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# Dead Bird Composting

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## I. INTRODUCTION

Composting has been demonstrated to be an environmentally sound, inexpensive method of processing poultry mortalities for disposal on land. Although composting does not dispose of mortalities, the process biologically transforms the mortalities into material that is amenable to land spreading for final disposal. To facilitate composting, the mortalities are combined with poultry litter, a carbon source such as wood chips, straw or peanut hulls, and water to achieve about 40% moisture in the total combined materials. The recommended procedure for composting poultry mortalities is to layer the materials in the compost bin in the following approximate ratio: 2 to 3 parts poultry litter; 1 part poultry carcasses: 0.1 parts wheat straw: 0.5 parts water (Alabama Cooperative Extension Service, 1991).

The purpose of this study was to determine volume, mass and compositional changes which occur during two-stage composting of poultry mortalities. Ten recipes containing poultry mortalities, poultry litter, water and peanut hulls, hay or no added carbon source were evaluated. Temperatures were monitored during the primary and secondary composting stages for each recipe. Microbiological safety was evaluated in the laboratory by measuring thermal death times of Escherichia coli, Listeria monocytogenes, and Salmonella typhimurium cultures in poultry litter incubated at 40. 50 and 60 C.

## II. MATERIALS AND METHODS

### Composting Studies

Ten recipes containing poultry mortalities, poultry litter, water and a supplementary carbon source of peanut hulls, hay or no added carbon source were evaluated on two commercial broiler poultry farms (Table 1). The carbon sources were selected based on their current use on each of the two broiler poultry farms. One farm routinely used peanut hulls and the other poor quality Coastal Bermudagrass hay which was not suitable for beef cattle feeding. Straw, which is an SCS recommended carbon source, was not used because it is not readily available in Alabama and its cost would prohibit its use for composting. Many poultry compost operations in Alabama do not add a supplementary carbon source in order to reduce cost and labor of composting. To evaluate this emerging composting practice, four of the ten compost recipes evaluated had no added carbon source.

The compost recipes selected for evaluation were based on proportions of compost ingredients routinely used on each farm and proven to compost satisfactorily. Variations of the recipes used on these farms served as the basis for the 10 compost recipes evaluated. Earlier studies (not reported here) attempted to evaluate compost recipes with carbon: nitrogen (C:N) ratios of 15:1 and higher, but none were practical or economical for composting poultry mortalities with broiler poultry litter. Compost recipes with C:N ratios of 15:1, 20:1 and even up to 30:1 are generally advocated to promote efficient composting. However, due to the low carbon content of broiler poultry litter and poultry mortalities, carbon from peanut hulls, straw, hay, wood chips or some other source must be added in substantial amounts to achieve C:N ratios of 15:1 or higher. With higher C:N ratios, a much higher percentage of the compost bin is occupied with the carbon amendment, making less space available for processing the waste products--poultry mortalities and poultry litter.

Composting studies were done in USDA/SCS approved compost bins with base dimensions of at least 8.00 m3. All compost bins were constructed of 2"x 6" treated lumber on concrete slabs in pole barns. Mass of compost ingredients used for each recipe depended on the stage of production of each poultry producer and averaged 4132 kg (range 1965 to 5115 kg). For each recipe, poultry mortalities, carbon source, water and poultry litter (in that order) were weighed in the given proportions and layered into the compost bin. The amount of material used per layer was determined by the weight of the poultry mortalities for that day. Two thermocouple wires for monitoring temperature were placed in each of the layers as the bin was filled. Two times the quantity of poultry litter used per layer during filling the composter was used as the base and cap on the compost pile. After each composter was filled, the quantity of all the ingredients was tallied to determine the weight ratio of ingredients loaded into the composter. Metal yardsticks placed at each of the four corners and at the middle of the back wall of the composter were used to determine volume reduction during primary and secondary stages of composting. Temperature of the primary compost was monitored daily for at- least 14 d. After the maximum temperature was reached and steadily declined for approximately one week, the compost was loaded onto a truck and weighed to determine weight loss during the primary compost stage. Samples of the compost were collected, pooled and mixed to yield representative samples for proximate and mineral analyses. The compost from the primary stage was mixed and aerated during cleanout and weighing, and then placed back into the same bin for the secondary compost stage. Thermocouple wires were placed into the material about 0.18 m above the concrete floor and every 0.15 m thereafter. At each height interval in the compost pile, two thermocouples were used to monitor temperature. After the maximum temperature was reached and the temperature declined for about one week (about 26 days of secondary composting) the compost was weighed and samples collected for analysis as described previously. Proximate analysis was conducted by AOAC procedures (1984). Mineral analysis was performed using inductively coupled argon plasma spectroscopy, according to procedures outlined by Hue and Evans (1986). Total Kjeldahl nitrogen was determined on wet samples and calculated on a dry matter basis. Ammonia-N and oxidized-N were determined in a KCl extract of the wet sample (AOAC, 1984). All other analyses were conducted on oven-dried samples.

### Bacterial Pathogen Survival Methodology

The fate of Escherichia coli 0157:H7, Listeria monocytogenes and Salmonella typhimurium inoculated into compost was determined by studies conducted in the laboratory and not on the commercial poultry farms to avoid contaminating the farms. High levels (˜$10^8$/g compost) of the bacterial pathogens were inoculated into 5 g of primary compost which had been sterilized by autoclaving five times for one hour, each time in a BioHazard bag. Sterilization of the compost was necessary to eliminate the indigenous microflora which would interfere with enumeration of the bacterial pathogens. The pH of the compost was determined before and after autoclaving to determine the decline in pH due to ammonia volatilization. After autoclaving, the pH of the compost was adjusted to the initial pH (from pH 7.2 to 8.2) with reagent grade ammonium hydroxide diluted 1:10 with sterile water. Approximately 0.3 mL of 1:10 diluted ammonium hydroxide per 5 g of compost was required to readjust the compost pH. The pH of the primary compost from each of the 10 compost studies ranged from pH 7.3 to 8.8 with an average pH of 8.1. When compost piles were moved, particularly primary compost, the compost always had an extremely intense ammonia odor. Therefore, the addition of ammonium hydroxide to the sterile compost to restore the original pH appeared to be appropriate. Under actual composting conditions the concentration of ammonia is likely to be higher than in the 5 g quantity of compost used to conduct the pathogen survival studies because the former has less surface area for release of ammonia. The ammonia as well as the indigenous microflora probably are major factors limiting the survival of bacterial pathogens during the composting of poultry mortalities with poultry litter. Therefore, the laboratory studies to determine the survival of E. coli 0157:H7, L. monocytogenes and S. typhimurium in poultry mortality/litter compost probably do not limit the survival of pathogens as much as the actual composting process.

To simulate composting conditions in the laboratory 5 g quantities of compost contained in 47 mm dishes were inoculated with 0.5 mL of broth culture of one pathogen and the dishes were placed inside a BioHazard bag containing a paper towel wetted with 10 mL of 1:10 diluted ammonium hydroxide solution. Replicates of each culture in 5 g of compost were placed in each of three BioHazard bags. A thermocouple wire was attached to one dish with 5 g of compost to monitor temperature inside the bag. One bag was incubated at 40 C, one at 50 C and one at 60 C. At time intervals a set of dishes which included each of the pathogens was removed from each of the bags and plated on agar medium to enumerate survivors. Listeria was enumerated on Brain Heart Infusion agar and Salmonella and Escherichia were enumerated on Xylose Lysine Desoxycholate agar. The agar plates were incubated for 2 d at 37 C prior to enumeration of the survivors.

## III. RESULTS AND DISCUSSION

The ten recipes evaluated for composting poultry mortalities with poultry litter are shown in Table 1. Three recipes evaluated three levels of peanut hulls as the carbon amendment, three recipes employed three levels of hay and four of the recipes used no added carbon source. Information on compost weight, volume, proximate analysis and temperature for each recipe is given in Appendix tables A1 to A10. The moisture content of the compost recipes averaged 35.2% and ranged from 26.5 to 39.8% (Table 2). The recipes were formulated to obtain a target moisture content of 40%; however, the moisture content of the compost may be different after primary and secondary composting due to variations of the compost in the compost bin. It might be advisable to increase the added water to compost to achieve between 35 and 45% moisture. Below 35% moisture the two-stage composted poultry mortalities/poultry litter will be too dry, which will limit digestion of the mortalities, and greater than 45% moisture will limit air penetration into the compost, also limiting organic matter digestion. All recipes had adequate moisture for composting except recipe PH-high. The two-stage compost was dry and dusty, although the poultry mortalities were adequately digested.

The C:N ratios of the compost recipes averaged 7.6:1 and ranged from 6.9:1 to 8.4:1 (Table 2). Initially, recipes with C:N ratios ranging from 10:1 to 14:1 were formulated, but when the compost piles were under construction, it became apparent that a high proportion of the compost bin would be occupied with added carbonaceous material rather than with the poultry mortalities and poultry litter which were the intended products to be composted. When no added carbon source was admixed with poultry mortalities and litter, the C:N ratio for four compost recipes ranged from 6.9:1 to 8.4:1. A higher C:N ratio may improve the compost process relative to decreasing the compost period. However, USDA/SCS design- plans provide more than adequate compost bin space; therefore, composting time is not a major consideration. Cost of the carbon amendment and labor involved to include the carbon source in the compost are important factors. The C:N ratios of ingredients used in the ten compost recipes are shown in Table 3.

The moisture content, bulk density and N-P-K content of the two-stage compost for each of the ten recipes are shown in Table 4. The moisture content of the final compost produced ranged from 27.7 to 40.7% and averaged 36.0%. The bulk density ranged from 484.7 to 730.4 kg/m3 and averaged 626.5 kg/m3. Bulk density comparison of the composts relative to the ratio of ingredients used in formulating the composts was difficult because moisture content of ingredients may vary from time to time. In general, compost recipes which employed no carbon amendments (NC recipes) appeared to have higher bulk densities than compost containing hay as the carbon amendment (Table 4). Compost ingredients amended with peanut hulls had a bulk density that appeared to be intermediate to hay (BH recipes) and the non-carbon (NC) amended recipes.

The nitrogen content of the finished compost for all recipes ranged from 3.85 to 8.23% and averaged 5.30%, expressed on a dry weight basis (Table 4). The compost from the non-carbon (NC) amended recipes had a higher N content (avg. 6.63% N) than the carbon amended recipes (avg. 4.42% N; PH and BH recipes). Because the carbon amendments have a low N content, their addition would be expected to reduce the content of N in the finished compost. The conversion of proteinaceous N in the poultry mortalities to ammonia might-also be limited in compost mixtures which lack adequate carbon reserves for microbial activity. A survey of broiler litter collected from 106 farms in Alabama showed that the N content of the litter ranged from 2.3 to 6.0% of dry matter and averaged 4.0% (Stephenson et. al., 1990). Therefore, poultry mortality/poultry litter compost in general had a higher N content than average quality poultry litter; however, the data also indicated that some of the recipes yielded compost with N contents similar to that of poultry litter alone. The P and K content of the finished compost show similar relationships to the levels found in poultry litter.

The temperatures achieved during first stage and second stage composting for each of the ten compost recipes are shown in Table 5. Based on the cumulative days during first stage and second stage composting, all compost recipes achieved > 50 C for at least 15 days except recipes BH-low and NC-1. Recipe NC-2 had similar ingredient levels compared to recipe BH-low, yet NC-2 achieved 26 d of heating above 50 C. Compost should achieve 55 C and maintain or exceed this temperature for at least 3 days to eliminate pathogens according to EPA recommendations. When this criterion was used to evaluate the 10 compost recipes, the following four recipes failed to achieve an average 55 C in all layers of the compost: PH-low, PH-medium, BH-low and NC-1. The lower temperatures of these compost mixtures cannot be explained on the basis of moisture content or C:N ratios of the recipes. Mass loss, which is indicative of biological activity was higher (avg. 20.1%)recipes, properties in these recipes compared to the other compost mixtures (avg. 16.8%). Although temperatures achieved in compost recipes PH-low, PH-medium, BH-low and NC-1 were lower than the other compost the compost mixtures exhibited good degradation properties. The major apparent difference of the compost mixtures was their inability to achieve 55 C.

High temperatures achieved during composting are necessary to eliminate bacterial pathogens that might be associated with the composting. Enteric pathogens such as Escherichia coli 0157:H7 and Salmonella species are killed within 0.5 h at 60 C. Listeria monocytogenes is more heat tolerant, but it too is easily killed by heat. Studies were conducted to determine the survival times of the bacteria in compost containing poultry mortalities and poultry litter. Three replicate studies demonstrated that the pathogens were killed in compost at 50 C within a few hours. Listeria was reduced from 199 million viable bacteria/g of compost to one bacterium/g in 10 h (Fig. 1). Escherichia coli 0157:H7 was reduced from 100 million bacteria to one bacterium in 6 h (Fig. 2), and Salmonella typhimurium from 100 million to one viable cell in about 5 h (Fig. 3). At 50 C the pathogen viable count was reduced by 8 logs in 10 h. It is unlikely that 100 million viable bacteria would be present in the initial compost. Therefore, lower initial counts reduced by 8 logs during composting would achieve adequate safety from the pathogens. Additional safety from the pathogens is apparent during the long time the material is composted. At 60 C the die-off of pathogens was faster than at 50 C, but at 40 C the pathogens persisted for more than 3 d at viable counts of over 100,00-0/g of compost (Figure 4). The determined O decimal reduction values for the pathogens in compost showed L. monocytogenes to be more heat-tolerant at 50 C than the other two pathogens. Listeria required 1.2 h at 50 C to reduce the viable count by 90%, Escherichia required 0.75 h and Salmonella 0.56 h (Table 6). The ammonia generated during the composting process probably contributes substantially to the die-off of pathogens in compost. As a general recommendation to ensure the elimination of L. monocytogenes, E. coli and S. typhimurium from poultry mortality/poultry litter compost, the average temperature of all compost or all portions of the compost should attain 50 C or higher for 5 days cumulative during the primary and secondary stages of composting.

A summary of the composting efficiencies of the 10 compost recipes is shown in Table 7. The average mass reduction during both stages of composting for the 10 compost recipes was 18.1% and varied from 8.2% to 28.8%. Due to variations in mass loss among the recipes, it is difficult to determine whether the addition of a carbon source or the type of carbon source had any effect on mass reduction. Mass reduction was not related to the temperature attained in the compost bin. Some compost recipes maintained >50 C for >15 d during both stages of composting and had some of the lower mass reductions, such as recipes BH-medium and NC-3. Recipe NC-1 had the second highest mass reduction (26.3%) but the compost did not attain a temperature of 50 C in either the primary or the secondary compost stage. Eight of the 10 recipes attained >50 C for 15 days or more, which indicated that this criterion should be adopted as a guideline for determining whether composters are working properly. This criterion also should be adopted as the minimum acceptable temperature and time for elimination of bacterial pathogens from compost.

Volume reductions during two-stage composting for the 10 compost recipes ranged from 4.3 to 26.3% and averaged 12.5% (Table 7). The extent of volume reduction was not related to mass reduction, temperature during composting or the initial moisture content of materials placed in the primary composter. Volume reductions would appear to be related to the amount of carbon addition to the compost recipe. This observation is based on recipe BH-high, which contained an excessive amount of hay. Recipe BH-high compost was not free-flowing but rather resembled a large bale of hay, making removal of the compost from the compost bin difficult with a loader tractor. The hay obviously compacted during the composting process, which accounted for the highest percent volume reduction (26.3%) of the 10 compost recipes evaluated. Bulk density of the final BH-high compost was the lowest (Table 4) of all the compost recipes, indicating that the compost was less dense and more subject to volume reduction. The bulk density of the BH-high compost increased 13.9% while the majority of the compost recipes decreased in bulk density. The increase was associated with settling or compaction of the compost characteristic of bulky materials. Nitrogen content of the final compost averaged 5.30% (dry basis)and ranged from 3.85 to 8.23% (Table 4). During two-stage composting the nitrogen content decreased an average of 14.6% and the loss ranged from 8.6 to 23.0% (Table 7). The addition of carbon to the compost mixture, either as peanut hulls or hay, increased nitrogen loss compared to mixtures without these carbon amendments. Nitrogen loss from carbon amended recipes averaged 17.9% while the loss from non-carbon amended recipes averaged 9.7%. The nitrogen content (dry basis) of the finished compost averaged 4.41% for the carbon amended recipes and 6.63% for the non-carbon amended recipes. Many poultry producers have discontinued the use of carbon amendments for composting of poultry mortalities with poultry litter. The reason appears to be a time-saving strategy and not a measure to reduce costs associated with the purchase of carbon amendments. Many poultry producers assume that poultry mortality/litter compost has a higher nitrogen content than poultry litter alone, and a greater value as fertilizer. Table 8 shows the N-P-K value of broiler litter alone, carbon-amended compost and non-carbon amended compost. Compost made using a carbon amendment had a lower N content than broiler litter (32.2 versus 28.7 kg/metric ton), although it was higher in $P_2O_5$ (28.2 versus 38.2 kg/metric ton). Compost made without an added carbon amendment was more valuable as a fertilizer than broiler litter or carbon-amended compost, which were similar in value.

The operating cost for composting poultry mortalities with poultry litter under on-farm conditions is shown in Table 9. Construction costs for the compost facilities are actual costs paid by the poultry producers including ASCS cost share. The higher construction cost for Farm B is attributed to two factors: 1) the facility was constructed about 3 years after the compost facility on Farm A; and 2) the entire base of the facility was poured concrete, whereas, only the floors of the compost bins on Farm A were concrete. Data concerning hours of labor and tractor use were supplied by the poultry producers. Costs for labor and tractor use were supplied by faculty in the Department of Agricultural Economics and Rural Sociology at Auburn University. Annual labor associated with composting of poultry mortalities with poultry litter was determined to be 155.5 hr. for Farm A and 82.75 hr. for Farm B. Labor cost at $6.00/hr was $933.00 annually for Farm A and $496.50 for Farm B. Total annual labor and tractor costs for composting mortalities for a 20,000 bird unit was $22.17 for Farm A and $24.22 for Farm B. The per unit cost was calculated using total broiler production of 990,000/yr. for Farm A and 495,000/yr. for Farm B and did not include amortization for facilities and equipment. Value of labor, facilities and equipment vary by region, and producers considering composting for mortality disposal should calculate budgets based on costs for their locations.

Guidelines for Composting Poultry Mortalities with Poultry Litter

1. Consult USDA/SCS for approved plans for construction of compost facilities.

2. Provide 5.74 $m^3$ of primary bin capacity for each 20,000 birds on hand and an equal amount of secondary bin capacity. For example, a poultry producer with a flock of 40,000 birds per brood would need 11.48 $m^3$ of primary bin and 11.48 $m^3$ of secondary bin capacity (Donald and Blake, 1991).

3. Remove poultry mortalities daily from poultry houses.

4. Use one of the following recipes (amounts given on a parts per weight basis):

   a) With carbon amendment (peanut hulls or chopped hay or straw)

| | |
|---|---|
| Litter | 3 to 4 parts |
| Carbon amendment | 0.2 to 0.4 parts |
| Mortalities | 1 part |
| Water | 0.5 to 1 parts |

   b) Without carbon amendment

| | |
|---|---|
| Litter | 4 to 6 parts |
| Mortalities | 1 part |
| Water | 0.75 to 1 parts |

   Regardless of recipe used, compost ingredients should be added to achieve about 30 to 40% moisture in the initial mix.

5. Temperature during composting should achieve >50 C for at least 5 days as an average throughout the composting mass. This temperature and time criterion can be achieved during either the primary or secondary composting stages or as the cumulative time >50 C in both stages.

6. Primary compost should remain in the bin until the temperature reaches a maximum and then shows a steady decline for one week. If the maximum temperature during primary composting is less than 50 C, the compost should be mixed and aerated to encourage heating (this is accomplished by moving the compost to the secondary bin). This step should be repeated (mixing and aeration) until the compost has achieved at least 5 days of >50 C. In most cases, heating during primary and secondary composting will be adequate.

7. When the compost has achieved >50 C for at least 5 days, the composting process is adequate to eliminate the bacterial pathogens Listeria monocytogenes, Escherichia cold 0157:H7 and Salmonella typhimurium.

8. After the previously described composting process, the compost is stable and can be stored until it is convenient for the operator to dispose of it by land spreading or sale to other individuals. Secondary bin area is usually adequate for compost storage, or the compost can be removed from the secondary bin and placed in a barn where it is protected from the weather. Compost should be tested for N-P-K and applied to land at levels appropriate for the type of crop grown.

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Table 1. Recipes evaluated for composting poultry mortalities with poultry litter. Ingredients are listed as a weight ratio.

| Compost Recipe | Ingredient | | | | |
|---|---|---|---|---|---|
| | Broiler Litter | Peanut Hulls | Hay | Poultry Mortalities | Water |
| Peanut hulls/low addition (PH - low) | 3.40 | 0.24 | | 1.00 | 0.50 |
| Peanut hulls/med. addition (PH - medium) | 2.00 | 0.35 | | 1.00 | 0.42 |
| Peanut hulls/high addition (PH - high) | 4.50 | 0.68 | | 1.00 | 0.29 |
| Bermuda hay/low addition (BH - low) | 5.00 | | 0.10 | 1.00 | 1.00 |
| Bermuda hay/med. addition (BH - medium) | 2.80 | | 0.10 | 1.00 | 0.50 |
| Bermuda hay/high addition (BH - high) | 3.00 | | 0.50 | 1.00 | 1.00 |
| No added carbon source 1 (NC - 1) | 6.00 | | | 1.00 | 0.50 |
| No added carbon source 2 (NC - 2) | 5.00 | | | 1.00 | 1.00 |
| No added carbon source 3 (NC - 3) | 4.50 | | | 1.00 | 1.00 |
| No added carbon source 4 (NC - 4) | 4.00 | | | 1.00 | 1.00 |

Table 2. Initial moisture and C:N ratio of compost recipes.

| Compost Recipe | Ingredient Ratio BL/CS/PM/WR[a] | Moisture % | C:N |
|---|---|---|---|
| PH - low | 3.40/0.24/1.00/0.50 | 37.9 | 7.2:1 |
| PH - medium | 2.00/0.35/1.00/0.42 | 39.8 | 7.7:1 |
| PH - high | 4.50/0.68/1.00/0.29 | 26.5 | 7.6:1 |
| BH - low | 5.00/0.10/1.00/1.00 | 35.4 | 8.3:1 |
| BH - medium | 2.80/0.10/1.00/0.50 | 33.9 | 8.3:1 |
| BH - high | 3.00/0.50/1.00/1.00 | 37.3 | 7.0:1 |
| NC - 1 | 6.00/0/1.00/1.00 | 34.7 | 7.3:1 |
| NC - 2 | 5.00/0/1.00/1.00 | 34.7 | 7.4:1 |
| NC - 3 | 4.50/0/1.00/0.75 | 36.0 | 6.9:1 |
| NC - 4 | 4.00/0/1.00/1.00 | 35.9 | 8.4:1 |
| Average | | 35.2 | 7.6:1 |
| Range | | 26.5 to 39.8 | 6.9 to 8.4:1 |

[a] BL=Broiler Litter; CS=Carbon Source; PM = Poultry Mortalities; WR=Water.

Table 3. C:N ratios of compost ingredients.

| Ingredient | C:N ratio |
|---|---|
| Broiler litter | 8.0:1 |
| Peanut hulls | 42.5:1 |
| Hay | 16.6:1 |
| Poultry mortalities[a] | 5.0:1 |
| Water | 0 |

[a] Murphy and Handwerker, 1988.

Table 4. Moisture, bulk density and N - P - K of final compost.

| Compost Recipe | Ingredient Ratio | Moisture | Density | N | P | K |
|---|---|---|---|---|---|---|
| | BL/CS/PM/WR[a]) | % | kg/m$^3$ | % of DM | | |
| PH - low | 3.40/0.24/1.00/0.50 | 36.2 | 606.5 | 4.99 | 2.16 | 3.09 |
| PH - medium | 2.00/0.35/1.00/0.42 | 36.1 | 677.4 | 4.47 | 2.42 | 3.47 |
| PH - high | 4.50/0.68/1.00/0.29 | 27.7 | 556.8 | 3.85 | 3.73 | 4.07 |
| BH - low | 5.00/0.10/1.00/1.00 | 40.7 | 637.3 | 4.46 | 2.47 | 3.16 |
| BH - medium | 2.80/0.10/1.00/0.50 | 39.9 | 597.3 | 4.04 | 2.81 | 2.35 |
| BH - high | 3.00/0.50/1.00/1.00 | 38.0 | 484.7 | 4.66 | 2.09 | 3.16 |
| NC - 1 | 6.00/0/1.00/1.00 | 35.1 | 641.8 | 5.80 | 2.53 | 3.17 |
| NC - 2 | 5.00/0/1.00/1.00 | 33.5 | 730.4 | 7.54 | 2.54 | 3.26 |
| NC - 3 | 4.50/0/1.00/0.75 | 36.7 | 688.3 | 8.23 | 2.97 | 3.67 |
| NC - 4 | 4.00/0/1.00/1.00 | 36.2 | 644.2 | 4.95 | 2.24 | 2.79 |
| Average | | 36.0 | 626.5 | 5.30 | 2.60 | 3.22 |
| Range | | 27.7 to 40.7 | 484.7 to 730.4 | 3.85 to 8.23 | 2.09 to 3.73 | 2.35 to 4.07 |

[a] BL=Broiler Litter; CS=Carbon Source; PM=Poultry Mortalities; WR=Water.

Table 5. Temperatures of primary and secondary compost

| Compost Recipe | Ingredient Ratio | Preliminary Compost | | | Secondary Compost | | |
|---|---|---|---|---|---|---|---|
| | BL/CS/PM/WR[a] | >50 C | >55 C | Max | >50 C | >55 C | Max |
| | | days[b] | | | days[b] | | |
| PH - low | 3.40/0.24/1.00/0.50 | 27 | 0 | 52.7 | 12 | 0 | 51.8 |
| PH - medium | 2.00/0.35/1.00/0.42 | 0 | 0 | 46.6 | 15 | 0 | 53.1 |
| PH - high | 4.50/0.68/1.00/0.29 | 37 | 25 | 64.2 | 32 | 13 | 57.9 |
| BH - low | 5.00/0.10/1.00/1.00 | 0 | 0 | 40.2 | 0 | 0 | 49.4 |
| BH - medium | 2.80/0.10/1.00/0.50 | 8 | 1 | 56.0 | 29 | 5 | 56.3 |
| BH - high | 3.00/0.50/1.00/1.00 | 21 | 10 | 58.1 | 8 | 7 | 62.3 |
| NC - 1 | 6.00/0/1.00/1.00 | 0 | 0 | 41.4 | 0 | 0 | 47.0 |
| NC - 2 | 5.00/0/1.00/1.00 | 0 | 0 | 49.9 | 26 | 16 | 59.4 |
| NC - 3 | 4.50/0/1.00/0.75 | 0 | 0 | 48.9 | 15 | 5 | 56.0 |
| NC - 4 | 4.00/0/1.00/1.00 | 6 | 3 | 56.9 | 26 | 2 | 55.2 |

[a] BL=Broiler Litter; CS=Carbon Source; PM=Poultry Mortalities; WR=Water.

[b] The number of days that the average temperature of all layers was >50 C or >55 C.

Table 6. Decimal reduction values[a] for elimination of bacterial pathogens during composting of poultry mortalities with poultry litter.

| Pathogen | 50 C | 60 C |
|---|---|---|
| | D value[a] | |
| Listeria monocytogenes | 1.20 | 0.48 |
| Escherichia coli 0157:H7 | 0.75 | 0.50 |
| Salmonella typhimurium | 0.56 | 0.39 |

[a] Time (hours) required to reduce number of survivors by 90% or 1 log.

Table 7. Summary of composting efficiency. Percent change is the difference between the raw materials and the secondary compost.

| Compost Recipe | Ingredient Ratio | Days >50 C[b] | Percent Change | | | |
|---|---|---|---|---|---|---|
| | BL/CS/PM/WR[a] | | Mass | Volume | Bulk Density | TKN |
| PH - low | 3.40/0.24/1.00/0.50 | 39 | -18.9 | -4.3 | -15.1 | -13.6 |
| PH - medium | 2.00/0.35/1.00/0.42 | 15 | -21.8 | -18.8 | -3.6 | -14.3 |
| PH - high | 4.50/0.68/1.00/0.29 | 69 | -28.8 | -12.0 | -19.2 | -20.7 |
| BH - low | 5.00/0.10/1.00/1.00 | 0 | -13.3 | -6.7 | -7.0 | -15.2 |
| BH - medium | 2.80/0.10/1.00/0.50 | 37 | -8.2 | -7.3 | -1.0 | -23.0 |
| BH - high | 3.00/0.50/1.00/1.00 | 29 | -16.0 | -26.3 | +13.9 | -20.5 |
| NC - 1 | 6.00/0/1.00/1.00 | 0 | -26.3 | -10.3 | -17.9 | -11.1 |
| NC - 2 | 5.00/0/1.00/1.00 | 26 | -14.9 | -12.2 | -3.1 | -9.1 |
| NC - 3 | 4.50/0/1.00/0.75 | 15 | -13.9 | -16.8 | +3.6 | -9.8 |
| NC - 4 | 4.00/0/1.00/1.00 | 32 | -18.9 | -9.8 | -10.1 | -8.6 |
| Average | | 26 | -18.1 | -12.5 | -6.0 | -14.6 |
| Range | | 0 to 69 | -8.2 to -28.8 | -4.3 to -6.3 | -19.2 to +13.2 | -8.6 to -23.0 |

[a] BL=Broiler Litter; CS=Carbon Source; PM=Poultry Mortalities; WR=Water.

[b] Cumulative days that temperature in primary and secondary composters was ≥5C

Table 8. Fertilizer value of broiler litter, carbon amended poultry mortality/broiler litter compost and non-carbon amended compost.

| Material | DM | N | $P_2O_5$ | $K_2O$ | Value[a] |
|---|---|---|---|---|---|
| | % | kg/metric ton (wet basis) | | | $/ton |
| Broiler litter[b] | 80.5 | 32.2 | 28.2 | 22.4 | 41.74 |
| Compost (no added carbon) | 65.0 | 43.1 | 37.6 | 25.1 | 54.18 |
| Compost (carbon added) | 65.0 | 28.7 | 38.2 | 25.1 | 45.56 |

[a] Value determined using \$0.62, \$0.51 and \$0.33 per kg of N, $P_2O_5$ and $K_2O$, respectively.

[b] Stephenson et. al, 1990.

Table 9. Operating costs for composting poultry mortalities with poultry litter on two Alabama broiler poultry farms.

| | Farm A | Farm B |
|---|---|---|
| Birds/brood | 180,000 | 90,000 |
| Broods/year | 5.5 | 5.5 |
| Total birds/year | 990,000 | 495,000 |
| Number of primary bins | 6 | 4 |
| Total capacity of primary bins, $m^3$ | 45.5 | 32.5 |
| Total capacity of primary and secondary bins, $m^3$ | 91.0 | 65 |
| Cost of compost facilities (actual) | $20,000 | $24,000 |
| Time spent composting, hr./brood | 21.0 | 10.5 |
| Yearly labor for composting, hr.[a] | | |
| a) Building compost pile | 115.5 | 57.75 |
| b) Transfer compost to secondary bin | 20 | 10 |
| c) Haul compost to field | 20 | 15 |
| d) Total labor, hr. | 155.5 | 82.75 |
| Annual Composting Cost[b] | | |
| a) Labor cost ($6.00/hr) | $ 933.00 | $496.50 |
| b) Tractor cost ($4.12/hr)[c] | $ 164.80 | $103.00 |
| Total Annual Composting Cost | $1097.80 | $599.50 |
| Total cost/20,000 birds | $ 22.17 | $ 24.22 |

[a] Labor for composting, operation of equipment and field spreading of compost is contributed by one person. Labor for collecting poultry mortalities is not included.

[b] Costs do not include the compost carbon amendment, electricity, water, field spreader or depreciation on compost facilities.

[c] Cost for use of a tractor with front-end loader is based on 40 hr annual use for Farm A and 25 hr for Farm B. The variable cost of operating a 50 HP tractor was $4.12/hr (fuel and maintenance).

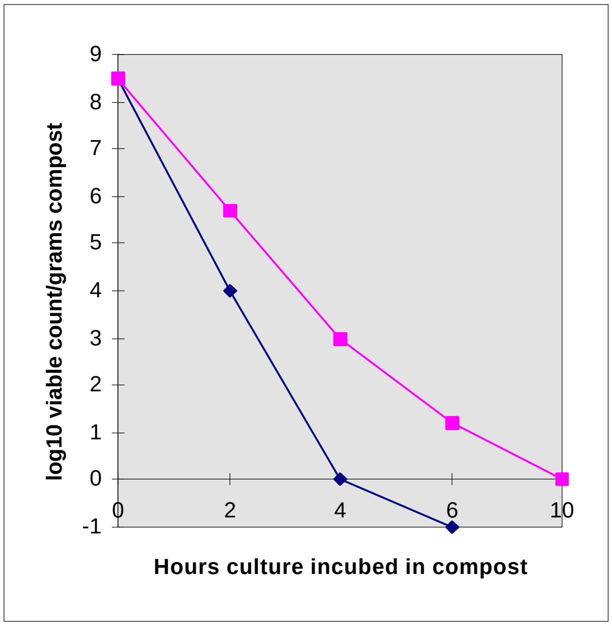

Figure 1. Viability of <u>Listeria monocytogenes</u> in compost incubated at 50 and 60 C.

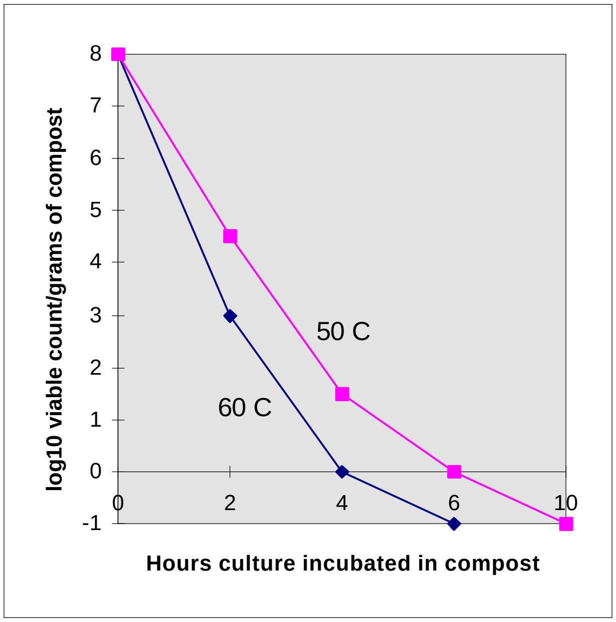

Figure 2. Viability of <u>Escherichia coli</u> O157:H7 in compost incubated at 50 and 60 C

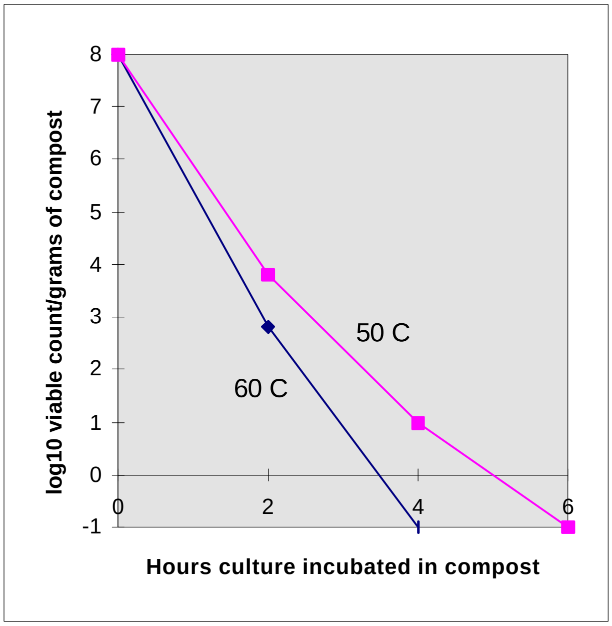

Figure 3. Viability of Salmonella typhimurim in compost incubated at 50 and 60 C

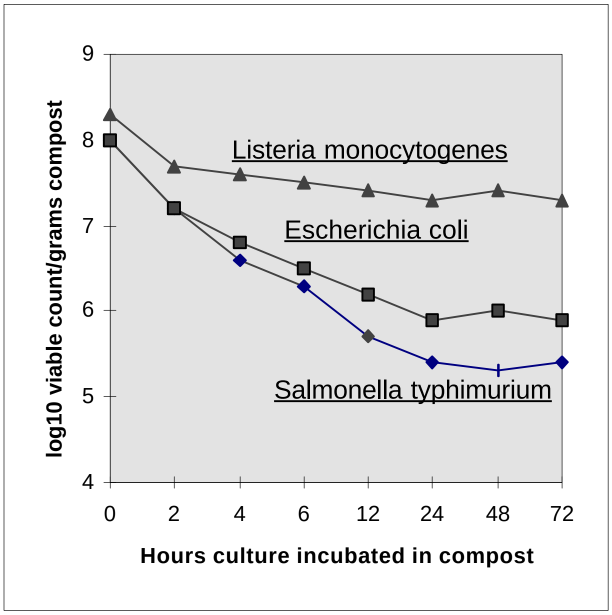

Figure 4. Viable counts of L. monocytogenes, E. coli, and S. typhimurium in compost incubated at 40 C.

# VII. APPENDIX TABLES

Table A1. Characterization of raw material, primary compost and secondary compost manufactured using recipe PH-low.

| Compost Recipe -- PH-low | Raw Material | Primary Compost | Secondary Compost |
|---|---|---|---|
| Mass, kg | 4127 | 3648 | 3348 |
| Volume, $m^3$ | 5.77 | 5.41 | 5.52 |
| Days to fill bin | 10 | | |
| Days composted | | 32[a] | 28[b] |
| Maximum temp, C | | 52.7 | 51.8 |
| Days to reach max. | | 20 | 6 |
| Days > 50 C | | 27 | 12 |
| Days > 55 C | | 0 | 0 |
| Bulk density, $kg/m^3$ | 715.2 | 674.3 | 606.5 |
| pH | 7.6 | 8.0 | 8.5 |
| Moisture, % | 37.88 | 41.37 | 36.22 |
| Dry matter, % | 62.12 | 58.63 | 63.78 |
| | - - - - - - - % of DM - - - - - - - - | | |
| Volatile solids | 74.59 | 70.47 | 69.76 |
| Fixed solids | 25.41 | 29.53 | 30.24 |
| Total N | 4.81 | 5.36 | 4.99 |
| $NH_3$-N | 0.48 | 1.43 | 1.01 |
| Oxidized N | 0.20 | 0.36 | 0.38 |
| Total P | 1.96 | 2.01 | 2.16 |
| Total K | 2.65 | 2.71 | 3.09 |
| Carbon | 34.68 | 34.75 | 33.31 |
| Carbon: Nitrogen | 7.2:1 | 6.5:1 | 6.7:1 |

[a] Time spent in primary composter does not include days to fill compost bin.

[b] Time spent in secondary composter.

Table A2. Characterization of raw material, primary compost and secondary compost manufactured using recipe PH-medium.

| Compost Recipe -- PH-medium | Raw Material | Primary Compost | Secondary Compost |
|---|---:|---:|---:|
| Mass, kg | 4331 | 3643 | 3387 |
| Volume, $m^3$ | 6.16 | 5.20 | 5.00 |
| Days to fill bin | 4 | | |
| Days composted | | 258) | 48b' |
| Maximum temp, C | | 46.6 | 53.1 |
| Days to reach max. | | 16 | 8 |
| Days > 50 C | | 0 | 15 |
| Days > 55 C | | 0 | 0 |
| Bulk density, $kg/m^3$ | 703.1 | 700.5 | 677.4 |
| pH | 6.5 | 8.8 | 8.9 |
| Moisture, % | 39.83 | 40.00 | 36.10 |
| Dry matter, % | 60.17 | 60.00 | 63.90 |
| | - - - - - - - % of DM - - - - - - - - | | |
| Volatile solids | 74.47 | 70.19 | 69.46 |
| Fixed solids | 25.53 | 29.81 | 30.54 |
| Total N | 4.65 | 4.30 | 4.47 |
| $NH_3$-N | 0.64 | 1.22 | 0.95 |
| Oxidized N | 0.15 | 0.12 | 0.13 |
| Total P | 2.14 | 2.34 | 2.42 |
| Total K | 2.97 | 3.01 | 3.47 |
| Carbon | 36.0 | 34.7 | 32.9 |

[a] Time spent in primary composter does not include days to fill compost bin.

[b] Time spent in secondary composter.

Table A3. Characterization of raw material, primary compost and secondary compost manufactured using recipe PH-high.

| Compost Recipe -- PH-high | Raw Material | Primary Compost | Secondary Compost |
|---|---|---|---|
| Mass, kg | 5109 | 3906 | 3636 |
| Volume, $m^3$ | 7.42 | 6.91 | 6.53 |
| Days to fill bin | 27 | | |
| Days composted | | 23[a] | 34[b] |
| Maximum temp, C | | 64.2 | 57.9 |
| Days to reach max. | | 33 | 9 |
| Days > 50 C | | 37 | 32 |
| Days > 55 C | | 25 | 13 |
| Bulk density, $kg/m^3$ | 688.5 | 565.3 | 556.8 |
| pH | 7.6 | 8.4 | 8.4 |
| Moisture, % | 26.48 | 29.96 | 27.67 |
| Dry matter, % | 73.52 | 70.04 | 72.33 |
| | - - - - - - - % of DM - - - - - - - | | |
| Volatile solids | 72.40 | 62.51 | 61.33 |
| Fixed solids | 27.60 | 37.49 | 38.67 |
| Total N | 3.87 | 4.48 | 3.85 |
| $NH_3$-N | 0.48 | 0.72 | 0.84 |
| Oxidized N | 0.11 | 0.09 | 0.25 |
| Total P | 2.74 | 3.65 | 3.73 |
| Total K | 2.93 | 4.09 | 4.07 |
| Carbon | 33.9 | 32.6 | 31.7 |
| Carbon:Nitrogen | 7.6:1 | 7.3:1 | 8.2:1 |

[a] Time spent in primary composter does not include days to fill compost bin.

[b] Time spent in secondary composter.

Table A4. Characterization of raw material, primary compost and secondary compost manufactured using recipe BH-low.

| Compost Recipe -- BH-low | Raw Material | Primary Compost | Secondary Compost |
|---|---|---|---|
| Mass, kg | 4470 | 4328 | 3875 |
| Volume, $m^3$ | 6.52 | 6.06 | 6.08 |
| Days to fill bin | 23 | | |
| Days composted | | 35a) | 44b) |
| Maximum temp, C | | 40.2 | 49.4 |
| Days to reach max. | | 28 | 38 |
| Days > 50 C | | 0 | 0 |
| Days > 55 C | | 0 | 0 |
| Bulk density, $kg/m^3$ | 685.6 | 714.2 | 637.3 |
| pH | 8.1 | 8.3 | 8.3 |
| Moisture, % | 35.43 | 44.64 | 40.68 |
| Dry matter, % | 64.57 | 55.36 | 59.32 |
| | - - - - - - - % of DM - - - - - - | | |
| Volatile solids | 73.71 | 69.47 | 69.78 |
| Fixed solids | 26.29 | 30.53 | 30.22 |
| Total N | 4.18 | 4.45 | 4.46 |
| $NH_3$-N | 0.45 | 1.05 | 1.10 |
| Oxidized N | 0.05 | 0.13 | 0.13 |
| Total P | 2.26 | 2.33 | 2.47 |
| Total K | 2.66 | 2.92 | 3.16 |
| Carbon | 34.74 | 32.62 | 32.82 |
| Carbon: Nitrogen | 8.3:1 | 7.3:1 | 7.4:1 |

[a] Time spent in primary composter does not include days to fill compost bin.

[b] Time spent in secondary composter.

Table A5. Characterization of raw material, primary compost and secondary compost manufactured using recipe BH-medium.

| Compost Recipe -- BH-medium | Raw Material | Primary Compost | Secondary Compost |
|---|---|---|---|
| Mass, kg | 3656 | 3548 | 3357 |
| Volume, $m^3$ | 6.06 | 5.57 | 5.62 |
| Days to fill bin | 25 | | |
| Days composted | | 14[a] | 32[b] |
| Maximum temp, C | | 56.0 | 56.3 |
| Days to reach max. | | 18 | 7 |
| Days > 50 C | | 8 | 29 |
| Days > 55 C | | 1 | 5 |
| Bulk density, kg/$m^3$ | 603.3 | 637.0 | 597.3 |
| pH | 7.4 | 8.0 | 8.2 |
| Moisture, % | 33.88 | 36.57 | 39.87 |
| Dry matter, % | 66.12 | 63.43 | 60.13 |
| | - - - - - - - % of DM - - - - - - | | |
| Volatile solids | 74.37 | 70.85 | 67.54 |
| Fixed solids | 25.63 | 29.15 | 32.46 |
| Total N | 4.38 | 4.48 | 4.04 |
| $NH_3$-N | 0.36 | 0.99 | 0.75 |
| Oxidized N | 0.05 | 0.06 | 0.05 |
| Total P | 2.16 | 2.14 | 2.81 |
| Total K | 2.79 | 2.64 | 2.35 |
| Carbon | 36.40 | 33.40 | 32.93 |
| Carbon: Nitrogen | 8.3:1 | 7.4:1 | 8.2:1 |

[a] Time spent in primary composter does not include days to fill compost bin.

[b] Time spent in secondary composter.

Table A6. Characterization of raw material, primary compost and secondary compost manufactured using recipe BH-high.

| Compost Recipe -- BH-high | Raw Material | Primary Compost | Secondary Compost |
|---|---|---|---|
| Mass, kg | 1696 | 1633 | 1425 |
| Volume, $m^3$ | 3.99 | 2.99 | 2.94 |
| Days to fill bin | 12 | | |
| Days composted | | 24[a] | 29[b] |
| Maximum temp, C | | 58.1 | 62.3 |
| Days to reach max. | | 16 | 4 |
| Days > 50 C | | 21 | 8 |
| Days > 55 C | | 10 | 7 |
| Bulk density, $kg/m^3$ | 425.5 | 546.3 | 484.7 |
| pH | 7.9 | 8.8 | 8.8 |
| Moisture, % | 37.29 | 44.06 | 38.02 |
| Dry matter, % | 62.71 | 55.94 | 61.98 |
| | - - - - - - - % of DM - - - - - - | | |
| Volatile solids | 73.46 | 70.32 | 67.99 |
| Fixed solids | 26.54 | 29.68 | 32.01 |
| Total N | 4.87 | 5.26 | 4.66 |
| $NH_3$-N | 0.67 | 1.28 | 1.02 |
| Oxidized N | 0.17 | 0.26 | 0.12 |
| Total P | 1.78 | 2.19 | 2.09 |
| Total K | 2.43 | 3.12 | 3.16 |
| Carbon | 33.9 | 32.3 | 31.2 |
| Carbon: Nitrogen | 7.0:1 | 6.1:1 | 6.7:1 |

Table A7. Characterization of raw material, primary compost and secondary compost manufactured using recipe NC-1.

| Compost Recipe -- NC-1 | Raw Material | Primary Compost | Secondary Compost |
|---|---|---|---|
| Mass, kg | 5025 | 4117 | 3703 |
| Volume, $m^3$ | 6.43 | 5.92 | 5.77 |
| Days to fill bin | 7 | | |
| Days composted | | 35" | 26b) |
| Maximum temp, C | | 41.4 | 47.0 |
| Days to reach max. | | 24 | 13 |
| Days > 50 C | | 0 | 0 |
| Days > 55 C | | 0 | 0 |
| Bulk density, $kg/m^3$ | 781.5 | 695.4 | 641.8 |
| pH | 8.2 | 7.5 | 6.8 |
| Moisture, % | 34.73 | 36.33 | 35.08 |
| Dry matter, % | 65.27 | 63.67 | 64.92 |
| | - - - - - - - % of DM - - - - - - | | |
| Volatile solids | 74.26 | 66.04 | 64.53 |
| Fixed solids | 25.74 | 33.96 | 35.47 |
| Total N | 4.78 | 4.50 | 5.80 |
| $NH_3$-N | 0.54 | 0.85 | 0.81 |
| Oxidized N | 0.06 | 0.48 | 0.41 |
| Total P | 2.11 | 2.24 | 2.53 |
| Total K | 2.82 | 2.74 | 3.17 |
| Carbon | 34.81 | 33.94 | 30.23 |
| Carbon: Nitrogen | 7.3:1 | 7.5:1 | 5.2:1 |

[a] Time spent in primary composter does not include days to fill compost bin.

[b] Time spent in secondary composter.

Table A8. Characterization of raw material, primary compost and secondary compost manufactured using recipe NC-2.

| Compost Recipe -- NC-2 | Raw Material | Primary Compost | Secondary Compost |
|---|---|---|---|
| Mass, kg | 3775 | 3374 | 3214 |
| Volume, $m^3$ | 5.01 | 4.56 | 4.40 |
| Days to fill bin | 9 | | |
| Days composted | | 438[a] | 38[b] |
| Maximum temp, C | | 49.9 | 59.4 |
| Days to reach max. | | 23 | 8 |
| Days > 50 C | | 0 | 26 |
| Days > 55 C | | 0 | 16 |
| Bulk density, $kg/m^3$ | 753.5 | 739.9 | 730.4 |
| pH | 8.0 | 7.5 | 7.9 |
| Moisture, % | 34.68 | 31.03 | 33.46 |
| Dry matter, % | 65.32 | 68.97 | 66.54 |
| | - - - - - - - % of DM - - - - - - | | |
| Volatile solids | 73.95 | 72.35 | 71.88 |
| Fixed solids | 26.05 | 27.65 | 28.12 |
| Total N | 4.79 | 4.74 | 7.54 |
| $NH_3$-N | 0.52 | 1.04 | 0.86 |
| Oxidized N | 0.08 | 0.08 | 0.14 |
| Total P | 2.24 | 2.19 | 2.54 |
| Total K | 3.03 | 2.84 | 3.26 |
| Carbon | 35.37 | 37.22 | 36.52 |
| Carbon: Nitrogen | 7.4:1 | 7.8:1 | 4.8:1 |

[a] Time spent in primary composter does not include days to fill compost bin.

[b] Time spent in secondary composter.

Table A9. Characterization of raw material, primary compost and secondary compost manufactured using recipe NC-3.

| Compost Recipe -- NC-3 | Raw Material | Primary Compost | Secondary Compost |
|---|---|---|---|
| Mass, kg | 3748 | 3444 | 3228 |
| Volume, $m^3$ | 5.64 | 4.89 | 4.69 |
| Days to fill bin | 5 | | |
| Days composted | | 388[a] | 38[b] |
| Maximum temp, C | | 48.9 | 56.0 |
| Days to reach max. | | 14 | 8 |
| Days > 50 C | | 0 | 15 |
| Days > 55 C | | 0 | 5 |
| Bulk density, $kg/m^3$ | 664.5 | 704.3 | 688.3 |
| pH | 7.9 | 7.3 | 7.4 |
| Moisture, % | 36.00 | 31.61 | 36.67 |
| Dry matter, % | 64.00 | 68.39 | 63.33 |
| | - - - - - - - % of DM - - - - - - | | |
| Volatile solids | 73.81 | 73.48 | 68.94 |
| Fixed solids | 26.19 | 26.52 | 31.06 |
| Total N | 4.92 | 5.10 | 8.23 |
| $NH_3$-N | 0.58 | 1.10 | 0.94 |
| Oxidized N | 0.05 | 0.14 | 0.09 |
| Total P | 2.44 | 2.66 | 2.97 |
| Total K | 3.13 | 2.99 | 3.67 |
| Carbon | 34.07 | 34.79 | 36.17 |
| Carbon: Nitrogen | 6.9:1 | 6.8:1 | 4.4:1 |

[a] Time spent in primary composter does not include days to fill compost bin.

[b] Time spent in secondary composter.

Table A10. Characterization of raw material, primary compost and secondary compost manufactured using recipe NC-4.

| Compost Recipe -- NC-4 | Raw Material | Primary Compost | Secondary Compost |
|---|---:|---:|---:|
| Mass, kg | 5115 | 4588 | 4149 |
| Volume, $m^3$ | 7.14 | 6.55 | 6.44 |
| Days to fill bin | 15 | | |
| Days composted | | l6[a] | 32[b] |
| Maximum temp, C | | 56.9 | 55.2 |
| Days to reach max. | | 12 | 15 |
| Days > 50 C | | 6 | 26 |
| Days > 55 C | | 3 | 2 |
| Bulk density, $kg/m^3$ | 716.4 | 700.4 | 644.2 |
| pH | 7.3 | 8.0 | 7.7 |
| Moisture, % | 35.89 | 40.35 | 36.20 |
| Dry matter, % | 64.11 | 59.65 | 63.80 |
| | - - - - - - - % of DM - - - - - - | | |
| Volatile solids | 74.79 | 75.92 | 70.22 |
| Fixed solids | 25.21 | 27.08 | 29.78 |
| Total N | 4.37 | 4.78 | 4.95 |
| $NH_3$-N | 0.21 | 0.10 | 0.22 |
| Oxidized N | 0.01 | 0.01 | 0.01 |
| Total P | 2.16 | 2.20 | 2.24 |
| Total K | 2.70 | 2.83 | 2.79 |
| Carbon | 36.59 | 36.34 | 34.98 |
| Carbon: Nitrogen | 8.4:1 | 7.6:1 | 7.1:1 |

[a] Time spent in primary composter does not include days to fill compost bin.

[b] Time spent in secondary composter.