PILOT STUDY
INITIAL RESULTS FOR
VERMICOMPOSTING YARD WASTE WITH BIOSOLIDS
FOR
MANSFIELD BOROUGH, TIOGA COUNTY

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1.0 BACKGROUND

The Pennsylvania Department of Environmental Protection (PaDEP), the Governor's Center for Local Government Services, the Pennsylvania State Association of Township Supervisors (PSATS) and the Solid Waste Association of North America (SWANA) formed a training partnership for Pennsylvania local governments interested in achieving higher recycling rates. Through this partnership, Mansfield Borough was awarded $6,000 in technical assistance services from Gannett Fleming, Inc. to assist with pilot studies for vermicomposting partially digested leaf waste (leaf compost) with biosolids at the Mansfield Wastewater Treatment Plant.

2.0 INTRODUCTION

The Borough of Mansfield and the Borough Water and Sewer Department work cooperatively to divert organic residuals from the landfill. Leaf and yard waste is collected in the Borough and transported to the wastewater treatment plant for composting in non-aerated static piles. Dewatered biosolids are composted at the treatment plant with tree bark. To date, the operation has been ineffective for composting material into a usable soil amendment for landscaping projects.

The Borough and the Water and Sewer Department are interested in testing various mixes of leaf compost and biosolids in earthworm digesters. The purpose of the testing is to determine the most effective ratio for creating useable products through a sustainable vermicomposting process. For the pilot study, three audit bins were constructed at the wastewater treatment plant. Gannett Fleming provided guidance on the initial mix ratios and sampling parameters. A portion of the technical assistance budget was allocated for the purchase of materials and equipment to setup the pilot study.

This report provides guidance on the fundamentals of operating a successful vermicomposting operation as well as summarizes the results of the first phase of pilot testing.

2.1 Scope of Services

The following Scope of Services was developed for this project:

Task 1 Borough staff will build three earthworm audit boxes to be used as test systems to evaluate the effectiveness of composting different combinations of yard waste with biosolids. The yard waste will include leaves, grass and chipped branch/shrub debris.

Task 2 Gannett Fleming will develop a tracking log to record testing methods and test results. The Borough staff will be responsible for lab tests and associated costs, but will provide the information to GF to be incorporated into the summary report (task 3). As part of the digester composting testing, tests will be conducted and vermicompost mixes will be visually and qualitatively analyzed as long as necessary by Borough staff to gain sufficient data to make solid determinations from this study.

Task 3 Gannett Fleming will prepare a brief summary report of the action steps and initial test results provided by the Borough.

3.0 PILOT STUDY OPERATION

3.1 Biosolids and Yard Waste Composition

Preconditioned mixes of biosolids and leaf waste were used for the vermicomposting pilot study. The biosolids were dewatered to 13% solids, and mixed with ground wood wastes as a bulking agent at a 1:1 ratio by volume. The wood waste used was from shrubs and yard waste collected in the community that had been processed with a tub grinder.

The leaf compost, taken from piles stored on-site at the wastewater treatment facility, was composed primarily of leaves, but also included some garden residuals, grass clippings, and pine needles. At the time the vermicomposting pilot study, the leaf compost had been conditioned for approximately seven months in uncovered in static piles. Temperatures at the center of the leaf pile averaged around 90º Fahrenheit. For the first trial run of the pilot, three mixes of biosolids and leaf compost were created and added to the three separate bins, as shown in **Table 1**.

3.2 Mix Ratios

Table 1: Initial Mixes

Parameter	Mix 1	Mix 2	Mix 3
Primary material	Biosolids	50% biosolids 50% leaf compost	Leaf compost
Bulking agent	50% ground wood waste by volume	50% ground wood waste by volume mixed with the biosolids only	50% ground wood waste by weight
Initial moisture (1)	80%	60%	50%
Estimated C:N (2)	> 6:1	> 30:1	> 60:1
Initial Red worms weight	12 pounds	12 pounds	12 pounds

Note 1: Initial moisture includes the estimated moisture content of the ground wood waste
Note 2: The estimated C:N ratio does not include the carbon content of the ground wood waste

3.3 Materials and Bin Construction

Thirty-six pounds of Red worms were purchased from Orner Farms in Camp Home, Pennsylvania for the start up of the pilot. The worms cost $15 per pound including delivery. Twelve pounds of worms were added to each bin, which was based on the recommended loading rate of one pound of redworms per square foot of bin surface area, as indicated in the OSCR manual.

Mansfield Borough staff constructed three identical vermicomposting bins using a set of Oregon Soil Corporation blue prints for reference. The OCSR blueprint documents were ordered at a cost of $50 for the license. Each bin measured 4 feet in length, 3 feet in width, and 3 feet in height. As shown in **Figure 1**, the bins were constructed of plywood, and protected with a white exterior paint. Air vents were placed on all four sides of the bins to help control moisture. A nylon cord grid was stretched across the bottom of the chamber to provide a screening mechanism. The nylon cord was placed 18 inches from the top of the bin to provide an effective processing volume of 18 cubic feet. **Figure 2** shows the nylon cord placed across the bottom of the vermicomposting chamber.

Figure 1: Vermicomposting Bins

Figure 2: Nylon Cord

3.4 Start-Up Procedure

The following procedure was used to load the bins on the first day of operation:

1. Newspaper was placed across the bottom of the bin chamber, about three to four sheets deep, overlapped, and rolled-up along the chamber side.
2. Four to six inches of mixed waste material was spread evenly across the bottom of the chamber and on top of the newspaper.
3. Water was added, when necessary, to achieve an optimum moisture content of 75%
4. Twelve pounds of redworms were added to the top of the waste material per bin.

After day 1, additional material was added in one to two-inch increments per day until a depth of 18 inches was achieved. The newspaper matting at the bottom of the bin chamber remained intact until the bins were fully loaded. When the bin was fully loaded, the newspaper was poked to allow harvested material to start passing through the screen. A garden rake was used to pull harvested material away from the nylon screen.

3.5 Sampling Parameters

Several operating parameters were measured daily to determine the environmental conditions within the vermicomposting bins. Worm mass sampling was completed near the end of the second month of operation to determine the change in worm mass. **Table 2** describes the daily sampling parameters and the method of measurement. These parameters were monitored for each of the three bins for two months except on weekends.

Table 2: Description and Method of Daily Sampling

Parameter	Description	Instrument/Method
Time	Record the time that sampling began.	Clock
Air Temp (F)	Record the air temperature in the room where the vermicomposting bins are housed.	Thermometer
Bin Temp (F)	Record the temperature inside of each bin at two locations.	Compost Thermometer
% Moisture	Record percent moisture at one central location of each bin.	Moisture Probe
% Oxygen	Record percent oxygen at one central location of each bin.	Oxygen Probe
pH (std)	pH readings might be possible without adding water. If the water is added, use distilled water and record the amount added so that dilution factor can be accounted for.	pH meter
Salinity	Salinity readings might be possible without adding water. If the water is added, use distilled water and record the amount added so that dilution factor can be accounted for.	Salinity meter
Ammonia Detected	Enter "Yes" if an ammonia odor was detected from a bin.	Nose
Rot Detected	Enter "Yes" if the smell of rot was detected from the bin.	Nose
Lid Cover Left Open	If the lid cover was left open for the previous 24 hours to vent heat or moisture, enter "Yes" for this column.	--
Inches of Material Added	Record the depth of waste that was uniformly added to the bin in inches	Visual Estimate
Grit Added	Enter "Yes" into this column if a handful of gritty material was added to the top of the waste mixture.	--
Screen Cleaned	Enter "Yes" if the screen at the bottom of the bin was checked for potential clogs and cleaned, if necessary	--
Material Harvested	Enter "Yes" if material was pushed through or scraped off the screen as finished compost.	--
Worms in Harvest	Enter "Yes" if are worms present in the harvested material.	Visual

Note 1: Biweekly means twice a week.

4.0 VERMICOMPOSTING FUNDAMENTALS

The following section provides background information on the various requirements necessary for sustaining the vermicomposting process.

4.1 Growth Requirements of Bacteria

The growth of both earthworms and mesophilic bacteria is essential to a successful vermicomposting operation. Mesophilic bacteria feed on the organic material within the waste and earthworms feed on the bacteria. For optimal growth, several operating conditions must be maintained, such as temperature, moisture, oxygen, and pH. These operating parameters are further defined below.

Mesophilic bacteria are the dominant bacteria type in a vermicomposting system. Under ideal conditions, mesophilic bacteria rapidly decompose waste. Ideal conditions for mesophilic bacteria include moderate temperatures, adequate moisture, sufficient oxygen, a slightly acidic to neutral pH, and a source of carbon and nitrogen as presented in **Table 3**.

Table 3: Mesophilic Bacteria Preferences

Temperatures in the range of 70 to 100° F Adequate moisture Oxygen in range of 5 to 15%	pH in the range of 5 to 9 C:N Ratio of between 25 to 40:1

4.2 The C:N Ratio is Critical to Microbial Growth

A critical design factor for efficient bacterial growth is the proportion of carbon to nitrogen in the system. Bacteria require carbon for energy and nitrogen for cell synthesis. The appropriate proportions of carbon and nitrogen for efficient cell growth are 25 to 40 parts carbon to 1 part nitrogen [25-40:1, C:N] with a target of 30:1. **Table 4** lists the C:N ratios of the materials of interest in to this vermicomposting project. The data was provided from the "On-Farm Composting Handbook," which is a publication of the Cornell Waste Management Institute, Table B-11 of the OSCR Manual, and compost data provided from the Borough of Mansfield.

Table 4: Carbon to Nitrogen Ratios of Raw Materials to be used in the Vermiculture

Raw Material	% Nitrogen Typical	C:N Ratio Range	C:N Ratio Typical	% Moisture
Leaves	0.9	40 to 80	54	38
Grass clippings	3.4	9 to 25	17	82
Wood chips	0.09	451 to 819	641	--
Activated Sludge	5.6	5 to 16	6	72 to 84
Mansfield Compost	**0.37**	**--**	**100**	**57.8**
Mansfield Biosolids	**5.48**	**--**	**6**	**87**

The Borough of Mansfield provided data for the percent total nitrogen in dry form and the percent volatile solids. In order to estimate a C:N ratio from this data, the carbon content of volatile solids must be assumed. For most biological materials, the carbon content is between 45 and 60 percent of the volatile solids fraction. Assuming 55 percent [Adams, et al, 1951], the formula to estimate the carbon content of volatile solids is: % Carbon = %VS x 0.55.

Problems result when the C to N ratio is not within the target range of 25-40:1. When the ratio is less than 25 to 1, then excess nitrogen will form ammonia gasses, which may harm the earthworms. Conversely, a lack of nitrogen limits the potential for microbial cell growth. When the C to N ratio is in doubt, the OSCR manual states that it is best to err on the side of excess carbon.

4.3 Estimating the C:N Ratio for a Mix of Waste Materials

The following equation provides guidance on estimating the C to N ratio and moisture content for a mix of waste materials simultaneously. The equation from the Cornell composting guide is:

$$R = \frac{Q1(C1 \times (100 - M1) + Q2(C2 \times (100 - M2) + Qn(Cn \times (100 - Mn)}{Q1(N1 \times (100 - M1) + Q2(N2 \times (100 - M2) + Qn(Nn \times (100 - Mn)}$$

Where:
R = C/N ratio
Q = mass of the material ("as is," or "wet weight")
C = percent carbon
N = percent nitrogen
M = percent moisture of the material

4.4 Environmental Requirements for Earthworms

Although several species of earthworms can be used in a vermicomposting operation, the species *Eisenia Foetida*, which is commonly referred to as redworms are used frequently. The redworm population has been observed to double every 90 days under ideal conditions. Redworms have also been observed to consume between one-half and their full body weight in raw material per day.

Redworms need oxygen, moisture, and moderate digester temperatures. The pH, ammonia, and salt concentrations in the bin are important variables to control and maintain during operation, as well. **Table 5** presents a list of ideal environmental conditions for redworms. Since the vermicomposting bins will be stored inside the wastewater treatment plant, low temperatures are not expected to be a problem. If bin temperature approach 90 degrees, however, there are several methods that can be used to reduce the temperature, as described in the next section.

Table 5: Ideal Environmental Conditions for Redworms

Bin temperatures in the range of 40 to 90° F Moisture in the range of 70 to 90% Oxygen in the range of 5 to 15%	pH in the range of 5 to 9 Low ammonia concentration (< 0.5 mg/g) Low salt concentration (< 0.5%)

4.5 Methods of Maintaining Suitable Bin Temperatures

In a flow-through system, such as the ones constructed for this pilot test, the redworms will be concentrated in the top four to six inches of material. The worms will move upward to feed on each layer of waste that is added to the system. When temperature exceeds the comfort range, earthworms will try to escape from the system by crawling to the surface of the material. Below is a list of methods for maintaining suitable bin temperatures.

4.5.1 Precondition the Waste

Preconditioning involves providing time for the pile to cool prior to placing it in the audit box. The temperature of the pile can be measured daily to ascertain mesophilic conditions.

4.5.2 Bin Loading Rate

Acceptable temperatures can also be maintained by adding waste to the bin in thin layers; the lower the loading rate in pounds of waste per square foot, the greater the effect of atmospheric cooling.

4.6 Methods of Maintaining Suitable Moisture

Moisture will be retained in the system with the lid cover. To ensure that the moisture content of the material is within a range of 70 to 90%, a scoop can be picked up by hand and squeezed. If squeezing forces a drop of water to fall out from the hand, then the moisture content is appropriate. A continuous stream of drops indicates that material is too saturated, and the lack of a drop indicates water should be added.

4.6.1 Reducing Moisture

If there is excess moisture in the bin, the cover can be lifted to allow for evaporation.

4.6.2 Increasing Moisture

Water can be added to the bin with a two-gallon bucket. Water should be sprinkled rather than poured over the surface.

4.7 Methods of Maintaining Sufficient Oxygen

Maintaining sufficient oxygen for earthworm survival is expected to be a challenge due the types waste materials to process. Leaves mat down, which creates anaerobic pockets. With biosolids, the high moisture content coupled with the small particle size (high bulk density) also tends to limit airflow through the vermicomposting bins. Anaerobic conditions will be obvious if the material smells like it is rotting. There are several methods for creating and maintaining sufficient oxygen within the system, such as incorporating bulky materials, thorough mixing, and altering particle size.

4.7.1 Incorporating Bulky Materials

The use of chipped wood, tree bark, and shredded paper will help to increase the porosity of the waste mix. Both hard and softwoods tend to degrade slowly. Therefore, it is best to use wood chips that are small enough to pass through the screen at the bottom of the bin.

4.7.2 Mixing

Thoroughly mixing the waste materials with bulking agents prior to placement in the vermicomposting bin will reduce the tendency for matting and clumping.

4.7.3 Altering Particle Size

Part of the mixing process includes breaking up material clumps. A large number of fines and particles of less than ½ inch in diameter results in narrow pore spaces. As the size of pore spaces decrease, there is an increased tendency for the pores to fill with water due to capillary action. Therefore, some large clumps (greater than 2 inches in diameter) are desirable to increase porosity.

4.8 Worm Mass Sampling

Worm mass sampling can help to determine the adequacy of environmental conditions within a vermicomposting bin. Monthly worm mass sampling provides an indication of the change in worm mass over time, and can be expressed in relation to material mass within the bin for comparison with other bins. To determine worm mass relative to material weight, a three-step process is required: produce a sampling core, separate the worms from the material, weigh the worms and the material separately. The result is expressed as the worm mass in pounds per material mass in pounds.

4.9 Sensitivity to Ammonia and Salts

Earthworms are sensitive to both ammonia and salts. Consequently, wastes with a low C:N ratio can pose a threat to the earthworms due to the increased potential for ammonia formation. Salt concentrations of greater than 0.5% have also been shown interfere with earthworm performance. Ammonia and salt concentrations can be controlled with periodically wetting the system.

5.0 INITIAL PILOT TEST RESULTS

5.1 Bin Performance

Spreadsheet results from the three study bins are provided in **Appendix A** for a two-month trial period from June 1 through July 30th, 2002. In the initial trial period, material was not harvested from the bottom of the three study bins. Material was harvested in subsequent months, however, as presented in the Appendix. The bins remained inside the Mansfield Borough wastewater treatment facility for the duration of the observations.

Bin 1 (biosolids bulked with ground wood waste) and Bin 2 (a 1:1 mix by weight of biosolids and leaf compost bulked with ground wood waste) reached relatively stable vermicomposting conditions through the two-month trial period. Bin 3 (leaf compost bulked with ground wood waste) did not reach stable vermicomposting conditions, and the worm population declined significantly within two months of startup. The following provides a qualitative description of the operating conditions observed in the first two months of the trial period, and **Table 6** provides a quantitative summary.

5.1.1 Bin 1: Biosolids Bulked with Ground Wood Waste

For Bin 1 (biosolids bulked with ground wood waste), the moisture content and moderate bin temperatures were relatively easy to maintain during the two-month trial period. A total of eight gallons of water was added over the two-month period, far less than was added to Bin 2 or Bin 3. Anaerobic conditions did not become a problem. Bin 1 had a low initial C:N ratio, which was a cause for concern due to the increased potential for ammonia formation. However, ammonia odors were not detected by smell during the trial period. Based on visual observations of the bin activity during the two-month time period, the worms appeared to remain active and productive.

5.1.2 Bin 2: 1:1 Mix by Weight of Biosolids to Leaf Compost

Relative to Bin 1, Bin 2 (a 1:1 mix of biosolids and leaf compost bulked with ground wood waste), moisture was more difficult to maintain, but not problematic. Twenty-two gallons of water was added over the two-month period. In this time, neither the smell of rot nor ammonia was detected. The average bin temperature across the two-month period was 89 degrees (F), nine degrees (F) higher than the average temperature for Bin 1, as presented in Table 6. Fourteen pounds of grass clippings was added to boost the nitrogen content of the mix. The worm population remained active, and worm growth appeared to be the most prolific of the three bins.

5.1.3 Bin 3: Leaf Compost Bulked with Ground Wood Waste

Maintaining moisture and moderate bin temperatures was problematic for Bin 3 (leaf compost bulked with ground wood waste). The bin lid remained open for the entire two-month period to allow for venting. Forty-five gallons of water was added to maintain moisture content. The bin temperature averaged 88 degrees (F) for the testing period. Fourteen pounds of grass clippings were added to boost the nitrogen content of the mix. Despite these efforts nearly all of the worm population had died off by the end of the two-month trial period.

5.2 Average Bin Values

Table 6 lists the average values for bin temperature, moisture, oxygen, and pH, and total values for the amount of water and compost material added. Complete sampling logs for the June and July are provided in the **Appendix**.

Table 6: Results of Daily Sampling After Two Months of Operation

Parameter	BIN 1 Biosolids	BIN 2 1:1 Mix of Biosolids and Leaf Compost	BIN 3 Leaf Compost	Target Range
Average Bin Temperature (F)	80	89	88	70 to 90
Average Moisture Content[1]	9.9	10.0	8.7	70 to 90%
Average Oxygen Content (%)	18.9	18.3	18.4	5 to 15
Average pH	6.9	7.0	7.1	5 to 9
Total Water Added (gal)	8	22	45	--
Total Material Added (lbs)	318	108	56	--

Note 1: The moisture probe uses a scale of 0 to 10, which is correlated to plant watering needs rather than percent moisture.

5.2.1 Bin Temperature

The average temperature of bins 2 and 3 remained consistently warmer than bin 1. This difference in temperature was expected due to the presence of partially composted leaf waste. In order to keep the temperatures below 90° F, the bin lids remained open nearly all of the time, and material loading rates were reduced proportionally.

5.2.2 Moisture Content

Average moisture was maintained at the higher end of the scale by adding water in one and two-gallon increments. The average moisture content of bins 1 and 2 was easier to maintain due to the presence of the biosolids, which tend to retain moisture.

5.2.3 Oxygen Content

The average oxygen content in the three bins was not only greater than expected, but oddly similar. Oxygen content is often measured at less than 10% within composting heaps. Comparatively, oxygen concentration should have been less in bins containing biosolids due the difference in density and moisture content. Use of a different probe appears to be necessary.

5.2.4 pH

Average pH readings appeared similar and within a neutral range for all three bins.

5.2.5 Worm Mass Sampling

Worm mass sampling is a good indicator of vermicomposting performance. Use of a two-inch diameter PVC pipe to produce a worm mass sampling core could not be accomplished. The downward force of the PVC pipe put excessive strain on the nylon cord support system. Qualitatively, worm mass appeared to be greatest in the bin containing the 1:1 mix by weight of biosolids and leaf compost. It also appeared to be adequate in the bin containing only biosolids and chipped wood in a 1:1 ratio by volume. At the time of the sampling, there were very few worms living in the bin of leaf compost and chipped wood.

5.3 Vermicompost End Product

Processed vermicompost material was removed from the bin by dragging a rake along the bottom of the nylon support mesh periodically. The harvested material was then separated by size using a sieve into coarse (1/2-inch or larger), fine (1/4-inch), and castings (1/8-inch or finer), and placed in a 55-gallon barrel for storage. The material harvest quantities for each bin are presented in **Table 7**. A month-to-month listing of harvested quantities is provided in the **Appendix**. Worm hatchlings appeared in the harvested material on several occasions. These hatchlings were collected and returned to the top of the bin.

Table 7: Total Harvest Quantities in Pounds (August 2002 to October 2002)

BIN 1 Biosolids			**BIN 2 1:1 Mix of Biosolids and Leaf Compost**			**BIN 3 Leaf Compost**		
Total Material Added		**786**	Total Material Added		**1,263**	Total Material Added		**735**
Coarse	Fine	Castings	Coarse	Fine	Castings	Coarse	Fine	Castings
213.5	142.5	222	174	*109	435	145	*79	230
Harvest Total		**498.5**	Harvest Total		**718**	Harvest Total		**454**

*Some of the material was returned to the bin and was not included harvest totals

6.0 CONCLUSIONS AND RECOMMENDATIONS

From the first phase of pilot testing, it appears that the combination of leaf compost and biosolids can provide a suitable environment for worm growth. Ground wood waste appears to have provided adequate porosity as a bulking agent for microbial and worm growth. Periodically wetting the system appears to have provided sufficient moisture. The best mix of the three tested, based on worm mass population, is the 1:1 mix of leaf compost and biosolids. This mixture also included ground wood waste as a bulking agent, which was mixed in at a 1:1 ratio by volume.

Pilot studies have continued since the initial two-month trial period for the purpose of identifying the ideal mixture of leaf compost and biosolids. Since July, Bin 3 was cleaned out and restarted with a 1:1 ratio of biosolids to leaf compost by *volume* rather than by *weight*. Bins 1 and 2 were operated for a period with the initial proportions of materials.

At this time the three Bins have been consolidated to one bin containing a 1:1 leaf waste and composted biosolids mix (and wood waste bulking agent) as the final bin. Based on this pilot, this final mix has produced the highest worm activity, most stable bin conditions, and best material end product in terms of rate and quality of the material produced.

Further testing will be done on the harvested material to determine its capacity to support plant growth. Employees of the Mansfield Borough WWTP are working with a local gardener to set up such an experiment. Tests will also be done eventually on the harvested material to determine the level of pathogen and vector attraction reduction achieved.

Recommendations (if not already performed) to consider for continued pilot testing include the following:

- The use of different oxygen and moisture probes would help to compare the results with other documented studies.
- The bin height could be extended by 12 to 18 inches to provide enough time and space for worm hatchlings to crawl upwards toward the fresh waste.
- The additional weight of 12 to 18 inches of material, however, is likely to produce excessive strain of the nylon support system. In such a case, the nylon cords should be replaced with rebar.