

**Development and Demonstration of a Management System
for Handling Liquid Swine Manure that Minimizes Odours
and Losses of Nutrients to the Environment**

Final Report

Submitted to:

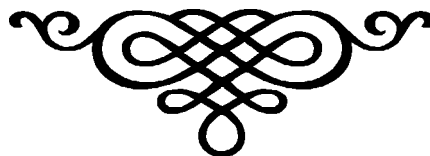
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May, 2001



Executive Summary

A liquid manure composting system has been developed and is now operating at Ridgetown College, University of Guelph, located in Ridgetown, Ontario. Operation began in March, 1998, and testing continues to the present. The composter is an in-vessel system, with forced aeration and mechanical turning. Liquid swine manure has been mixed with a variety of substrates to produce a material that can be composted. Straw, wood fibre, wood chips, corn stalks, corn cobs, tree leaves, solid bedded beef manure and combinations of these materials have been tested.

The composter is designed to operate as a batch system, where the channels are filled, the materials composts, and the entire channel of partially composted material is removed from the channels after two to four weeks (depending on management strategy). This material is then stacked in a separate area for the curing process. The total time to produce finished compost is approximately 12 to 16 weeks. Over the duration of the project, 32 batches have been studied.

Main findings of the study:

- With monitoring of the C:N ratio, moisture level and aeration level, we have had excellent success in controlling odours from liquid pig manure.
- The ratio, by weight, of liquid manure to substrate ranged from 1.9:1 to 8.4:1 for straw, and was lower for wood fibre (average 1.1:1), corn stalks (average 3.1:1), leaves (average 1.7:1), and corn cobs (average 2.6:1). A design target of 5.0:1 should be achievable for straw.
- The amount of manure processed, expressed as a function of time and compost channel area, was as high as 31.9 L/day/m² using straw and 39.0 L/day/m² using leaves (based on leaving material in the channels for only two weeks).
- The compost should cure for a period of at least two months after removal from the composter. This will allow it to break down to the point where it can be marketed (i.e. off-farm uses).
- Total losses of Nitrogen during the first five weeks of composting (i.e. the most active stage) averaged 19% (average of all samples - for all materials).
- Moisture contents as high as 80% (at two weeks into the process) do not adversely affect the composting process.
- The range of C:N ratios in compost at 10 weeks or greater into the process was between 9.5 and 29.4, depending on the material used as a carbon source. Straw compost had a C:N ratio of about 11. Ratios as low as 9.5 (using corn cobs) do not adversely affect the composting process.
- Concentrations of molybdenum exceeded the Ontario compost standard in compost made using pig manure and straw. The main source was the manure. Levels of copper and zinc

were acceptable in the compost but were also high in the liquid swine manure. This must be considered in the context of marketing the compost, and measures may be needed to reduce levels in animal diets or to dilute levels in the compost.

- The composting process was very effective at killing pathogenic organisms (represented by *E. coli*, *salmonella*, and *fecal streptococcus*) and weed seeds. There is a danger of re-infection if care is not taken in handling the curing and finished compost.
- Curing is an essential part of composting. This process continues the organic matter breakdown, though at lower temperatures. It generally does not need much management for the 10 to 14 weeks of curing (assuming two weeks in the channels to start).
- Compost is a useful source of nutrients for crop growth.

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Background

Liquid manure systems are used on most swine farm operations in Ontario, especially in the new barns. The handling, storage and land-application of liquid swine manure have raised considerable environmental concerns - especially with odour. The potential to contaminate surface water or groundwater is also very real, and various studies have attempted to quantify this problem and come up with ways to prevent it (Fleming, 1994; McLellan et al., 1993; Fleming and Bradshaw, 1992).

The odour issue has been a challenge to swine farmers for many years. A great deal of research effort has gone into developing and testing products or systems to reduce or eliminate manure odours. Composting is a proven system for solid manure and is well documented (eg. NRAES, 1992). Very little has been done with liquid manure, however. Patni et al. (1992) reported on a study where liquid poultry manure was composted using peat and chopped straw in a passively aerated pile. While this was encouraging, peat is not a suitable material for widespread use because of high cost and the fact that its use is non-sustainable. Patni (1997) completed a study using passive aeration with liquid manure and straw. The preliminary results showed that straw could successfully be used and that the heat produced during composting helped to evaporate a considerable portion of the liquid in the manure.

Composting of liquid manure would have the benefits of controlling odours from storage and spreading, two of the biggest problems with swine manure. Besides odour control, composting can provide the following benefits:

- a) the potential to avoid the water quality problems that some producers have experienced on spreading liquid manure,
- b) the potential to kill pathogens before land application (e.g. bacteria, protozoa and weed seeds),
- c) overall volume reduction, thus decreasing travel times to distant fields, and
- d) creation of a product for sale off of the farm - allowing farmers to export nutrients from the farm (an advantage for many farmers who are concerned about nutrient management planning).

Objective

To develop a composting system for liquid swine manure, capable of becoming an integral part of a typical on-farm manure management system.

Project History - Activities

- ' 1996 and 1997 - applications for funding, permits, etc.
- ' May, 1997 - beginning of construction of facility at Ridgetown College
- ' Fall 1997 - setup of building, wiring, plumbing, aeration and installation of instruments.

- ' January 1998 - delivery of prototype turner to site and beginning of assembly and setup, and testing
- ' March, 1998 - beginning of composting trials
- ' August, 1998 - open house
- ' October 1998 - aeration channel changes - changed floor in channel 3
- ' ongoing - Substrate testing - evaluating straw, corn stalks, wood fibre, wood chips, corn cobs, tree leaves, solid bedded beef manure as a source of carbon in the process
- ' Fall, 1998 onward - Crop growth trials by Agriculture and Agri-Food Canada, Harrow, looking at compost as a soil amendments for soil remediation
- ' 1998 to 2000 - evaluation of curing techniques - assessment of windrows and static piles
- ' January to March, 1999 - Greenhouse trials - weed seed survival and plant growth growing season, 1999 - Chris Brown, OMAFRA, mineralization of N - field trials
- ' spring 1999 - educational video on compost system
- ' summer, 1999 - Windrow trials - assessment of windrows as alternative composting method
- ' fall 1999 to fall 2000 - Doug Young, Ridgetown College, plot trials - compost as crop nutrient source
- ' ongoing in 1999, 2000 - Pathogen testing of manure and compost
- ' summer 1999, ongoing - Computer program for composter sizing and design
- ' summer, 1999 - consult on composter installation at John Stolp farm
- ' May 15, 2000 to July 26, 2000 - composter repairs and upgrades
- ' fall, 2000 - greenhouse gas measurements
- ' fall 2000 and winter of 2001 - consultation on potential composter installations at University of Alberta, Edmonton - North Carolina State University, Raleigh, NC, Premium Standard Farms, Princeton, MO
- ' summer, 2000 - odour measurements
- ' summer, 2000 - consult on composter installation at Tom Fritz farm

Composter Setup

In conjunction with Global Earth Products, an on-farm composting and processing unit was installed at Ridgetown College (University of Guelph), Ridgetown, Ontario. The unit is covered to exclude all precipitation and consists of three adjacent channels, each 2.2 m wide, 1.8 m deep and 15.2 m long (channel volume = 60.2 m³). The overall layout is shown in Figure 1. The walls separating the three channels are of reinforced concrete. The compost turner is a prototype - the MARVEL, designed by Lagace Systech Corporation. It is hydraulically operated, originally powered by a 7.5 kW electric motor driving a hydraulic pump. This powered a 7.3 kW hydraulic motor to operate the apron and the hydraulic cylinders needed to lift the apron. A 2.25 kW electric motor drives a second hydraulic pump that powers four hydraulic motors to operate the drive wheels. The control panel includes a PLC controller to operate the turner. The turner

travels down each channel on steel tracks - it can be moved from one channel to the next at one end on a steel transfer cart.

Liquid manure is stored nearby in an underground covered holding tank. It is pumped into the compost building, when needed, using a Goulds sewage pump (Model: WS1012BF, 0.75 kW, 473 L/min at 6.0 m head). The transfer line is 50 mm PVC water pipe. This is all mounted on an overhead wooden beam and is designed to be self-draining. Inside the building, manure is transferred to the turner through a 50 mm x 23 m flexible plastic “milk truck” pipe. Incoming manure flow is measured using a Greyline Instruments DFM-III Doppler Flow Meter.

Excess liquid manure is allowed to drain out of the channels and is collected in an underground sump and pumped back to the outside storage using a Myers Sewage Pump (Model: WHR5P-2, 0.38 kW, 150 L/min at 6.0 m head). Running time is recorded by the data logger and related to the volume of liquid pumped.

The initial electrical service for the installation consisted of a 200 amp, 240 volt, single phase service. The main panel is located in an instrument hut located beside the compost building - kept separate to prevent damage due to high humidity levels. Modifications to this setup are discussed later.

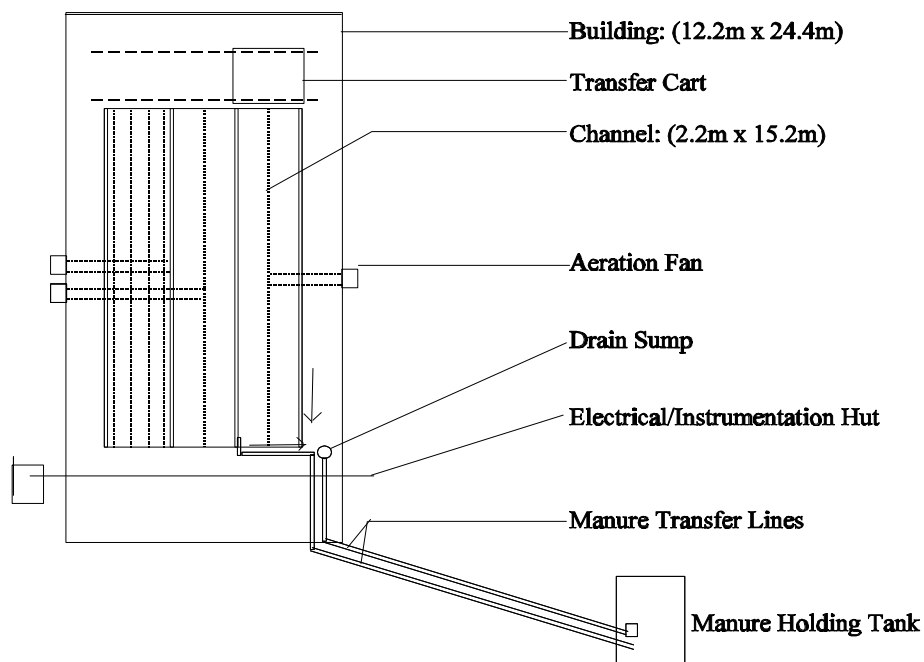


Figure 1 Overall layout of the composting building, showing channels, manure supply and aeration fans

One aeration fan is provided for each of the three channels. The fans are Airstream Inline Centrifugal Fans (Model # ILC-318, 2.25 kW electric). They are rated at 1650 L/sec at a static pressure of 100 mm. The fans force outside air through a transition plenum to two 250 mm PVC water pipes and then to the individual aeration floors. In each of these ducts is a pressure

transducer (Omega Canada Inc., model PX154-025D1). These three devices are connected to the data-logger and record the static pressures.

The aeration floor in Channel 1 is a spigot floor system, consisting of four lengths of 100 mm PVC pipe buried in the concrete floor. On top of each pipe, at 30 mm intervals, is a plastic spigot (a cone about 75 mm high). The top (small end) is recessed slightly below the finished floor level. In it is a 6 mm diameter hole (they were drilled out to 10 mm diameter October 26, 1999, to allow for more air flow), through which air enters the compost. Channel 2 contains a concrete floor with a central plenum 200 mm wide having regularly spaced holes to allow air to enter the pile in the centre. The original floor in Channel 3 consisted of a sub-floor of concrete, covered by crushed stone, in which a 150 mm diameter PVC pipe was buried. On the underside of this pipe were two rows of holes to allow air out into the stone before being forced up through the compost.

Temperatures in each channel are measured using six thermocouples, connected to the data-logger (Campbell Scientific CR10 data logger, shielded thermocouple cable type T 24-AWG). There are also thermocouples set up to measure outside air temperatures and the temperature of air inside the building.

The data logger is programmed to read the temperatures and operate the aeration fans. A base level of aeration is maintained (i.e. 3 minutes operation in each hour) and when any one of the 6 thermocouples in a channel exceeds a predetermined level (e.g. 66 °C), a second level of aeration is initiated - 2 minutes out of 10 (to prevent excessive heat and subsequent die-off of bacteria, and to provide the extra oxygen needed in the process).

Composter Operation

Unlike many commercial systems, this is operated as a batch system. This was chosen to allow the flexibility to experiment with turning frequencies, etc. and to develop the best recipe without having to regularly remove small amounts of “finished” compost. We felt that many farmers would prefer to remove an entire batch every few weeks rather than have to deal with relatively small amounts every day or two.

The process operates as follows:

- a) Substrate (a material with a high C:N ratio - such as straw) is added to the channels using a tractor and loader. Substrate is only added at the start of each batch.
- b) Liquid manure is dropped from a pipe mounted on the turning device. All drainage liquid is intercepted, and pumped back into the holding tank.
- c) The mechanical turner moves down the channel, mixing the substrate and manure. The speed of travel is pre-set at 1.2 m/min. The turner consists of an inclined apron and a series of slats that lift the material up and drop it on the back side, displacing the material about 2.5 m. Since this is a batch system, the machine must move in two directions - it is designed to allow for turning going both ways. Only one turning device is used and it is moved from one channel to the next on a transfer cart located at one end of the channels.
- d) Aeration from beneath is supplied as needed to maintain aerobic conditions.
- e) The material is turned and manure is added on about three different days during the first

two weeks - until the final desirable moisture condition is achieved (i.e. between 60 and 80%).

f) After a period of time ranging from two to six weeks (discussed later), material is removed. A portion is held back and used as “seed” compost for the next batch.

g) The compost that is removed is placed in bulk in a storage area for “curing” - for further breakdown of organic matter and further moisture loss.

h) After a total period of 12 to 16 weeks, “finished” compost is ready for use.

Composter Evaluation - Results

Evaluation of the turning equipment

Since the equipment was initially set up, there have been a number of changes/improvements to the Marvel turner. For certain materials, the machine was underpowered. We changed the drive to a 15 kW 3-phase electric motor, with a 15 kW hydraulic motor on the apron. The turner has now operated successfully in leaves, wood fibre, corn stover and straw. This has meant switching to 3-phase power. Power of at least 15 kW for each 2.2 m of apron width is required. Since most farms do not have 3-phase power, they will need to install a phase converter.

Corrosion in the composting building has not been a problem. Metal parts (most of the turner is made of steel) have shown virtually no rust in spite of an environment with liquid hog manure. There has been little or no rust and limited wear on any moving parts.

Work environment issues are of some concern. Some compost materials can be very dusty and mouldy. Shredded straw was the worst for dust but once manure was applied the dust was controlled. Wearing a dust mask was essential when turning straw and corn stover. We have seen no evidence of the presence of any gases that could present a breathing hazard. Manure can be a hazard in the work environment due to the presence of pathogens and offensive odours. Limited contact with manure is possible by wearing proper clothing such as gloves and coveralls, and taking care in handling hoses and fittings. Valves to drain connections have been installed, as have valves that can shut off the flow of manure. Noise during operation of the turner has not been an issue. The hydraulic and electrical motors produce very little noise. There is some chain clatter as the machine is operating, but it is minimal.

The method for applying manure has undergone some improvements. We now use three evenly-spaced manure application nozzles (from Husky Farm Equipment Ltd.). These are set so that the deflector plate faces downward. These nozzles give relatively even coverage and have no problem with plugging.

Evaluation of the aeration system

Aeration is scheduled based on the temperature in the compost. Each channel uses three pairs of temperature probes, spaced near the ends and in the middle. Paired temperature probes are inserted, one near the surface and the other near the bottom of the mass. The probes are removed during the turning operation. Originally, the data-logger/controller was set to switch

from the constant level of aeration to an increased level when the average temperature of all six probes exceeded 55 °C. It soon became obvious that, even though there were high temperatures, there was a range in temperatures. In fact, the average temperature in any of the channels is often below 55 °C, depending on the materials being composted. The program was re-set to switch the fans onto the high rate when the temperature at one of the probes exceeded 66 °C. This has worked well and apparently has supplied enough air to the composting material - temperatures have rarely exceeded 70 °C and there has been no evidence that the process has gone into an anaerobic state. The variation of temperatures within the channel is greatest near the start of the process and evens out as time goes on - it appears to be related to evenness of application of liquid manure.

The plenum static pressure is measured at each fan. Static pressures are typically in the 120 to 165 mm range. Static pressure seems to be unrelated to compost material - i.e. dense materials have not led to an increase in static pressure. Pressure drop in the aeration system has not been measured, but it does not appear that under-sizing of the ducts is leading to the high static pressures. As mentioned earlier, the evidence suggests all parts of the channels are receiving adequate levels of aeration (though the turning process is likely helping).

The performance of the aeration systems in Channels 1 and 2 was similar. The original expectation was that the spigot floor system in Channel 1 would out-perform the centre plenum of Channel 2. It did not increase the speed of the composting process. It did not affect the static pressure at the fan. The temperatures were similar. Observations so far suggest that the added expense of installing the spigot floor system is not justified for this type of system. Unfortunately, we do not have documentation of the difference in costs of the two floors. The spigot floor took approximately twice as long to prepare before placing concrete in the channels. Then the holes were drilled in the spigots. Normally, the supplies would cost more for this system. The floor in Channel 2 was much easier to install. If anything, the spigot floor has had more problems, as the holes tend to plug easily when compost is removed from the channel. As a result of this concern, the holes were drilled out to 10 mm diameter on October 26, 1999 to reduce the chance for plugging and to increase airflow.

The crushed stone floor used in Channel 3 was replaced with a concrete floor similar to that in Channel 2 between Batches 4 and 5. There were two reasons for this: a) It was difficult to drive on the floor to add materials and remove compost, and b) The temperatures never reached as high levels in Channel 3 as in the other two channels - whether this was related to the aeration system or drainage or something else is unknown. When we removed the crushed stone from Channel 3 to prepare for pouring the concrete floor, we found that the stone was filled with compost in parts of the channel. This would have prevented uniform aeration in the channel.

In an attempt to document differences between the aeration floors, temperature profiles were measured in each channel on several occasions during June to August, 1998. Up to 30 temperature readings were taken from each channel, representing two different depths, five positions along the length of the channel and three locations across the channel (i.e. close to each channel sidewall, and in the centre). In general, the temperatures near the surface of the pile were slightly lower than those from deeper in the pile. There was no tendency to have warmer temperatures in the centres of the channels compared to near the walls. The variations of temperatures within the three channels were similar - no floor type appeared to give a more

uniform temperature.

With the onset of winter in January 1999, it was obvious that the aeration fans in areas with significant snowfall should be located under cover or inside the compost shelter. It was first feared that gases and moisture produced in the compost building would damage the fans. Corrosive gases do not appear to be a problem. Placing the fans inside the compost shelter may be practical - alternatively, a shelter should be constructed for the fans for installations in areas of significant snowfall.

Evaluation of the physical setup

During the first two batches, we did not have experience at judging moisture levels of composting material. As a result, this material had a higher moisture content than desirable, thus slowing down the process. As might be expected, the solids content of the manure affects the ability to produce compost. Manure with dry matter content of less than two percent (used for our first few batches) raised the moisture content of the compost too high and still did not supply adequate nutrients to allow proper composting. A microwave oven and balance were then used to quickly determine moisture levels, with a high degree of accuracy. Generally, dry matters start at about 90% (e.g. dry straw) and eventually drop to about 20 to 35%. With experience, it is possible to judge compost moisture levels fairly quickly by appearance and by the squeeze test.

The turner design provided the most challenges in the first part of the project. The turner was expected to tear up big round bales, operate in channels full of dry material, operate in much wetter, heavier material, and do all of this with rather limited power. Eventually, modifications were made to allow it to operate efficiently in a variety of consistencies of material.

Removal of composted material was very difficult in Channel 3, with the crushed stone. This floor type lends itself much better to a continuous flow system. The skid steer loader dug into the stones if the driver was not very careful.

Channel width has created some problems. The channels are narrow enough that a tractor with front-end loader has a hard time making the turn into Channels 1 and 3 after coming through the doorway of the building. It still appears to be wise to have a building covering the composter, to prevent precipitation onto the compost. There may be cases, however, where end walls are not needed. Wider channels would make channel loading and unloading much easier, whether end walls are used or not.

Evaluation of the compost process

a) Odours - At the start of the project, odour assessments were made on a rather subjective basis using college staff working in the building. Since odour concerns were the main driving force for this project, it was important that the project be run in manner that would minimize odours. In fact, it was soon obvious that odours were not an issue with this system. The composting system and the manner of adding the liquid manure both contributed to an environment where there was seldom any evidence of liquid manure odours. Similarly, there never have been the types of odours that some other compost operations have had to deal with. So far, the facility has had over 900 visitors and there has never been any mention of unacceptable odours - most people have

been surprised at the lack of odour.

During the summer of 2000, a four-person odour assessment team was assembled. This group used an odour measurement device called a Scentometer (Barnebey and Sutcliffe). The user breathes through ports on the Scentometer and records the air dilution where they are first able to detect an odour. The device contains a carbon filter and allows the user to change the ratio of odorous air with filtered (non-odorous) air. By starting at very low dilutions and progressing to high, the user can identify the dilution level where they start to notice an odour. This level is referred to as “dilutions to threshold” - it is equivalent to “odour units”, which is used by some jurisdictions. The possible values for the Scentometer are: 350, 170, 31, 15, 7 and 2 dilutions to threshold.

Besides odour intensity, character of the odour can be described. This was done during each site visit by the odour panel. The character descriptors were those used by the wastewater treatment industry, and are shown in Figure 2.

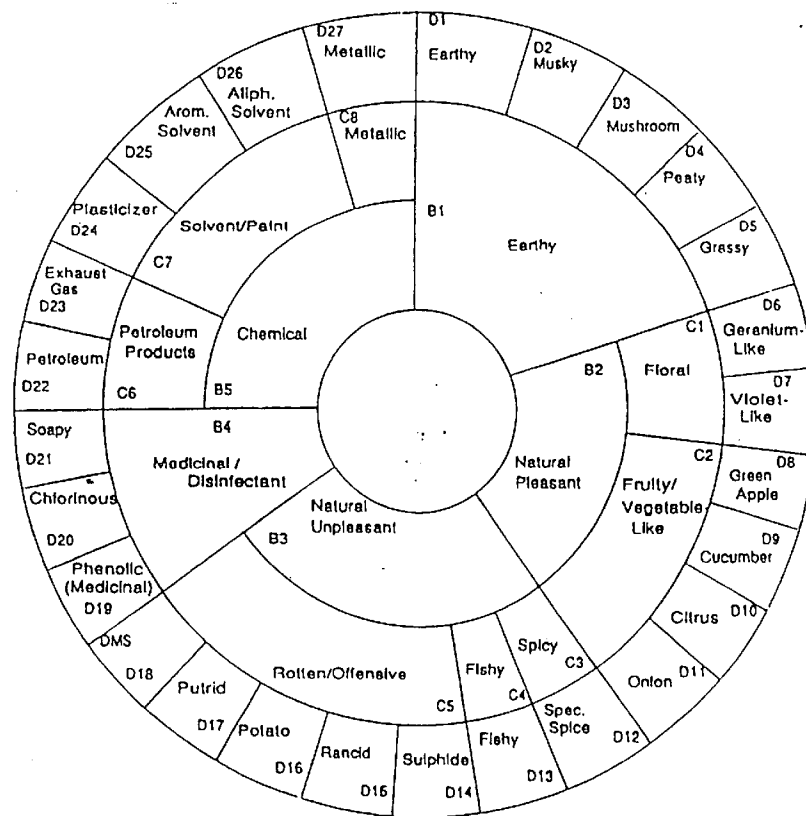


Figure 2 Character descriptors used by the wastewater treatment industry

A group of swine farms was visited on two different occasions (in most cases) during the summer, 2000. An odour measurement was made downwind of the source of odour, whether barn or manure storage or both. Wind speed, relative humidity, temperature, distance to odour source, odour level, odour character, time of day, cloud cover and depth of manure in the tank (if applicable) were all recorded. Two Scentometers were shared among the four panel members. Each person had their own set of glass nasal inserts. The odour panellists wore carbon filter face masks until it was their turn to use the Scentometer. They then removed the face mask and started breathing carbon-filtered air through the Scentometer. After a minute or longer, they began pulling the tape from the holes at the end of the device, starting with the smallest hole. After a few breaths, they were able to say whether or not they could detect an odour. If not, they covered that hole again and proceeded to the next larger opening. When they were convinced they could detect an odour, they usually proceeded to the next larger hole, just to make sure. The Dilutions to Threshold corresponding to the Scentometer hole size was recorded.

The geometric mean value of the dilutions to threshold from the four odour panel members was later calculated. These values, along with the odour character rating are shown in Table 1. There was an attempt to maintain a distance of 30 meters from the odour source but this was not always possible or practical.

The composter was actually visited four times. At fairly close distances to the building, no odour could be detected using the Scentometer. When the device was not used, the panellists could still detect no odour, thus the "Not Detected" entry in the table. The Scentometer minimum rating is "2". Most of the barn and manure storage odours were in the range of 5 to 20 dilutions to threshold (geometric mean), with a few cases of Non Detection, and one as high as 47 (geom. mean). In almost every case, these barn and manure storage odours were described as "Rotten/offensive". In contrast, the compost odours were not rated because they were not detected. Inside the compost building there was a faint smell that was characterized as "B1 - earthy."

The weather conditions were recorded during each site visit, but no analysis has been done yet of this data. The dispersion of odours is highly dependent on the atmospheric stability, and a classification system exists to rate different stability classes. The reason why some barn systems had no odour detected may be due to highly unstable air conditions, where odours dissipate very quickly. Additional site visits will be made during 2001, including trips to the Fritz farm, where a composter is now in operation. Further analysis will include a summary of atmospheric stability class impacts on odours.

Table 1 Results of odour panel assessments during summer, 2000 - compost odours compared to typical swine barns and liquid manure storages

| Site ID | Site | Visit #1 | | Visit #2 | | Odour Character* |
|---------|-----------------------------|------------------------------|------------------------|------------------------------|------------------------|------------------|
| | | Distance to odour source (m) | Dilutions to Threshold | Distance to odour source (m) | Dilutions to Threshold | |
| 1 | Ridgetown College composter | 10 | ND** | 15 | ND | |
| 2 | barn + manure storage | 50 | 13 | 30 | 12 | C5 |
| 3 | barn | 38 | 5 | 30 | 9 | C5 |
| 4 | manure storage | 38 | 9 | 30 | 47 | C5 |
| 5 | barn | 14 | 12 | 30 | ND | C5 |
| 6 | barn | 13 | 5 | 30 | 7 | C5 |
| 7 | barn | 30 | 7 | 30 | 18 | C5 |
| 8 | barn | 20 | 9 | - | - | C5 |
| 9 | barn + manure storage | 30 | 12 | 30 | 9 | C5 |
| 10 | barn + manure storage | 30 | 18 | 30 | 11 | C5 |
| 11 | barn + manure storage | 30 | ND | 30 | 18 | C5 |
| 12 | barn + manure storage | 15 | ND | 30 | ND | |
| 13 | barn + manure storage | 30 | 3 | 30 | 10 | C5 |

* - odour character, based on descriptors used by the wastewater industry, where C5 represents an odour that is "Rotten/offensive" and belongs to the more general group, B3, which is "Natural Unpleasant"

** - Not Detected

b) Management - During the first four batches, manure was added and the material was turned four or five times in the first week. After that, manure was only added if the material appeared to be drying out somewhat. The channels were turned when it appeared that the material was drying out on the surface, or every five days or so. Typically, manure was added six to eight times and each channel was turned 11 to 13 times during Batches 1 to 4. The first quantity of manure applied was very dilute, with a dry matter content of only 0.60 %. Subsequent loads of manure had a higher dry matter content. The low dry matter content, however, meant that a much larger amount of liquid had to be dealt with in relation to the amount of N applied. From Batch 5 onward, manure was added three to five times, and the material was turned a maximum of five to seven times.

The management strategy that seems to work the best for straw, based on three years of running the composter, is as follows:

- a) the straw is turned and manure is applied in three passes on Day 1 (three passes does a better job of mixing the straw and manure);
- b) the material is turned and more manure is applied in two passes on Day 4;
- c) the material is turned and manure applied in one pass (or two if needed) on about Day 8;
- d) the material is removed on Day 14 and placed into a pile or windrow where it finishes composting and curing.

This process has worked well for most of the materials tested in the study. Materials that are fine and tend to pack more tightly usually need to be turned more often, as it is more difficult for air to move through the mass. The turning helps aerate the material.

Two quantities are especially important to farmers considering a composting system. The “**Manure per floor area**” represents the amount of manure per day that went into each channel. The amount of manure expressed as a function of time and compost channel area ranged from 3.2 to 9.7 L/day/m² during the first year of operation. During the second and third years, however, more emphasis was placed on maximizing throughput of the system. Considering that manure is only added during the first two weeks of the process, if compost is removed from the channels at two weeks, it has the effect of maximizing the amount of manure processed. As a result of using this strategy, rates as high as 31.9 L/day/m² (straw) and 39.0 L/day/m² (tree leaves) have been achieved. For reference, a feeder pig produces about 4 to 8 L of manure per day - after the addition of dilution liquid - requiring about 0.2 m² of composter floor area per feeder pig housing capacity.

The **ratio, by weight, of liquid manure to substrate** is also important. Farmers will want to maximize this number in order to minimize the amount of straw or other material that they must have available. The ratio ranged from 1.9:1 to 8.4:1 for wheat straw, and was lower for wood fibre (average 1.1:1), corn stover (average 3.1:1), leaves (average 1.7:1), corn cobs (average 2.6:1), and solid bedded beef manure (average 0.4:1). A design target of 5.0:1 is achievable, especially for straw. It appears that we are approaching maximum efficiency on straw with a value of 8.4, which involves applying manure to increase the moisture content of the compost in the channels to around 80%. This relies on high moisture losses during curing to bring the final moisture down closer to 60%. We experienced conditions that favoured this practice in the rather dry summer of 1999, with outdoor curing. In 2000, however, the wetter

conditions seemed to slow down the curing process. Covered curing piles would have been an advantage.

There were other differences between the substrates. The wood fibre needed to be turned more often than the other materials in order to keep it aerobic - the aeration air was not moving through the mass as easily. Also, because the wood fibre and corn cobs were more dense than the straw, the total loadings for the channels (carbon material and manure) were higher.

There was a considerable amount of shrink of material in the channels during the first few weeks of composting. One would expect straw, corn stalks and tree leaves to shrink, if only due to the lower density of the loose material, compared to wood chips. However, all materials were reduced in volume to less than half of the initial volume during the first two to four weeks of composting. A summary of volume reductions during composting is shown in Table 2. This is an important consideration in system design. The volumes of selected batches were measured after the curing period. These further reductions are also shown in Table 2. The volume of straw after about 10 weeks of composting/curing was only about 6% of the initial volume. Part of this is due to the increase in density and part is the result of the reduction in total mass as composting progresses. For the straw and corn stalks, the initial volume was measured after the turner had broken open the bales. The other materials tested did not give as large a reduction in volume, mainly because initial densities were higher - see Table 3.

Table 2 - Reductions in volume during composting (per batch)

| Carbon Source | Average Total Amount Carbon Added (m³) | Average Total Amount Manure Added (m³) | Average Total Amount Out of Channels (m³)* | Average Volume Change % | Average Volume after 10 weeks (m³) | Average Change from Initial Volume % |
|--------------------------|----------------------------------------------------------|----------------------------------------------------------|--------------------------------------------------------------|--------------------------------|------------------------------------------------------|---------------------------------------------|
| Straw @ 2 Weeks | 60.2 | 9.34 | 21.0 | - 65.2 | 4.0 | - 93.3 |
| Straw @ 4 Weeks | 65.0 | 8.93 | 16.4 | - 74.8 | 4.0 | - 93.8 |
| Corn Cobs | 58.0 | 20.40 | 18.4 | - 68.3 | 8.3 | - 85.7 |
| Wood Fibre | 41.7 | 10.36 | 22.9 | - 45.1 | NA | NA |
| Tree Leaves | 64.5 | 10.67 | 21.1 | - 67.2 | 18 | -72.1 |
| Corn Stalks | 60.0 | 9.36 | 20.2 | - 66.3 | NA | NA |
| Solid Beef Manure | 54.1 | 8.78 | 29.2 | - 46.0 | NA | NA |

* removed at about 4 to 6 weeks except straw, as noted

Table 2 is based on the assumption that the addition of liquid manure to the raw materials did not increase the total volume of material - only the total mass. The total volume (level full) of the channels 60.2 m³. Table 2 confirms that for most materials the channels were at least level full, but for the wood materials and for the solid beef manure, the channels were not filled completely. This is the only reference to solid beef manure in this report. It was used as a substrate because it was available on campus and because the ratio of straw to manure was relatively high. There was a fear initially that the total nitrogen from the beef manure and the swine manure may create an undesirably low C:N ratio, but this did not appear to be the case. In general, the material worked well.

Changes in density are summarized in Table 3. This does not include any material that had finished the curing process - only material as it came out of the channels. As expected, there was an increase in density for all of the carbon materials as a result of composting (and addition of the liquid swine manure).

Table 3 - Changes in density during composting

| Carbon Source | Average Density at start of composting (kg/m³) | Average Density when compost removed from composter * (kg/m³) | Average Increase in Density % |
|--------------------------|------------------------------------------------------------------|---------------------------------------------------------------------------------|--------------------------------------|
| Straw 2 Weeks | 197.5 | 336.3 | 170.3 |
| Straw 4 Weeks | 187.2 | 364.5 | 194.7 |
| Corn Cobs | 489.6 | 924.6 | 188.8 |
| Wood Fibre | 567.5 | 692.0 | 121.9 |
| Tree Leaves | 346.2 | 768.8 | 222.1 |
| Corn Stalks | 220.3 | 371.9 | 168.8 |
| Solid Beef Manure | 616.2 | 884.3 | 143.5 |

* removed at about 4 to 6 weeks except straw, as noted

During composting, the main losses to the environment are water vapour, carbon dioxide and heat. Losses of a variety of constituents were calculated and are shown in Table 4. This shows the percentage of each constituent remaining in the compost at the time the material was removed from the channels (i.e. at the 35-day stage, on average). It shows that just over 80.9%, on average, of total Nitrogen remained in the material at this stage. This represents better N retention than is typical for conventional manure systems.

Table 4 shows that during the first 35 days, about one half of total mass is lost and about one half of total carbon is lost. The ash content was measured, in order to allow for projections of losses during curing, where it is much less convenient to measure the mass of materials. The expectation is that the ash content remains constant throughout the entire composting process, so

everything else can be related to the total amount of ash present. For this to be true, the amount of ash remaining should be 100% - the table value is 104%. However, so far, this method has proved to be a relatively inaccurate way to estimate curing losses, so these values are not presented here. The most likely reason for the variability in ash amounts is the variability of ash contents in the samples of raw materials. Further analysis will be done to assess whether ash content when compost is removed from the channels is a better number to use for estimating compost properties after curing.

It is unclear why P and K numbers were so far from 100% - there are really no opportunities for these nutrients to be lost.

Table 4 - Average amounts of various compost constituents remaining after removal from compost channels - grouped by carbon material used in composting and expressed as a percentage of the total constituents available at the start of the process.

| Constituent | Straw | Corn Cobs | Corn Stalks | Wood Fibre | Leaves | Overall |
|----------------|-------|-----------|-------------|------------|--------|---------|
| Total Mass | 48.7% | 30.0% | 54.8% | 64.6% | 69.4% | 50.3% |
| Carbon | 47.5% | 91.8% | 68.6% | 53.6% | 54.1% | 52.1% |
| Organic Matter | 46.6% | 88.3% | 70.6% | 57.7% | 53.4% | 51.6% |
| Ash | 93.6% | 171% | 141% | 141% | 125% | 104% |
| Total N | 78.7% | 93.0% | 86.8% | 83.0% | 99.0% | 80.9% |
| Total P | 138% | 110% | 190% | 171% | 154% | 141% |
| Total K | 71.0% | 90.2% | 121% | 84.9% | 74.1% | 76.2% |
| Average # days | 32.1 | 51.0 | 44.3 | 41.7 | 33 | 35 |

Loss of mass for the compost created using straw is shown in Figure 3. This shows the wide variability from one batch to the next. Part of the reason for this is likely due to the experimental nature of the setup - a variety of management options were tried to develop the most efficient approach. Part of the reason is likely related to variability within the channels and difficulty in getting a truly representative sample at any point in time. A further reason for variability is that the moisture content at the time of sampling was different from sample to sample. They were all within a narrow range, but no attempt was made to normalize the values using a standard moisture content.

There is a statistically significant relationship between loss of mass and number of days ($p < .001$). Figure 3 includes a linear model showing this relationship. The equation for the best fitted line is:

$$\text{Loss of mass (\% of original)} = 37.0 + 0.50 (\text{Number of days})$$

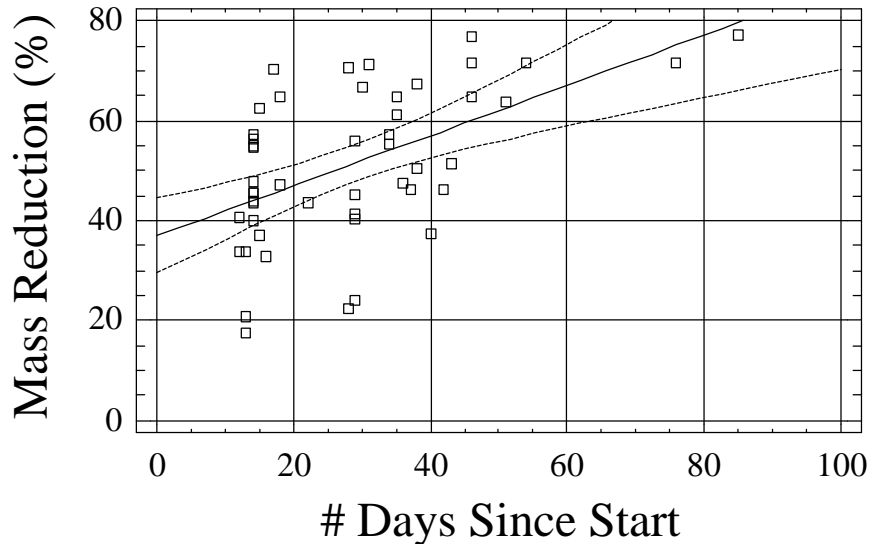


Figure 3 Loss of mass over time for various batches of compost created using straw and liquid swine manure - showing best fitted line (linear model) and 95% confidence limits

The 95% confidence limit of this line is also plotted. For this relationship, $r^2 = 29.0\%$. Figure 4 shows the same data but gives a logarithmic model of the relationship (and 95% confidence limits). For this model, $r^2 = 27.6.0\%$, but it still is likely a better representation of what is happening, at least near the start and end of the process. The equation of this line is:

$$\text{Loss of mass (\% of original)} = 3.58 + 14.9 \times \ln(\text{Number of days})$$

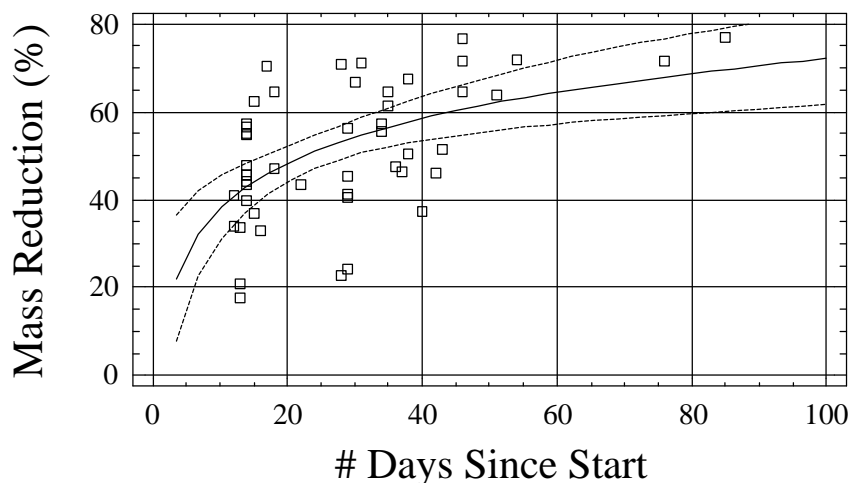


Figure 4 Loss of mass over time for various batches of compost created using straw and liquid swine manure - showing best fitted line (logarithmic model) and 95% confidence limits

An important issue for farmers is the total number of days to keep material in the composter. During the first several batches, the total time per batch was in the range of about four to six weeks. It became obvious that the part of the process requiring the most management was likely to be complete in less than four weeks. Several batches were run where the straw compost was removed from two channels at week two and combined in the third channel for the following two weeks (while new batches were started in the first two channels). This had the impact of increasing throughput by 50% and it also created a greater depth of material - which allowed for higher temperatures. The average numbers of days for compost in the channels, given in Table 4, is higher than is necessary, for two reasons - some of the early batches were left longer in order to more carefully monitor the process; and when modifications to equipment took place, compost was usually left in the channels.

The next modification to the management involved removing the material at week two and stacking it outside where it could finish composting/curing. This basically removed our ability to aerate and turn the compost, but the process appears to have had no detrimental effect. It has not created an odour problem. The material is still quite hot at the 2-week period, but composting appears to proceed in the outside piles. This has allowed an increase of 100% in throughput of manure compared to early batches. This practice has worked successfully for the past year, although the curing process slowed down during the winter of 2000/2001 to the point where most of the curing piles froze.

Normally, the C:N ratios should be in a range of about 15 to 25 for efficient composting. When it is higher, composting takes longer. When it is lower, there is often a loss of nitrogen to the air in the form of ammonia. There can also be an increase in odour at low C:N ratios. As we have learned how to run the system we have been able to keep the final C:N levels on the low end

of the desired range (see Table 5). We have not experienced the odours or N losses that might be expected with a low C:N ratio. C:N values typically start off high, and as manure is added (thus more N), the values drop.

The temperatures of the various batches were recorded. This temperature data revealed two things:

- a) The average temperatures were behaving as expected - rising to about 40 °C after one day, to 50 °C after 2 days and staying in the range of 55 to 65 °C for the next few weeks; and
- b) Temperatures within the channels varied from location to location, and from day to day, especially during the first week. Of the six thermocouples in each channel, at a given time, the temperatures could be spread out over a 20 degree range. The most likely reasons seem to be related to variations in moisture level, as it was difficult to be completely uniform with manure applications. These differences became less pronounced as the composting/mixing progressed. The system was quite responsive to additions of manure. If the temperature appeared to be dropping prematurely, addition of manure was all that was needed to restart the heating process. This rapid temperature response to fresh manure has been found on several occasions, and even when compost temperatures have dropped to near freezing (e.g. January, 1999).

At the start of the project, there was some fear that winter air temperatures would be so cold that it would be difficult to maintain the high temperatures needed in the compost. That has not been the case during three winter seasons. As a precaution, we dropped back our aeration schedule to prevent freezing the compost but found no problem in maintaining high temperatures. The key seemed to be related to additions of manure and frequency of turning - any time we needed to boost the temperature, we simply added manure. The temperature rose within 24 hours.

c) Nutrients - At regular intervals, composite samples of substrate, liquid manure, and composting material were gathered from each channel and sent to the Laboratory Services Division, University of Guelph. Measurements included: carbon, ammonium-N, total N, P, K, pH, ash and moisture content. Whenever possible (i.e. in most cases), sampling of the compost was done just after the turner had mixed the channel contents. Total amounts of substrate and liquid manure added, and total weights of compost coming out were measured.

Selected results of the nutrient analysis are given in Table 5. This shows concentrations of nutrients in the raw materials - liquid manure and carbon materials. The table represents average values of several samples. To give an appreciation of the variability between samples, the standard deviation is listed.

Most of the study has used wheat straw as the carbon source. This was stored on the site as big round bales. For part of the study, the bales were stored under cover, but for most of the time, the bales were uncovered. One load of demolition wood was tested. This consisted of previously-used wood building materials that had been ground into small chips. The high ash content of this material is likely a result of a higher than average amount of fine material, comprised mostly of dirt. The sawmill wood came from an area sawmill and consisted of waste wood from the manufacture of new lumber - these wood scraps were passed through a crusher.

Corn cobs came from area mills that were in the business of shelling dry cob corn. Most of the tree leaves came from the Town of Ridgetown, where the leaves were collected from the roadsides using a vacuum truck and brought to the site in bulk. The corn stalks consisted of big round bales and, like the straw bales, these were stored outside.

Two sources of liquid manure were used. For the initial trials, manure from the college swine herd was used. This manure was fairly dilute (average 1.38 % dry matter) compared to the industry in general. A second manure was used for part of the study to assess the impact of dry matter content on composting ease. This manure came from an area swine farm that used wet/dry feeders - thus resulting in drier manure (average 2.73 % dry matter).

The C:N ratio for each material is listed in the table. In general, the manure had a C:N in the range of 2.25 to 2.6. The materials used to supply carbon had much higher C:N ratios. Tree leaves had the lowest value - 40.2 and the wood materials had the highest values. With the exception of the manure, the material nutrient concentrations are within the ranges for the materials listed in NRAES (1992). Manure values in the NRAES handbook are for solid manure, so do not apply to this study.

Table 5 - Average nutrient content of raw materials (Standard Deviation listed in brackets)

| Material | NH₄-N mg/kg Dry weight | % N Dry weight | % P Dry weight | % K Dry weight | % Dry Matter Wet weight | % Ash Dry weight | pH | % C Dry weight | C:N ratio by weight |
|------------------------|------------------------------------------------------|-------------------------------|-------------------------------|-------------------------------|--------------------------------------------|---------------------------------|-----------------------|-------------------------------|----------------------------------------|
| wheat straw | 49.2 (25.6) | 0.49 (0.12) | 0.08 (0.03) | 1.40 (0.35) | 90.4 (2.9) | 6.04 (0.68) | 7.51 (0.71) | 43.9 (1.72) | 96.1 (27.8) |
| demolition wood | 12.6 (7.8) | 0.31 (0.04) | 0.03 (0.02) | 0.22 (0.11) | 64.7 (13.3) | 38.6 (3.8) | 7.68 (0.02) | 35.0 (1.8) | 116 (20.8) |
| sawmill wood | 25.6 (17.8) | 0.30 (0.09) | 0.03 (0.01) | 0.17 (0.05) | 67.4 (12.9) | 5.45 (1.5) | 6.55 (0.06) | 48.3 (0.2) | 177 (52) |
| corn cobs | 49.0 (6.8) | 0.49 (0.07) | 0.06 (0.01) | 1.61 (0.64) | 79.1 (0.16) | 3.55 (1.1) | 7.60 | 46.2 (0.75) | 96.3 (17.5) |
| tree leaves | 39.3 (15.8) | 1.15 (0.13) | 0.12 (0.01) | 0.83 (0.11) | 47.4 (11.4) | 17.8 (2.6) | 6.95 (0.55) | 45.5 (1.2) | 40.2 (5.5) |
| corn stalks | 19.3 | 0.6 | 0.11 | 0.6 | 72.5 | 11.3 | 7.0 | 43.4 | 71.5 |
| manure 1* | 77820 (36000) | 12.7 (3.3) | 2.31 (1.2) | 14.5 (4.2) | 1.38 (0.56) | 44.7 (9.1) | 7.10 (1.5) | 31.2 (5.2) | 2.60 (0.7) |
| manure 2** | 70000 (49900) | 17.3 (4.9) | 3.44 (0.51) | 11.8 (3.6) | 2.73 (1.3) | 38.6 (5.2) | 7.64 (0.2) | 36.2 (3.3) | 2.27 (0.64) |

* manure 1 from college swine herd

** manure 2 from local farmer with wet dry feeders

Concentration values are reported on a “dry weight” basis. For some of the parameters, the end user usually sees the result on a “wet weight (or “as is”)” basis. Dry weight values are

given to allow for easier comparison of materials with different moisture contents. For the Manure 2 samples, the average Total N is shown as 17.3 % (dry weight basis). This is equivalent to 0.42 % N on a wet weight basis (for the moisture content of the samples tested).

Average nutrient concentrations of the compost are shown in Table 6. This table includes only the results for compost that was at least 10 weeks old - in other words, very close to being mature compost, if not already stabilized. There is not nearly the same variability between composted materials as is seen in the previous table of raw materials.

In raw manure, most of the nitrogen is typically in the ammonium form (i.e. NH₄-N). This is relatively volatile - while it is readily available to plants, it is also easily lost to the air if not covered with soil immediately after spreading. It also can cause serious environmental problems if it enters surface water. As a nutrient source, compost will therefore provide a “slow release” form of nitrogen. When considering total N losses from a manure system, there is a potential for lower losses with composting, since many current systems have high losses of ammonia-N to the air (during storage, during spreading, and before incorporation).

Table 6 - Average nutrient content of composted materials (Standard Deviation listed in brackets) at least 10 weeks after start of composting

| Material | NH₄-N mg/kg Dry weight | % N Dry weight | % P Dry weight | % K Dry weight | % Dry Matter Wet weight | % Ash Dry weight | pH | % C Dry weight | C:N ratio by weight |
|-----------------------------|------------------------------------------------------|-------------------------------|-------------------------------|-------------------------------|--------------------------------------------|---------------------------------|-----------------------|-------------------------------|----------------------------------------|
| straw (manure 1) | 1035 (1880) | 2.86 (0.75) | 1.45 (0.56) | 3.64 (1.25) | 29.6 (12.5) | 34.9 (8.7) | 7.9 (0.45) | 31.8 (4.6) | 11.5 (3.0) |
| straw (manure 2) | 367 (152) | 3.20 (0.45) | 1.59 (0.24) | 4.30 (1.04) | 40.9 (17.9) | 31.8 (1.3) | 8.1 (0.14) | 33.8 (2.0) | 10.7 (1.2) |
| corn cobs | 197.5 (222) | 2.34 (0.31) | 0.86 (0.16) | 2.63 (1.11) | 43.9 (7.0) | 29.5 (14.9) | 7.62 (0.7) | 31.9 (4.6) | 9.5 (7.0) |
| demolition wood | 136.1 (168) | 0.80 (0.28) | 0.33 (0.11) | 0.74 (0.17) | 46.9 (3.6) | 41.5 (6.7) | 7.27 (0.25) | 32.4 (2.9) | 29.4 (28) |
| sawmill wood | 157.3 (58.4) | 1.27 (0.22) | 0.61 (0.20) | 0.79 (0.16) | 37.1 (8.9) | 32.7 (0.55) | 7.8 (0.8) | 34.3 (5.5) | 27.1 (0.5) |
| tree leaves | 407.2 (396) | 2.26 (0.18) | 0.78 (0.07) | 1.61 (0.04) | 30.4 (1.1) | 41.3 (2.3) | 8.3 (0.2) | 34.0 (0.65) | 15.1 (0.9) |
| corn stalks | 208.8 (236) | 2.24 (0.28) | 1.23 (0.30) | 2.45 (0.39) | 33.2 (18.2) | 28.2 (4.7) | 8.0 (0.1) | 36.4 (4.1) | 16.7 (3.6) |

The nutrients in the compost are more concentrated than in the raw materials, because so much moisture and carbon have been given off during the process. This needs to be considered for farmers creating nutrient management plans for their farms. The higher concentration of nutrients affects spreading rates and makes transport to distant fields a more viable option - currently, travel time represents a significant cost of spreading for many farmers.

Though not listed in the tables, the concentrations of organic and inorganic C were

measured. At least 93 % of the total carbon was in the organic form. The lowest value, for all the samples used in the test, was 93 %, for the demolition wood chips. Most materials were 98 or 99 % organic carbon (as a percentage of total carbon).

Table 7 gives nutrient values for three composts from other sources and shows a comparison to one of the Ridgetown College compost types. This gives an idea of relative nutrient levels. Only one sample from each of the “outside” sources was analyzed. The “retail compost” was material being sold as compost through a local garden centre. The turkey litter compost was produced during the past year on an Ontario facility. The hog carcass compost was several years old and appeared to have lost a significant amount of organic material from just sitting un-used for so long - presumably accounting for the higher ash content. The Ridgetown compost shown for comparison (i.e. using straw and manure 2) had a higher concentration of N, P, and K than the three other types of compost.

Table 7 - Average nutrient content of a variety of composts - compared with a manure/straw compost from Ridgetown College

| Material | NH ₄ -N mg/kg Dry weight | % N Dry weight | % P Dry weight | % K Dry weight | % Dry Matter Wet weight | % Ash Dry weight | pH | % C Dry weight | C:N ratio by weight |
|----------------------------------------|----------------------------------------------|----------------------|----------------------|----------------------|----------------------------------|------------------------|-----|----------------------|------------------------------|
| straw (manure 2) (Ridgetown) | 367 | 3.20 | 1.59 | 4.30 | 40.9 | 31.8 | 8.1 | 33.8 | 10.7 |
| retail compost (garden centre) | 16.5 | 1.7 | 0.66 | 1.8 | 57.2 | 62.2 | 7.2 | 21.3 | 12.2 |
| composted turkey litter | 6356 | 2.4 | 0.63 | 2.1 | 44.8 | 41.3 | 8.8 | 30.4 | 12.7 |
| hog carcass compost (well- aged) | 500 | 1.0 | 0.31 | 1.5 | 65.1 | 78.1 | 9.0 | 13.3 | 13.7 |

d) Metals - The concentrations of various metals (also called: heavy metals, toxic metals) in manure has not traditionally been an issue. It is a concern with sewage biosolids spread onto farmland, and standards are enforced for metals application to land. Standards also exist for organic material marketed as “compost”. During the latter portion of the study, selected samples were analyzed for a variety of metals, in addition to the normal suite of nutrients. The same sampling procedures were used. The samples were tested at the Laboratory Services Division, University of Guelph. Metals tested were: Arsenic, Cadmium, Cobalt, Chromium, Copper, Mercury, Molybdenum, Nickel, Lead, Selenium, and Zinc. When the data was examined, many concentrations were reported as being below the detection limit for the test. Rather than enter a zero for these values, the actual concentration was assumed to be one half of the lower detection limit. Mean values were calculated based on this assumption

Results of this testing are shown in Table 8. For comparison, the current Ontario compost quality standards are included. The background levels of copper, molybdenum and zinc were higher than this standard for liquid manure (based on only two samples). However, once composting is completed (and mixing with straw or leaves), the levels of copper and zinc were at acceptable levels. The concentration of molybdenum in the compost made with straw and liquid manure is the only quantity that does not meet the Ontario compost guidelines (based on the average of 10 compost samples). There is a Canadian standard for compost, and it tends to have the same or slightly higher limits for the various elements. The Canadian type A standard for Molybdenum is 5 mg/kg and the type B standard is 20 mg/kg.

Table 8 Mean concentrations (dry matter basis) of trace elements in raw materials and finished compost

| Trace Elements | Lower Detection Limit* (mg/kg) | Ontario Compost Standard (mg/kg) | Straw (mg/kg) | Tree leaves (mg/kg) | Swine manure (mg/kg) | Straw compost > 70 days (mg/kg) | Leaf compost > 70 days (mg/kg) |
|-----------------|--------------------------------|----------------------------------|---------------|---------------------|----------------------|---------------------------------|--------------------------------|
| Arsenic (As) | 1 | 10 | 0.5 | 0.8 | 1.3 | 0.9 | 1.7 |
| Cadmium (Cd) | 0.5 | 3 | 0.3 | 0.3 | 0.6 | 0.3 | 0.3 |
| Cobalt (Co) | 2.5 | 25 | 1.3 | 1.3 | 2 | 1.1 | 1 |
| Chromium (Cr) | 5 | 50 | 2.5 | 4.9 | 7.3 | 5.2 | 18 |
| Copper (Cu) | 5 | 60 | 2.5 | 8.1 | 153 | 35.9 | 22.8 |
| Mercury (Hg) | 0.01 | 0.15 | 0.01 | 0.05 | 2 | 0.02 | 0.02 |
| Molybdenum (Mo) | 2.5 or 1.0 | 2 | 0.6 | 1.3 | 12.5 | 4.2 | 1.1 |
| Nickel (Ni) | 5 | 60 | 2.5 | 4.3 | 6.5 | 3.2 | 11 |
| Lead (Pb) | 5 | 150 | 2.5 | 15.3 | 6.2 | 10.1 | 29 |
| Selenium (Se) | 0.01 | 2 | 0.8 | 0.4 | 1.8 | 0.7 | 0.7 |
| Zinc (Zn) | 25 | 500 | 12.5 | 61.3 | 921 | 224 | 131 |
| Number Samples | | | 2 | 7 | 2 | 10 | 4 |

* - In cases where the concentration was less than the lower detection limit, a value representing one half the lower detection limit was used to calculate the average values (this was a frequent occurrence)

What this analysis shows us is that farmers who choose to market the compost they produce will need to be aware of the compost quality standards in their jurisdiction. They will

need to test for metals. Assuming, the main source of these metals is feed supplements, they may need to look at ways to adjust their feed formulations to reduce metals in the manure. The specific metals that need attention (at least in swine rations) appear to be copper, zinc and molybdenum.

e) Curing - An important aspect of the process is the curing of the compost after removal from the channels. It can undergo further breakdown of organic matter if allowed to “cure”. The material taken out of the channels at four weeks (for example) still showed signs that much of the substrate material had not completely broken down. By sitting in a pile for a up to two additional months, most of the initial structure was eliminated, leaving a “finished” compost material - especially for straw, tree leaves and corn cobs.

For part of the study, the curing piles were located on a concrete pad. Alternatively, some compost was piled on the soil. A third strategy involved piling the curing compost in windrows, on soil. For a few batches early in the study, the piles on concrete were covered with a tarpaulin, to keep rainfall out, though it was not clear how important it was to cover the material. Further breakdown occurs, so there is a further reduction in total mass - and therefore a further concentration of nutrients. Covering the piles with tarps tended to retain moisture when curing which seemed to help with the breakdown of the straw particles. Some method of leachate recovery should be in place if an uncovered storage is used, though we did no measurements to verify the volume or constituents of any runoff.

No odours were associated with the curing in our study.

f) Bacteria survival - Raw manure contains high populations of bacteria and certain strains are pathogenic. While most strains of *E. coli* are not pathogenic, it is quite often used as an “indicator” bacteria. It has similar survival properties to other, more harmful organisms, and its presence is associated with the presence of other “fecal” organisms. Other organisms often tracked in compost include fecal streptococcus and salmonella.

Bacteria survival was measured in two separate studies. The first, in 1999, was intended to give a quick look at numbers of organisms. The second, in 2000, was set up to confirm initial results and to improve the sampling protocol to minimize the potential for contamination of samples.

1999 study: The 1999 testing ran from May to August. In total, 64 samples were analysed, including fresh manure, partly composted material and cured (finished) compost. Raw liquid manure samples were collected in sanitised plastic bottles, after pit agitation on four occasions over the test period. Compost samples were collected at various stages, to track die-off of bacteria throughout the process. As many as six samples (and as few as one sample) were collected per individual batch of compost. These samples were stored in sterile plastic bags.

Samples were delivered to GAP EnviroMicrobial Services, London, for analysis. Samples were cooled and delivered so that analysis could begin within 24 hours of collection. Each sample was tested for *E. coli* and for *Fecal streptococcus* using the Most Probable Number technique.

Geometric mean concentrations of bacteria in raw manure were: 1.5×10^6 organisms per 100 mL for *E. coli*, and 2.7×10^6 for *Fecal streptococcus*. Numbers were greatly reduced after time in the compost channels, and for the most part, after curing, organisms were not detected

(the lower detection limit for most samples was 200 organisms/100 mL). The values after curing are the most important, as fresh manure was added throughout the time in the channels (typically during the first eight days). Of the 16 different batches of compost represented in the testing, 14 showed no detectable levels of either organism in the cured compost. The two positive tests (only at low concentrations) may have been the result of contamination of the compost due to the manner that the compost was moved (using a tractor and front-end loader) and sampled (using a fork). At the time, we did not realize how sensitive compost could be to re-infection with various organisms, and unfortunately, not enough care was taken to minimize the potential for re-infection. In general, the level of bacteria die-off was very good, and at about two weeks after manure was applied, the bacteria counts were below detection limits.

2000 study: For testing of *E. coli*, raw liquid manure samples were collected in sanitised plastic bottles, after pit agitation. The sampler was thoroughly cleaned before sampling. Samples were collected from the “seed” compost used to restart the new batch of, using fresh disposable vinyl gloves grabbing individual small samples combined to make a composite sample. No pails were used for mixing - collection was straight into the sterile bags. The person collecting the samples took caution not to walk over material that would be collected. After the final liquid manure application (about day eight) two samples from each channel were collected, after turning. Two samples per channel from the finished compost were collected prior to removal. In addition, samples were collected from areas known to have reached high temperatures and from areas known to have had lower temperatures.

When the compost was removed, all three channels were windrowed together, for curing. Samples were taken from the windrows at approximately weeks four, six, eight, and 12. The total number of samples collected was 93, between August 3, 2000 and February 1, 2001.

Salmonella was sampled in a similar way but on a reduced schedule (37 samples were analysed). Samples were collected at three stages: from raw manure, when the compost was removed from the channels and when the compost was fully cured, in about 12 weeks.

Sample analysis was performed at the Laboratory Services Division, University of Guelph. Samples were delivered to the lab on the day they were collected. For *E. coli*, the Most Probable Number technique was used (Analytical Method MID-104) and for *salmonella*, a presence/absence test was performed.

The lower detection limit for *E. coli* was 50 cfu/g (colony forming units per gram), for part of the test, and 3 cfu/g for most of the test period. The highest test result was 140,000 cfu/g. It was apparent that the survival rate of *E. coli* was very low, and that at the 20 to 30 day stage in the process, the levels were down to the lower detection limit. These non-detects persisted throughout the remaining curing period, so that from the 100 day period and onward no organisms were detected (the lab reported a value of 4 cfu/g for two of these samples, and the lower detection level was 3 - it is unclear what significance to put on these low values).

Of the 37 samples tested for salmonella, seven tested positive. Four of these corresponded to significant levels of *E. coli* and the other three were in compost that was just five days into the process (therefore, at a time when fresh manure was still being applied).

Based on these tests, during 1999, 2000, and into 2001, it appears safe to conclude that composting is effective at killing *E. coli*, *salmonella*, and *fecal streptococcus*. The compost

operator must be careful in the handling of curing and finished compost to avoid re-introducing bacteria that may then re-establish a population in the warm, moist, rich compost.

g) Weed seed survival - We have tested the finished compost for the presence of weed seeds in a greenhouse study in which a number of finished composts were compared to sterilized soil and field soil. The compost was mixed with sterilized soil in a three to one mix to dilute the compost to a level that would allow germination. The composting process effectively killed virtually all weed seeds. There is, however, a similar concern to that mentioned for bacteria in compost. It is very easy to introduce weed seeds to compost during and after the curing process - compost must be stored in areas that prevent re-contamination. This was not a concern in the greenhouse trials, but weeds have grown up in areas surrounding the curing piles - weed control in these areas is important.

h) Greenhouse gas production - In the fall of 2000, a study was started to measure greenhouse gas emissions from the composter. Objectives of this study are:

- To quantify the emission of methane from a composting operation.
- To quantify the emission of nitrous oxide from a composting operation.
- To compare the emission of these two greenhouse gases (in CO₂ equivalents) during the composting process to the emissions from liquid swine manure in storage (non-composted, anaerobic).

This part of the project is being supervised by Dr. Claudia Wagner-Riddle, Department of Land Resource Science. Andrew Thompson, M.Sc. candidate is assisting with data collection and analysis.

The site measurements were taken between September 13 and October 6 2000, at the Ridgetown College compost facility. On September 12, 2000, the production of compost began, by filling the compost channels with wheat straw. Large round straw bales were used, eight bales per channel for a total of 5460 kg.

Manure was first mixed with straw on September 13, for a total application of 9,754 L to all three channels. The second manure application was September 15, where 10,607 L was applied to the three channels. On September 19 the compost was again mixed and received 6,096 L of manure.

After the last application of manure the compost was left for one week, leaving the material ready for curing. To mimic the curing process, where the compost is piled or windrowed, on September 26 the compost from all three channels was combined into the centre channel. Due to the high temperatures and dryness of the combined compost it was found to be necessary to apply additional manure. The compost was turned while receiving 6,096 L of manure on September 26. The compost was then left to cure until it was noticed, from increased odours, that the compost had started to become partially anaerobic. In an attempt to alleviate this problem, on October 4, the compost was turned again. The compost then continued to cure until October 6, when the measurements were concluded.

Fluxes of N₂O and CH₄ from the composting system were measured using a mass balance technique in an open 'megachamber', calculated as follows:

$$F = (\dot{A}C \times FR) / A \quad (1)$$

where $\dot{A}C$ is the difference between the quantity of the gases in the air entering and leaving the chamber, FR is the flow rate of air through the chamber and A is the surface area of the compost. The building housing the composting system, approximately airtight, was used as the chamber.

Gas concentrations were measured using Tuneable Diode Laser Trace Gas Analyzers (TDLTGA) (Model 100, Campbell Scientific, Logan, Utah) designed to measure the concentrations of N_2O and CH_4 . Four air samples were used to measure the concentrations in the air entering and leaving the chamber, for a total of eight samples. The samples were taken through intakes consisting of a 0.45 μm disposable filter (ACRO 50, PTFE Membrane Filter, Gelman Sciences, Ann Arbor, MI), attached to a needle valve (Nupro Company, Willoughby, OH) used to adjust the flow rates to 1.0 Lpm. The intakes were connected to sampling tubing (polyethylene, 3.2 mm i.d., 6.4 mm o.d.) which carried the air samples to the TDLTGA's, housed in a modified camping trailer.

The air samples were drawn through the TDLTGA's by a vacuum pump (RA 0021, Busch, Virginia Beach, VA), passing through a valve manifold (Campbell Scientific, Logan, Utah) which allowed for switching between the different samples and analyzers. The samples were then passed through two dryers (Perma Pure, Toms River, NJ), one set for each analyzer, to remove water vapour before the air reached the TDLTGA's. The samples not going to the analyzers were passed through an exhaust manifold and exhausted.

The software controlling the TDLTGA's utilized a master/slave option, which enabled the N_2O TDLTGA computer to control the switching between sample sites and analyzers in the valve manifold, and collect the data from the CH_4 TDLTGA computer. Concentrations of N_2O and CH_4 in the samples were continually recorded, with gaps in the data arising from power-outs and a period between 10:36 and 12:00, September 26, when the combining of the compost into one channel required that the chamber be opened. Measurements of concentrations cycled between the eight intakes, examining each site for 25 seconds. The concentration data were then averaged over 10 minutes, and saved on the computer housing the software.

The laser (s/n 6169-03, Laser Photonics, Wilmington, MA) used by the N_2O system was housed in a liquid nitrogen cooled dewar (s/n 93-2156, Laser Photonics, Wilmington, MA), and operated at a current of 388.4 mA, and a temperature of 83.0 K. The CH_4 laser (s/n 444-HV-1-82, Laser Components, Olching, Germany), also housed in a liquid nitrogen cooled dewar (s/n 90-2264, Laser Photonics, Wilmington, MA), operated at a current of 388.3 mA, and a temperature of 93.3 K. The system of both TDLTGA's ran a pressure of 45 mb.

Using the building housing the composting system as the physical chamber, two large barn fans, 112 cm, (s/n V-3207, Model 6-91, electric (1.5 Hp), Wickham, Johnson, QB), were used to provide air flow, one fan to draw air into the chamber and the other to expel air. Straw bales were used to fill the gaps around the fans, to minimize air leaks.

To calculate the air flow through the chamber, both the volume of the chamber and the air flow of the fan must be known. The volume of the building that houses the composting facilities (12.2m wide, 24.4m long, with a solid 1m tall wall on top of which is a semi-circular dome) was calculated to be 1723.84m³. The flow rate of the barn fans was determined by a wind speed profile with a hotwire anemometer (Linear Air Meter, Model LAM-5K, Hastings) after the

construction of a 1.5m column over the end of the fans, done to minimize turbulence. Only the flow rate of the fan drawing air into the chamber was calculated as windy conditions prevented the construction of the column on the fan expelling the air. It was assumed that the fans produced a similar wind speed profile, with an average wind speed of 4.03 m/s, equaling a flow rate of 3.98 m³/sec.

In order to test the accuracy of the flow rate calculation a 1.06% nitrous oxide tracer gas was released at the air intake fan of the chamber at a rate of 15 Lpm. The concentration difference between the incoming air (excluding the released nitrous oxide) and the air leaving the chamber was determined with the TDLTGA. Knowing the flow rate and concentration of the tracer gas, and the concentration gradient in the chamber it was possible to determine the flow rate of the chamber, using the following equation:

$$FR(\text{tracer}) \times C(\text{tracer}) = FR(\text{chamber}) \times \Delta C(\text{chamber}) \quad (2)$$

The concentration difference of the nitrous oxide in the chamber, after the release of the tracer, was found to be 62.7 ppb giving a flow rate of 253,600 Lpm or 4.23 m³/sec. This indicates that there is a 6.28% discrepancy in the flow rate determination between the tracer method and the airflow of the fans coupled with the volume of the chamber.

Assuming an average static pressure of 50 mm, the additional air supplied to the chamber from aeration of the compost was found to increase the flow rate through the chamber by 2 to 20%, depending upon the temperature of the compost. This would result in an underestimation of the emissions fluxes.

Early estimates: Total overall emissions were 748.070 g of CH₄ / m² (full composting period, 22.67 days). Total overall emissions were 5.666 e+009 ng of N₂O/ m² (full composting period, 22.67 days). Results of the 2000 trials have not been fully analyzed.

i) Economic analysis - Only a limited amount could be done on an economic analysis using the Ridgetown College prototype compost system. An on-farm setup has been built, at the farm of Tom Fritz, Chepstow. Information from the installation and operation of this facility is needed to give realistic data about a typical farm. This phase of the project has now been started. Because of delays in startup at the Fritz farm, most of the necessary details are not yet available.

A spreadsheet is being constructed which will compare different swine production systems and the economic viability of on-farm composting units for each system. Each scenario includes the cost of the composting unit as well as the storage building used for curing the compost. The size of the unit is dependent on the type and size of the swine production system.

A 250 sow farrow to finish unit, 2,500 head nursery, 600 sow early wean unit and a 1,000 head finishing barn are being analyzed. The initial investment in the unit as well as other on-going costs including labour, carbon source, interest, utilities, fuel and depreciation will be assessed on each operation. Revenue from the sale of the compost will be used to help offset the expenses.

This analysis will also assess different carbon sources i.e. straw, corn stover, leaves and the costs/benefits associated with using each of them from an economic point of view.

An attempt will be made to determine whether it is more cost effective to buy land for manure disposal or to purchase a composting unit. Land values are very high in certain areas of Ontario and a comparison of land purchase versus composter purchase will be explored. Other factors to be explored include the hydro installation and the capital cost of each unit which are critical in the analysis.

The **expectation**, based on Ridgetown College results, may be summarized as follows:

- the cost to obtain a source of carbon material will be critical to the profitability of composting - for example, if a farmer has to purchase straw, the cost will be higher than if a material can be delivered to the site at little or no cost
- if the composter is built as part of a new installation, part of the extra cost may be offset with savings on liquid manure storage capacity
- if the farmer is able to sell the compost, not only will this allow for exporting of nutrients from the farm (desirable by some) but it will generate income that could turn into a profit centre on the farm (much different from current manure systems)
- there will be a certain economy of scale, where large operations will have an easier time justifying the installation costs - the current analysis hopes to show this relationship

Agronomic Trials

Several attempts have been made to measure the value of compost as a soil amendment and/or fertility source.

Oxford Soil & Crop Field Tests - 1999 - In 1999, Christine Brown, Ontario Ministry of Agriculture, Food and Rural Affairs, coordinated a study with the Oxford Soil and Crop Improvement Association. Its aim was to evaluate the availability of nutrients (especially nitrogen) from manure and compost and compare these to fertilizer nitrogen availability. Compost from Ridgetown College was used at the Andrew Brown farm. The treatments were: compost + N fertilizer, compost with no fertilizer, and no compost with no fertilizer. Corn was grown, and the yield was measured. Soil N tests were done over the growing period. There was very little difference in yield among the treatments. Unfortunately, background soil nitrogen levels were fairly high - this field had red clover plow-down in 1998 and received dairy manure in 1997. Even the plot that received no additional fertility (from compost or inorganic fertilizer) had yields in line with the fertilized plots. There was no yield advantage involved with adding the inorganic fertilizer.

Agriculture and Agri-Food Canada - 1999, 2000, 2001 - A study to measure the impacts on soil quality, corn yield, and emissions of N₂O (during the growing season) was carried out by Craig Drury and others at the Greenhouse and Processing Crops Research Centre, Harrow. Compost from Ridgetown College, food waste compost, and yard waste compost were used. A final report is not yet available for this project. The soil type was Brookston clay. The 1999

growing season was very dry (about ½ the normal precipitation), which had a negative effect on yields. The compost from Ridgetown College resulted in emissions of 5.35 kg/ha of N₂O-N, the highest value of the three composts. At the application rate of 75 dry t/ha, this compost had the highest corn yield of 5.42 t/ha, compared to the other composts.

A separate study was started in 2000 that will give information about crop yield and nutrient leaching potential. No results are available on this study so far.

Ridgetown Test Plots - 2000 - Crop growth trials were carried out by Doug Young at Ridgetown in 2000 to assess the merits of using compost as a fertility source for corn production. The following treatments were examined:

- No manure or compost
- Compost applied in the fall at 550 kg/plot
- Compost applied in the fall at 275 kg/plot
- Liquid swine manure applied in fall at 600 gal/plot
- Liquid swine manure applied in fall at 300 gal/plot
- Compost applied in the spring at 550 kg/plot
- Compost applied in the spring at 275 kg/plot
- Liquid swine manure applied in spring at 600 gal/plot
- Liquid swine manure applied in spring at 300 gal/plot

Each plot was split into the following N application rates (additional N in the form listed):

- 0 kg N/ha
- 60 kg N/ha applied Sidedress as 28% UAN solution
- 120 kg N/ha applied Sidedress as 28% UAN solution
- 180 kg N/ha applied Sidedress as 28% UAN solution
- 240 kg N/ha applied Sidedress as 28% UAN solution

Four reps were used and each plot was approximately 6 m by 30 m. Compost and manure were applied in the fall of 1999 and worked into the soil.

There were no significant differences in plant population for any of the treatments.

There were significant differences in silking dates in corn. The 0 kg N/ha nitrogen rate had significantly later silking date than the 120 kg N/ha and 240 kg N/ha rates. There was an approximate delay in silking of .9 days for the 0 kg N/ha rate compared to the other two. The delay in silking carried through to harvest resulting in increased grain moisture contents at harvest. The 120 kg N/ha rate had a significantly lower grain moisture content than the 180 kg N/ha and 0 kg N/ha rates. The 0 kg N/ha rate had significantly higher grain moisture contents than all other treatments.

There was a significant interaction between soil treatment and nitrogen rate for grain moisture content. In general, grain moisture contents decreased with increasing nitrogen rates for the various compost or manure treatments. However, the fall applied manure treatment @ 300 gal/plot grain moistures increased with added nitrogen. Grain moisture contents of the spring applied compost and spring applied manure at the high rate did not change with increased

nitrogen rates. This may be because of increased nitrogen availability from the composts and manures. More nitrogen from the composts and manures would have masked any effect from the added N.

Grain yields were not significantly affected by compost or manure treatment. There was a main effect of N on corn yield. The 0 kg N/ha treatment was significantly lower-yielding than all the other treatments. The 60 kg N/ha treatment was significantly lower yielding than the three higher nitrogen rates. The 120, 180 and 240 kg N/ha treatment corn yields were not significantly different from each other.

There was a significant interaction between compost and manure treatment and nitrogen rate. In general, yields increased with increasing nitrogen rates, except for the fall manure application at the high rate. With this treatment, as the amount of nitrogen applied increased, the yield decreased. This could be a result of high levels of nitrogen in the soil creating toxic conditions, reducing crop yield.

This study should not be considered to be a comprehensive picture of the impact of compost nutrients on crop production. There were sources of variability in the plot area that could not be avoided - for example: a windbreak along one side, recent additions of manure to the site, tile drainage running along the plot instead of across the plot, and the recent plow-down of alfalfa at the site. The study was set up well, and should be a model for other future studies to expand on these results.

Ridgetown Turf Trial - 2001 - A study on the use of compost on turf grasses will be carried out in 2001 at Ridgetown. Of special interest will be prevalence or possible suppression of turf diseases when compost is used.

Technology Transfer

Technology transfer activities for this project have taken a variety of forms, some already mentioned, summarized below:

- Open house - Aug. 1998 - over 200 people - farmers, municipal officials, press
- Press coverage - newspapers, farm press, radio
- Other print media - BioCycle magazine (very important publication for compost technology)
- Video - about 70 circulated
- Student activities - course lab for the "Farm Structures and Environment" course
- Visitors - a) groups - Summerfest tours, municipal councils (recently Middlesex), Stewardship councils from Kent and Lambton, the Huron Surface Water Coalition, Agri-Development Kent, OFA environmental committee, Ontario Pork, Huron Pork Producers, 3 groups from China, a group from Denmark
b) individuals - farmers, visitors (ag minister from Netherlands), + several from other provinces (Manitoba) or countries

- total visitors over 3 year period including open house + students = about 900 + many phone calls
- Presentations - a) scientific community - CSAE, Compost Council of Canada, (ASAE, NABEC upcoming)
 - b) farm groups - Swine Research Update (1999), Southwest Pork Congress (2001)
 - c) other environmental groups - Tallgrass Prairie, North Carolina State University, Stewardship Kent, Americana (recent international environmental conference in Montreal)
 - d) other - seminar to staff, presentation at college “applicant tour day”
- Computer program - design aid - may incorporate into Manure & Nutrient Mgt Suite (MCLONE + NMAN)
- internet - web page report for download

Future Directions

This project has achieved the goals originally set. As the project progressed, however, a few new issues came to light and some of these have been reported. Some of these have been started and are not yet finished.

- Measuring the impact of composting on greenhouse gas production is one of these issues. This project component is now partially complete and a report will be prepared by early 2002.
- Paper sludge is a waste product of the paper recycling industry. It is high in carbon and low in most other constituents. It may be a useful product for farmers, as it may be shipped to the farm on demand at little or no cost to the farmer. We are currently testing some of this material to assess its suitability as a carbon source for composting.
- Testing of an on-farm system is needed and is currently underway. This will provide confirmation of the design numbers from the Ridgetown College installation. More importantly, it will provide valuable information on labour and costs associated with installation of a commercial unit on a working swine farm.
- Additional evaluation is underway to measure N mineralization rates of compost used as a crop nutrient source.
- Testing will be carried out this year using compost on turf to assess its ability to prevent diseases.
- More analysis of the “conservation of ash” data will be carried out to assess the usefulness of this technique in estimating compost properties. A slightly different approach will be tested. This technique has been used by others and offers certain advantages. Once the density of cured compost is known, total mass remaining + losses may be calculated without having to weigh the material.
- A computer program has been created to aid in sizing of new compost systems. It needs only a few updates based on information in this report before it can be used for farm system designs.

- Additional measurements will be carried out in 2001 to assess the odour potential of compost systems. A discussion of atmospheric stability class will be used in the comparison of odours from traditional systems.
- Suitability of compost as a potting soil amendment will be assessed in a greenhouse trial. This has implications for marketing the finished compost.
- A separate greenhouse study is underway to assess the use of compost as a component of a growing medium for starting trees and shrubs.

Conclusions

1. With monitoring of the C:N ratio, moisture level and aeration level, we have had excellent success in controlling odours from liquid pig manure.
2. The ratio, by weight, of liquid manure to substrate ranged from 1.9:1 to 8.4:1 for straw, and was lower for wood fibre (average 1.1:1), corn stalks (average 3.1:1), leaves (average 1.7:1), and corn cobs (average 2.6:1). A design target of 5.0:1 should be achievable for straw.
3. The amount of manure processed, expressed as a function of time and compost channel area, was as high as 31.9 L/day/m² using straw and 39.0 L/day/m² using leaves (based on leaving material in the channels for only two weeks).
4. The compost should cure for a period of at least two months after removal from the composter. This will allow it to break down to the point where it can be marketed (i.e. off-farm uses).
5. Total losses of Nitrogen during the first five weeks of composting (i.e. the most active stage) averaged 19% (average of all samples - for all materials).
6. Moisture contents as high as 80% (at two weeks into the process) do not adversely affect the composting process.
7. The range of C:N ratios in compost at 10 weeks or greater into the process was between 9.5 and 29.4, depending on the material used as a carbon source. Straw compost had a C:N ratio of about 11. Ratios as low as 9.5 (using corn cobs) do not adversely affect the composting process.
8. Concentrations of molybdenum exceeded the Ontario compost standard in compost made using pig manure and straw. The main source was the manure. Levels of copper and zinc were acceptable in the compost but were also high in the liquid swine manure. This must be considered in the context of marketing the compost, and measures may be needed to reduce levels in animal diets or to dilute levels in the compost.

9. The composting process was very effective at killing pathogenic organisms (represented by *E. coli*, *salmonella*, and *fecal streptococcus*) and weed seeds. There is a danger of re-infection if care is not taken in handling the curing and finished compost.
10. Curing is an essential part of composting. This process continues the organic matter breakdown, though at lower temperatures. It generally does not need much management for the 10 to 14 weeks of curing (assuming two weeks in the channels to start).
11. Compost is a useful source of nutrients for crop growth.

Acknowledgements

In addition to the Stewardship Fund (OMAFRA/OSCIA), this project has received funding from several sources, including Agricultural Adaptation Council, Industrial Research Assistance Program, Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), Kent County Pork Producers, Ontario Pork, Stewardship Kent, Agri-Development Kent, and the Rondeau Bay Conservation Club. The project was initiated by Global Earth Products, the industry partner for the project, and supplier of the compost turner.

Others have shown an interest in the project and supported it by supplying materials, including carbon materials for composting. We are very grateful for all the support we have had.

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Appendix - Selected Photos