Evaluation of Co-Composter Results Versus On-Farm Composting Systems

Thomas Crone, A. Edward Staehr, Molly Moffe, Douglas Haith

Introduction

Cornell's Biological and Environmental Engineering Department and Waste Management Institute have developed Co-Composter, an Excel spreadsheet for the planning of co-composting systems for mixtures of dairy manure and other organic wastes. Co-Composter provides mass and volume balances, area estimations, and a cost analysis of alternative composting systems based on inputs provided by a user.

This report describes a study comparing Co-Composter results with characteristics of four actual on-farm composting operations. The comparisons identified ways to increase the usability of the model and provided feedback on the model's performance. The study also helped to highlight model advantages and limitations.

Four composting operations which differed in methods, feedstock, and equipment were studied. The farms are referred to in this report as Farm 1, Farm 2, Farm 3, and Farm 4. Co-Composter was run for each farm, producing estimated annual costs for the individual composting system. Simultaneously, an economic report and the physical parameters were compiled independently for each of the farms. The economic report determined actual costs of the composting operations on each farm, and calculated the total annual cost to the farm. The physical parameters which were reported included the characteristics of the final compost, the number of windrows, the windrow dimensions, and the final compost volume.

Economic Report

Costs were divided into two types, returns and savings from composting, and total costs. Returns and savings from composting could include final compost sales, tipping fees, or as savings in fertilizer, bedding, or manure hauling costs. Total costs are displayed as variable and fixed costs.

<u>Variable Costs</u>
Variable costs include operating and maintenance (O&M), labor, and electricity. The O&M costs provided by the composters are broken down into fuel, lubrication, and repairs while Co-Composter displays a total O&M cost for each individual piece of equipment.

<u>Fixed Costs</u>
Fixed Costs cover the annualized cost of building and owning the facilities and equipment over a specified number of years, as well as insurance costs. The fixed cost are displayed in two forms, due to a difference in the method that they were calculated. The actual figures from the composters are represented in two categories, depreciation and average annual interest on investment. These were calculated from expected life, salvage value, and interest rates given by the composter. These given values were also entered into Co-Composter to calculate the annual cost of the equipment and facility. Co-Composter amortizes the total cost over the expected life using the interest rate and the salvage value to calculate the annual cost. Although these methods do differ, both are reasonable and provide similar results.

Results
Results are displayed three ways: Total economic cost to farm, annual cost to farm, and cost per hundred weight of milk (where applicable). Total economic cost to farm includes the sum of the variable and fixed costs. Annual cost to farm is the total economic cost to farm minus the returns and savings from composting. Cost per hundred weight of milk is the annual cost to farm divided by the total milk produced divided by 100. All cost are also displayed per yard of compost output.

Physical Parameters

Compost Characteristics
The final compost was sampled and tested to determine the moisture content, carbon to nitrogen ratio, and bulk density of the final product. Results were recorded for comparison to the Co-Composter's estimates for the initial compost mix.

Pad and Windrow Characteristics
The pad/building size, number of windrows present and the dimensions of each windrow were recorded and compared to Co-Composter's results. Co-Composter reports the area required for each composting phase: raw material storage, active composting, curing storage, and cured storage. These areas measured only on Farm 2, and consequently are not compared for the other farms.

Time
Composters provided the approximate hours each piece of their equipment was used in composting operations. These numbers were used to calculate costs and were compared with Co-Composter's results.

Co-Composter's results were reviewed and compared to the economic report and the measured or reported physical parameters. Comparisons are presented for each of the farms and differences or similarities in the two sets of numbers are discussed. An overall comparison is also presented, comparing the mean costs of the four farms.

Farm 1

Farm 1 is composting manure from 115 heifers and dry cows. The manure includes wood shaving bedding and is amended with food waste, yard waste, wood chips, and straw. Farm 1 is turning all of the compost using a bucket loader.

The physical parameters in Table 1 matched well at certain points in the composting process. During active composting the number of rows were very close. Due to the variety of lengths and number of windrows Farm 1 has, comparison was difficult. In order to make this comparison Farm 1's total windrow length was divided by 100. This allows the volume and number of windrows to be compared easily but does affect the comparison of total pad size, which is significantly different. Curing storage is where most differences are apparent. In the curing area the number of windrows is overestimated, which ultimately leads to Co-Composter overestimating the final annual product. A similar adjustment had to be made to the number of windrows, due to the model's inability to use different lengths of windrows during the same phase. The difference in windrows and volume is most likely due to unpredictable composting practices. Farm 1 uses a large amount of amendments because the farm accepts whatever amendments can be utilized and/or are available at that time. With a large volume and variety of amendments the task of predicting the compost recipe characteristics becomes an even more difficult task. Although differences in bulk density and total annual production does exist, if they are used in calculations of total tonnage the total tons of product are nearly the same.

The annual cost to farm results showed a 15% difference (Table 2). Once again the majority of the difference was due to variable costs. This difference, unlike previous examples, is due to the O&M costs. Labor costs were extremely close. The O&M cost for the loader was nearly $15,000 higher than the reported values. To explain this, a closer look is needed at the composting operation. Farm 1 reported a total of 1,816 hours of labor spread over the operation of a skid steer, a payloader, a spreader, and a stack rack truck. Because the model only assumes one piece of equipment in this scenario, all turning/handling/moving is performed with the payloader. Co-Composter calculated that if only the loader is used, 1,768 hours would be required. This similarity in total hours causes the labor costs to be the same, but because of the variety of equipment the O&M costs are very different. Farm 1 results were not that similar, but did provide interesting issues and challenges in modeling such complicated operations.

Table 1: Physical Characteristic Comparison for Farm 1

Parameter	Actual	Model	Parameter	Actual	Model
Moisture content (%)	52	37	**Total annual production (yd3)**	2,400	6,521
C/N	12	46	**Total area (acre)**	8	5.38
Bulk Density (lb/ft^3)	53	20	**Total pad area (acre)**	7	4
Raw Storage Area (ft^2)	*	101,440	**Curing compost area (ft^2)**	-	30,550
# of rows	*	12	# of rows	5.4	10
Row height (ft)	*	14	Row height (ft)	12	12
Row width (ft)	*	94	Row width (ft)	16	16
Row length (ft)	*	50	Row length (ft)	100	100
Active compost area (ft^2)	-	43,680	**Cured compost storage (ft^2)**	0	0
# of rows	19.8	21	# of rows	0	0
Row height (ft)	8	8	Row height (ft)	0	0
Row width (ft)	12	12	Row width (ft)	0	0
Row length (ft)	100	100	Row length (ft)	0	0

wood/straw – 14’20’, food waste – 6’*20’*40’, manure – 6’*50’*80’

Table 2: Economic Comparison for Farm 1

Returns and Savings from Composting				
	Actual		**Model**	
Annual Income Received				
Compost Sales &	$117,284		$52,500	
Tipping Fees			$65,114	
Total Returns and Savings	$117,284		$117,614	
Total Costs				
	Actual		**Model**	
	Annual	Per Yard	Annual	Per Yard
Variable Expenses				
Operating and Maintenance Cost				
Payloader	-	-	$30,998	$4.75
Separator, Pipes, and Pumps	-	-	-	-
Screener Rental	$3,000	$1.27	$3,000	$0.46
Fuel	$10,878	$4.60	-	-
Lubrication	$1,632	$0.96	-	-
Repairs	$3,715	$1.57	-	-
Electricity	$0	$0.00	$0	$0.00
Record Keeping	$0	$0.00	-	-
Marketing	$0	$0.00	-	-
Labor	$29,914	$12.64	$28,844	$4.42
Total Variable Expenses	**$49,139**	**$20.77**	**$62,844**	**$9.64**
Fixed Expenses				
Insurance	$752	$0.32	$1,018	$0.16
Facility Depreciation	$2,045	$0.86	-	-
Composting Equipment Depreciation	$5,507	$2.33	-	-
Average Annual Interest on Investment	$2,336	$0.99	-	-
Facility Annualized Cost	-	-	$3,132	$0.48
Equipment Annualized Cost	-	-	$1,664	$0.26
Total Fixed Expenses	**$10,640**	**$4.50**	**$5,814**	**$0.89**
Total Economic Cost to Farm (Total Fixed and Variable Expenses)	$59,779	$25.27	$68,656	$10.53
Annual Cost to Farm (less Savings and Generated Income)	**-$57,505**	**-$24.30**	**-$48,958**	**-$7.51**

Farm 2

Farm 2 is composts manure from 1240 dairy cattle. The liquid manure is separated and the separated solids are composted without any amendments. The farms use finished compost for bedding, which also serves as a bulking agent. Composting is done in a forced aeration building, with no turning.

The physical parameters in Table 3 compare very well. Both the dimensions and the compost characteristics are very close. This farm provided some valuable insight into the importance of a separator being used with a composting system. Co-Composter originally assumed that 30% of the solids were separated from the liquid manure during the separating process. However, Farm 2 uses a roller press separator, which tends to be less efficient. Lab results showed that they were only separating 22% of the solids. When this was changed in the model the total annual production was reduced from 4,435 yd^3 to the present 3,200 yd^3, a 29% reduction and a much more accurate fit with the actual volume. Due to this finding the percent of solids separated from the manure is now something the user must input to Co-Composter.

In Table 4, the final economic results compared well with an actual annual cost of $32,056 versus the model's value of $28,682. This is a difference of $3,374, or 10.5%. There were, however, some visible differences in the two sets of variable and fixed costs. Under variable costs a difference can be seen in operating and maintenance costs. This difference of nearly $4,000 dollars is explainable through the difference in equipment hours. Farm 2 reported using their skid loader for only 156 hours per year. Co-Composter calculated an annual use of 390 hours. Normally this could be explained by a difference in volume of material being handled, however, there was only a difference of 100 yd^3 of final product. This difference instead stems from the use of a conveyer system which moves the separated solids from the separator to the active composting building. Co-Composter assumes the material will be moved from the separator to the building using only the skid loader, and this accounts for the difference in operating and maintenance costs.

Co-Composter also underestimated the annual cost of electricity. The model only takes into account the electricity needed to run the separator and blowers in the building. The reported value of $7,800 by the composter likely also includes electricity used for lighting, monitoring equipment, conveyor system, and other miscellaneous use. The other difference in variable costs is that of labor, a large difference of $10,744. Because the same hourly wage of $15.00 an hour was used both in the economic report and Co-Composter, the discrepancy is a result in a difference of labor hours. Farm 2 reported a general labor figure of 1040 hours, yet only 156 of it was operating the skid loader. Therefore, 884 hours are on other various tasks annually. These tasks could include time spent on working with the conveyer system, monitoring of the composting process or other miscellaneous tasks. None of these labor components are included in Co-Composter. The only considerable difference seen in fixed cost is with insurance. The model requires a yearly insurance cost as a percent of the capital cost to determine the annual insurance cost. A value of 2% is suggested and normally used to calculate the annual insurance cost. In this case the typical value was not appropriate due to large capital cost of constructing a composting building. The value of 2% has proven to be accurate in other circumstances, demonstrating the difficulty of predicting insurance costs. Overall, Co-Composter managed to produce satisfactory results for this farm.

Table 3: Physical Characteristic Comparison for Farm 2.

Parameter	Actual	Model	Parameter	Actual	Model
Moisture content (%)	76	76	**Total annual production (yd^3)**	3100	3200
C/N	30	20	**Total area (acre)**	.09	.09
Bulk Density (lb/ft^3)	32	35	**Total pad area (acre)**	0	0
Raw Storage Area (ft^2)	0	0	**Curing compost area (ft^2)**	0	0
# of rows	0	0	# of rows	0	0
Row height (ft)	0	0	Row height (ft)	0	0
Row width (ft)	0	0	Row width (ft)	0	0
Row length (ft)	0	0	Row length (ft)	0	0
Active compost area (ft^2)	4000	4080	**Cured compost storage (ft^2)**	0	0
# of rows	10	9	# of rows	0	0
Row height (ft)	10	10	Row height (ft)	0	0
Row width (ft)	8	8	Row width (ft)	0	0
Row length (ft)	10	10	Row length (ft)	0	0

Table 4: Economic Comparison for Farm 2.

Returns and Savings from Composting		
	Actual	**Model**
Annual Income Received		
Compost Sales	$0.00	$0.00
Reduced Expenses		
Purchased bedding savings	$22,400	$22,376
Total Returns and Savings	$22,400	$22,376

Total Costs				
	Actual		**Model**	
	Annual	Per Yard	Annual	Per Yard
Variable Expenses				
Operating and Maintenance Cost				
Skid Steer	-	-	$2,095	$0.64
Separator, Pipes, and Pumps	-	-	$8,689	$2.67
Fuel	$936	$0.31	-	-
Lubrication	$140	$0.05	-	-
Repairs	$5,700	$1.90	-	-
Electricity	$7,800	$2.60	$4,971	$1.53
Record Keeping	$0	$0.00	-	-
Marketing	$0	$0.00	-	-
Labor	$16,582	$5.53	$5,838	$1.80
Total Variable Expenses	**$31,158**	**$10.39**	**$21,593**	**$6.64**
Fixed Expenses				
Insurance	$752	$0.25	$5,292	$1.63
Facility Depreciation	$9,998	$3.33	-	-
Composting Equipment Depreciation	$6,105	$2.04	-	-
Average Annual Interest on Investment	$6,443	$2.15	-	-
Facility Annualized Cost	-	-	$19,116	$5.88
Equipment Annualized Cost	-	-	$5,057	$1.56
Total Fixed Expenses	**$23,298**	**$7.77**	**$29,465**	**$9.06**
Total Economic Cost to Farm (Total Fixed and Variable Expenses)	$54,456	$18.15	$51,058	$15.70
Annual Cost to Farm (less Savings and Generated Income)	**$32,056**	**$10.69**	**$28,682**	**$8.82**
Annual Cost per Hundred Weight of Milk	$0.26	-	$0.23	-

Farm 3

Farm 3 is using manure from 1,100 cattle. Primarily from heifers, the manure includes straw and sand bedding. Although, because a minimal amount of sand actually enters the manure, the sand was ignored. The manure/bedding mixture is then combined with additional straw and turned using a front end loader.

The physical parameters of Farm 3 compared relatively well (Table 5). The bulk densities were close enough to allow volumes to be compared directly. Co-Composter underestimated both the active and curing compost volumes, then overestimated the cured compost and the total annual production. Model results are based on a storage period of 365 days for the final compost, because the composter reported that at some point the product might be stored for that long. The model therefore assumes all of the compost is stored for that period and calculates the windrows on that basis. The difference in final product can be explained by the conflicting numbers reported by the composter. Using the reported number of active and curing windrows and dimensions, a total annual product can be calculated. This volume greatly exceeds the reported volume the composter is storing in cured storage as well as the total annual product. The probable solution to these conflicting numbers is the screening practices of the composter. Presently the model assumes that 2/3 of wood chips and corn stalks are removed. However, if the composter is using different screening parameters then it is feasible the production would be much less than predicted.

The economic comparisons (Table 6) were close, with a difference of $2,122 in annual cost to the farm (17%). Similarities in variable costs were due to similar total labor hours and the total volume of compost produced being somewhat close. Similar to Farm 1, Farm 3 used the loader and the spreader/mixer for material handling, but the total annual hours were close, 535 versus the model's 582. This is again due to the model only being able to handle compost with one piece of equipment, a front end loader. All other moving, handling, and forming is done with the loader. Typically these actions are spread across many pieces of equipment.

The most obvious difference could be seen in the composting equipment annualization/depreciation. This result is just a difference in reported numbers and not calculations. Farm 3 reported a $42,000 cost in various equipment, and the model only calculates the cost from the loader capital cost, which is $9,130. This large difference in reported numbers is likely due to the fact that Co-Composter reports costs only for the composting operation. For example, if the loader cost $40,000 and is used 25% of the time on composting then the cost is $10,000. It is likely that Farm 3 did not take this type of calculation into account when reporting the equipment costs.

Table 5: Physical Characteristic Comparison for Farm 3

Parameter	Actual	Model	Parameter	Actual	Model
Moisture content (%)	57	81.1	**Total annual production (yd3)**	2,000	4,046
C/N	20	26.8	**Total area (acre)**	3	2.5
Bulk Density (lb/ft^3)	52	44.2	**Total pad area (acre)**	2	2.5
Raw Storage Area (ft^2)	5,000	26,240	**Curing compost area (ft^2)**	-	12,090
# of rows	-	14	# of rows	6	4
Row height (ft)	10	10	Row height (ft)	8	8
Row width (ft)	12	12	Row width (ft)	12	12
Row length (ft)	-	50	Row length (ft)	100	100
Active compost area (ft^2)	-	18,200	**Cured compost storage (ft^2)**	-	54,000
# of rows	12	7	# of rows	6	23
Row height (ft)	8	8	Row height (ft)	8	8
Row width (ft)	12	12	Row width (ft)	12	12
Row length (ft)	100	100	Row length (ft)	100	100

Table 6: Economic Comparison for Farm 3

Returns and Savings from Composting		
	Actual	**Model**
Annual Income Received Compost Sales & Tipping Fees	$16,915	$16,911
Total Returns and Savings	$16,915	$16,911

Total Costs				
	Actual		**Model**	
	Annual	Per Yard	Annual	Per Yard
Variable Expenses				
Operating and Maintenance Cost				
Payloader	-	-	$11,677	$2.89
Separator, Pipes, and Pumps	-	-	-	-
Screener Rental	$3,000	$1.50	$3,005	$0.74
Bulking Agents	$1,519	$0.76	$1,519	$0.37
Fuel	$2,675	$1.34	-	-
Lubrication	$402	$0.20	-	-
Repairs	$4,832	$2.42	-	-
Electricity	$0	$0.00	$0	$0.00
Record Keeping	$0	$0.00	-	-
Marketing	$0	$0.00	-	-
Labor	$8,827	$4.41	$8,767	$2.17
Total Variable Expenses	**$21,255**	**$10.63**	**$24,964**	**$6.17**
Fixed Expenses				
Insurance	$1,320	$0.66	$265	$0.07
Facility Depreciation	$146	$0.07	-	-
Composting Equipment Depreciation	$5,284	$2.64	-	-
Average Annual Interest on Investment	$1,123	$0.56	-	-
Facility Annualized Cost	-	-	$329	$0.08
Equipment Annualized Cost	-	-	$1,444	$0.36
Total Fixed Expenses	**$7,873**	**$3.94**	**$2,038**	**$0.50**
Total Economic Cost to Farm (Total Fixed and Variable Expenses)	$29,128	$14.56	$27,002	$6.67
Annual Cost to Farm (less Savings and Generated Income)	**$12,213**	**$6.11**	**$10,091**	**$2.49**

Farm 4

Farm 4 is composting manure from 500 lactating cows plus their bedding of kiln-dried wood shavings. The manure is anaerobically digested and separated and the separated solids are composted without amendments. A turned windrow system is used with a self-powered turner.

Farm 4 provided the study with interesting observations and problems. Prior to this study Co-Composter calculated manure production using herd size and management techniques (bedding, flushing, etc). However, modeling Farm 4 forced the model to handle digested manure. Co-Composter was modified, and consequently manure production can now be based on herd size or entered directly.

The physical results were inconsistent. As seen in Table 7, the number of active windrows was underestimated, the number of curing windrows was greatly overestimated, and the volume of final product was slightly overestimated. These differences can most easily be explained by examining the inputs and following them through the composting system. The composter reported 387 ft^3/day of manure from the digester/separator and an active composting period of only 21 days. Over that 21 days, 7,938 ft^3 of compost would be accumulated. This would only fill 3.17 active windrows of the specified dimensions. However, there are currently 12 active windrows on site. Similar conclusions can be drawn from the difference in curing windrow numbers. Farm 4 reported curing material for as long as 1 year. Due to modeling constraints, this leads to large amount of storage space required for curing compost. Upon observation of only 5 windrows, the conclusion is made that although at some point compost may be stored for 365 days, most is likely stored for a much shorter period. The reported final volume of 1,670 yd^3 is also questionable. With 12 windrows actively composting for 21 days, and assuming an unlikely 50% reduction in volume (due to the shortened composting period) Farm 4 should be producing 9,656 yd^3 of final compost. From these contradicting numbers it was concluded the difference did not result in model error, but rather in attempting to model a complex, unpredictable operation.

Co-Composter underestimated total economic costs by $8,135 or 30%. This underestimate originated from a large difference in variable costs, shown in Table 8. The large discrepancies in the physical parameters lead to a $11,191 difference in variable costs. The largest difference was found in labor and O&M costs. Co-Composter underestimated the volume of compost produced and therefore underestimated the annual cost to handle and turn the compost. A small difference in electrical cost also appears for this farm. In this case the only electricity the model estimates is the electricity required to run the separator, and once again, it is likely Farm 4 reported the electricity used for a variety of tasks. This farm provided Co-Composter a chance to model a very complicated system and proved exactly how difficult it may be to do this accurately.

Table 7: Physical Characteristic Comparison for Farm 4

Parameter	Actual	Model	Parameter	Actual	Model
Moisture content (%)	72	77	**Total annual production (yd3)**	1,670	2,555
C/N	12	30	**Total area (acre)**	2	.75
Bulk Density (lb/ft^3)	42	31	**Total pad area (acre)**	2	.70
Raw Storage Area (ft^2)	0	0	**Curing compost area (ft^2)**	-	25,200
# of rows	0	0	# of rows	5	17
Row height (ft)	0	0	Row height (ft)	10	10
Row width (ft)	0	0	Row width (ft)	10	10
Row length (ft)	0	0	Row length (ft)	60	60
Active compost area (ft^2)	-	9,880	**Cured compost storage (ft^2)**	0	0
# of rows	12	3	# of rows	0	0
Row height (ft)	5	5	Row height (ft)	0	0
Row width (ft)	10	10	Row width (ft)	0	0
Row length (ft)	100	100	Row length (ft)	0	0

Table 8: Economic Comparison for Farm 4

Returns and Savings from Composting		
	Actual	**Model**
Annual Income Received		
Compost Sales	$20,004	$25,505
Reduced Expenses		
Manure Hauling	$5,490	$0
Total Returns and Savings	$25,494	$25,505

Total Costs				
	Actual		**Model**	
	Annual	Per Yard	Annual	Per Yard
Variable Expenses				
Operating and Maintenance Cost				
Payloader	-	-	$1,080	$0.42
Self-Powered Turner	-	-	$636	$0.24
Medium 85 hp Tractor	-	-	$175	$0.07
Separator, Pipes, and Pumps	-	-	$6,996	$2.74
Fuel	$6,198	$3.71	-	-
Lubrication	$930	$0.56	-	-
Repairs	$5,500	$3.29	-	-
Electricity	$3,600	$2.16	$1,266	$0.50
Record Keeping	$0	$0.00	-	-
Marketing	$0	$0.00	-	-
Labor	$6,105	$3.66	$989	$0.39
Total Variable Expenses	**$22,333**	**$13.37**	**$11,142**	**$4.36**
Fixed Expenses				
Insurance	$752	$0.45	$897	$0.35
Facility Depreciation	$0	$0.00	-	-
Composting Equipment Depreciation	$3,285	$1.97	-	-
Average Annual Interest on Investment	$763	$0.46	-	-
Facility Annualized Cost	-	-	$0	$0
Equipment Annualized Cost	-	-	$6,970	$2.73
Total Fixed Expenses	**$4,800**	**$2.87**	**$7,867**	**$3.08**
Total Economic Cost to Farm (Total Fixed and Variable Expenses)	$27,133	$16.25	$19,009	$7.44
Annual Cost to Farm (less Savings and Generated Income)	**$1,639**	**$0.98**	**-$6,496**	**-$2.54**
Annual Cost per Hundred Weight of Milk	$0.01	-	-$0.06	-

Comparison of Mean Values

A final comparison can be made with the average total results. Total annual product, pad size, variable costs, fixed costs, and total economic cost to farm were averaged for the four farms and compared to Co-Composter's averages.

Table 9: Average Comparison of Four Farms

	Farms' Averaged Results	Co-Composter's Averaged Results	Percent Difference
Total Annual Product (yd^3)	2292	4080	78%
Pad Size (ac)	3.27	2.18	33%
Total Variable Costs ($)	$30,971	$30,135	2.7%
Total Fixed Costs ($)	$11,653	$11,296	3.1%
Total Economic Cost To Farm ($)	$42,624	$41,431	2.8%

From the results in Table 9 it is clear that Co-Composter was able to estimate costs relatively well. There were large differences in compost production volumes, however, primarily due to uncertainties in final compost bulk densities. Co-Composter volumes are based on the initial bulk density of the compost mix. The final bulk density, which is influenced in unpredictable ways by weather and management, may be significantly different than the initial density. Co-Composter underestimated the pad size needed. This happens for a variety of reasons. Co-Composter does not calculate access driveways, machinery storage, or farm lanes, and it is likely the pad size composters are reporting does include such areas. Also, Co-Composter organizes the material storage very efficiently; a compost operation might not organize everything quite so efficiently, and therefore require more land.

Overall the average results are very encouraging. Co-Composter results on average were close to the actual costs reported by actual composting operations.

Conclusions

This project provided many examples of things that the model needed to be able to handle, and on few occasions things the model could ignore. Many differences were observed and subsequent changes were made during the comparison project. For example, after comparing Farm 4 results the model had a digested manure section added to it, allowing the user to have the choice of composting digested manure. Also, two of the farms were renting screening equipment, and this led to allowing the user to not only rent a screener, but also turning equipment. Farm 1 had a large portion of income from tipping fees, and paid for amendments as well. Therefore tipping fees and costs were added as an input in the model. Another issue that arose during the project was selecting the correct loader. The model offers a 1/3 yard, a 1 yard, and a 3 yard bucket, but two farms had other size buckets. Therefore a fourth, user specified, loader was added to the model. Also a variation in the percent of separated solids from certain separators was discovered, so the model was then changed to allow the user to set that value to the correct percentage. Labor was always a major issue. Presently the model only calculates labor required to operate composting equipment. No marketing, record keeping or monitoring labor is included in the model. This was something that was not changed. It was decided this is something the model should not handle and necessary corrections were made to the numbers reported by the composters in the economic report. Similarly Farm 3 reported costs in professional services, dues, membership, and fees, and these too were excluded from the comparison as the model does not handle these types of costs.

Throughout this project many things were learned about the model itself and about modeling actual systems in general. It is important to remember Co-Composter is not meant for modeling existing systems, but instead it is a planning device to be used by composters and farmers to aid in the decision-making process. For these reasons, similar results were not necessarily expected. Instead it was hoped errors in the model could be found and important issues in modeling could be dealt with. Fortunately all three were true, similar results were returned, errors were found, and problems were corrected.