EVALUATION OF THE COMPOST PROCESS,

ANALYSIS OF THE MANURE-BEDDING MIXTURE INPUTS AND

COMPOSTED PRODUCT MEASUREMENTS

FOR DAYS END FARM

December 31, 2017

Gary K. Felton
University of Maryland Environmental Science and Technology Dept.
College Park, MD 20742-2315
(310) 405-8039 gfelton@umd.edu

Table of contents

EVALUATION OF THE COMPOST PROCESS,

ANALYSIS OF THE MANURE-BEDDING MIXTURE INPUTS AND

COMPOSTED PRODUCT MEASUREMENTS

FOR DAYS END FARM

Gary K. Felton
University of Maryland Environmental Science and Technology Dept.
College Park, MD 20742-2315
(310) 405-8039 gfelton@umd.edu

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 Co. Soil Conservation District) provided invaluable system supervision, input and data.

Introduction:

Days End Farm Horse Rescue™ Inc. is a 501(c)3, nonprofit, volunteer-based animal welfare organization established in 1989 to ensure quality care and treatment of horses through intervention, education and outreach. The farm is located at 1372 Woodbine Road, Woodbine, Maryland. Days End Farm shelters 110 to 150 horses annually on 58 acres. The horses that arrive often are treated for helminthic infections. The ova of helminths are among the most difficult to destroy and hence the need for attaining high composting temperatures (≥55^{0}C).

The horse manure and shavings is generically called stable waste (SW). Green Mountain Technologies (Bainbridge Island, WA.) has a turn-key composting system called an EarthFlow (EF) system which was installed in December 2015 at the Days End Farm.

The Earth Flow In-vessel Composting System is an automated in-vessel composting system designed for on-site composting and loads of 300 lbs to 10,000 lbs of feedstock per day. Since mixing and aeration is automated, this system requires very little labor beyond loading and unloading. In the EF system at Days End Farm, the moisture control was not automated. The Earth Flow system claims to provide excellent control over odors, vectors, and leachate. Side wall aeration is in this system rather than floor aeration that is more typical in other EF systems. Traveling auger technology mixes the feedstock and moves it down the channel.

GMT Claims to be tested:

The GMT proposal listed several things that their product would provide. The list below includes comments concerning details of what testing the claim entails.

1. Speed the compost process
   This is relatively meaningless because the only real benchmark is the speed of natural decay in an un-manipulated situation such as leaves on a forest floor. Any compost system will be accelerated relative to the natural decay of a forest floor. However, they claim a three week composting time within the EF unit. This can be measured.

2. Control the environmental impacts of the waste stream
   There are several environmental impacts that are relatively minor, but cannot be easily tested, such as air emissions, heat emissions, etc. The nutrient content of the feedstock is changed by the compost process. Before and after nutrient analysis will characterize these changes.

   The subsequent use of the material controls the environmental impacts, which is independent of the compost system and, therefore, is not related to system performance.

3. Create stable compost
   "Stable" is slightly differently defined by different entities (see Appendix 1). In this case, compost that is not giving off much ammonia and that does not exhibit a large amount of microbial respiration is a stable compost.

4. Negate ill effects of nitrogen and phosphorus
   This claim, like 2 above, is subject to the subsequent use of the material and is independent of the compost system.

5. Reduce the weight by 50% or more.
   Composting reduces weight by A) heat causing evaporation of water and B) converting feedstock carbon to CO_2. Measurement of input weight and output weight can quantify this claim.

6. Reduce pathogens, weed seeds, and parasites.
   Pathogen reduction is assumed to occur when time-temperature requirements are met. Measurement of temperature is the basic method for accepting that pathogen kill has occurred. Microbial analysis of the final product is a more expensive and time-consuming process, but a more accurate assessment of pathogen kill.

7. Have a through-put of 2.5-3.0 tons feedstock/day
   Weight of input can quantify this claim.

Physical Set-up and Operations in the Earth Flow Unit

Temperatures were recorded by continuous LogTag dataloggers on the wall positions inside the EF unit (fig. 1). The dataloggers were duct-taped to the interior walls of the unit. The loggers at positions 1 and 4 came loose during the composting process and were not recovered, so there are no records for them. However, records for positions 2, 3, 5, and 6 were recorded and graphed. Temperatures were taken using the 36" long Reotemp thermometer at 6" and 36" at two centrally located positions along the length of the EF unit and at the load and unload ends.

Ambient temperatures directly outside the east and west sides of the EarthFlow (EF) unit were collected using continuous dataloggers (LogTag®) with environmental protective covers.

Samples and operation of the EF unit in December 2015 reflect the initial start-up period in which personnel were trained in the operation of the unit and in the sampling and coordination with analytical laboratories. The training included loading/unloading of horse manure mixed with bedding (SW), temperature testing of the material in the unit, including installation of continuous data recording devices at specific loci on the interior walls of the unit, recording of the temperature data and the amounts and dates of loading and unloading of compostable feedstock and composted product. As often occurs with initial startup operation that involve new staff dealing with new equipment and procedures, staff had to troubleshoot with a variety of issues during this period.

The unit was loaded regularly and the volume was reduced approximately by 50% during the period it composted in the EF unit. At the end of two weeks in the ER unit, material was unloaded to the 'curing' phase, in a covered structure where it was accumulated in a single small pile (fig. 2).

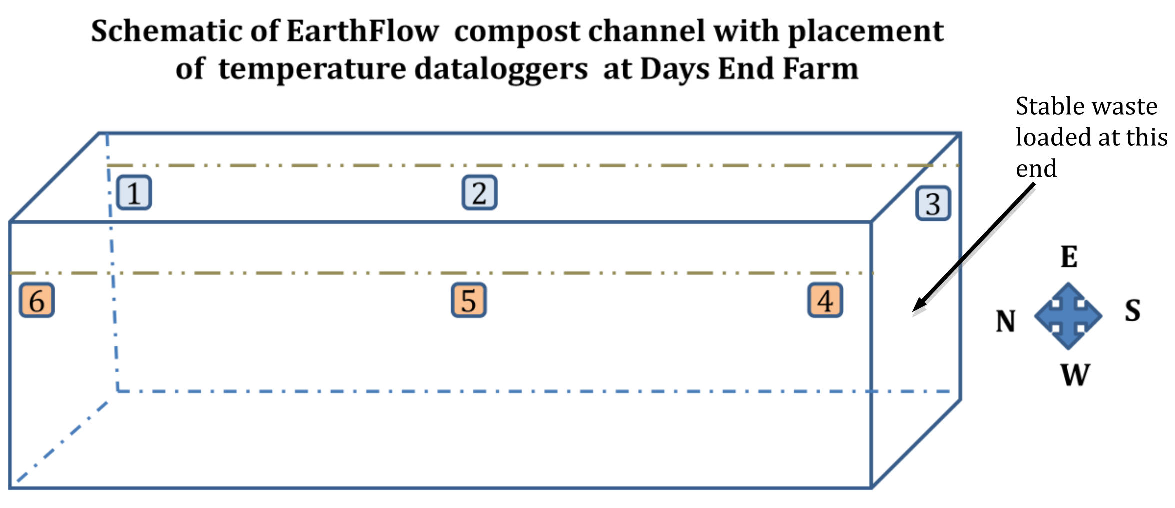

Figure 1. Schematic of EarthFlow compost system and data collection sensors.

Figure 2. Earth Flow compost unit, storage/curing bunker, and manure drop.

Dataloggers were approximately 8-12” below the surface of the SW in the Earth Flow unit.

Air is injected through the side walls of the unit and is controlled by the PLC units and ultimately by Green Mountain. Moisture can be added as part of the process, but must be done manually. Moisture was not added as part of this evaluation.

Green Mountain remotely controlled the frequency of turning and the air injection.

Bulk Density

Bulk density is mass of compost/unit volume. The mass of compost is on a wet weight basis and, therefore, bulk density changes somewhat on a daily basis because moisture content is constantly changing. The other factor controlling mass is microbial degradation of carbon to CO_2. The bulk density of finished compost is typically 600-900 lbs/cubic yard. In July of 2016, ten samples were collected 2-3 days apart for input feedstock, compost from the EF unit, and compost from the finishing pile. The average bulk density dropped from 934 lbs/cubic yard to 652 lbs/cubic yard while in the EF unit (see Appendix 3 for data). This was an average of a 30% drop in bulk density. The average bulk density dropped from 652 lbs/cubic yard to 617 lbs/cubic yard while curing, an average loss of 5%.

The finished bulk density of 617 lbs/cubic yard is a fairly low bulk density. Moisture data suggests that much of this loss was water.

Temperature Data/Pathogen Kill

Temperatures were recorded for winter conditions for the period 12/2/2015-1/7/2016. The temperatures at positions 1-6 were taken on the interior wall of the channel. Figure 3 shows data from position 2 and figure 4 shows data from position 3. Where it occurs, there is a red bar in the graphs at temperature = 131°F (55°C). Only position 6 (fig 5) achieved temperatures >131°F (55^0C) for 3 consecutive days. These data are taken from inside the channel but adjacent to the exterior channel walls and represent the coldest temperatures in a cross section.

The main issue is that the temperature data do not ensure that all the material has been subjected to the high temperatures and duration needed to inactivate all pathogens, particularly helminth ova which are extremely resistant. Because of the high percentage of animals at this facility that arrive with and are treated for helminths, it is essential that the process for helminth destruction be validated and/or improved, if the EF product is to be re-used for stall bedding. This is in the interest of animal health, safety, and welfare.

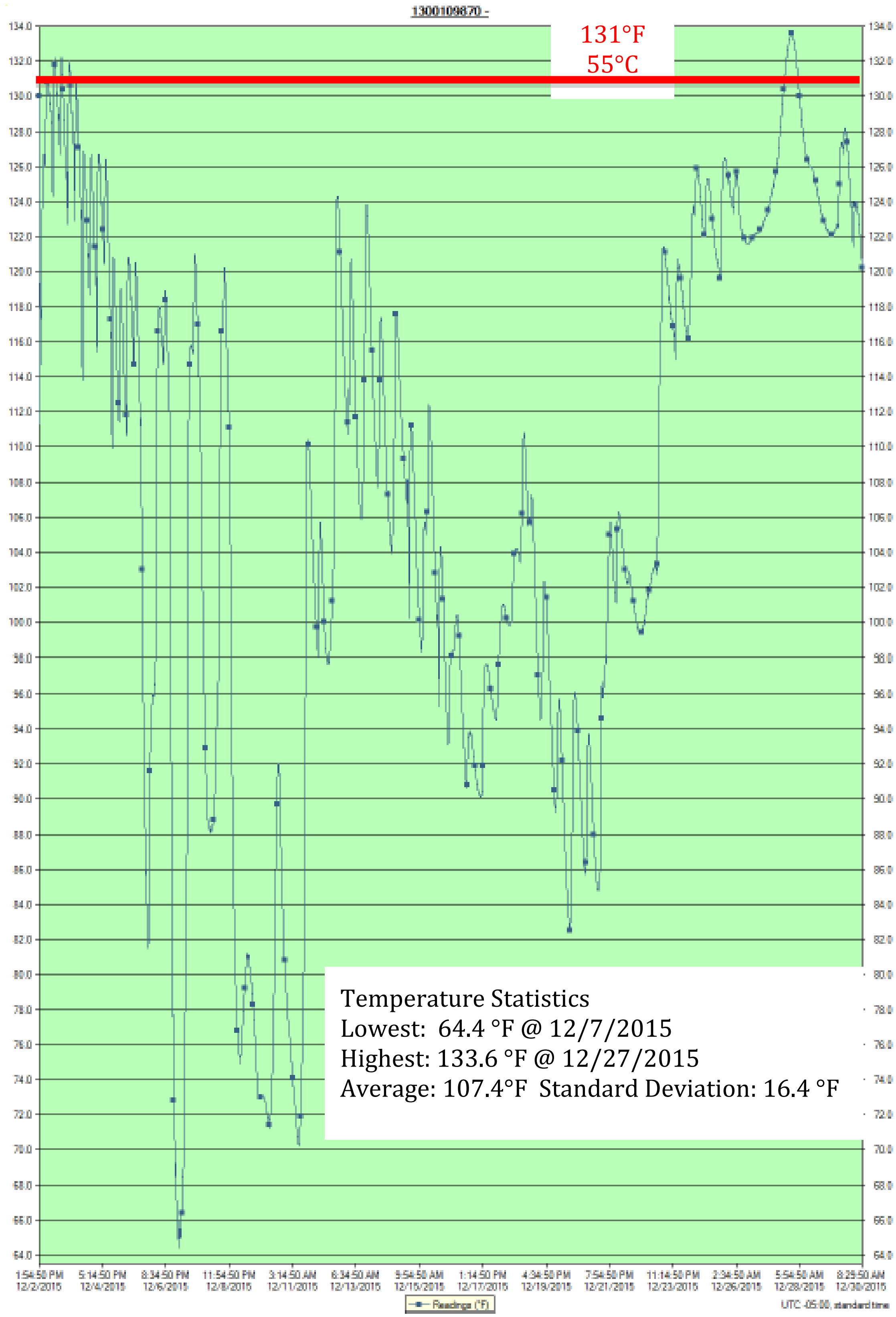

Figure 3. Temperatures for position 2 (mid-channel) during winter conditions.

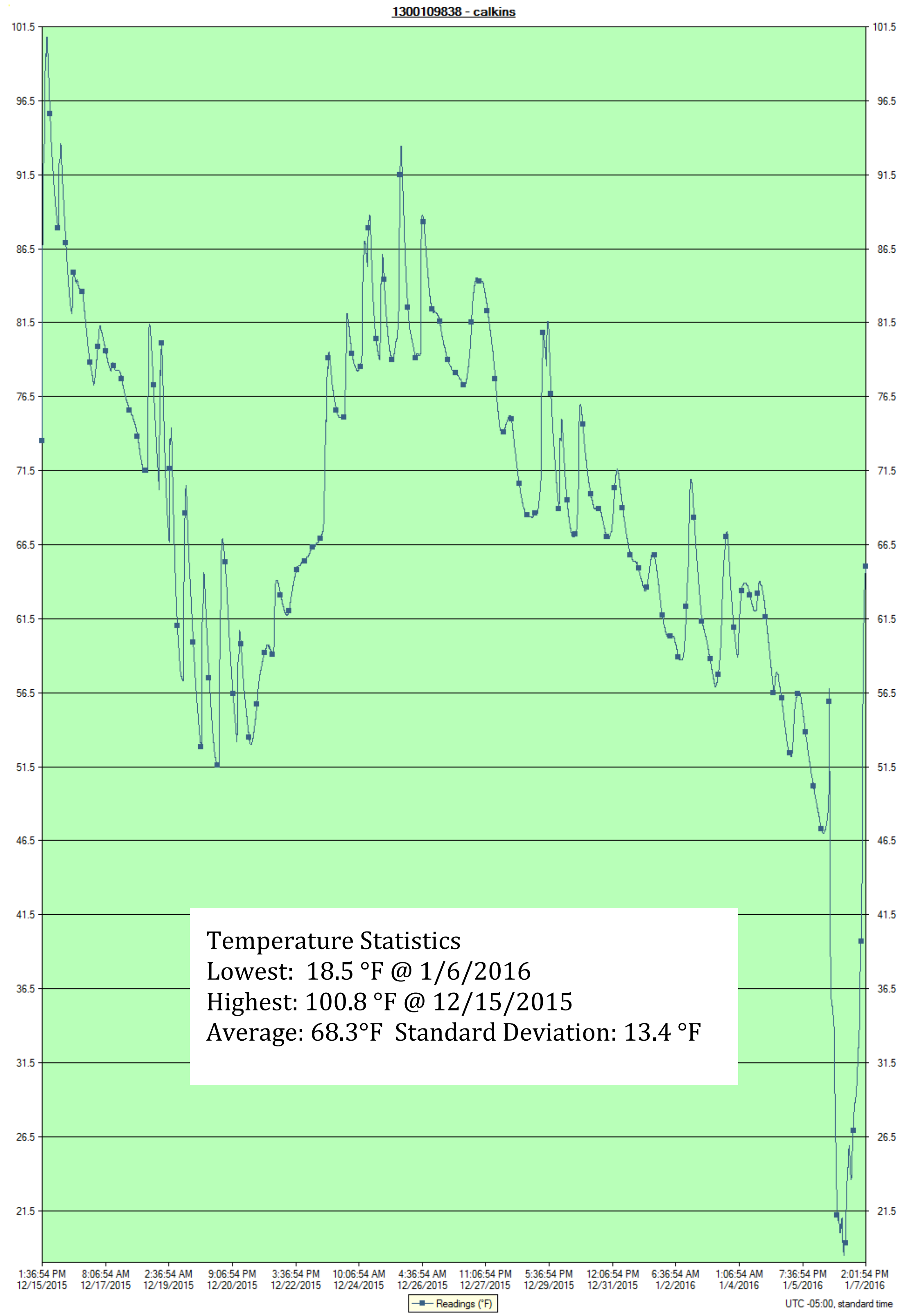

Figure 4. Temperatures for position 3 (loading end) during winter conditions.

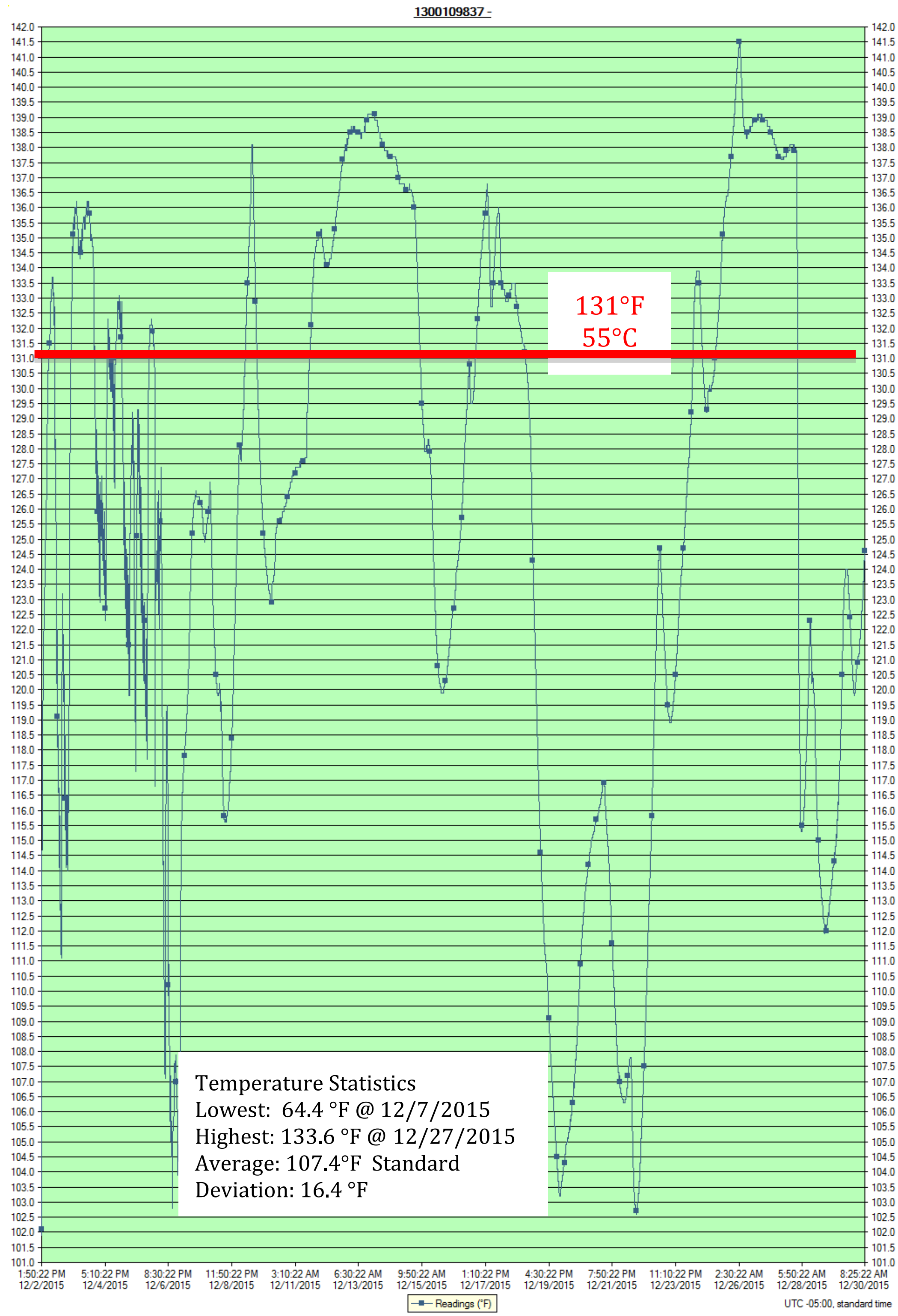

Figure 5. Temperatures for position 6 (unloading end) during winter conditions.

Summertime data were collected outside the EF unit. Ambient data show that the exterior position on the east side of the EF frequently achieved temperatures above 55^{0}C (Figure 6) and that there was a clear diurnal cycling of temperature. In contrast, the ambient temperatures outside the west side of the EF, achieved 55^{0}C for periods in July and August, but not as often in the early part of July (fig 7) as did the loggers on the east side

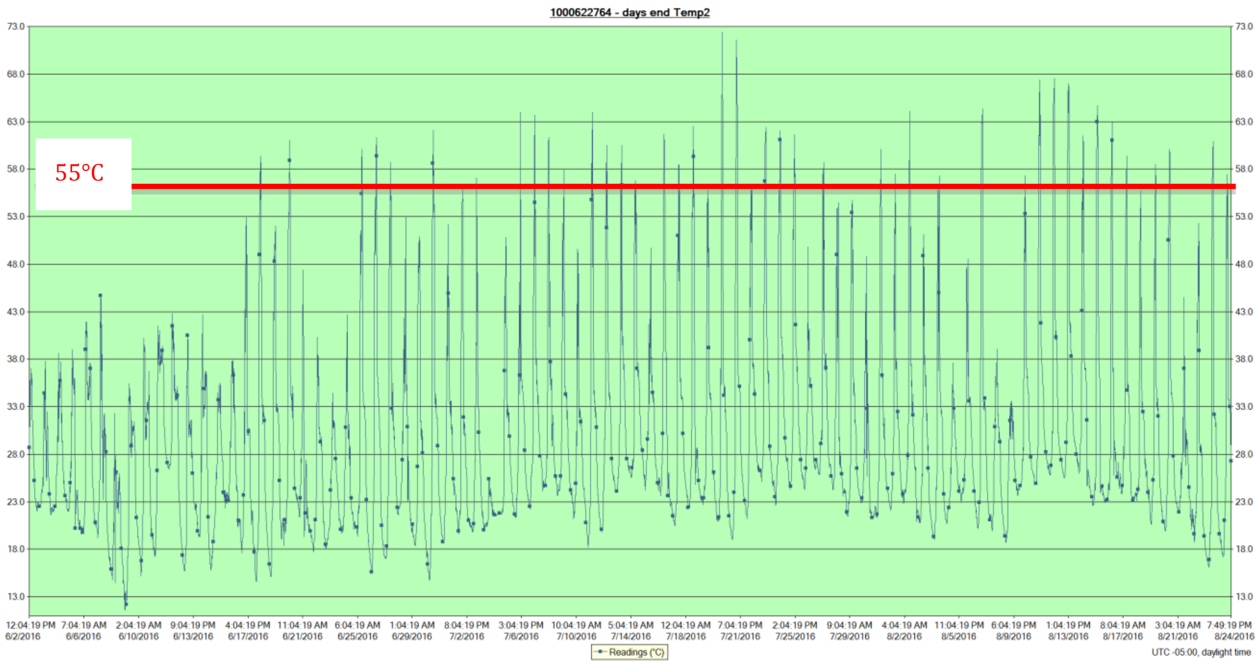

Figure 6. Ambient temperatures outside the east side of the EF unit (°C) during summer conditions..

The summertime temperature of the outside indicates that the metal was heating to above 55°C due to solar heating on a daily basis in late June, July, and August.

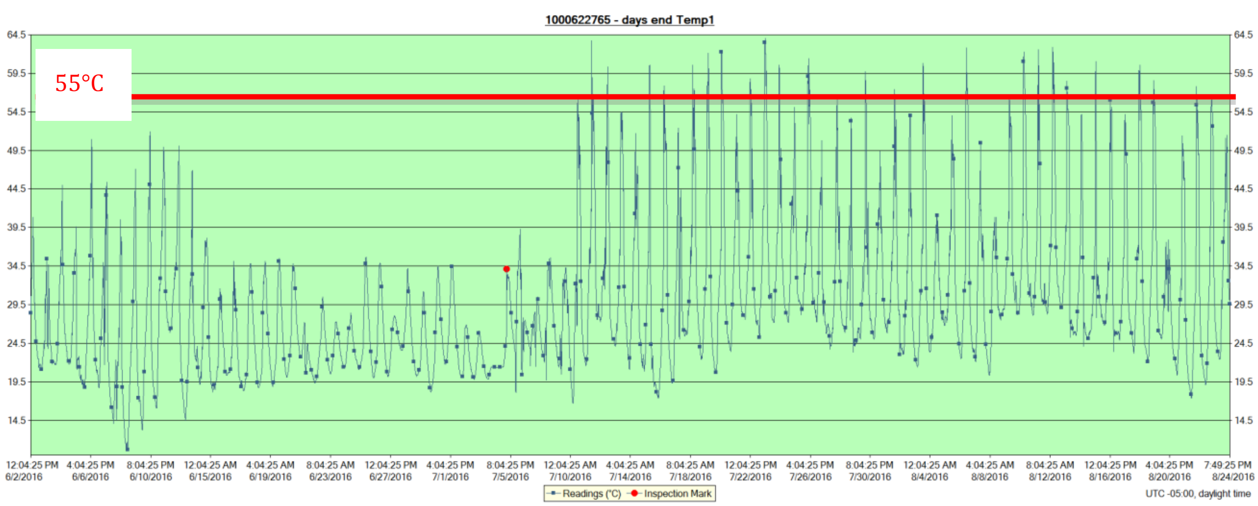

Figure 7. Ambient temperatures outside the west side of the EF unit (°C) during summer conditions.

In contrast, outside summertime temperature of the west side indicates that the metal was briefly heating to above 55°C due to solar heating on a daily basis in mid-July, and early-August. Hence, the east side experienced more solar gain than the west side. One would expect the interior temperatures to reflect the heat gain if the EF walls were not well-insulated. Note also that there were roughly 40°C (72°F) diurnal temperature fluctuations (figs. 6 & 7) in the summer.

The interior temperatures at positions 4, 5, and 6 (fig. 1) are shown in figures A.2, 7, and A.3, respectively. Only position 5 ever exceeded 55°C, and then only for a very brief time. Hence, compost adjacent to the west side of the EF unit wall did not meet PFRP time and temperature requirements for pathogen reduction.

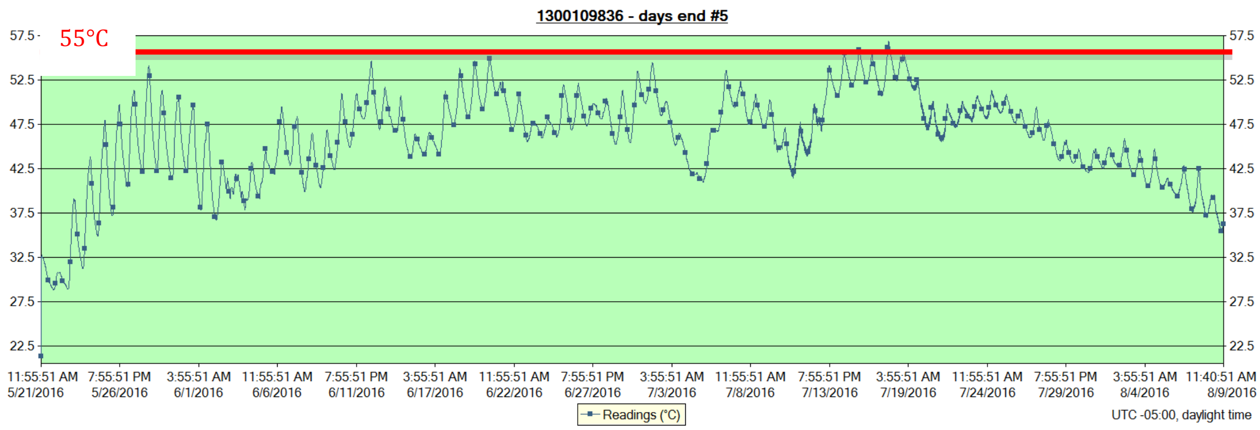

Figure 8. Interior temperatures at position 5 on the west side of the EF unit (°C) during summer conditions.

In addition to the datalogger temperature data, manual temperatures were collected using 36" long-stem Reotemp® compost thermometer inserted through three access ports located on the east (sunny) side of the unit at the 25%, 50% and 75% (of total length) points and recording temperatures at 6-inch, 12-inch, and 36-inch insertions (fig. 9).

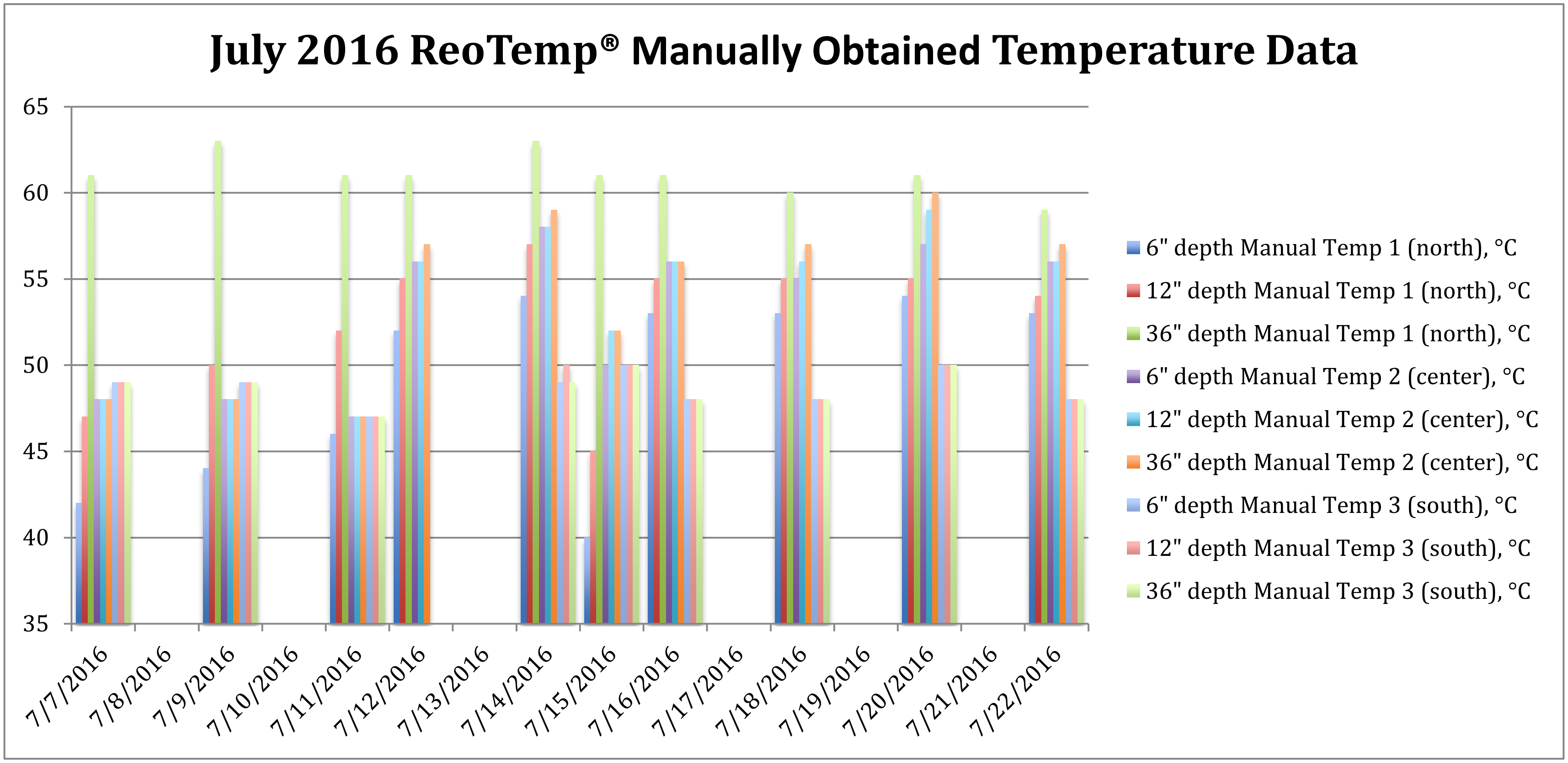

Figure 9. Manually collected July temperatures (°C) of compost at 25%, 50%, and 75% of the composter length from location 1 (unloading end). Probes were inserted from the side inward 6", 12", and 36" at each location.

If the average ambient temperature is assumed to be 90°F (32°C), then we can see that all temperatures are well above ambient temperature, evidence that compost heating is occurring. Factors that control heating are sufficient oxygen, sufficient moisture, and appropriate C:N ratio. Additional factors that effect cooling are the aeration rate and the turning frequency.

Temperatures at the 36" depth at the unloading end (light green bar) were consistently above 55°C. Temperatures at the 36" depth at the loading end (2nd light green bar) were consistently below 50°C.

Temperatures at the unloading end were always higher than temperatures at the loading end.

Temperature Summary and Discussion

The great majority of the composting mass reached 131°F (55°C) for an extended period at some time in the process. However, there were always edges that did not achieve PFRP time-temperature benchmarks, suggesting that pathogen kill will not be anywhere near complete.

Additional effort is needed to determine if all material loaded into the DEF composting unit is exposed to ≥55^{0}C for an adequate period of time to destroy pathogens and parasites (i.e., meet PFRP time-temperature targets). It should be determined whether the system operates more like a windrow or like a static aerated pile system. The current set of measurements obtained during the June-July 2016 study period indicates that achievement of PFRP time-temperature targets is sporadic and sometimes inadequate. As a result, the health status of the horses may be compromised during their recovery period. Recycling of the compost as bedding at DEF should include confirmation of achievement of time-temperature targets, which will require a validation test.

Pathogen Testing

Table 1 shows the results from fecal coliform analyses (conducted using EPA method 1681) of manure-bedding mix input and compost produced for each date for which samples were collected. The fecal coliform populations declined approximately 1000-fold during the composting periods. The major decrease in moisture content of the compost compared to that in the input mixture (tables 2, 3, and 4), and the exposure to some periods of ≥55^{0}C likely contributed to the decline in fecal coliform populations. However, the decline in fecal coliform populations cannot be used as an indicator of destruction of helminth ova which are well-documented to require sustained exposure to high temperatures.

Separate analyses are required to ascertain destruction of helminth ova in the Days End compost unit and an approach to accomplish this was presented to the project directors at Green Mountain Technologies. It is unclear if the very dry state of the DEF compost unloaded from the EF unit would contribute, to some extent, in the destruction of helminth ova. Given the health status of many of the horses at DEF, their high helminthic egg counts, and the intended use of the compost as recycled bedding in the stalls, it is highly recommended that the efficacy of destroying the ova during EF system operations be conducted.

Table 1. Results of Fecal Coliform enumeration for designated samples from Days End for manure mixed with bedding material input to compost units, and compost removed from the unit on 7/06 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							
	3 tube	**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**
DEFM	629	3/3	3/3	3/3	3/3	2/3	1/3	0/3	1.5×10^6
DEFM	706	3/3	3/3	3/3	3/3	1/3	0/3	0/3	4.6×10^5
DEFM	711	3/3	3/3	3/3	3/3	2/3	2/3	0/3	2.1×10^6
DEFC	629	3/3	1/3	2/3	0/3	0/3	0/3	0/3	1.6×10^3
DEFC	706	3/3	3/3	0/3	0/3	0/3	0/3	0/3	2.4×10^2
DEFC	711	3/3	1/3	0/3	0/3	0/3	0/3	0/3	4.3×10^1

[a] DEFM designates samples of manure mixed with bedding input for composting; DEFC designates unloaded compost samples.

Nutrient Data at Days End Farm

Data from Winter Conditions

The nutrient changes between the feedstock and the unloaded compost from the EF unit are shown in the analyses of samples from Waypoint laboratories.

Table 2. Nutrient analysis from December 2015 samples. Average of three samples.

Average results for **Compost Feedstock** Loaded into the Earth Flow unit at Days End Farm in December 2015			Average results for **Compost Unloaded** from Earth Flow unit at Days End Farm in December 2015		
TEST	December 2015 Summary	Average result-Dec 2015	**TEST**$^{\alpha}$	December 2015 Summary (**%**)	Average result-Dec2015 (**mg/Kg**)
	As Received	Dry basis			
Nitrogen, N %	0.39	0.95			
Ammonical-N %	0.07	0.16	Total Kjeldahl Nitrogen	1.12	11200.00
Phosphorus, P %	0.10	0.23	Total Phosphorus	0.33	3346.67
Potassium, K %	0.36	0.87	Total Potassium	1.10	11033.33
Sulfur, S %	0.06	0.14	Total Sulfur	0.19	1923.33*
Magnesium, Mg %	0.13	0.32	Total Magnesium	0.38	3760.00*
Calcium, Ca %	1.76	4.53	Total Calcium	2.35	23466.67*
Sodium, Na ppm	602.00	1480.00	Total Sodium	0.18	1773.33*
Iron, Fe ppm	889.00	2173.33	Total Iron		4310.00*
Aluminum, Al ppm	368.33	873.00	Total Aluminum		3500.00*
Manganese, Mn ppm	93.07	230.00	Total Manganese		278.67*
Copper, Cu ppm	8.05	19.77	Total Copper		26.33*
Zinc, Zn ppm	33.60	82.93	Total Zinc		91.33*
Boron, B ppm	2.50	6.12	Total Volatile Solids	78.14	781400.00
Test	Result	Result			
Moisture %	59.5		Moisture †	31.46	Moisture †
Solid %	40.5		Total Solids †	68.54	685366.67
Additional Tests	Result				
P2O5 (as received) , %	16.41		C/N RATIO †	40.67	
K2O (as received) , %	0.428		Carbon (TOC) †	45.43	454333.33

$^{\alpha}$All values are on a dry weight basis, except as noted by†; Detection limit on all N series is on a wet basis.

*Within normal range. Analyses by Waypoint Laboratories, Richmond, VA

The C:N of unloaded compost reflects the relatively high amount of wood(lignin)-based bedding from the stalls. In concert with the high amount of sawdust, the phosphorus content is relatively low compared to many other types of compost. The nitrogen, at 1.12%, is comparable to a yard-waste compost.

The moisture content dropped from 59.5% to 31.5% between loading and unloading. The moisture content at unloading is too low for good composting. However, we do not know when the moisture content went below the lower end of the optimal range, i.e., 40%.

The high C:N and high solids content (more than 20% greater than at the start) at the unload time point corroborates the high moisture loss during the process. This combination of characteristics in the final product suggests that the physical properties of the material may be suitable for re-use as bedding.

Data from Summer Conditions

Nutrient data for feedstock (table 3) and resulting compost (table 4) are indicative of the impact of both feedstock influence and compost processes. The average total feedstock N of 0.68% comprised 0.03% Ammonia-N of the loaded mixture (over the study period) with 52% moisture and 48% solids, with a total carbon content of about 40%, resulting in a C:N ratio of 29. Total phosphorus in the loaded mixture was 0.17%.

For the compost produced (table 4), the total N averaged 0.6% (5980 mg/kg) of which 0.06% was Ammonia (577 mg/kg), 0.54% was organic nitrogen (5436 mg/kg), and 470 mg/kg nitrate-nitrite nitrogen. The total C was 44.87% (44867 mg/kg), resulting in a C:N ratio of 214 with an average moisture content of 20%. Minerals analyzed from the manure and unloaded compost showed variability between samples collected on the different dates, but all measured concentrations of Ca, Mg, Na, Fe, Al, Mn, Cu, and were within acceptable ranges.

There were only three samples analyzed for C:N ratio (table 4). The values were 313, 300, and 29. The resulting large variability calls into question the sampling process. Additional samples should be collected and analyzed both in the winter and in the spring. The difference between the winter C:N average (40.7) and summer C:N (214) is large and seasonal changes in weather seem to be a weak explanation for this difference.

The drop from approximately 60% moisture to 30 % moisture over the composting period is remarkable, as the composting process is optimal at 50% moisture content with a workable range from 40-60%. When moisture reaches 35% or less, the material is suitable for screening when producing a product for landscape or horticultural uses.

In addition, at low moisture contents, microbial decomposition (metabolic) activity decreases substantially resulting in insufficient metabolically generated heat within the compost mass. This apparently occurred in the EF unit during this period as the temperature profiles in the zone between the mid-south zone and the unload end (fig. 9) suggest. The very large average C:N ratio (214) of the unloaded compost corroborates incomplete composting from the perspective of carbon decomposition.

Table 3. Physico-chemical analyses feedstock; Horse Manure with bedding samples from DEF.

	Average				DEFM62916		DEFM70616		DEFM71116	
Parameter	As rec'd	stddev	dry basis	stddev	As rec'd	dry basis	As rec'd	dry basis	As rec'd	dry basis
Nitrogen, N %	**0.68**	**0.215**	**1.39**	**0.254**	0.542	1.34	0.568	1.26	0.927	1.58
Ammonia N, %	**0.03**	**0.004**	**0.39**	**0.001**	0.024	0.59	0.032	0.07	0.03	0.51
Phosphorus, P %	**0.17**	**0.078**	**0.35**	**0.078**	0.11	0.27	0.15	0.33	0.26	0.44
Potassium, K %	**0.59**	**0.096**	**1.23**	**0.049**	0.49	1.21	0.61	1.34	0.68	1.15
Moisture, %	**51.9**				59.7		54.8		41.3	
Solids, %	**48.1**				40.3		45.2		58.7	
Carbon (TOC) %	**39.92**				37.76		40.91		41.09	
K_20 (as rec'd) %	**0.71**				0.588		0.732		0.816	
P_2O_5 (as rec'd) %	**0.40**				0.251		0.343		0.595	
Total Volatile Solids %	**68.66**				64.94		70.36		70.68	
C/N RATIO *	**29**				28		33		26	

Table 4. Physico-chemical analyses of compost made from Horse Manure-bedding from DEF.

Parameter	Average RESULTS		DEFC62916 RESULTS		DEF70616 RESULTS		DEF71116 RESULTS		QUANTITATION LIMIT
	(%)	(mg/kg)	(%)	(mg/kg)	(%)	(mg/kg)	(%)	(mg/kg)	(mg/kg*)
Total Solids *	**79.96**	**799600**	78	779700	75.79	757900	86.12	861200	100
Moisture *	**20.04**		22		24.21		13.88		100
Total Kjeldahl N	**0.60**	**5980**	0.15	1450	0.15	1490	1.51	15000	10
Total Phosphorus	**0.40**	**4007**	0.39	3930	0.41	4050	0.4	4040	100
Total Potassium	**1.35**	**13533**	1.31	13100	1.38	13800	1.37	13700	100
Ammonia N	**0.06**	**577**	0.06	590	0.06	607	0.05	534	10
Organic N	**0.54**	**5436**	0.09	860	0.08	883	1.46	14566	0
Nitrate+Nitrite-N		**470**		496		454		459	2
Total Volatile Solids	**77.18**	**771533**	78	77900	77.01	770100	76.55	765500	CALCULATION
C/N	**214**		313		300		29		CALCULATION
Carbon (TOC)	**44.87**	**44867**	45.3	45300	44.8	448000	44.5	44500	CALCULATION

Stability Tests

No mention of stability was found in the quarterly reports. Hence, no stability can be determined. However, C:N ratios for the output compost product were extremely high in the compost product during the winter. The C:N ratios in the input were normal. This could be a result of the operation of the EF unit if the constant turning and aeration exhausted the nitrogen and caused excessive NH_4 volatilization occurred before the N could be used in the compost process. Alternatively, measurement or sample collection error could have caused input samples to be artificially low in the input samples. This could occur if the samples collected had more manure than was representative of the actual input feedstock. In any event, the output from the EF unit had such a high carbon content that the product could not be considered "stabilized to the point that it is beneficial to plant growth" or "that the product may be …. applied to the land or used as a soil conditioner in an environmentally acceptable manner without adversely affecting plant growth." The phrases in quotes are from the USCC and COMAR definitions of compost (Appendix 1). However, the reason for the product failing to meet the stability criteria for compost may be operator-based or Earth Flow design/operation-based. It would be to Green Mountains advantage to determine which.

The compost was turned twice a day every day. Turning releases a great deal of heat and moisture. This can cause A) the temperature to drop resulting in depresses microbial activity and B) loss of moisture can cause depression of microbial activity when moisture content drops below 40%. Air was injected into the sides of the EF unit continuously. Air cools the compost process and dries the process, with resulting depressed microbial activity.

Below, figure 10 is a lab report from the original project proposal provided by Green Mountain (it is <u>not</u> from EF). The C:N ratio is a bit high (29) for finished compost. The stability rating is *stable*. Figure 11 is a second report from the original project proposal. In this second sample, the C:N ratio is also a bit high (31) for finished compost and the stability rating is *very stable*. The average C:N ratio from three winter samples at the Days End project was 214; roughly ten times the C:N ratio from the Green Mountain proposal.

US Composting Council STA Certified Lab

soiltest farm consultants, inc.

2925 Driggs Dr., Moses Lake, Wa 98837 - www.soiltestlab.com
Office: (509)765-1622 - Fax:(509)765-0314 - (800)764-1622

Page 1

Client: **Concurrent Technologies**	Product: **Ft. Meyer Curing Mix Pile**	Date Reported: 01/14/13
Attn: Shannon Siart	Date Sampled: 12/18/12	Laboratory # C12-587
1225 S Clark ST Suite 500	Date Received: 12/31/12	Reviewed by Brent Thyssen, CPSSc
Arlington, VA 22202	Job#: 120600134	
703-310-5680		Amount: $ 280.00

Nutrients

	Method	As Rcvd.	Dry Wt.	Units	Low	Normal	High	Typical Range
Moisture	70 C	30		%	****************			15 to 40
Solids	70 C	70		%	*****************			60 to 85
pH	1:5	8.3	NA	SU	*****************			5.5 to 8.5
E.C	1:5	2.64	3.79	mmhos/cm	**************			below 5.0
Total N	TMECC 04.02D	0.79	1.14	%	*************			1 to 5
Organic C	TMECC 04.01A	22.2	31.9	%	*****************			18 to 45
Organic Matter	TMECC 05.07A	43.9	63.1	%	*********************************			40 to 60
Ash	550 C	25.7	36.9	%	*******			40 to 60
Ammonium -N	TMECC 05.02C	515.0	739.8	mg/kg	**************************			90 to 450
Nitrate-N	TMECC 04.02B	82.0	117.8	mg/kg	**********************			50 to 250
Chloride	TMECC 04.12D	3588	5154	mg/kg	***************************			500 to 5000
Sulfate-S	TMECC 04.12D	126	181	mg/kg				
$CaCO_3$	TMECC 04.08A	70	100	lbs/T	******************************			20 to 80
Phosphorous	TMECC 04.12B/04.14A	0.13	0.19	%				
P_2O_5		0.30	0.43	%	***			1 to 8
Potassium	TMECC 04.12B/04.14A	0.54	0.78	%				
K_2O		0.65	0.93	%	****			3 to 12
Calcium	TMECC 04.12B/04.14A	1.13	1.6	%	*************			0.5 to 10
Magnesium	TMECC 04.12B/04.14A	0.48	0.68	%	************************			0.05 to 0.7
Sodium	TMECC 04.12B/04.14A	0.21	0.30	%	************************			0.05 to 0.7
Sulfur	TMECC 04.12B/04.14A	0.09	0.13	%	****************			0.1 to 1.0
Boron	TMECC 04.12B/04.14A	7	11	mg/kg	************			25 to 150
Zinc	TMECC 04.12B/04.14A	41	58	mg/kg	*******			100 to 600
Manganese	TMECC 04.12B/04.14A	157	226	mg/kg	*******			250 to 750
Copper	TMECC 04.12B/04.14A	19	27	mg/kg	***			100 to 500
Iron	TMECC 04.12B/04.14A	6197	8902	mg/kg	*****************			1000 to 25000
C/N ratio			28	ratio	*****************************			18 to 24
C/P Ratio			170	ratio	**			80 to 140
Ag Index			3	ratio	*****			3 to 10

Respiration & Stability

	Method		Units	Low	Normal	High	Normal
CO2 Evolution	TMECC 05.08	1	mg CO_2-C/g OM/day	************			1 to 7
	TMECC 05.08	1	mg CO_2-C/g TS/day	*************			0.5 to 5
	TMECC 05.08	10	mg NH_3-N /kg /day	************			10 to 100
Stability Rating		Stable					

Sample was received, handled and tested in accordance with TMECC procedures

Figure 10. Compost analysis from sample collected 12/18/12 at Ft. Myer (Arlington, VA) project.

US Composting Council STA Certified Lab

soiltest farm consultants, inc.

2925 Driggs Dr., Moses Lake, Wa 98837 - www.soiltestlab.com
Office: (509)765-1622 - Fax:(509)765-0314 - (800)764-1622

Client: **Green Mountain Technologies**	Product: **Ios Ranch Screened Compost**	Date Reported: 09/05/12
5350 McDonald Ave. NE	Date Sampled: 08/14/12	Laboratory # C12-389
Bainbridge Island, WA 98110	Date Received: 08/16/12	Reviewed by Brent Thyssen, CPSSc
Attn: Pam Heater		
802-368-7291		Amount: $ 120.00

Nutrients

	Method	As Rcvd.	Dry Wt.	Units	Low	Normal	High	Typical Range
Moisture	70 C	29		%	*****************			15 to 40
Solids	70 C	71		%	******************			60 to 85
pH	1:5	8.1	NA	SU	******************			5.5 to 8.5
E.C	1:5	2.63	3.70	mmhos/cm	***************			below 5.0
Total N	TMECC 04.02D	0.52	0.73	%	******			1 to 5
Organic C	TMECC 04.01A	15.9	22.4	%	**************			18 to 45
Organic Matter	TMECC 05.07A	36.6	51.5	%	************************			40 to 60
Ash	550 C	34.4	48.5	%	**************			40 to 60
Ammonium -N	TMECC 05.02C	9.5	13.4	mg/kg	***			90 to 450
Nitrate-N	TMECC 04.02B	1.0	1.4	mg/kg	***			50 to 250
C/N ratio			31	ratio	******************************			18 to 24

Respiration & Stability

	Method		Units	Low	Normal	High	Normal
CO2 Evolution	TMECC 05.08	1	mg CO_2-C/g OM/day	*************			1 to 7
	TMECC 05.08	1	mg CO_2-C/g TS/day	**************			0.5 to 5
	TMECC 05.08	0.2	mg NH_3-N /kg /day	***			10 to 100
Stability Rating		Very Stable					

Cucumber Bioassay

	Method		Units	Low	Normal	Normal
Emergence	TMECC 05.05A	100	%	*************************************		80 to 100
Vigor	TMECC 05.05A	99	%	**********************************		85 to 100
Plant Description		Mature				

Sample was received, handled and tested in accordance with TMECC procedures

Figure 11. Compost analysis from sample collected 8/14/12 at IOS Ranch (Bainbridge Island, WA) project.

Throughput

Due to the lack of information on the amounts and frequency of manure-bedding mix additions to and unloadings from the EF unit, calculations of throughput (mass of compost produced per unit time) cannot be presented here. Input and output bulk densities were determined but no record of input volume or output volume was presented. A blank data sheet is found in the quarterly report dated January 31, 2016.

The cycle in the EF unit is 14-17 days and this is not an unusual period for active composting. While there is no data to support it, it is quite plausible that the primary composting process is finished at this point, but it would be to Green Mountain's advantage to conduct mass balance experiments and travel time experiments.

Discussion and Summary

Turning frequency. Because the compost is turned twice a day, the temperature drops dramatically following the turn. At the same time, moisture is released. Some of the heat loss is tolerable but at some point, the cumulative heat loss results in lower temperatures and failure to meet PFRP time-temperature requirements for pathogen kill. The amount of turning prior to significant temperature drop varies seasonally.

At the same time, some amount of turning is necessary in order to get the compost mixed and moved toward the unloading end of the channel.

The final moisture content is too low for good composting and for good curing. The number/frequency of turns seems excessive in this situation. Some research into both the appropriate turning frequency and how to measure the appropriate turning would enhance the usefulness of the GMT Earth Flow (EF) unit.

Air injection. This unit injects air in the side of the unit which is an unusual way to handle air injection. Being sure that the compost is operating in an aerobic condition is important. One might think that frequent turning would help with maintaining aerobic conditions, but research has shown that oxygen incorporated during turning is depleted in approximately 20 minutes under active composting conditions. Hence, bottom air injection would be a better configuration for maintaining aerobic conditions. Additionally, air follows a certain path and at some point, the air becomes saturated with water vapor and unable to take in any more moisture. The longer the path, the less moisture that will leave the compost and overall drying will be less. For this reason also, bottom injection would be a better configuration.

Moisture addition. The moisture got too low in the compost at some time in the process. The ability to add moisture is built into the EF unit. However, the controls are completely manual and left up to the on-site operator. Moisture measurement in compost is a somewhat complicated operation for hourly farm hands to be expected to master. One of the best additions to this unit would be a moisture measurement and control system that GMT could operate and monitor remotely.

Temperature/PFRP. The center of the compost mass met PFRP most of the time except at the six inch depth. The edges of the Channel seldom made PFRP. There was no data collected six inches from the bottom of the channel, so those conditions are unknown. Because the compost is turned so frequently, this may be less of a problem than for other systems. We don't know if compost migrates in the channel or merely move up and down, staying near where it was loaded. Some study of particle migration would greatly add to understanding of the EF system efficiency and perhaps give more confidence that PFRP was sufficient for pathogen kill. Ultimately, microbiological proof of helminth ova kill would provide irrefutable proof of pathogen kill.

Impact of wall insulation. Diurnal temperature variation on the outside of the channel wall was as much as 40°C. On the inside of the wall, diurnal temperature varied by no more than 10°C. However, over a six day period (May 21 - May 27, 2016), inside wall temperature varied by 22°C and this corresponded with an increase in ambient temperature. The addition of insulation in the wall space would improve temperature stability and would reduce the low temperatures found near the walls (positions 1-6).

C:N ratio. The feedstock input had optimal C:N ratios (~30). The output C:N ratios were between 40 and 313, when they should be near 20. It is hypothesizes that premature drying and depressed temperatures prohibited the microorganisms from respiring for some period in the compost process. This would leave the N relatively depleted, as much of the N is consumed in the early part of active composting. Additionally, the lignin, cellulose, and hemi-cellulose would not have been consumed. The resulting material could not be called compost by any definition. This may be a result of drying and low temperatures, but is could also be a result of properties of the feedstock itself. Finally, because one of three summer samples had a C:N ratio of 29, it is possible that sampling technique for input material or of final compost may be inappropriate for the material. The C:N ratios give us suspicion about EF composting but not concrete conclusions.

Financial performance. This was relegated to the Environmental Finance Center at the University of Maryland and I have no results from them.

GMT Claims

1. The Earth Flow unit does speed the compost process. No claim of exactly how mature or stable the compost would be was made. The resulting compost went to a curing area, which is normal. This claim was met.
2. The claim about controlling the environmental impacts of the waste stream is not exactly a function of the EF unit, but more a function of the final disposition of waste stream. The EF unit enabled better handling and transformed most nitrogen from a soluble form to an organically bound form. It made managing the environmental impacts easier.
3. GMT claimed that the system would create stable compost, but the definition of stable was not part of the proposal. By any definition in the compost industry or Maryland law, the material exiting the EF unit was not stable. If left in the curing area any compost would eventually become stable, but the resulting material from the EF unit was not. This is, in part, because of the EF unit management which was done both by GMT remotely and by the onsite management.
4. Negate ill effects of nitrogen and phosphorus. See 2. Above.
5. Reduce weight by 50% or more. This was not tested. It is normal for a compost operation to do this.
6. Reduce pathogens, weed seeds, and parasites. The e. coli tests showed approximately a 1,000 fold reduction. Weed seeds were not tested. The helminth ova parasite would not have been destroyed by the heat in the EF unit, but the numbers would have been reduced because much of the unit reached appropriate temperatures for an appropriate length of time.
7. Have a through-put of 2.5-3.0 tons of feedstock/day. Not quantified.

In general, GMT and the EF unit provide a turn-key completely covered compost unit that performs acceptably.

Appendix 1. Definitions of compost.

CalRecycle (http://www.calrecycle.ca.gov) web site:

The product resulting from the decomposition of organic material. Material used to make compost includes landscape trimmings, agricultural crop residues, paper pulp, food scrap, wood chips, manure, and biosolids. These are typically referred to as feedstock.

US Composting Council (https://compostingcouncil.org) web site:

Compost is the product resulting from the controlled biological decomposition of organic material that has been sanitized through the generation of heat and stabilized to the point that it is beneficial to plant growth.

Mid-Atlantic Better Composting School:

Composting accelerates and directs the natural process of decomposition of organic materials by controlling mixtures of organic materials and the environment in which they are transformed into a useful and stable product called compost.

On-Farm Composting Handbook (aka NRAES-54):

Composting is a biological process in which microorganisms convert organic materials such as manure, sludge, leaves, paper and food wastes into a soil like material called compost.

State of Maryland Regulations (COMAR)15.18.04.01 (B)5

"Compost" means a stabilized organic product produced by the controlled aerobic decomposition process in such a manner that the product may be handled, stored, and applied to the land or used as a soil conditioner in an environmentally acceptable manner without adversely affecting plant growth.

Appendix 2. Temperature graphs.

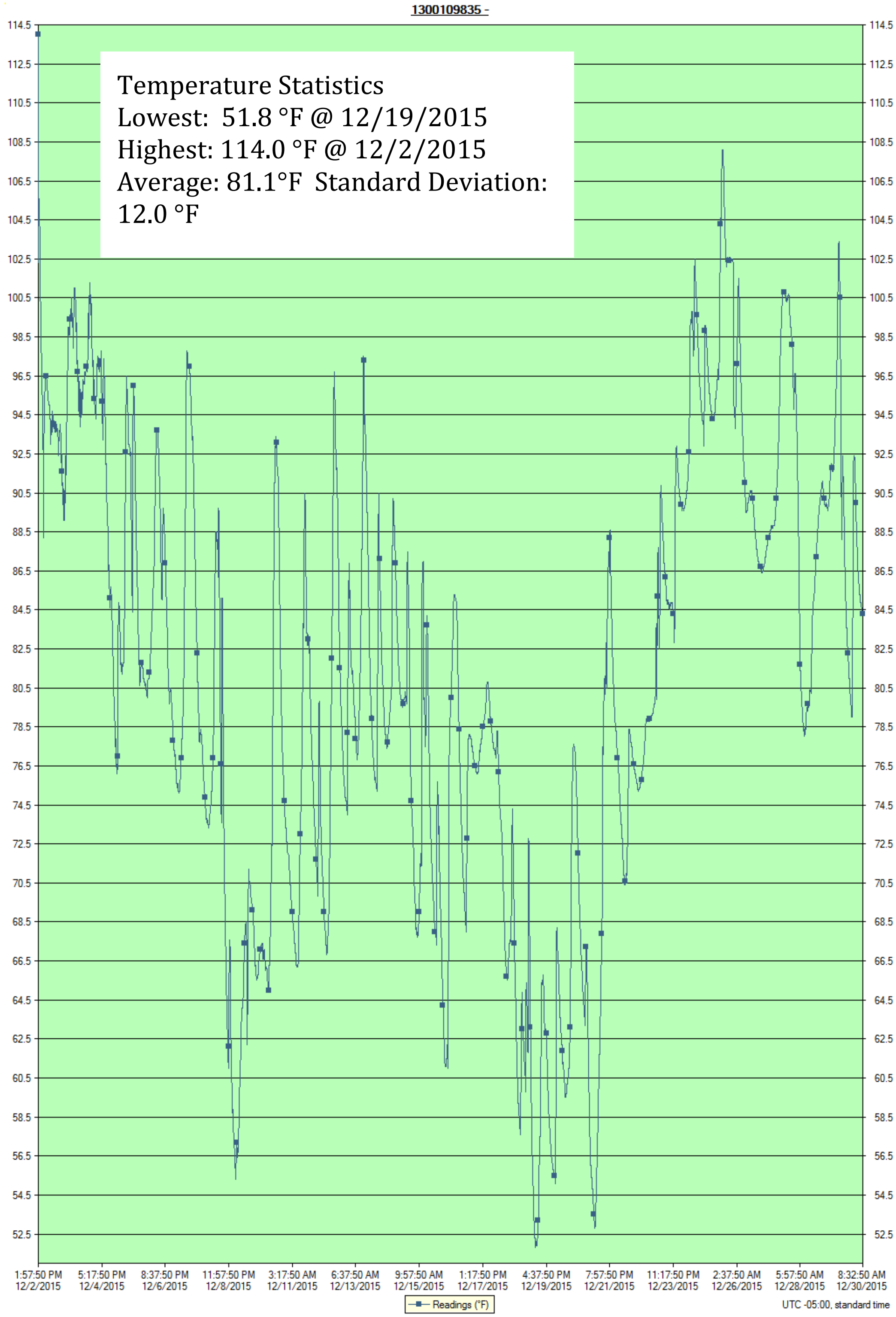

Figure A1. Temperatures for position 5 during winter conditions.

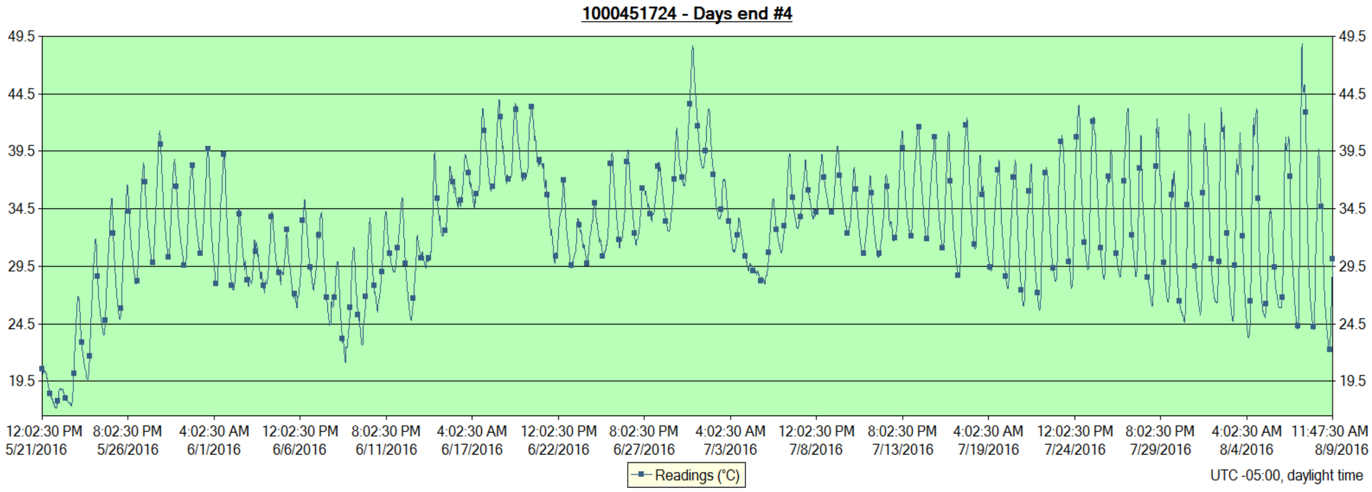

Figure A.2 Interior temperatures at position 4 on the west side of the EF unit (°C) during summer conditions.

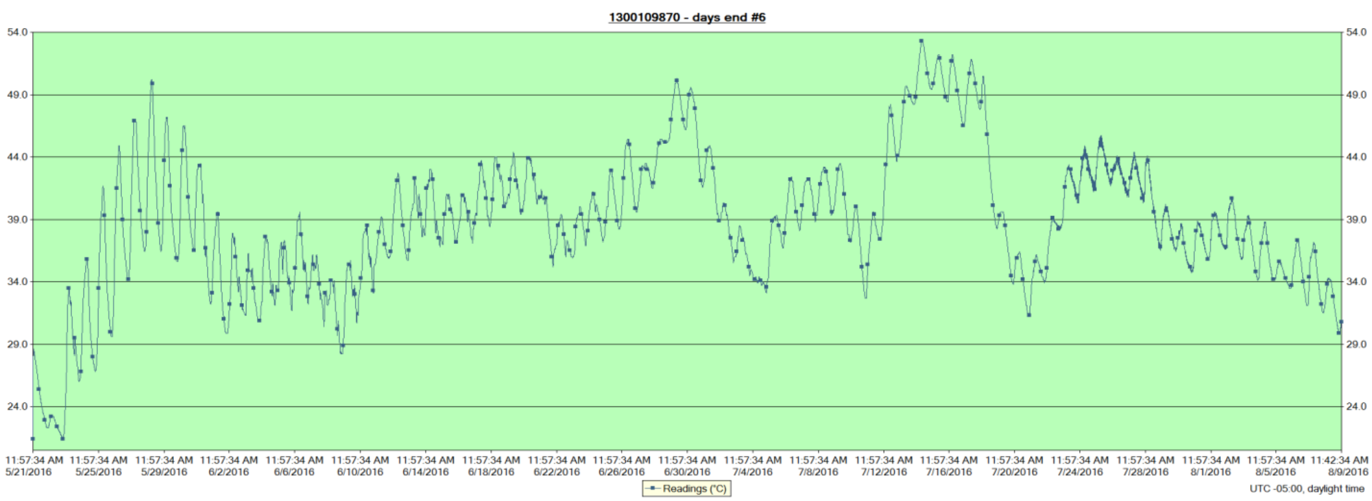

Figure A.3 Interior temperatures at position 6 on the west side of the EF unit (°C) during summer conditions.

Appendix 3. Bulk density data.

Table A3.1. Days End Farm - Bulk Density using 5 gallon bucket procedure					
Date mm/dd/yy	**Starting mix input to EF (lbs/5gal)**	**Product removed from EF (lbs/5gal)**	**Density Change during Composting**	**Cured product removed from Curing pile (lbs/5gal)**	**Length of curing time (days)**
7/5/2016	23.4	16.2	30.77%	15.4	3
7/7/2016	23.1	16.4	29.00%	15.4	5
7/9/2016	23.5	16.6	29.36%	15.2	7
7/11/2016	22.8	15.9	30.26%	15.6	0
7/12/2016	23.2	16.1	30.60%	15.4	1
7/14/2016	23.2	16.2	30.17%	15.3	3
7/16/2016	23	16.1	30.00%	15.1	5
7/18/2016	23.1	16	30.74%	15.1	7
7/20/2016	22.9	15.9	30.57%	15.2	9
7/22/2016	23.1	16	30.74%	15.1	11

bucket weight 1.93 lbs