TREATING AND HANDLING MANURE ON DAIRY FARMS TO PROTECT THE ENVIRONMENT
Part 2: Biodrying System

Prepared for

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NOTICE

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Dairy farmers are coming under increasing pressure to control the release of contaminants from their establishments to air and water. Comprehensive Nutrient Management Plans (CNMP) to protect water quality often prescribed long-term manure storage as the Best Management Practices (BMP). Unfortunately, objectionable odors were produced during storage and then released to the atmosphere during mixing of the storage and during spreading. Thus a conflict existed between BMP for water quality and air contamination by the release of odors. Alternative manure treatment and handling systems were needed. Two systems were assembled and demonstrated at two dairy farms in the New York City Watershed. The first system treated the separated liquid in an anaerobic digester while the solids would be composted and sold. The initial digester used a fixed film and was designated as “ANFF”. This system is reported on in Final Report, Part I. The second system treated the manure aerobically as a solid. The system was designated as “biodrying”. This system is reported on in this Final Report, Part 2.

The intent of the biodrying system was to reduce the weight of the manure, control odor and concentrate the phosphorus making it easier to haul longer distances, out of a watershed if necessary. The system was designed to use the heat produced during composting, an aerobic biological process, to evaporate water, thus reducing the weight of the mixture. If managed carefully, the heat generated would provide the energy to reduce the moisture content (MC) from 88 percent to 40 percent. Forced air composting, under a roof, with airflow carefully controlled is needed to optimize this process. Composting works best when initial moisture content is below 70 percent. Initially, recycled compost or a mix of compost and sawdust or other amendment would be spread in the cow alleys to absorb one days manure production. By-product sales are the most important factor in reducing the cost of this manure treatment system. Costs of the system have been estimated to decrease from around $748 per cow-yr at a market price of $5 per cubic yard (cy) to a profit of $209 per cow-yr if all the manure were composted for nine months of the year and the product were sold for $30 per cy .

The biodrying system was designed and installed at the Mar-bil Farm in Delaware County. The composting building was 40 ft wide by 100 ft long. Curtains like those used in freestall barns were installed on the backside of the barn, and plastic shade cloth was installed on the open end to keep snow from blowing into the barn. The barn was divided into twelve-8 ft bays, each with three air channels in the floor and a 2 hp centrifugal blower. The aeration system was controllable by a personal computer with analog input/output hardware and feedback from thermocouples inserted in the center of the composting piles.

The biodrying process would be successful if:

- The cost of operating the system minus the additional benefits including off site sales was found to be less than the cost of conventional storage and land spreading that would meet the environmental regulations for the farm.
- The system produced usable solids for recycling into the barn gutters and alleyways
- The system produced compost that could be sold off the farm
- The biodrying produced compost with a moisture content below 40% after composting 21 days

Over the duration of the study the producer utilized the system such that the cost of the biodrying system was less than that of a conventional liquid storage system, and was comparable to the costs of the existing daily spreading practice. The production of usable solids for recycling into the barn gutters and alleyways was not achieved. The production of compost for sale off the farm was achieved, however not at the projected production rate. The production of biodried material below 40% after 21 days was only achieved a few times during the project period.

The project confirmed the understanding that successful composting requires that the material, manure and amendment, have enough pore space for good air movement. Good air movement was found to be difficult to achieve when compost mixes had moisture contents exceeding 60 percent . To limit restriction of air flow it was also found important not to pile the compost mixture more than 4 ft deep. During cold weather and positive pressure air flow, moisture condensed at the surface of the pile causing a wet layer. Reversing the air flow through the pile (negative pressure) removed moisture from this surface layer and improved air flow. However this moisture condenses at the junction of the in-floor channels and the vertical pipe from the air plenum. During construction a low point was inadvertently produced at this junction. This collected water and restricted water from flowing out of the channel which in-turn restricts air flow. This water can be removed by returning to a positive pressure air flow. Careful management of the system and good control of the air handling system is essential.

A test was run using *Ascaris sum* eggs to test the effectiveness of the biodrying system to reduce pathogens. *Ascaris sum* eggs are generally more robust than *Crytosporidium parvum* Oocysts. Initial results showed that after 4 days in the compost pile the cysts were no longer viable which led to the conclusion that most pathogens in the compost were dying.

SECTION 1
BACKGROUND

Dairy farmers are coming under increasing pressure to control the release of contaminants from their establishments. Comprehensive Nutrient Management Plans (CNMP) as described by EPA and USDA to protect water quality will often prescribe long-term manure storage. Unfortunately, stored manure will produce significant amounts of objectionable odors that will be released when the storage is mixed prior to spreading and during spreading. Thus a conflict arises between Best Management Practice (storage) to reduce the potential for water pollution and practices (daily spreading) that would reduce odor development. There was a need for alternative manure treatment and handling systems that address both the water quality and quality of life (odor) issues simultaneously.

The New York City Watershed wanted to investigate alternative manure treatment and handling systems that will reduce odors and the population of viable pathogenic organism and develop a product that would allow exporting nutrients out of a watershed. Two alternative manure treatment and handling system were assembled and demonstrated. The first system treated the separated liquid in an anaerobic fixed film digester. The separated solid would be composted or sold directly. This system is designated as "ANFF". The second system treated the manure as a solid with aerobic biodrying. This system is designated as "biodrying".

SECTION 2
BIODRYING SYSTEM

INTRODUCTION

There is an increased need for manure treatment that concentrates the phosphorous and reduces manure mass making it easier to haul longer distances. There is increasing pressure to reduce pathogens or indicator organisms in the sources of drinking water and contact recreational water. Treatment systems that reduce pathogens will be needed in the future. Using an all solid treatment and storage will reduce the risk of major losses to the environment during storage and spreading. A method of composting dairy manure called "biodrying" holds potential for meeting these needs..

Biodrying of dairy manure is the process of drying manure with the heat of aerobic reactions. Biodrying of the manure using forced air static piles, and recycling dry compost as a litter in the cow alleys has been proposed (Wright et al., 2002). Odor, volume, weight, and pathogen reduction would occur. Equipment for solids handling exists on most farms, allowing for adoption by many producers. Composted material after curing may be marketed as an income source and to move the nutrients off the farm. The management of the drying process will be critical, and the costs of the operation may be high. Additional amendment may be required.

Using the heat of composting to evaporate water and dry compost has been practiced in municipal systems for quite some time (Haug et al., 1998). Biodrying had been shown to work on animal wastes (Jewell et al., 1984, and Richard and Choi, 1996), but the in-vessel machinery was seen as too expensive and complex to run on a dairy farm. Recent catastrophic failures of liquid storages, high costs of liquid handling and the odor problems associated with liquid manure storage started the search for a solid handling system for dairy manure. Systems that quickly composted and dried the solids under a roof and without turning made biodrying in a composting shed seem possible. This idea has been reinforced by studies showing that composting could remove significant moisture when liquid manure was added.

If managed carefully, the heat generated by aerobic composting can provide the energy to reduce 88% moisture content (MC) raw manure, mixed with an amendment to a mixture MC of 60%, down to a 40% MC residual. Forced air composting, under a roof, with the airflow carefully controlled can be used to optimize this process. Composting works best with products with initial moisture content below 70%. Recent applications of composting operations have shown the feasibility of this process by using forced air to compost layers of manure 6 ft deep in 21 days. Recycled compost or a mix of compost and sawdust, or other amendment, at 40% MC could be spread in the cow alleys about 8 inches thick to absorb one day's production of 88% MC manure. Theoretically, the resulting mixture could be scraped into a shed, piled 6 ft deep and aerated to produce 40% MC compost in about three weeks (Wright et al., 2001).

To explore the idea of biodrying on a farm, a biodrying facility on an 85-cow dairy farm in the NYC watershed was designed and built. This consisted of designing and building a composting shed with a forced air system. The purpose was to optimize and document the process. Evaluating the on-going process in varying weather conditions would allow adjustment of the operating procedures to obtain the best compost, the least amount of amendment, and lowest cost for the farm operation. Documenting the operating procedures would allow this process to be adopted by many dairy farms. This process would be successful if

- The cost of operating the system minus the additional benefits including off site sales were less than the cost of conventional storage and land spreading that would meet the environmental regulations for the farm.
- The system produced usable solids for recycling into the barn gutters and alleyways
- The system produced compost that could be sold off the farm
- The biodrying produced compost with a moisture content below 40% after composting 21 days

DESCRIPTION OF BIODRYING SYSTEM

The biodrying system was installed at the Mar-bil Farm, owned by Randy and Lynette Inman. The farm has 85 cows in a tiestall bedded with sawdust and shavings, 100 heifers in straw bedded pack, and 30 calves in a fabric covered calf facility bedded with straw.

This system consisted of a three-sided composting shed with a forced aeration system installed in the floor. The composting shed was designed large enough to compost manure mix piled 6 ft high for a 21-day period. Additional storage for the completed compost would be provided on a pad with controls for rainwater runoff.

A cross sectional view, plan view, and front elevation for the 100 ft x 40 ft biodrying building are shown in Figure A-2. The building was designed with a high overshot roof peak, open sidewalls, and four-foot eaves to provide good ventilation while keeping the process protected from precipitation. Plastic shade cloth was installed on the open ends of the barn to keep snow from blowing into the barn. Conventional curtains used in freestall dairy barns were installed on the back side of the composting barn. Manure and recycled compost can be loaded from either side, although generally a side delivery manure spreader working from the open side of the barn can build a 6 ft high pile, 8 ft wide and 40 ft long. A backstop was suspended from tracks on the back wall to stop the manure and amendment mixture from shooting through the barn as it was placed in the piles. To make piles the same depth across the barn, some of the mixture was loaded from the backside of the building.

Twelve, 2 hp blowers were installed, one for each composting area or “bay”. Each blower had a rated capacity of 700 cubic feet per minute (cfm) at 5.5 in of water column (wc). Half of the blowers had stainless steel housing while the other half were painted steel. The blowers were mounted under the eves at the plate on the backside of the barn. Channels to deliver air to the piles were 4 in x 4 in and were formed in the floor 32 in on-center. There are three channels per bay or blower. Each bay is 8 ft wide. The airflow rate was designed to provide 0.36 cfm of air for each cubic foot of compost. Although the fans are rated at 700 cfm with 5.5 in wc static pressure, the maximum measured static pressure of the fans was found to be lower than designed at 3 in wc. This creates doubt that the fans actually created the airflow needed to properly run the system.

The aeration was designed to dry the compost so that the resulting material could then be mixed with an amendment, if needed, and remixed with manure. This recycle loop could be continued indefinitely. The expectation was that one-third of the compost produced each day would not need to be recycled and would be stock piled for sale or land application on the farm. This process could potentially compost all of the manure produced with little additional amendment needed.

The control for the aeration system utilized a personal computer with analog input/output hardware. Type T thermocouples are inserted in the center of the composting pile to get a representative temperature. The temperatures were inputs for a timing algorithm programmed with LabVIEW™ software. The control system for the blowers was equipped with variable frequency drives (VFD). The controls were initially set to run the fans 5 minutes per hour when the temperature of the compost was below 130°F. At temperatures above 130°F, the fans would run continuously. When the temperature falls below 120°F, the compost would be aerated for 5 minutes per hour again. After 14 days the fans would run continuously to dry the compost. Temperature control included a provision to shut off the fans in the drying phase if the temperature in the compost fell below 40°F.

During the winter, as saturated warm air leaves the compost, some of the moisture would condense and saturate the compost on the top surface. With VFDs on the fan motors, the rotation of the fans could be reversed with a signal from the control system in the winter to bring air down through the pile such that condensation would occur in the floor channels instead of the top of the pile. A gravity drain was installed to allow this water to leave while still maintaining the pressure [positive and negative] in the air channels.

ON-FARM PROCEDURES

Each composting pile, 8 ft wide and 40 ft long, was made using fresh manure from either the dairy tiestall or the heifer bedded pack. No recycled compost was placed in the tiestall barn as first planned. The manure was mixed primarily with poor quality alfalfa hay. Other materials were used when available. Between September 2001and July 2003, 400 bales of old hay each weighing 900 lbs were chopped and utilized as amendment. The employees filled the side delivery manure spreader with half of the manure produced in the tiestall building then added amendment until the mix was considered dry enough or the manure spreader was full. All composting runs were actively composted for 21 days in the building. The amount of time the fans ran was adjusted with ambient temperature and compost temperature. Use of the system started in early September 2001.

Methods

Samples for analysis were obtained by taking grab samples at various locations within the pile. These grab samples were mixed and a sub-sample removed for analysis.

The moisture content of the composting material was determined using a standard procedure developed for measuring dry matter in forage. Drying was done in a microwave. If the material was in the 50 to 70 percent range a sample was placed in the oven for 4 minutes. (If the sample is drier, then this first drying time would be reduced.) The sample was weighed and placed in the oven for an additional minute. This process was repeated using shorter times in the oven until the change in weight was less than 2 grams or there was charring. If there was charring, the previous weight was used to calculate dry matter. There were not enough samples analyzed to perform any statistical analysis of the moisture content.

Samples for chemical analysis were sent to Dairy One for analysis. [Dairy One Cooperative, Inc., Ithaca, NY]. The wet basis (as sampled) results from the analysis of one initial mix and one finished compost composite sample taken on 12/6/2001 are given in Table 2-1. The results show little change in the components between the two samples, except for an increase in ammonia nitrogen. Additional testing would be needed to make conclusions about what changes in components would be expected during successful steady state composting..

Table 2-1. Manure Analysis Report.

Component	Initial Mix	Finished compost
Total Nitrogen (N), %	1.01	1.01
Ammonia Nitrogen (NH3-N), %	0.08	0.18
Organic Nitrogen (N), %	0.93	0.82
Phosphorus (P), %	0.18	0.21
Potassium (K), %	1.12	1.19
Total Solids, %	29.9	31.8
Ash, %	5.30	6.74

RESULTS

Over the duration of the project there were 40 runs made in the biodrying facility. This report includes seven [7] runs that were representative of the 40 runs that were completed. The bays for the other 33 runs also were loaded with compost mixes with moisture contents between 60 – 65%. These included material that was a mix of fresh manure from the barn mixed with amendment, and runs that were re-mixed or fluffed windrows already 21 days old. Data on other runs not graphed in this report are available from Scott Inglis at Cornell University.

Seven [7] runs made in the biodrying facility during this study are analyzed below. The consistency of the initial manure and amendment mixture was different for each run. Each run used one bay. Generally, at any one time, there was more than one bay being utilized. At no time was it possible to develop a continuous operation where the finished compost (21-day-old) was used as amendment, along with other amendment when needed, to start a second bay with the nearly the same initial conditions. In other words, “steady state” was not achieved for any of the runs.

A list of the operating parameters for the seven composting runs is shown in Table 2-2. Five of the runs were conducted with a positive pressure (air moving up through the pile) and two runs were conducted with negative pressure (air moving down through the pile).

Table 2-2. Operating Parameters for Biodrying Composting Runs.

Figure No.	Mixture	Initial Moisture Content	Depth ft	Final Moisture Content	Pressure	Date
2-1	Fresh Manure – dairy barn Chopped alfalfa hay Unfinished compost Moldy corn silage	60	4	30	Positive	9/11/01 – 9/27/01
2-2	Fresh manure – dairy barn Chopped moldy alfalfa hay Unfinished compost	65	6	60	Positive	11/8/01 – 11/29/01
2-3	Heifer manure from bedded pack, Unfinished compost, Alfalfa hay	60	6	58	Positive	11/14/01 – 11/29/01
2-4	Fresh manure – dairy barn Alfalfa hay Composted dairy manure	65	6	60	Positive	12/6/01 – 1/3/02
2-5	Fresh manure – dairy barn Alfalfa hay Unfinished compost		6		Positive	12/22/01 – 1/3/02
2-6	Fresh manure – low quality chopped Alfalfa hay Unfinished compost	60		50	Negative	11/26/02 – 12/7/02
2-7	Fresh manure – low quality chopped Alfalfa hay Unfinished compost	65		59	Negative	12/5/02 – 12/26/02

Figure 2-1 shows temperature and fan operation for a pile that was composed of fresh manure from the dairy barn, chopped alfalfa hay, unfinished composted manure and moldy corn silage. The pile was 4 ft deep. The mixture had an initial moisture content of 60% and a final moisture content of 30%. The performance of this pile was exactly what was anticipated. In hindsight the warm fall temperatures and low humidity for this time period may have contributed to the drying and excellent performance of this composting pile. The 4 ft depth allowed the pile to reach a temperature 132 °F and the fan control system maintained the temperatures in the pile for 8 days.

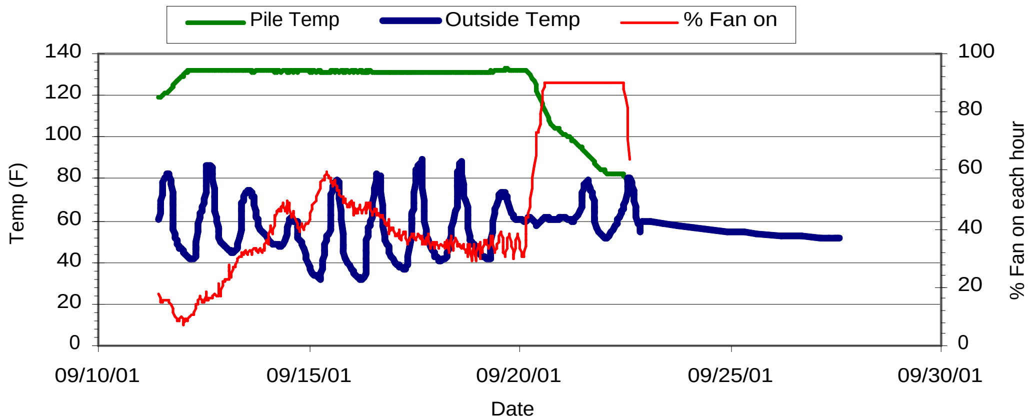

Figure 2-1. Successful Composting Run with Good Fan Control and Drying, Bay 1.

Drying removed moisture from the top few inches of the pile so no wet layer was present at the finish of the pile. The fans ran at full speed [90% = full speed] for nearly 3 days before the pile temperature reached 70°F. The corn silage amendment may have given the pile more energy and porosity so airflow was maintained throughout the entire pile. Of the seven runs described in this repot, this was the most successful run achieved with the composting process in this system.

The results shown in Figure 2-2 came from a pile constructed of chopped moldy alfalfa hay, unfinished compost manure and fresh dairy manure. The pile documented in Figure 2-2 was 6 ft deep. Within 24 hours the pile settled to a depth of 4 ft decreasing the porosity Additional material was added increasing the depth of the pile from 4 ft to 6 ft. This caused further compaction. The initial moisture content of this pile was 65% and ending moisture content had decreased to only 60%. The airflow in the pile became preferential and some areas of the pile did not get ample airflow. A 3 in layer of wet compost formed at the top of the pile where moisture, leaving the lower portions of the pile, condensed. This resulted in low moisture loss from the pile. The airflow to the pile did not affect the temperature of the pile and did not reduce the moisture of the pile as expected. Manometer readings indicated a pressure of 3 in wc at the air inlet to air channel. This is less than the 5 in wc of static pressure the system was designed for indicating that there was sufficient air flow through the pile and the average porosity was good. Initially the fans came on as the temperature exceeded 130°F. Continuous blower operation did not significantly reduce the temperature. At the end of the 14-day period there was about 1 day where the fans held the temperature at 130°F. After 14 days the program controls the fans to run continuously but yet the pile was not cool below about 120°F.

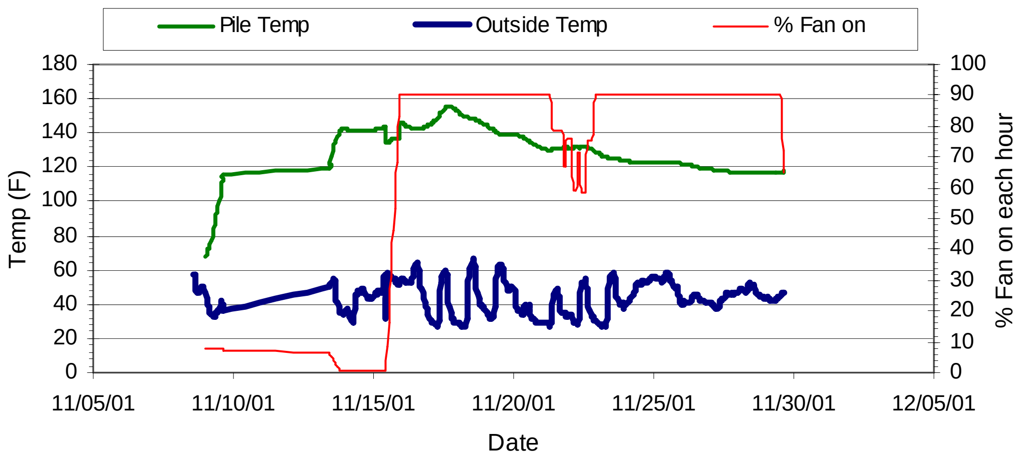

Figure 2-2. Unsuccessful Composting Run with Inadequate Air Delivery, Bay 1.

A pile was produced using heifer manure from a bedded pack mixed with unfinished composted dairy manure and some alfalfa hay. The initial mixture piled in the compost barn had a 60% MC, and compost removed after 21 days at 58% moisture. The conditions during composting are shown in Figure 2-3. The initial and final manometer readings on this pile were 2 in wc. The pile was 6 ft deep. The manure from the bedded pack was already partially decomposed. The manure and hay from the bedded pack was initially 60% moisture, so little amendment was added. This material was not well mixed as the mixture left the side delivery manure spreader. Large clumps of heavily compacted manure from the bedded pack went into the pile. These pieces helped maintain the structure of the pile for ample airflow. However, these pieces did not compost thus reducing the energy available to heat the pile. This combined with lower ambient temperatures limited the fan operation. This lack of heat production and air movement limited the evaporation of moisture from the pile to only a 2% reduction in moisture content.

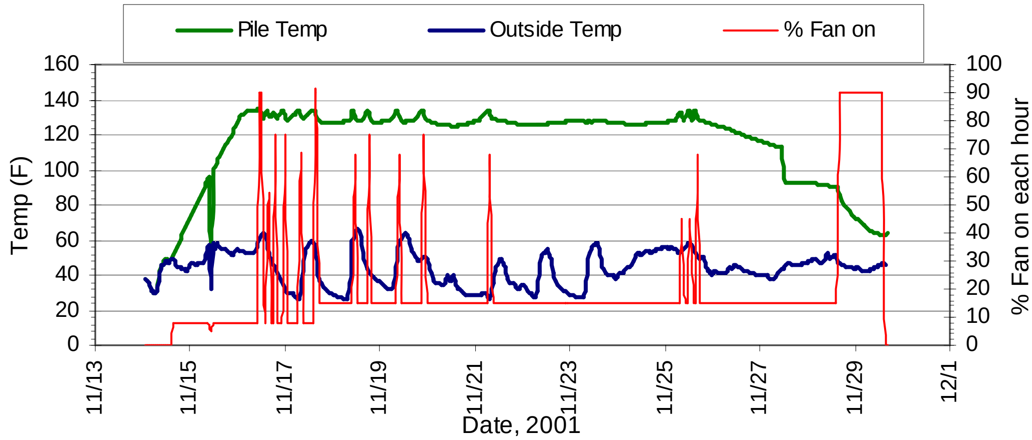

Figure 2-3. Composting Run with Heifer Manure, Resulting in Inadequate Air for Moisture Removal, Bay 5.

Figure 2-4 shows the results from a test on a pile constructed with alfalfa hay, composted dairy manure and fresh dairy manure. Initial moisture content was 65%, and the ending moisture content was 60%. Manometer readings for this pile were initially 1.5" wc and ended at 3" wc of static pressure. This pile was 6 ft deep. The cold outdoor temperatures and snow drifting into the building over the composting piles may have contributed to the failure to achieve satisfactory moisture content. Missing data is due to a loss of the computer control system. The computer was repaired and returned to service on December 21, 2001. This pile heated well initially. The cold ambient temperatures and over aeration of the pile cooled the pile quickly in the first few days. When the fans were turned off, the pile regained temperature within a few days. On an intermittent schedule of 5 minutes on and 55 minutes off, the pile slowly lost heat without losing moisture. This pile developed a 3 in wet layer on the top of the pile where moisture condensed before the air left the pile. This layer may have held other water in the pile in the later stages of composting. After January 1, 2002 a fault in the variable frequency drive kept the fan off for the last few days of composting. During this time the pile temperature gained about 8 degrees before the fan started and the pile was cooled to 60°F.

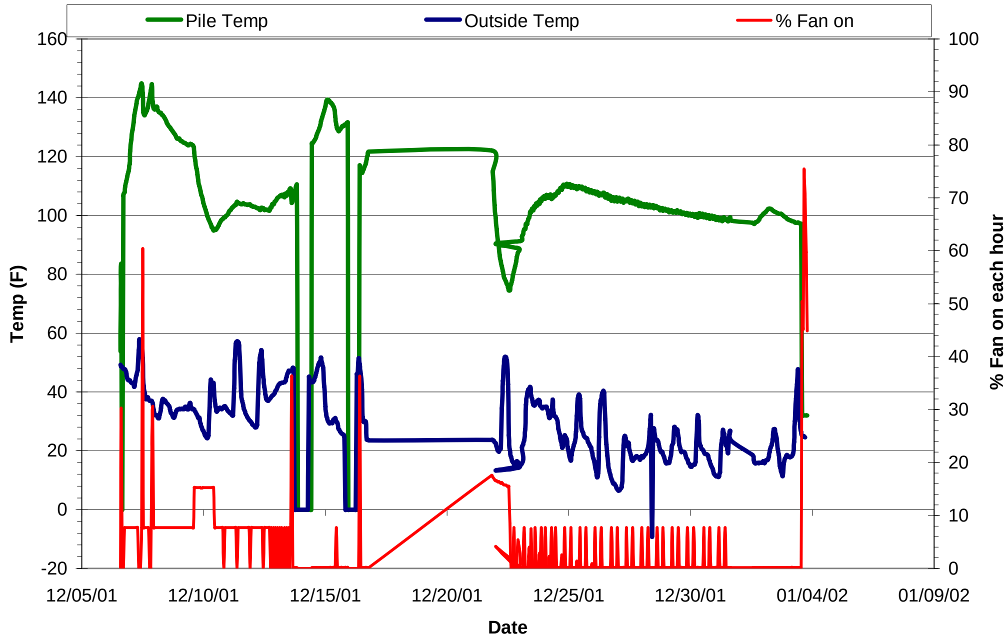

Figure 2-4. Composting Run with Over Aeration in Cold Weather, Bay 6.

Figure 2-5 shows a pile that was 6 ft deep created from alfalfa hay, fresh dairy manure, and unfinished composted dairy manure. The initial and ending manometer reading was 3" wc static pressure. The cold ambient temperatures during this run kept the pile at low temperatures throughout the composting process. At this point the computer program was changed to reduce the minimum time the fans would run to maintain an aerobic composting process without over cooling the composting pile. The 5 minutes of on time and 55 minutes of off time did not allow the pile to reach the 140F target temperature. The target temperature for this run was changed to conserve electricity and to allow for colder ambient air entering the bottom of the pile. The on time was changed to 1 minute with an off time to 59 minutes. The pile stayed below 104°F for the duration. All fan-off time was caused by a fault in the variable frequency drive that went unnoticed.

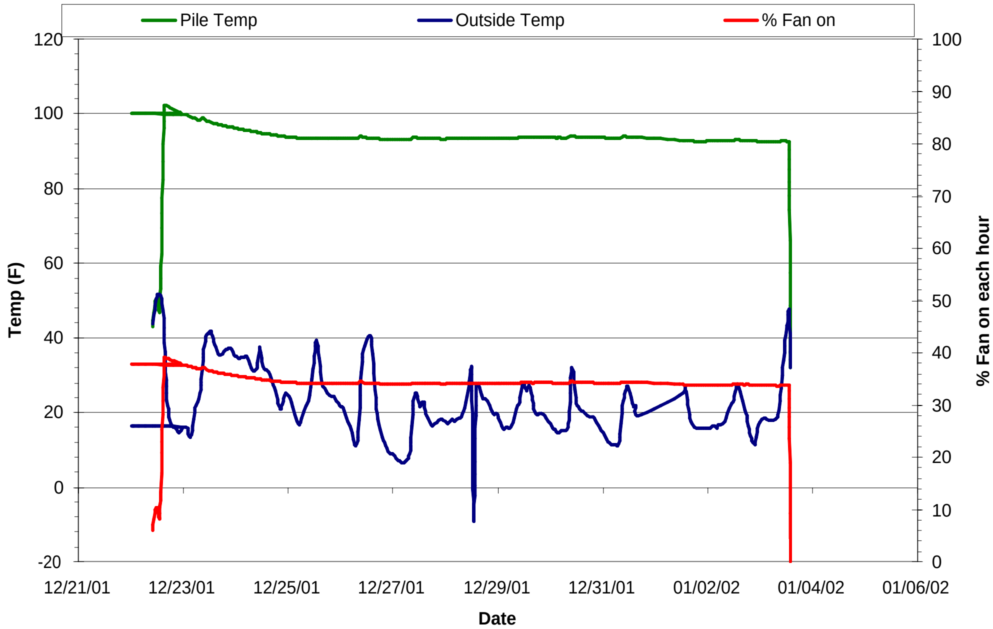

Figure 2-5. Low Heat Composting Run with Minimum Fan On-Time in Cold Weather, Bay 8.

Negative pressure trials were run on 6 bays from 11/7 – 11/21/02. These trials produced drier compost material. The negative pressure mode did require increased management time because the air channels plugged with condensate every few days. When designed, the slope of the air channels was set to drain any condensation to an outlet. When the channels were constructed, the connection of the sloped air channels in the floor and the vertical pipe from the plenum created a choke point in the system, resulting in a constriction that prevented free drainage and then occasionally blocked the air flow. To remove the plug, the airflow needed to be reversed for 10 min or more to blow the water away to drain. After the airway has been cleared, negative airflow could be reestablished. Temperature and percent "on" fan curves below show the results of the negative pressure usage. Figure 2-6 shows the results from bay 1. The starting moisture content was 60% and the final M.C. after mixing was 50%. Bay 5, shown in Figure 2-7 started with a M.C. of 65%. The final M.C. was 59% after mixing. The pile that started at 60% lost enough water to reduce the M.C. by 10 percent, while for the pile starting at 65% M.C., the reduction was only 6%.

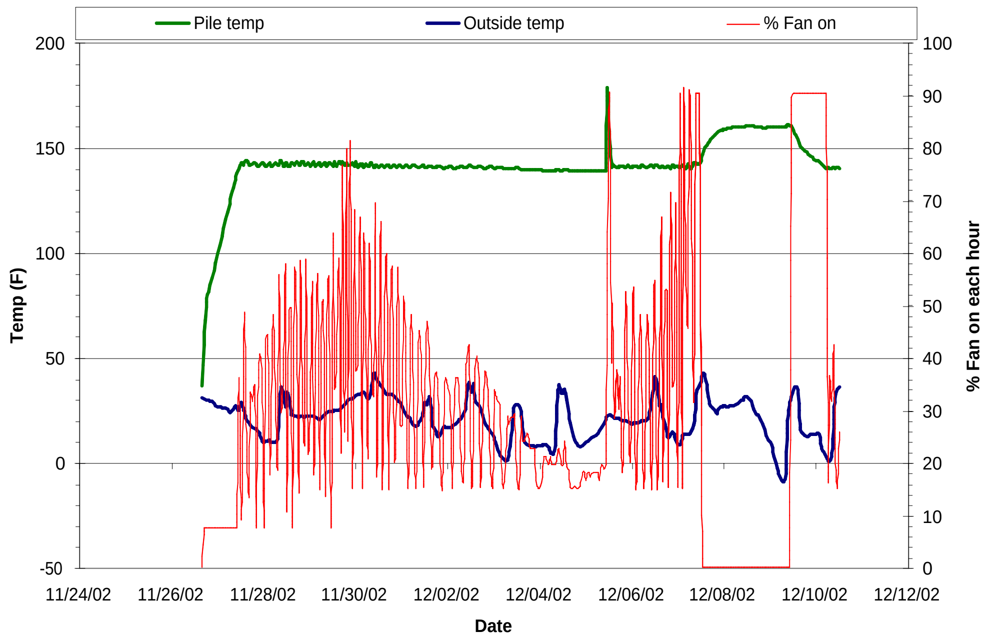

Figure 2-6: The Pile Temperature and Percent per Hour the Fan Ran for Bay 1 in Negative Pressure.

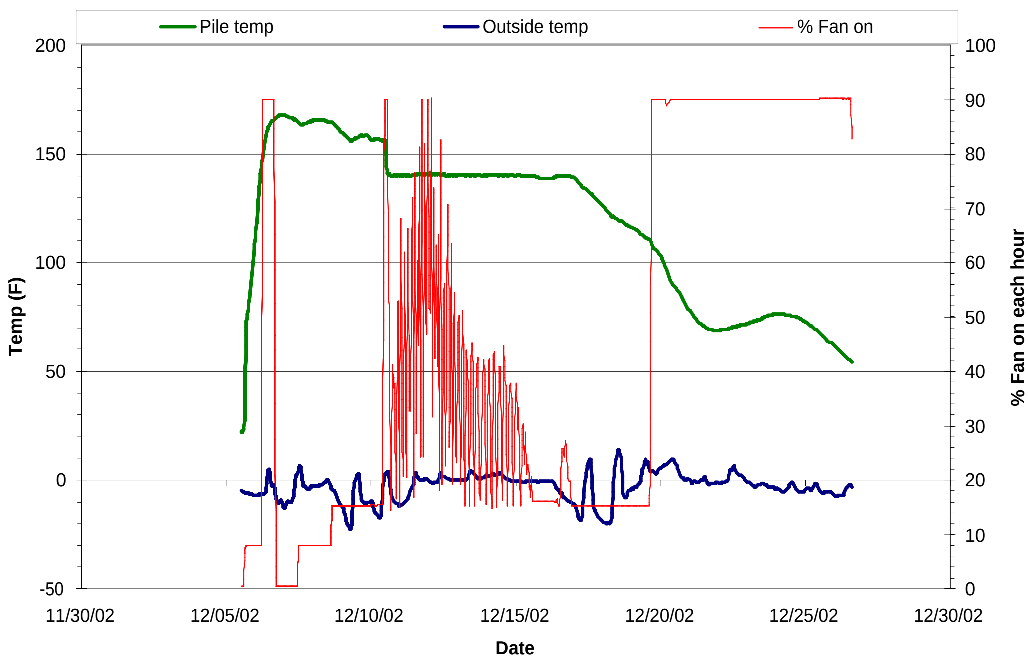

Figure 2-7: The Pile Temperature and Percent per Hour the Fan Ran for Bay 5 in Negative Pressure.

FINDINGS

- The fan control system has the potential to maintain pile temperatures by cycling the fans and to dry the compost after the composting process was finished.
- The moisture of the mixture (fresh manure and amendment) must have a moisture content of less than 60 percent when piled, in order to have enough void spaces for good air movement. This will obviously require that more amendment be added which increases the volume of mixture being composted.
- Piles should not be more than 4 ft deep to avoid compression of the lower layers that will restrict air flow.
- The amendment must have enough structural strength and size to support the pile to maintain void space. Piles built with poor quality chopped alfalfa hay and dairy manure settled to approximately half their original height in the first few days of composting. This complicates getting good air flow through out the pile.
- Negative pressure aeration was successful in preventing the buildup of condensation in the top layer of the piles. Better design of the channels would reduce the accumulation of condensate in the channel and reduce the need to reverse the air flow to blow out the condensate.
- Rain and snow must be kept from entering the composting barn as this adds more moisture which must be evaporated. There is limited energy from composting to evaporate water to say nothing about melting snow.
- The electrical energy used by the blowers in the compost barn averaged about 14 kWh per ton of compost. This was based 8,932 kWh used in 371 days during which 628 tons (from 30 bays) of compost were produced from 1/15/02 – 1/21/03. The compost averaged 890 ± 120 lbs/cu yd.

CRYPTOSPORIDIUM DATA

To document the system's ability to reduce pathogens one trial was run from 9/24/02 – 10/15/02 with 130 sentry chambers with *Ascaris suun* eggs placed at three levels throughout the composting pile. Twelve of these chambers were removed every 4 days to determine if there were any viable cysts left. Initial results show that after 4 days in the pile the cysts are no longer viable. The temperature in the pile reached 160^{o}F. The *Ascaris suun* eggs are generally more robust than the *Cryptosporidium parvum* Oocysts so the conclusion can be drawn with some confidence that most such pathogens in the mixture/ composts are dying. This testing cost $4,500. The final reporting was submitted January 2, 2003 and is available by request from Scott Inglis at Cornell University. An excerpt from the results and discussion is presented in Appendix B.

ECONOMIC ANALYSIS OF MANURE HANDLING AND TREATMENT AT THE MAR-BIL FARM

When this Project was initiated at the Mar-bil Farm, the major concern was the level of nutrient loading of the farm land, timely spreading of manure, and reducing pathogens and odor. Several systems were considered. 1) The first included on-farm liquid storage that would permit application of manure to land when there was the greatest need for nutrients and less danger of runoff. However, this system would increase the odor problem and would not facilitate the movement of nutrients out of the watershed. 2) The second system would add aeration to the liquid storage to reduce the odor level and perhaps remove some nitrogen prior to land application. 3) The third system was the biodrying system that was designed to treat the manure aerobically in a solid form. This process would greatly reduce the odor, reduce the mass of material to be handled thus affording the possibility of economically transporting manure (nutrients) out of the watershed. When applied to the land in a solid state the possibility of runoff would be reduced and there was the possibility that proper composting would reduce the viable population of pathogens. For the biodrying alternative two scenarios were evaluated based on different disposition of the compost produced: 3a where all the compost would be sold and 3b where all the compost would be spread on the farm land. The economic analyses also include the costs of managing the milking center wastes, with different projections depending on whether the alternatives are liquid or solid based systems.

The projected economic analyses for these five systems, including the original, are presented in Tables A1-A5 in Appendix A. Tables A4 and A5 show what the biodrying system could do if all the manure collected from the barn was loaded for a 21 day retention time. Two additional tables, Tables A-6 and A-7 adjust the biodrying cost estimates to account for the project finding that not all the collected dairy manure was composted in the biodrying process. These two tables show revised estimates based on about 40% of the collected manure being processed through the biodrying system with the remainder being land applied as before.

A summary of the findings is presented in Table 2-3. The original system appeared to have an annual cost of $36,695. The liquid system increased the fixed costs by a factor of 6, added between $22,000 and $28,000 to the annual costs, and because of farm specific problems, would still not have provided for an adequate solution

Table 2-3. Manure Systems Analysis Projections – Mar-bil Farm.

System Description	Total Annual Fixed Costs	Annual Manure System Operation Costs	Annual Other Systems Operating Costs	Revenue Generated Due to Manure	Total Annual Operating Costs	Total Net Annual Costs
Original System	$6,368	$23,467	$6,860	$0	$30,327	$36,695
Liquid System Including Storage without Aeration	$33,665	$19,631	$5,360	$0	$24,991	$58,656
Liquid System Including Storage with Aeration	$35,465	$23,931	$5,360	$0	$29,291	$64,756
Biodrying System, Sell All Compost, Based on Potential Production*	$25,772	$45,772	$8,360	$97,680	-$43,548	-$17,776
Biodrying System, Spread Compost On-Farm, Based on Potential Production*	$25,772	$58,854	$2,360	$0	$61,214	$86,986
Biodrying System, Sell All Compost, Based on Actual Amount Processed**	$25,772	$35,215	$7,505	$33,300	$9,420	$35,192
Biodrying System, Spread Compost On-Farm, Based on Actual Amount Processed**	$25,772	$40,051	$6,215	$0	$46,266	$72,038

*Biodrying System operated using manure collected for 9 months per year.
**Biodrying System processed 40% of manure collected for 9 months per year with the rest spread on-farm.

The biodrying system was the alternative installed at the Mar-bil Farm. Figure A-1 contains a schematic diagram showing the projected quantities of materials flowing through the biodrying process steps based on the Mar-bil Farm's typical operation in which cows are on pasture 3 months per year and manure is collected and managed for the remaining 9 months. The fixed and operating costs shown in Table 2-3 for the first two biodrying system alternatives are projected based on how the system would work if all the manure collected over the 9 months was put through the composting barn. The estimates for the final two biodrying systems are based on how the composting system was actually used, to compost about 40% of the manure collected. . Thus the design and costs for all biodrying systems analyzed are for 9 months, with the later two adjusted for the reduced composting and more land spreading that actually took place due to reduced use of the composting system during those 9 months of manure collection.

.In all cases the fixed costs of the biodrying systems was projected to increase by a factor of 4 over the original system while the operating costs were projected to increase by a factor of 2.5. One reason the operating costs are high is the purchase cost of big bales of amendment at a price of $22 per bale. If the farm had run all the manure through the system, 3,256 cy of compost would be produced (88 piles or bays with 37 cy of compost from each pile).

The sale price for the solids product was set at $30 per cy. For the projection assuming all manure collected during the 9 months is composted, this revenue offsets the total operating costs and leaves a projected profit of $17,776. Based on these projections the break-even price for the compost of $25 per cy would result in a projected zero annual cost for management of the farms collected manure and milk house waste. Furthermore comparing the projected annual profit of $17,776 to the current annual cost of $36,695, a total net improvement of $54,000 can be projected. Based on this projected improvement, the farm would still have a reduced cost of managing manure and milk house waste even if the price it received for compost were less than $25 per cy.

As the system was actually run by the farm, not all the manure collected over the 9 months was biodried and the farm produced about1, 110 cy of compost (30 piles or bays with 37 cy of compost from each pile). At the solids sale price of $30 per cy the revenue generated from the sale of the composted solids reduced the cost of the system to a level that is comparable to the cost of the original system.. In order to achieve a projected zero cost for management of the farm’s collected manure and milk house waste, the break even price for the sale of compost with 30 bays a year would have to be approximately $62 per cy.

The last scenario studied was the situation where all the solids product of the biodrying facility was spread on the farm land. This was the most expensive treatment system because there was no revenue except for a relatively small credit for the fertilizer value of the compost and for the ability to use better fields. Obviously there is the possibility of selling some of the compost for revenue and land spread the remainder of the compost.

CONCLUSIONS

With some modifications in the design of the compost facility and enhancements of the control system, the biodrying system could be an alternative treatment and handling system for small dairy farms. The system accomplished all the following goals set forth: odor was controlled so that land application was not limited; the quality of solids produced made it possible to export nutrients out of the watershed; and the potential for runoff following land spreading was reduced. Testing also indicated that the composting could reduce the concentration of viable pathogens.

The economic feasibility of biodrying systems and widespread adoption will require modification of the system design and operation to produce better moisture removal. Other important requirements include the availability of low cost amendment and adequate and reliable compost markets. It is likely that the biodrying system will not be adopted until daily spreading is discouraged and compost marketing is more feasible.

Modifications to the process include reducing the initial moisture content of the feedstock and lowering the height of the compost piles from 6ft to 4ft should reduce the density and increase the air flow making drying more likely. To achieve both of these changes the composting barn would have to be built larger. To control the moisture content initially better management will be needed to control the mixing of amendment with the incoming raw manure. These changes would increase both the operating cost of this system and increase the capital cost of future systems.

Reduced costs of a quality amendment are critical for the success of this system. Purchasing significant amounts of amendment will increase the cost of the system. Purchasing the amendment with more energy and more structure may be beneficial. The piles in this study were built primarily from poor quality alfalfa hay and fresh dairy manure. These piles settled to half their original height in the first few days of composting making good airflow through the piles difficult. Tree bark and appropriate spoiled silage may be considered as a bulking agent for the compost to create greater porosity and more energy. Keeping the amendment dry is also important. This may require an even larger roofed area.

By-product sales are the most important factor in reducing the cost of such manure handling systems. Marketing the by-products from the manure can help pay for treatment systems. For this 85 cow farm, costs of the system have been estimated to decrease from around $748 per cow per year with sales at $5 per cy to a profit of around $209 per cow per year if the compost is sold for $30 per cy. To consistently achieve this, higher priced roofed storage for the completed compost may be needed as part of the system.

Meeting environmental concerns with traditional liquid storage will increase costs and create potential odor problems. While existing manure management costs at different farms range from $50 per cow per year to $350 and more, the costs for alternative manure handling systems that meet environmental objectives may increase these cost considerably. The costs for a traditional liquid storage and handling system on the example farm have been estimated to be $690 per cow per year.

For any proposed alternative manure handling method on farms verification of the actual functioning and costs of the system is needed.

RECOMMENDATIONS FOR FURTHER WORK

1. Modify the air delivery system to eliminate the restriction.
2. Modify the control system to take advantage of the adjustable frequency drives on the blowers using better automatic controls with temperature static pressure feedback.
3. Add amendment storage for better control quality.
4. Investigate amendment choppers, mixers and loading equipment.
5. Establish good operating procedures when the weather is favorable in preparation for operating when the weather is less desirable.

APPENDIX A

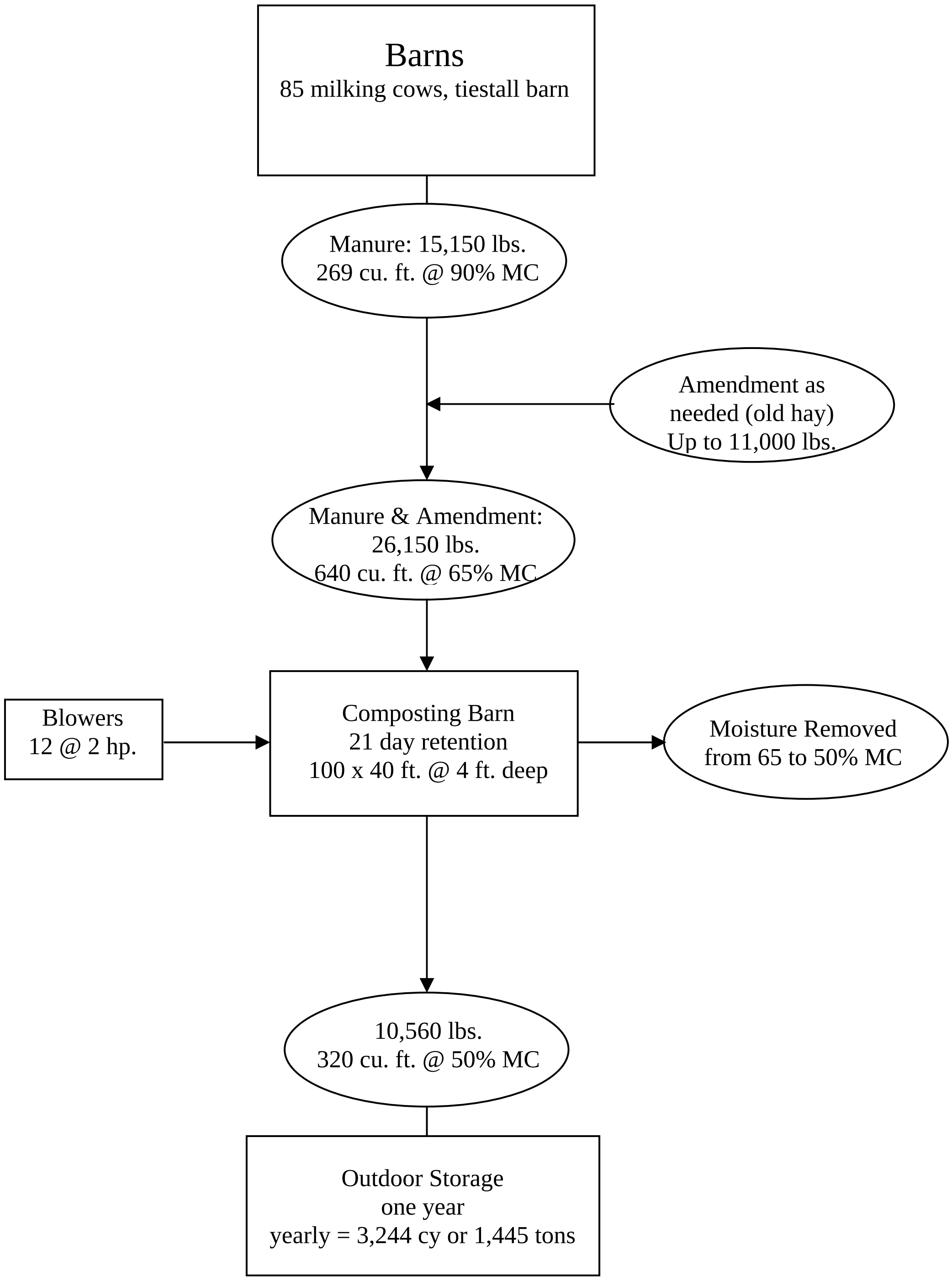

Figure A-1. Schematic of Biodrying System on a Farm Showing Estimated Daily Amounts.

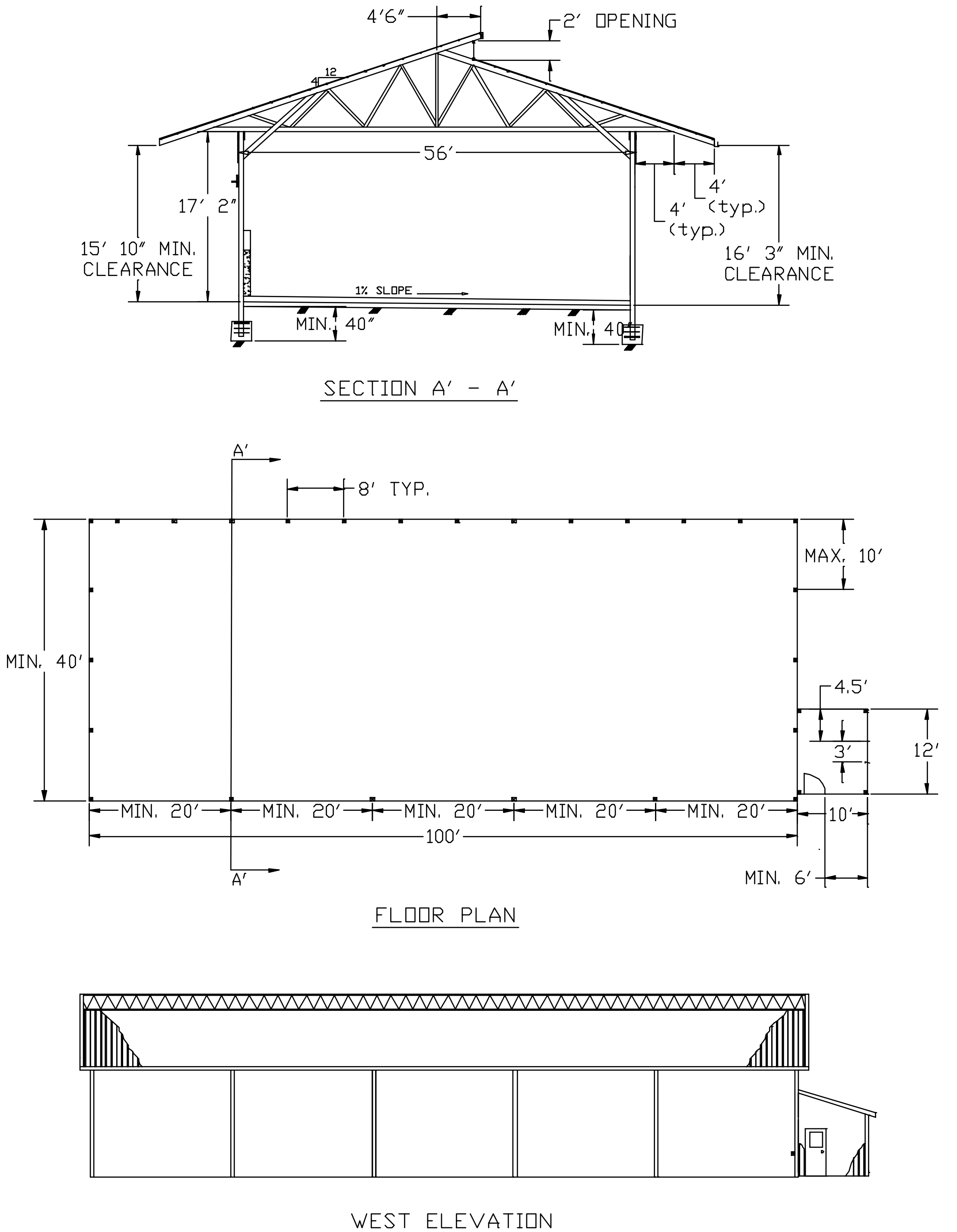

Figure A-2. Biodrying Building.

Table A-1. Manure Systems Analysis Projections, Mar-bil Farm, Original System.

Initial Investments and Fixed Cost Calculation — Real Interest Rate 0.05

Fixed Costs	V Spreader	Fixed costs	Loader
Initial Investment	15000	Initial Investment	20,000
Useful Life	7	Useful Life	10
Salvage Value	0	Salvage Value	2000
Interest Investment	0.05	Interest Investment	0.05
Average Investment	7500	Average Investment	11000
Annual Interest charge	375	Annual Interest charge	550
Depreciation	2143	Depreciation	1800

Fixed costs	Milk House Waste
Initial Investment	12000
Useful Life	10
Salvage Value	0
Interest Investment	0.05
Average Investment	6000
Annual Interest charge	300
Depreciation	1200

Total Annual Fixed Costs **$6,368**

Annual Operating Costs

Operating costs of manure system, over annual period, dollars

		Livestock Facility Removal	Manure Systems	Field Applicati
Repairs/Maintenance, including parts and service fees		0	0	3100
Utilities		540	0	0
Gas		0	0	0
Hired Labor		0	0	0
Management Labor	$15/hr 462 hrs	0	6390	0
Owner Labor & Management		0	0	0
Fuel	40hp * .0504 * 1.80fuel price *60hours	0	0	257
Supplies		0	0	0
Consulting		0	0	0
Insurance		0	400	0
Taxes		0	0	0
Other	Tractor Rent, 30 dollars an hour, 426 hrs.	0	0	12780
	TOTAL of Columns	540	6790	16137

Total Annual Manure System Operating Costs **$23,467**

Operating costs of other systems impacted by manure system,
such as crop enterprise, dairy enterprise, or overall business
Negative is a benefit

Bedding		5360
Field usage		0
Fertilizer		1500
Herbicides		0
Crop Rotations		0
Tillage operations		0
Other	Improved soils	0

Total Annual Operating Costs, Other Systems **$6,860** Added to Total

Revenue Generation due to manure system

electricity	0
solids	0
liquids	0
related farm products	0

Total Annual Revenue Generation due to Manure **$0** Subtracted from Total

Total Annual Operating Costs **$30,327**

Total Annual Costs, All Areas **$36,695**

Table A-2. Manure Systems Analysis Projections, Mar-bil Farm, Liquid System including Storage without Aeration.

Initial Investements and Fixed Cost Calculation — Real Interest Rate 0.05

Fixed Costs	Slurry Storage	Fixed costs	Pipes,Valves, Loading Pump	Fixed costs	Access Road
Initial Investement	168000	Initial Investement	72,000	Initial Investement	12000
Useful Life	20	Useful Life	10	Useful Life	20
Salvage Value	8400	Salvage Value	0	Salvage Value	0
Interest Investement	0.05	Interest Investement	0.05	Interest Investement	0.05
Average Investement	88200	Average Investement	36000	Average Investement	6000
Annual Interest charge	4410	Annual Interest charge	1800	Annual Interest charge	300
Depreciation	7980	Depreciation	7200	Depreciation	600

Fixed Costs	Truck Mounted Spreader	Fixed costs	Milk House Waste	Fixed costs	Box Spreader
Initial Investement	70000	Initial Investement	4800	Initial Investement	5000
Useful Life	8	Useful Life	10	Useful Life	10
Salvage Value	3500	Salvage Value	0	Salvage Value	0
Interest Investement	0.05	Interest Investement	0.05	Interest Investement	0.05
Average Investement	36750	Average Investement	2400	Average Investement	2500
Annual Interest charge	1838	Annual Interest charge	120	Annual Interest charge	125
Depreciation	8313	Depreciation	480	Depreciation	500

Total Annual Fixed Costs **$33,665**

Annual Operating Costs

Operating costs of manure system, over annual period, dollars

	Livestock Facility Removal	Manure Systems	Field Application
Repairs/Maintenance, including parts and service fees	0	1800	3500
Utilities	540	0	0
Gas	0	0	0
Hired Labor	0	0	0
Management Labor $20/hr 312 hrs	0	6240	0
Owner Labor & Management	0	0	0
Fuel 250hp * .0504 * 1.80fuel price *228hours	0	0	5171
Supplies	0	0	0
Consulting	0	0	0
Insurance	0	400	0
Taxes	0	0	0
Other Tractor Rent, 30 / hr. (includes all cots), 66 hrs.	0	0	1980
TOTAL of Columns	$540	$8,440	$10,651

Total Annual Manure System Operating Costs **$19,631**

Operating costs of other systems impacted by manure system, such as crop enterprise, dairy enterprise, or overall business	Negative is a benefit
Bedding	5360
Field usage	0
Fertilizer	0
Herbicides	0
Crop Rotations	0
Tillage operations	0
Other Improved soils	0

Total Annual Operating Costs, Other Systems **$5,360** Added to Total

Revenue Generation due to manure system	
gas	0
electricity	0
solids	0
liquids	0
related farm products	0

Total Annual Revenue Generation due to Manure **$0** Subtracted from Total

Total Annual Operating Cost **$24,991**

Total Annual Costs, All Areas **$58,656**

Table A-3. Manure Systems Analysis Projections, Mar-bil Farm, Liquid System including Storage with Aeration.

Initial Investments and Fixed Cost Calculation — Real Interest Rate 0.05

Fixed Costs	Slurry Storage	Fixed costs	Pipes,Valves, Loading Pump	Fixed costs	Access Road
Initial Investement	168000	Initial Investement	72,000	Initial Investement	12000
Useful Life	20	Useful Life	10	Useful Life	20
Salvage Value	8400	Salvage Value	0	Salvage Value	0
Interest Investement	0.05	Interest Investement	0.05	Interest Investement	0.05
Average Investement	88200	Average Investement	36000	Average Investement	6000
Annual Interest charge	4410	Annual Interest charge	1800	Annual Interest charge	300
Depreciation	7980	Depreciation	7200	Depreciation	600

Fixed Costs	Truck Mounted Spreader	Fixed costs	Milk House Waste	Fixed costs	Box Spreader
Initial Investement	70000	Initial Investement	4800	Initial Investement	5000
Useful Life	8	Useful Life	10	Useful Life	10
Salvage Value	3500	Salvage Value	0	Salvage Value	0
Interest Investement	0.05	Interest Investement	0.05	Interest Investement	0.05
Average Investement	36750	Average Investement	2400	Average Investement	2500
Annual Interest charge	1838	Annual Interest charge	120	Annual Interest charge	125
Depreciation	8313	Depreciation	480	Depreciation	500

Fixed Costs	Aerator
Initial Investement	8000
Useful Life	5
Salvage Value	0
Interest Investement	0.05
Average Investement	4000
Annual Interest charge	200
Depreciation	1600

Total Annual Fixed Costs **$35,465**

Annual Operating Costs
Operating costs of manure system, over annual period, dollars

			Livestock Facility Removal	Manure Systems	Field Application
Repairs/Maintenance, including parts and service fees			0	2600	3500
Utilities			540	3500	0
Gas			0	0	0
Hired Labor			0	0	0
Management Labor	$20/hr	312 hrs	0	6240	0
Owner Labor & Management			0	0	0
Fuel	250hp * .0504 * 1.80fuel price *228hours		0	0	5171
Supplies			0	0	0
Consulting			0	0	0
Insurance			0	400	0
Taxes			0	0	0
Other	Tractor Rent, 30 dollars an hour, 49 hours + 17 hrs.		0	0	1980
		TOTAL of Columns	$540	$12,740	$10,651

Total Annual Manure System Operating Costs **$23,931**

Operating costs of other systems impacted by manure system, such as crop enterprise, dairy enterprise, or overall business		Negative is a benefit
Bedding		5360
Feed usage		0
Fertilizer		0
Herbicides		0
Crop Rotations		0
Tillage operations		0
Other	Improved soils	0

Total Annual Operating Costs, Other Systems **$5,360**

Revenue Generation due to manure system	
gas	0
electricity	0
solids	0
liquids	0
related farm products	0

Total Annual Revenue Generation due to Manure **$0** Subtracted from Total

Total Annual Operating Cost **$29,291**

Total Annual Costs, All Areas **$64,756**

Table A-4. Manure Systems Analysis Projections, Mar-bil Farm, Biodrying System, Sell All Compost, Based on Potential Production.

Initial Investments and Fixed Cost Calculation — Real Interest Rate 0.05

Fixed Costs	Compost Bldg.	Fixed costs	Curing Pad	Fixed costs	Pay loader	Fixed costs	Controls/Fans
Initial Investment	142911	Initial Investment	2,626	Initial Investment	29950	Initial Investment	31763
Useful Life	30	Useful Life	10	Useful Life	10	Useful Life	5
Salvage Value	0	Salvage Value	0	Salvage Value	3000	Salvage Value	0
Interest Investment	0.05	Interest Investment	0.05	Interest Investment	0.05	Interest Investment	0.05
Average Investment	71456	Average Investment	1313	Average Investment	16475	Average Investment	15881.5
Annual Interest charge	3573	Annual Interest charge	65.65	Annual Interest charge	823.75	Annual Interest charge	794.075
Depreciation	4764	Depreciation	262.6	Depreciation	2695	Depreciation	6352.6

Fixed Costs	Manure Spreader	Fixed costs	Milk House Waste	Fixed costs	bedding storage building	Fixed costs	barn modifications
Initial Investment	20994	Initial Investment	12000	Initial Investment	0	Initial Investment	3732
Useful Life	5	Useful Life	10	Useful Life	10	Useful Life	30
Salvage Value	0	Salvage Value	0	Salvage Value	0	Salvage Value	0
Interest Investment	0.05	Interest Investment	0.05	Interest Investment	0.05	Interest Investment	0.05
Average Investment	10497	Average Investment	6000	Average Investment	0	Average Investment	1866
Annual Interest charge	524.85	Annual Interest charge	300	Annual Interest charge	0.0	Annual Interest charge	93.3
Depreciation	4198.8	Depreciation	1200	Depreciation	0	Depreciation	124.4

Total Annual Fixed Costs **$25,772**

Operating Costs, 9 months

Operating costs of manure system, over 9 month period, dollars

		Livestock Facility Removal	Manure Systems	Field Application
Repairs/Maintenance, including parts and service fees		0	6240	0
Utilities		540	3144	0
Gas		0	0	0
Hired Labor	$10/hr 2.5hrs/day 9 mon.	0	6825	0
Management Labor	$20/hr 1.25hrs/day 9 mon	0	6825	0
Owner Labor & Management		0	0	0
Fuel	100hp * .0504 * 1.80fuel price *909hours	0	8246	0
Supplies		0	0	0
Ammendment	7bales/pile 88 piles (10bays 21 day cycle)	0	13552	0
Insurance		0	400	0
Taxes		0	0	0
Other		0	0	0
	TOTAL of Columns	$540	$45,232	$0

Total Annual Manure System Operating Costs **$45,772**

Operating costs of other systems impacted by manure system, such as crop enterprise, dairy enterprise, or overall business
Negative is a benefit

Bedding	5360
Field usage	0
Fertilizer	3000
Herbicides	0
Crop Rotations	0
Tillage operations	0
Other	

Total Annual Operating Costs, Other Systems **$8,360** Added to Total

Revenue Generation due to manure system

gas		0
electricity		0
solids	Marketed Compost - $30/yc 88 piles, 37yd/bay	97680
liquids		0
related farm products		0

Total Annual Revenue Generation due to Manure **$97,680** Subtracted from Total

Total Annual Operating Cost **-$43,548**

Total Annual Costs, All Areas **-$17,776**

Table A-5. Manure Systems Analysis, Mar-bil Farm, Spread Compost On-Farm, Based on Potential Production.

Initial Investments and Fixed Cost Calculation — Real Interest Rate 0.05

Fixed Costs	Compost Bldg.	Curing Pad	Pay Loader	Fans/Control
Initial Investment	142,911	2,626	29950	31,763
Useful Life	30	10	10	5
Salvage Value	0	0	3000	0
Interest Investment	0.05	0.05	0.05	0.05
Average Investment	71456	1313	16475	15882
Annual Interest charge	3573	65.65	823.75	794.08
Depreciation	4764	262.6	2695	6352.6

Fixed Costs	Manure Spreader	Milk House Waste	Bedding storage building	Barn Modifications
Initial Investment	20994	12000	0	3732
Useful Life	5	10	30	30
Salvage Value	0	0	0	0
Interest Investment	0.05	0.05	0.05	0.05
Average Investment	10497	6000	0	1866
Annual Interest charge	524.85	300	0	93.3
Depreciation	4198.8	1200	0	124.4

Total Annual Fixed Costs **$25,772**

Operating costs 9 months

Operating costs of manure system, over 9 months, dollars

		Livestock Facility Removal	Manure Systems		Field Application
Repairs/Maintenance, including parts and service fees		0	6240		2350
Utilities		540	3144		0
Gas		0	0		0
Hired Labor	$10/hr 2.5hrs/day 9 mon.	0	6825		0
Management Labor	$20/hr 1.25hrs/day 9 mon	0	6825		0
Owner Labor & Management	$10/hr	0	0	0	0
Fuel	100hp * .0504 * 1.80fuel price *909hours	0	8246		0
Supplies		0	0		0
Ammendment	7bales/pile 88 piles (10bays 21 day cycle)	0	13398		0
Insurance		0	400		0
Taxes		0	0		0
Other	150hp * .0504 * 1.80fuel price *800hours	0	0		10886
	TOTAL of Columns	$540	$45,078		$13,236

Total Annual Manure System Operating Costs **$58,854**

Operating costs of other systems impacted by manure system, such as crop enterprise, dairy enterprise, or overall business
Negative is a benefit

Bedding	5360
Field usage	-1500
Fertilizer	-1500
Herbicides	0
Crop Rotations	0
Tillage operations	0
Other	0

Total Annual Operating Costs, Other Systems **$2,360** Added to Total

Revenue Generation due to manure system

electricity	0
solids	0
liquids	0

Total Annual Revenue Generation due to Manure **$0** Subtracted from Total

Total Annual Operating Cost **$61,214**

Total Annual Costs, All Areas **$86,986**

Table A-6. Manure Systems Analysis Projections, Mar-bil Farm, Biodrying System, Sell All Compost, Based on Actual Amount Processed.

Initial Investments and Fixed Cost Calculation — Real Interest Rate 0.05

Fixed Costs	Compost Bldg.	Fixed costs	Curing Pad	Fixed costs	Pay loader	Fixed costs	Controls/Fans
Initial Investment	142911	Initial Investment	2,626	Initial Investment	29950	Initial Investment	31763
Useful Life	30	Useful Life	10	Useful Life	10	Useful Life	5
Salvage Value	0	Salvage Value	0	Salvage Value	3000	Salvage Value	0
Interest Investment	0.05	Interest Investment	0.05	Interest Investment	0.05	Interest Investment	0.05
Average Investment	71456	Average Investment	1313	Average Investment	16475	Average Investment	15882
Annual Interest charge	3573	Annual Interest charge	66	Annual Interest charge	824	Annual Interest charge	794
Depreciation	4764	Depreciation	263	Depreciation	2695	Depreciation	6353

Fixed Costs	Manure Spreader	Fixed costs	Milk House Waste	Fixed costs	bedding storage building	Fixed costs	barn modifications
Initial Investment	20994	Initial Investment	12000	Initial Investment	0	Initial Investment	3732
Useful Life	5	Useful Life	10	Useful Life	10	Useful Life	30
Salvage Value	0	Salvage Value	0	Salvage Value	0	Salvage Value	0
Interest Investment	0.05	Interest Investment	0.05	Interest Investment	0.05	Interest Investment	0.05
Average Investment	10497	Average Investment	6000	Average Investment	0	Average Investment	1866
Annual Interest charge	525	Annual Interest charge	300	Annual Interest charge	0	Annual Interest charge	93
Depreciation	4199	Depreciation	1200	Depreciation	0	Depreciation	124

Total Annual Fixed Costs **$25,772**

Operating Costs, 9 months

Operating costs of manure system, over 9 month period, dollars

		Livestock Facility Removal	Manure Systems	Field Application
Repairs/Maintenance, including parts and service fees		0	6240	1209
Utilities		540	1071	0
Gas		0	0	0
Hired Labor	2hr/day $10/hr 9months	0	5475	0
Management Labor	1hr/day $20/hr 9 months	0	5475	0
Owner Labor & Management		0	0	0
Fuel	100hp * .0504 * 1.80fuel price *303hours	0	3000	0
Supplies		0	0	0
Ammendment	7bales/pile 30 piles $22/bale	0	4620	0
Insurance		0	400	0
Taxes		0	0	0
Other	150hp * .0504 * 1.80fuel price*528hours	0	0	7185
	TOTAL of Columns	$540	$26,281	$8,394

Total Annual Manure System Operating Costs **$35,215**

Operating costs of other systems impacted by manure system, such as crop enterprise, dairy enterprise, or overall business
Negative is a benefit

Bedding	5360
Field usage	0
Fertilizer	2145
Herbicides	0
Crop Rotations	0
Tillage operations	0
Other	0

Total Annual Operating Costs, Other Systems **$7,505** Added to Total

Revenue Generation due to manure system

electricity		0
solids	Marketed Compost - $30/yd 30 bays, 37yd/bay	33300
liquids		0

Total Annual Revenue Generation due to Manure **$ 33,300** Subtracted from Total

Total Annual Operating Cost **$9,420**

Total Annual Costs, All Areas **$35,192**

Table A-7. Manure Systems Analysis Projections, Mar-bil Farm, Spread Compost On-Farm, Based on Actual Amount Processed.

Initial Investments and Fixed Cost Calculation — Real Interest Rate 0.05

Fixed Costs	Compost Bldg.	Fixed costs	Curing Pad	Fixed costs	Pay Loader	Fixed costs	Fans/Control
Initial Investment	142,911	Initial Investment	2,626	Initial Investment	29950	Initial Investment	31,763
Useful Life	30	Useful Life	10	Useful Life	10	Useful Life	5
Salvage Value	0	Salvage Value	0	Salvage Value	3000	Salvage Value	0
Interest Investment	0.05	Interest Investment	0.05	Interest Investment	0.05	Interest Investment	0.05
Average Investment	71456	Average Investment	1313	Average Investment	16475	Average Investment	15882
Annual Interest charge	3573	Annual Interest charge	65.65	Annual Interest charge	823.75	Annual Interest charge	794.08
Depreciation	4764	Depreciation	262.6	Depreciation	2695	Depreciation	6352.6

Fixed Costs	Manure Spreader	Fixed costs	Milk House Waste	Fixed costs	Bedding storage building	Fixed costs	Barn Modifications
Initial Investment	20994	Initial Investment	12000	Initial Investment	0	Initial Investment	3732
Useful Life	5	Useful Life	10	Useful Life	30	Useful Life	30
Salvage Value	0	Salvage Value	0	Salvage Value	0	Salvage Value	0
Interest Investment	0.05	Interest Investment	0.05	Interest Investment	0.05	Interest Investment	0.05
Average Investment	10497	Average Investment	6000	Average Investment	0	Average Investment	1866
Annual Interest charge	524.85	Annual Interest charge	300	Annual Interest charge	0	Annual Interest charge	93.3
Depreciation	4198.8	Depreciation	1200	Depreciation	0	Depreciation	124.4

Total Annual Fixed Costs **$25,772**

Annual Operating Costs

Operating costs of manure system, over annual period, dollars		Livestock Facility Removal	Manure Systems	Field Application
Repairs/Maintenance, including parts and service fees		0	6240	2350
Utilities		540	1071	0
Gas		0	0	0
Hired Labor	2hr/day $10/hr	0	5475	0
Management Labor	1hr/day $20/hr	0	5475	0
Owner Labor & Management	$10/hr	0	0	0
Fuel	100hp * .0504 * 1.80fuel price *303hours	0	3000	
Supplies		0	0	0
Ammendment	7bales/pile 30 piles $22/bale	0	4620	0
Insurance		0	0	0
Taxes		0	400	0
Other	150hp * .0504 * 1.80fuel price *800hours	0	0	10880
		0	0	0
	TOTAL of Columns	$540	$26,281	$13,230

Total Annual Manure System Operating Costs **$40,051**

Operating costs of other systems impacted by manure system, such as crop enterprise, dairy enterprise, or overall business
Negative is a benefit

Bedding	5360
Field usage	-645
Fertilizer	1500
Herbicides	0
Crop Rotations	0
Tillage operations	0
Other	0

Total Annual Operating Costs, Other Systems **$6,215** Added to Total

Revenue Generation due to manure system

gas	0
electricity	0
solids	0
liquids	0
related farm products	0

Total Annual Revenue Generation due to Manure **$0** Subtracted from Total

Total Annual Operating Cost **$46,266**

Total Annual Costs, All Areas **$72,038**

APPENDIX B

Excerpts from:

Inactivation of *Ascaris suum* in a biodrying compost system, unpublished, Amy S. Collick

"Sentinel Chambers™ have proven effective in monitoring the survival of *Ascaris suum* in the biodrying system. The high viability results from the control chambers ensured the initial viability of the *A. suum* eggs and the efficacy of the chamber processing and egg extraction and incubation methods. Therefore, the inactivation observed in the compost chamber samples was caused by the biodrying process and not by laboratory processing.

Two key factors most likely causing the inactivation of *A. suum* eggs exposed to the biodrying system were high temperatures (>55^{o}C) in much of the pile and the drying out of the bottom portion of the pile. The influence of time and temperature on *Ascaris* eggs has been extensively studied. According to a compilation of several of these studies, total inactivation of Ascaris eggs occurred in less than 2 hours in conditions in which temperatures remained above 55^{o}C (Feachem et al., 1983). Eggs subjected to temperatures of 55^{o}C and below in various conditions required more than 1 year for complete inactivation (Feachem et al., 1983). The inactivation of the top chamber samples (B- and B-samples) can be explained by the high temperatures observed in proximity of these samples. However, the chambers located in the bottom of the pile were associated with temperatures near 30^{o}C, and the eggs in these chambers also experienced total inactivation within 4 days. Therefore, other factors besides temperature were responsible for the rapid inactivation of the eggs in the chambers situated in the bottom of the pile. For example, desiccation is deleterious to *Ascaris* eggs (Feachem et al., 1983). The extent of drying that occurred in the bottom portion of the compost pile may have been the cause of the inactivation. Other microbial and composting processes may also be important factors responsible for inactivating *A. suum* eggs.

Aerobic composting with the addition of a bulking agent has been effective in eliminating *Ascaris* eggs in other studies, as well (Feachem et al., 1983). Careful composting process management through the regulation of moisture content, carbon-nitrogen ratio, and pile temperature was necessary to inactivate the eggs. Pile temperature was deemed the crucial factor in the elimination of the eggs (Feachem et al., 1983). The biodrying system provided additional proof to the effectiveness of temperature and moisture regulation on the management of pathogens in composting processes.

Although additional adjustments to the biodrying system may be required to ensure a thoroughly dried and composted product, the complete elimination of *A. suum* eggs justifies continued research into this system as a potentially feasible and environmentally sound manure storage and handling practice for small and medium dairy farms."

APPENDIX C

Disclaimer

PUBLICATIONS

Wright, P., C. Gooch, S. Inglis. 2001. Biodrying dairy manure: Initial experiences. ASAE Annual Meeting Paper No. 012292. St. Joseph, Mich: ASAE.

Inglis, S., Wright, P., and C. Gooch. 2002. Computerized Control System for Static Pile Composting of Dairy Manure. 2002 ASAE Annual Meeting Paper No. 024140. Chicago, Illinois: ASAE.

Wright, P.. and S. Inglis. 2002. Biodrying Manure. Composting and Compost Utilization. 2002 International Symposium, Columbus, Ohio. Compost Science & Utilization, 419 State Avenue, Emmaus, PA 18049.

Wright, P. and S. Inglis. 2002. Moisture, Density and Porosity Changes as Dairy Manure is Biodried. ASAE Annual Meeting Paper No. 024151. Chicago, Illinois: ASAE.