Final Report on the Evaluation of Three Manure Composting Methods for Nitrogen Conservation, Environmental Impact, Crop Growth Response and Operating and Maintenance Costs

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1.0 INTRODUCTION

1.1 Background

The value of animal manures has long been recognized in crop production systems. Greek and Roman writings from the late BC and early AD periods expound on the benefits of livestock excrement for crop production. As early as the sixteenth century, researchers became aware of the potential for nutrient loss from manures by leaching and volatilization. Prior to World War II, crop production in Canada was still heavily dependant on the use of manures as a resource for maintaining soil productivity. With the post World War II introduction of commercial fertilizers, which were relatively inexpensive and easily applied, a new trend in farm production emerged. Manure became more of a waste material rather than a resource, and crop production became increasingly dependant on commercial fertilizers to meet crop nutrient requirements. As agricultural production continued to become more industrialized, and specialized, manure management took on more of a disposal objective. Efforts were concentrated on developing management practices which minimized the labour requirements and costs to dispose of livestock manures. This emphasis resulted in a manure management trend away from bedded systems to liquid manure management systems, particularly for large scale operations.

In the 1970's a variety of concerns began to surface regarding manure management. Potential nutrient benefits of manure were not being realized due to poor manure storage and land application practices. As well, environmentalists began to recognize the extent of the environmental threat to ground and surface waters that existed, from improper manure management practices.

As a result of concerns which began receiving attention in the 1970's, much research has been carried out in the past 20 years on manure management and the economic and environmental ramifications of various practices. As a result of this research work, the environmental impacts of many traditional practices such as winter manure application, use of liquid manure, and manure application without incorporation are now better understood by researchers. However, not by the general farming community. Manure management practices responsible for nutrient loss, soil degradation, and pollution, are still being widely practiced. Research in the 1980's has unquestionably identified past and current manure management practices as a significant source of surface and ground water contamination, primarily from phosphorous, nitrates, organic sediment and bacteria in surface runoff, percolation of nitrates to the groundwater table, and transport of nitrates and bacteria to tile drainage water. The use of nitrogen fertilizers has also been recognized as a source of groundwater nitrate contamination. Research as early as 1972 by Evans and Owen documented extreme elevations of fecal coliform bacteria in tile drainage water hours after the irrigation of liquid manure. More recent research by Dean and Foran (1991) collaborates earlier research indicating either surface or injected liquid manure poses a threat to groundwater by virtue of contaminant movement through macro pores.

Liquid manure systems were developed primarily for economic reasons. Liquid systems have long been a source of odour complaints and liquid manure storage lagoons have been suspected of leaking, causing groundwater contamination.

More stringent regulations regarding manure management have been enforced in recent years. For example, in Quebec winter application of manure on snow covered or frozen ground is forbidden. Regulations will also continue to become more stringent in up coming years, as a better understanding of the environmental hazards associated with various manure management practices are achieved.

Animal rights activists are lobbying for better conditions for livestock and wish to see slotted floor systems necessary for liquid manure collection, banned. Current research has shown that the use of liquid manure can result in depletion of soil organic matter, (Ndayegamiye, et. al., 1989). The fluid nature of liquid manure also makes it a potentially greater contamination threat to groundwater, by virtue of its natural movement through soil macro pores.

Current research and a change in the populations view of the environment are forcing researchers to examine new or renew old methods of manure management. Management methods which minimize the environmental threat from manure and maximize nutrient recycling for crop production, are being emphasized.

As more farmers adopt environmentally sustainable practices, the use of liquid manure systems will diminish. Farmers are now taking a closer look at soil management practices as a means of increasing productivity. They are adopting tillage practices to improve soil structure. They are also examining and adopting methods to increase soil organic matter, reduce farm inputs and maximize recycling of farm nutrients through effective use of manures.

Farm manures are a valuable resource. In 1990, manure production in Canada totalled 129,000,000 m^3 with a fertilizer value of 900 million dollars at current fertilizer costs (Patni, 1991). Based on research to date, solid manure systems appear to have less detrimental effects on the environment, when handled using sound practices, than liquid systems. Solid systems also have more favourable effects on soil productivity because of the high percentage of organic matter in solid manure.

Manure is currently being mismanaged in a large proportion of instances in Canada due to a variety of reasons. Economics, lack of understanding by farmers, poor dissemination of information and the treatment of manure as waste rather than a resource are a few. This mismanagement not only results in loss of a valuable resource, it in many instances contributes to the pollution of surface and groundwaters.

In recent years, composting has been receiving increased attention as an alternative manure management practice to biologically stabilize manure, trap plant nutrient in microbial biomass, kill pathogens and weed seeds and reduce the mass and volume of manure requiring disposal. Researchers are still currently in two camps regarding the benefits of composting. Beauchamps (1992) has expressed concerns about nitrogen loss from composting systems through volatilization and leaching, loss of degradable organic matter and the costs associated with composting. Mathur (1992) has summarized research by himself and other researchers which document the superiority of using compost for rebuilding soil humus over raw manure.

This project has been initiated to provide needed information on the nitrogen retention, environmental soundness, crop growth response and economics of solid manure composting. In Southern Ontario, approximately 83 percent of all livestock manures produced are handled as a solid (Coleman, 1987). With this high ratio of solid manure production, the implementation of composting is a feasible option for a large percentage of farm enterprises.

1.2 Project Objectives

1. Compare the relative nitrogen conservation potential during the composting process for three composting technologies suitable for farm application. The technologies to be compared include:

    - static pile passive aeration
    - mixed forced aeration
    - turned windrow

2. Determine the nitrogen and phosphorous leaching potential of each of the finished composts generated by the three composting technologies listed in Objective 1.

3. Compare the crop response to each of the composts generated by the three technologies listed in Objective 1, to raw manure and commercial fertilizer at relative nutrient application levels.

4. Compare the relative economics of the three composting technologies listed in Objective 1.

5. Examine the effect of fall/winter versus spring/summer application of the three composts on crop growth response.

1.3 Composting

Composting in general terms is the biological degradation of organic substances to a stable, humus rich material. The micro-organisms which are involved in composting break down organic materials to obtain the necessary elements for microbial biomass synthesis. The stable humus material generated is composed largely of synthesized biomass. Composting is a natural process. It occurs endlessly in nature, in every part of the world every time any living plant or animal dies and decomposes.

References to composting as part of mans activities can be found back to Biblical times. Since the early 1900's, composting has been an integral part of crop production by a relatively small group of gardeners and farmers. Many of this small group utilize organic methods of crop production, developed between 1905 and 1935 by Sir Albert Howard, a British government agronomist (Martin et. al., 1992).

Research and developments in agricultural production in recent years has concentrated on low input agricultural practices which are environmentally sustainable. The roots of this technology are based to some extent on organic agricultural practices which date to the small organic movement of the early 1900's.

Composting has been receiving a significant amount of attention in the past ten years as a stabilization process for a wide variety of organic waste materials ranging from solid municipal waste to cannery wastes and livestock manures.

On farm composting of livestock manures has been promoted as a method of handling manure in a more environmentally friendly manner. General information on successfully producing manure compost is available, however, there are still some concerns regarding the environmental impact of composting, particularly in terms of nitrogen loss by leaching and volatilization.

Manure composting is presently being carried out by an ever increasing number of farmers. In most cases the turned pile windrow system is being utilized. Manure is piled in windrows on the edge of a farm field and turned using either a front end loader tractor or a commercial windrow turner. This method of handling manure does successfully produce stable compost. However, piling manure in a windrow in a field to compost is subject to the same environmental concerns as stock piling manure in the barnyard. It is subjected to rain and snow melt which produces leachate and runoff containing nutrients, bacteria and soluble organic matter. These contaminants can end up in surface runoff entering streams or percolate to the ground water or tile drainage water. Many farmers who advocate composting do not accept or are not aware of the possible environmental threat from poor composting practices.

The benefits of composting are well documented. Finished compost has a high percentage of stable organic matter in the form of humus. The addition of this humus rich material dramatically improves soil tilth. The result is improved soil aeration which is important for crop production. Improved tilth also reduces soil draft which in turn reduces energy requirements for seed bed preparation and planting activities.

Composting converts volatile nitrogen compounds found in raw manure to organic forms during the synthesis of microbial biomass. Nitrogen volatilization losses do occur during composting, but to no greater degree than during spreading of raw manure, particularly if it is not immediately incorporated in the soil after application. Composting manure under aerobic conditions also reduces odours and generates a rich earthy scented material that can be spread without objectionable odours being released. The exothermic enzymatic activity of the microbial biomass, responsible for composting, raises compost pile temperatures to 60 degrees C. These high temperatures kill many weed seeds, parasites and infectious bacteria which pass through livestock in the feces. The high temperatures also reduce fly larvae infestations. Finished compost has been documented to have disease suppressing qualities particularly under some greenhouse production systems. Composting of manure reduces the mass, volume and bulk density of manure by 30 to 50 percent, depending on the composting method used. This reduction of volume and bulk density means fewer field application trips are required and less soil compaction will occur during field spreading of compost. Composting of manure also re-distributes manure handling labour requirements. Labour normally expended to spread manure is reduced by virtue of the mass and volume reduction which occurs during composting. The labour requirements saved at spreading time can be allocated to other composting tasks throughout the year. Field application of raw manure has been documented to reduce soil oxygen levels to the point of being detrimental to crop growth. Easily synthesized constituents of raw manure produce a flush of microbial activity which can rapidly deplete soil oxygen levels. Compost on the other hand does not have this dramatic effect because the easily synthesized components have already been converted to microbial biomass. Compost is considered a slow release fertilizer. The nutrients are released as the soil microorganisms utilize microbial biomass in the finished compost for their own synthesis.

Although the turned pile windrow method of manure composting is most widely used at the present time, some larger commercial farm operations do use an in vessel type of mechanically mixed forced aeration composting system. This method requires relatively high initial capital investment.

Another system, which has been promoted by researchers at Agriculture Canada's Land Resource Science Centre in Ottawa, is referred to as a passively aerated system. It is a low input technology which does not require turning or mixing for aeration.

Regardless of the method of composting used, if the system is exposed to the natural elements of rain and snow melt, without appropriate confinement, detrimental environmental effects are likely to occur. Like any waste management or resource management system, proper design will ensure that process objectives are met. In the case of composting, the author feels that all such activities should take place on concrete pads properly graded to collect runoff and leachate, with provisions for recycling this liquid through the composting manure. Such provisions ensure that composting does not produce any environmental concerns and also ensures a greater proportion of nutrients are retained in the compost.

This project was undertaken partly to establish environmental effects of composting. The project examines the relative leaching potential of nitrogen and phosphorous compounds from raw manure, compost and a clay loam soil. Such information will provide a basis to confirm the potential for groundwater contamination from leachate which originates at any composting site carried out without an impermeable base and leachate collection and recycling system. The majority of farms identified by the author are composting using the turned pile method on bare ground. The author does not condone this practice and wishes to make it clear that composting should be carried out at a properly designed site.

2.0 EXPERIMENTAL PROCEDURES

This particular research project was set up to study composting under covered conditions. By doing so, nitrogen losses could be examined in terms of the processes rather than a combination of process, leaching and runoff losses. As well, mass reduction due to moisture loss and organic matter degradation could be identified and documented.

2.1 Raw Manure Characterization

Manure used for composting trials was obtained over a three week period from a group of heavy cattle on a balanced finishing ration. Table 2.1 lists the ingredients of the feed ration. All cattle were straw bedded at a rate characteristic of normal practices carried out by dairy and beef producers. Figure 2.1 shows the cattle facilities from which the manure was collected. No attempt was made to optimize the manure C:N ratio. Animals were bedded at a normal farm operation rate to maintain dry pen conditions. The intent of the experiment was to compare composting technologies using manures characteristic of those generally produced by farmers using bedded livestock facilities. Manure was obtained in four lots from the same group of animals bedded in the same fashion. Each manure lot was sampled independently. Ten grab samples were combined to form composite samples of the manure. Each lot sampling was replicated three times.

The manure samples were subjected to Regulation 309 leachate tests using distilled water and acetic acid as leaching agents. Manure leachates were analyzed for total Kjeldahl Nitrogen, ammonia, nitrate, nitrite and total phosphorus. The manure samples were also analyzed for total solids, ash, organic carbon, total nitrogen, ammoniacal nitrogen ($NH_4^+ + NH_3$), nitrate nitrogen, nitrite nitrogen, phosphorous, potassium and pH. Laboratory analysis procedures can be found in Appendix A.

Leachate tests were carried out by CANVIRO Analytical Laboratories of Waterloo Ontario. All other analysis were carried out by the Land Resource Science Laboratory at the University of Guelph.

Table 2.1 Feed Ration Of Cattle From Which Manure was Collected for Composting

Figure 2.1 Cattle Facilities From Which Manure Was Collected

2.2 Composting Procedures

The intent of the experiment was to compare various aspects of composting using three technologies currently used at farm scale. The three technologies compared include the turned pile method, passive aeration method and mechanically mixed forced aeration method.

Manure quantities composted using the three technologies varied dependant on process requirements. The mechanically mixed forced aeration system required 340 tonnes to produce an effective process that could be replicated three times. The other two processes required considerably smaller quantities, and were also replicated three times.

2.2.1 Mechanically Mixed Forced Aeration Composting Technology

Composting facilities at AAT in New Dundee, Ontario, were used to perform the mechanical mixed forced aeration trials. The facility was owner built approximately 13 years ago in an old poultry barn. Figure 2.2 shows a picture of the facility from the manure input end.

AAT carries out feed trials for a variety of clients which produce feed additives. AAT has a relatively small land base, and composts the majority of their manure for off farm sales as a soil conditioner for the home gardener market. AAT has facilities for housing in excess of 1,000 head of cattle.

The composting facility consists of a covered channel with a centre discharge point. Manure can be loaded in either end of the structure and is slowly moved to the centre discharge point by the mixing mechanism shown in Figure 2.3. The manure is mixed once daily and aerated on an hourly basis using a blower system which forces air through the composting manure in the channel. Aeration occurs for two minutes every two hours. The mixing action takes approximately 17 days to move the manure from the west input end to the discharge point. Composting is complete by the time it reaches the centre discharge point.

Figure 2.2 Mechanically Mixed Forced Aeration Composting Facility

Figure 2.3 Mechanical Mixing Equipment

2.2.2 Turned Pile Composting Technology

The turned pile composting process was carried out under covered conditions and replicated three times. Three short windrows were formed of approximately 6 m in length and 2 m in height. Each windrow was moved and mixed using a front end loader every three days. During the last month of composting, the mixing frequency was reduced to conserve process heat, as ambient temperatures were below 0EC. Mixing was carried out until the temperature of the composting manure dropped below 8E C. The turned pile process was started in late September and continued for approximately a four month period. Figure 2.4 shows one of the turned pile windrows being mixed.

2.2.3 Passive Aeration Composting Technology

The passive aeration composting process was constructed as one continuous windrow approximately 8 metres in length, 1.5 m in height and 3 m in width. The windrow was evenly divided into three sections to achieve three replicates of the process. One continuous windrow was set up to maximize heat retention, as it was anticipated that the process operation would run into the early winter, and heat loss was a concern. Passive aeration processes utilize a cover skin to trap volatilized nitrogen and to retain heat. The cover skin is generally about 10 cm in thickness and can be either sphagnum peat moss or finished compost. Sphagnum peat was used for this particular experiment.

Figure 2.5 shows the partially constructed passive aeration windrow. A 10 cm layer of peat was used as a base. Perforated drain pipes were placed every 0.5 m along the windrow and then the manure was stacked on the aeration pipes and covered with the outer skin material. The sides of the windrow were tapered and the initial height of the placed manure was 1.5 m. Figure 2.6 shows the finished windrow.

Figure 2.4 Tractor Turning of Windrows

Figure 2.5 Cross-Section of Passive Aeration Windrow Being Constructed

Figure 2.6 Finished Passive Aeration Windrow

2.3 Compost and Manure Temperature Monitoring

Compost temperature data was collected for the sole purpose of establishing that rapid biological degradation was occurring and to determine when the rapid microbial composting was complete. The stored manure temperature was monitored to obtain a comparison of aerobic microbial activity between stored manure and "composting" manure.

Temperature monitoring was carried out on the turned pile and passive aeration windrow composting processes only. Each replicate of the passive aeration windrow was monitored in five locations. The turned pile compost replicates were monitored for temperature at a single location. Temperature of the manure stored for use in crop growth trials was also monitored at a single location. A J type thermocouple, approximately one metre in length, was used to obtain temperature data. Figure 2.7 shows a picture of the probe and thermocouple reading device.

2.4 Compost Characterization

Three composite samples were taken and analyzed from each replicate for each of the three composting technologies studied. The composite samples contained 10 grab samples each. Samples were all split in two with one half being used for leachate tests and the other half for bulk analysis. Three composite samples from each replicate were further combined to form one composite compost sample, for each compost technology replicate. These samples were subjected to Ontario Ministry of the Environment Regulation 309 leachate tests using distilled water and acetic acid. Compost leachates were analyzed for total Kjeldahl Nitrogen, ammonia, nitrate, nitrite and total phosphorus. Regulation 309 leaching test procedures can be found in Appendix A. All leaching tests were conducted by Canviro Analytical Laboratories in Waterloo, Ontario.

The bulk analysis carried out on the compost samples included dry matter, ash, organic carbon, total nitrogen, ammoniacal nitrogen ($NH_4^+ + NH_3$), nitrate nitrogen, nitrite nitrogen, phosphorous, potassium and pH. All bulk analysis were performed by the Land

Figure 2.7 Temperature Probe for Monitoring Compost Temperature

Resource Science Laboratory at the University of Guelph, Guelph, Ontario. Laboratory procedures used can be found in Appendix A.

Losses which occurred during composting were calculated for nitrogen, ammonia, nitrate, nitrite, organic carbon, and moisture. Changes in C:N ratio and pH were also calculated.

Changes in the monitored parameters were calculated based on the principle of conservation of ash during the composting process, using the equation:

$$\left(1 - \left(\frac{As}{Af} x \frac{Pf}{Ps}\right)\right) \ x \ 100$$

As = % Ash - Start
Af = % Ash - Finish
Ps = % Parameter - Start
Pf = % Parameter - Finish

All processes were carried out under covered conditions to eliminate any leaching effects from precipitation, to enable the use of this method of balance. Nitrogen, phosphorus and potassium content of manures and compost are determined from a single common laboratory extraction process, making the sum of phosphorus and potassium a good basis for nitrogen balance calculations. The ash portion of manures and compost, determined by Leco furnace combustion, contain the phosphorus and potassium elements which were present in the organic and inorganic forms, prior to burning. The sum of phosphorus and potassium were used as a basis for all loss and balance calculations. Analysis results were analyzed statistically using analysis of variance techniques. Raw data and analysis of variance tables can be found in Appendix B.

2.5 Field Plot Growth Response Trials

The field plots for the growth response trials were laid out in the fall of 1991 using a randomized block design. The plots were laid out for two experiments, in two separate but adjacent field sites, with each of nine treatments replicated four times. The nine treatments which were compared include:

1. control;
2. raw manure (pre-plant incorporated);
3. chemical fertilizer (pre-plant broadcast and incorporated);
4. passive aeration compost (late winter application);
5. turned pile compost (late winter application);

6. forced aeration compost (late winter application);
7. passive aeration compost (pre-plant incorporated);
8. turned pile compost (pre-plant incorporated); and
9. forced aeration compost (pre-plant incorporated).

A total of 36 plot sites were laid out for each of the two experiments. Each plot consisted of six rows of corn with a 76.2 cm (30 in.) row spacing and a row length of approximately 4 m. Plants from two rows approximately 2 m in length, from the centre of each six row plot, were harvested for analysis. Corn with a heat unit rating of 2,650 was used for the trials. The plot site is in a 2,750 to 2,800 heat unit area. The lower heat unit corn was selected to ensure that natural maturity was reached before any frost mortality occurred. Plot planting populations were equivalent to 69,200 plants per hectare (28,000 plants per acre). Assignment of the plot treatment replicates was carried out using random number tables. Weed control was maintained on a daily basis by hand.

Growth response to the various treatments was compared in two separate experiments. In the first experiment, corn plants were harvested seven weeks after planting, when nitrogen uptake is greatest. Figure 2.8 shows a curve of nitrogen uptake versus corn plant age. Twenty-five whole corn plants from each plot were dried and weighed to compare dry weight between treatments. A composite sample of corn tissue from the 25 plants, from each treatment plot, was analyzed for nitrogen, phosphorous and potassium content and a comparison made between treatments.

In the second experiment, the corn was allowed to reach physiological maturity. Cobs from twenty-five corn plants, from approximately the middle 2 m's of the centre two rows of each plot, were harvested to determine grain corn yields. Ten whole plants, from which cobs had been removed, were harvested at ground level to compare whole plant dry matter yields. The results from both experiments were statistically analyzed using analysis of variance techniques. Raw data and analysis of variance tables can be found in Appendix B.

An 18 cm soil core sample was taken from the centre of each field plot site in the late fall of 1991. Two composite samples, one for each experiment site, were formed and

Figure 2.8 Nitrogen Uptake Curve for Corn (Aldrich et. al., 1978)

analyzed for TKN, ammonia, nitrate, nitrite, phosphorous, potassium, organic carbon and pH. Each soil sample was also subjected to Ministry of the Environment (MOE) Regulation 309 acetic acid and distilled water leachate tests.

The compost application rate was based on corn growth and yield response to nitrogen, nitrogen content of the compost material, theoretical availability of compost nitrogen and available soil nitrogen. Compost application rates on all treatment plots were based on providing equivalent levels of nitrogen. Corn yield is most sensitive to additional units of nitrogen up to approximately 115 kg of nitrogen per hectare. Figure 2.9 shows a curve of corn yield versus nitrogen application rate. To enable response differences between treatments to be most readily detected, compost application rates were set such that the total of soil and compost nitrogen was within the range where corn response to additional units of nitrogen is greatest. Manure and commercial fertilizer applications were applied at rates which provided nitrogen levels equivalent to the compost nitrogen.

Literature reviewed to date, indicates that researchers assume that 50 percent of the nitrogen in compost is available in the first crop year (Reider et. al., 1991). To ensure that nitrogen was limiting in all plot sites, compost application rates were set based on total nitrogen content plus total soil nitrogen being approximately equivalent to 115 kg of nitrogen per hectare. This was done to ensure that nitrogen availability was within the range where corn is most sensitive to additional units of nitrogen. A granular 10-4-8 fertilizer was used for the fertilizer treatments. The 10-4-8 ratio was selected to match as closely as possible the average N-P-K ratio, approximately 2-1-2, of the raw manure and composts. Fertilizer was applied at 50 percent of the 115 kg/hectare nitrogen rate used for the composts, assuming 50 percent of the compost nitrogen would be available in the first crop year.

Figure 2.9 Corn Yield Versus Nitrogen Application Rate (Aldrich et. al., 1978)

2.6 Manure, Compost and Soil Leaching Tests

One composite sample from each lot of manure, composting replicate, and field trial soil, was subjected to MOE Regulation 309 distilled water and acetic acid leachate tests. All leachates were analyzed for TKN, ammonia, nitrate, nitrite and total phosphorus. Procedures used for forming composite samples of manure and compost are described in sections 2.1 and 2.4 respectively. The composite soil samples were made up of thirty-six 18 cm long by 2.5 cm diameter soil cores. One core was taken from each treatment plot within the trial sites. Two trials were run and a separate soil sample was submitted for each trial site. Manure and compost leachate results were analyzed statistically using analysis of variance techniques. Raw data and analysis of variance tables can be found in Appendix B.

2.7 Operating and Maintenance Costs

The three composting technologies were evaluated in terms of energy usage and labour requirements. Energy costs were based on diesel fuel costs of 31 cents per litre and hydro costs of 6.2 cents per kilowatt hour of energy consumed. A preliminary estimate of capital costs has been included, however, it can only be assumed to be in the -25 to +40 percent range customary for costs based on conceptual designs. More accurate costing would required detailed design which is beyond the scope or intention of this project.

3.0 RESULTS AND DISCUSSION

The results of this project are presented in six sections. Characterization data pertaining to the raw manure used in the composting processes can be found in Section 3.1. Temperature monitoring data for the control pile of manure, passive aeration compost and turned pile compost are presented in Section 3.2. Section 3.3 contains the characterization data collected for the composts produced by the three different technologies examined, and a control pile of manure. Leachate data collected for the field trial soils, raw manure, and finished compost are presented in Section 3.4. Section 3.5 provides comparative information on crop response to the various treatments, seven weeks after planting and at harvest. Section 3.6 provides a comparison of labour and energy requirements for the three composting technologies examined. Section 3.6 also provides capital cost estimates for composting facilities, based on conceptual designs. Where applicable, discussion of the results is included.

3.1 Raw Manure Characterization

Table 3.1 shows the mean, standard deviation, variance, and number of samples analyzed for each of the four lots of manure used in the composting experiments. An analysis of variance was carried out on the raw data for each parameter. At a 99 percent level of confidence, all parameter mean differences were insignificant, except for moisture and potassium. One lot had elevated moisture levels and one lot had elevated potassium levels. However, moisture and potassium were not limiting in any of the manure lots with respect to composting.

The manure carbon to nitrogen (C:N) ratio is of particular concern with respect to composting, because it is an important factor in nitrogen conservation. Bacteria responsible for the initial high temperature degradation, considered to be active composting, require carbon and nitrogen in an approximate ratio of 10 to 1 respectively, for microbial biomass synthesis. They also must oxidize 2 units of carbon, for energy, for every unit of carbon retained for microbial biomass. For this reason, a C:N ratio of approximately 30 is considered optimum for nitrogen retention (Mathur, 1992). The C:N ratio of the manures used in this experiment averaged approximately 13.5, considerably

Table 3.1 Bulk Characteristics of Raw Manure below the optimum. However, the moisture levels averaged 59 percent, and it would not be economical for commercial farm operations to add the required bedding to obtain a C:N ratio of 30. The C:N ratio between manures used for the composting experiments exhibited no significant differences at a 99 percent level of confidence and did not show any signs of significance above the 75 percent level of confidence.

For the purposes of this experiment, the four lots of manure were considered to have insignificant differences between them. Leachate characteristics are presented in Section 3.5. Raw data and significance tests for the 99, 97.5, 95, 90 and 75 percent levels of confidence can be found in Appendix B.

3.2 Compost and Stored Manure Temperature Monitoring

Figure 3.1 shows a graph comparing the temperature profile over time for the passive aeration composting process, the turned pile composting process, and a pile of manure stored as a control.

All three temperature profiles followed the same general pattern of temperature increase and gradual decline over time. Temperatures of the control pile of manure, turned pile compost, and passive aeration compost peaked approximately three weeks after commencement of the research. During the first three weeks of the experiment, the control pile of manure temperature remained between that of the turned pile compost and passive aeration compost. For the majority of the remaining period, the control pile of manure temperature remained 8 to 10EC below that of the passive aeration compost. The temperature profiles are indicative of the level of bacterial activity. However, the temperature differences between the composts and the stored manure do not necessarily indicate differences in biological activity level. These differences may, in part, be due to differences in heat loss, as well.

3.3 Compost Characterization and Process Results

Table 3.2 shows the mean, standard deviation, variance, number of samples analyzed and statistically significant differences for characteristics of the three different composts

Figure 3.1 Temperature Profiles for Compost and Control Pile of Manure

Table 3.2 Bulk Characteristics of Finished Compost produced and control pile of manure. The data indicates that the control pile of manure underwent similar biological transformations as did the manures which were handled in a fashion to promote "composting" (rapid biological degradation). Differences in mean composting characteristics between composting methods were found at a significance level of 99 percent. Total nitrogen content and C:N ratio were the only parameters which did not exhibit any statistically significant difference between treatments. The passive aeration compost had the highest level of ammoniacal nitrogen at 0.25 percent, on a dry matter basis. The forced aeration mechanically mixed compost had the lowest level at 0.09 percent. Ammoniacal nitrogen differences were statistically significant at a 99 percent level of confidence.

Statistically, the manures used for the experiments contained similar levels of carbon and ash. However, percentages of ash and carbon in the composts and control pile of manure were different and statistically significant at a 99 percent level of confidence, indicating that stabilization between treatments was not the same.

The moisture content of the passive aeration compost averaged 21.8 percent, approximately 10 percentage points below the other two composts. This low level of moisture is the result of moisture loss due to a combination of heat and high rate of air diffusion, indicating the high potential for air exchange in the passive aeration system. Early research work by the U.S. Public Health Services people found that 570 m^3 of air is consumed daily for each tonne of biologically active compost, in raised bed (passive aeration type) composting systems (Marten, L., et. al., 1992). POS (1991) has indicated that 30 - 70 m^3 of air per day-tonne of composting manure is adequate. Significantly less than natural air exchange rates reported, due to heat gradient in passive aeration composting systems. During the active phase of the passive aeration composing processes monitored in this project, it was observed that the composting manure dried from the bottom of the windrow up. As a result, the active zone as indicated by temperature, gradually moved up towards the top surface. This continued until there was just a narrow biologically active layer near the upper surface, where moisture continually condensed.

Table 3.3 contains a summary of the nitrogen, carbon, dry matter and moisture losses, and changes in pH and C:N ratio observed for the different composting methods and control pile of manure. Mean nitrogen losses ranged between 31 percent for the forced aeration and passive aeration composts, to 44 percent for the control pile of manure.

Table 3.3 Summary of Composting Losses and Changes

Statistically, at the 99 percent level of confidence, these differences were not significant. Ammonia changes during composting ranged from a loss of 65 percent for the turned pile compost to a net increase of 71 percent for the passive aeration compost. These values are relative to the starting ammonia content, as ammonia is continuously produced as a by product of microbial degradation during composting processes. Differences in mean ammonia changes were significant at a 99 percent level of confidence as shown in Table 3.3. Carbon losses were lowest for the forced aeration and passive aeration composts, with losses of 18 percent and 19 percent, respectively, and highest for the turned pile compost at 39 percent. The control pile of manure had carbon losses of 28 percent. The carbon loss is a direct indication of the level of biological degradation that has occurred. The mean differences in carbon losses, between the forced aeration and turned pile and between the passive aeration and turned pile treatments were statistically significant at the 99 percent level of confidence. This indicates that the forced aeration and passive aeration composts underwent significantly less biological degradation than did the turned pile compost. Moisture becoming a limiting factor during the composting process is the most likely cause.

Moisture losses ranged between 71 percent for the forced aeration compost and 87 percent for the stored pile of manure. These differences were all statistically significant at the 99 percent level of confidence, except for differences between the turned pile and passive aeration composts. The moisture loss occurred over a 17 day period for the forced aeration compost, 84 days for the passive aeration compost, 130 days for the turned pile compost and 167 days for the control pile of manure, based on dates of sampling. Moisture loss from the forced aeration and to a lesser extent passive aeration composting processes would have been rapid compared to the loss rate of the turned pile compost and control pile of manure. As a result, moisture would have been a limiting factor early in the biological degradation process. Moisture starts to become a limiting factor when it drops below 45 percent (Marten, 1992).

Mean nitrogen losses, although not statistically different, did correlate to some extent with the mean carbon losses. Nitrogen loss appears to be as much a function of degree of stabilization as method of stabilization. Planned composting of manure did not result in higher nitrogen losses than were experienced from the control pile of stored manure.

Figure 3.2 The Effect of pH and Ammonia Nitrogen Concentration (NH_3 + NH_4^+) on the Concentration of Free Ammonia in Water (Sawyer, C., et. al., 1978)

Nitrogen losses, under aerobic conditions, occur as a result of ammonia volatilization. Organic nitrogen is converted to ammonia during biological degradation. Raw manure also contains ammonia, particularly from urine, when excreted. It exists within particle film moisture as either NH_4^+ or NH_3, depending on the pH of the moisture film. Figure 3.2 shows a general graph of the ratio of NH_4^+ and NH_3 present at any given time as a function of pH. The pH of the manures used for the composting experiments ranged between 8.7 and 9.1. This relatively high pH would result in approximately 50 percent of the ammoniacal nitrogen (NH_4^+ and NH_3) present, being in the NH_3 form, making it susceptible to volatilization.

Figure 3.3 shows a general set of curves for the relationship between nitrogen forms, as a function of time, for aerobic biological degradation of organic waste in water. Although the graph is for aerobic degradation of organic wastes in water, the same general trends apply to any aerobic decomposition of organic matter. Less than 10 percent of the total nitrogen present in all finished composts was in the ammoniacal form, the same ratio as the starting manures and less than 1 percent of the total nitrogen was in the nitrate form.

This may be because of volatilization losses of ammonia, because the biological degradation state was still in the early phases indicated in Figure 3.3 or because the nitrogen was efficiently assimilated by the bacteria. Nitrite levels found in the finished composts represented less than 0.25 percent of the total nitrogen present. As such, it is assumed that nitrogen loss as N_2O or N_2 was not significant. The three types of compost and stored pile of manure were retained under cover for between 8 and 12 months after final sampling of the materials. After this curing period, they were irrigated and independently mixed to achieve a 50-60 percent moisture content, and monitored for a 3 week period in late October for temperature increases. All three composts and the control pile of manure became fully active biologically as indicated by temperature.

The passively aerated compost became fully active very rapidly after mixing and moisture addition with temperatures reaching 62.7EC after 9 days. Moderate temperature elevations were initially observed in the turned pile compost with temperatures reaching 35EC after nine days and 57.2EC after 15 days. Temperatures of 57.6EC were observed in

Figure 3.3 Changes Occurring in Forms of Nitrogen Present in Polluted Water Under Aerobic Conditions (Sawyer, C., et. al., 1978) the forced aeration compost after 9 days. The raw manure was slower heating than the passively aerated compost, but did reach the 60EC range after 15 days.

Data for the peat moss cover skin used on the passive aeration compost windrow, are presented in Table 3.4. The initial low pH of the cover skin effectively retained ammoniacal nitrogen volatilized during composting, as seen by the increase in total nitrogen and ammoniacal nitrogen. Total nitrogen increased by a factor of 1.87. Ammoniacal nitrogen represented approximately one-third of the total nitrogen in the peat skin, after the composting process was finished. Moisture content increased from 21.8 percent in the fresh cover skin peat to 79.1 percent during the composting process. The high moisture content and readily available nitrogen resulted in significant degradation of the peat moss, demonstrated by the 51 percent loss in carbon. The data indicates that the use of a cover skin is an effective nitrogen trap.

Table 3.4 Peat Moss Cover Skin Characteristics Before and After Composting

During sampling of the passive aeration compost, extensive grayish coloured mold-like material was visible, characteristics of mycelia produced by actinomyce bacteria. These organisms produce the nice earthy scent characteristic of finished compost, and are not as visible in composting materials which are continually mixed.

A high degree of mouse colonization within the passive aeration pipes was observed over the coarse of the passive aeration composting process. Many pipes were completely plugged with nesting materials. When the pipes were removed, it was also very apparent that the pipes had partially collapsed due to softening from the initial high temperatures of the composting manure, and the weight of the composting manure.

Raw data and analysis of variance tests for the 99, 97.5, 95, 90 and 75 percent levels of confidence can be found in appendix B.

3.4 Comparison of Leachate Characteristics

Table 3.5 summarizes the leachate analysis results for the raw manure prior to composting, the finished composts and the field trial soil, which is a Huron clay loam. The leachate extraction process prescribed under MOE Regulation 309 requires that leachates be passed through a glass fibre micro filter (GFC) with a nominal pore size of 1.2 microns. Figure 3.4 shows the leachate after settling of particulate matter, which has passed through the 1.2 micron GFC filter. Figure 3.5 shows the leachates with all particulate matter in suspension. The turned pile compost leachates contained the lowest level of total Kjeldahl nitrogen (TKN) with 252 mg/l in the acetic acid leachate and 240 mg/l in the distilled water leachate. The passive aeration compost leachates contained the highest levels of TKN with 533 and 481 mg/l in the acetic acid and distilled water leachates, respectively. The raw manure leachates were in between with TKN levels of 440 mg/l for the acetic acid leachate and 390 mg/l for the distilled water leachates. The mean TKN differences, between manure treatments, were not statistically significant at the 99 percent level of confidence. Ammonia levels in the leachates followed the same general pattern as TKN.

Table 3.5 Summary of Leachate Characteristics

Figure 3.4 Leachate Samples After Settling of Particulate Matter

Figure 3.5 Leachate Samples With Particulate Matter in Suspension

Differences in mean levels of ammonia in the leachate, were not statistically significant. Leachates from the soil samples did not contain TKN or ammonia nitrogen above the detection limits of 0.5 mg/l. Although TKN mean differences were not statistically significant, they did follow a trend of lower TKN levels in the leachate from the composts with the highest levels of degradation. Also, TKN levels in the leachate from composts showed substantially less variance compared to leachates from the raw manure.

Nitrates were detected in two of three turned pile compost acetic acid leachate samples. The mean was 5.13 mg/l. No detectable level of nitrates was found in any other leachate tests. No detectable level of nitrites was found in any of the leachates.

The turned pile compost leachate contained the highest level of total phosphorous with 423 and 103 mg/l in the acetic acid and distilled water leachates, respectively. The raw manure had the lowest levels of phosphorous in the acetic acid leachate amongst the manure and composts at 250 mg/l. The forced aeration compost, distilled water leachate, had the lowest levels of phosphorous at 76.7 mg/l. Leachates from the soils contained comparatively low levels of phosphorous with 0.86 mg/l in the acetic acid leachate and 0.64 mg/l in the distilled water leachate. The differences in phosphorous content of the acetic acid leachates from the raw manure before composting or storage and turned pile composts were statistically significant at the 99 percent level of confidence. The concentration of phosphorous from manure and compost in the acetic acid leachate was between 3 and 4 times higher compared to the distilled water leachate. This is probably the result of organic matter undergoing mild digestion by the acetic acid, and releasing organic phosphorus. The soil leachates, however, both contained comparable levels of phosphorous.

Composting did not statistically reduce the potential for nitrogen leaching. However, there was a trend of lower nitrogen levels in leachates from the composts with the highest levels of organic degradation. Carbon analysis on the turned pile compost indicated this material had undergone the most extensive level of biological degradation. It also had the lowest level of nitrogen leaching. The lack of significance in nitrogen leaching is likely due to the fact that low moisture levels prevented the composts from undergoing the extent of biological degradation necessary, to observe a decrease in nitrogen leaching potential.

Raw data pertaining to the composts, and analysis of variance tests for the 99, 97.5, 95, 90 and 75 percent levels of confidence can be found in appendix B.

3.5 Field Plot Growth Response Trials

The growth trials were carried out in the summer of 1992, rather an unusually cool and wet growing year. Corn plots were planted in late May and had a good uniform emergence. By early-June, the corn plots as a whole were under stress due to unusually cool temperatures and were a pale green colour. The corn recovered by the beginning of July and regained its characteristic green colour. The first trial plots were harvested 7 weeks after planting and a definite variation in plant heights, between treatment plots, was visible.

Table 3.6 summarizes the data collected for the first corn plot harvest. The mean dry mass values are for 25 whole plants. The treatment plots receiving pre-plant incorporated fertilizer had the highest mean dry mass of 283 g. The treatment plots receiving winter applied forced aeration compost had the lowest mean mass of 214 g. Mean dry mass differences between pre-plant incorporated treatments were not statistically significant at a 99 percent level confidence but were at a 75 percent level.

The cool, wet weather of the 1992 growing season made soil conditions unfavourable for aerobic microbial activity necessary for mineralization of organic forms of plant nutrients. Soils were frequently water-logged, providing anaerobic conditions favourable for denitrification, resulting in soil nitrogen being lost to the atmosphere. Organic forms of plant nutrients, applied to the treatment plots as manure and compost, were likely not available for plant growth to the normal extent. This partially explains why, response differences between treatments were not more pronounced or significant at a higher level of confidence.

Dry mass yields from the pre-plant incorporated compost treatment plots harvested in July, were all higher than yields from the respective winter compost treatment plots.

Table 3.6 First Corn Plot Harvest Results

Mean differences in mass yields between winter and pre-plant treatments were statistically significant at the 99 percent level of confidence. Mean plant tissue nitrogen, phosphorus and potassium levels were not statistically different between treatments, regardless of application time, at a 99 percent level of confidence.

Distinct differences in treatment plots became more visible as the growing season progressed. Corn plants on the border rows of the field trial site were slightly taller, and appeared healthier than interior plants for the same treatments. Plots which received fertilizer, showed no visible signs of nitrogen deficiency. All other plots showed varying levels of nitrogen deficiency in the form of yellow lower leaves and reduced level of maturity. Figures 3.6 to 3.9 show the field plot site in various stages of maturity.

Table 3.7 summarizes the data collected from the second plot trial harvest. The plots were harvested October 31 and November 1.

Grain corn yield was highest and most consistent from the plots receiving fertilizer, with a mean dry matter yield of 2.74 kg for 25 plants. However, at least one replicate from each set of compost treatments, applied pre-plant incorporated, achieved grain yields equivalent to the fertilizer plot yields. Mean differences in grain yields from spring applied treatments were not statistically significant at a 99 percent level of confidence. The compost plots, however, demonstrated the potential to achieve yields equivalent to fertilizer, when applied pre-plant at equivalent rates, assuming 50 percent of the nitrogen in compost is available in the first crop year. Mean grain yield from the control, manure and compost pre-plant treatment plots were all below that of the fertilizer plots. Variance amongst treatment plot grain yields were greatest for the compost plots and lowest for the fertilizer plots. Mean yields from winter treatment plots were consistently lower than the spring applied treatment plots; but differences were not significant at a 99 percent level of confidence.

Mean grain corn moisture levels ranged between 53 and 55 percent. Mean differences were not significant between treatments. Whole plant yields followed the same trends as the grain corn yields.

Raw data and significance tests for differences between treatments at a 99, 97.5, 95, 90 and 75 percent level of confidence can be found in appendix B.

Figure 3.6 Corn Plots Early June 1992

Figure 3.7 Corn Plots Early July 1992

Figure 3.8 Early Harvested Corn Plot

Figure 3.9 Corn Plots Late September 1992

Table 3.7 Second Corn Plot Harvest Results

3.6 Operating and Maintenance Costs

The intent of this section is to compare direct labour and energy requirements between the three methods of composting studied in this project. Labour requirements and equipment operating times were recorded throughout the project, and used in part to estimate average energy costs and man hours per tonne and per m^3 of compost produced. Manures used in this project had a mean bulk density of 2.21 kg/m^3. This will be highly variable between farms depending on the type and amount of bedding used, and will influence costs per tonne and per m^3.

Table 3.8 summarizes the labour requirements in terms of man hours and the energy costs associated with each type of composting. Capital costs for aeration piping were included for passive aeration composting. Cover skin and base materials for passive aeration composting are required at a rate of 0.3 m^3 per m^3 of composting manure, assuming windrow dimension of 3 m wide by 1.5 m high, and a cover skin and base thickness of 15 cm. Peat moss was used as a base and outer skin cover material for this particular project. However, peat moss retails for approximately $40.00/$m^3$, and is not considered a sustainable resource (Environment Canada, 1988). Use of this material at a commercial farm scale is not considered economically or environmentally viable. Finished compost is a suitable option (Mathur, 1992). For the purposes of this comparison, it has been assumed that at a commercial farm scale, a portion of finished compost produced on the farm, would be recycled for the base and cover skin. A cost based on energy, and labour requirements at $12.00/hr, was used to estimate a value for the compost used for the base and cover skin. This cost is included in Table 3.8.

Labour requirements to transport manure from barns to the composting sites are assumed equal and have not been included in Table 3.8. Additional labour requirements required to build the passive aeration windrow have been included. The additional labour is that over and above requirements to stack the manure randomly in a storage yard. Energy costs for the turned pile method, assume that at commercial farm scale, turning frequency would not exceed the minimum requirement of 3 mixes.

Table 3.8 Economic Comparison of Composting Methods

Capital costs have been included in Table 3.8. These are estimates only and should be considered in the range of -25 percent to +40 percent, customary for estimates based on conceptual designs.

The mechanically mixed forced aeration compost had no labour associated with it, over and above that required to transport manure from barns, to the composting facility. As such, it has the lowest labour requirements followed by the passive aeration system and then the mechanically mixed system. Energy costs associated with the passive aeration composting system were equivalent to those required for the mechanically mixed forced aeration system. The turned pile system had the highest energy requirements, even when it was assumed that the minimum amount of mixing would be carried out. The aeration pipes were assumed to have a life expectancy of 5 composting cycles, when used in a commercial farm operation. Problems were experienced with the use of the traditional perforated septic system weeping bed pipes, during the composting trials carried out for this project. The high temperatures of the passive aeration compost softened the pipe to the point where the weight of the manure resulted in ovalization of the pipe, and loss of structural integrity for successive process cycles. A five year life cycle is probably over optimistic, but it is assumed that possibly a more appropriate substitute material can be found. This significantly increased the costs associated with passive aeration composting. Placing a value on the compost recycled for use as the cover skin also adds a significant cost to the process.

Capital costs for passive aeration and turned pile composting are equivalent because of the similarities in the concrete pad and leachate recycle structures required, and are estimated at $19,300. The capital costs for the mechanical mix forced aeration system were significantly higher because of the mixing unit, aeration blower and associated piping. Capitol costs are estimated at $80,000. Capital costs are based on equivalent tonnage capacities.

4.0 CONCLUSIONS

The data collected for the passive aeration, turned pile and forced aeration composts and a control pile of stored manure did not indicate a significant difference in nitrogen volatilization losses between treatments. The losses ranged from 30.1 percent for the passive aeration compost process to 44.4 percent for the control pile of manure. The data did indicate that the three composts and control pile of manure underwent different degrees of stabilization, as indicated by the significant differences in carbon loss. Carbon losses ranged from 18 percent for the forced aeration compost to 36 percent for the turned pile compost. The data showed a general trend of higher nitrogen losses from the manures which underwent the highest levels of stabilization. The control pile of manure actually showed the highest level of nitrogen volatilization losses, although not statistically significant.

The peat moss cover skin on the passive aeration windrow demonstrated an excellent capacity for nitrogen retention. Nitrogen increased by a factor of 1.87 during the composting process. However, approximately one third of it was in the ammoniacal form and would be very susceptible to loss during handling and spreading of the solid material. It would also require thorough mixing with the compost in order to make effective use of the additional nitrogen. The data indicated that a 50.8 percent reduction in carbon occurred in the cover skin resulting in a concentration of nitrogen to 4.3 percent on a dry matter basis.

It was observed that composting of livestock manures can not be completed under covered conditions without the addition of moisture, to maintain levels above the 45 percent range at which moisture becomes limiting to the biological process. Moisture levels in the finished composts ranged between 21.8 percent for the passive aeration compost to 33.3 percent for the turned pile compost. The three composts and control pile of manure were retained under cover for an 8 to 12 month curing period, irrigated to a 50-60 percent moisture level and mixed to assess their potential for reheating. All materials reheated to active composting temperatures in the 45 to 60EC range, indicating that the rapid biological stabilization activity associated with composting was not complete. The high evaporative capacity of composting manure indicates it has potential as a treatment process for barnyard runoffs and dairy farm milkhouse washwater.

Leachate analysis indicated that the potential for nitrogen loss by leaching was not significantly altered by the composting processes examined. But, the compost with the greatest degree of biological stabilization had the lowest mean nitrogen levels in the leachates, indicating a possible trend. Distilled water leachates contained TKN ranging from a mean of 240 mg/l for the turned pile compost to 399 mg/l for the raw manure used in the composting processes. Differences were not statistically significant, however, composting did result in higher levels of phosphorus in the acetic acid leachates from compost, compared to raw manures. There was no significant difference in phosphorus leaching between treatments in the distilled water leachate.

The crop growth response trials showed a definite trend of more consistent yields from the plots receiving commercial fertilizers compared to all other treatments. However, at least one treatment plot from each of the compost treatments achieved yields equivalent to the fertilizer yields.

There was no significant difference in corn yields between treatments, even at a 75 percent level of confidence. The cold, wet growing season experienced during the plot trial experiment is thought to have confounded the results to some degree, due to the slow rate of nutrient mineralization from organic amendments and potential for denitrification in cold, waterlogged soils.

Corn plants harvested in July for comparison of total plant dry weight and tissue nutrient analysis had higher plant weights for plots receiving compost pre-plant incorporated compared to winter application. Fall harvested grain corn and whole corn plants did not show any significant difference in yields between pre-plant and winter compost applications. Mean grain corn moisture levels were all in the 53 to 55 percent range, indicating that no difference in corn maturity resulted from the various treatments.

The economic comparison indicated that the mechanically mixed forced aeration composting system has the lowest energy requirements at $0.185/tonne of manure composted followed by $0.190/tonne for the passive aeration compost and $0.72/tonne for the turned pile compost. The mechanically mixed forced aeration composting method has no direct labour requirements associated with the process itself. The passive aeration method requires 0.039 hours/tonne followed by the turned pile method with 0.147 hours/tonne. The capital cost estimates indicate that the turned pile and passive aeration composts have similar capital costs of $19,300, for concrete pads and leachate collection and re-distribution systems. The mechanically mixed forced aeration system had the highest capital cost of $80,000, assuming equivalent tonnage capacity.

5.0 REFERENCES

Aldrich, S., Scott, W., Leng, E. 1978. Modern Corn Production. A & L Publications.

Beauchamps, E. 1992. Presentation to Waterloo County Federation of Agriculture, Maryhill in Kitchener Waterloo Record.

Coleman, D., Roberts, P., 1987. Cropping, Tillage and Land Management Practices in Southwestern Ontario, Soil and Water Environmental Enhancement Program Report.

Dean D. and M. Foran. 1991. The Effect of Farm Liquid Waste Application on Receiving Water Quality. Final Report, RAC Projects 4306 and 5126, Ontario Ministry of the Environment, Toronto.

Environment Canada. National Wetlands Working Group, Canada Committee on Ecological Land Classification, 1988. Wetlands of Canada.

Evans, M.R. and J.D. Owens. 1972. Factors Affecting the Concentration of Fecal Bacterian Land Drainage Water. Journal of General Microbiology. 71:477-485.

Hansen, R., Keener, H., Marugg, C., Dick, W., Hoitink, H. 1993. Composting of Poultry Manure, Science and Engineering of Composting. Renaissance Publications, Ohio.

Haug, T. Compost Engineering Principles and Practice, 1980. Ann Arbor Science Publications Inc. Michigan.

Jobin P. 1993. Centre de développement d'agrobiologie, Sainte-Elizabeth-de Warwick, personal communication.

Lau, A., Liad, P., Lo, K. 1993. Swine Waste Composting in Vertical Reactors, Proceedings 2nd Annual Meeting, Composting Council of Canada, Ottawa.

Martin, D., Gershuny, G. 1992. The Rodale Book of Composting. Rodale Press, Emmaus, Pennsylvania.

Mathur, S.P. 1992. Composting as a Strategy for Restoring Soil Organic matter and for Reducing Net Emissions of Greenhouse Gasses, Methane and Nitrous Oxide. Centre for Land and Biological Resources Research Centre. Ottawa.

Mathur, S. 1993. A New Compost Biomaturity Test, Proceedings 2nd Annual Meeting, Composting Council of Canada.

McConnel, A. 1993. Sweet Smell of Success. Agricultural Engineering. March 1993.

Miller, F. 1993. Minimizing Odour Generation. Science and Engineering of Composting. Renaissance Publications. Ohio.

Morel, J. 1984. Methods of Evaluating the Maturity of Municipal Refuse, Composting of Agricultural and Industrial Wastes. Elsevier Applied Science Publishers. New York.

Ndayegamiye, A. and D. Coté. 1989. Effect of Land Tern Pig Slurry and Solid Cattle Manure Application on Soil Chemical and Biological Properties. Canadian Journal of Soil Science, 69:39-47.

Patni, N.K. 1991. Overview of Land Application of Animal Manure in Canada. Proceedings of the National Workshop of Land Application of Animal Manure.

Pos, J. Composting - Theoretical Applications, 1991, Municipal and Commercial Composting Workshop. University of Guelph.

Reider, C., Janke, R., Moyer, J. 1991. Compost Utilization for Field Crop Production. Rohdale Institute Research Centre Technical Report.

Sawyer, C., McCarty, P. 1978. Chemistry for Environmental Engineering, Third Edition, McGraw-Hill Book Company.

Smith, R., Marteil, A. 1974. Critical Stability Constants. Plenum Press. New York, N.Y.

St. Jean, R. Ecologistics Limited, 1993. Draft Final Report, Evaluation of Three Manure Composting Methods. National Soil Conservation Project.

Termeer, W., Warman, P. 1993. Use of Mineral Amendments to Reduce Ammonia Losses from Dairy-Cattle and Chicken-Manure Slurries. Bioresource Technology 44.

Appendix A
Laboratory Analysis Procedures

Appendix B
Raw Data and Analysis of Variance Tables

Bulk Manure, Compost and Soil Laboratory Analysis Procedures

Manure, Compost and
Soil Leachate Analysis Procedures