	18/1	20/1	20/1
Method of preparation	Layered	Mixed	Layered	Mixed
Moisture % (wb)	76.9	61.4	71.6	64.1
Volatile Solids % (db)	87.4	77.0	82.2	82.7
Fixed Solids % (db)	12.6	23.0	17.8	17.3
NH_3 % (db)	0.360	0.331	0.359	0.203
NO_3 % (db)	0.00198	0.00687	0.00219	0.0108
TKN % (db)	4.55	4.21	3.82	3.79
P % (db)	5 94	5.13	5.28	2.07
K % (db)	1.54	1.43	1.29	1.11
C % (db)	48.6	42.8	45.7	46.0
pH	7.67	7.67	7.80	7.73
C/N Ratio	10.7	10.2	12.6	12.2
Weight (lbs)	4.17	3.83	3.25	3.08
E. Coli cols/100 grams	2.20e7	2.33e7	4.20e7	4.50e7

[1]Includes pathogen testing results.

RESULTS AND DISCUSSION

A number of problems developed during the course of the study. These were not unexpected, but did necessitate changes during the course of the study. Some of the problems have been alluded to above, but will be restated as follows:

- The relatively small mass of the compost piles made it important that the containers be well-insulated to sustain the biological heating. Even so, the process of re-aeration (turning) was critical since some heat was lost from the pile. The expected pile temperature of 145-160 F° was never attained. However, consultation with other researchers who have experience with similar compost units indicated that the typical peak temperatures that we established of 125-130 F° were very good, and could be assumed to represent the kind of composting activity we wanted to achieve.

- Exact mixing to obtain the desired C/N ratio for each treatment was difficult. This was due to the highly variable nature of both manure and straw. Consequently, the C/N ratio could only be approximated.

- The difficulty of obtaining uniform mixing of manure and carbon source (straw) was not anticipated. This problem probably contributed to relatively slow composting activity of units at the higher (25/1 and 30/1) C/N ratios. Laboratory analysis following Experimental Run 1 showed that the 25/1 and 30/1 C/N ratios were actually 18/1 and 20/1. Because of lack of appreciable activity at the higher levels, additional composter treatments to reflect 25/1 and 30/1 ratios were not added since results to that point indicated they would be relatively inactive. It was also observed that the straw used was tough with a: gloss-like stem, and was probably initially resistant to breakdown by microorganisms. Therefore, although indicated a particular C:N ratio was attained, the actual effective ratio may have been somewhat higher.

Criteria for Recipe Evaluation

Criteria selected for evaluating recipe mixes included:

- Mixing method (mixed or layered)
- Carbon:Nitrogen ratio
- Turning frequency

The following sections discuss the criteria and the best mixture types, C/N ratios, and turning frequency. Performance is discussed in terms of temperatures achieved, weight loss, nitrogen loss, methane generated, and pathogen kill.

Temperature

Peaks and valleys in the temperature curves for each of the composters was highly variable. Therefore, it is difficult to compare the temperatures for each treatment on a day by day basis. Also, the higher air temperatures during the second run may have contributed to higher overall composter temperatures for Run 2. In order to compare all options on an equal basis, the difference between individual composter average temperature over a test run, and the average ambient air temperature over that run were compared. This average accounts for the difficulties mentioned above.

Temperature, as mentioned earlier, is a good indication of biological activity in the compost. Polprasert (1989) noted that as temperature increases (to the upper limit of 160 °F), the more likely the compost is to be of better quality (more decomposed). In addition, the higher temperatures will kill certain types of pathogens in the compost.

Table 9 shows the difference between the mean compost and mean air temperatures in degrees F. The first column shows the C/N Ratio and Mixture Type, such as 16 m for a C/N Ratio of 16/1 with the hand mixing method (layered method is labeled with an 'l'). Also, Run 1 C/N ratios are represented by their corresponding "actual" ratio.

Table 9. Mean difference between compost and air temperatures, °F.

C/N Ratio	Run 1	Run 2	Run 3	Avg	Rank
14 1	15.7	26.0	16.2	19.3	8
14 m	28.2	33.1	24.8	28.7	1
16 1	17.5	24.4	18.5	20.1	5
16 m	21.3	25.4	23.5	23.4	2
18 1	14.6	26.2	17.5	19.4	6
18 m	18.8	27.2	23.7	23.2	3
20 1	15.0	24.7	18.4	19.4	7
20 m	18.3	24.6	22.0	21.6	4
Avg	18.7	26.4	20.6	21.9	
Rank	3	1	2		

Note: These values are based on mean composter temperatures over the entire composting cycle.

Mean values in Table 9 are ranked 1 to 8 (1 = best) to aid in analysis. The best turning frequency is Run 2, which involved turning the compost pile every four days. Examination of the last column reveals that the hand-mixing method resulted in better performance in terms of higher composting temperatures. Finally, the best C/N ratio based on mean temperature rise was 14/l.

Compost Weight Loss

Another indicator of composter performance is the amount of weight loss during the process. Table 10 shows the percent weight loss of the final compost compared to the initial compost mixture.

Table 10. Percent Weight Loss of Compost Process[1]

Run 1

C/N Ratio	Initial	Final	
	(lbs)	(lbs)	% change
14 1	9.88	8.71	-11.81
14 m	9.88	8.46	-14.35
16 1	6.50	5.71	-12.18
16 m	6.50	5.48	-15.71
18 1	4.94	4.23	-14.35
18 m	4.94	4.17	-15.61
20 1	4.00	3.33	-16.67
20 m	4.00	3.50	-12.50

Run 2:

C/N Ratio			
141	8.56	7.29	-14.92
14 m	8.56	6.96	-18.73
16 1	6.13	5.15	-15.99
16 m	6.13	5.06	-17.35
181	4.81	3.92	-18.61
18 m	4.81	3.50	-27.27
20 1	3.94	3.02	-23.28
20 m	3.94	2.88	-26.98

Run 3:

C/N Ratio			
14 1	8.56	7.73	-9.73
14 m	8.56	7.40	-13.63
16 1	6.13	5.35	-12.59
16 m	6.13	5.15	-15.99
18 1	4.81	4.17	-13.42
18 m	4.81	3.83	-20.35
201	3.94	3.25	-17.46
20 m	3.94	3.08	-21.69

Table 10 (Continued)

Average for all runs C/N Ratio	Average Percent change	Rank		Average Percent Change	Rank
14 1	-12.15	8	Run 1	-14.13	3
14 m	-15.57	5	Run 2	-20.39	1
16 1	-13.58	7	Run 3	-15.61	2
16 m	-16.35	4			
18 1	-15.46	6			
18 m	-21.08	1			
20 1	-19.14	3			
20 m	-20.39	2			

[1] m = mixed raw compost; 1 = layered raw compost

Based on the above data, the best turning frequency was Run 2 with turning every four days. The hand-mixing method generally appeared to be superior to the layering technique, although the higher C/N ratios (18 and 20) showed more weight loss. Finally, the best C/N ratio based on the weight loss criteria is 18/1. The 18/1 hand-mixed method for Run 2 lost over a quarter of its mass during the composting process.

Nitrogen Loss

Direct land application of manure often is associated with a problem of excess nitrogen for disposal. The organic nitrogen in the manure is converted in the soil to plant available forms. Polprasert (1989) lists reactions where the nitrogen is first converted to ammonium, then is further converted to nitrite and nitrate forms. Brady (1990) says that, while plants require certain nitrate levels, excess nitrates can leach out of the soil into the ground water. In order to minimize the nitrate leaching, the compost added to the soil should have lower total nitrogen levels than the original manure.

Table 11 shows the percentage change of total nitrogen from the initial mixture to the final mixture. The results of nitrogen loss analysis is inconclusive. Negative percentages indicate laboratory tests found more nitrogen in the final sample than the initial sample, which, of course, should be an impossibility. This discrepancy may be due to variability of samples, laboratory error, and the relatively low levels of nitrogen present.

Run 2 appears, once again, to be the best turning frequency with turning every four days. The ranking method is inconclusive as to which is the better mixing method. The best two ratio types are layered, but are the higher ratios, which had small amounts of manure. As mentioned before, the variability of the samples and low amount of nitrogen tends to make this comparison less reliable. Finally, evaluation for the best C/N ratio is also inconclusive. The 18/1 layered method for Run 2 provided the best results, but neither of the other runs for this C/N ratio and mixture type showed positive nitrogen loss. The only conclusion that can be gleaned from this comparison is that Run 2 perhaps volatilize more nitrogen than the treatments.

Because of the discrepancies and inconsistencies in the nitrogen data, these results are not included in the overall performance rankings of the mixing methods and C:N ratios for the study.

Table 11. Percentage Change in Total Nitrogen in Finished Compost When Compared to Initial Mixture.

C/N Ratio[1]	Run 1	Run 2	Run 3	Avg	Rank
14 1	-30.5	2.77	-27.64	-18.45	1
14 m	-37.06	-9.90	-8.74	-18.57	2
16 1	-25.49	-1.83	-44.36	-23.89	5
16 m	-48.85	5.22	-13.07	-18.90	3
18 1	-24.68	0.27	-72.79	-32.40	6
18 m	-18.68	-28.53	-60.03	-35.75	7
20 1	-25.05	4.54	-48.49	-23.00	4
20 m	-44.65	-31.73	-48.12	-41.50	8
Avg	-31.87	-7.40	-40.40	-26.56	
Rank	2	1	3		

[1] m = mixed MW compost; 1 = layered raw compost

Methane Levels

As mentioned previously, methane levels contained within the compost pile provide an indication of anaerobic activity at some level within the pile. Low levels of methane indicate that the composting is relatively more aerobic than anaerobic.

Measurement of methane was not a part of the original study plan, but was later deemed useful as a part of the evaluation procedure. However, because of the expense involved, performance from the standpoint of methane level was only evaluated for Run 3. Table 12 shows the average amount of methane present in each treatment for Run 3. Concentration levels are ranked from least (1) to most (8).

Table 12. Methane Concentration within Compost Pile Treatments, Run 3.

C/N Ratio	Run 1	Rank
14 1	0.0255	7
14 m	0.00721	5
16 1	0.0306	8
16 m	0.00221	2
18 1	0.0164	6
18 m	0.00296	4
20 1	0.00263	3
20 m	0.00148	1
Avg	0.0111	

[1] m = mixed raw compost; 1 = layered raw compost

There is a clear indication that the composters which were hand-mixed produced less methane than those that were layered. The composters with the higher C/N ratios (20/1) produced the least methane, but contained less manure, and would have been expected to be less anaerobic in any case. The 16/1 C/N ratio also produced low methane levels, but piles were composting almost twice as much manure as those with the 20/1 C/N ratio. It can be concluded that the 16:1 C/N ratio performed best based on lower levels of methane gas produced.

Pathogen Destruction

Golueke (1977) noted that "one of the major advantages of composting wastes is the destruction of disease-causing organisms." Other methods of pathogen destruction are much more expensive, time consuming, and generally ineffective with large quantities of compost.

Table 13 shows the pathogen (E. Coli) level change for Experimental Run 3 (the only run with pathogen determination).

Table 13. Percentage Change in E. Coli Levels After Composting (Run 3~.

C:N Ratio	Initial cols/l00 g	Final cols/l00 g	% Change	Rank
14 1	4.239e+07	5.333e+07	25.80	8
14 m	4.239e+07	2.400e+07	-43.39	2
16 1	4.016e+07	2.800e+07	-30.28	5
16 m	4.016e+07	1.867e+07	-53.52	1
18 1	3.803e+07	2.200e+07	-42.14	3
18 m	3.803e+07	2.333e+07	-38.64	4
20 1	3.581e+07	4.200e+07	17.29	6
20 m	3.581e+07	4.500e+07	25.66	7

[1] Negative % change indicates a decrease in relative coliform indicator.

Total elimination of the indicator pathogens in the finished compost was not achieved in this study. This was probably due to the small size of the laboratory-scale composters. The final E. Coli results show reduction in the number of colonies in the test runs which achieved higher temperatures. However, while the small amount of materials composted did reach temperatures high enough to reduce organism levels, temperatures were usually not sustained more than one or two days, so not all indicators died. In addition, because the laboratory-scale composters were kept loosely covered, evaporated water condensed on the inside of the lids and on the side walls. After the initial temperature peak, the temperatures dipped to a level which, aided by the high moisture content, probably tended to allow organisms to re-grow in the condensed water and to re-inoculated the compost mass as it cooled.

In general, the hand-mixing method resulted in greater pathogen decline. The best C/N ratio was 16/1. This ratio had over half of the pathogens killed during the composting process. Haug (1980) states that higher temperatures for a few days, or lower temperatures for a longer period of time, can result in pathogen inactivation and death. As shown earlier, the 16/1 C/N ratio was also one of the best in this study for achieving higher composting temperatures.

Evaluation of Criteria

All of the criteria used to determine the optimum mixing method, C/N ratio, and turning frequency are interrelated. Higher temperatures result in larger pathogen decline. Nitrogen losses depend partially upon the turning frequency, which can in turn affect temperature increases, aeration, and biological activity. Depending upon the end use of the compost, each of these criteria may be more or less important. However, to evaluate between the various methods, all the criteria were considered to be of equal weight. Tables 14, 15, and 16 show the mean ranking for turning frequency, mixing method, and C/N ratio. The ranks for methane and pathogens were only used for C/N ratio and mixing method.

Table 14. Average Performance Rank for Turning Frequency.

Experimental Run	Temp	Wght	N	Avg	Mean Rank
Run 1	3	3	2	2.67	3
Run 2	1	1	1	1.00	1
Run 3	2	2	3	2.33	2

Table 14 suggests that Run 2, with turning every four days, offered the best performance based on all five criteria used. During the experimental runs, Run 2 heated faster and recovered from turning better than Runs 1 and 3.

Table 15. Average Performance Rank for Each Mixing Method.

Preparation Method	Temp	Wght	N	Meth	E.C.	Avg.	Mean Ranking
Layered	6.5	6	3.5	6	5.5	5.5	2
Hand-Mixed	2.5	3	5.5	3	3.5	3.5	1

The hand-mixed preparation of compost offered the best performance. While the layered mixes performed well in a few cases, the hand-mixed composters performed best overall. During the initial test runs, the layered compost did not initially heat as well as those that were hand-mixed. However, once the layered compost piles were turned, heating improved but did approach the peaks achieved with the hand-mixed piles.

Table 16. Average Performance Rank for Carbon/Nitrogen Ratio.

C/N Ratio and Mixture Type	Temp	Wght	Meth	E.C.	Avg.	Mean Rank
14 1	8	8	7	8	7.2	8
14 m	1	5	5	2	3.4	3
16 1	5	7	8	5	6.2	7
16 m	2	4	2	1	2.4	1
18 1	6	6	6	3	4.4	6
18 m	3	1	4	4	3.8	2
20 1	7	3	3	6	4.2	5
20 m	4	2	1	7	4.4	4

The 16/1 C/N ratio, based on the evaluation criteria, offered the best overall performance. During the test runs, the 16/1 ratio composters tended to achieve the hottest temperatures. This mixture had a balance of manure and straw which still allowed good aeration, while having enough manure nitrogen to allow a high level of bacterial activity and, consequently, excellent heating. The other C/N ratios where either too moist (14/1), which prevented good aeration, or had such small amounts of manure (20/1) that after initial heating the nitrogen supply was so low that composting activity could not recover after turning.

The mixed composters rated better in overall performance rank than the layered composters. Under conditions of a full scale field operation, after several windrow turns, it is possible that layered piles would began to become better mixed and perform equivalently to fully mixed piles. Mixtures which were mixed before placing in the windrow may be difficult to justify in field practice.

The analysis of the finished compost for the 16/1 C/N composters is shown in Table 17.

Table 17. Analysis Results for 16/1 C/N Ratio, Hand-mixed, Turned Every 4 Days.

	Mean	Min.	Max.	Std. Dev.
Moisture % (wb)	65.5	60.3	65.7	2.82
Volatile Solids % (db)	84.5	83.4	85.1	0.92
Fixed Solids % (db)	15.5	14.9	16.6	0.92
NH3 % (db)	0.55	0.47	0.65	0.09
NO3 % (db)	0.817e-3	0.607e-3	0.117e-2	0.305e-3
TKN % (db)	3.00	2.52	3.49	0.48
P % (db)	4.71	3.90	5.38	0.75
K % (db)	1.80	1.76	1.84	0.04
C % (db)	46.9	46.3	47.3	0.51
pH	7.40	7.20	7.60	0.20
C/N Ratio	15.9	13.5	18.37	2.43

RECOMMENDATIONS FOR PLANNING SWINE MANURE COMPOSTING OPERATIONS

A successful on-farm composting operation will depend upon establishment and maintenance of key conditions that encourage the growth of aerobic microorganisms. These conditions include:

- Appropriately mixed manure or other organic materials needed for the growth and activity of the microorganisms, with a key ingredient being a balanced supply of carbon and nitrogen (C:N ratio)
- Maintaining oxygen at levels to support aerobic microorganisms
- Moisture suitable to support biological activity without hindering good aeration
- Ability to develop and maintain temperatures that encourage vigorous activity from thermophilic microorganisms

An excellent discussion is provided by Rynk, et. al. (1992) on all aspects of farm composting, including technical and economic data on equipment, raw materials, and troubleshooting. Some of the important considerations are presented in the following discussion.

Development of Composting Mixture

Although trial and error will be involved in development of a composting operation, the practitioner will be well served by trying to achieve a target mix recipe at the outset. Proportions of manure and a carbon source, such as straw, will need to be adjusted to a desired C:N ratio and for a workable moisture content. If the mixture is too wet, anaerobic conditions may develop causing high odors and poor performance. Additional dry material will need to be added to bring the moisture level back to an acceptable point. If the mixture is too dry, composting activity will be slow, or perhaps non-existent. Moisture will need to be slowly added along with turning and mixing to re-establish composting activity. The best C:N ratios for the bench scale study discussed in this report were 16:1 and 18:1. However, in a larger field scale operation, it may be found that higher C:N ratios may work as well, or even better. Reports in the literature suggest that composting of many materials work well between C:N ratios of 20:1 and 30:1, with lower ratios tending to release more ammonia gas. Development of a composting operation using raw swine waste will likely be difficult due to the sticky nature of the waste material. Based on the results of this study, a C:N ratio of between 16:1 to 18:1 should work well.

Manure should be tested if possible to determine the total nitrogen and carbon content. If possible, the straw or other carbonaceous material to be used in the recipe should also be tested. If this is not feasible, tabular values can be used (Table 1 and Table 2). If carbon content is not available from test results, and total ash content (fixed solids, db) can be determined by test or from the literature, % carbon can be estimated from the following empirical relationship:

$$\%\ \text{Carbon} = \frac{100\ -\ \%\text{Ash}}{1.8}$$

The following equations may be used to balance a compostable mixture:

$$\text{Moisture content} = \frac{\text{weight of water in ingredient a + water in ingredient b}}{\text{total weight of all ingredients}}$$

where,

$$\text{C:N Ratio} = \frac{[\%C_a \times a \times (1 - m_a)] + [\%C_b \times b \times (1 - m_b)]}{[\%N_a \times a \times (1\ m_a)] + [\%N_b \times b \times (1 - m_b)]}$$

a = total weight of ingredient a
b = total weight of ingredient b
m_a = moisture content of ingredient a

m_b = moisture content of ingredient b
% N_a and N_b = %Nitrogen of ingredients a and b (% of dry weight)
% C_a and C_b = %carbon content of ingredients a and b (% of dry weight)

EXAMPLE:

A farmer would like to compose raw swine feces. The manure typically has a moisture content of 88 percent, and a total nitrogen content of 5 percent (db). Carbon content of the manure is 32.2 percent (db), with a C:N ratio of 6.45. In order to develop a compostable mixture, the farmer must develop a mixture of manure and wheat straw with a C:N ratio of 18:1. The straw chosen has a nitrogen content of 1 percent (db), a moisture content of 10 percent, and a carbon content of 53 percent (db). C:N ratio of the straw is 53. What is an appropriate trial mix to achieve the desired C:N ratio? An appropriate moisture content of 60%?

<u>Mix based on blending materials to the desired C:N ratio:</u>

Weight of water = total weight x moisture content

Weight of dry matter = total weight - weight of water
Weight of nitrogen = weight of dry matter x [%N x 0.01]
Weight of carbon = C:N ratio x weight of N

1 pound of wet manure contains:

Water	1 lb. x 0.88 = 0.88 lbs.
Dry matter	1 lb. - 0.88 = 0.12 lbs
N	0.12 x 0.05 = 0.006 lbs.
C	0.006 x 6.45 = 0.0387 lbs.

1 pound of straw contains:

Water	1 lb. x 0.10 = 0.10 lbs.
Dry matter	1 lb. - 0.10 = 0.90 lbs.
N	0.90 x 0.01 = 0.009 lbs.
C	0.009 x 53 = 0.477 lbs.

The desired C:N ratio is 18:1. For one pound of wet manure,

$$C:N = \frac{(\text{C in 1 pound of manure}) + S \times (\text{C in 1 pound of straw})}{(\text{N in 1 pound of manure}) + S \times (\text{N in 1 pound of straw})}$$

where S is the amount of straw needed per pound of raw manure.

$$18 = \frac{0.0387 + S(0.477)}{0.006 + S(0.009)}$$

S = 0.22 *pounds of straw per pound of manure.*

Checking the moisture content of the mix,

$$MC = \frac{\text{(weight of water in 1 pound of manure) + (weight of water in 1 pound of straw)}}{\text{total weight}}$$

$$MC = \frac{0\ 88 + 0.22(0.10)}{1 + 0.22}$$

= 0.74 = 74 percent moisture content

The moisture content is a little high for a starting mix. Options that might be considered for improvement are to mix a little more straw in the mix and settle for a higher C:N ratio; add another type of dry material to the mix; initially turn the mix more frequently to try and obtain faster drying with the initial lower heat; or switch to a carbon source that is dryer than the straw.

Mix based on blending materials to the desired moisture content:

Using the previous example, estimate the amount of straw that will be need to be added to the swine manure to obtain the target moisture content of 60%.

For 1 pound of wet manure:

$$\text{Moisture content (MC)} = \frac{\text{weight of water in manure + weight of water in straw total weight}}{\text{total weight}}$$

MC = 60% = 0 60 = $\underline{0.88 + (0.10 \times S)}$

where,

S = amount of straw needed per pound of wet manure
MC = 0.60 + 0.60S = 0.88 + 0.10S
0.5S = 0.22
S = 0.44 pounds of straw per pound of manure

Checking the C:N ratio:

$$C:N = \frac{C_{manure} + C_{straw}}{N_{manure} + Nstraw}$$

$$= \frac{0.0387 + (0.44 \times 0.477)}{0.006 + (0.44 \times 0.009)}$$

$$= \frac{0.24858}{0.00996}$$

$$= 25$$

Since this is a larger C:N ratio than was desired, the amount of straw may be reduced to lower the C:N ratio.

Composting Methods

Windrow Systems

A popular method of composting large amounts of organic waste materials is the windrow arrangement. Windrows are piles of materials placed in long rows which are agitated or turned on a regular basis. Depending on the materials being composting, the piles can be made from 3 feet high for more dense materials such as manure, to 12 feet high for more fluffy materials. The height chosen is related to the tendency for the windrow to compact due to its weight and thereby hinder air movement through the windrow. A heavy mix will likely require a lower height, and a light fluffy mix may tolerate a higher windrow. On the other hand, smaller windrows do not have the mass and volume to hold heat and may not achieve temperatures to evaporate moisture and kill pathogens and weed seeds.

Windrow width may vary from 10 to 20 feet. Actual width is related to the height chosen, the angle of repose of the mix, and to the equipment used to handle the compost mixture. The equipment which will be used to build the windrows and turn the piles will largely determine the size, shape, and spacing of the windrows.

Two criteria are suggested for windrow turning. The first is temperature based turning (such as used in Run 1 of the study reported here). The second criterion is frequent planned turning (such as used in Run 2 and 3). In practice, the frequency of turning will depend on the rate of decomposition, the moisture content, and the porosity of the composting mixture. The decomposition is greatest at the start of the process, so turning frequency is also greatest at that stage in order to maintain high aeration to sustain the process. As the composting process proceeds, frequency of turning may be reduced as the windrow ages. The size of windrows should be noticeably reduced as the compost process proceeds. It may then be prudent to combine two windrows into a single windrow during the turning process. This consolidation process will enable the compost to better retain and hold heat to sustain more complete stabilization.

Flies may be attracted to the compost mixture at certain seasons, especially in the early stages of the process. During such periods, the windrows should be turned once each 4 to 7 days, depending upon the prevalent fly species, regardless of pile temperature.

Windrow temperatures should be monitored throughout the composting process. Long-stemmed dial thermometers are available, or electronic thermocouple thermometers may be adapted for this purpose. Measurements should be taken at approximately 40 foot intervals along the windrow. When low temperatures or objectionable odors are noted, they may signal the need for aeration. When the average temperature drops below about 120°F, the windrow should be turned. If large drops over a 4 or 5 day period occur, they may also signal the need for turning.

The windrow may also gain too much heat. If the pile temperature gets above 140°F, the windrow should be turned to maintain an optimum environment for all thermophilic microorganisms to be present and function. If temperatures cannot be kept below this threshold by turning, the windrow size is probably too large and should be reduced.

The windrow method of composting will actively compost for three to nine weeks, depending upon the composting mixture and the frequency of turning. More rapid composting may generally be accomplished by turning the compost once or twice per day during the first week of processing, and every 3 to 5 days thereafter.

Forced Aeration

An effective, but more expense method of composting organic waste is forced aeration which incorporates a network of perforated pipes beneath the windrows. This method allows direct control of the process through regulation of air movement through the windrow and permits larger windrows to be formed. Once the windrow is formed, and if the air supply is properly designed and installed, the process should be completed in three to five weeks.

Air is forced through the windrows by high pressure fans which either apply pressure to the pipes (positive pressure system) or apply a vacuum (negative pressure system) within the windrow or pile. Air movement is generally controlled by intermittent timer or thermostatic control of fans. The forced aeration method of composting has relatively large start-up costs. Energy costs for operating the fans is off-set by reduction in windrow turning labor and associated costs. Savings accrue in the form of reduced composting area requirements, rapid composting time, and potential reduction of odors.

Forced aeration systems planning and design is discussed in detail by Rynk (1992).

Composting Site Development

Farm composting operations rarely require site space for more than storing and mixing raw materials, windrow or pile formation, curing of mature compost, and storage of finished compost. *The Virginia Yardwaste Management Manual* (1990) suggests one acre of site for each 4,000 to

5,000 cubic yards of organic material being composted. Suggestions are also made for dividing the site into the following areas:

1) Staging Area—This area is used to unload the raw composting materials, and for preparing the various compost mixes. (Mixing may also be done on the windrowing site, depending upon the methods and equipment used in the operation). The size of this area will depend upon the volume of materials being composted and the equipment used to mix materials.

2) Windrowing Area—This area should be on a gently sloping, well drained site. The windrows should be aligned up and down the slope. Soils in the windrow area should provide good protection for groundwater, but also provide good trafficability for equipment and not subject to erosion in the work alleys between windrows. Depending upon the amounts of leachate generated from the compost, a water collection system may need to be established, including runoff retention ponds. Most of the area allotted for composting will be required by the windrows.

3) Curing and Storage Area—This area will normally be adjacent to the windrowing area, and will be where mature compost is processed (shredded, dried, etc.) and stored. If the compost will be immediately moved to other locations upon completion of composting (field application, off-farm sales), this area may not be required.

4) Buffer Zone—Usually this is a 100 to 500 foot perimeter around the composting area. Depending upon the land use of adjacent sites (agricultural, residential, industrial) this zone may be larger on smaller. Odors, dust, and other aspects of the enterprise that may develop from time to time may require a large buffer zone.

5) Environmental Considerations Many states have regulations concerning composting sites to ensure the site does not adversely affect surface and groundwater. Local government agencies should be able to provide information to address this conncern.

Machinery Required

A front-end loader or bucket for a tractor is the workhorse for most farm composting operations. Most of the composting operations, such as mixing, compost pile or windrow formation, and turning, can be performed by these versatile machines. A buck wall in the handling areas will assist the use of this equipment.

If the composting site is remote from the mixing area, a dump truck or dump wagon is useful for transporting compost mix to the site and building the windrow or pile. Manure spreaders can sometimes be useful for both mixing and windrow building. Care must be taken to place alternate amounts of manure and other ingredient into the spreader to encourage rough mixing.

Batch livestock feed mixers have been successful in mixing manure and ingredients for composting. Some companies market modified feed mixers specifically for composting operations. Specialized equipment is also available for the serious composter. Rotary drum mixers are available which are designed specifically for composting operations.

Other specialized equipment is available if composting is to become a major effort on the farm. Screening equipment of various designs is available to remove unwanted materials, such as rocks and bottles, from the raw waste stream. Trommel screens, shaker screens, and vibrating screens are examples of equipment available to separate particles of various sizes from the processed compost, or to remove bulking materials such as wood chips from the processed compost for reuse in a future composting process.

For some operations, windrow turning can become time consuming and expensive using a front end loader. Larger operations may need to invest in one of the specialized machines for turning windrows. The least expensive of these machines attach to large farm tractors, and rely on the PTO for powering the machine. Others have a self-contained engine for powering the turning machinery. The most expensive machines are totally self-driven for both propulsion and turning.

The amount of equipment needed for composting depends on the size of the operation, the frequency of turning, amount of time allowed for labor, and the final market involved.

RECOMMENDATIONS

Based on the results of this study, the best combination of straw and raw swine finisher manure for composting was a C/N ratio of 16/1 (5.125 lbs of fresh manure per 1.0 lbs of dry straw). Manure should be well mixed with straw to prevent, as much as possible, the separation of clumps of "balled" straw and manure. Otherwise, composting will be slow in being established. While maintenance of moisture levels in compost piles was not a major effort in the study described here, due to condensation in the composter buckets and rewetting of compost, it will likely require attention in field scale programs. During turning operations, moisture level should be checked, and water sprayed on the pile during turning, to maintain moisture content at 50-70 percent. In addition, pile temperature should be monitored, and turning should be accomplished as internal pile temperature peaks. Normally this will be expected to occur at 4 day intervals. Continue turning of compost piles until re-heating no longer occurs.

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