EVALUATION OF THE COMPOST PROCESS, ANALYSIS OF THE MANURE-BEDDING MIXTURE INPUTS AND COMPOSTED PRODUCT MEASUREMENTS FOR IAGER BUILT-IN-PLACE COMPOST UNIT:

FINAL REPORT

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Preface:

The data and much of the text was originated by Dr. Patricia Millner (USDA-ARS-BARC-Environmental Microbial and Food Safety and Sustainable Agricultural Systems Laboratories, Beltsville, MD 20705. 301-504-5631, Pat.Milllner@ars.usda.gov). The analysis and evaluation is built on her data and analysis. Additionally, Mr. Michael Calkin (Howard Soil Conservation District) provided invaluable system supervision, input, and data.

Introduction:

The composting unit on this dairy farm aids in the processing of dairy manure waste to create a safer and easier-to-manage product. Removal of the manure and bedding material from the site would add additional costs. Surface application to crop fields of unprocessed manure may increase the probability that nutrients could leach or runoff to the waters of the state. By composting the manure mixture, it can reused as bedding, used more safely and efficiently as a nutrient source for land application and/or sold to local landscapers or farmers for their farmland. The Green Mountain Technologies site-built compost unit (SBCU) is a covered channel, aerated, and mixed compost system (trade name earthflow). While loading can occur over time, this is essentially a batch system.

The nutrients in manure are a mixture of inorganic and organic forms. Many of the inorganic nutrients in manure are the same as those available from a commercial fertilizer. These nutrients include ammonium nitrogen, soluble phosphate, and potassium salts. They are more or less soluble in water, and plants and soil microbes can utilize them right away. Because the raw bedded manure is non-homogenous and the nutrients are not immobilized, there is still potential for leaching of N and P from uncomposted bedded manure. Nutrients that reach surface and ground water cause water quality degradation through eutrophication and algal blooms. Composting reduces soluble phosphorus and potassium salts by microbial immobilization according to Cornell Study "Effects of Aerobic Composting on Nutrient Content" March 2006, Northeast Dairymen. During composting, nitrogen is reduced through ammonia loss in vapor (volatilization) and immobilization in the biomass. One of the goals of this project is to more clearly document the nutrient fate and impacts of manure in the paddock and stall environments and how composting impacts nutrient fate and transport.

GMT Claims to be tested

1. Output material from the site-built system is stable.
2. Finished compost will be suitable for bedding re-use.
3. Finished compost will be suitable for soil amendment for field application.
4. Finished compost will be suitable to be sold off site commercially to local organic growers for cropping or landscaping.

Physical Set-up and Operations for the Built-In-Place Compost Unit.

The site originally selected for building the compost unit changed to another Iager farm in Frederick County. The Iagers farm in Fulton sold the dairy cows and was put to other uses that did not generate the necessary waste and bedding products. The layout and plan view in the proposal (pp17-19) bears little resemblance to the project as-built. However, the facility that was built in Frederick is very appropriate for a dairy operation such as the Frederick County Iager operation.

The unit was first started when the installation was complete in December 2015, while the GMT installation crew was still on-site. The manure waste material was loaded and the unit turned on. It ran successfully for the duration of their visit. Shortly thereafter the weather made access to the unit impossible. Much of the entire farm was under construction during the previous summer and fall months, leaving the ground unstable once rain, snow, and freezing and thawing temperatures took place. After months of inactivity, the unit was put back to work. There were a few minor adjustments that were taken with a sensor switch and the drive chain due to overloading of the unit. Once the feedstock (manure and dairy barn waste) was removed to the height stipulated in the operation manual, the unit functioned appropriately.

Financial analysis of the site-built compost unit

This was relegated to the Environmental Finance Center at the University of Maryland and results are posted at mda.maryland.gov. Some qualitative benefits of the system are listed below that indicate where improved economics might come from.

Economic benefits

- Cost of manure removal from farm system - cost avoidance.
- Nutrient stability – reduced nutrient losses translates to better water quality and is a societal benefit. Cost share from state or federal sources would make this a farm operation income benefit.
- Reuse as bedding or sale of product off farm as bedding would become either a cost avoidance or a value-added farm income.
- Reuse/recycling of stabilized nutrients – reduced fertilizer costs.
- Pathogen reduction may result in improved herd health – better production (income) and lower herd health care costs (cost avoidance).
- Offsite sales of compost product – additional farm income stream

Expenses

- Management/labor costs to manage the system appropriately and perform extra tasks associated with compost operation.

- Electrical costs for mixing auger, air compressor.
- Depreciation, interest, repairs, taxes, and insurance.

Temperature Data/Pathogen Kill

The site-built Earth Flow compost unit at the Iager's Glamour View farm was used approximately 3 times a year to compost bedding from the heifer barn. When it is operating, the compost is stirred twice a day at approximately 6 AM and 8 PM, based on temperature readings (figure 2). It operates for approximately 21-30 days, it is unloaded, and sits idle for 60 or more days (figure 1).

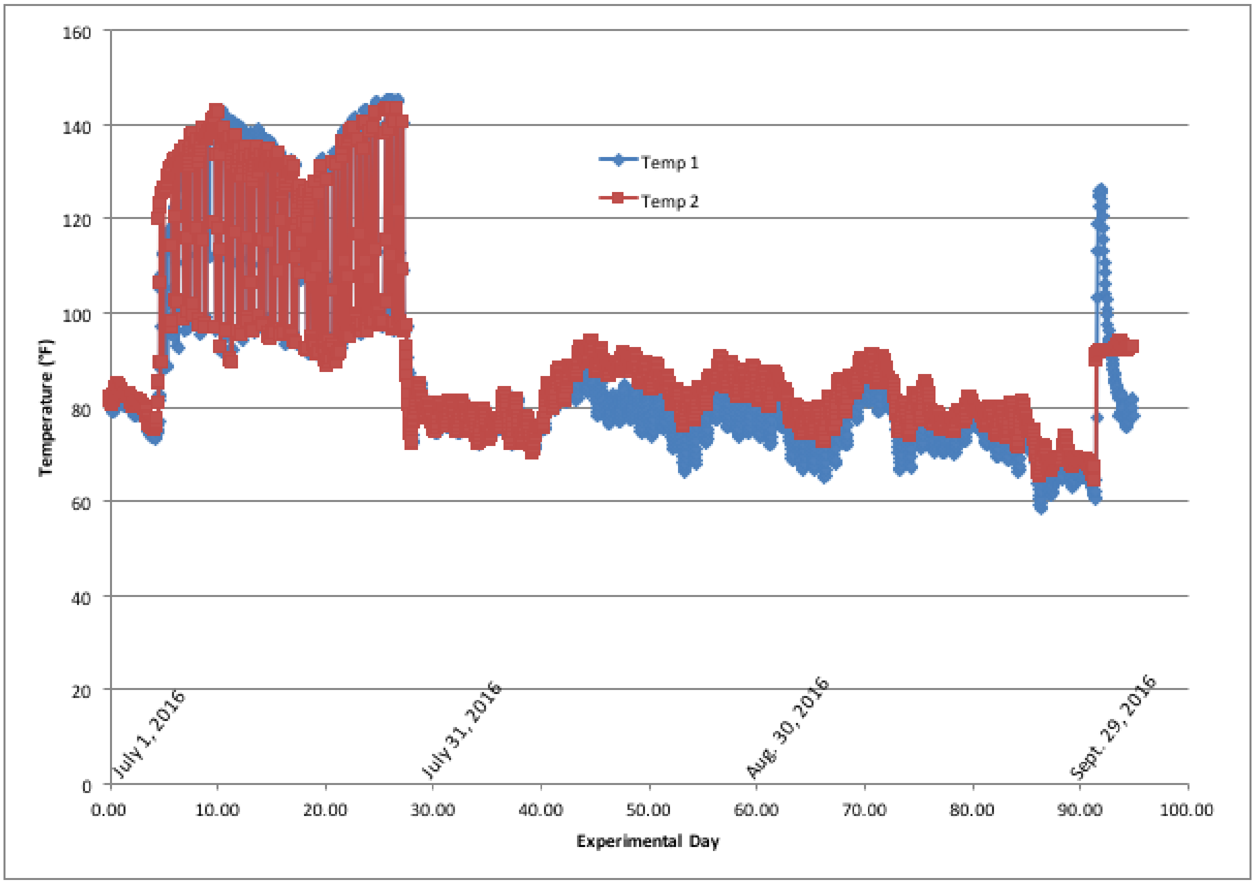

Figure 1 Temperature logs of site-built earthflow compost unit illustrating the compost cycle and the idle time.

Temperatures are measured at two locations (Temp 1 and Temp 2 in figure 1). Each location is one third of the length from an end and halfway up from the bottom of the channel. Temperature probes penetrate horizontally approximately 36 inches into the channel and are inserted automatically and withdrawn only while the auger mixing is occurring. Hence, temperatures are taken at locations that are most likely to undergo sufficient heat.

During idle times (mid July to the end of September in figure 1), when the channel is empty, there is a difference in temperatures at the two locations. While active composting is occurring, there is not much of a difference between temperatures at the two locations.

Figure 2 illustrates the temperature at one location during active composting. PFRP is the Process to Further Reduce Pathogens specified in 40 CFR part 503 and as part of the definition specifies that compost in a static pile reach 55°C (131°F) and remain at or above this temperature for 3 days. The time between compost initialization and reaching 131°F (PFRP temperature) was approximately 3 days. Because the channel is stirred every day, it does not maintain temperature for more than approximately 12 hours. This is problematic for the definition of PFRP, but functionally, the compost maintains heat generation for approximately 21 days and the daily peak is continuously in excess of 131°F until the day it is unloaded. The compost gradually cooled from day 10 to about day 18 or 19. At that time, the maximum temperature dropped to approximately 124-125°F. It then went through a second increase in temperature. There are no notes to indicate if more feedstock was put into the channel, or water added, or anything else that might cause increased heat generation.

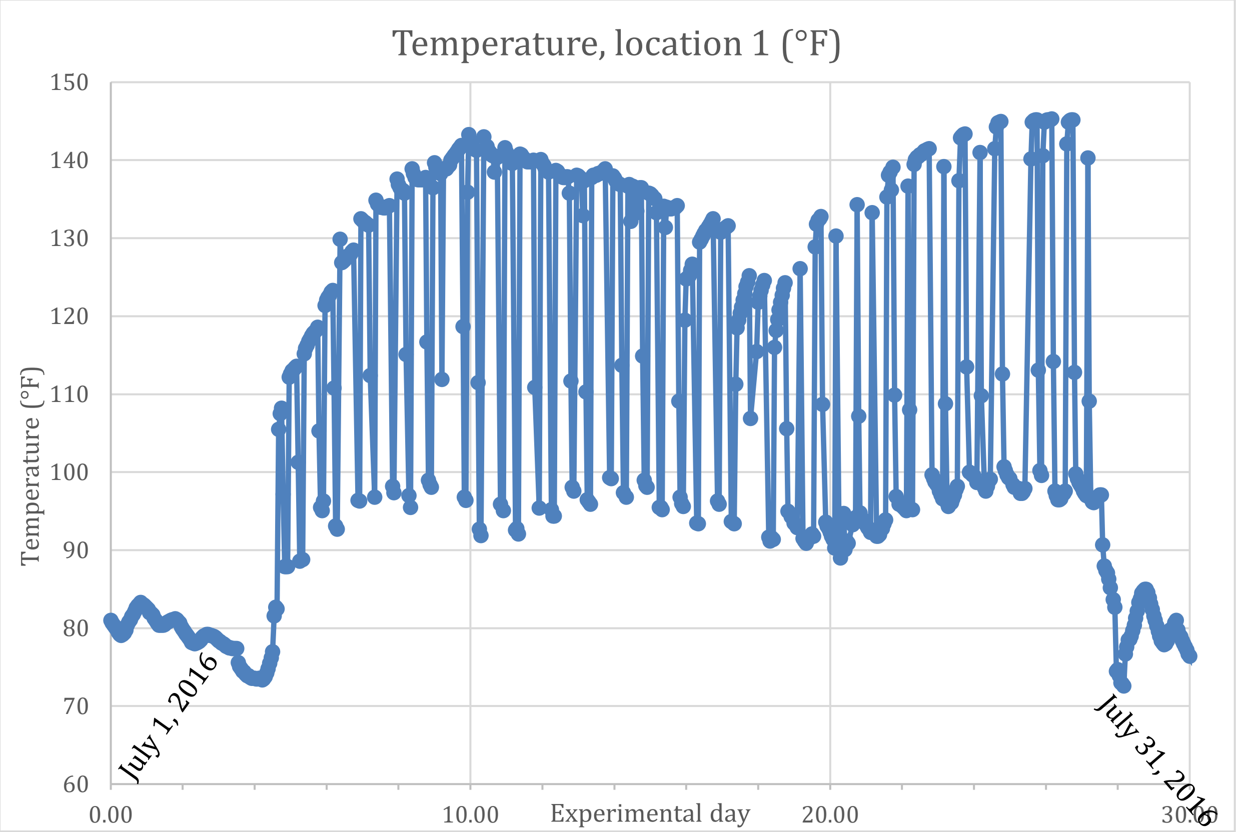

Figure 2. Compost temperatures during active composting at one location in the site-built earthflow compost unit at the Iager Glamor View farm during July, 2016.

Figure 3 is figure 2 with the second temperature measurement location overlaid. Though maximum and minimum daily temperatures vary by a few degrees and there is a time lag of a few hours at some points, the overall temperature response is comparable. That provides some confidence that we are seeing real responses and the sensors are responding appropriately. Figures 2 and 3 also provide data to suggest management changes. The material is still heating up at the time of unloading. That means the material had not finished the active phase of composting and should be allowed to compost until the peak temperatures drop much lower. The compost coming out will continue to be biologically active. Field application at this point would result in nitrogen capture by the biologically active compost and would induce nitrogen starvation in any plants on the field or planted just following application. There is no data concerning curing time or to indicate that curing occurred. Hence, if the compost was to be used immediately from the channel, it would be much more beneficial to allow it to actively compost much longer than the 21 days it composted in this cycle. This is purely a management choice and does not reflect on the design and construction of the SBCU.

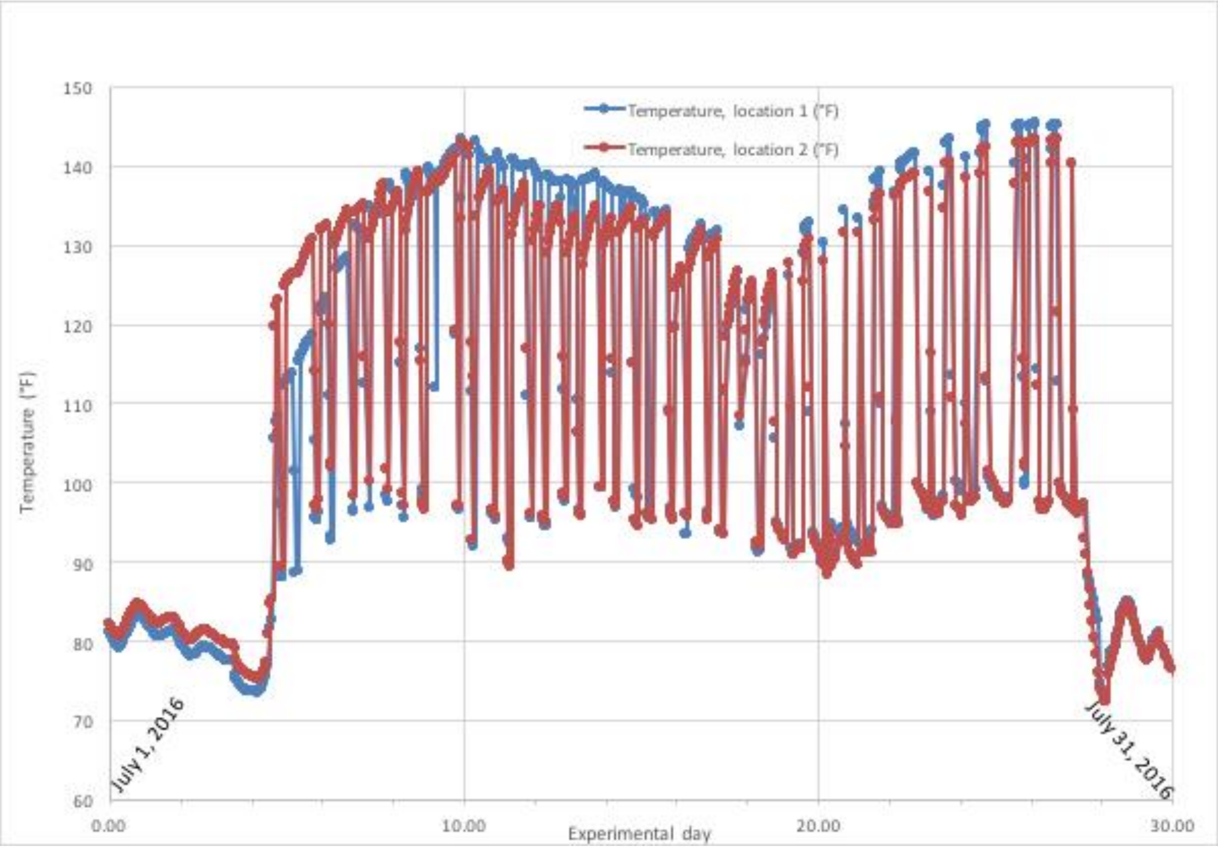

Figure 3 Compost temperatures during active composting at both locations in the site-built earthflow compost unit at the Iager Glamor View farm during July, 2016.

Bedding from a clean-out of the heifer barn was again composted in January, 2017 (see fig. 4). The temperature data were almost useless because of sensor failures. The sensor at location 2 failed on January 2, January 7, and January 10. The failure was permanent on January 10. As a result, no data for sensor 2 was collected between January 10 and January 21, when the channel was unloaded. The sensor at location 1 was somewhat more reliable but there were still significant gaps. Temperatures were above 131°F on January 1 and 2. All temperatures that were collected for the duration, through January 21, were below

131°F. That suggests that PFRP may not be met during winter conditions. Oddly, the few temperatures that were available during this composting process did not have daily fluctuations, suggesting that the daily mixing was not occurring. No information on reasons for sensor failure was provided. This may be the one structural failure of the SBCU design and specifications.

We have no data on the air injection component of the compost operation, so we don't know if oxygen was sufficient for vigorous microbial growth. It is possible that the temperatures dropped below PFRP levels because of oxygen limitations on microbial growth.

In a typical windrow, heat from the compost process (microbial growth) rises through the pile and exits the top of the windrow. Make-up air is pulled from the bottom of the pile and a convective air current is established that provides a constant supply of oxygen to the microbes.

Without air injection and auger mixing, the GMT channel is a concrete box with virtually no way for air to enter the bottom of the pile and heat to create convective air flow currents that would bring oxygen to the microbes throughout the composting material.

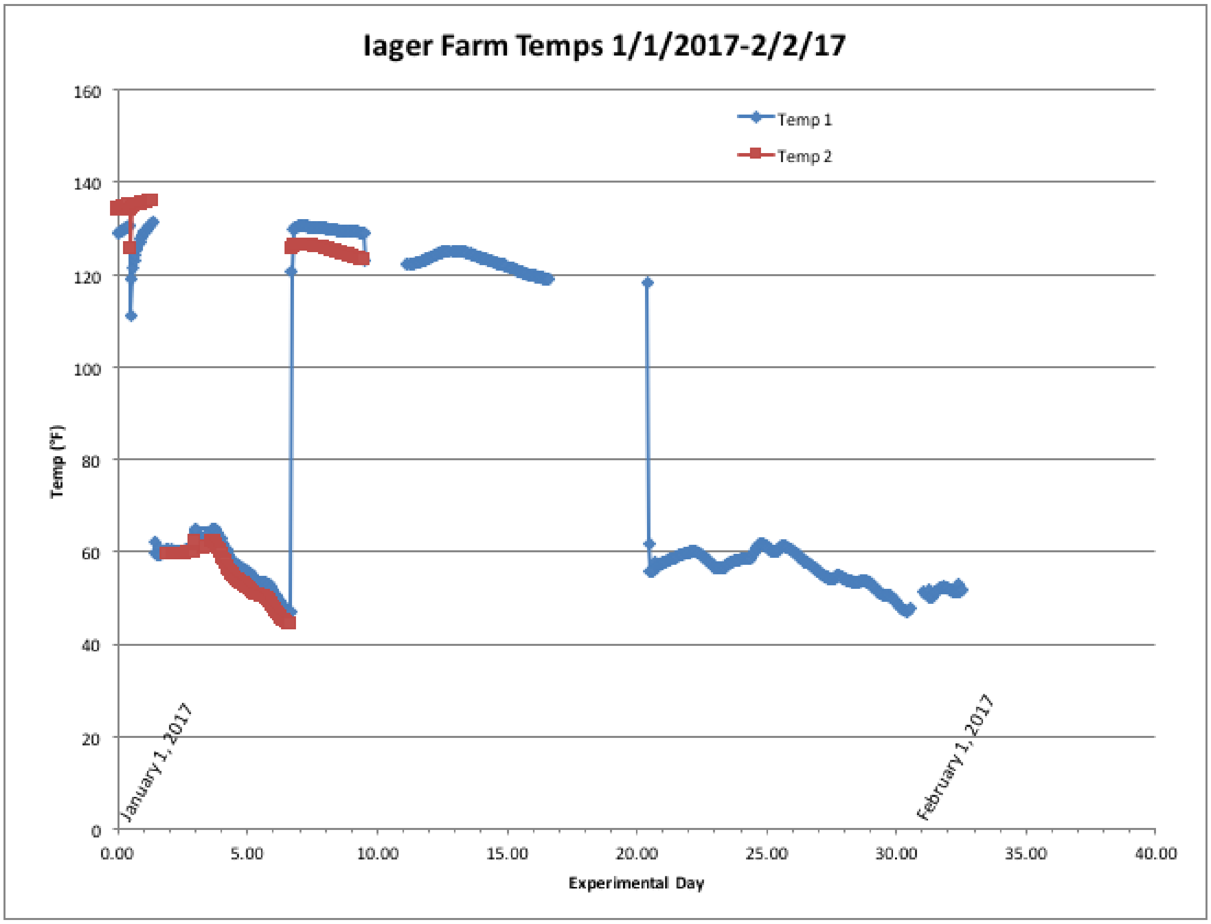

Figure 4 Winter compost temperatures in site-built earthflow compost unit at the Iager Glamor View farm during January 2017,

Pathogen Testing

The Most Probable Number (MPN) method is a method of getting quantitative data on concentrations of discrete items from positive/negative (incidence) data. While the MPN method does not exactly measure the number of coliforms present in a sample, it does give an estimate and can determine whether or not the water is below the safe threshold for potable water. The process is to dilute the sample to such a degree that sample tubes will sometimes but not always contain viable organisms. The total number of tubes and the number of tubes with growth at each dilution, will imply an estimate of the original, undiluted concentration of bacteria in the sample. In order to obtain estimates over a broad range of possible concentrations, serial dilutions are used.

The fecal coliform populations in compost samples were approximately 1000-fold less than those in the starting manure-bedding mix samples (Table 1). This reduction is significant and consistent with findings from other effective compost operations.

Table 1 Results of Fecal Coliform enumeration for designated samples from GVF for manure mixed with bedding material input to compost units, and compost removed from the corresponding units on 6/29, 7/06, 7/11, and 7/27/ 2016.

EPA Method 1681

MPN results (number of tubes positive per 3 tubes per dilution level) for fecal coliforms (fc) /gm wet wt

		30 g/270mL	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	
FARM[a]	**Sample#**	**primary dilution, 1:10**	**MPN diln1 Fc**	**MPN diln2 Fc**	**MPN diln3 Fc**	**MPN diln4 Fc**	**MPN diln5 Fc**	**MPN diln6 Fc**	**MPN/gww**
GVM	629	3/3	3/3	3/3	3/3	3/3	2/3	0/3	1.1 x 10^{7}
GVM	706	3/3	3/3	3/3	3/3	3/3	3/3	0/3	2.4x 10^{7}
GVM	711	3/3	3/3	3/3	3/3	3/3	3/3	0/3	2.4x 10^{7}
GVM	727	3/3	3/3	3/3	3/3	3/3	3/3	0/3	2.4x 10^{7}
GVC	629	3/3	3/3	3/3	2/3	0/3	0/3	0/3	1.1 x 10^{5}
GVC	706	3/3	3/3	1/3	0/3	0/3	0/3	0/3	4.6 x 10^{3}
GVC	711	3/3	3/3	0/3	0/3	0/3	0/3	0/3	2.4 x 10^{2}
GVC	727	3/3	2/3	2/3	0/3	0/3	0/3	0/3	2.1 x 10^{2}

[a] GVM indicate samples of manure mixed with bedding input for composting;
GVC designate unloaded compost samples.

Bulk density

No bulk density data were found for the Iager farm feedstocks or final compost product. No data were found for curing, it is not known if curing occurred.

Moisture content

The moisture content of the GFV compost increased slightly compared to that in the starting mix (Tables 2 and 3) and was within acceptable ranges for the continued metabolical-heat-generating microbial decomposition during the period.

Nutrient Data from Iager Built-In-Place Compost Unit

Samples were collected for nutrient analysis four times during the July 2016 composting event. The samples were collected on June 29, 2016 and this was a pre-composting sample collected as the feedstock was loaded into the site-built composter. Samples were then collected on July 6, July 11, and July 27 of 2016 (Tables 2 and 3).

For the input feedstock mix, the average total nitrogen (N) of 0.39% was comprised of 0.04% ammonia-N in the loaded mixture (over the study period) with 51% moisture and 49% solids, and a total carbon content of about 44%, resulting in a C:N ratio of 53. Total phosphorus in the loaded mixture was 0.04% (wet weight basis). P_2O_5 was 28% of the total P (Table 2).

For the compost produced during this period, the total nitrogen averaged 0.97% (9703 mg/kg) of which 0.09% was Ammonia (868 mg/kg) and 0.89% was organic Nitrogen (8835 mg/kg) and 444 mg/kg nitrate-nitrite Nitrogen. The total carbon was 48.98% (489,750 mg/kg), resulting in a C:N ratio of 50.75 with an average moisture content of 53.39% (Table 3). Minerals analyzed from the manure (data not shown) and unloaded compost showed variability between samples collected on the different dates, but all measured concentrations of Calcium, Magnesium, Sodium, Iron, Aluminum, Manganese, Copper, and Zinc were within acceptable ranges.

The average C:N ratio of 50.75 in the unloaded compost (Table 3) indicates incomplete composting from the perspective of carbon decomposition. Use of this product as a soil amendment will lead to immobilization of the approximately 1% nitrogen in the compost and can result in adverse plant growth impacts due to the shortage of nitrogen, unless additional nitrogen fertilizer is supplied at the time of compost application. Curing may reduce the C:N ratio. The average N:P ratio for the unloaded compost was 2.34.

Table 2 Chemical analyses of dairy manure with bedding samples from GVF composting system input.

	Average				GVM62916		GVM70616		GVM71116		GVM72716	
Parameter	As rec'd	stddev	dry basis	As rec'd	As rec'd	dry basis	As rec'd	dry basis	As rec'd	dry basis	As rec'd	dry basis
Nitrogen, N %	0.39	0.093	0.79	0.081	0.483	0.87	0.264	0.542	0.374	0.867	0.422	0.895
Ammonia N, %	0.04	0.024	0.06	0.029	0.026	0.046	0.022	0.045	0.059	0.136	0.002	0.004
Phosphorus, P %	0.04	0.017	0.18	0.006	0.021	0.37	0.06	0.12	0.05	0.11	0.05	0.1
Potassium, K %	0.23	0.266	0.80	0.292	0.13	0.23	0.03	0.61	0.53	1.22	0.54	1.14
Moisture, %	50.9	5.168			44.5		51.3		56.9		52.9	
Solid, %	49.1	5.168			55.5		48.7		43.1		47.1	
Carbon (TOC) %	43.99	15.504			57.71		22.42		51.84		41.17	
K20 (as rec'd) %	0.57	0.155			0.708		0.36		0.636		0.648	
P2O5 (as rec'd) %	0.28	0.229			0.58		0.137		0.114		0.114	
Volatile Solids %	71.36	23.216			86.35		38.57		89.16		70.81	
C/N RATIO *	52.9	9.145			57.71		41		60		46	

Table 3 Chemical analyses of GVF composted dairy manure with bedding output.

Parameter	GVC72716 RESULTS		GVC71116 RESULTS		GVC70616 RESULTS		GVC62917 RESULTS		QUANTITATION LIMIT
	(%)	(mg/kg)	(%)	(mg/kg)	(%)	(mg/kg)	(%)	(mg/kg)	(mg/kg*)
Total Solids *	45.48	454800	41.59	415900	34.26	342600	65.09		100
Moisture *	54.52		58.4		65.74		34.91		100
Total Kjeldahl N	1	10000	1.02	10200	0.89	8900	0.97		10
Total Phosphorus	0.41	4140	0.44	4390	0.47	4720	0.33		100
Total Potassium	1.1	11000	1.04	10400	0.95	9500	1.22		100
Ammonia N	0.03	330	0.11	1110	0.13	1310	0.07		10
Organic N	0.97	9670	0.91	9090	0.76	7590	0.90		0.001
Nitrate+Nitrite-N		183	1720	2		1530			2
Volatile Solids	87.36	873600	87.39	873900	90.88	908800	71.41	714100	CALCULATION
C/N	51		50		59	43			CALCULATION
Carbon (TOC)	50.8	508000	50.8	508000	52.8	528000	41.50	415000	CALCULATION

During the January 2017 21-day composting cycle, Green Mountain Technologies collected samples at both ends of the channel (loading end and unloading end). These samples were collected at three times: the start, the middle, and the end of the 21 day composting period. These samples were analyzed for total N, NH_4-N, total P, total K, total Ca, total Mg, total S and water extractable phosphorus (WEP). Additionally, the samples were analyzed for total Cu, total Zn, total Mn, total Fe, total Na, and total Al. Table 4 presents the average values (average of 6 samples) and standard deviation on a dry weight basis.

Table 4 Average nutrient and metals content (dry weight basis) of compost from site built composting operation during January, 2017.

	Total N	NH_4-N	Total P	Total K	Total Ca	Total Mg	Total S
Average % (Stdev %)	1.880 (0.200)	0.011 (0.005)	0.867 (0.224)	0.559 (0.164)	1.190 (0.253)	0.426 (0.097)	0.377 (0.076)
	Total Cu	Total Zn	Total Mn	Total Fe	Total Na	Total Al	
Average mg/kg (Stdev mg/kg)	64.9 (16.7)	123.5 (24.4)	204.4 (15.2)	2353.5 (564.8)	5052.0 (873.8)	1666.0 (427.9)	

Water Extractable Phosphorus (WEP) is more or less an estimate of phosphorus that might leave the material if it was surface-applied and exposed to a runoff-generating storm. Figure 5 illustrates the WEP in these samples.

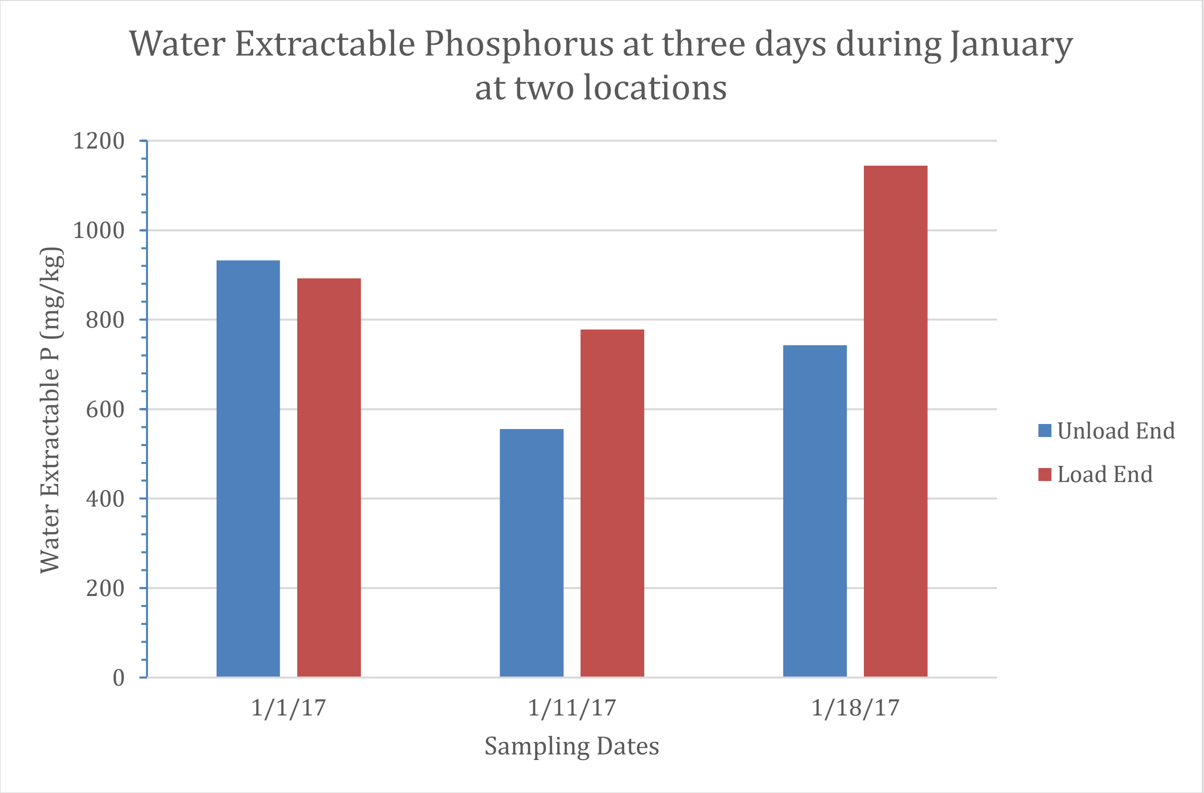

Figure 5. Water extractable phosphorus from the GMT-Iager composting unit.

As composting occurs, mass, in the form of CO_2, is lost from the pile due to microbial respiration. An increase in WEP with time due to loss of mass would be expected but was not apparent. The WEP varied between approximately 580 mg/kg and 1170 mg/kg. The variation is most likely normal variation for a heterogeneous feedstock of manure and bedding. The overall average of 841 mg/kg is as representative as any number for WEP from dairy manure and bedding compost. Normal variation between samples is probably dominant and masking any increase in WEP due to microbial respiration with associated decrease in total mass.

Stability Tests

No conventional stability tests were done on the compost material. However, temperature data suggests the material was removed from the channel because the temperature was cycling on a daily basis with high temperatures in excess of 131°F (55°C) until the 21 day cycle was over and the temperature returned to ambient the next day and remained there. Because the composting material was removed while it was still generating significant heat, the compost was no where near stabile or mature.

Nutrient analysis determined that the average C:N ratio of 50.75 in the unloaded compost indicates incomplete composting from the perspective of carbon decomposition. Use of this product as a soil amendment will lead to immobilization of the approximately 1% nitrogen in the compost and can result in adverse plant growth impacts due to the shortage of nitrogen. This also supports the conclusion that the compost was not stabile or mature.

Mass Flow

Due to the lack of information on the amounts and frequency of manure-bedding mix additions to and unloadings from the composting system, calculations of mass of compost produced per unit time cannot be presented here. It is unclear if the compost was cured, because no meta-data about anything that was done with the compost and the frequency, temperatures, and management were not annotated on any data files that were transmitted. No temperatures were provided for any curing pile if curing was conducted. No samples were collected and analyzed post-curing.

Built-In-Place Compost Unit Durability

There were several unexpected down times, related to broken parts in the composter. It is my supposition that a lack of familiarity with the daily activities on a dairy farm caused the design team to overlook some of the things that can be brought in during feedstock loading. In most compost operations, this is referred to as “contamination”. In many operations, this is often plastic bags and glass shards.

A dairy operation, or many livestock operations for that matter, uses a front end loader to clean out the heifer barns and load the composter. The manure pack can have large pieces of metal (door handles, hinges, bolts for a door (24”X 3”X 1/2” piece of steel), large rocks from the surrounding farm yard, cinder blocks, and assorted other large, heavy, potentially-damaging objects.

These types of objects were responsible for most of the breakdowns. For use in an agricultural setting such as dairy farms, these objects should be managed before the feedstock gets into the composter. A pair of vibrating screens at the loading end (6” and 3” mesh for example) might be one way to manage the contamination. This seemed to be the single outstanding design change that would improve function and end product. The SBCU compost unit was quite suitable for performing the composting operations.

Summary

GMT Claims

1. Output material from the site-built system is stable.

   This was addressed and the compost shows no evidence of being stable. Management regime changes could easily change this.

2. Finished compost will be suitable for bedding re-use.

   The meaning of “suitable for bedding re-use” was not quantified in the proposal, so there was no way to objectively test this claim.

3. Finished compost will be suitable for soil amendment for field application.

   This was addressed and the compost shows no evidence of being suitable for soil amendment for field application. Again, the problem is stability and maturity and management regime changes could easily change this.

4. Finished compost will be suitable to be sold off site commercially to local organic growers for cropping or landscaping.

   The meaning of “suitable to be sold off site commercially to local organic growers for cropping or landscaping” was not quantified in the proposal, so there was no way to objectively test this claim

Structural design issues.

There are two structural/design issues. The failure of the temperature probes during the January 2017 cycle needs to be investigated and solved. As was illustrated several times in this report, temperature is the major feedback mechanism to determine how well the compost system is operating. Consistent and dependable temperature measurement and recording is essential.

The second issue is the impact of “large foreign bodies” (e.g. large pieces of metal (door handles, hinges, bolts for a door (24”X 3”X 1/2” piece of steel), large rocks from the surrounding farm yard, cinder blocks, and assorted other large, heavy, potentially-damaging objects) should be addressed. Possible approaches include i) prescreening all materials apart from the SBCU, ii) adding a vibrating screen system to the loading end of the SBCU, iii) using labor to hand-pick large foreign bodies out of the incoming feedstock, iv) developing an auger resistance module to lift the auger out of the compost when resistance became extensive. This is not an exhaustive list, but only some ideas that might make the SBCU more robust in the face of everyday operating conditions in normal agricultural operations.

Management

The compost leaving the SBCU will be biologically active as long as the cycle is 21 days and no curing occurs. It is likely that this would not meet theState of Maryland's definition of compost (see COMAR) and could not be sold. Management regime changes to a longer cycle that used decreasing temperature as an indicator of approaching stability in concert with a curing period would easily fix this.

Data collection issues.

There were several failures in data collection.

Bulk density data is not hard to do. A data sheet was provided. It must be that close supervision of the person or persons responsible for this work was necessary, but didn't occur. It is also possible that insufficient labor was provided in the monitoring contract.

Stability tests should have been performed when the compost was unloaded from the SBCU. If curing occurred, stability tests should have been performed when the compost was moved from the curing site to the field. These are relative simple tests and can be done with only a small amount of training and supplies.

Mass flow has been the most difficult parameter to collect on many compost projects. It almost requires dedicated scales (usually expensive) and a supervisor that will not allow a sale of compost to occur without a mass measurement. This requires a dedication to the data collection portion of the project.

Is the SBCU adequate and did it live up to the claims: The structural SBCU is adequate for composting. It falls a bit short in adequacy of operating in an operational dairy environment. The failure of temperature sensors needs to be addressed. The claims were not met in two of the four claims, due to management rather than structural failure. The other two claims were not defined satisfactorily and could not be evaluated. This system does a good job of composting but falls just a bit short. A few management and structural changes and additions would make this a very suitable turn-key compost system for a dairy operation.