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OPTIMIZING DESIGN AND OPERATION OF DAIRY MANURE COMPOSTING SYSTEMS USING PILOT AND FULL SCALE KINETIC STUDIES

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ABSTRACT

Manure management has become a major issue on dairy farms as they have expanded and required a larger land base for application. With increased hauling distances, liquid manure systems become less economical. Dairy farmers are adopting composting as a method to process manure, which reduces transportation cost and facilitates utilization while protecting the environment. Full scale studies in 2001-2002 for dairy manure (free stall, 85% moisture wb) mixed with sawdust or straw using turned windrows showed total weight losses of 82 and 80% w/w and volume reductions of 81 and 89% v/v for the compost mixes, respectively, over a time period of 150 days. Normalized to the original manure weights and volumes, reductions from composting were 77 and 73.5% w/w and 42 and 58% v/v. Dry matter losses were approximately 72%. Nitrogen losses were 26-42% w/w. However, 2001 pilot scale studies using intermittent aeration had 16% NH_3-N losses, while maintaining a rate of decomposition of about 0.015 kg/kgvs-day. These latter results imply by day 42-44 a 50% reduction in organic matter would occur for the compost mix and it may be stable enough to be piled for curing. Optimization studies using Excel® spreadsheets and parameters evaluated from the pilot scale and full scale windrow composting were done. Dry matter and moisture loss, compost pad area and energy cost were evaluated as functions of, materials used and mixing ratio, fan sizing and on/off operation, pile shape and size and consolidation frequency. Results showed composting manure in two stages reduced cost significantly. For example, composting 28 days using windrows and then curing for 152 days using large blocks reduced pad area by 15% compared to composting in windrows for 35 days and curing 145 days.

KEYWORDS. aeration, composting, dairy manure, design, feedstock, optimization, parameters, systems

INTRODUCTION

During the past decade the US livestock industries have become increasingly aware of environmental issues associated with the production, storage, treatment and utilization of animal wastes. In regions where animals have become concentrated, excessive manure loading rates to land pose problems such as the accumulation of nitrates in ground water and of phosphorus and nitrates in surface waters. These issues are major constraints to the profitability and growth of livestock industries. In particular, Ohio's dairy industry is facing these issues.

Composting of animal manures offers benefits to managing manures (Rynk, 1992). Mass and volume reduction, through moisture and dry matter loss, improves the economics of transportation and allows for a wider area of distribution. The stabilized compost does not emit odors or attract flies; has reduced pathogen levels and can also suppress diseases of plants and thus reduce pesticide use. However, economical and operational issues as well as technical understanding of the process have limited the adoption of composting by dairy farmers.

BACKGROUND

Manure from free stall housed dairy cattle poses unique problems for handling and disposal because of its high water content. Typical water content for this manure is 87.3% (Geiser, 1985). Separation has been used as an approach to produce a solid (75-85% water) which can be composted without amendment and then recycled as bedding or marketed offsite. However, separation adds fixed and variable costs and still requires the operator to deal with a liquid containing a high percentage of the nutrients. This liquid requires large acreage per cow for land application to meet EPA regulations. Other approaches to deal with wet manures are drying with fossil fuels or composting by adding dry amendments to achieve an acceptable moisture range. Estimated fuel and electric cost for drying manure from 90% moisture down to 15% is $165-200 per ton generated (15% moisture). Composting is estimated to cost $5-$10 per ton of raw material (Rynk, 1992). Based on a blending ratio for dairy manure to amendment of 3:1 w/w and an 80% reduction in weight during composting (Keener et al., 2002b), cost would be $34-$67 per ton generated.

Haug (1986) outlined procedures to determine appropriate initial moisture levels and substrate mixes for successful bio-solids composting. Rynk (1992) detailed the design and operation of on-farm composting systems. Richard (1998) discussed composting wet animal manure and the effect of compost temperature and decomposition rate on water removal rate. Keener *et al*. (1996) developed equations based on heat and mass balances to predict moisture removal from compost over time as a function of biomass conversion, composting temperature and ambient air conditions. Keener *et al.* (2000) used this theory and results of pilot scale studies to determine the theoretical moisture limits for composting non-separated dairy manure. Results showed: aeration was critical in reducing compost moisture levels and generally the initial compost moisture needed to be less than 70% for dairy manures. Elwell *et al*. (2001), using pilot scale composting studies of swine manure/sawdust mixes, showed that aeration controls not only moisture loss, but also NH_3 and VOC emissions.

Keener *et al*. (2002b) reported results for full scale turned windrow studies involving scraped free stall dairy manure (DM) mixed with sawdust (SD) or straw. Weight losses and volume losses at 155 days of composting were over 80% for the compost mixes. Normalized to the original manure weights and volumes, reductions from composting were 77% w/w and 42% v/v with the sawdust amendment and 73.5% w/w and 58%v/v with the straw amendment. Studies using oxygen levels to set aeration patterns showed aeration increased dry matter, C and water loss. Nitrogen loss also increased. Studies using a fleece blanket to cover the windrow showed covering piles during composting reduce rates of dry matter, carbon, and nitrogen losses. Results suggest that compost moisture could be significantly lowered with covers, due to the covers shedding rainfall, an important factor under winter and spring conditions in Ohio.

Keener *et al*., (2002c) developed spreadsheet computer models for decision making in the design and management of compost systems. They used the models to analyze composting of biosolid/yardwaste/sawdust/recycle mixes for various composting temperatures (50 C to 69 C) and composting times (14, 21, 28 and 35 days stage 1) with a total residence time of 90 days for composting and curing. Results on fan energy cost, solids left, final moisture, and total area were predicted for various combinations. The study showed selecting a fan size to compost initially at temperatures 5-10 C above the optimum, although slowing the process initially, was a cost effective approach to minimize fan size, and power consumption. Time to maturity was not appreciably increased. Reducing composting time in the windrow was very effective in reducing composting/curing area required.

The goal of this study was to optimize the practice of composting dairy manure. It investigated for DM/SD mixes the effect of composting/curing time and recycling of compost on composting rates using full scale, pilot scale and computer simulation studies.

Full Scale Studies

Full scale composting of a dairy manure/sawdust mix (Test 6) was done on the Ohio Agricultural Research and Development Center (OARDC) compost pad, located at Wooster, Ohio. The concrete pad is 52 m x 53 m (170 ft x 175 ft) in size and had eight aeration ducts built into it for supplying air to compost windrows of 28 m (92 ft) in length. Each duct is a 10 cm (4 inches) PVC pipe buried 5 cm (2 inches) below the surface of the pad. Eighty-six 1 cm (3/8 inch) holes were drilled into the pipe on 25 cm (1 ft) centers. Attached to each pipe is a 0.75 kw (1 hp) fan capable of delivering 6.37 m^3/min (225 cfm) of air at 17.8 cm (7 inches) of water pressure. The fans were equipped with programmable timers which allow their intermittent operation to be on from as little as 30 seconds in 1 hour up to continuous operation. Equipment available at the pad for mixing, moving material, and turning windrows were a feed mixing wagon with load cell, skid steer loader, and a tractor-assisted, Aeromaster™ 120 windrow turner. Slope of the composting pad is 1%, with a catch basin located at the lower end. Runoff from the pad is collected by the catch basin and then carried by a pipe to a 3-cell staged wetland. The design of the wetland was based on NRCS standards using a 25 year-24 hour storm event.

Test 6 was a composting study using aeration **(ae)** with removal of the windrow compost to storage at 28, 42, 56 and 70 days (treatments A, B, C & D). No cover was used. For comparison, one windrow was unaerated **(nae)** for 70 days (trt. E). The material composted was a DM/SD mix of 3:1 w/w. Dairy manure (cow feces and urine, recycled dairy solids and sawdust) was removed from the OARDC dairy barn at Wooster, Ohio, transported to the composting pad, and then mixed with hardwood sawdust using the feed mix wagon as described by Keener et al (2002b). Because of the time required to accumulate enough manure for a windrow, windrows were built seven days apart. Approximately 10,000 kg (22,000 lb) of mix was placed for each treatment. Windrows were turned on day 1 during the first week and then bi-weekly, or weekly or less frequently, depending on composting activity, i.e. temperature, until the compost was removed and placed in curing piles. Water was added to the composting windrows if moisture fell below 45%, wb. The study was conducted from June 4 to August 20, 2002. Rainfall during the test period was 13 cm (5.28 in.). The aeration rate was about 1.35 $kg_a/kg_{co}\cdot$day and the fans were operated intermittently.

Samples of the manure and sawdust were taken at the start of the test and were analyzed for dry matter, total carbon, total nitrogen, ash and pH (Table 1). Compost samples were collected from each windrow on day 0 and then at various intervals throughout each test (Table 2). Details of the sampling procedures and chemical analysis of the dairy compost mixes are in Keener *et al*. (2002b). Initial mix C:N ratio was 36-39 and moisture was 62-64% wb.

Table 1. Mean chemical properties of compost feedstocks ± one standard deviation used in Test 6 studies at OARDC, Wooster, Ohio, June 2002.

ID	DATE	n		Solids %	Ash* %	Carbon* %	Nitrogen* %	C/N	pH
Dairy Manure	6/4/02	4	ave	18.3	14.0	44.5	2.69	16.6	7.39
			sd	1.69	1.81	0.57	0.26	1.64	0.31
Heifer Manure	6/4/02	4	ave	19.3	16.0	44.7	2.59	17.5	7.66
			sd	0.92	1.76	2.50	0.33	2.51	0.49
Sawdust	6/4/02	2	ave	92.5		48.1	0.11	437	
			sd	1.64		0.04	0.00	12.7	

*Reported on a dry weight basis.

Results: Temperature histories for Test 6 showed the compost heated rapidly for all treatments to 70 ^{o}C and remained above 55 ^{o}C for several weeks (Figure 1). Oxygen levels during the study were below 5% for the **nae** windrow through the first 28 days (Figure 2). Changes in dry matter, volatile solids, moisture, ash, carbon and nitrogen, content observed during composting are given in Table 3. Results showed losses of 34-42% and 52% for dry matter and 31-40% and 52.7%,

Table 2. Weights of raw materials used to prepare experimental windrows and mean chemical properties of windrow composts for Test 6, OARDC, Wooster, Ohio, June 2002.

Compost	Weight (kg) Manure	Sawdust	Total	Moisture (%)	Ash§ (%)	Carbon§ (%)	Nitrogen§ (%)	C:N
DM/SD(6/4)-ae	15800	5155	20955	62.8 ±0.6	9.12* ±1.3	44.0 ±2.5	1.26 ±0.01	34.9 ±2.0
DM/SD(6/12)-ae	16623	5509	22132	64.0 ±0.3	9.51* ±2.2	46.2 ±0.6	1.20 ±0.03	38.5 ±1.4
DM/SD(6/4&12)-nae	6768	2250	9018	62.2 ±1.3	8.27* ±1.3	45.7 ±2.5	1.25 ±0.01	36.6 ±2.3

§ Reported on a dry weight basis. *Ash content calculated from material weights and chemical analysis were ~6% which suggest sample ash values of mixes are high.

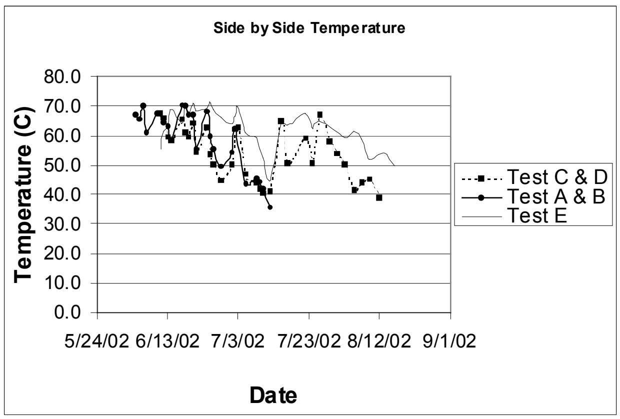

Figure 1. Average temperature during dairy manure composting in windrows, aerated (Trt. A-D) vs. unaerated (Trt. E). Data points represent an average of 18 measurements taken 3 times per week per windrow.

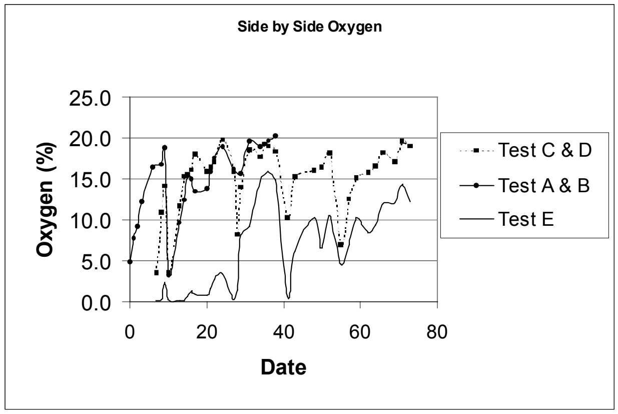

Figure 2. Average oxygen levels during dairy manure composting in aerated (Trt. A-D) and unaerated (Trt. E) windrows. Data points represent an average of 9 measurements per windrow.

Table 3. Chemical composition of compost in Test 6 on day 70, and losses of dry matter, VS, water, C, N and water per unit dry matter loss.

Trt.	Description	Total Mass kg	n	Moisture %wb	Ash %db	Total Carbon %db	Total Nitrogen %db	C/N	Losses DM %	VS %	H2O %	C %	N %	H20 kg_w/kg_{dm}
A	Aerated 28/42	8680	2	32.4	7.63	46.2	1.75	26.4	34.1	33.0	81.3	30.8	8.4	4.03
B	Aerated 42/28	7700	2	37.5	9.28	45.3	1.86	24.4	41.6	41.7	79.3	39.9	13.9	3.21
C	Aerated 56/14	9189	2	42.4		44.9	1.72	26.1	38.2	43.5	74.4#	40.0	11.5	3.45
D	Aerated 70/0	9460	2	38.9	9.0	44.7	1.70	26.3	35.7	35.3	76.9#	37.8	8.9	3.82
E	Unaerated 70/0	7200	2	50.0	9.7	45.0	2.06	21.9	51.9	52.7	70.8#	52.7	20.7	2.25

Water was added to windrows during composting.

for carbon for the **ae** and **nae** compost, respectively. The water weight lost through evaporation was 71-81% for all studies. Water was added to windrows in test C, D and E during composting. The **ae** compost lost 3.2-4.0 kg water per kg dry matter and the **nae** compost lost 2.3 kg water per kg dry matter. The **ae** compost lost 9-14% of the starting nitrogen compared to 20.7% for the **nae** compost.

Results for Test 6 showed **ae** had a higher water loss per unit of dry matter lost. Also, with rapid drying occurring for **ae**, nitrogen loss was lower (appeared to correlate with dry matter loss) These results support the idea of short composting time and recycling dry compost in place of new amendment to reduce cost of composting dairy manure.

PILOT SCALE STUDIES

Dairy manure and sawdust were composted in 208-L reactor vessels at the OARDC/OSU Composting Center, according to Elwell *et al*. (2002). Mixes were prepared similarly to that described under full scale studies, with the exception that aged manure (12 day old) was used in some test. The fans that supplied air to the reactors were operated in a high/low (approximately 0.9 or 0.3 L min^{-1} kg_{DM}^{-1}) thermostatically controlled (60°C, 1.5°C differential) continuous mode (continuously aerated), or in an on/off (nominal 5 min on high fan during each hour) timer controlled intermittent mode (intermittently aerated). Pressure drops across orifice plates, used to measure supply air flow, were recorded every 10 minutes. The system was monitored for temperature histories, airflow rates, O_2 uptake, and CO_2, NH_3 and heat evolution. Ammonia evolution was measured by bubbling exhaust air through a boric acid solution followed by titration with HCl (Elwell *et al.*, 2001). Moisture content of the compost was based on drying at 100°C (72 hr). A total of eight pilot-scale studies (any where from 4 to eight reactors in a study) were ran, 3 in year 2001 (Elwell *et al.,* 2002) and 5 in year 2002. Experiments lasted from 16 to 28 days. Vessel contents were remixed weekly during the runs and water was added at these times if the moisture content was <46%wb. Results from 3 test in year 2001 and the 1st test in 2002 are reported here.

Results: Keener *et al*. (1997) analyzed pilot scale studies of various compost mixes to determine the kinetic parameters k and β_o , where k is defined as the rate of disappearance of dry matter per unit of compostable dry matter, day^{-1} and β_o is the non compostable fraction of the compost mix at the start of composting. The analysis by Keener *et al.* (1997) assumed a first order decomposition process would apply to the high rate initial stage of composting. That methodology was used here to evaluate the rates of decomposition for dairy manure/sawdust mixes (Table 4).

The k is a function of substrate compounds, microbial populations, temperature, moisture content, particle surface area, and interstitial atmosphere (oxygen, NH_3…). Haug (1993) expressed it as a function of compost temperature (Tc), moisture content (wc), oxygen concentration (O_2), and free air space (FAS). Ekinci (2002) expressed it as a function of C/N. The functional relationship for k is

$k = k_{max} X_T X_{wc} X_{O2} X_{FAS} X_{C/N}$

(1)

The terms X_T ,X_{wc} and $X_{C/N}$ were incorporated into the spreadsheet model (see next section) as Gausian functions of the form (Keener *et al*., 2002a):

X_{Tc} = (2)

X_{wc} = (3)

$X_{C/N}$ =(4)

X_{O2} and X_{FAS} were set equal to 1. Results for the pilot studies gave k = 0.015/day (evaluated k_{max} was 0.020/day) and a beta value of 0.08 (beta = 1-VS). It was this data that was used in the optimization studies.

Table 4. Evaluations of k and β_o using results of pilot scale studies on dairy manure/sawdust mixes[a].

Test	CompostMix[b]	n	time	Temp	H2O	C/N	rho	re-mix[c]	k (1/day)	β_o
			day	C	%		kg/m3	days	ave	ave
1	dm_0/sd - I	4	15	58	68.9	31.2	165	7	0.0174	0.08
1	dm_0/sd - C	4	15	58	-	-	-	7	0.0185	0.08
2	dm_{12}/sd - I	4	21	58	65.5	29.3	169	7	0.0111	0.08
2	dm_{12}/sd - C	4	21	58	-	-	-	7	0.0129	0.08
3	dm-/sd - I	4	20	58	64.7	30.2	142	7	0.0134	0.08
3	dm-/sd - C	4	20	58	-	-	-	7	0.0133	0.08
4	hm_0/sd - C	2	21	58	63.9	33.2[d]	177	7	0.0173	0.08
4	hm_0/sd - I	2	21	58	-	-	-	7	0.0167	0.08
	dm/sd, AVE			58	65.8	31.0	163	7	0.015	0.08
	dm, sd, SD			58	2.2	1.7	15		0.003	0

[a] Temperature, moisture, C/N, and compost density, dry basis, are shown for test conditions.

[b] dm_0 - fresh free stall dairy manure, dm_{12} - aged dairy manure, hm_0 - heifer manure, sd - sawdust.

[c] Remix days were intervals used during experimental studies. [d] Calculated from mixing ratios.

OPTIMIZATION STUDIES

Figure 3 illustrates material flow in conventional composting. For this process, primary ingredients, amendments and recycled compost are mixed to achieve acceptable ranges for initial C/N, moisture, etc. and then the mix is put into a pile for composting to occur. In addition, material may be placed over the compost to serve as a biofilter to manage odors early in the process. Depending on the process the mix gets turned daily, every three or four days, or sometimes only weekly or monthly. In some cases air is forced through the compost to control temperature and keep the pile supplied with oxygen. When little or no heat output is observed, the material is put in a curing pile. Length of curing will depend on marketing opportunities (uses) for the compost. Keener et al. (2002c) developed a computer spreadsheet model for analyzing this schematic of the composting systems. It consisted of four sections: 1) Formulation of Compost Mix - meet C/N and moisture requirements, 2) Design of Pad - pile sizes, pile numbers, areas for composting and curing, 3) Evaluation of Process - dry matter and moisture losses, airflow and fan size requirements, 4) Summary Sections - input and output masses and volumes, fan energy cost, etc. Details on the equations used in the computer model and parameter evaluations were given by Keener(2002c). This model was used in the analysis presented here.

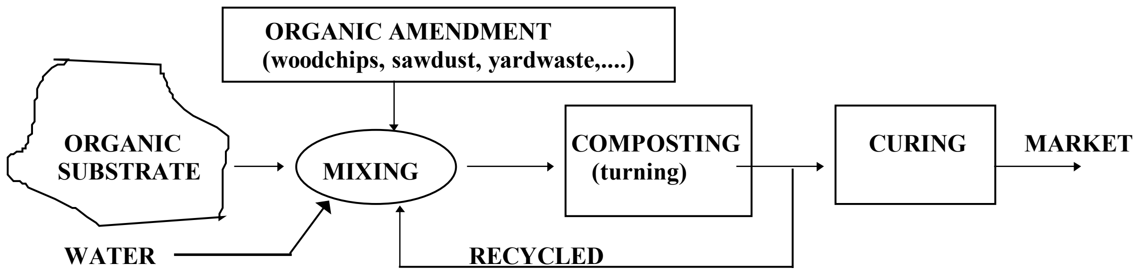

Figure 3. Material flow for the conventional composting process. Airflow into the composting and curing pile, also a part of the process, is not shown.

<u>Study:</u> Optimization studies were done on a dairy manure/sawdust mix with a mass ratio of 3:1, C/N ratio of 41.2, and initial moisture 64.9%. Initial bulk density was 649 kg/m^3 , assuming a mixing shrinkage factor of 0.9. No biofilter was used in the analysis. Appendix Table A1 shows the input and output for the spreadsheet model sections 1. Table A2 gives results for the design of the compost pad for a 300 cow dairy. Manure from other livestock (dry cows, heifers, etc.) are excluded in the analysis. In this case a lateral turning machine was used with a base width of 4.5 m and height of 1.8 m. Cross section of the windrow was assumed to be parabolic and had an area of 5.4 m^2. For this operation, input of dairy manure was 18.6 t/day and of sawdust 6.2 t/day. Composting time was 28 days and storage time was 152 days. Seven windrows were required to keep windrow lengths below 30 m. Composting pad area was 2551 m^2 and curing pad area was 598 m^2. Curing area was minimized by using a block arrangement, no aisle and a pile height of 5 m.

Table A3 gives a summary of the process parameters for the DM/SD mix. Assumptions used in the analysis were an initial beta of 0.072 and k value of 0.014/day (after accounting for compost temperature, moisture and C/N). For each kg of compost into the process, it was estimated 44.5% would go to the curing pad and eventually 26.8% would be marketed. Moisture going into curing was 44.6 % based on airflow through the compost and drying efficiencies of 65%. Projected water removal (-PHE) was 4.34 kg water/kg of dry matter lost, similar to laboratory experiments. Airflow was based on 0.46 kga/day-kgco. Fan size was projected at 0.394 kW/windrow (fan efficiency 0.5, pressure 12.4 cm H_2O). Fan operating cost was $0.99/t marketed.

Figure 4 shows the ideal temperature, moisture and fan operation histories during composting at 65 C. From day 0 to day 25 compost temperature was projected above 60 C and then began to decrease rapidly. Fan operation became intermittent on day 28. Compost moisture slowly decreased from 68.3% to 43.5%.

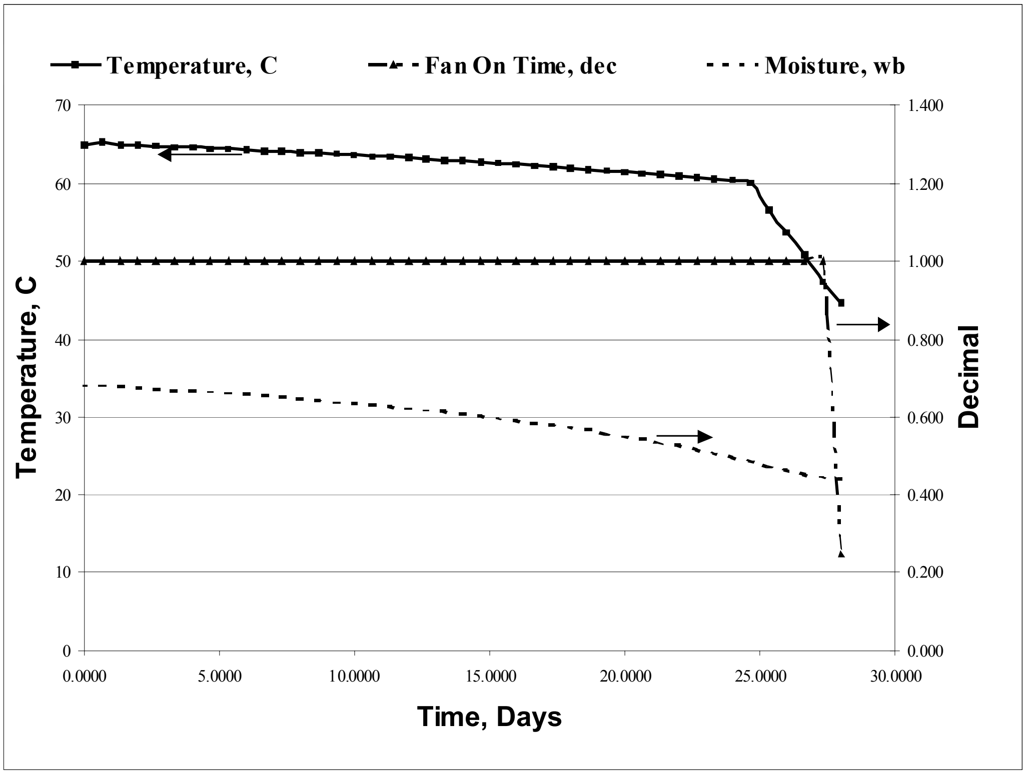

Figure 4. Operating conditions predicted by simulation spreadsheet for dairy manure/sawdust mixture with aeration controlled for maximum temperature of 65 C.

Table 5 shows the effects of composting time (7, 14, 21, 28 and 35 days) and a total time of 180 days on fan energy cost, solids left (after composting and curing, i.e. marketed), final moisture, and total area for composting & curing. Minimum pad area occurred for 21/159 day compost/cure days. Fan cost increased with compost time.

Table 5. Performance factors predicted by simulation spreadsheet for dairy manure/sawdust mixture (3:1 w/w) with aeration[#] controlling compost temperature ≤ 65 C. Stage one composting times were 7, 14, 21, 28 and 35 days. Total composting and curing times were 180 days.

Description	unit					
Compost Cycle Time Period	days	7	14	21	28	35
Input Compost	tonne/day	24.79	24.79	24.79	24.79	24.79
sawdust	tonne/day	6.19	6.19	6.19	6.19	6.19
Curing Time Period	days	173	166	159	152	145

Compost Final m/mo	%, dry basis	91.3	82.9	75.0	70.4	69.3
Final moisture	% wb	61.9	57.7	51.7	44.6	42.3
-PHE		4.226	4.209	4.193	4.336	4.369
Cured	tonne/day	20.82	17.05	13.51	11.04	10.45
Marketed	tonne/day	14.47	11.48	8.66	6.65	6.27
Final moisture	%wb	74.38	69.51	61.97	51.95	48.28
Dry Tonne Marketed	tonne/day	3.71	3.50	3.29	3.20	3.24
Number Windrows		2	4	5	7	8
Windrow mass, in	tonne	86.78	86.78	104.13	99.18	108.47
Windrow dry mass, in	tonne	30.45	30.45	36.54	34.80	38.06
Filling Time per Windrow	days	3.50	3.50	4.20	4.00	4.38
Windrow Airflow	m3/s	0.138	0.138	0.166	0.158	0.173
Windrow Fan Size	kW	0.345	0.345	0.414	0.394	0.431
Fan Time	days	7.000	14.000	21.000	28.000	30.821
Fan Operating Cost (compost in)	$/tonne	0.07	0.13	0.20	0.27	0.29
Fan Operating Cost (compost out)	$/tonne	0.11	0.29	0.57	0.99	1.16
Compost area	m2/tonne/year	0.085	0.154	0.214	0.282	0.341
Curing area	m2/tonne/year	0.267	0.172	0.103	0.066	0.056
Total area	m2/tonne/year	0.352	0.326	0.317	0.348	0.397

[#]Electricity @ 0.10 $/kw-h, Fan pressure 12.7 cm H2O, fan efficiency 0.5, airflow 0.463 kga/day-kgco.

Figures 5-10 show the effects of reducing mixing ratios for amendment:manure and recycling compost into the mix for 28 day composting, 180 day total time, and an input of 18.6 t/day of dairy manure. For the chemical properties assumed, simulation results showed reducing amendment ratio from 0.33 to 0.167 and recycling 60% of compost from stage 1 would give a compost mix below 65% initial moisture (Figure 5), similar to a 0.33 mix ratio; reduce pad area from 0.35 m2/t/yr to 0.28 m2/t/yr (Figure 7); increase fan energy cost to $2/t finished compost, up from $1/t (Figure 8); decrease product output from 6.7 t/day to 3.8 t/day (Figure 9) while maintaining the same moisture (Figure 10) and reduce weight that the farmer has to haul to field by 80% (original manure weight 18.6 t/day). Note the total fan energy cost per year for operator would be same for both systems.

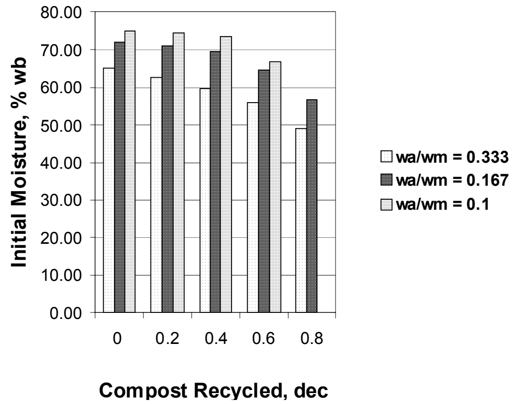

Figure 5. Initial compost moisture versus amendment:manure ratio (w/w) and compost recycle fraction.

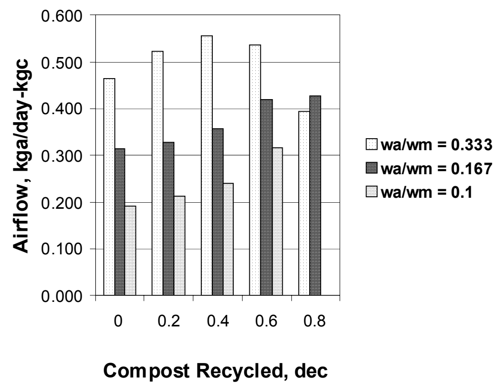

Figure 6. Airflow versus amendment:manure ratio (w/w) and compost recycle fraction.

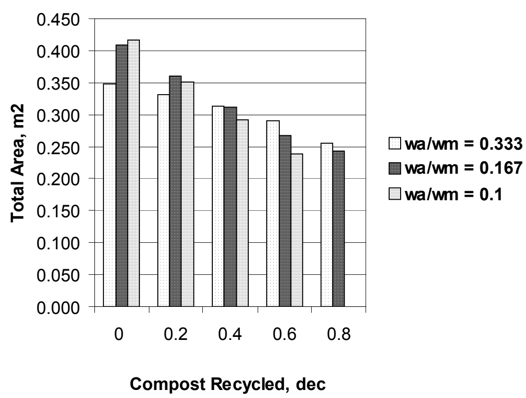

Figure 7. Compost & curing area versus amendment:manure ratio (w/w) and compost recycle fraction.

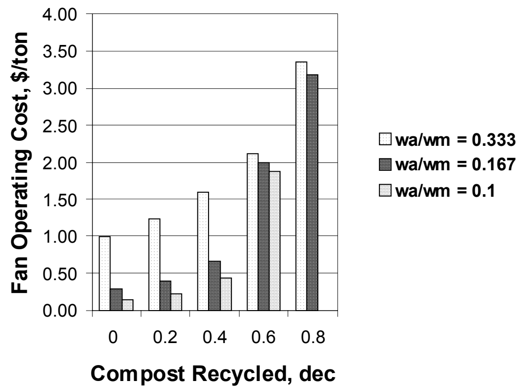

Figure 8. Fan operating cost per ton of compost marketed versus amendment :manure ratio (w/w) and compost recycle fraction.

CONCLUSIONS

Studies on composting free stall dairy manure with sawdust, based on full scale, pilot, and simulation experiments, were described. Chemical, physical, and kinetic data on composting materials that allows rational design and operation of composting systems are summarized. Results showed a compost mix of 3:1 w/w for dairy manure and sawdust had desirable chemical and physical properties for composting. From full scale studies, aeration of windrows was shown to increase moisture loss significantly and provide a product by day 28 that could be recycled back into the system to reduce amendment cost. To minimize fan fixed and operating cost, simulation analysis assumed a 5-10^{o}C above optimal temperature for decomposition during the first 1-2 weeks of composting (based on earlier studies). Minimizing composting time (stage 1) and maximizing curing time (stage 2) reduced fixed cost significantly. Recycling product can reduce amendment cost, pad area and volume of product with little to no increase in total fan energy cost. Future pilot scale and full scale studies are recommended to verify results of the simulation studies.

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APPENDIX

1. Computer spreadsheet for analysis of composting systems, section 1. Input data are shaded blocks.

MIXING RATIO - BASED ON MASS	Contact: Harold Keener, FABE Department	330-263-3856; 330-263-3670 (fax)
REVISED 3/2000, 9/2002	OARDC/OSU, Wooster, OH 44691	keener.3@osu.edu

Description	Dairy + sawdust + recycle			Mixing Parameters	
Herd Size	300	manure	manure	Mixing Shrinkage Factor	0.90
milk kg/cow-day	40.9	kg /cow-day	tonne/herd-day	Amendment/Manure	0.333
Lactating Cows	300	61.82	18.55	Recycle Ratio	0
Dry Cows (17%)	0	48.18	0.00		

ITEM MATERIAL	Moist wb %	VS %	C %	N %	C/N	Den kg/m3	Vol m3	Vol Ratio dec	Mass (wet) tonne	Mass Ratio dec	Dry Mass tonne	Water Mass tonne
dairy manure(free stall)	81.2	85.0	44.6	2.64	16.9	950	19.6	1.00	18.6	1.00	3.5	15.1
sawdust	16.0	99.0	49.8	0.16	311.0	271	22.9	1.17	6.2	0.33	5.2	1.0
leaves	62.1	93.0	46.8	0.85	55.0	380	0.0	0.00	0.0	0.00	0.0	0.0
woodchips	40.2	1.0	48.0	0.35	137.0	363	0.0	0.00	0.0	0.00	0.0	0.0
yardwaste	31.8	80.0	46.8	0.65	72.0	297	0.0	0.00	0.0	0.00	0.0	0.0
site overs	44.6	10.0	44.4	1.20	37.0	438	0.0	0.00	0.0	0.00	0.0	0.0
recycle site compost	44.6	90.6	43.5	1.50	29.0	653	0.0	0.00	0.0	0.00	0.0	0.0
water	1.0		0.0	0.00		1000			0.0		0.0	0.0
AVE or Sum	64.9	93.4	47.7	1.16	41.2	649	38.2	1.95	24.8	1.33	8.7	16.1

Ash Free Moisture	66.5	recycle moisture	44.6
BioFilter Depth, m	0.00		

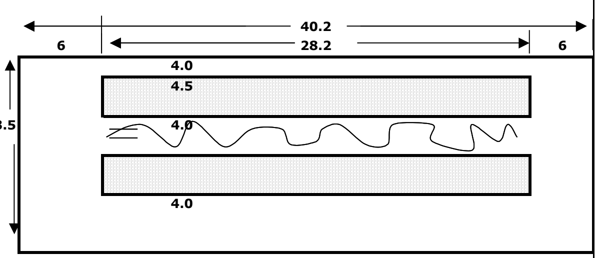
ITEM MATERIAL	Moist wb %	VS %	C %	N %	C/N	Den kg/m3	Vol m3		Wet Mass tonne		Dry Mass tonne	Water Mass tonne
biofilter	50.0	60	46.8	0.65	72.0	653	0.0	0.14	0.0	0.00	0.0	0.0

Fill Time Batch, day	1						
Composting Time, day	28	Maximun Tc, C	65.0	Pressure, cm H2O	12.70	fan efficiency	0.50
Total Time to Mkt, day	180	Fan Lower Setpt Temp,C	45	Cost ($/kW-h)	0.10		

Description: Topturn 3500 with laterial shifting device (Norton Environmental)

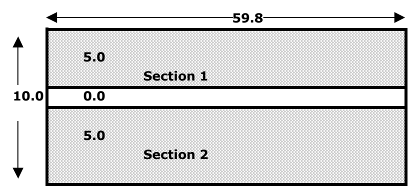
Windrow Height	1.80	m
Windrow Base Width	4.50	m
Cross Section Shape	B	
Area Windrow	5.4	m2
Fill Time Batch	1	days
Total Time, compost + cure	180	days
Composting Time	28	days
Storage Time	152	days

A	B	C	D	E
Rectangle	Parabola	Triangle	Semicircle	Trapazoid



Composting Pad - Compost and Biofilter

			dairy manure(free stall)
Compost Mass	694.2	tonne	520.8
Compost Volume	1070.3	m3	548.2
Number Windrows	7		
Windrow Length (L<30m)	28.2	m	
End Aisles	6.0	m	
Composting Pad Length	40.2	m	
Side,Between,Side	4.0	4.0	4.0
Composting Pad Width	63.5	m	
Composting Pad Area	2551	m2	



Curing Pad - Compost and Biofilter

Mass	1678.3	tonne
Volume	2989.6	m3
Pile Height	5.0	m
Storage Pile Area In	598	m2
Aisle width	0.0	m
Storage Pad Width	10.0	m
Compost Storage Length	59.8	m
Curing Pad Area	597.9	m2

Summary: Area for Composting

Composting	2551	m2	0.63	acres
Curing	598	m2	0.15	acres
Other	0	m2	0.00	acres
Total	3149	m2	0.78	acres

Table A2. Computer spreadsheet for analysis of composting systems, section 2. Input data are shaded blocks.

Summary:	Composting Results per Batch Through System						YEARLY					
	Mass Balances		Volume Balances				Mass & Volume			Mass & Volume		
	tonne	% m/m(0)	m3	% vol/vol(0)	Moisture	Beta	tonne	m3	yd3	tonne	m3	yd3
Compost IN	24.8		38.2		64.9	0.072	dairy manure(free stall)			Compost In		
Losses	13.8		-5.9				6789	7146	9347	9050	13952	18249
Compost OUT1	11.0	44.5	44.2	115.5	44.6	0.103	sawdust					
Biofilter IN	0.0		0.0		50.0	0.800	2261	8356	10929			
Losses	0.0		0.0				leaves					
Biofilter OUT	0.0	64.0	0.0	64.0	32.5	0.925						
Compost&Biofilter Recycled	0.0	0.0	0.0	0.0	44.6	0.103	woodchips					
Compost&Biofilter Cured	11.0	44.5	19.7	51.5	44.6	0.103				Cured Compost Out		
Compost Marketed1	6.7	26.8	12.8	33.5	51.9	0.197				2429	4669	6107
Compost Mkt/Dairy Manure In		35.8		68.8								

1Calculated volume using 250.00 kg/m3 dry density

SUMMARY COMPOSTING PROCESS

dairy manure(free stall)	18.60	tonne/day	Number Windrows	7		Compost Final m/mo	0.704	
Amendment Ratio (ma/mm)	0.333		Windrow Length	28.17	m	Compost Final moisture, wb	44.6	
sawdust	6.19	tonne/day	Windrow mass, in	99.18	tonne	-PHE	4.336	
Recycled Ratio	0		Windrow dry mass, in	34.80	tonne	Compost Cured	11.04	tonne/day
Recycle Compost	0.00	tonne/day	Filling Time per Windrow	4.00	days	Compost Marketed	6.65	tonne/day
Input Compost Mix	24.79	tonne/day	Windrow Airflow	0.158	m3/s	Final moisture, wb	51.95	
Inital Moisture, wb	64.91		Windrow Fan Size	0.394	kW	Dry Compost Mkt	3.20	tonne/day
C/No	41.23							
k(0)	0.014	1/day	Fan Time	28.000		Compost area	0.282	m2/tonne/year
beta(0)	0.072		Energy Cost	0.10		Curing area	0.066	m2/tonne/year
Compost Cycle Time Period	28.0	days	Operating Cost (compost in)	0.27	$/tonne	Total area	0.348	m2/tonne/year
Curing Time Period	152		Fan Operating Cost (compost out)	0.99	$/tonne			
Maximun Tc	65.0	C						
Fan Lower Setpt Temp	45.0	C						
Airflow	0.463	kga/day-kgco						
Pressure	12.7	cm H2O						
fan efficiency	0.5							

Table A3. Output of computer spreadsheet for analysis of composting systems, sections 3 and 4. Input data are shaded blocks