RESEARCH SUB-PROGRAM

ON-FARM MANURE COMPOSTING TECHNIQUES - UNDERSTANDING NITROGEN AND CARBON CONSERVATION

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FORWARD

This report is one of a series of **COESA** (Canada-Ontario Environmental Sustainability Accord) reports from the Research Sub-Program of the Canada-Ontario Green Plan. The **GREEN PLAN** agreement, signed Sept. 21, 1992, is an equally-shared Canada-Ontario program totalling $64.2 M, to be delivered over a five-year period starting April 1, 1992 and ending March 31, 1997. It is designed to encourage and assist farmers with the implementation of appropriate farm management practices within the framework of environmentally sustainable agriculture. The Federal component will be delivered by Agriculture and Agrifood Canada and the Ontario component will be delivered by the Ontario Ministry of Agriculture and Food and Rural Assistance.

From the 30 recommendations crafted at the Kempenfelt Stakeholders conference (Barrie, October 1991), the Agreement Management Committee (AMC) identified nine program areas for Green Plan activities of which the three comprising research activities are (with Team Leaders):

1. **Manure/Nutrient Management and Utilization of Biodegradable Organic Wastes** through land application, with emphasis on water quality implications
   - **A.** Animal Manure Management (nutrients and bacteria)
   - **B.** Biodegradable organic urban waste application on agricultural lands (closed loop recycling) (Dr. Bruce T. Bowman, Pest Management Research Centre, London, ONT)

2. **On-Farm Research**: Tillage and crop management in a sustainable agriculture system. (Dr. Al Hamill, Harrow Research Station, Harrow, ONT)

3. **Development of an integrated monitoring capability** to track and diagnose aspects of resource quality and sustainability. (Dr. Bruce MacDonald, Centre for Land and Biological Resource Research, Guelph, ONT)

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This Research Sub-Program is being managed by the Pest Management Research Centre, Agriculture and Agri-Food Canada, 1391 Sandford St., London, ONT. N5V 4T3.

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ON-FARM MANURE COMPOSTING TECHNIQUES - UNDERSTANDING NITROGEN AND CARBON CONSERVATION

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Appendix I Laboratory Analysis Procedures

EXECUTIVE SUMMARY

Conventional as well as ecological on-farm manure composting techniques were studied in this project using a series of 16 composting trials. The composting trials examined carbon and nitrogen losses as well as nitrogen, phosphorus and potassium leaching losses. The effect of composting techniques on off-gas and pore-space methane (CH_4), carbon dioxide (CO_2), ammonia (NH_3), and oxygen (O_2) concentrations was also examined. Data were collected to track process temperatures, moisture losses and, in some experiments, weight changes. Germination tests were completed using cress seed to compare seed germination inhibition levels at the end of the active composting process determined as the point at which the compost process temperature approaches ambient temperatures. Germination inhibition of the compost was also assessed after 30, 60 and 90 days of curing.

Manures were sampled from beef, dairy and poultry operations in Ontario to asses their suitability for composting in terms of moisture levels and carbon to nitrogen (C/N) ratio.
Manures used and composts produced as part of this project were sampled and analyzed for total nitrogen (N), phosphorus (P), potassium (K), ammoniacal nitrogen (ammonium and ammonia), nitrate (NO_3) nitrogen, nitrite (NO_2) nitrogen, dry matter (DM), organic matter, (OM), total carbon (TC), pH, and ash.

Solid manures produced on the dairy and beef farms sampled during this study were found to have moisture levels in the range of 70 to 80%, significantly above the optimum of 60%. Solid poultry manures were found to average 33%, significantly below the optimum. All manures had C/N ratios significantly below the optimum of 30/1 and C/N ratios ranged from 10 for poultry manures to 16 to 17 for dairy and beef.

Data collected from three different composting processes used by ecological farm operators did not indicate any advantage to these processes over conventional farm composting techniques in terms of nitrogen conservation, reduced leachate losses, or maturity as indicated by seed germination inhibition.

Comparison of traditional turned-pile, passive-aeration, and forced-aeration composting processes with similar windrow dimensions of 3 m wide by 1.2 m high, did not indicate that one process was advantageous over the other in terms of carbon or nitrogen conservation, leaching potential, or degree of seed germination inhibition.

Outside and inside composting were observed to have similar nitrogen and carbon losses and nutrient leaching potential. The outside composting manure was observed to form a hard surface due to the sun's drying, which effectively shedded water. This hard surface reduces the potential for nitrogen leaching during the process despite the fact that it is exposed to rainfall. The net moisture loss was approximately 20% greater for the covered processes compared to the outside process. The outside process had a net moisture loss of 43.2% compared to 69.6% for the covered control process.

Composting processes, manipulated for nitrogen conservation, were observed to have insufficient moisture loss to make them suitable for treatment of farm-generated liquids (e.g. barnyard runoff).

Composting was found to reduce the potential for N, P and K leaching compared to raw manure. Fourteen out of sixteen processes studied showed a reduction in N, P and K leaching losses as a result of composting.

The study indicated that windrows 3 m wide and 1.2 m high have sufficient natural convection through them to maintain aerobic conditions without aeration enhancements such as forced-aeration, static aeration tubes or mixing. Mixing, however, was observed to stimulate bacterial activity (as indicated by a temperature increase after mixing), even when pore-space oxygen levels were not limiting. This is believed to be due to the redistribution of bacteria, enzymes, and substrate. Mixing using a tractor loader was found to cause significantly greater heat losses during mixing than the use of a compost windrow turner for mixing. This initial heat loss was observed to reduce the rate of natural convention and create a temporary oxygen deficit, increasing the potential for CH_4 production, until the temperature recovered. Based on the data collected, mixing is warranted for bacteria, enzyme and substrate distribution as opposed to aeration and should be carried out using a compost windrow turner to minimize heat losses.

The data collected did not indicate that one composting technique was advantageous over another in reducing the production of CH_4. Anaerobic microsites were found to exist regardless of the technology used. Establishment of anaerobic microsites is a function of the non-homogenous nature of manure. Forced-aeration processes without mixing were not observed to reduce CH_4 concentrations in pore-spaces or off-gases. It is believed that mixing will help reduce the level of anaerobic microsites.

Compost curing for up to 90 days was observed to be insufficient time for the chemical transformations necessary to eliminate seed germination inhibition, characteristic of composts at the end of the active heating cycle of composting processes. There was no evidence from the data collected that compost curing up to 90 days would reduce the potential for nitrogen leaching.

The benefit of a 50% reduction in manure volumes due to composting is typically offset by the value of the nitrogen lost during the composting process. Nitrogen losses during composting for beef cattle manure were found to be equivalent in value to the reduced spreading costs. The reduced spreading costs for dairy cattle manure as a result of composting were found to yield a net benefit of $0.41/T (wet) manure composted after N losses were accounted for. In the case of poultry manure, the cost of nitrogen loss exceeds the benefit of reduced spreading costs by $5.10/T (wet).

SOMMAIRE

On a effectué 16 essais dans le but d'étudier différentes techniques traditionnelles et écologiques de compostage de fumiers à la ferme. Ces essais visaient à mesurer les pertes de carbone et d'azote ainsi que les pertes d'azote, de phosphore et de potassium par lessivage. De plus, on a déterminé les effets des techniques de compostage sur les concentrations de méthane (CH_4), de dioxyde de carbone (CO_2), d'ammoniac (NH_3) et d'oxygène (O_2) se dégageant dans l'air et dans les espaces interstitiels. Des données ont été recueillies pour la surveillance des températures, des pertes d'eau et, dans certaines expériences, des changements de poids. Des essais de germination, effectués avec des graines de cresson, ont permis de comparer les niveaux d'inhibition de la germination des graines à la fin du processus de compostage actif, soit au moment où la température du compost est proche de la température ambiante. On a également évalué l'inhibition de la germination par le compost après 30, 60 et 90 jours de séchage.

Des échantillons de fumier de bovins de boucherie et de bovins laitiers et de volaille ont été soumis à des analyses visant à déterminer s'ils conviennent au compostage aux points de vue du taux d'humidité et du rapport carbone-azote (C-N). En outre, les fumiers utilisés et les composts produits au cours de l'étude ont fait l'objet d'échantillonnages et d'analyses pour le dosage des éléments suivants : azote total (N), phosphore (P), potassium (K), azote ammoniacal (ammonium et ammoniac), azote sous forme de nitrate (NO_3), azote sous forme de nitrite (NO_2), matières sèches (MS), matières organiques (MO), carbone total (CT), pH et cendre.

Le taux d'humidité des fumiers complets de bovins de boucherie et de bovins laitiers dont on a utilisé des échantillons pendant l'étude allait de 70 à 80%, bien au-delà du taux optimal de 60 %. En ce qui concerne le fumier de volaille, il s'élevait en moyenne à 33 %, bien en deçà du taux optimal. Dans tous les fumiers, le rapport C-N était très inférieur au rapport optimal de 30-1 (depuis 10-1 dans le fumier de volaille jusqu'à 16-1 à 17-1 dans le fumier de bovin).

Selon les données sur trois techniques de compostage écologique employées par des agriculteurs, celles-ci ne présentent pas d'avantages sur les techniques traditionnelles quant à la conservation de l'azote, à la réduction des pertes par lessivage ou à la maturité indiquée par l'inhibition de la germination des graines.

La comparaison de techniques traditionnelles de compostage en tas, par aération passive et par aération forcée, avec des tas comparables de 3 m de diamètre et de 1,2 m de hauteur, n'a pas permis de déterminer que l'une d'elles était supérieure en ce qui touche la conservation du carbone ou de l'azote, le potentiel de perte par lessivage ou le degré d'inhibition de la germination des graines.

Les pertes d'azote et de carbone et le potentiel de perte de matières nutritives par lessivage étaient semblables, que le compost soit abrité ou non. Dans le premier cas, le fumier en voie de compostage, l'action des rayons du soleil formait une croûte, qui réduit le potentiel de perte d'azote par lessivage pendant le compostage même si les tas sont exposés à la pluie. La perte nette d'eau dans le compost abrité dépassait d'environ 20 % celle qu'on a mesurée dans le compost non abrité. Par ailleurs, dans le compost non abrité, cette perte était de 43,2 %, en comparaison de 69,6 % dans le compost témoin abrité. Les processus de compostage, manipulés à des fins de conservation de l'azote, n'entraînaient pas une

perte d'eau suffisante pour qu'ils conviennent au traitement des résidus liquides de la ferme (p. ex. les eaux de ruissellement d'étable).

Dans le fumier composté, le potentiel de perte d'azote, de phosphore et de potassium par lessivage était moindre que dans le fumier non composté. Au terme de 14 des 16 essais effectués, le compostage réduisait les pertes d'azote, de phosphore et de potassium par lessivage.

L'étude a révélé que, dans des tas de 3 m de diamètre et de 1,2 m de hauteur, la convection naturelle est suffisante pour maintenir des conditions aérobies sans qu'il soit nécessaire de recourir à l'aération forcée, à des tubes d'aération statiques ou au mélange. Toutefois, on a constaté que le mélange stimule l'activité bactérienne (comme l'indiquait la hausse de la température après le mélange), même quand la concentration d'oxygène dans les espaces interstitiels n'est pas limitative. On estime que cela s'explique par la redistribution des bactéries, des enzymes et du substrat. L'utilisation d'un tracteur équipé d'une chargeuse pour le mélange du compost entraînait des pertes de chaleur beaucoup plus grandes que le recours à un culbuteur de compost. Cette perte de chaleur initiale réduisait la convection naturelle et créait un déficit en oxygène temporaire augmentant le potentiel de production de CH_4 jusqu'à ce que la température se rétablisse. Selon les données recueillies, le mélange favorise davantage la distribution des bactéries, des enzymes et du substrat que l'aération, et il faudrait l'effectuer à l'aide d'un culbuteur de compost pour réduire les pertes de chaleur.

Les résultats des essais ne permettent pas de déterminer si une technique de compostage est supérieure aux autres en ce qui concerne la réduction de la quantité de CH_4 produite, car il existait des microsites anaérobies dans tous les cas. La présence de ces microsites est fonction de l'hétérogénéité du fumier. L'aération forcée sans mélange ne permettait pas de réduire les concentrations de CH_4 dans les espaces interstitiels ni dans les dégagements gazeux. On estime que le mélange aide à réduire le nombre de microsites anaérobies.

Le séchage pendant 90 jours n'était pas suffisant pour permettre les transformations chimiques qui doivent s'opérer pour éliminer l'inhibition de la germination des graines qui caractérise les composts au terme du cycle de chauffage actif du processus de compostage. Rien n'indique, dans les résultats obtenus, que le séchage du compost pendant une période allant jusqu'à 90 jours réduit le potentiel de pertes d'azote par lessivage.

En règle générale, la réduction de 50 % du volume des fumiers par suite du compostage est contrebalancée par la perte d'azote pendant le compostage. Pour le fumier de bovins, le coût de cette perte équivalait à la baisse du coût d'épandage. Dans le cas du fumier de bovins laitiers, la réduction du coût de l'épandage attribuable au compostage entraînait un bénéfice net de 0,41 $ par tonne (poids humide) de fumier composté, après la prise en compte des pertes d'azote. Dans le cas du fumier de volaille, le coût des pertes d'azote dépasse la réduction du coût de l'épandage de 5,10 $ la tonne (poids humide).

GLOSSARY OF TERMS AND ABBREVIATIONS

Af	Ash - Finish
Ammoniacal nitrogen	The sum of ammonia (NH_3) and ammonium (NH_4) nitrogen reported as equivalent ammonium nitrogen
Anova	Analysis of Variance
As	Ash - Start
"As is" basis	Wet basis as sampled
C/N ratio	Carbon to Nitrogen ratio
CH_4	Methane
cm	centimetre
Compost	Organic material which has completed the heat phase of controlled aerobic bacterial degradation process.
Cured Compost	Organic material which has completed the heat phase of controlled aerobic bacterial degradation and has been allowed to sit for sufficient time for secondary bacterial and chemical stabilization reactions to take place which eliminate seed germination inhibition.
Inhibition compounds	Compounds which inhibit the germination of seeds.
Curing period	The period of time which compost material is allowed to sit to enable secondary stabilization processes to take place.
CO_2	Carbon Dioxide
D.M.	Dry Matter
dia	diameter
Dry weight basis	Weight values based on the dry matter content of a sample.
hp	Horsepower
hr	Hour
K	Potassium
kg	Kilogram
L	Litre
m	Metre
m^3	Cubic Metre
mg	Milligram
min	Minute
mV	Millivolt
MOEE	Ontario Ministry of Environment and Energy
NH_4^+-N	Ammonium ion nitrogen
NH_3-N	Ammonia gas nitrogen
NO_2-N	Nitrite nitrogen
NO_3-N	Nitrate nitrogen
O_2	Oxygen

O.M.	Organic Matter
P	Phosphorus
Pf	Parameter - Finish (e.g.: nitrogen - finish)
pH	A unit which represents the relative acidic or akalinic characteristic of a sample.
ppm	parts per million
Ps	Parameter - Start (e.g.: nitrogen - start)
Raw Manure	This term refers to the source manure used as the input for establishing the compost trials in the study. The terms "raw manure" and "manure" are used interchangeably throughout the report.
Significant difference	A difference between treatments which is greater than the differences observed between samples within a treatment as determined by statistical analysis techniques.
Statistically significant	A difference between treatments which is greater than the differences observed between replicates within a treatment as determined by statistical analysis techniques.
s	second
T	metric tonne
TKN	Total Kjeldhal Nitrogen
Total Nitrogen	This term is used to refer to all forms of nitrogen (mineral and organic) that may be present. The terms "total nitrogen" and "nitrogen" are used interchangeably throughout the report.
Uncured compost	Organic material which has completed the heating phase of controlled aerobic bacterial degradation.
V	Volt
% V/V	Percentage is expressed on a volumetric basis.
Wet weight basis	Results presented as a percentage of the wet weight (as sampled weight) of a sample.
%	percent

1.0 INTRODUCTION

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. However, as early as the sixteenth century, researchers became aware of the potential for nutrient loss from manures by leaching and volatilization.

In recent years, composting has been receiving increased attention as an alternative manure management practice to biologically stabilize manure, trap plant nutrients in microbial biomass, kill pathogens and weed seeds and reduce the mass and volume of manure requiring disposal. Temperatures of 55-60EC are considered sufficient to kill essentially all pathogenic virus, bacteria, protozoa (including cysts) and helminth ova to acceptably low levels (Haug 1980). Researchers are still in two camps regarding the benefits or need to compost. Beauchamp (1992) has expressed concerns about nitrogen loss from composting systems through volatilization and leaching, loss of organic matter and costs associated with composting. Mathur (1992) has summarized research by himself and other researchers which documents the superiority of using compost for rebuilding soil humus over raw manure.

Composting in general terms is a biological degradation process which reduces organic substances to a stable, humus-rich material. The microorganisms which are involved in composting, break down organic materials to obtain the necessary elements for microbial biomass synthesis. Natural organic degradation occurs endlessly in nature, and commences every time any living plant or animal dies or defecates. It is nature's means of recycling nutrients within ecosystems. Composting is a human manipulated biological degradation process which mimics the natural biological degradation of organic matter.

References to composting as part of man's activities can be found back to Biblical times. Since the 1940's, composting principles have been studied in an effort to optimize conditions for bacterial degradation of a wide variety of organic wastes, and thus reduce the time required to produce stable compost. However, only in recent years have researchers considered the environmental impacts of composting and composting process optimization to maximize nutrient and organic matter retention during the composting process.

2.0 STUDY OBJECTIVES

The overall objective of this project was to evaluate on-farm composting techniques suitable for use in Ontario by commercial livestock and poultry farm operations. The evaluation assessed the composting techniques in terms of their carbon and nutrient transformations and losses, sustainability, environmental impacts, economic viability and their potential for implementation as part of a farm manure nutrient management strategy.

Specific objectives of this investigation were as follows:

1. Track and compare carbon, nitrogen and other nutrient transformations and losses during manure composting at farm scale, using a combination of on-line, continuous monitoring equipment and bulk sampling and analysis techniques.

2. Determine the economic and physical limitations of optimizing carbon to nitrogen ratios using traditional bedding materials, as a strategy for improving nitrogen retention during composting.

3. Determine the moisture evaporation potential of composting manure, to assess moisture addition requirements and the viability of using actively composting manure as a treatment and nutrient recycling process for barnyard runoff.

4. Determine the relative nutrient leaching potential of manures and composts as a function of composting processes and degree of compost maturity.

5. Compare traditional composting techniques with those practiced by members of the Ecological Farmers Association of Ontario.

6. Determine the significance of seeding raw manure with compost as a technique for reducing nitrogen loss.

7. Quantify greenhouse gas concentrations in off-gases from composting manure and identify composting process factors which affect their production.

8. Determine the economic viability of each composting technology examined, and compare composting processes in terms of labour requirements, energy requirements, nutrient losses, greenhouse gas production, suitability for implementation as part of an integrated manure and nutrient management system, and quality of finished compost.

3.0 BACKGROUND

Over the past ten years a considerable amount of research has been carried out with respect to composting processes. In recent years, research levels have been skewed towards municipal and industrial waste composting, as opposed to manure composting, in an effort to divert solid wastes from landfill sites.

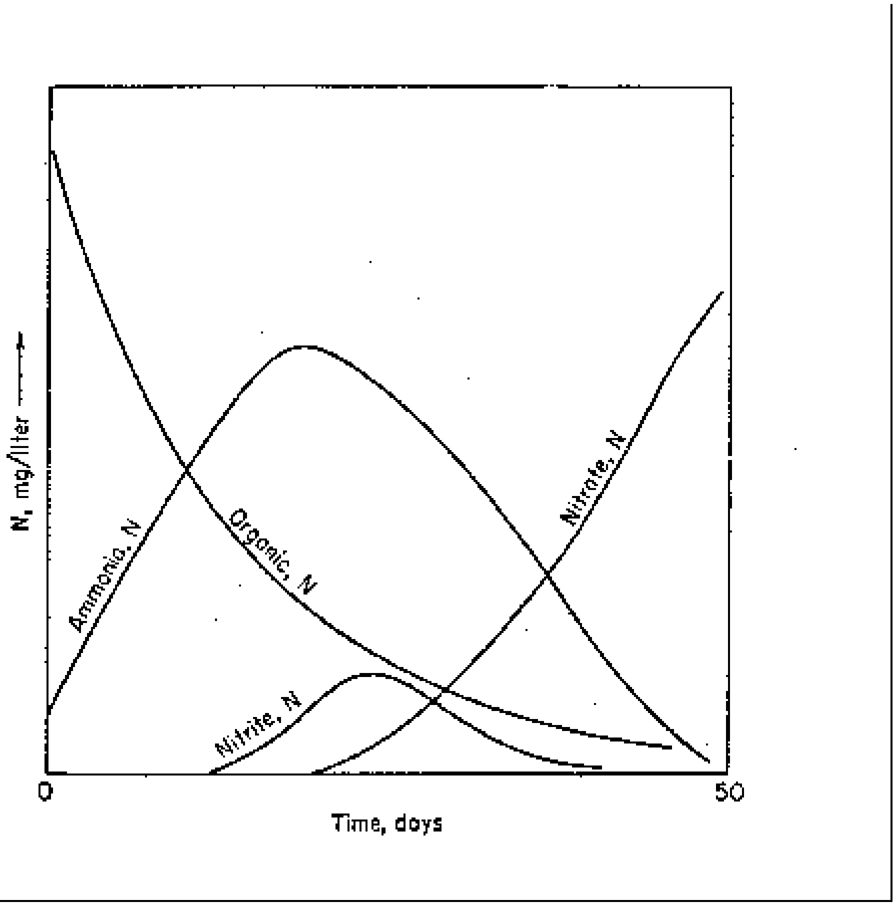
Composting of a wide variety of manures ranging from swine to beef, dairy and poultry are being carried out on a limited number of commercial farms in Ontario. One of four basic principles are generally employed for on-farm composting. These include passive-aeration composting, turned-pile-windrow composting, aerated-static-pile composting and in-vessel mechanically-mixed-forced-aeration composting. Some variations of these processes exist such as bin composting, short-term sheet composting used by some of the Ecological Farmers in Ontario, and turned-pile composting under covered conditions.

Manure composting processes are well understood from the standpoint of optimizing conditions for microbial decomposition. However, nutrient losses and the environmental impact aspects of composting are not as well researched, and some contradictions are cited in literature.

It is well accepted by researchers that nitrogen loss does occur during the manure composting process, but the extent of the loss is not confirmed. Nitrogen loss occurs as a result of leaching during rainfall and snow-melts, from volatilization of NH_3 nitrogen and to a limited extent from nitrogen release due to denitrification if aerobic conditions are not maintained. In-vessel composting systems can minimize nitrogen losses, however these systems are costly compared to traditional turned-pile or static-pile-passive or forced-aeration processes historically used for on-farm composting of manures.

Figure 3.1 shows a general set of curves for the nitrogen transformations which occur during the aerobic decomposition of organic wastes in water. The same general trends apply to composting manure, however, the curves representing the mineral forms would shift somewhat depending on the composting technology employed and ultimately on the rate of biological degradation (composting).

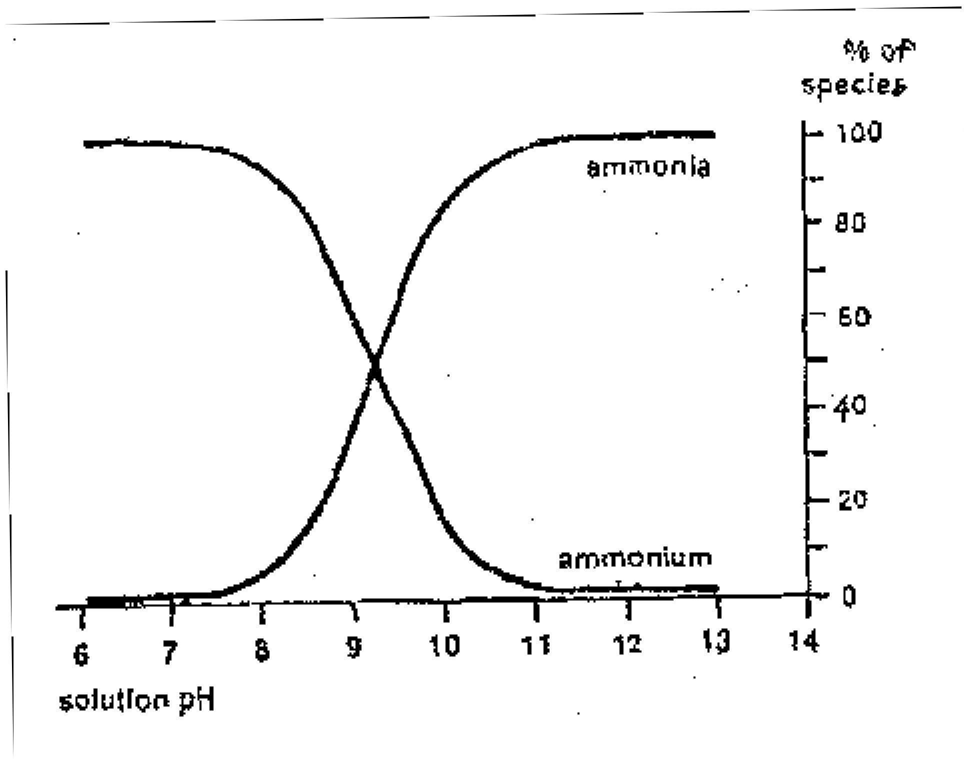
Figure 3.1. Nitrogen Transformation During Aerobic Decomposition of Organic Wastes in Water (Sawyer, C., *et al*. 1978)



Hansen *et al*. (1993) found that 85% of the NH_3 emitted during high rate composting of poultry manure occurred within the first four to five days. These results are in agreement with observations by a commercial farmer (Bechtel 1992), who has noticed that high levels of NH_3 odour are present during the first four or five days of high rate composting of beef cattle manure. After this period noticeable NH_3 smells are not present.

Ammonia volatilization is dependent on four factors, pH, moisture, air exchange rate and C/N ratio of the raw material being composted. Figure 3.2 shows the relationship between free NH_3 and NH_4 ion as a function of pH. The total of NH_3 and NH_4 species is referred to as ammoniacal nitrogen. As ammoniacal nitrogen concentration and/or pH increases, a greater percentage of ammoniacal nitrogen is present in the NH_3 form, which is highly volatile compared to the stable ammonium (NH_4^+) form. The reduction of moisture has a

Figure 3.2. **Relationship Between Free Ammonia and Ammonium Ion as a Function of pH (Smith, R. *et al*. 1974)**



concentrating effect on the NH_3 present, and results in greater volatilization losses (Termeer 1992). Air exchange within the compost mass can also greatly affect NH_3 volatilization. Air stripping of NH_3 is a technology well developed in wastewater treatment. Air passed up through a packed bed chamber in which wastewater flows down, is used to strip NH_3. Accelerated aeration rates used in high rate composting processes for cooling, as well as aeration, can have the same effect.

Research by Lau, *et al*. (1993), used air flow rates of 0.1 L/min/kg volatile matter for pilot scale high rate composting of liquid pig manure mixed with peat moss, and was successful in producing compost. Pos (1991) indicates that aeration of 30 m^3/day/T to 70 m^3/day/T, supplied over 3 min to 7 min intervals every hour, is adequate for high rate manure composting. Research by the United States Health Services Department found that 1 T of actively composting organic material consumed 570 m^3 of air/day, in raised bed (passive-aeration type) composting (Martin 1992). This equates to 0.4 L/min/kg of composting material, significantly higher than levels used in Lau's high rate process research, or Pos's guideline. This would indicate that passive-aeration systems may have potential for high NH_3 losses as well.

Carbon/nitrogen (C/N) ratio is well documented as being an important factor in compost processes, as well as in nitrogen conservation. C/N ratios in the 20 to 30 range are generally accepted as optimum. Haug (1980) has indicated the optimum range is based on the fact that aerobic microorganisms utilize C/N in the ratio of 15-30:1 during active growth. This is generally corroborated by other researchers. Hansen *et al*. (1993) demonstrated that increasing C/N ratio from 15:1 to 20:1 had a significant effect on reducing NH_3 volatilization during composting of poultry manure.

Obtaining the optimum C/N ratio in fresh manures has practical implications at commercial farm scale. Ecologistics Limited (1993) found that fresh manures from heavily bedded beef cattle on a finishing feed ration had a C/N ratio of 13.5:1. Jobin (1993) found that it was not practical to achieve a C/N ratio over 18 for dairy cattle manure. Hansen, *et al*. (1993), indicated that in order to obtain a C/N ratio of 30 with poultry manure, it took 3 units of carbon amendment per unit of manure on a weight basis. This would have a significant impact on costs, volumes of material to be processed and labour requirements at commercial farm scale.

Ecologistics Limited (1993) found that in-vessel composting (forced-aeration-mechanically-mixed), passive-aeration composting, and turned-pile manure composting processes carried out under covered conditions require moisture addition in order to reach biological maturity. All processes lost between 71% and 85% of their original moisture during the active composting period, resulting in moisture becoming a limiting factor to biological activity. The low moisture composts were also found to be relatively inactive during a six to eight month curing period, but became fully active after the curing period when moisture was added and the materials mixed, with temperatures reaching the 62EC range. This has practical implications in that it indicates that composting processes in general can be integrated into an overall farm nutrient management system, using biologically active compost to treat barnyard runoff and dairy farm milk house washwater. This would eliminate the need for duplicated waste handling equipment on many farms and retain valuable nutrients for use in farm production.

Composting literature indicates that maturity is not an easily defined parameter. Compost maturity refers to the extent of biological degradation. Generally, it is accepted that composting is the rapid heat producing phase of biological degradation, and that once heat production subsides, provided conditions of moisture and air are not limiting, the active composting phase is complete. Degradation continues, but at a much slower rate from this point on. The compost is considered to reach maturity after a curing period during which the composted materials under go primarily chemical transformations.

Numerous maturity tests exist and are used by researchers and composters. However, there has been no unanimous consensus, and in fact, in Canada and the United States, government agencies are trying to establish explicit sets of maturity criteria for composts based on the nature of the original feed stock and ultimate use of the finished compost. Morel, *et al*. (1984), summarized seven tests used for determining the level of maturity of municipal refuse compost. Mathur (1992) has reviewed 29 compost maturity tests including those cited by Morel. Mathur has indicated that none of the 29 tests was free of conceptual deficiencies or easily applied reliably at reasonable cost.

In general, manure compost maturity will be achieved if the starting material is amenable to composting and air and moisture levels are maintained at suitable levels during composting. An appropriate C/N ratio, based on total nitrogen and total carbon, is generally considered to be in the range of 25:1 to 30:1 for manures (Rynke 1992). Pore-space O_2 levels above 5% and moisture levels between 40% and 65% are suitable levels (Rynke 1992). Solid manures have been demonstrated extensively, to be amenable to composting. McConnel (1993) has stated that the ability to control composting process air and moisture ensures consistent compost quality (maturity). Compost maturity is of concern because immature compost contains phytotoxins which can inhibit seed germination and retard plant growth (Mathur 1993, Logsdon 1989). In fact, when used as a mulch, uncured compost can inhibit weed seed germination, providing a benefit. As well, immature compost contains nitrogen and phosphorus in forms susceptible to leaching, Ecologistics Limited (1993).

Numerous studies have been conducted using peat moss as a manure amendment for carbon addition, solidifying liquid manures for composting, and for trapping volatilized NH_3. However, peat moss is not considered a renewable resource (Environment Canada 1988). The draining of wetlands and the mining of peat has detrimental effects on the environment. Existing wetlands in Canada accumulate peat at a rate of 2.89 to 10.6 cm per hundred years (Environment Canada 1988). In Ontario alone, 34.1

million tonnes of livestock and poultry manure are produced annually, based on livestock numbers from the 1991 Census of Agriculture. The promotion of peat as a manure composting amendment would result in the consumption of considerable quantities of peat, and would be contradictory to promoting environmentally sound, sustainable agricultural practices.

Odours generated from composting processes originate from the release of gaseous intermediate compounds. Miller (1993) listed 25 compounds identified by various researchers as contributing to compost odours. Odours are generally more of a problem at facilities located in close proximity to urban areas. The use of bio-filters and chemical scrubbing are two means frequently used for control of odours at municipal and industrial composting sites. Optimization of the composting process to promote rapid degradation at the start of the process can be effective in reducing composting odours. Aerobic composting of manures does not increase odour levels above levels that would be experienced during land application, particularly if manures were anaerobic prior to spreading.

Mass balances for various composting parameters at pilot or full scale are frequently based on conservation of ash principles. The effectiveness of conservation of ash mass balance techniques were examined as part of the project described herein using actual weight loss data for comparison.

4.0 EXPERIMENTAL PROCEDURES

This report documents the results of 16 composting processes conducted over a 3 year period. Key descriptors and features of the composting processes assessed are presented in Table 4.1 Thirteen of the 16 composting processes were conducted at a base site with facilities for indoor composting and on-line monitoring of temperature, moisture, weight change, and monitoring of off-gas and pore-space concentrations of O_2, CO_2, NH_3 and CH_4. The base site was a conventional cow-calf beef operation, and all base site composting processes were carried out using beef cattle manure from a manure pack.

Three processes were conducted the first year; turned-pile, passive-aeration and intermittent-forced-aeration composting processes. In the second year, six composting processes were conducted. Three of the second year composting processes were carried out at the base site, and three at ecological farming operations which routinely compost manure as part of their manure management program. Within the ecological farming sector in Ontario, somewhat unconventional methods of composting are used. The intent of conducting experiments at these organic farms was to determine what measurable benefits in terms of carbon, nitrogen and other nutrient conservation could be identified and attributed to the manure characteristics or composting methods used. Three cooperator farms were selected that each use a different technique for composting their livestock manure.

The ecological cooperator farms included a dairy operation, a dairy and beef operation and a mixed farming operation which had mixed manure from dairy, beef, poultry, swine and horses. The dairy operation uses a modified-static-pile method, the dairy and beef operation uses a field windrow method and the mixed farming operation uses a process referred to as the Luptke Method which consists of following a specific manure amendment recipe. This amendment recipe is described in detail in Section 4.2.7 of this report.

The three second year composting processes, carried out at the base site, examined relative differences in carbon, nitrogen and other nutrient conservation between composting under covered conditions, composting under open conditions and composting with barnyard runoff addition to the compost. These experiments were conducted simultaneously using turned-pile composting methods.

Table 4.1. **Overview of Composting Processes Evaluated**

Experiment Year	Process Type	Process Abbreviation	Process Number	Special Features	Composting Environment	Report Section
Year One	Static-Pile-Forced-Aeration	FA	1	Intermittent forced-aeration	Covered conditions	4.3.1.1
	Static-Pile-Passive-Aeration	PA	2	Passive-aeration using perforated pipe.	Covered conditions	4.3.1.2
	Turned-Pile	TP	3	Loader tractor mixed.	Covered conditions	4.3.1.3
Year Two	Turned-Pile	TPR	4	Loader tractor mixed. runoff addition.	Covered conditions	4.3.2.1
	Turned-Pile	TPO	5	Loader tractor mixed.	Outside	4.3.2.2
	Turned-Pile	TPI	6	Loader tractor mixed.	Covered conditions	4.3.2.3
	Sittler-Turned-Pile-Luptke-Method (Sittler Process)	ES	7	Mixed using commercial windrow turner. Ecological farm process.	Outside with air porus water shedding cover.	4.3.2.4
	Zettle-Modified-Static-Pile (Zettle Process)	TZ	8	Passive-aeration. Ecological farm process.	Covered conditions.	4.3.2.5
	Lindner-Field-Windrow	FL	9	Field windrow. Ecological farm process.	Outside	4.3.2.6
Year Three	Static-Pile-Forced-Aeration	FAC	10	Continuous forced-aeration. Aeration initiated 21 days after process start.	Covered conditions	4.3.3.1

Experiment Year	Process Type	Process Abbreviation	Process Number	Special Features	Composting Environment	Report Section
	Static-Pile-Forced-Aeration	FA	1	Intermittent forced-aeration	Covered conditions	4.3.1.1
	Static-Pile-Passive-Aeration	PAC	11	Passive-aeration using perforated pipe. Aeration pipe sealed for first 21 days.	Covered conditions.	4.3.3.2
	Static-Pile-Passive-Aeration	PAO	12	Passive-aeration using perforated pipe.	Covered conditions.	4.3.3.3
	Turned-Pile	TPS	13	Loader tractor mixed. Manure amended with finished compost.	Covered conditions.	4.3.3.4
	Turned-Pile	TP21	14	Loader tractor mixed. Mixed 21 days after process start.	Covered conditions.	4.3.3.5
	Compost curing	PACC	15	Windrow curing of process #11 compost.	Covered conditions.	4.3.3.6
	Compost curing	PAOC	16	Windrow curing of process #12 compost.	Covered conditions.	4.3.3.7

Seven composting experiments were conducted in the third year. The effect of restricting O_2 for the first 21 days of composting, considered the peak NH_3 loss period for composting, was examined using passive-aeration, continuous-forced-aeration and turned-pile composting processes. The effect of "seeding" manure with finished compost was examined using turned-pile composting. The effect of curing periods of one, two and three months were examined using compost produced by passive-aeration composting techniques.

No attempt was made to alter the C/N ratio of manures used for the composting trials. The intent of the experiments was to compare composting practises using manures characteristic of those generally produced by farmers using bedded livestock facilities. All processes were replicated three times.

4.1 Statistical Analysis

Laboratory and numerical data, such as nutrient levels, organic matter levels and moisture collected for experiments conducted in the same year were statistically analyzed and compared using ANOVA techniques. A one-way classification analysis of variance technique, as described by Snedecor (1980), was completed using an Excel spreadsheet program to compare data between treatments (composting processes). The analysis of variance software provided an "F" value indicating the relative level of difference in data variance between treatments compared to data variance within treatments. Significant differences between treatments at a 99% level of confidence were assessed based on a comparison of the "F" value calculated by the spreadsheet software and Table "F" values at the 99% level of confidence. The spreadsheet results were verified using the Statgraphics statistical analysis software package. (Statistical Graphics Corporation 1987).

The differences between treatment means were compared using Scheffe's comparison techniques. These techniques, described by Maxwell (1983), were used to determine the significance of mean observation differences. The comparison procedure uses the calculated "F" value from the ANOVA table and table "F" values to determine a critical value above which mean differences are considered significant. The number of sample points in a data set is also factored into the calculations. Differences in treatment means were analyzed for significance at a 99% level of confidence.

Mean differences that are above the critical 99% level of confidence value generated by Scheffe's procedure are referred to as "statistically significant differences" or "significant differences" throughout the text. A mean difference above this critical level, observed for a particular parameter measured, indicates that the variability in the parameter's value between treatments is greater than the variability of data within treatments and therefore the differences are considered statistically significant. Statistical results are summarized at the bottom of the various data tables in the Results and Discussion section of this report. Mean differences of particular parameters that are statistically significant between compared treatments are identified by using treatment abbreviation symbols separated by an "X". For example, if the statistical analysis showed a significant difference existed in the nitrogen content of the finished compost between the open passive aeration process (PAO) and the turned-pile process (TP), the code "PAO X TP" would have been entered in the bottom of the data table under the "Nitrogen" column.

4.2 Raw Manure Characterization

Four composite manure samples were taken for each process replicate for each of the composting trials conducted. The composite samples contained a minimum of 10 grab samples each. Sufficient grab samples were taken to fill a 23 L sample pail. The composite pail sample material was hand mixed prior to filling 1 L bags for laboratory submission and analysis. The initial composite pail samples were divided in two with one of the resulting samples used for leachate tests and the other sample used for bulk analysis. Four samples from each process replicate were submitted for bulk analysis. Four samples for each process technology were submitted for leachate tests (see Appendix A).

All manure samples were analyzed for total solids, moisture, ash, organic carbon, inorganic carbon, total carbon, total nitrogen, ammoniacal nitrogen (NH_4^++NH_3) reported as ammonium (NH_4) nitrogen[1], nitrate (NO_3) nitrogen, nitrite (NO_2) nitrogen, phosphorous (P), potassium (K) and pH. These analyses were carried out at the Analytical Services Laboratory, located at the University of Guelph. Data for experiments conducted in the first, second and third year experiments are presented in Tables 5.1, 5.2 and 5.3, respectively in the Results and Discussion section of this report.

Four composite manure samples, representative of the manure used for each composting process, were subjected to Ontario Ministry of Environment and Energy (MOEE) Regulation 347 leachate tests using distilled water as the leaching agent. Manure leachates were analyzed for total Kjeldahl nitrogen, NH_3 nitrogen, NO_3 nitrogen, NO_2 nitrogen, total phosphorus and total potassium. Tables 5.11, 5.12 and 5.13 in the Results and Discussion section of this report present the leachate data for the experiments conducted in this study. Leachate tests were carried out by CANVIRO Analytical Laboratories Ltd. of Waterloo, Ontario.

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[1] Note that manure laboratory analysis procedures for NH_4 concentrations include NH_3 which is converted to NH_4 during the analysis of the sample.

4.3 Composting Procedures

The composting procedures used for each trial are described in the following sections.
Composting facilities and monitoring equipment at the main research site, a conventional cow calf beef farm, were set up to monitor concurrent composting processes. This allowed a direct comparison of processes using the same manure lot under the same climatic influences. Composting procedures carried out at cooperator farms were conducted in the manner typical for the operation.

Manure quantities composted during each trial at the main research site were similar. Each replicate involved the composting of approximately 3,600 kg of raw manure. The manures used for the processes carried out each year at the base site were obtained from a manure pack, which had accumulated over approximately a six month period just prior to establishing the trials. The manure was generated by a cow-calf herd on a roughage diet. The cattle were bedded with wheat straw at a rate characteristic of normal practices used by beef and dairy producers to maintain dry pen conditions.

Composting trials were set up to dimensionally represent a section of a typical farm scale composting processes with base widths of 2.4 to 3.0 m. All composting trials were replicated three times. Sixteen composting trials were carried out in total. Table 4.1 provides a summary of the 16 trials. Details of each trial can be found in the appropriate section listed in table 4.1.

4.3.1 Description of Year 1 Trials

4.3.1.1 Static-Pile-Forced-Aeration Composting - Intermittent Aeration - Process #1

Three static-pile-forced-aeration composting process replicates were conducted on weigh scale platforms suspended from overhead I-beams. The platforms were supported by chains at each corner with a load cell (described in Section 4.4.6) incorporated into each suspension chain. Each platform had inside dimensions of 3 m by 1.8 m and peripheral walls with a height of 1.2 m. The floor and walls of the platforms were insulated with 5 cm thick styrofoam insulation board to conserve heat during cold weather composting and reduce the influence of heat loss from aeration. The process was conducted inside to protect it from rain.

Each platform bin had an aeration grid made up of four, 10 cm dia. perforated pipes of the type used for septic system weeping beds. The pipes were perforated on approximately one third of their circumference. The pipes were evenly spaced across the base of the bins with the perforated part of the pipes facing down to help eliminate vertical short-circuiting of air flow. Forced-aeration was provided by three Gast Regenair R2 Series oil-less regenerative blowers. Aeration was provided for 5 min every hour for the duration of the composting process. The air flowrate was set at 0.7 m^3/min based on providing air at a rate of approximately 1 m^3 air/hr/dry T of composting manure.

The three bins were filled slightly over the top wall at the start of the composting processes. During the filling operations, each bin had a perforated pipe with an approximate length of 1 m installed in the manure mass, approximately 0.8 m above the bin base. A gas sampling line and filter were installed in this tube to monitor internal gas concentrations of ammonia (NH_3), oxygen (O_2), carbon dioxide (CO_2) and methane (CH_4). A single moisture monitoring probe (described in Section 4.4.5) and temperature probe (described in Section 4.4.4) were also inserted into the manure mass. The surface of the manure mass was partially covered with a styrofoam hood with a narrow opening along the length of the peak. A gas sampling line and filter were installed in the hood to monitor the composition of the air which was being emitted from the composting manure. Temperature, moisture, weight, and gas composition for internal and external sampling points were sampled every 6 hr for the duration of the composting processes, and daily averages calculated and stored in a data file. Temperature was used as an indication of biological activity and extent of biological degradation. The first year composting processes were terminated when the internal temperature dropped below 6EC with ambient temperatures in the range of -5EC to 5EC.

4.3.1.2 Static-Pile-Passive-Aeration Composting - Process #2

Static-pile-passive-aeration replicates were conducted on a concrete floor under covered conditions. A passive aeration grid was set up using 3 m long perforated pipe of the type used for septic system weeping beds. The pipes were placed on the concrete floor spaced approximately 0.5 m apart. The passive-aeration process replicates had dimensions of 3 m wide by 2.3 m long by 1.3 m high. The process replicates were set up in one continuous windrow to eliminate process variations which may result from short windrows with open ends. The set up and apparatus used for temperature, moisture and off-gas and pore-space gas monitoring was as described in Section 4.3.1.1. Temperature was used as an indication of biological activity and extent of biological degradation and the first year composting processes were terminated when the internal temperature dropped below 6EC with ambient temperatures in the -5EC to 5EC range.

4.3.1.3 Turned-Pile Composting - Process #3

Individual turned-pile windrow replicates were set up on a concrete floor under covered conditions. The windrows had approximate dimensions of 3 m wide by 3 m long by 1.3 m high. The set up and apparatus used for temperature, moisture and off-gas and pore-space gas monitoring was as described in Section 4.3.1.1. Pore-space O_2 concentration was used as an indicator to assess the need for mixing the manure in this trial. As with processes 1 and 2, the pile's temperature was used as an indication of biological activity and extent of biological degradation and the first year composting processes were terminated when the internal temperature dropped to 6EC with ambient temperatures in the -5EC to 5EC.

4.3.2 Description of Year 2 Trials

4.3.2.1 Turned-Pile Composting With Barnyard Runoff Addition - Process #4

Turned-pile composting process replicates to evaluate the effect of runoff addition were conducted on the weigh scale platforms described and used for Process #1. For Process #4, however, the platform's 1.8 m end walls were made of wire mesh to allow peripheral passive air movement through the composting mass. The floor and walls of the platforms remained insulated to conserve heat during cold weather composting.

The three bins were filled slightly over the top wall height at the start of the composting processes with raw manure and the process was monitored in a manner identical to that described for Process #1 (see Section 4.3.1.1). Pore-space O_2 concentration was used as an indicator to assess the need for mixing the manure in this trial.

Mixing only occurred once during the process and this was to facilitate runoff addition rather than to promote aeration because the pore-space O_2 concentration remained above the acceptable range of 5% (Rynk 1992). For mixing purposes, the manure was removed from the bins with a loader tractor, after removal of the bin side walls. Once mixed, the manure was returned to the bins.

Runoff addition was to be based on maintaining moisture levels in the 60% range for this experiment. However, after 110 days of composting, moisture levels had still not dropped below the target value of 60%. Despite these conditions, the decision was made to examine the effect of runoff addition to the composting manure. Barnyard runoff was added to the three composting replicates 120 days after commencing the composting processes. Two hundred L of runoff was added to each replicate. The runoff added to each replicate had a total weight of approximately 200 kg based on the total weight change observed on the load cells after runoff addition. This weight was equivalent to approximately 10% of the total compost weight, at the time of addition, for each replicate. Three composite samples of the runoff were taken for each replicate, generating a total of 9 runoff samples. Each sample was analyzed for TKN, NH_3, NO_3, NO_2, total phosphorus and total potassium.

Temperature was used as an indication of biological activity and extent of biological degradation. The turned-pile composting process with runoff addition was terminated when the internal temperature dropped to 6EC for a 5 day period, with ambient temperatures in the 0EC range.

4.3.2.2 Outside-Turned-Pile Composting - Process #5

Process #5 was set up identical to process #3 with the exception that process #5 was conducted outside on a concrete yard and thus exposed to the weather elements (rainfall, sunlight etc.). Temperature, moisture and gas monitoring were set up and carried out as described in Section 4.3.1.1. The processes were terminated when the internal temperature dropped below 6EC.

Manure mixing was carried out using a New Holland Model 455 skid steer loader.

4.3.2.3 Inside-Turned-Pile Composting - Process #6

Composting replicates were set up as described in Section 4.3.1.3, under covered conditions, to act as a control for direct comparison with outdoor-turned-pile composting and turned-pile composting with runoff addition.

4.3.2.4 Sittler-Turned-Pile Composting Using Luptke Method - Process #7

Manures generated at the Sittler farm originate from a mixture of livestock which includes poultry, swine, dairy, beef and horses. Livestock manures, accumulated over several months, were used in combination with a number of composting amendments added according to a specific recipe defined as the Luptke Method. The recipe consists of the following amendments and addition rates:

Ingredient	**Quantity**
Clean Straw	25 cm depth applied as a base for windrow
Broiler manure	15% of total pile volume
Barnyard manure mix	50% - 55% of total pile volume

Ingredient	**Quantity**
Chopped green hay (1st cut)	20% of total pile volume
Clay (subsoil)	10% of total pile volume
Rock dust[1]	2.5 tons applied per 300 feet of windrow

The amendments were added in layers as the compost windrow was constructed. The windrow was constructed with a base width of 3.5 m and a height of 1.2 m. After completion of the windrow, the compost materials were mixed three times using a windrow compost turner. The windrow mixing unit used for the composting trial was designed and manufactured by Edwin Sittler and is commercially sold. During the initial mixing, the compost turner was operated high enough off the ground to prevent the straw base from being disturbed. At the completion of the initial mixing, an air porus, water shedding cover was placed on the windrow. The compost cover is a non-woven needle-punched agro-textile made of polyester and polypropylene fibres. One side is heat treated to promote rain shedding but the material also allows air movement through it and is considered air porus. The material looks similar in texture to drainage filter cloth and is marketed under the trade name of Compostex Cover.

The constructed and mixed windrow was divided into three 10 m sections, with 5 m between each 10 m section to establish 3 distinct replicates. The first replicate was located 15 m from the windrow end to avoid the possibility of having the composting process affected by the difference in surface exposure to air that exists at the end of the windrow compared to along the length of the windrow. The raw manure compost mixture was sampled after the initial three mixes as outlined in Section 4.1, Raw Manure Characterization.

During the first week of mixing the compost, the straw base was gradually mixed into the windrow by lowering the mixing unit incrementally. A bio-dynamic compost starter mix, supplied by Pfeiffer

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[1] Rockdust is defined as a blend of equal parts of greenstone, gypsum and aregonite.

Greenstone is a paramagnetic mix of basalt, calciums, silicates and metals. Aregonite is a material mined from the ocean off the coast of the Bahamas and contains approximately 54% calcium oxide and 40% carbonate. Both materials are distributed by A.B.M. Farms Ltd., Bluevale, Ontario.

Foundation Inc. (New York) was applied to the windrow at a rate of approximately 57 mL/T of raw manure in the windrow.

The windrow underwent 15 mixes over a 110 day composting period. Each replicate in the windrow was monitored daily for temperature using a 0.9 m long Accutel temperature probe inserted in the centre of the pile.

4.3.2.5 Zettle-Covered-Static-Pile-Windrow Composting - Process #8

Manures at the Zettle farm originate from a dairy herd. Composting at this site is carried out in a concrete bunker silo with a cement floor and wood frame roof. The bunker silo is divided in two by a centre concrete wall. During the fall and early winter months, manure is added to one half of the bunker silo on an approximate 10 day cycle, for composting. The other half is used for bedding storage. When the bedding is all used and the first half of the bunker has reached its manure holding capacity, composting is started in the second half.

Manure is removed from the barn on a daily basis by a stable cleaner and allowed to accumulate under the stable cleaner for approximately 10 days. The manure is removed from below the stable cleaner stack every 10 days and combined with manures generated in pen areas cleaned by loader tractor. This mass of manure is stored in a temporary pile and composting allowed to proceed in this pile for about 10 days. It is then moved to the unheated bunker silo and allowed to compost at ambient temperatures, relying on passive air movement for aeration for the remaining duration of the composting process. The manure is mixed once when the stack and pen manure is combined to form the temporary manure stack. Any liquid which may initially seep from the composting manure is collected in a concrete storage tank and land-applied. No runoff is added to the composting manure.

The manures composted using this method have varied composting time periods, depending on the time of year they are generated. The composted manure is all land-applied in late summer or early fall to make room for bedding storage and winter manure composting. The manures for this trial were composted for 138 days, which was considered an average composting period for this operation.

Three replicates were established for this trial by dividing one temporary pile into three equal amounts. These amounts were added to the covered composting area as usual, taking care to identify the three replicate areas using marker flags. The raw manure was sampled as outlined in Section 4.1 (Raw Manure Characterization), during formation of the temporary piles.

The monitoring program set up for the Zettle farm consisted of daily temperature recording of the cental portion of the process replicates. The cooperator, however, failed to meet his obligation of daily temperature monitoring and no daily temperatures are available for this process.

4.3.2.6 Lindner-Field-Windrow Composting - Process #9

Manures at the Lindner farm originate from dairy and beef livestock. The manure is cleaned from livestock housing areas using a stable cleaner system and loader tractor as required throughout the fall and winter months and stored in an open air storage area with a concrete floor and retaining wall. Manures accumulated in the concrete storage area are moved on an annual basis to a field location for windrow composting in late May. The field windrow is formed using a flail type New Idea box type manure spreader. The manure mass receives some mixing as it is loaded into the manure spreader and during its discharge from the manure spreader.

Three separate field windrows were established to provide three replicates for the trial. Normally the farmer composts in one long windrow. The decision to use three separate windrows was made to eliminate the potential for replicate manures becoming inter-mixed, due to the varied distances that the spreader hurls manure particles, as windrows are being formed by the spreader. Each windrow was formed using three manure spreader loads. The raw manure was sampled as outlined in Section 4.1 (Raw Manure Characterization), during formation of the windrow replicates.

Passive air movement is relied on to provide aeration during the field windrow composting. Temperature was monitored and recorded daily for each replicate windrow. The windrow composting trial was conducted over a 55 day period, typical for this farm operation.

4.3.3 Description of Year 3 Trials

4.3.3.1 Static-Pile-Forced-Aeration Composting - Continuous Aeration - Process #10

Static-pile-continuous-forced-aeration composting process replicates were set up as described in Section 4.3.1.1, except for process #10, aeration was started 21 days after process start-up. This was done to determine if delayed aeration could be used as a technique to reduce nitrogen losses due to NH_3 volatilization during the early stages of composting. Aeration was provided continuously 24 hr a day after day 22, for the duration of the process. The air flowrate was set to provide approximately 1 m^3 air/hr/dry T of composting manure.

4.3.3.2 Static-Pile-Passive-Aeration Composting - Aeration Tubes Sealed for First 21 Days of Process - Process #11

Static-pile-passive-aeration replicates were set up as described in Section 4.3.1.2 with the exception that the passive-aeration tubes were capped and left sealed for the first 21 days of the process. The caps were removed after 21 days and the process allowed to continue to completion without further alterations to the process.

4.3.3.3 Static-Pile-Passive-Aeration Composting - Process #12

Static-pile-passive-aeration replicates were set up as described in Section 4.3.1.2 as a control for comparison with passive-aeration composting with aeration tubes capped for the first 21 days as a strategy to conserve nitrogen.

4.3.3.4 Turned-Pile Composting - Manure Amended with Finished Compost - Process #13

Process replicates were set up as described in Section 4.3.1.3, however, raw manure amended with compost was used for the process. Manure and finished compost were blended using a manure spreader for mixing at a ratio of approximately 40% finished compost and 60% manure by volume.

The intent was to determine if seeding fresh manure with finished compost would result in a reduction in nitrogen losses.

4.3.3.5 Turned-Pile Composting - Process #14

Process replicates were set up as described in Section 4.3.1.3. as a control for comparison with turned-pile composting using manure seeded with finished compost (process #13).

4.3.3.6 Compost Curing - Process #15

Compost produced in process #11 using passive-aeration composting techniques was mixed after completion of the composting process and left to cure for three months. During the curing process, off-gas and pore-space concentrations of NH_3, O_2, CO_2 and CH_4 were monitored. The curing compost was sampled after 30 days, 60 days and 90 days and, like all the other processes studied, the resulting product was analyzed as described in Section 4.5, Compost Characterization.

4.3.3.7 Compost Curing - Process #16

This trial was set-up, monitored and analyzed identical to process #15. The only difference between the two trials was the source of the compost used in the trial. Compost produced in process #12 (passive-aeration composting with the aeration tubes sealed for the first 21 days) was the raw material used for this trial.

4.4 On-Line Compost Process Monitoring and Control

On-line process monitoring was carried out at the main research site for moisture, temperature, weight, and internal and external gaseous concentrations of NH_3, O_2, CO_2, and CH_4. The monitoring and control system was supplied by Sciemetric Instruments Inc. The system used an IBM compatible 486 computer to provide operator interface with sensor input and equipment control boards. A packaged monitoring and control software program called Co-Pilot (Howell Mayhew Engineering, Edmonton, Alberta) was used for monitoring and control functions. The software had built-in routines for calibrating instruments, setting sampling frequencies, setting data averaging periods, setting data save frequencies and controlling process equipment.

The gas sampling system consisted of a heated sampling tube for each internal and external gas sampling point. Three process replicates were conducted for each composting technology. Each process replicate had two gas sampling points, resulting in a total of 18 gas monitoring points. One of the two points in each replicate was located within the composting manure as described in Sections 4.3.1.1. A second point was located at the surface of the composting manure, also described in Section 4.3.1.1. Ambient air in the building, where the composting processes were being conducted, was also monitored. The gas samples withdrawn from all sampling points were maintained at a temperature of 60EC to eliminate condensation at any point in the sampling system.

The gas samples passed through an inlet filter, and a vacuum pump filter, prior to entering the gas analyzers, to prevent dirt contamination of the analyzing equipment. A 12-point rotary sampling valve, in combination with a series of three-way solenoid valves, were used to direct the gases from the appropriate sample points to the analyzers. The software provided the flexibility to set up purge times for each sample point, prior to recording concentration data. All flow meters, filters and valving were maintained at 60EC in a heated equipment control box to prevent condensation problems.

Sampling frequencies are given in Section 4.3.1, describing the set up for each experiment conducted over the three year period.

4.4.1 Ammonia

The on-line NH_3 analysis was performed by a Siemens Ultramat 5 high performance non-dispersive infrared analyzer. The analyzer had four NH_3 measuring ranges. These were 0-200 ppm, 0-500 ppm, 0-1000 ppm and 0-2000 ppm. The unit also had an auto-ranging function which changed ranges when a sample concentration of 80% of full range was detected. The Ultramat 5 had a precision of 0.5 ppm and a response time of 3 s at 90% of full scale. Range calibrations were checked using prepared NH_3/N_2 gas mixtures with ammonia concentrations of 75% of the full scale range. The unit zero was checked using nitrogen gas. The gas mixtures used were prepared by Matheson Gas Products, Whitby, Ontario. A heated version of infrared analyzer that maintained the gas flow tubing and analysis chamber at 65EC was purchased for this project to eliminate condensation problems. Sample tubing from the heated gas sampling control box to the Ultramat 5 analyzer was also heated and maintained at 60EC. A flow rate of 1 L/min was maintained through the analyzer during sampling of all process points.

4.4.2 Oxygen and Carbon Dioxide

The on-line monitoring of O_2 and CO_2 were performed by a Siemens Ultramat 21/Oxy analyzer. The unit used an electrochemical cell for O_2 analysis and non-dispersive infrared technology for CO_2 analysis. The analyzer had dual O_2 measuring ranges. These were 0-10% and 0-25%. The unit also had an auto-ranging function which changed ranges when a sample concentration of 80% of full range was detected. The CO_2 measuring range was 0-10%. The analyzer had a resolution of 0.01% for O_2 and 0.02% for CO_2. Range calibrations were checked using prepared CO_2/N_2 and O_2/air gas mixtures. CO_2 concentrations of 75% of the full scale range and oxygen concentrations of 20.96% were used as calibration standards. The unit zero was checked using nitrogen gas. The gas mixtures used were prepared by Matheson Gas Products. The response time for the unit was 3 s at 90% of full scale. A flow rate of 2 L/min was maintained through the analyzer during sampling of all process points.

4.4.3 Methane

The on-line monitoring of CH_4 was performed by a model 4-20 IQ Intelligent Stand-Alone Sensor Module manufactured by International Sensor Technology. The unit had a full scale range of 0-100 ppm and a resolution of 0.1 ppm. The unit calibration was checked using a CH_4/air gas mixture prepared by Matheson Gas Products. CH_4 concentrations of 50% of full scale were used. The unit was a solid state sensor which worked on a thermal resistance principle. A heater and collector were imbedded into a metal oxide material. Operating at constant power, the sensor had a fixed resistance. When the gas of interest was present, the sensor's resistance changed in proportion to the gas concentration. The electronics of the instrument processed this change and converted it to a ppm equivalence. A flow rate of 0.5 L/min was maintained across the sensor during sampling of all process points.

4.4.4 Temperature

Temperature data was collected for the purpose of establishing the level of microbial biological activity in each process replicate. Temperature monitoring at cooperator sites was performed using a 90 cm long temperature probe (REOTEMP, San Diego, California) with a mechanical temperature dial. Temperature monitoring at the main research site was performed using Type "T" thermocouples permanently imbedded in each compost replicate. Temperatures were monitored every hour and a daily average temperature for each process replicate was saved to a daily data file. The temperature of the ambient air in the building in which the composting processes were conducted at the main research site was also monitored.

4.4.5 Moisture

On-line moisture data was collected at the main research site to determine when and if moisture level in the composting material dropped to the point where it was limiting to bacterial activity. A single Aqua-Tel type AT210 moisture probe, embedded in each process replicate, was used for this purpose. The Aqua-Tel units measure the dielectric constant of the medium in which they are embedded. The unit consists of two flat parallel strips approximately 1 m in length. The unit measures the average dielectric constant of a cylinder of medium with a radius approximately 10 cm beyond the probe edges. The probes were inserted diagonally in each process replicate and positioned to monitor changes in manure moisture content over approximately one-third of the composting manure depth. Moisture content in the centre one-third depth region was monitored. A linear calibration curve was developed for the units using compost at various stages of degradation and moisture levels. The resulting calibration equation was as follows:

$$\% \text{ moisture} = 15.215 * \text{voltage output}$$

This equation was used to convert the moisture probe's voltage output to a gravimetric moisture concentration in %.

4.4.6 Weight Monitoring

Compost processes monitored for weight change were conducted on platforms with dimensions of 3 m by 1.8 m. Three individual platforms were suspended by chains in each corner from over-head I-beams. Turnbuckles were fastened to the corners of each platform and used to raise the platforms off the ground for weight change monitoring. Each support chain had an Artech model 20210 type "S" load cell with a 2250 kg load capacity incorporated into it. The mV output from the load cells was converted to a weight measurement by the data acquisition system. The load cells had a mV output of 3 mV/V and were powered by a 12 V regulated power supply from the data acquisition system. The data acquisition system summed the four load cells for each platform and saved an average daily total weight.

4.5 Compost Characterization

The sampling procedure, used to collect samples for compost characterization, was identical to the procedure described for the raw manure characterization (see Section 4.2). As with the raw manure characterization, four samples from each process replicate were submitted for bulk analysis and four samples for each process technology were submitted for leachate tests (see Appendix A).

Bulk analysis carried out on all compost samples included the same parameters analyzed for in the raw manure samples (see Section 4.2).

Like the raw manure samples, the compost samples were subjected to Ontario Ministry of Environment and Energy Regulation 309 leachate tests and the leachate was analyzed for the same parameters. All tests were completed at the same labs which were used to analyze the raw manure samples (see Section 4.2)

Upon receipt of both the raw manure and the process replicate's corresponding compost analysis results, transformations which occurred during composting were calculated for total nitrogen, ammoniacal nitrogen, NO_3 nitrogen, NO_2 nitrogen, organic carbon, and moisture. Changes in C/N ratio and changes in pH were also calculated. The changes that occurred in the monitored parameters

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

during the composting process were calculated based on the principle of conservation of ash using the equation:

As = % Ash - Start

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

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.

Analysis results were analyzed statistically using analysis of variance techniques and Scheffe comparison procedures as described in Section 4.1.

4.6 Compost Seed Germination Tests

Seed germination tests, using the compost produced under the different processes, were conducted to determine if there was any detectable differences in the compost maturity in terms of seed germination inhibition. The procedures described here and used in this study follow those used for compost testing by the Rodale Institute (Martin 1992). Cress seeds (Ontario Seed Company, Waterloo) were used for the germination tests. Each germination test was replicated three times using an 8 cm diameter plastic growing pot for each replication, with ten seeds planted in each pot. Seeds were planted in pure compost, a 50/50 compost/potting soil mix (Potting and Planter Soil, Nu-Grow Corporation, Woodstock) and pure potting soil to check seed viability.

The total number of seeds that germinated and emerged over a 7 day period were recorded and a seed germination percentage calculated for each of the three replicates. The average seed germination percentage for each test was recorded and reported in the Results and Discussion section (Section 5.9) of this report.

5.0 RESULTS AND DISCUSSION

The results of the 16 composting trials and associated investigations are presented in thirteen sections. Characterization data pertaining to the raw manure used in the composting processes can be found in Section 5.1. Section 5.2 summarizes the results of compost characterization data collected. The results of compost process transformations and losses with respect to total nitrogen, ammoniacal nitrogen, NO_3 nitrogen, NO_2 nitrogen, organic matter, moisture, dry matter, C/N ratio, and pH are presented in Section 5.3. Section 5.4 describes the results of the raw manure and corresponding compost leachate tests. Section 5.5 presents the results of the pore-space and off-gas concentration monitoring that occurred during the composting processes. Temperature and moisture data are presented in Sections 5.6 and 5.7 respectively. Section 5.8 includes weight loss data collected during on-line monitoring of two forced-aeration composting processes, and one turned-pile process with runoff addition. Germination test results for all composts produced during the studies are presented in Section 5.9. The results of compost curing tests are presented in Section 5.10. Section 5.11 provides a comparison of conservation of ash and actual weight-based parameter balances. Section 5.12 includes the results of studies to determine the economic and physical limitations of optimizing C/N ratios as a strategy to improve nitrogen retention. Section 5.13 provides economic considerations for the various composting processes studied during the project.

5.1 Raw Manure Characterization

The raw manure (characteristic) tables (Tables 5.1 through 5.3) show the mean, standard deviation, variance and number of samples analyzed for the manures composted. Significant differences are presented at the bottom of each table.

The manure 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 (Mathur 1992). They also must oxidize, for energy purposes, 2 units of carbon for every unit of carbon retained for microbial biomass (Mathur,1992). For this reason, a C/N ratio of approximately 30:1 is considered optimum for nitrogen retention (Mathur 1992). The C/N ratio of the raw

Table 5.1. Raw Manure Characteristics - First Year Experiments

Process Description	Statistic	N % D.M. Basis	P % D.M. Basis	K % D.M. Basis	NH_4-N mg/kg D.M. Basis	NO_3-N mg/kg D.M. Basis	NO_2-N mg/kg D.M. Basis	O.M. % D.M. Basis	ASH % D.M. Basis	D.M. % As Is Basis	C/N Ratio	pH
Forced-Aeration Intermittent Aeration Process #1 (FA)	Mean	2.49	0.41	3.23	1,736	26.2	1.6	85.75	14.26	24.24	18.34	9.13
	Std.Dev.	0.23	0.05	0.25	636	20.68	1.44	0.69	14.54	0.33	1.49	0.49
	Var.	0.05	0.003	0.06	403,954	427.5	2.08	0.48	13.73	0.11	2.23	0.24
	# Samples	4	4	4	4	4	4	4	4	4	4	
Passive-Aeration Process #2 (PA)	Mean	2.54	0.37	3.58	1,415	25.75	0.98	85.46	14.54	24.39	18.64	8.91
	Std.Dev.	0.46	0.05	0.27	152	22.12	1.34	1.02	1.02	0.46	3.89	0.007
	Var.	0.21	0.003	0.07	23,076	489.2	1.81	1.05	1.05	0.21	15.13	0.001
	# Samples	4	4	4	4	4	4	4	4	4	4	4
Turned-Pile Process #3 (TP)	Mean	2.72	0.39	3.04	1,093	17.62	0.60	86.27	13.73	25.14	17.33	9.00
	Std.Dev.	0.47	0.05	0.24	104	2.79	0.56	2.02	2.02	1.9	2.82	0.10
	Var.	0.22	0.003	0.06	10,763	7.76	0.31	4.09	4.09	3.6	7.94	0.01
	# Samples	4	4	4	4	4	4	4	4	4	4	4
Significant Differences 99% Level of Confidence[1]												

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[1] Each entry in this row of the table indicates that a significant difference was found between the processes compared for the parameter identified at the top of the table column. The two processes compared are identified by their abbreviations separated by an "X". No entry in this table row means no significant differences were observed between any of the processes.

Table 5.2. Raw Manure Characteristics - Second Year Experiments

Process Description	Statistic	N % D.M. Basis	P % D.M. Basis	K % D.M. Basis	NH_4-N mg/kg D.M. Basis	NO_3-N mg/kg D.M. Basis	NO_2-N mg/kg D.M. Basis	O.M. % D.M. Basis	ASH % D.M. Basis	D.M. % As Is Basis	C/N Ratio	pH
Turned-Pile Runoff Addition Process #4 (TPR)	Mean	2.90	0.31	2.59	2024	32.08	0.80	87.62	12.38	27.64	15.35	8.52
	Std.Dev.	0.30	0.04	0.23	727	4.76	0.25	0.84	0.84	2.57	1.64	0.49
	Var.	0.08	0.001	0.05	484380	20.75	0.057	0.64	0.64	6.05	2.46	0.22
	# Samples	12	12	12	12	12	12	12	12	12	12	12
Turned-Pile Outside Process #5 (TPO)	Mean	2.84	0.40	2.69	2985	32.50	2.86	86.98	13.02	28.49	16.98	8.09
	Std.Dev.	0.79	0.18	0.38	1376	9.21	4.43	2.51	2.51	2.76	5.29	0.90
	Var.	0.57	0.03	0.13	1735149	77.82	17.95	5.75	5.75	6.97	25.68	0.73
	# Samples	12	12	12	12	12	12	12	12	12	12	12
Inside-Turned-Pile Process #6 (TPI)	Mean	2.67	0.30	2.61	1864	32.42	0.84	87.58	12.42	28.24	17.53	8.45
	Std.Dev.	0.60	0.05	0.45	645	4.49	0.44	0.81	0.81	2.86	4.35	0.50
	Var.	0.33	0.002	0.18	381405	18.46	0.179	0.60	0.60	7.51	17.36	0.23
	# Samples	12	12	12	12	12	12	12	12	12	12	12
Sittler-Turned-Pile Luptke Method Process #7 (ES)	Mean	1.66	0.72	1.91	3632	23.01	0.70	55.14	44.86	29.42	19.17	8.16
	Std.Dev.	0.50	0.23	0.53	896	9.95	0.13	10.92	10.92	5.15	4.75	0.26
	Var.	0.23	0.05	0.26	736340	90.77	0.016	109.38	109.38	24.34	20.66	0.06
	# Samples	12	12	12	12	12	12	12	12	12	12	12
Zettle-Modified-Static-Pile Process #8 (TZ)	Mean	1.67	0.22	1.74	4001	1.92	0.88	90.04	9.96	22.83	26.80	8.61
	Std.Dev.	0.27	0.03	0.33	563	0.96	0.05	1.12	1.12	1.26	4.73	0.09
	Var.	0.07	0.001	0.10	290444	0.84	0.002	1.15	1.15	1.45	20.53	0.001
	# Samples	12	12	12	12	12	12	12	12	12	12	12
Lindner-Field-Windrow Process #9 (FL)	Mean	1.67	0.43	2.24	2390	35.60	1.02	84.80	15.20	19.82	26.89	8.54
	Std.Dev.	0.21	0.24	0.72	604	5.39	0.08	3.15	3.15	1.79	4.29	0.15
	Var.	0.04	0.05	0.48	334034	26.68	0.006	9.08	9.08	2.95	16.86	0.20
	# Samples	12	12	12	12	12	12	12	12	12	12	12
Significant Differences 99% Level of Confidence[1]		TPO x TZ TPO x FL TPO x ES TPI x TZ TPI x FL TPI x ES TPR x TZ TPR x FL TPR X ES	TPO x ES TPI x ES TPR x ES TZ x ES FL x ES	TPO x TZ TPO x ES TPI x TZ TPR x TZ	TPI x TZ TPI x ES TPR x TZ TPR x ES TZ x FL	TPO x TZ TPI x TZ TPR x TZ TZ x FL TZ x ES FL x ES		TPO x ES TPI x ES TPR x ES TZ x ES FL x ES	TPO x ES TPI x ES TPR x ES TZ x ES FL x ES	TPO x TZ TPO x FL TPI x TZ TPI X FL TPR x FL TZ x ES FL x ES	TPO x TZ TPO x FL TPI x TZ TPI x FL TPR x TZ TPR x FL TZ x ES FL x ES	

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[1] Each entry in this row of the table indicates that a significant difference was found between the processes compared for the parameter identified at the top of the table column. The two processes compared are identified by their abbreviations separated by an "X". No entry in this table row means no significant differences were observed between any of the processes.

manures used in this study ranged from 13.9 to 26.9 with 9 out of the 16 manures having a C/N ratio less than 20 which is considerably below the optimum of 30. The C/N ratios for raw manures used in the composting studies was consistent with both dairy and beef cattle solid manure C/N ratios from eight Ontario farms sampled as part of this study. Data from the Ontario farms sampled are presented in Table 5.19 in Section 5.12.

Composting trials were set up each year at the base site using manures from the same manure pack and beef cow calf herd. In spite of using the same raw manure source, the analysis of bulk samples indicated some significant differences in manure characteristics between trials.

The C/N ratio of manures used in the first year experiments were not significantly different between process trials, ranging between 17.3 and 18.6. C/N ratios for manures from two ecological farms used in the second year experiments were significantly different from the other manures used for the trials. The C/N ratio of the manures used in the second year experiments ranged from highs of 26.8 and 26.9 for the Zettle and Lindner raw manures to a low of 15.4 for raw manures from the main research site. The C/N ratio of manures from the Zettle farm and the Lindner farm were significantly different from the other manures used in the composting trials. The C/N ratio for manures from the main research site and the Sittler farm were not significantly different and were consistent with C/N ratio data for both dairy and beef cattle solid manure in Ontario.

The raw manures from the Sittler farm consistently exhibited significant differences (for most parameters) from the rest of the manure sources used for the second year composting experiments, because of the recipe used to form the compost windrow. Of particular interest was the high ash content and low organic matter content associated with this process's resulting product.

The nitrogen content of the raw manures from the main research site were significantly higher than the nitrogen levels in the manures from the three ecological cooperator farms. All three cooperator farms handle the manure at least once and in some cases store the manure outdoors for a considerable period of time prior to commencing regimented composting procedures. The manure used at the main research site was acquired directly from a straw bedded manure pack which was allowed to accumulate in the barn for approximately a six month period and then removed and composted immediately. Allowing the manure to accumulate in a pack and only handling the manure once before composting is believed to conserve nitrogen in the raw manure.

Manures used for the third year experiments all came from the same manure pack. In spite of this, manure used in the turned-pile process exhibited significantly different characteristics from the rest of the manures sampled as shown in Table 5.3. The characteristics of the manure/compost blend used in process #13 were significantly different from the manures used in the other four trials that same year because of the compost blend, as was anticipated.

Moisture levels in all the manures used in the experiments were significantly above the optimum moisture level of 60% (Midwest Plan Service 1985), which is consistent with manures sampled at Ontario farms as part of this project (see Table 5.19).

5.2 Compost Characterization Results

Compost characterization data are presented in three sections. Section 5.2.1 presents the compost characteristics for the first year's composting trials. The first year trials compared composts produced by static-pile-intermittent-forced-aeration, passive-aeration and turned-pile composting processes. Section 5.2.2 contains compost characterization data for year two and compares three ecological composting processes with turned-pile composting under covered conditions, turned-pile composting outdoors and turned-pile composting with runoff addition. Section 5.2.3 contains compost data for year three trials and compares a number of composting concepts. Turned-pile composting of pack manure, turned-pile composting of manure amended with compost at a rate of 40% V/V, passive-aeration composting, modified passive-aeration composting in which aeration tubes are closed for the first 21 days, and forced-continuous-aeration composting are all compared in Section 5.2.3. Compost Characterization Tables 5.4, 5.5 and 5.6 show the mean, standard deviation, variance and number of samples analyzed for each composting process in years one, two and three respectively. Significant differences are presented at the bottom of each table where applicable.

Table 5.3. Raw Manure Characteristics - Year 3 Experiments

Process Description	Statistic	N % D.M. Basis	P % D.M. Basis	K % D.M. Basis	NH_4-N mg/kg D.M. Basis	NO_3-N mg/kg D.M. Basis	NO_2-N mg/kg D.M. Basis	O.M. % D.M. Basis	ASH % D.M. Basis	D.M. % As Is Basis	C/N Ratio	pH
Forced-Aeration	Mean	2.12	0.26	3.12	3159	7.24	1.36	84.00	16.00	30.54	20.80	8.40
Continuous Aeration	Std.Dev.	0.23	0.04	0.30	845	2.41	2.59	3.11	3.11	1.97	2.23	0.27
Process #10	Var.	0.047	0.002	0.081	654826	5.30	6.14	8.86	8.86	3.57	4.56	0.07
(FAC)	# Samples	12	12	12	12	12	12	12	12	12	12	12
Passive-Aeration	Mean	1.94	0.32	2.85	3412	7.49	0.32	85.04	14.96	30.90	23.61	8.13
Tubes Closed 21 Days	Std.Dev.	0.3	0.09	0.34	652	1.99	0.44	1.99	1.99	1.8	3.12	0.30
Process #11	Var.	0.084	0.007	0.107	390420	3.64	0.17	3.63	3.63	2.96	8.94	0.08
(PAC)	# Samples	12	12	12	12	12	12	12	12	12	12	12
Passive-Aeration	Mean	1.88	0.30	2.68	2491	6.18	0.29	84.36	15.64	30.65	24.64	8.57
Process #12	Std.Dev.	0.32	0.06	0.34	893	2.66	0.33	1.73	1.73	1.76	3.44	0.39
(PAO)	Var.	0.097	0.004	0.106	731746	6.48	0.10	2.73	2.73	2.83	10.85	0.14
	# Samples	12	12	12	12	12	12	12	12	12	12	12
Turned-Pile	Mean	3.05	0.55	3.08	883	11.79	0.45	80.67	19.33	24.53	13.93	8.84
Manure Amended with	Std.Dev.	0.31	0.08	0.23	200	5.55	0.15	1.68	1.68	1.18	2.30	0.08
Compost	Var.	0.087	0.006	0.050	36885	28.27	0.02	2.57	2.57	1.28	4.87	0.005
Process #13	# Samples	12	12	12	12	12	12	12	12	12	12	12
(TPS)												
Turned-Pile	Mean	2.39	0.42	3.60	3048	13.41	0.41	85.51	14.49	24.27	19.26	8.51
Turned After 21 Days	Std.Dev.	0.21	0.06	0.35	764	2.3	0.02	1.24	1.24	1.09	1.55	0.26
Process #14	Var.	0.042	0.003	0.110	535610	4.85	0.00112	1.42	1.42	1.09	2.22	0.06
(TP)	# Samples	12	12	12	12	12		12	12	12	12	12
Significant Differences 99% Level of Confidence[1]		PAO x TP PAO x TPS PAC x TP PAC x TPS FA x TPS TP x TPS	PAO x TP PAO x TPS PAC x TPS FA x TP FA x TPS TP x TPS	PAO x TP PAC x TP TP x TPS	PAO x TPS PAC x TPS FA x TPS TP x TPS	PAO x TP PAO x TPS PAC x TP FA x TP		PAO X TPS PAC x TPS FA x TPS TP x TPS	PAO x TPS PAC x TPS FA x TPS TP x TPS	PAO x TP PAO x TPS PAC x TP PAC x TPS FA x TPS	PAO x TP PAO x TPS PAC x TP PAC x TPS FA x TPS TP x TPS	PAC x TPS

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[1] Each entry in this row of the table indicates that a significant difference was found between the processes compared for the parameter identified at the top of the table column. The two processes compared are identified by their abbreviations separated by an "X". No entry in this table row means no significant differences were observed between any of the processes.

5.2.1 Compost Characteristics - First Year Experiments

Nitrogen levels ranged from a maximum of 3.32% for turned-pile compost to a minimum of 2.64% for the passive-aeration compost. This was unexpected as the raw manure nitrogen levels were the same and it was assumed that the forced-aeration process would result in the greatest NH_3 stripping and the least amount of nitrogen content in the finished compost. Compost transformation data presented in Section 5.3 does not indicate a significant difference in nitrogen loss between the two processes. Compaction of the manures due to natural settling after windrow formation is believed to have reduced the effectiveness of forced-aeration, and resulted in aeration short-circuiting. It is believed that natural settling also reduces the effectiveness of passive-aeration composting techniques. Pore-space O_2 concentration data presented in Section 5.5 indicates that natural convection is sufficient to maintain pore-space O_2 concentrations above 5% which is considered adequate for aerobic composting (Rynk 1992).

Ammonia levels were highest in the turned-pile process compost and lowest in the forced-aeration process compost. Differences were statistically significant. The low NH_3 levels in the forced-aeration compost are believed to be the result of NH_3 stripping due to aeration. The differences between the passive-aeration and turned-pile processes are the result of differences in biological activity. They are the reverse of that anticipated with respect to process susceptibility to NH_3 volatilization.

The gravimetric moisture content of the finished composts were not significantly different between passive-aeration and intermittent-forced-aeration processes although they were significantly higher than that experienced with the turned-pile process. Moisture losses ranged from 64.1% for the turned-pile process to 69.8% for the forced-aeration process.

Although the original manures used for the three trials did not exhibit significant differences in phosphorus or potassium levels, the final compost materials were significantly different. The fact that the dry matter and organic matter losses for all three processes were not significantly different makes this difficult to explain. Some seepage of manure juices was noted from the passive-aeration and forced-aeration windrows around the aeration pipes, due to manure settling after windrow formation. This only occurred around the aeration pipes and was not experienced with the turned-pile windrow which did not have the aeration pipes.

Table 5.4. Compost Characteristics - First Year Experiments

Process Description	Statistic	N % D.M. Basis	P % D.M. Basis	K % D.M. Basis	NH_4-N mg/kg D.M.Basis	NO_3-N mg/kg D.M.Basis	NO_2-N mg/kg D.M.Basis	O.M. % D.M. Basis	ASH % D.M. Basis	D.M. % As Is Basis	C/N Ratio	pH
Forced-Aeration	Mean	3.05	0.61	4.76	14.42	2,789	0.45	72.55	27.45	30.23	13.31	8.49
Process #1	Std.Dev.	0.17	0.05	0.30	7.93	384.2	0.20	1.47	1.47	1.11	0.78	0.12
(FA)	Var.	0.028	0.003	0.09	62.92	147,607	0.422	2.17	2.17	1.22	0.60	0.01
	# Samples	12	12	12	12	12	124	12	12	12	12	12
Passive-Aeration	Mean	2.64	0.49	5.26	77.04	2,815	0.35	72.75	27.25	31.02	16.62	8.21
Process #2	Std.Dev.	0.59	0.11	0.45	15.71	524.9	0.15	1.27	1.27	2.83	4.06	0.21
(PA)	Var.	0.35	0.012	0.20	246.6	275,614	0.23	1.62	1.62	8.01	16.5	0.04
	# Samples	12	12	12	12	12	12	12	12	12	12	12
Turned-Pile	Mean	3.32	0.60	4.75	142.2	2,961	2.20	73.41	26.59	35.90	12.71	8.25
Process #3	Std.Dev.	0.42	0.04	0.30	12.90	231.5	2.86	1.09	1.09	2.76	1.71	0.13
(TP)	Var.	0.18	0.001	0.09	166.5	53,581	8.18	1.19	1.19	7.64	2.91	0.02
	# Samples	12	12	12	12	12	12	12	12	12	12	12
Significant Differences 99% Confidence Level[1]		PA x TP	FA x PA TP x PA	TP x PA	FA x PA FA x TP PA x TP						PA x TP	FA x TP PA x TP

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[1] Each entry in this row of the table indicates that a significant difference was found between the processes compared for the parameter identified at the top of the table column. The two processes compared are identified by their abbreviations separated by an "X". No entry in this table row means no significant differences were observed between any of the processes.

Seepage losses is a possible explanation, however, it is not completely consistent with the data since the passive-aeration process had the highest potassium levels. Seepage was very minor and not truly believed to be sufficient to be detectable in bulk analysis.

5.2.2 Compost Characteristics - Second Year Experiments

Table 5.5 summarizes the compost characteristics for the second year composting trials. The table includes the mean, standard deviation, variance, and number of samples analyzed for each characteristic. Differences that are significant are shown at the bottom of the table. Differences between compost levels of total N, K, NH_4-N, NO_3-N, NO_2-N, moisture, pH, and C/N ratio were found to be significant primarily between the ecological processes and the conventional processes.

Nitrogen levels ranged from a minimum of 1.39% for the Sittler-turned-pile-Luptke composting process to a maximum of 3.91% for the covered turned-pile process conducted at the base site for the project. No significant difference in compost total nitrogen concentration was found between composting outside (subject to rain etc.), composting inside, or composting with runoff addition.

NH_4-N in the turned-pile process with barnyard runoff addition was significantly greater than all other processes with concentrations nearly an order of magnitude greater. This can be attributed to the effect of barnyard runoff addition. NH_4-N levels ranged from 20.76 mg/kg in the Sittler-turned-pile-Luptke compost to 1,781 mg/kg in the turned-pile process with barnyard runoff addition. The low NH_4-N levels in the Sittler-turned-pile-Luptke process are the result of volatilization losses from mixing and also because of the relatively low nitrogen concentrations in the starting compost recipe mix used (see Section 4.3.7).

Nitrate levels ranged from a low of 153.2 mg/kg dry weight basis for the compost produced at the Lindner ecological farm using a field windrow process to a high of 2769 mg/kg dry weight basis for the covered turned-pile process conducted at the base site. Nitrate levels are an indication of the stage of biological decomposition of organic matter (Sawyer 1978). As manure decomposes during composting processes the nitrogen present changes form as part of the natural nitrogen cycle. Organic forms of nitrogen are first transformed to ammoniacal nitrogen forms and then NO_2 and NO_3 forms. The compost data generally shows this switch to higher levels of NO_3 nitrogen in the finished compost. This is discussed further in

Table 5.5. Compost Characteristics - Second Year Experiments

Process Description	Statistic	N % D.M.	P % D.M.	K % D.M.	NH_4-N mg/kg D.M.Basis	NO_3-N mg/kg D.M.Basis	NO_2-N mg/kg D.M.Basis	O.M. % D.M.	ASH %	D.M. %	C/N Ratio	pH
Turned-Pile	Mean	3.68	0.57	4.98	1,781.18	740.49	254.68	74.93	25.07	42.67	11.86	8.35
Runoff Addition	Std.Dev.	0.63	0.10	0.29	126.01	366.83	152.19	0.77	0.77	3.19	2.51	0.05
Process #4	Var.	0.36	0.001	0.08	14,556	123,351	21,232	0.55	0.55	9.31	5.75	0.003
(TPR)	# Samples	12	12	12	12	12	12	12	12	12	12	12
Turned-Pile-	Mean	3.86	0.61	3.89	234.73	1,792	0.71	76.82	23.19	28.46	11.12	8.19
Outside	Std.Dev.	0.32	0.08	0.40	66.46	630	0.07	1.76	1.76	2.92	1.17	0.14
Process #5	Var.	0.10	0.006	0.15	4,049	363,789	0.004	2.84	2.85	7.84	1.25	0.02
(TPO)	# Samples	12	12	12	12	12	124	12	12	12	12	12
Inside-Turned-Pile	Mean	3.91	0.59	4.43	288.37	2,769	0.49	76.46	23.55	40.76	10.79	8.05
Process #6	Std.Dev.	0.28	0.06	0.34	136.15	376	0.02	2.04	2.04	2.06	0.87	0.07
(TPI)	Var.	0.07	0.003	0.11	16,992	129,865	0.001	3.81	3.81	3.90	0.70	0.004
	# Samples	12	12	12	12	12	12	12	12	12	12	12
Sittler-Turned-Pile-	Mean	1.39	0.90	1.76	20.76	934.12	0.33	22.11	77.90	63.13	11.39	6.93
Luptke Method	Std.Dev.	0.70	0.49	0.79	11.58	470.06	0.09	3.97	3.97	9.51	4.51	0.12
Process #7	Var.	0.45	0.217	0.58	122.84	202545	0.007	14.47	14.47	82.92	18.66	0.014
(ES)	# Samples	12	12	12	12	12	12	12	12	12	12	12
Zettle-Modified-	Mean	3.13	0.75	4.26	445.25	1,864	51.04	70.12	29.88	28.03	12.76	8.43
Static-Pile	Std.Dev.	0.62	0.18	0.77	550.94	272.98	52.62	8.66	8.66	4.98	2.33	0.14
Process #8	Var.	0.35	0.031	0.54	278,240	68,310	2,538	68.77	68.78	22.71	4.96	0.019
(TZ)	# Samples	12	12	12	12	12	12	12	12	12	12	12
Lindner-Field-	Mean	2.40	0.67	2.44	250.11	153.19	3.86	77.45	22.55	17.69	17.14	8.34
Windrow	Std.Dev.	0.18	0.08	0.24	179.36	58.10	2.65	3.35	3.35	1.17	1.08	0.24
Process #9	Var.	0.03	0.006	0.05	29,491	3,095	6.45	10.31	10.31	1.25	1.06	0.051
(FL)	# Samples	12	12	12	12	12	12	12	12	12	12	12
Significant Differences 99% Confidence Level[1]		TPO x FL TPO x ES TPI x FL TPI x ES TPR X FL TPR x ES TZ x ES		TPO x TPR TPO x FL TPO x ES TPI x FL TPI x ES TPR x FL TPR x ES TZ x FL TZ x ES	TPO x TPR TPI x TPR TPR x TZ TPR x FL TPR x ES TZ x ES	TPO x TPR TPO x TPR TPO x FL TPO x ES TPI x TPR TPI x TZ TPI x FL TPI x ES TPR x TZ TZ x FL TZ x ES FL X ES	TPO x TPR TPI x TPR TPR x TZ TPR x FL TPR x ES	TPO x ES TPI x ES TPR x ES TZ x ES FL x ES	TPO x ES TPI x ES TPR x ES TZ x FL TZ x ES FL x ES	TPO x TPI TPO x TPR TPO x FL TPO x ES TPI x TZ TPI x FL TPI x ES TPR X TZ TPR x FL TPR x ES TZ x FL TZ x ES FL x ES	TPO x FL TPI x FL TPR x FL TZ x FL FL x ES	TPO x TZ TPO x ES TPI x TPR TPI x TZ TPI x FL TPI x ES TPR x ES TZ x ES FL x ES

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[1] Each entry in this row of the table indicates that a significant difference was found between the processes compared for the parameter identified at the top of th were observed between any of the processes.

Section 5.3 (Compost Transformation Results). It should be noted that the mineral forms of nitrogen represent a very small portion of the total nitrogen present in the biologically stable compost and typically are less than 0.1% of the total nitrogen present. The low mineral nitrogen content of biologically stable compost results in reduced nitrogen leaching potential.

Organic matter content was significantly different between the Sittler-turned-pile-Luptke process and all other process composts. Typically all composts had an average organic matter content of 75.2% compared to 22.1% for the Sittler-turned-pile-Luptke process. This is due to the high initial ash content of the amended manures (Section 4.3.2.4) used for the process. The gravimetric moisture content of the finished composts in the second year trials was highly variable. It ranged from a low of 36.9% expressed on a wet weight "as is" basis for the Sittler-turned-pile-Luptke process compost to 82.3% for the Lindner-field-windrow compost.

5.2.3 Compost Characteristics - Third Year Experiments

Table 5.6 summarizes the compost characteristics for the third year compost trials. Differences between compost levels of potassium, ammoniacal-nitrogen, NO_2-nitrogen, dry matter, and pH, were found to be significant. In spite of the differences in technology and process manipulation between trials no significant difference in the compost total nitrogen or organic matter content was observed.

Potassium levels in the compost produced from the manure amended with compost, prior to composting, were significantly lower than the other four composts produced in the third year trials.

Ammoniacal nitrogen levels in the compost from the turned-pile process using compost amended manure was significantly lower than all other process composts in the third year trials. This is attributed to the "inoculation" of the manure with biologically stable compost rich in aerobic bacteria, prior to composting. The compost inoculation had two effects; it reduced the percentage of raw manure requiring stabilization and increased the aerobic bacterial population immediately available for nitrogen assimilation in the compost mixture. As a result lower levels of NH_3 were released at any given time during the process and higher aerobic bacterial populations were in existence to assimilate the NH_3 released during

Table 5.6. Compost Characteristics - Third Year Experiments

Process Description	Statistic	N % D.M.	P % D.M.	K % D.M.	NH_4-N mg/kg D.M.Basis	NO_3-N mg/kg D.M.Basis	NO_2-N mg/kg D.M.Basis	O.M. % D.M.	ASH %	D.M. %	C/N Ratio	pH
Forced-Aeration	Mean	2.77	0.53	5.86	77.45	1113	40.21	70.90	29.10	45.37	14.95	8.74
Continuous Aeration	Std.Dev.	0.70	0.14	1.08	35.60	280	27.76	4.69	4.69	5.53	4.23	0.22
Process #10	Var.	0.46	0.02	1.06	1161	72146	706	20.17	20.17	28.05	16.37	0.04
(FAC)	# Samples	12	12	12	12	12	12	12	12	12	12	12
Passive-Aeration	Mean	2.96	0.65	6.01	63.73	1110	5.01	71.41	28,59	37.58	13.32	8.35
Tubes Closed 21	Std.Dev.	0.44	0.08	0.48	18.07	452	6.28	2.25	2.25	2.06	2.15	0.23
Days	Var.	0.17	0.006	0.21	299	187984	36.10	4.63	4.63	3.90	4.24	0.05
(PAC)	# Samples	12	12	12	12	12	12	12	12	12	12	12
Process #11												
Passive-Aeration	Mean	2.82	0.62	5.55	77.18	1109	7.08	70.70	29.30	35.24	14.26	8.62
Control	Std.Dev.	0.53	0.12	0.84	33.64	527	12.48	3.33	3.33	3.71	3,54	0.26
Process #12	Var.	0.26	0.014	0.65	1037	255479	142	10.16	10.17	12.60	11.48	0.06
(PAO)	# Samples	12	12	12	12	12	12	12	12	12	12	12
Turned-Pile	Mean	3.16	0.68	3.95	23.29	1240	0.74	70.23	29.77	35.03	12.67	8.37
Manure/Compost	Std.Dev.	0.43	0.09	0.58	7.71	172	1.48	1.58	1.58	4.08	1.32	0.10
Mix	Var.	0.17	0.008	0.31	54.48	27126	1.99	2.30	2.30	15.23	1.61	0.009
Process #13	# Samples	12	12	12	12	12	12	12	12	12	12	12
(TPS)												
Turned-Pile	Mean	2.45	0.56	5.39	62.62	1085	3.98	71.26	28.74	34.88	15.99	8.78
Turned After 21 Days	Std.Dev.	0.37	0.10	0.58	20.24	187	4.14	1.11	1.11	3.38	3.12	0.16
Process #14	Var.	0.13	0.009	0.31	375	32120	15.69	1.12	1.12	10.48	8.91	0.02
(TP21)	# Samples		12	12	12	12	12	12	12	12	12	12
Significant Differences 99% Level of Confidence[1]				PAO x TPS PAC x TPS FAC x TPS TP21 x TPS	PAO x TPS PAC x TPS FA x TPS		PAO x FA PAC x FA FAC x TP TP21 xTPS			PAO x FA PAC x FA FAC x TP21 FAC x TPS		PAC x FA PAC x TP21 FAC x TPS TP21 x TPS

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[1] Each entry in this row of the table indicates that a significant difference was found between the processes comp the table column. The two processes compared are identified by their abbreviations separated by an "X". No entry i differences were observed between any of the processes.

aerobic decomposition of the raw manure component of the compost mix. Ammoniacal nitrogen ranged from a low of 23.29 mg/kg for the turned-pile process using manure amended with compost to 77.45 mg/kg for the continuous-forced-aeration process. The forced-aeration compost had the highest level of ammoniacal nitrogen. This was unexpected as it was anticipated that the forced-aeration would result in NH_3 stripping and result in low ammoniacal nitrogen levels.

Nitrite-nitrogen levels ranged from a high of 40.21 mg/kg (dry weight basis) for the forced-aeration compost to a low of 0.74 mg/kg (dry weight basis) for the turned-pile compost produced from manure amended with compost. High NO_2-nitrogen levels are an indication of a less stabilized organic material. Nitrite-nitrogen is converted to NO_3 nitrogen by aerobic microbial activity as the natural degradation of organic material progresses (Sawyer,1978). This process can be reversed if anaerobic conditions are present. Anaerobic bacterial activity results in a reduction reaction in which NO_3-N is reduced to NO_2-N. The high NO_2 levels in the static-pile-forced-aeration process may be the result of aeration short-circuiting which was visibly observable during the removal of compost. Anaerobic zones would have existed within the composting mass as a result of the short-circuiting. Pore-space O_2 analysis results indicated that aerobic conditions did predominately prevail in the composting mass in spite of short-circuiting evidence.

The forced-aeration process produced compost with the highest dry matter content at 45.37% compared to between 34.88% and 37.58% for all other processes conducted in the third year. This result is as would be expected considering the potential for additional drying due to the continuous aeration.

5.3 Compost Transformation Results

Compost transformation data is presented on a yearly basis in three sections with one section for each year of experiments. All the transformation data were calculated using the conservation of ash principle described in Section 4.5. Compost transformation Tables 5.7, 5.9 and 5.10 show the mean, standard deviation, variance and number of samples analyzed for each composting process in years one, two and three respectively. Significant differences are presented at the bottom of each table where applicable.

5.3.1 Compost Transformations - First Year Experiments

The compost transformations for the first year composting trials compare composts produced by static-pile-intermittent-forced-aeration, passive-aeration and turned-pile composting processes. Table 5.7 summarizes nitrogen, organic matter, dry matter and moisture losses, and changes in pH and C/N ratio for the three different composting processes observed in the first year. The initial raw manure values for each process can be found in Table 5.1 and the compost values can be found in Table 5.4.

Significant differences in total nitrogen loss, ammoniacal nitrogen conversion and moisture loss were observed between composting processes. Organic matter and dry matter losses between processes were not statistically significant.

Mean nitrogen losses, calculated using the method described in Section 4.5, ranged from 24.5% for the turned-pile process to 39.9% for the passive-aeration process. Initial nitrogen content of the starting manures was very similar and ranged from 2.72% for the raw manure used for the turned-pile process to 2.54% for the raw manure used for the passive-aeration process. Nitrogen losses from the turned-pile process were significantly lower than from the two static-pile processes. This is believed to be the result of enhanced air movement through the static piles due to the presence of passive aeration tubes or the use of forced-aeration. Such conditions would increase the potential for NH_3 loss to the atmosphere in the off gases from the composting mass. Ammoniacal nitrogen change was lowest for the turned-pile process at 94.64% and highest for the forced-aeration process at 99.48%. Initial ammoniacal nitrogen content in the raw manures ranged from 1,093 mg/kg (dry weight basis) for the raw manures used for the turned-pile process to 1,415 mg/kg (dry weight basis) for the raw manures used for the passive-aeration process. The organic matter losses ranged from 54.3% for the turned-pile process with an initial raw manure organic matter content of 86.27%, to 58.2% for the forced-aeration process which had an initial raw manure organic matter content of 85.75% and were not significantly different. Moisture losses ranged from 55.8% for the forced-aeration process to 65.5% for the turned-pile process. Differences in moisture loss between processes were not statistically different. Starting moisture content of the raw manures ranged from 73.76% to 74.86% for the raw manures used for the forced-aeration and turned-pile processes respectively.

Table 5.7. Summary of Compost Transformations - First Year Experiments

Process Description	Statistic	N % Loss	NH_4-N % Loss	NO_3-N % Increase	NO_2-N % Loss	O.M. % Loss	H_2O % Loss	D.M. % Loss	C/N Ratio Change	pH Change
Forced-Aeration Intermittent Aeration Process #1 (FA)	Mean	38.91	99.48	6,143	78.24	58.16	55.75	48.22	-4.79	-0.53
	Std.Dev.	3.62	0.29	1,013	9.96	4.75	2.39	2.85	0.78	0.12
	Var.	13.06	0.08	1,026,631	99.20	22.5	5.7	8.14	0.60	0.01
	# Samples	12	12	12	12	12	12	12	12	12
Passive-Aeration Process #2 (PA)	Mean	39.99	97.15	6,220	83.06	55.79	56.96	47.88	-1.48	-0.80
	Std.Dev.	13.51	0.65	1,186	7.04	2.75	5.45	2.36	4.06	0.21
	Var.	182.4	0.42	1,407,264	49.61	7.55	29.70	5.56	16.5	0.04
	# Samples	12	12	12	12	12	12	12	12	12
Turned-Pile Process #3 (TP)	Mean	24.52	94.64	6,720	-10.71	54.30	65.53	46.60	-5.39	-0.76
	Std.Dev.	9.61	0.50	612	144.5	2.58	4.00	2.21	1.71	0.13
	Var.	92.38	0.25	374,643	20,873	6.64	16.03	4.89	2.9	0.02
	# Samples	12	12	12	12	12	12	12	12	12
Significant Differences 99% Confidence Level[1]		FA x TP PA x TP	FA x PA FA x TP PA x TP				FA x TP PA x TP		PA x TP	FA x PA FA x TP PA x TP

Notes: A) Raw manure analysis results for the first year experiments can be found in Table 5.1.
B) Compost analysis results for the first year experiments can be found in Table 5.4.

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[1] Each entry in this row of the table indicates that a significant difference was found between the processes comp the table column. The two processes compared are identified by their abbreviations separated by an "X". No entry i differences were observed between any of the processes.

The nitrogen, organic matter and moisture loss data were somewhat unexpected as it was anticipated that the nitrogen and moisture losses from the forced-aeration process would be significantly higher than the passive-aeration and turned-pile processes. During sampling and removal of the compost materials it was noted that natural settling and compaction had occurred in both the static-pile-forced-aeration process and the passive-aeration process which is believed to have reduced the effectiveness of aeration exchange through the piles. Both processes showed definite signs of aeration short-circuiting with dryer compost highly colonized by actinomycetes filaments above the aeration tubes compared to the compost material between the aeration tubes.

Table 5.8 shows the difference in characteristics between the dry compost material located above the aeration tubes and the more moist compost in the region between the aeration tubes for the forced-aeration process. The nitrogen loss in the dry compost above the aeration pipes averaged 45.9% compared to 34.4% in the moist compost between the aeration piping. This difference was not significant. The initial nitrogen content of the raw manure used for the forced-aeration process was 2.49%. The organic matter loss for the dry compost material from directly above the aeration pipes was significantly less than that from the moist material from between the pipes. The organic matter loss for the dry compost was 47.9% compared to 59.0% for the moist material from between the aeration pipes with an initial organic matter content in the raw manure of 85.75%. The moisture losses ranged from 50.1% to 64.2% and were significant.

Moisture losses when composting indoors are similar to losses when composting outdoors during summer months. Wind and sun tend to accelerate moisture loss and appear to compensate for any added moisture due to rainfall. In other composting research where the composting processes were covered but not enclosed, wind action has been noted to increase moisture losses and result in higher moisture losses than organic matter losses (Ecologistics Limited 1993).

Table 5.8. Comparison of Forced-Aeration Compost - Dry And Moist Regions

Process Description	Statistic	N % Loss	O.M. % Loss	H_2O % Loss	D.M. % Loss
Forced-Aeration: Dry Compost Region of Aerated Compost Pile	Mean	45.87	47.91	64.18	44.46
	Std.Dev.	5.46	0.99	1.29	1.06
	Var.	29.85	0.97	1.67	1.13
	# Samples	4	4	4	4
Forced-Aeration: Moist Compost Region of Aerated Compost Pile	Mean	34.40	59.01	50.12	56.66
	Std.Dev.	9.83	1.20	0.40	1.16
	Var.	96.69	1.43	0.16	1.34
	# Samples	4	4	4	4

5.3.2 Compost Transformations - Second Year Experiments

The compost transformation data for year two experiments compare three ecological composting processes with turned-pile composting under covered conditions, turned-pile composting outdoors and turned-pile composting with barnyard runoff addition.

Table 5.9 summarizes the changes in the parameters monitored for the six different composting trials conducted during the second year of experiments. Initial raw manure values for each parameter and process can be found in Table 5.2. The actual concentration of parameters in the compost at the completion of each process can be found in Table 5.5.

Mean nitrogen losses ranged from 8.43% (manure N-1.67%) for the Lindner-field-windrow process to 52.67% (manure N-1.66%) for the Sittler-turned-pile-Luptke process. The Lindner-field-windrow nitrogen losses were numerically lower than the Sittler-turned-pile-Luptke process losses and statistically significant but the Lindner-field-windrow process's nitrogen losses were not statistically different from the other four processes undertaken in the same year. Nitrogen losses for the Sittler-turned-pile-Luptke process were significantly higher than the turned-pile processes conducted indoors and outdoors at the base site and were statistically different. Nitrogen losses for the Sittler-turned-pile-Luptke process, however, were not statistically different from the turned-pile process with barnyard runoff addition. In spite of being mixed 15 times, the Sittler-turned-pile-Luptke process did not show statistically higher nitrogen losses than the turned-pile process with runoff addition which was turned only three times.

Table 5.9. Summary of Compost Transformations - Second Year Experiments

Process Description	Statistic	N % Loss	NH_4-N % Decrease	NO_3-N % Increase	NO_2-N % Decrease	O.M. % Loss	H_2O % Loss	D.M. % Loss	C/N Ratio Change	pH Change
Turned-Pile	Mean	36.24	56.49	1,036	-13,923	57.73	76.20	50.59	-3.52	-0.17
Barnyard Runoff Addition	Std.Dev.	11.89	3.54	538	8,389	1.72	3.39	1.51	2.51	0.05
Process #4	Var.	129.60	11.47	265,578	64,504,753	2.71	10.55	2.08	5.75	0.003
(TPR)	# Samples	12	12	12	12	12	12	12	12	12
Turned-Pile	Mean	23.77	95.59	3,003	86.10	50.04	43.22	43.52	-5.85	0.10
Outside	Std.Dev.	4.31	1.19	1,042	0.70	5.25	4.57	4.57	1.17	0.14
Process #5	Var.	16.99	1.30	994,385	0.45	25.28	19.17	19.13	1.25	0.018
(TPO)	# Samples	12	12	12	12	12	12	12	12	12
Inside-Turned-Pile	Mean	22.35	92.01	4,472	69.03	53.52	69.66	46.87	-6.74	-0.40
Process #6	Std.Dev.	7.72	3.43	903	1.58	5.23	1.43	4.58	0.87	0.07
(TPI)	Var.	54.57	10.79	746,763	2.27	25.04	1.88	19.21	0.70	0.004
	# Samples	12	12	12	12	12	12	12	12	12
Sittler-Turned-Pile	Mean	52.67	99.67	2,260	72.78	76.67	84.32	42.27	-7.77	-1.23
Luptke Method	Std.Dev.	22.17	0.20	1,269	8.09	5.18	11.21	2.86	4.51	0.12
Process #7	Var.	450.35	0.04	1,476,694	60.01	24.58	115.27	7.47	18.66	0.014
(ES)	# Samples	12	12	12	12	12	12	12	12	12
Zettle-Modified-Static-Pile	Mean	32.69	95.70	34,205	-2,130	71.73	71.35	64.58	-14.04	-0.17
Process #8	Std.Dev.	23.57	5.27	8,220	2,237	8.84	10.31	7.96	2.33	0.14
(TZ)	Var.	509.20	25.47	61,939,026	4,585,979	71.60	97.44	58.04	4.96	0.019
	# Samples	12	12	12	12	12	12	12	12	12
Lindner-Field-Windrow	Mean	8.43	92.92	201	-160	36.91	20.14	31.30	-9.75	-0.20
Process #9	Std.Dev.	10.80	5.28	142	189	11.42	15.55	9.68	1.08	0.24
(FL)	Var.	106.83	25.55	18,548	32,804	119.45	221.75	85.90	1.06	0.051
	# Samples	12	12	12	12	12	12	12	12	12
Significant Differences 99% Confidence Level[1]		TPO x ES TPI x ES TPR x FL FL x ES	TPO x TPR TPI x TPR TPI x ES TPR x TZ TPR x FL TPR x ES FL x ES	TPO x TZ TPI x TZ TPR x TZ TZ x FL TZ x ES TZ x FL	TPO x TPR TPI x TPR TPR x TZ TPR x FL TPR x ES	TPO x TZ TPO x FL TPO x ES TPI X TZ TPI x FL TPI x ES TPR x TZ TPR x FL TPR x ES TZ x FL FL x ES	TPO x TPI TPO x TPR TPO x TZ TPO x FL TPO x ES TPI x FL TPR x FL TZ x FL FL x ES	TPO x TZ TPO x FL TPI x TZ TPI X FL TPR x TZ TPR x FL TZ x FL TZ x ES FL x ES	TPO x TZ TPI X TZ TPR x TZ TPR x FL TPR x ES TZ x FL TZ X ES	TPO X TPR TPO X TPR TPO X TZ TPO x FL TPO X ES TPI X ES TPR x ES TZ x ES FL x ES

Notes: A) Raw manure analysis results for the second year experiments can be found in Table 5.2

B) Compost analysis results for the second year experiments can be found in Table 5.5.

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[1] Each entry in this row of the table indicates that a significant difference was found between the processes compared for the parameter identified at the top of the table column. The two processes compared are identified by their abbreviations separated by an "X". No entry in this table row means no significant differences were observed between any of the processes.

This suggests that runoff addition has the tendency to increase nitrogen losses by increasing the levels of ammoniacal nitrogen present in the composting manure after runoff addition. Nitrogen losses were not statistically different between indoor composting and outdoor composting.

The change in concentration of ammoniacal nitrogen present in the raw manure compared to the compost ranged from a decrease of 56.9% for the turned-pile process with runoff addition to a decrease of 99.67% for the Sittler-turned-pile-Luptke process. Ammoniacal nitrogen present in the raw manures ranged from 2024 mg/kg for the manures used for the turned-pile process with runoff addition to 3632 mg/kg for the manures used for the Sittler-turned-pile-Luptke composting process. Composting indoors compared to outdoors did not have a statistically significant effect on the change in ammoniacal nitrogen content. The decrease in ammoniacal nitrogen present, resulting from composting of manure was lowest for the turned-pile process with runoff addition, and statistically different from all other composting processes studied during the second year experiments. This lack of a decrease in ammoniacal nitrogen results in higher levels of NH_3 being present which are susceptible to volatilization losses. Runoff addition was observed to have a significant effect on nitrogen transformations, resulting in higher nitrogen losses and differences in mineral nitrogen concentrations in the compost produced.

Nitrate concentration changes were highest for the Zettle process with NO_3 levels increasing from the raw manure to the compost by a factor of 342 times. Nitrate levels in the raw manure used for the Zettle process were 1.92 mg/kg. The NO_3 increase experienced in the Zettle process was statistically different from the other 5 composting processes being compared. Nitrate changes which occurred in the other composting processes ranged from an increase of 2 times for the Lindner process to an increase of 45 times for the turned-pile process conducted under covered conditions and were not statistically different. The NO_3 level in the raw manures used for the Lindner-field-windrow process were 35.60 mg/kg and 32.42 mg/kg for the raw manures used for the inside turned-pile composting process.

The change in concentration of NO_2-nitrogen in raw manure compared to compost ranged from a decrease of 72.78% for the Sittler-turned-pile-Luptke process to an increase 139 times for the turned-pile process with runoff addition. Initial NO_2 concentrations in the raw manure ranged from 0.70 mg/kg for the manures used for the Sittler process to 0.80 mg/kg for the raw manure used for the turned-pile process with runoff addition. Composting with runoff addition was observed to increase the concentration of NO_2-nitrogen present in the end compost compared to composting without runoff addition. The Sittler-turned-pile-Luptke process, and two turned-pile processes conducted at the base site all had NO_2 decreases associated with them. The Lindner and Zettle processes, both static-pile processes, had NO_2 increases associated with them indicating possibly that, within the static piles, anaerobic zones existed that promoted anaerobic bacterial activity which reduced NO_3 back to NO_2.

The organic matter losses ranged from 36.9% for the field windrow process conducted at the Lindner ecological farm to 76.67% for the turned-pile process used at the Sittler ecological farm. The initial raw manure organic matter levels ranged from 84.80% for the manures used for the Lindner process to 55.14% for the raw manures used for the Sittler process. Organic matter losses were significantly lower for the three turned-pile processes conducted at the base site than for the Zettle-modified-passive-aeration process and Sittler-turned-pile-Luptke process. The Zettle and Lindner processes were both static-pile processes, but had significantly different organic matter losses. The results of the experiments did not show a tendency of lower organic matter losses from static-pile processes compared to mixed pile processes.

Dry matter losses ranged from 31.3% for the Lindner-field-windrow process to 64.6% for the Zettle-modified-static-pile process, with starting raw manure organic matter levels of 84.80% and 90.04% respectively. Dry matter losses followed the same general trend as organic matter losses as would be expected. The Sittler-turned-pile-Luptke process was an exception and experienced a significantly lower dry matter loss than organic matter loss. This was due to the high inorganic content of the recipe mix used at the Sittler farm.

Net moisture changes ranged from a decrease of 20.14% for the Lindner-field-windrow process to a decrease of 84.32% for the Sittler-turned-pile-Luptke process. Moisture levels in the raw manures used for the Lindner-field-windrow process averaged 79.18% and averaged 70.58% for the raw manures used for the Sittler-turned-pile-Luptke process. The Lindner-field-windrow process and turned-pile process #5 conducted at the base site were both outside processes. The results show that these two processes had a much lower net decrease in moisture than the other four processes which were covered processes. This can be attributed to the impact of precipitation on the processes. The Sittler-turned-pile-Luptke process uses a cover placed directly on the windrow for shedding rain and is considered a covered process. The results indicate that composting inside results in a higher net decrease in moisture compared to composting outside due to moisture contributions from rainfall, but the moisture levels still remained above the 40% level considered acceptable for composting (Rynk

1992). The results illustrate that moisture levels should be monitored more closely for indoor processes, particularly if the raw manures have a low moisture content (Below 55%) due to a high proportion of bedding in the raw manure.

5.3.3 Compost Transformations - Third Year Experiments

The compost transformation data for year three trials compared the following composting concepts:

- Turned-pile composting of pack manure
- Turned-pile composting of manure amended with compost at a rate of 40% by volume
- Passive-aeration composting
- Modified-passive-aeration composting in which aeration tubes are closed for the first 21 days, and
- Forced-continuous-aeration composting

Table 5.10 summarizes the nitrogen, organic matter, dry matter and moisture losses, and changes in pH and C/N ratio for the five different composting trials conducted during the third year of experiments. Initial raw manure values for each parameter and process can be found in Table 5.3. The actual concentration of parameters in the compost at the completion of each process can be found in Table 5.6.

Mean nitrogen losses were lowest at 18.34% for the turned-pile process using manure amended with finished compost and highest for the continuous-forced-aeration process with a loss of 31.34%. The nitrogen content of the raw manure compost blend at the start of the composting process was 3.05% and nitrogen levels in the raw manure used for the continuous-forced-aeration process averaged 2.12%. Nitrogen loss differences between the forced-aeration, turned-pile and passive-aeration composting processes were not significant. Although not statistically significant, the data shows a trend of decreasing nitrogen losses with the forced-aeration losses > turned-pile composting losses > passive-aeration losses > turned-pile composting using compost amended manure. No significant difference in

Table 5.10. Compost Transformations - Third Year Experiments

Process Description	Statistic	N % Loss	NH_4-N % Decrease	NO_3-N % Increase	NO_2-N % Increase	O.M. % Loss	H_2O % Loss	D.M. % Loss	C/N Ratio Change	pH Change
Forced-Aeration	Mean	31.34	98.63	8214	1459	52.46	69.35	44.07	-5.85	0.34
Continuous Aeration	Std.Dev.	10.30	0.74	2564	1122	7.75	7.79	6.51	4.23	0.22
Process #10	Var.	97.28	0.50	602717	1154054	55.07	55.59	38.86	16.37	0.04
(FAC)	# Samples	12	12	12	12	12	12	12	12	12
Passive-Aeration	Mean	27.75	99.09	6892	629	55.67	60.67	47.34	-10.29	0.23
Tubes Closed 21 Days	Std.Dev.	7.05	0.31	2617	875	5.16	5.52	4.39	2.15	0.23
(PAC)	Var.	45.52	0.08	6278307	701207	24.38	27.92	17.63	4.24	0.05
Process #11	# Samples	12	12	12	12	12	12	12	12	12
Passive-Aeration-Control	Mean	27.28	98.39	8370	1222	54.49	55.03	45.97	-10.38	0.05
Process #12	Std.Dev.	7.40	0.98	3384	2546	7.60	10.83	6.41	3.54	0.26
(PAO)	Var.	50.20	0.88	10499242	5940894	52.95	107.57	37.69	11.48	0.06
	# Samples	12	12	12	12	12	12	12	12	12
Turned-Pile	Mean	18.34	97.94	8192	28.43	43.29	59.92	34.93	-1.26	-0.48
Manure/Compost Mix	Std.Dev.	9.20	0.60	793	258	3.92	8.75	3.17	1.32	0.10
Process #13	Var.	77.51	0.33	576273	60878	14.11	70.12	9.18	1.61	0.009
(TPS)	# Samples	12	12	12	12	12	12	12	12	12
Turned-Pile	Mean	31.17	98.62	5416	605	57.92	69.43	49.53	-3.27	0.27
Turned After 21 Days	Std.Dev.	5.40	0.40	1086	812	2.30	4.43	1.96	3.12	0.16
Process #14	Var.	26.70	0.15	1080213	604631	4.83	17.99	3.53	8.91	0.02
(TP)	# Samples		12	12	4.14	12	12	12	12	12
					15.69					
					12					
Significant Differences 99% Level of Confidence[1]		FA x TPS TP x TPS	PAC x TPS			PAO x TPS PAC x TPS FA x TPS TP x TPS	PAO x FA PAO x TP	PAO x TPS PAC x TPS FA x TPS TP x TPS	PAO x TP PAO x TPS PAC x TP PAC x TPS	PAO x TPS PAC x TPS FA x TPS TP x TPS

Notes:
A) Raw manure analysis results for the third year experiments can be found in Table 5.3.
B) Compost analysis results for the third year experiments can be found in Table 5.6.

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[1] Each entry in this row of the table indicates that a significant difference was found between the processes compared for the parameter identified at the top of the table column. The two processes compared are identified by their abbreviations separated by an "X". No entry in this table row means no significant differences were observed between any of the processes

nitrogen loss was observed between the passive-aeration process with the tubes sealed for the first 21 days and the control passive-aeration process. Although gas monitoring data shows that the highest concentrations of NH_3 in compost pore-spaces and off gases does occur during the first 21 days, restricting aeration by closing off the aeration tubes did not reduce nitrogen losses. This may be due to manure settling and compaction which actually reduces the effectiveness of the aeration pipes, possibly to the point where they are actually of no measurable benefit. The same explanation holds true for the continuous-forced-aeration process. It is believed that natural settling and compaction after windrow formation reduces the effectiveness of static-pile-forced-aeration and results in aeration short-circuiting and only localized aeration attributed to mechanical aeration occurs. The results of pore-space O_2 concentration monitoring presented in Section 5.5 indicates, however, that passive aeration was sufficient to maintain aerobic conditions in composting manure in windrows with dimensions of 3 meters wide by 1.2 meters high.

The low nitrogen loss observed in the turned-pile process using manure amended with compost is believed to be the result of a combination of factors. A large portion of the total nitrogen in the blended raw manure and compost mixture originated from the added compost and was in a more stable organic form than the organic nitrogen which originated from the raw manure portion of the mixture. As a result, the release of NH_3 from the continued degradation of the compost-supplied portion of nitrogen was lower. It was also assumed that the compost would act as a microorganism "inoculation" for the manure and result in more effective bacterial utilization of the NH_3 released during the early rapid decomposition phase of composting. The data indicate that lower nitrogen losses did result.

The change in concentration of ammoniacal nitrogen present in the compost produced, compared to the raw manure used, ranged from a decrease of 97.94% for the turned-pile process conducted with compost-amended manure to a decrease of 99.09% for the passive-aeration process conducted with the aeration tubes closed for the first 21 days of the process. Ammoniacal nitrogen concentrations in the raw manures were 883 mg/kg for the turned-pile process conducted using manure amended with compost and 3,412 mg/kg for the passive-aeration process with the aeration tubes closed for the first 21 days. The results show that the turned-pile process conducted using manure amended with compost had a lower rate of ammoniacal nitrogen conversion than the passive-aeration process conducted with the aeration tubes closed for the first 21 days of the process. The results did not indicate any trend with respect to ammoniacal nitrogen concentration changes attributable to a specific composting process.

The change in concentration of NO_3-nitrogen in the composts produced, compared to the raw manures used, ranged from an increase by a factor of 54 times for the turned-pile process conducted with compost-amended manure, to an increase of 84 times for the passive-aeration process. Nitrate-nitrogen concentrations in the raw manures were 11.79 mg/kg for the turned-pile process using manure amended with compost and 6.18 mg/kg for the passive-aeration process respectively. Nitrate-nitrogen changes were not statistically different between processes, and no trend was evident.

Changes in NO_2-nitrogen concentrations present in the compost produced, compared to the raw manures used, ranged from an increase of 0.28 times to 14.6 times. The corresponding raw manure NO_2 concentrations were 0.45 mg/kg and 1.36 mg/kg respectively. Differences in NO_2 concentration changes between processes studied were not statistically significant. The results did not indicate a trend between processes.

The organic matter losses ranged from a low of 43.29% for the turned-pile process using manure amended with compost, which had an organic matter content of 80.67% at the start of the composting process, to an organic matter loss of 57.92% for the turned-pile control process which had a raw manure organic matter content of 85.51% at the start of the composting process. There was no significant difference in organic matter losses between the continuous-forced-aeration, passive-aeration, modified-passive-aeration and turned-pile composting processes. The organic matter loss observed for the turned-pile process conducted using manure amended with compost, was 11.85 percentage points below the average organic matter loss for the other four processes studied. The lower organic matter loss is in part accounted for by the fact that 40% by volume of the composting mass was already in a relatively stable organic form at the start of the process and underwent a relatively small change over the course of the process compared to the raw manure. If it is assumed that the raw manure portion of the manure-compost mix used for this process underwent similar degradation levels as the other four processes, it becomes apparent that the compost portion of the manure-compost mix would have actually had an organic matter loss of approximately 18% associated with it. If it is assumed that the compost portion of the manure-compost mix actually underwent very little further biological degradation during the composting process, it follows that the raw manure fraction of the mix would have actually underwent a higher organic matter loss than occurred with the other four processes. We believe that the raw manure actually underwent a higher degree of organic matter loss than experienced in the other four processes due to the bacterial inoculation associated with the mixing of compost with the raw manure.

The dry matter losses ranged from 34.93% for the turned-pile process using compost amended manure to 49.53% for the turned-pile control process. Dry matter losses therefore followed the same general trend as organic matter losses. The initial dry matter contents were 24.53% and 24.27% respectively.

Moisture losses ranged from a low of 55.03% for the passive-aeration control process to a high of 69.43% for the turned-pile control process. Moisture levels in the raw manures were 69.45% to 75.73% respectively. Moisture losses were not significantly different between the forced-aeration, turned-pile control, turned-pile using manure amended with compost and modified passive-aeration processes. The lack of difference in moisture loss between the continuous-forced-aeration and turned-pile control or modified passive-aeration processes further suggests that natural settling caused air flows to short-circuit in the static-pile processes. A trend of higher moisture losses for forced-aeration and turned-pile processes compared to static-pile-passive-aeration processes was observed.

The C/N ratio decreased during composting for all processes examined in the third year experiments as an outcome of higher organic matter losses than nitrogen losses. Table 5.10 shows the C/N ratio changes which are significant. The two passive-aeration processes had the highest C/N ratio decrease which indicates they had a higher loss of organic matter compared to nitrogen.

A pH increase during composting was observed in the two passive-aeration processes, the turned-pile control process and the continuous-forced-aeration process. The pH changes are shown in Table 5.10. The turned-pile process which used manure amended with compost showed a pH decrease of 0.48 pH units. The pH increase observed for the other processes ranged from 0.05 pH units for the passive-aeration control process to 0.34 pH units for the continuous-forced-aeration process. The pH is of significance during composting. As the pH increases the ammoniacal nitrogen equilibrium moves more to the volatile NH_3 form and as pH decreases the equilibrium moves to the stable ammonium form.

5.4 Compost and Raw Manure Leachate Losses

The raw manure and corresponding compost leachate losses are presented in three sections. Section 5.4.1 presents the total nitrogen, phosphorus and potassium leachate loss results for the first year composting trials. The first year composting trials compares leachate losses from composts produced by static-pile-intermittent-forced-aeration, passive-aeration and turned-pile composting processes and the corresponding raw manures used for each process. Section 5.4.2 contains the total nitrogen, phosphorus and potassium leachate loss results for year two experiments and compares leachate losses from composts produced from three ecological composting processes, turned-pile composting under covered conditions, turned-pile composting outdoors, turned-pile composting with barnyard runoff addition and the corresponding raw manures. Section 5.4.3 contains nitrogen, phosphorus and potassium leachate loss results for year three trials and compares leachate losses from composts produced using a number of composting concepts and the corresponding raw manures. Leachate losses from compost produced using turned-pile composting of pack manure, turned-pile composting of manure amended with compost at a rate of 40% by volume, passive-aeration composting, modified-passive-aeration composting in which aeration tubes were closed for the first 21 days, forced-continuous-aeration composting and the corresponding raw manures are all compared in Section 5.4.3.

5.4.1 Compost And Raw Manure Leachate Losses - First Year Experiments

Table 5.11 shows the total nitrogen, phosphorus and potassium leachate losses for raw manures and composts produced from the raw manures using passive-aeration, turned-pile and intermittent-static-pile-forced-aeration processes. Differences observed in the leachate losses between the three compost materials are not statistically significant at a 99% level of confidence, however the differences between the raw manure leachate and the compost leachates were statistically significant at this confidence level. The concentrations of nitrogen, phosphorus and potassium were generally higher in the compost leachate compared to the raw manure leachate. Leachate losses for each process considered were calculated using the ratio of mass of N, P, or K present in leachate from a known mass of manure or compost to the mass of N, P, or K present in the mass of manure or compost used for leachate testing. Nitrogen concentrations in the raw manure leachate were 183 mg/L compared to a range of 227 to 382 mg/L for the compost leachates. Phosphorus leachate

Table 5.11. Compost And Raw Manure Leachate Losses - First Year Experiments

Process Description	N % Loss	P % Loss	K % Loss
Forced-Aeration	24.9	68.5	104[1]
Passive-Aeration	18.5	78.8	86.1
Turned-Pile	13.9	58.5	92.8
Raw Manure	14.3	17.9	49.3

concentrations ranged from 0.35 to 0.42 mg/L for the compost leachates compared to 0.07 mg/L for the raw manure leachate. Potassium concentrations in the raw manure leachate were 1.61 mg/L compared to a range of 4.41 to 4.99 mg/L in the compost leachates. To some extent this is surprising because composting literature generally cites the conversion of manure nitrogen to stable microbial body forms as a benefit to composting. The bulk analysis results indicate a 99% reduction in NH_3 quantities, which would result in a decrease in volatilization losses during field application compared to raw manure, but, from the data generated it also appears that composting may increase the potential for nutrient losses by leaching in some instances.

The leachate extraction process prescribed under MOEE Regulation 347 requires that the leachate be passed through a glass fibre micro filter (GFC) with a nominal pore size of 1.2 microns. It may be that composting results in the formation of microparticles which can pass through the filter and result in the higher nutrient values in the compost leachate.

5.4.2 Compost and Raw Manure Leachate Losses - Second Year Experiments

Table 5.12 shows the total nitrogen, phosphorus and potassium leachate losses for raw manure and for the corresponding compost produced during the second year experiments. The table presents leachate loss results for composts produced using three ecological composting processes, turned-pile composting under covered conditions, turned-pile composting outdoors, turned-pile composting with barnyard runoff addition and raw manure.

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[1] **This percentage >100 is a result of lab analysis and sample variability.**

Table 5.12. Compost And Raw Manure Leachate Losses - Second Year Experiments

Process Description	N % Loss	P % Loss	K % Loss
Turned-Pile Barnyard Runoff Addition Process #4 (TPR)	14.4	12.5	68.3
Raw Manure	12.1	16.1	53.7
Turned-Pile Outside Process #5 (TPO)	11.2	14.8	76.0
Raw Manure	21.7	18.0	75.1
Inside-Turned-Pile Process #6 (TPI)	12.1	5.6	73.1
Raw Manure	22.3	26.7	46.6
Sittler-Turned-Pile Luptke Method Process #7 (ES)	9.2	2.1	53.3
Raw Manure	46.4	38.6	65.5
Zettle- Modified-Static-Pile Process #8 (TZ)	6.9	4.3	55.6
Raw Manure	79.3	52.3	122.1
Lindner- Field -Windrow process #9 (FL)	5.6	8.2	46.5
Raw manure	16.4	12.4	35.9

Nitrogen, phosphorus and potassium leachate losses were generally higher for raw manures than for the compost produced. This is not consistent with results from the first year of composting trials shown in Table 5.11. Nitrogen concentrations in the raw manure leachates ranged from 137 mg/L to 663 mg/L compared to a range of 64 to 264 mg/L for the compost leachates. This is consistent with composting literature which generally cites the conversion of manure nitrogen to stable microbial body forms as a benefit to composting. Total nitrogen levels in the composts produced during the second year experiments ranged from 1.39% to 3.91% on a dry matter basis. Of this total nitrogen, mineral forms of nitrogen (ammoniacal nitrogen, NO_3-nitrogen and NO_2-nitrogen) considered readily leachable, represented a range of 6.9% of the total nitrogen in the Sittler compost to 9.0% of the total nitrogen in the inside turned-pile compost. The nitrogen leachate losses for the Sittler compost were 9.2% of the total nitrogen, which is slightly above the mineral nitrogen content. The nitrogen leachate losses for the inside turned-pile compost were 12.1% again slightly above the mineral nitrogen content of the compost. The nitrogen leachate losses for the six compost materials produced ranged from 5.6% of the total nitrogen present to 14.4% of the total nitrogen present.

Phosphorus leachate concentrations ranged from 9.4 to 45 mg/L for the compost leachates compared to a range of 25 to 58 mg/L for the raw manure leachates. Potassium concentrations in the raw manure leachates ranged from 403 to 1062 mg/L compared to a range of 469 to 1701 mg/L in the compost leachates.

Phosphorus leachability was reduced by composting, particularly in the compost produced by the ecological farm composting processes. The leachability of potassium was not consistently reduced by composting and in some cases potassium leachability was actually increased by composting.

5.4.3 Compost And Raw Manure Leachate Losses - Third Year Experiments

Table 5.13 shows the total nitrogen, phosphorus and potassium leachate losses for raw manure and the corresponding compost produced during the third year experiments. Leachate loss results are presented in table 5.13 for composts produced using turned-pile composting of pack manure, turned-pile composting of manure amended with compost at a rate of 40% by volume, passive-aeration composting, modified passive-aeration composting in which aeration tubes are closed for the first 21 days, continuous-forced-aeration composting and the corresponding raw manures.

Nitrogen, phosphorus and potassium leachate losses were higher for raw manures than for the compost produced. This is consistent with the second year experiment results but not consistent with the results from the first year of composting trials. The higher manure leachate losses are consistent with composting literature which generally cites the conversion of unstable manure nitrogen to stable microbial biomass forms as a benefit to composting. Nitrogen concentrations in the raw manure leachates ranged from 233 mg/L to 461 mg/L compared to a range of 159 to 328 mg/L for the compost leachates. Phosphorus leachate concentrations ranged from 25 to 56 mg/L for the compost leachates compared to a range of

Table 5.13. Compost And Raw Manure Leachate Losses - Third Year Experiments

Process Description	N % Loss	P % Loss	K % Loss
Forced-Aeration Continuous Aeration Compost Process #10 (FAC)	23.72	21.13	57.17
Raw Manure	43.51	28.27	95.19
Passive-Aeration Tubes Closed 21 Days Compost Process #11 (PAC)	18.38	12.92	42.43
Raw Manure	41.37	28.13	97.37
Passive-Aeration-Control-Compost Process #12 (PAO)	15.37	10.08	41.26
Raw Manure	45.45	29.67	96.46
Turned-Pile Manure /Compost Mix Compost Process #13 (TPS)	11.5	7.21	40.89
Raw Manure	15.34	14.55	80.86
Turned-Pile Turned after 21 Days Compost Process #14 (TP)	13.00	11.16	39.15
Raw manure	33.02	18.81	79.03

37 to 45 mg/L for the raw manure leachates. Potassium concentrations in the raw manure leachates ranged from 1243 to 1423 mg/L compared to a range of 808 to 1675 mg/L in the compost leachates.

Total nitrogen levels in the finished composts produced during the third year experiments ranged from 2.45% on a dry matter basis in the turned-pile compost to 3.16% on a dry matter basis in the turned-pile compost produced using manure amended with compost. Of this total nitrogen, mineral forms of nitrogen (ammoniacal nitrogen, NO_3-nitrogen and NO_2-nitrogen) considered readily leachable, represented between 4.0% of the total nitrogen in the turned-pile compost produced using compost amended manure and 4.7% of the total nitrogen in the turned-pile compost. The nitrogen leachate losses for the turned-pile compost produced using manure amended with compost were 11.5% of the total nitrogen which is almost three times the mineral nitrogen content. The nitrogen leachate losses for the turned-pile compost were 13.0% again almost three times the mineral nitrogen content of the compost. This indicates that organic nitrogen must be present in the leachate analyzed. The nitrogen leachate losses for the five compost materials produced ranged from 11.5% of the total nitrogen present to 23.7% of the total nitrogen present.

Phosphorus leachability was reduced consistently by composting for all compost trials conducted during the third year of experiments. The leachability of potassium was also consistently reduced by composting during the third year experiments.

5.5 Pore-Space And Off-Gas Characterization Monitoring

The gas monitoring system used for this project was purchased from and installed by Sciemetric Instruments Inc. Unfortunately the design and commissioning of the system turned out to be a real challenge for Sciemetrics Inc. and was a source of problems for the duration of the project. Monitoring the off-gas and pore-space concentrations of NH_3, O_2, CO_2 and CH_4 proved to be a difficult task because the sampled gases had to be maintained at temperatures in the 60 EC range in order to prevent condensation in the sampling tubing, line switching valves and gas monitoring instruments. This temperature operating range was not ideal for the proper operation of the main 12 point rotary sampling valve, resulting in it frequently malfunctioning. In the third year this sampling valve had to finally be removed. As a result the number of sampling points was reduced from 18 to 6. The systems 7 existing 3-way solenoid valves were then used for sample point switching.

The high temperatures maintained for sampling purposes also proved difficult for the vacuum sampling pump bearings which failed three times during the coarse of the project. Other electrical components in the system also caused problems. As a result of the numerous component problems, frequent and in some cases extended down-time periods were experienced. As well, line voltage fluctuations, in spite of surge suppression on the electrical supplies resulted in analyzer malfunctions due to low voltage. This was a very difficult problem to detect because it sent the NH_3 analyzer in particular into an error mode that did not relate to a voltage problem. Priority interrupt problems with the monitoring system also resulted in intermittent missing of data save routines or incomplete data save routines being carried out.

Because of the numerous gas monitoring problems, the data collected is not consistently replicated. The data have been plotted and relevant plots have been included but should not be assumed to necessarily be replicated data, as it is not feasible to try and denote sections of data which are and are not replicated. Relevant off-gas and pore-space concentration data for NH_3, CO_2, O_2 and CH_4 are presented in Sections 5.5.1, 5.5.2, 5.5.3, and 5.5.4 respectively, in a series of graphs.

5.5.1 Pore-Space And Off-Gas Ammonia Concentration Monitoring Results

The concentration of NH_3 in off-gas and compost pore-spaces was monitored because nitrogen loss during aerobic composting is primarily due to NH_3 volatilization during microbial degradation of organic substrates in raw manure. Off-gas and pore-space NH_3 concentrations are a direct indication of the relative level of NH_3 volatilization potential. Comparing NH_3 concentrations between composting techniques offers an opportunity to compare the relative potential for nitrogen loss between composting techniques.

Figures 5.1, 5.2, 5.3, 5.4, and 5.5 are graphs of the pore-space NH_3 concentrations for the turned-pile composting process conducted using raw manure amended with compost, a conventional turned-pile process, a passive-aeration process, a modified-passive-aeration process in which the aeration tubes were sealed for the first 21 days, and a static-pile-continuous-forced-aeration composting process. The off-gas concentrations for composting processes studied followed similar patterns as the pore-space NH_3 concentrations and are shown in Figures 5.6, 5.7, 5.8, 5.9, and 5.10 for the turned-pile composting process conducted using compost amended manure, a conventional turned-pile process, a passive-aeration process, a modified-passive-aeration process in which the aeration tubes were sealed for the first 21 days, and a static-pile-continuous-forced-aeration composting process respectively.

The turned-pile composting process (Figure 5.1) which was conducted with manure amended with compost did not exhibit appreciably lower pore-space NH_3 concentrations during the first 21 days compared to turned-pile composting with straight manure (Figure 5.2), as was

FIGURE 5.1. PORE SPACE AMMONIA CONCENTRATION - TURNED PILE COMPOSTING - MANURE AMENDED WITH 40% BY VOLUME FINISHED COMPOST

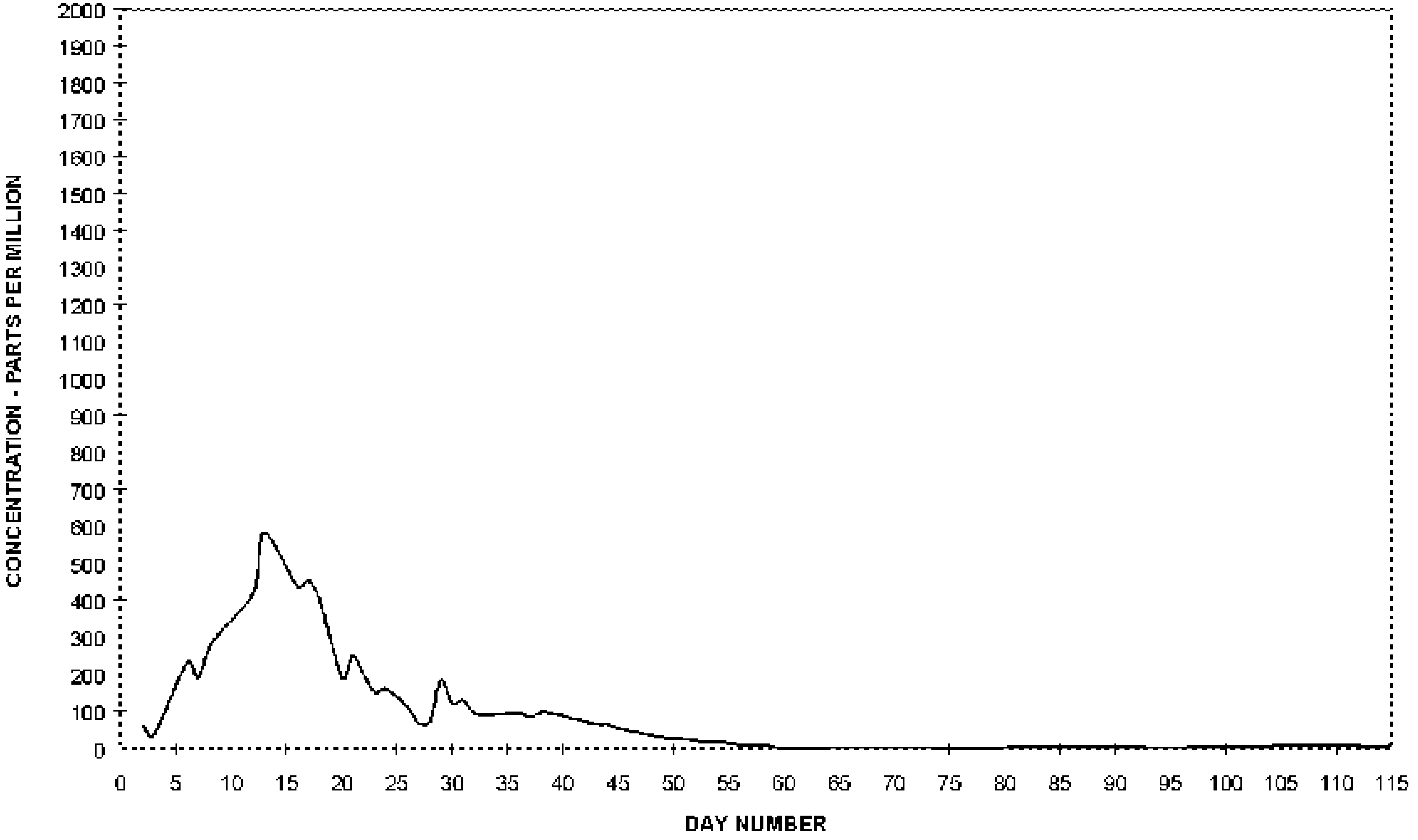


FIGURE 5.2. PORE SPACE AMMONIA CONCENTRATION - TURNED PILE COMPOSTING INSIDE - YEAR THREE EXPERIMENT

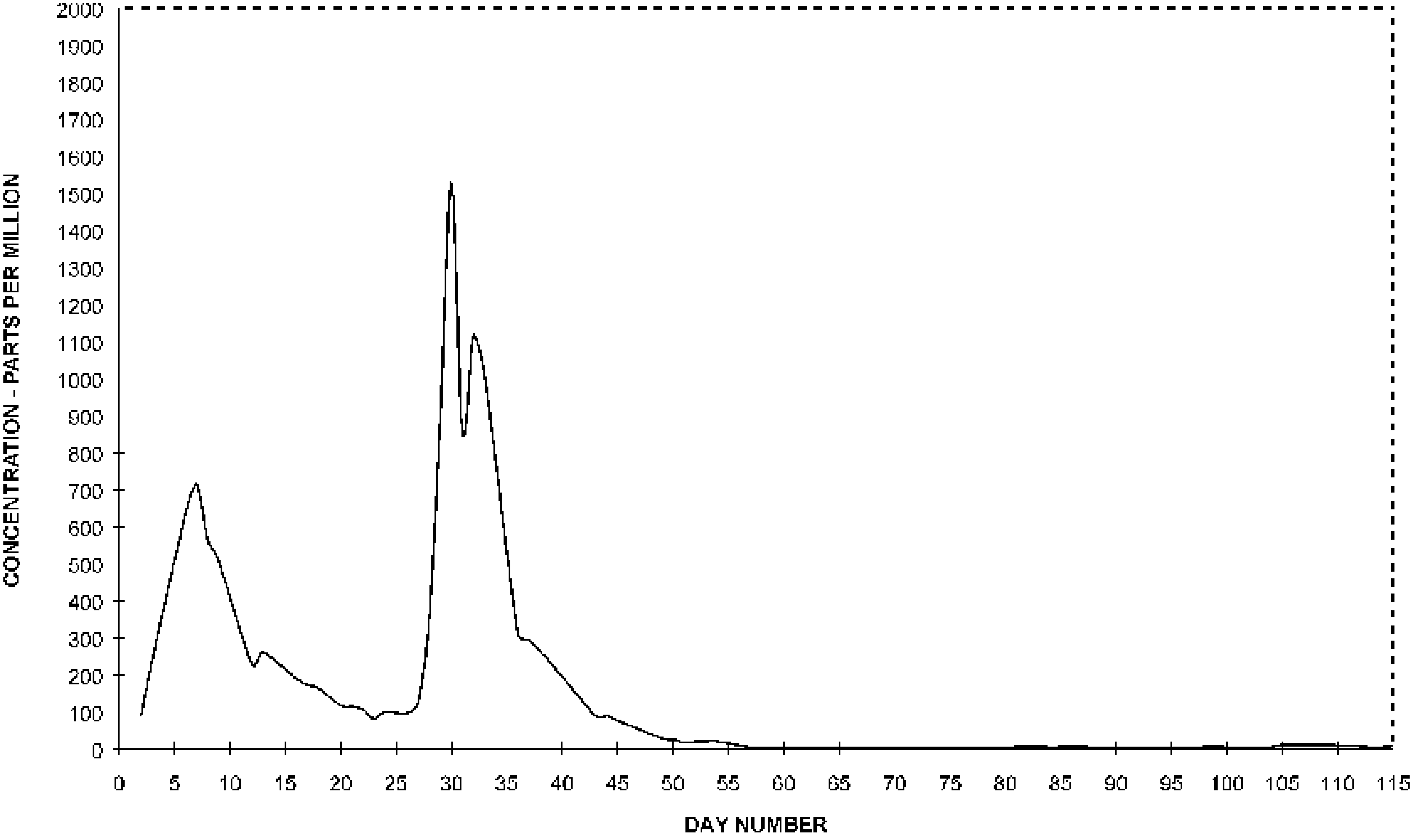


FIGURE 5.3. PORE SPACE AMMONIA CONCENTRATION - PASSIVE AERATION COMPOSTING - AERATION TUBES OPEN FOR FULL DURATION OF COMPOSTING PROCESS

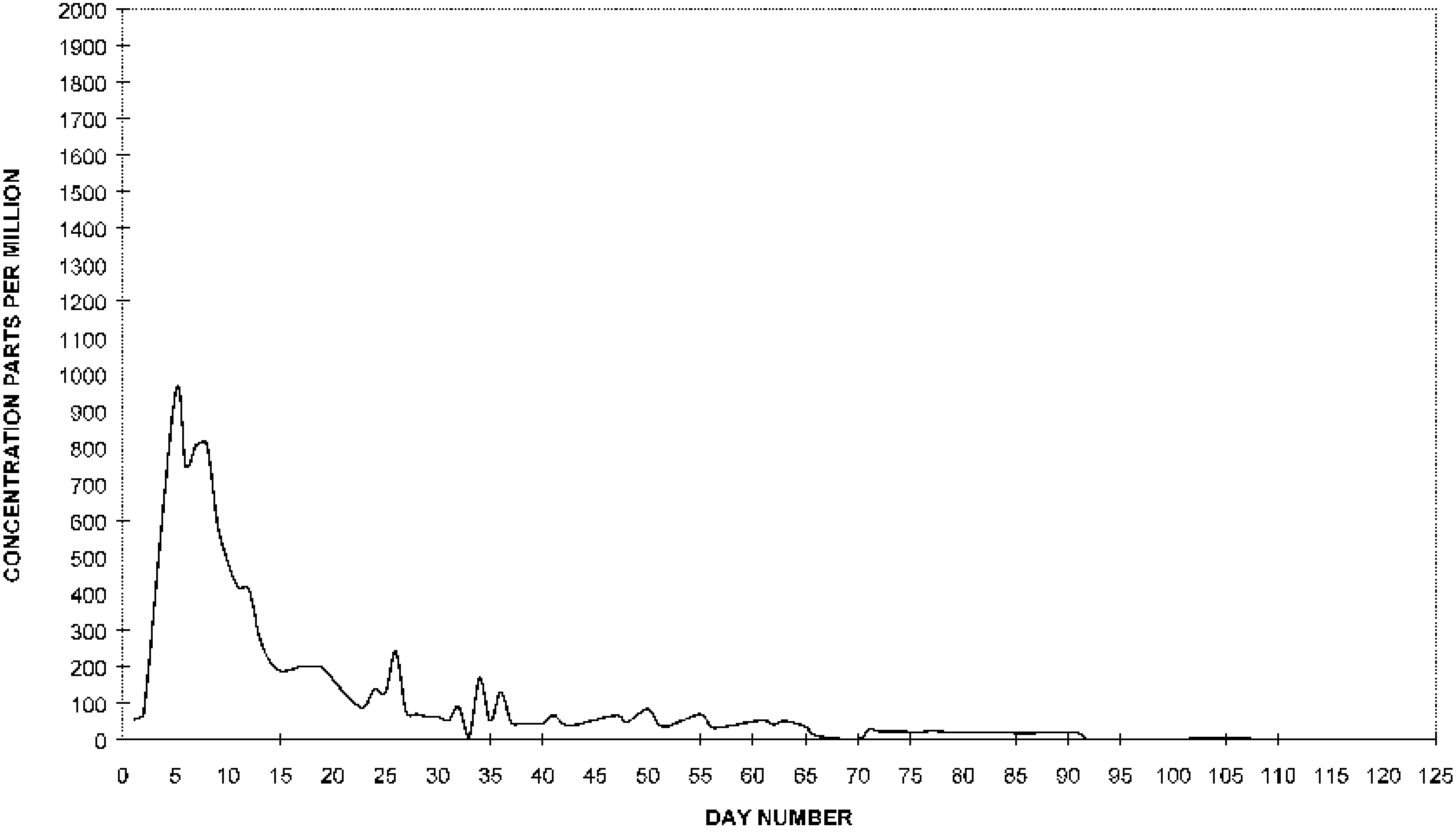


FIGURE 5.4. PORE SPACE AMMONIA CONCENTRATION - PASSIVE AERATION COMPOSTING - AERATION TUBES SEALED FOR 21 DAYS AFTER WINDROW FORMATION

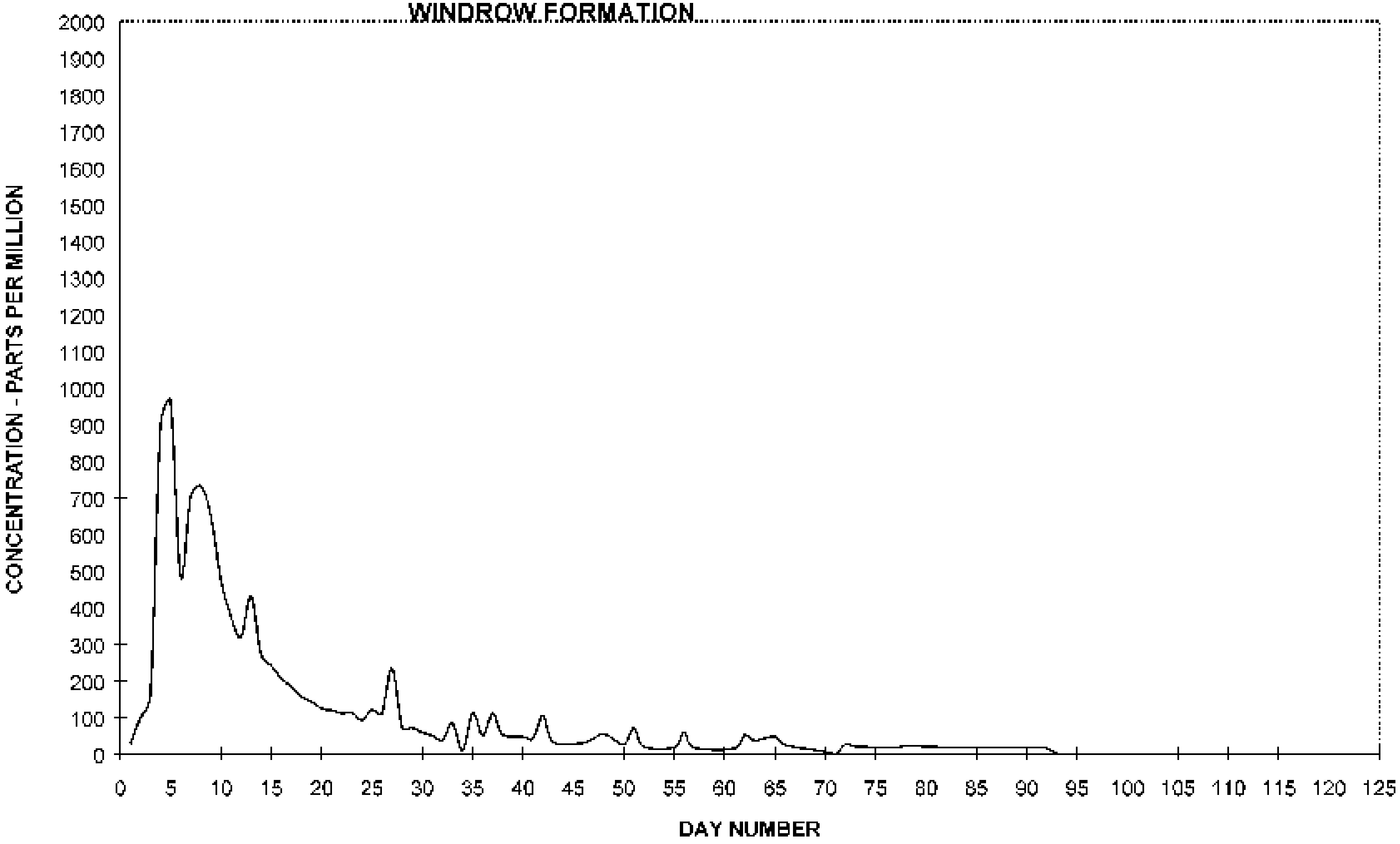


FIGURE 5.5. PORE SPACE AMMONIA CONCENTRATION - CONTINUOUS FORCED AERATION COMPOSTING - AERATION STARTED 21 DAYS AFTER WINDROW FORMATION

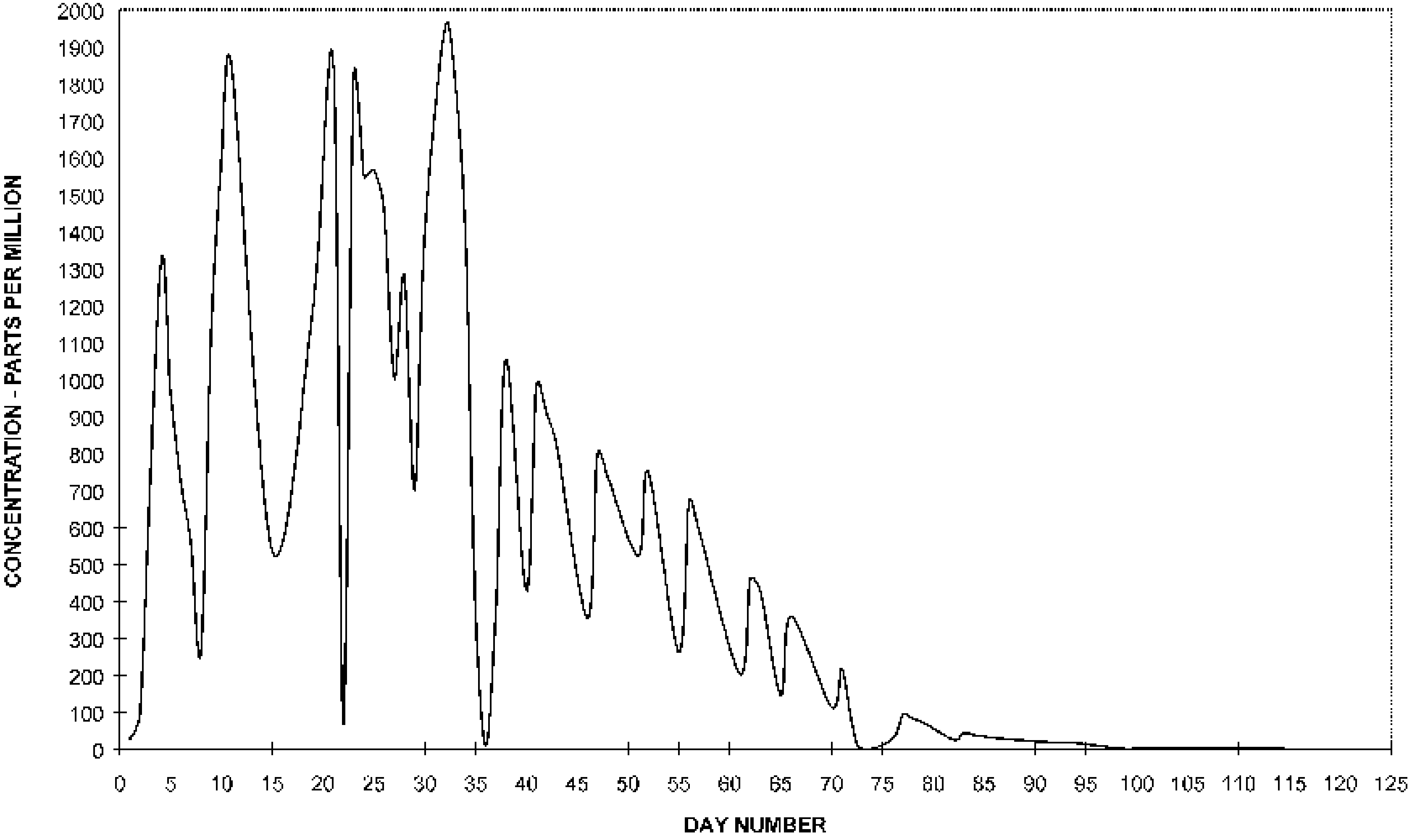


FIGURE 5.6. OFF-GAS AMMONIA CONCENTARATION - TURNED PILE COMPOSTING - MANURE AMENDED WITH 40% BY VOLUME FINISHED COMPOST

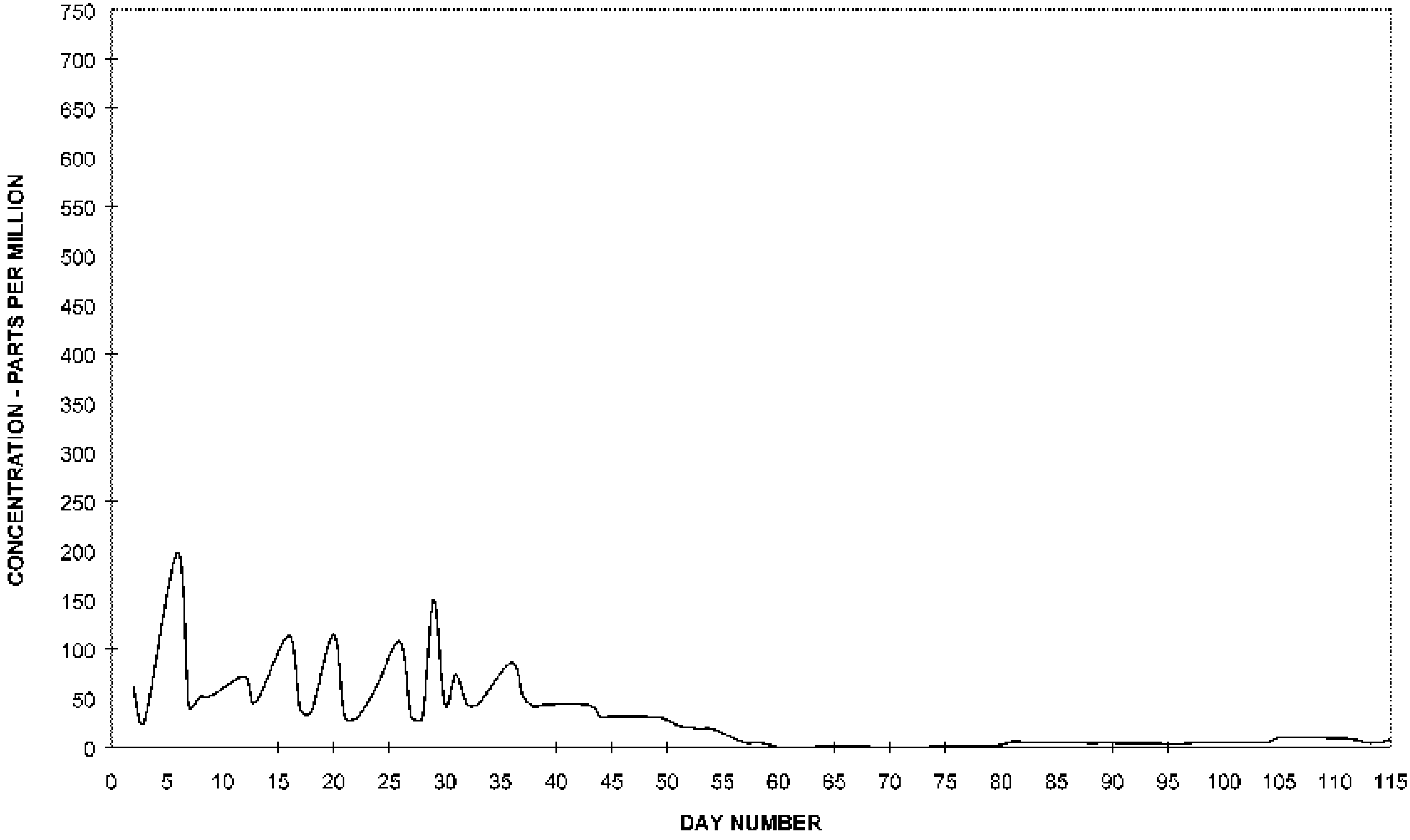


FIGURE 5.7. OFF-GAS AMMONIA CONCENTRATION - TURNED PILE COMPOSTING INSIDE - YEAR THREE EXPERIMENT

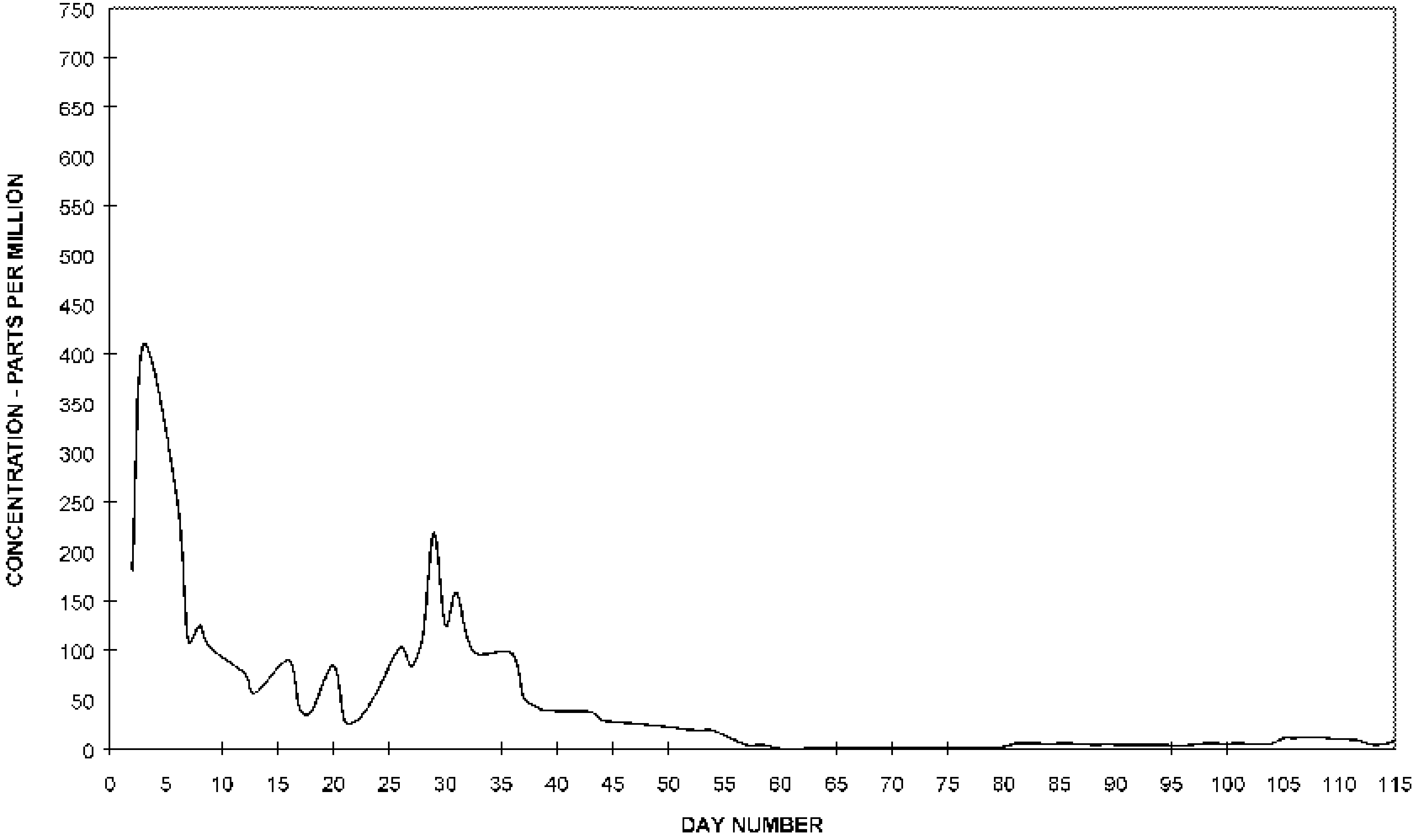


FIGURE 5.8. OFF-GAS AMMONIA CONCENTRATION - PASSIVE AERATION COMPOSTING - AERATION TUBES OPEN FOR FULL DURATION OF COMPOSTING PROCESS

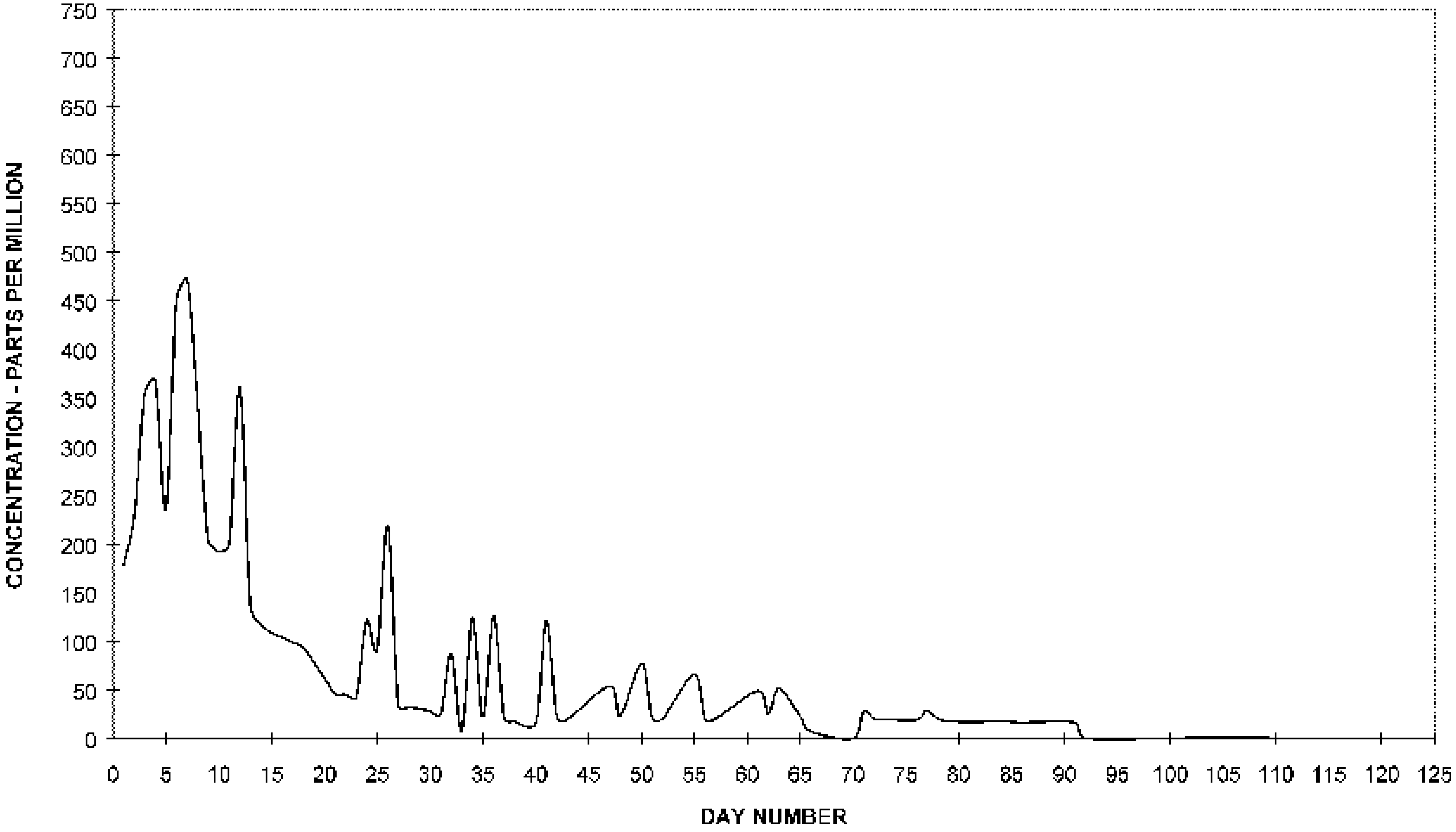


FIGURE 5.9. OFF-GAS AMMONIA CONCENTRATION - PASSIVE AERATION COMPOSTING - AERATION TUBES SEALED FOR 21 DAYS AFTER WINDROW FORMATION

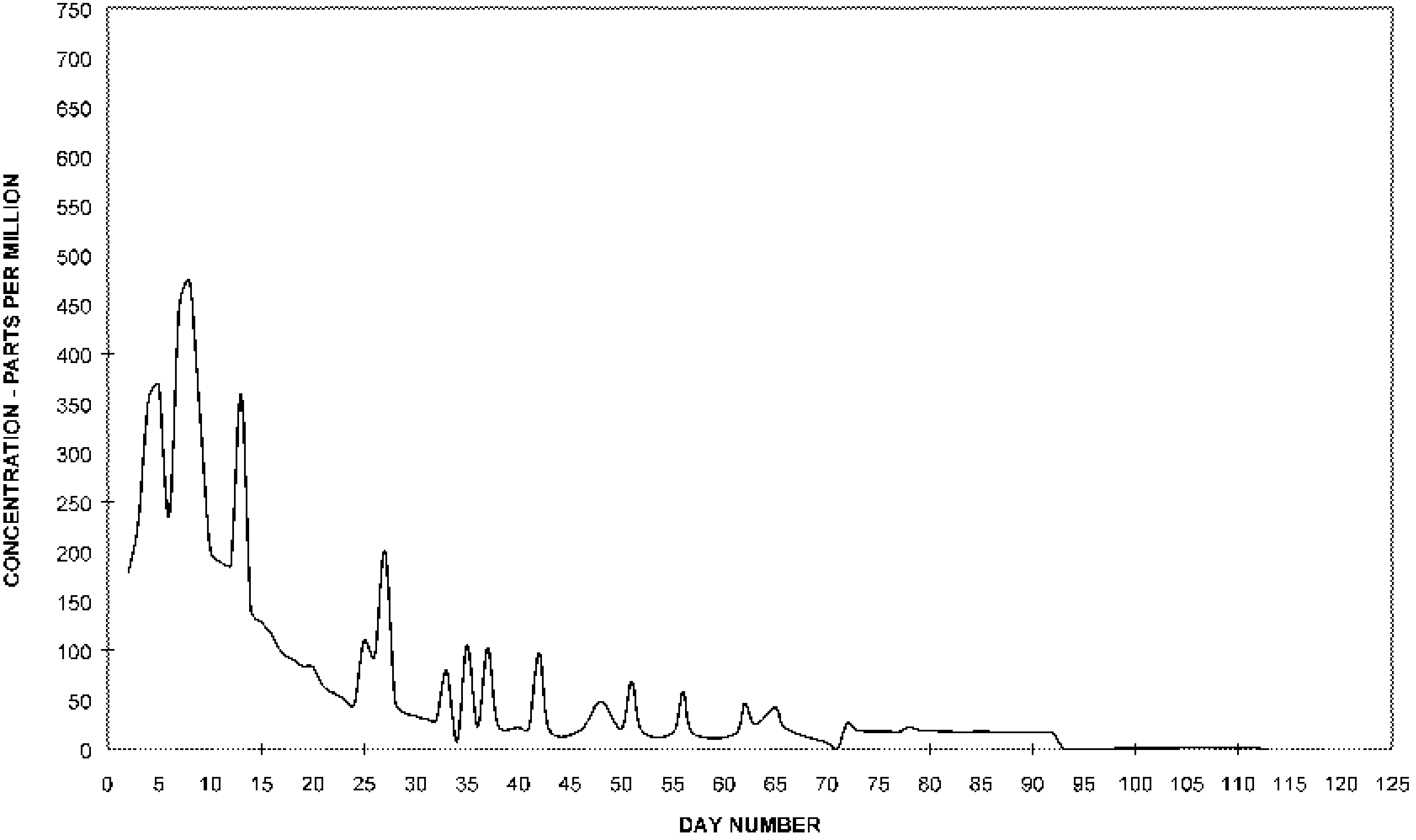
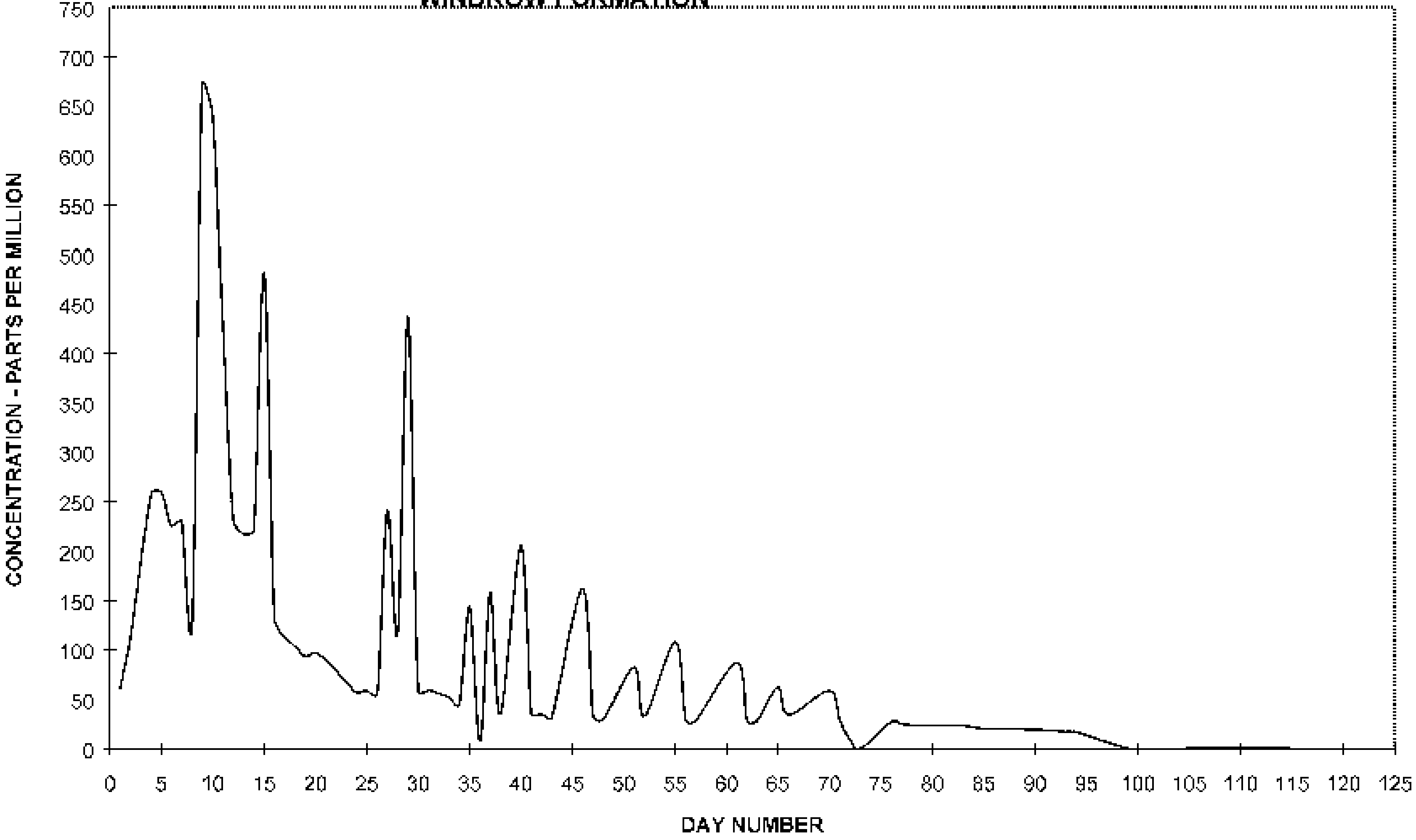


FIGURE 5.10. OFF-GAS AMMONIA CONCENTRATION - CONTINUOUS FORCED AERATION COMPOSTING - AERATION STARTED 21 DAYS AFTER WINDROW FORMATION



anticipated. In fact the pore-space NH_3 concentrations followed the same general pattern and levels, for both processes, for the first 21 days. Pore-space NH_3 concentrations however were quite different for approximately 30 days after the first mix on day 25. Mixing resulted in a substantial increase in pore-space NH_3 concentrations in the conventional turned-pile process compared to the turned-pile process conducted with compost amended manure. The concept of adding finished compost to raw manure prior to composting was anticipated to provide bacterial populations which would effectively utilize a greater percentage of the NH_3 released during the early stages of composting. The NH_3 pore-space concentration and off-gas concentration data does not substantiate this. However, the turned-pile composting process which was conducted with the raw manure amended with compost did have a lower nitrogen loss than the conventional turned-pile compost.

The pore-space NH_3 concentration data shows much lower pore-space NH_3 concentrations for approximately a 30 day period from day 25 to day 55 which may account for the lower nitrogen losses.

Pore-space NH_3 concentrations for the passive-aeration composting process (Figure 5.3) and modified passive-aeration composting process in which the aeration tubes were sealed for the first 21 days (Figure 5.4) did not exhibit different patterns or levels of NH_3 concentration indicating that restricting aeration by closing the passive aeration tubes is not an effective means of reducing nitrogen losses through NH_3 volatilization. This is most likely because of natural manure settling and compaction in static-pile processes which reduces the effectiveness of passive aeration enhancements.

Pore-space NH_3 concentrations remained the highest for the longest duration in the static-pile-continuous-forced-aeration composting process, but this process did not exhibit nitrogen losses which were different statistically, from turned-pile or passive-aeration processes.

5.5.2 Pore-space And Off-Gas Oxygen Concentration Monitoring Results

Figures 5.11, 5.12, 5.13, 5.14, and 5.15 are graphs of the pore-space O_2 concentrations for the turned-pile composting process conducted using compost amended manure, a conventional turned-pile process, a passive-aeration process, a modified-passive-aeration process in which the aeration tubes were sealed for the first 21 days, and a static-pile-

FIGURE 5.11. PORE SPACE OXYGEN CONCENTRATION - TURNED PILE COMPOSTING - MANURE AMENDED WITH 40% BY VOLUME FINISHED COMPOST

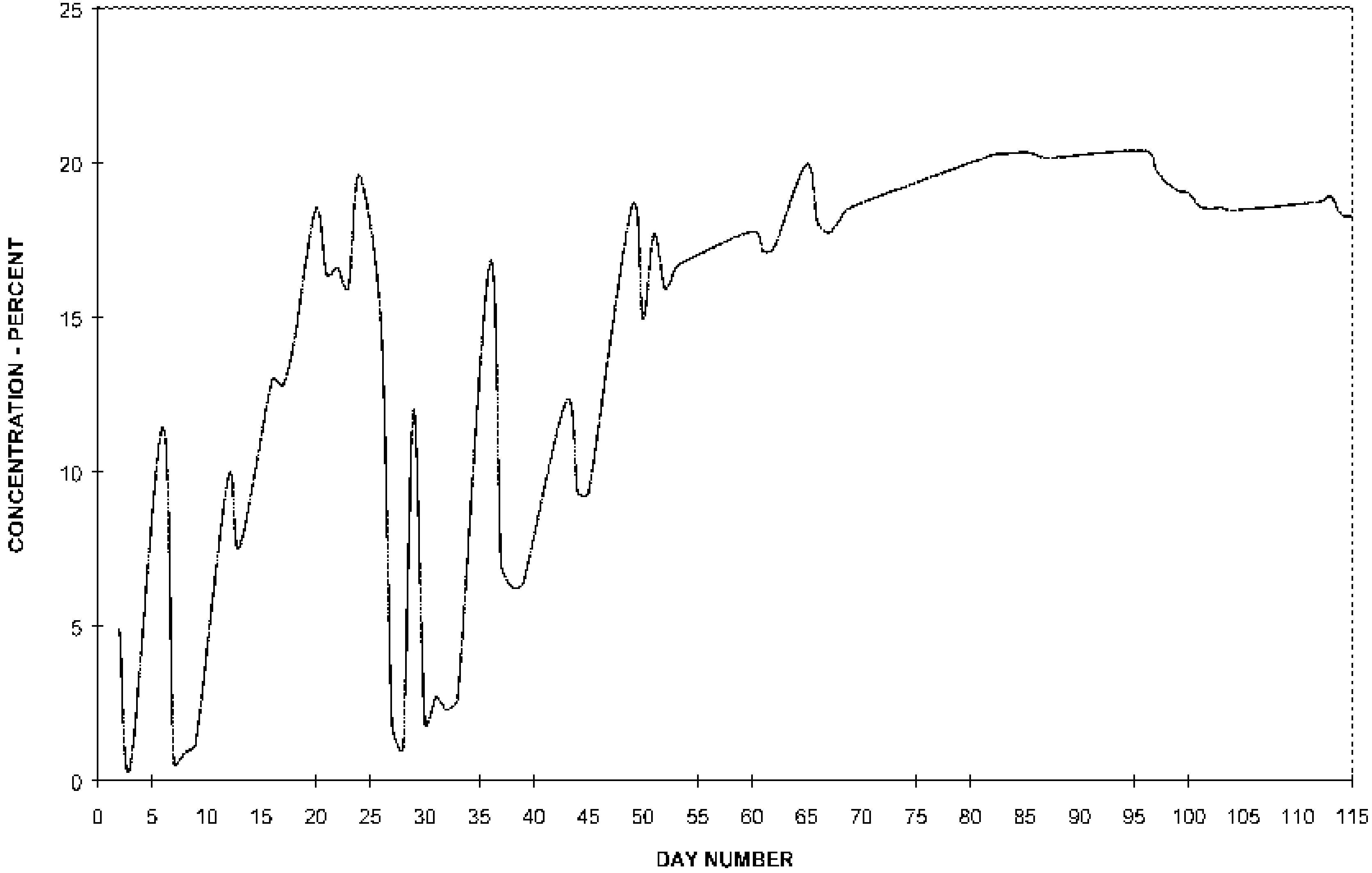


FIGURE 5.12. PORE SPACE OXYGEN CONCENTRATION - TURNED PILE COMPOSTING INSIDE - YEAR THREE EXPERIMENT

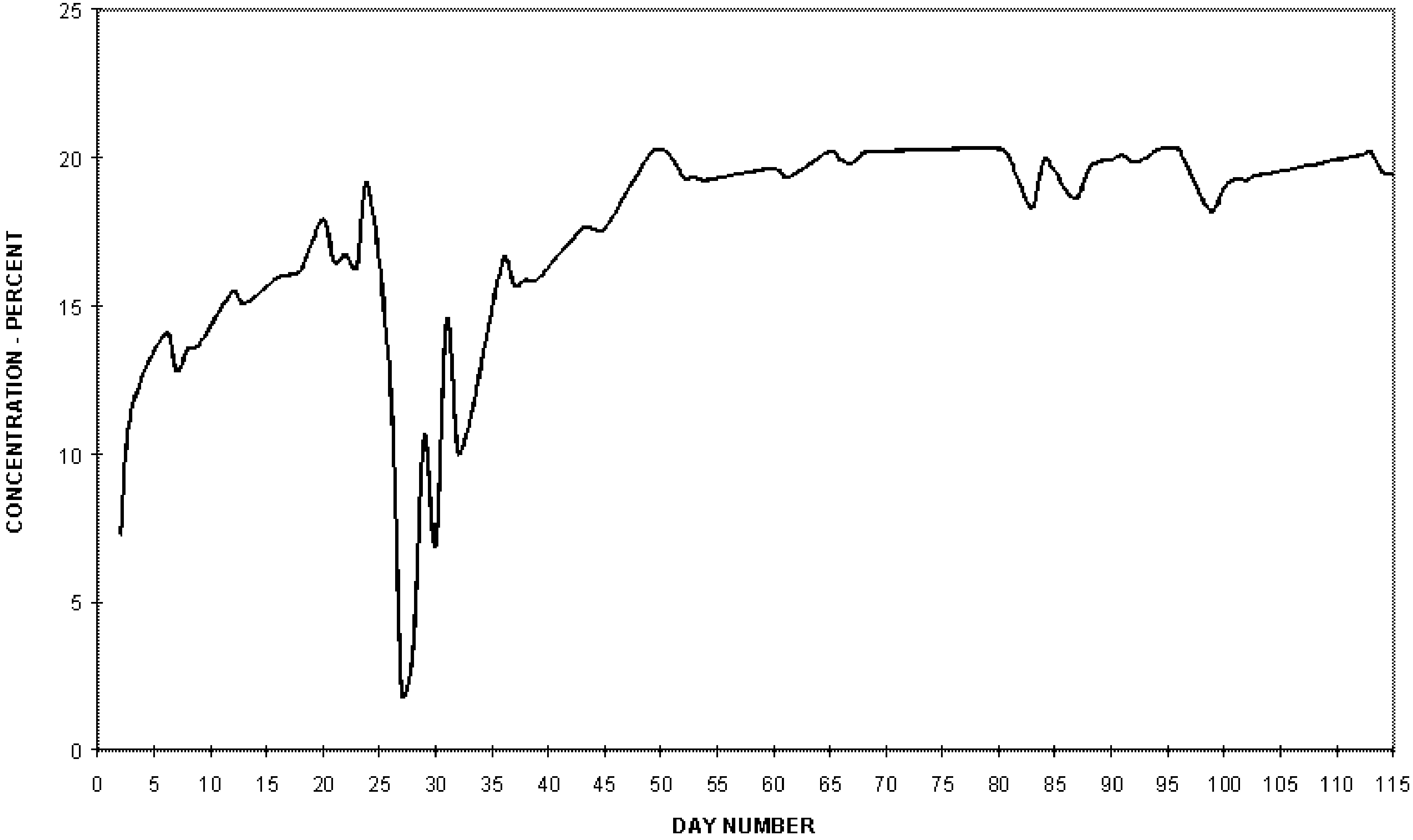
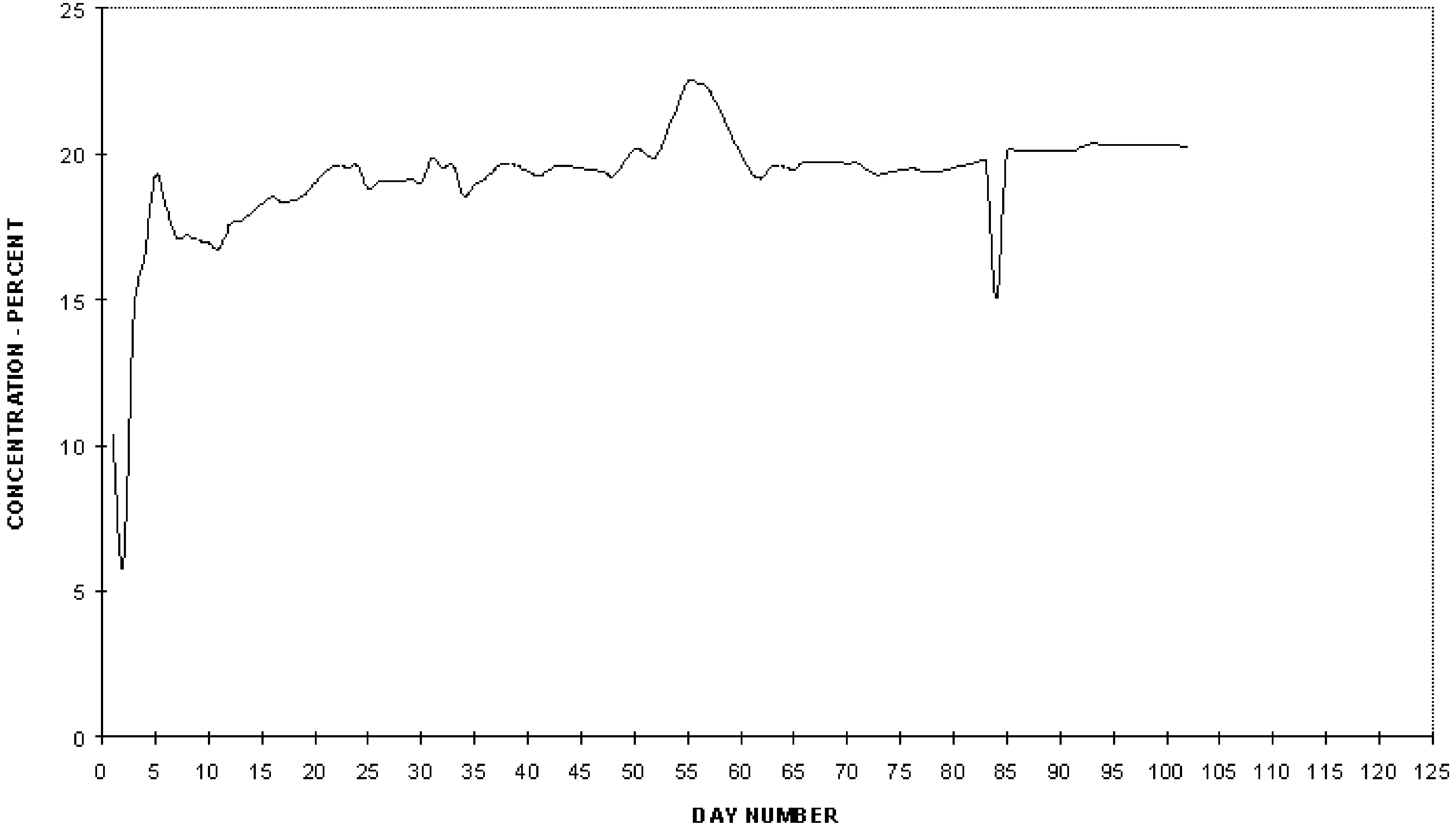


FIGURE 5.13. PORE SPACE OXYGEN CONCENTRATION - PASSIVE AERATION COMPOSTING - AERATION TUBES OPEN FOR FULL DURATION OF COMPOSTING PROCESS



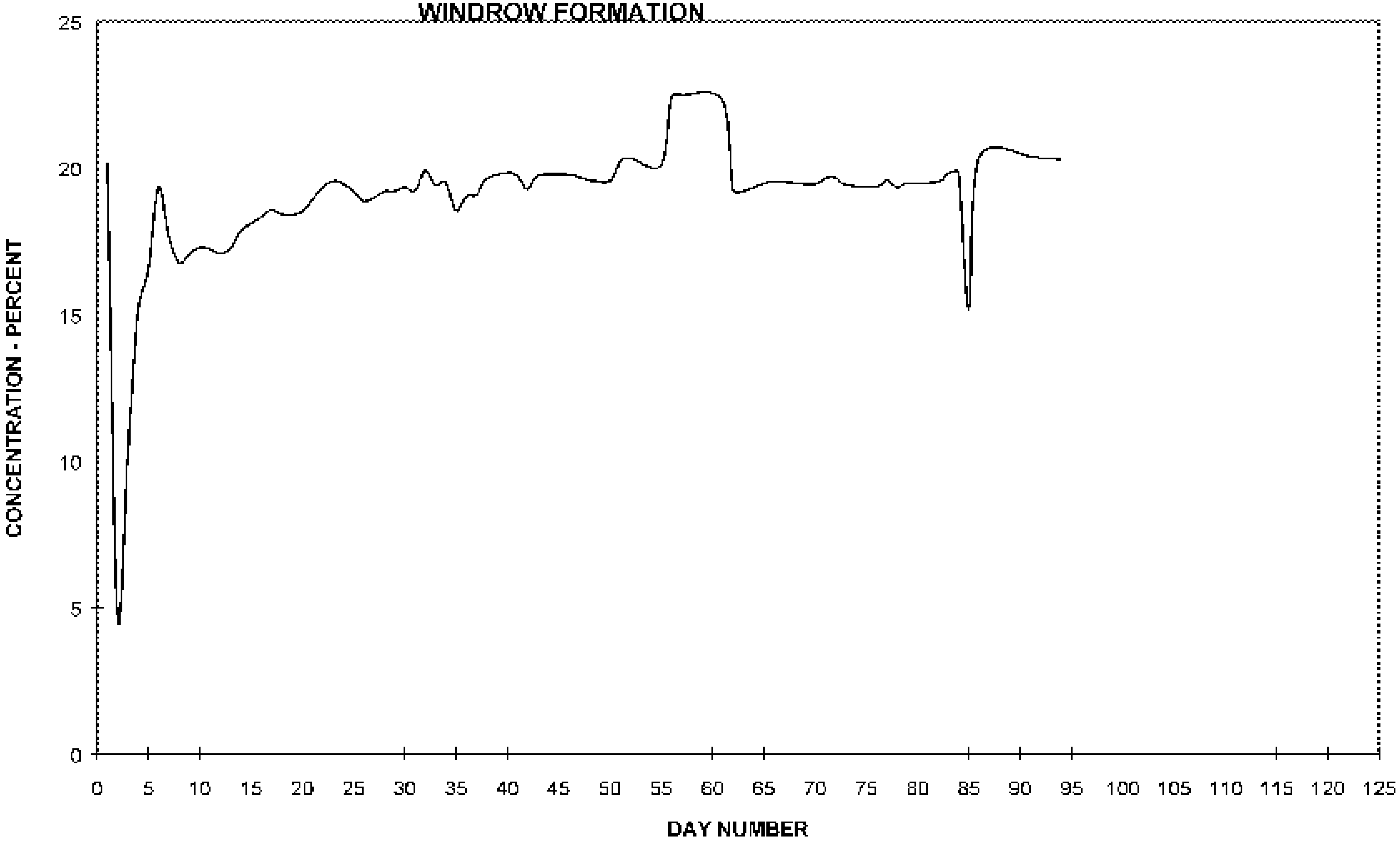
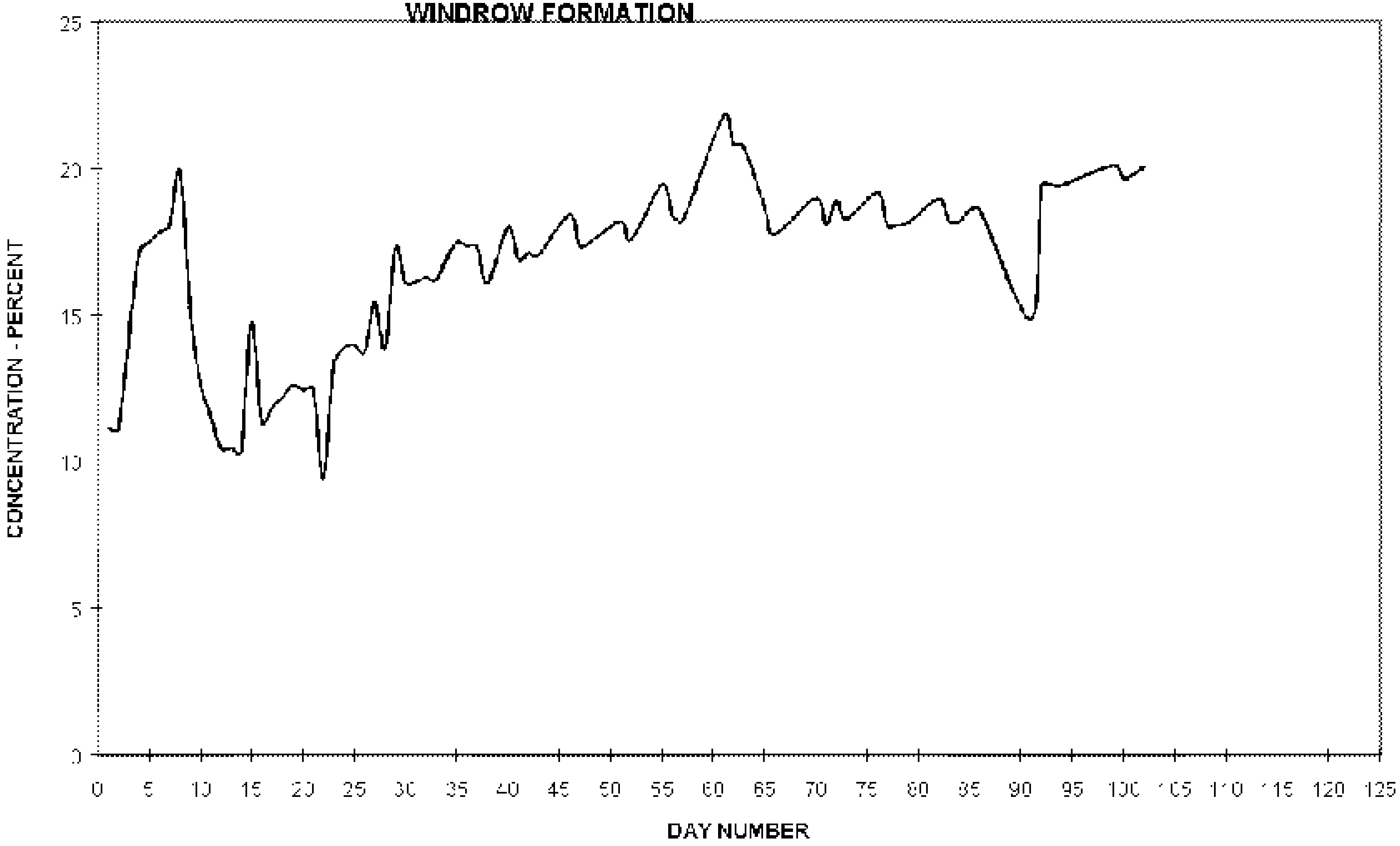


FIGURE 5.14. PORE SPACE OXYGEN CONCENTRATION - PASSIVE AERATION COMPOSTING - AERATION TUBES SEALED FOR 21 DAYS AFTER WINDROW FORMATION

FIGURE 5.15. PORE SPACE OXYGEN CONCENTRATION - CONTINUOUS FORCED AERATION COMPOSTING - AERATION STARTED 21 DAYS AFTER WINDROW FORMATION



continuous-forced-aeration composting process. Oxygen concentrations were monitored to determine if various composting techniques were more effective than others in maintaining aerobic conditions throughout the composting manure mass for the duration of each composting technique studied.

Pore-space O_2 concentration levels and concentration trends were similar for static-pile-passive-aeration and static-pile-forced-aeration processes, indicating that there is no process advantage to providing forced-aeration under static-pile composting process conditions. This is believed to be the result of natural manure settling and compaction which reduces the effectiveness of aeration enhancements.

Pore-space O_2 concentration draw-downs (reduction in O_2 over time) were observed for all processes during the first few days of composting. The high temperature produced during active composting is the driving force for air movement through turned-pile and passive-aeration processes as well as forced-aeration processes to some extent, depending on the aeration frequency, duration and rate. During the initial start up of composting processes, air movement through the initially ambient temperature manure is not significant and results in an initial O_2 draw down which is alleviated once heating occurs. Static-pile composting processes have windrow dimension limitations and typically windrow widths should not exceed 3 meters, and heights should not exceed 1.5 meters to allow effective air transfer through the composting manure.

The O_2 draw-down observed at the start of composting was also observed after mixing of turned-pile processes. This is believed to be the result of process cooling during mixing. The cooling reduces air movement through the compost after mixing. The pore-space O_2 concentration was observed to recover as the process temperature recovered. The turned-pile process conducted using raw manure amended with compost took longer for temperature recovery after mixing and maintained a lower process temperature after mixing than the turned-pile process. This can explain the differences in O_2 draw-down patterns. A definite pore-space O_2 concentration draw-down was observed after addition of barnyard runoff in experiment two (Fig 5.15). This O_2 draw-down was believed to be the result of accelerated microbial activity from the runoff addition. Results of experiment 3 (Figure 5.12) do not substantiate this theory and in fact the draw down was the result of temperature reduction from runoff addition and mixing at the time of runoff addition. Pore-space O_2 concentrations of 5% are considered adequate for effective O_2 exchange and aerobic bacterial activity (Rynk 1992). Passive-aeration processes were observed to maintain pore-space O_2 concentrations in excess of 5% for the duration of the process indicating that O_2 was not a limiting factor in these experiments. Pore-space O_2 concentrations in the turned-pile processes remained above the 5% level for the majority of the active composting period. Ironically the periods of pore-space O_2 draw-down occurred immediately after mixing which was in fact performed to enhance pore-space O_2 concentrations. This indicates that mixing should be performed in a manner which minimizes heat loss. To this end, commercial windrow turners are likely to result in less heat loss than loader mixing and turning.

5.5.3 Pore-space and Off-Gas Carbon Dioxide Concentration Monitoring Results

Figures 5.16, 5.17, 5.18, 5.19, and 5.20 are graphs of the pore-space CO_2 concentrations for a turned-pile composting process conducted using compost amended manure, a conventional turned-pile process, a passive-aeration process, a modified-passive-aeration process in which the aeration tubes were sealed for the first 21 days, and a static-pile-continuous-forced-aeration composting process.

The pore-space CO_2 concentration has been used as an indication of the level of microbial activity in combination with process temperature. Turned-pile composting, passive-aeration composting and forced-aeration composting all exhibited the same general trend with respect to pore-space CO_2 concentrations. Pore-space CO_2 levels were generally highest at the start of composting processes and declined in an asymptotic fashion with reducing peaks and valleys as the decline continued over time. Pore-space CO_2 concentrations were observed to rise dramatically after mixing of turned-pile processes. This is believed to be the result of substrate mixing rather than O_2 introduction. Pore-space O_2 concentrations were consistently observed to be above the acceptable level of 5% (Rynk 1992) and yet CO_2 concentrations would steadily decline until mixing. Bacterial decomposition takes place through enzymatic break down of organic matter which releases require nutrients for bacterial assimilation (Martin *et al*. 1992). Based on the results of this study we believe that localized colonization takes place in the proximity of pore-spaces and enzyme movement is localized. Mixing we believe breaks up anaerobic micro and macro sites and redistributes bacterial populations as well as enzymes released by bacterial populations, resulting in the increase of bacterial activity after mixing.

FIGURE 5.16 PORE SPACE CARBON DIOXIDE CONCENTRATION - TURNED PILE COMPOSTING - MANURE AMENDED WITH 40% BY VOLUME FINISHED COMPOST

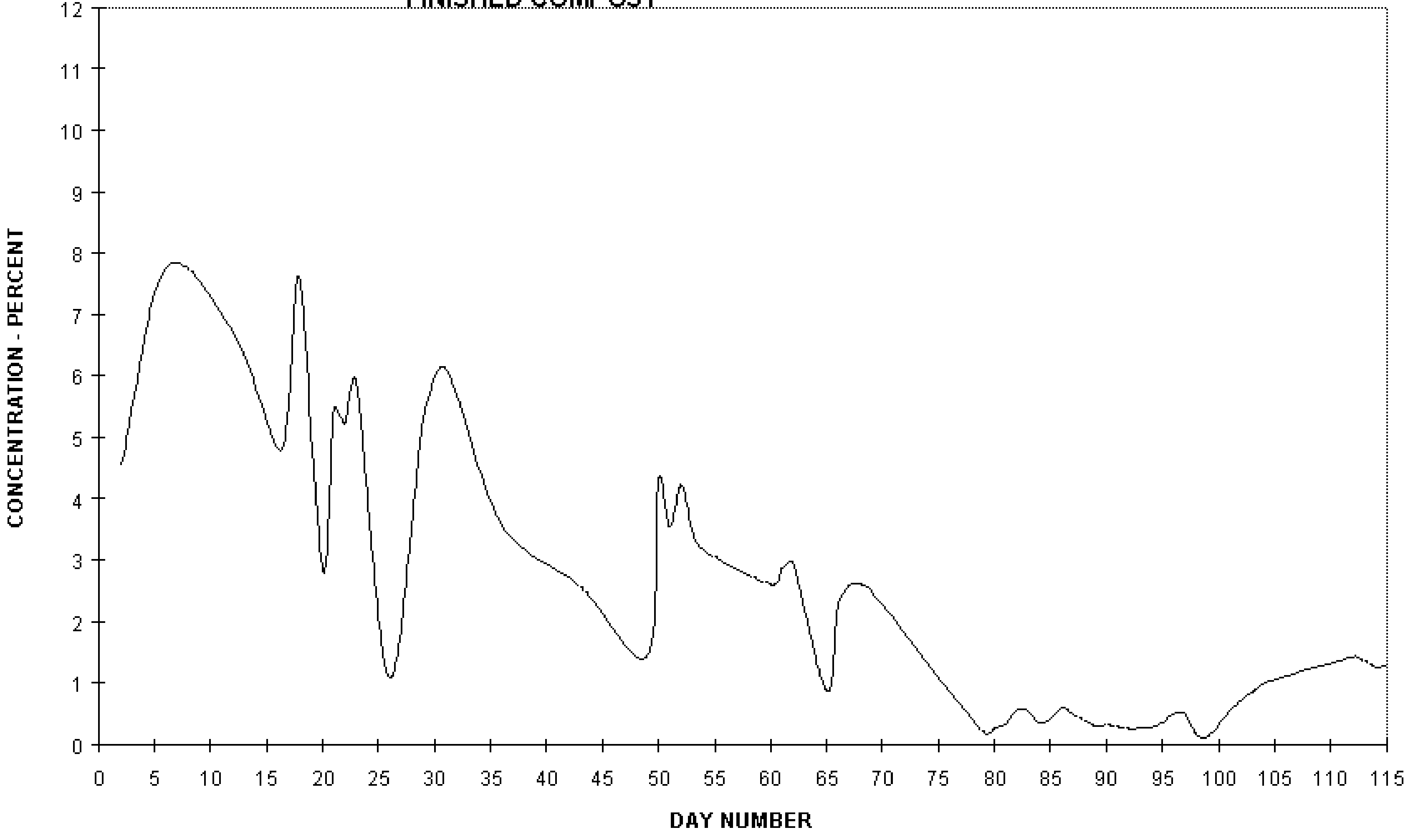


FIGURE 5.17. PORE SPACE CARBON DIOXIDE CONCENTRATION - TURNED PILE COMPOSTING INSIDE - YEAR THREE EXPERIMENT

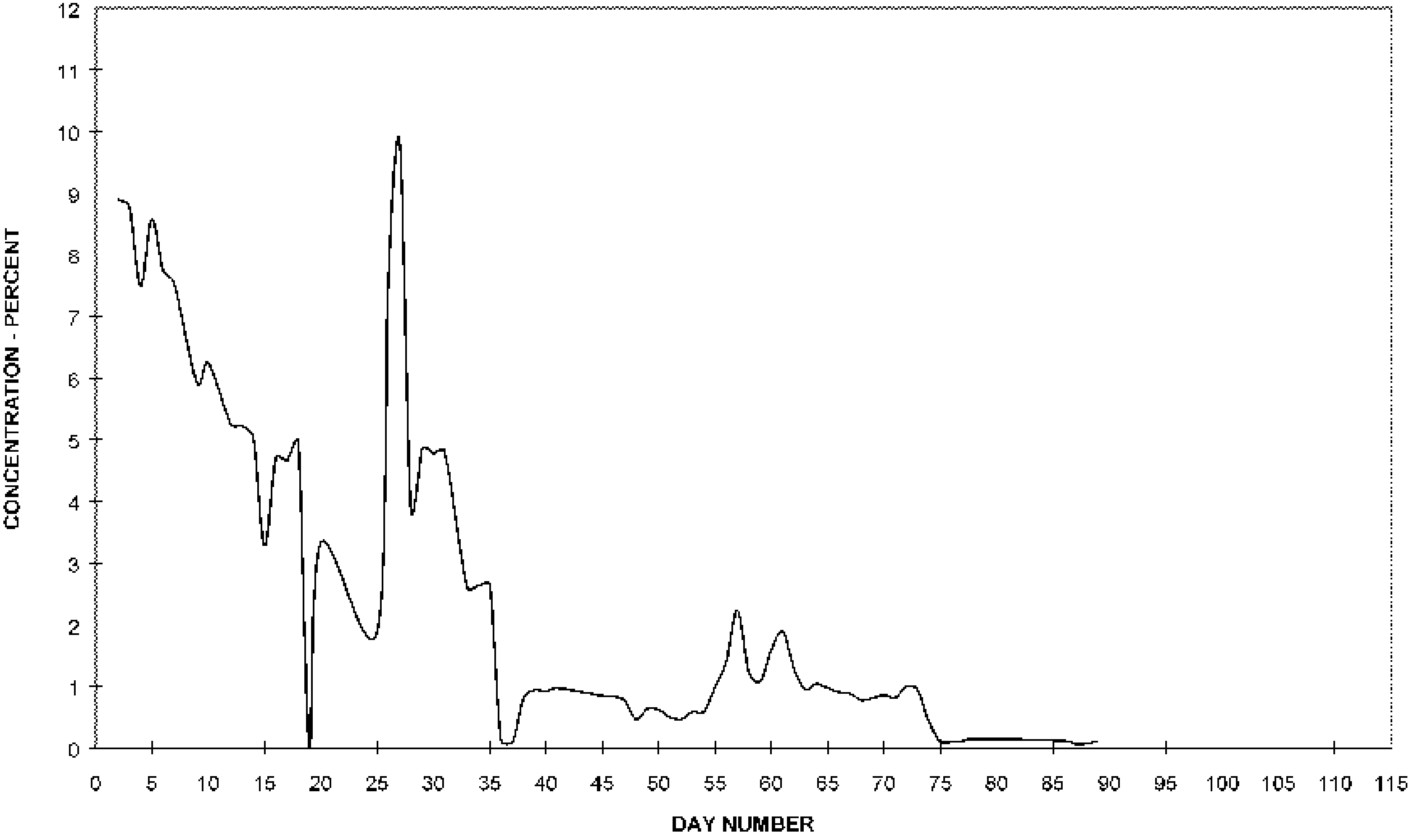


FIGURE 5.18. PORE SPACE CARBON DIOXIDE CONCENTRATION - PASSIVE AERATION COMPOSTING - AERATION TUBES OPEN FOR FULL DURATION OF COMPOSTING PROCESS

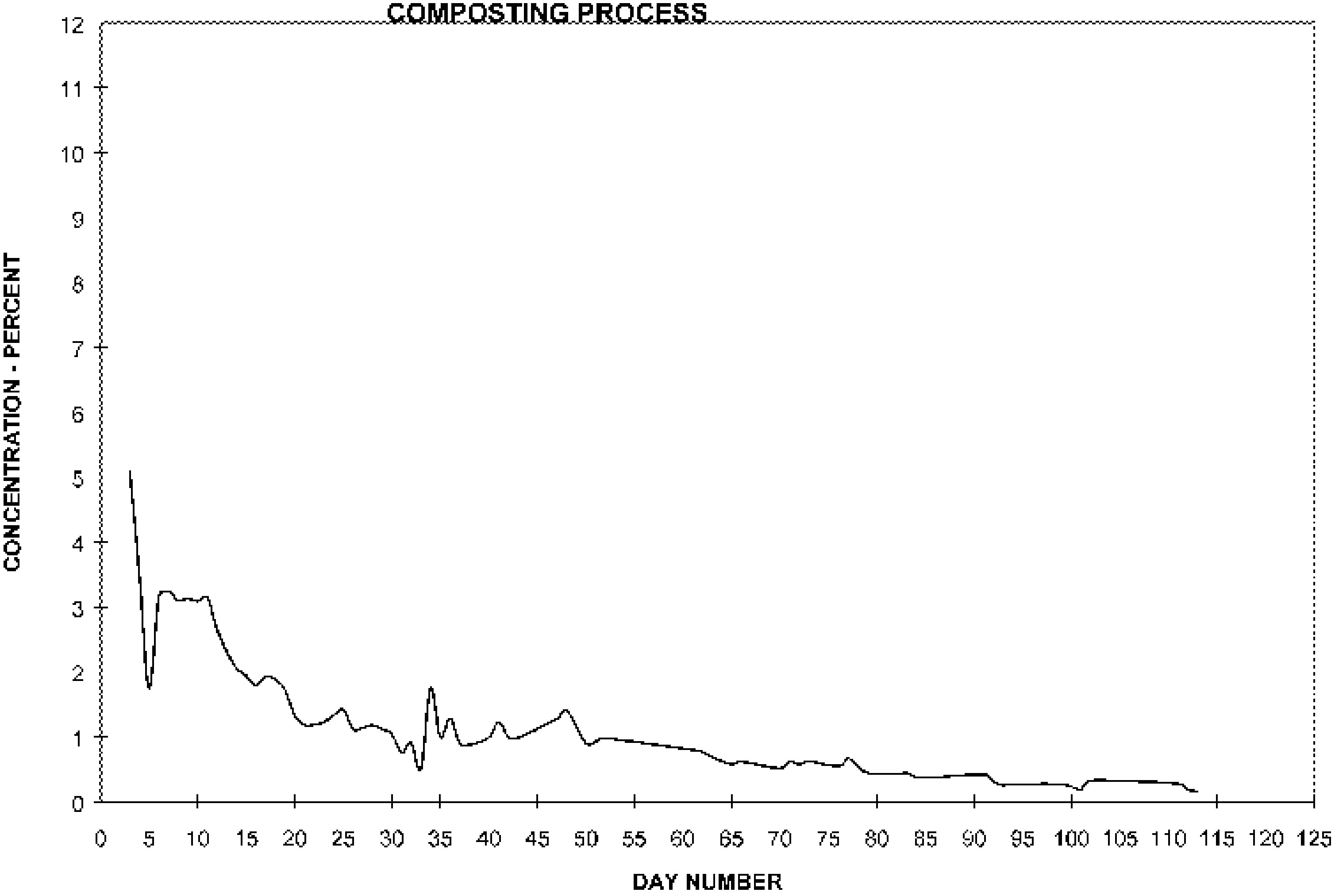


FIGURE 5.19. PORE SPACE CARBON DIOXIDE CONCENTRATION - PASSIVE AERATION COMPOSTING - AERATION TUBES SEALED FOR 21 DAYS AFTER WINDROW FORMATION

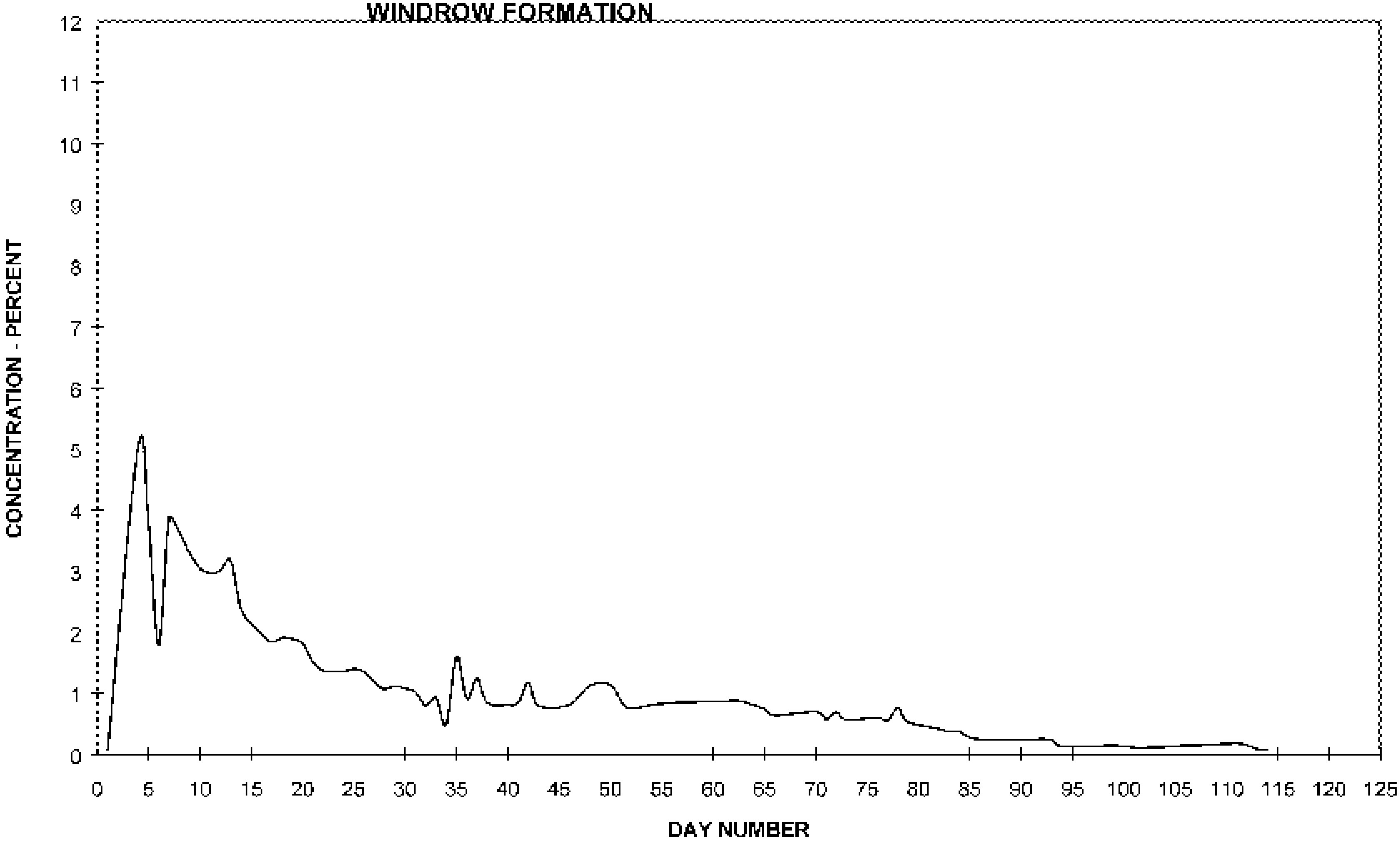
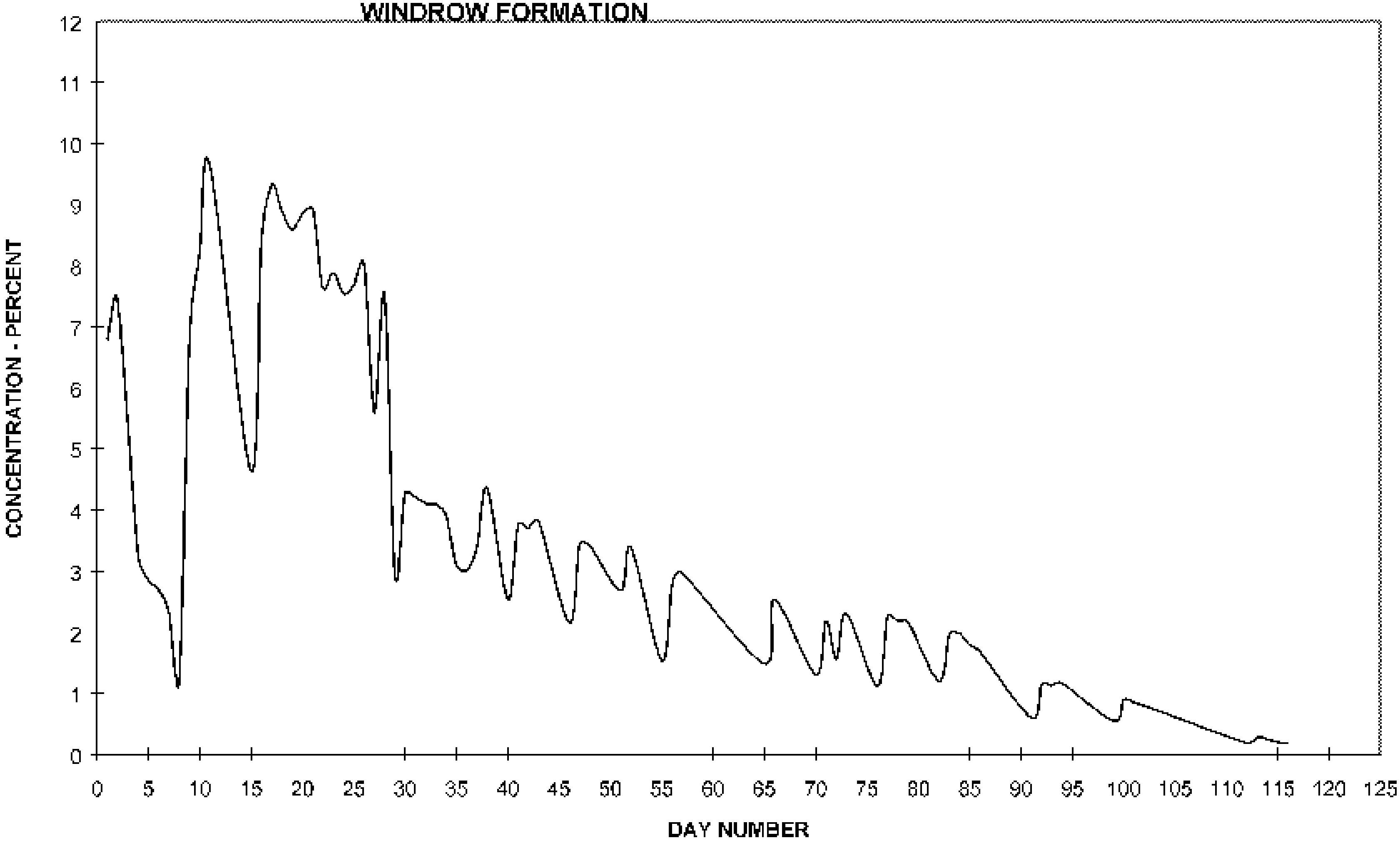


FIGURE 5.20. PORE SPACE CARBON DIOXIDE CONCENTRATION - CONTINUOUS FORCED AERATION COMPOSTING - AERATION STARTED 21 DAYS AFTER WINDROW FORMATION



Pore-space and Off-Gas Methane Concentration Monitoring Results

The off-gas and pore-space CH_4 concentrations were monitored to determine the relative degree of anaerobic micro sites present using each composting technique. Methane is considered a green house gas and composting techniques with the lowest relative potential for having anaerobic micro sites are favourable because they reduce the level of CH_4 released during aerobic composting. If composting materials could be maintained aerobic throughout, CH_4 would not be produced, however, because of the nature of manures this is not possible.

Figures 5.21, 5.22, 5.23, 5.24, and 5.25 are graphs of the off-gas concentrations for the turned-pile composting process conducted using raw manure amended with compost, a conventional turned-pile process, a passive-aeration process, a modified-passive-aeration process in which the aeration tubes were sealed for the first 21 days, and a static-pile-continuous-forced-aeration composting process.

All composting processes studied were observed to release CH_4 in the off-gases, particularly during the early stages of composting when there was an abundance of fresh organic substrate for anaerobic bacteria to assimilate. Even though pore-space O_2 levels were observed to be above 5%, the release of CH_4 occurred in the off-gases. The rate of CH_4 production is affected by the degree of porosity of the compost medium and level of O_2 exchange. Composting processes conducted using the same manure source did not produce identifiable differences in CH_4 concentrations in off-gases that could be attributed to process differences between static-pile-forced-aeration, static-pile-passive-aeration or turned-pile processes. Static-pile processes are more susceptible to the formation of anaerobic micro sites because of natural compaction with no opportunity for the break up of these sites as is possible with mixed processes. Concentrations of CH_4 in the off-gases were less variable during the first 20 to 35 days of composting.

5.6 Compost Temperature Monitoring

Compost temperature monitoring results are presented in a series of graphs which compare specific processes or process manipulation factors. Figure 5.26 shows compost temperature data collected during year one experiments that compared passive-aeration, turned-pile

FIGURE 5.21. OFF-GAS METHANE CONCENTRATION - TURNED PILE COMPOSTING - MANURE AMENDED WITH 40% BY VOLUME FINISHED COMPOST

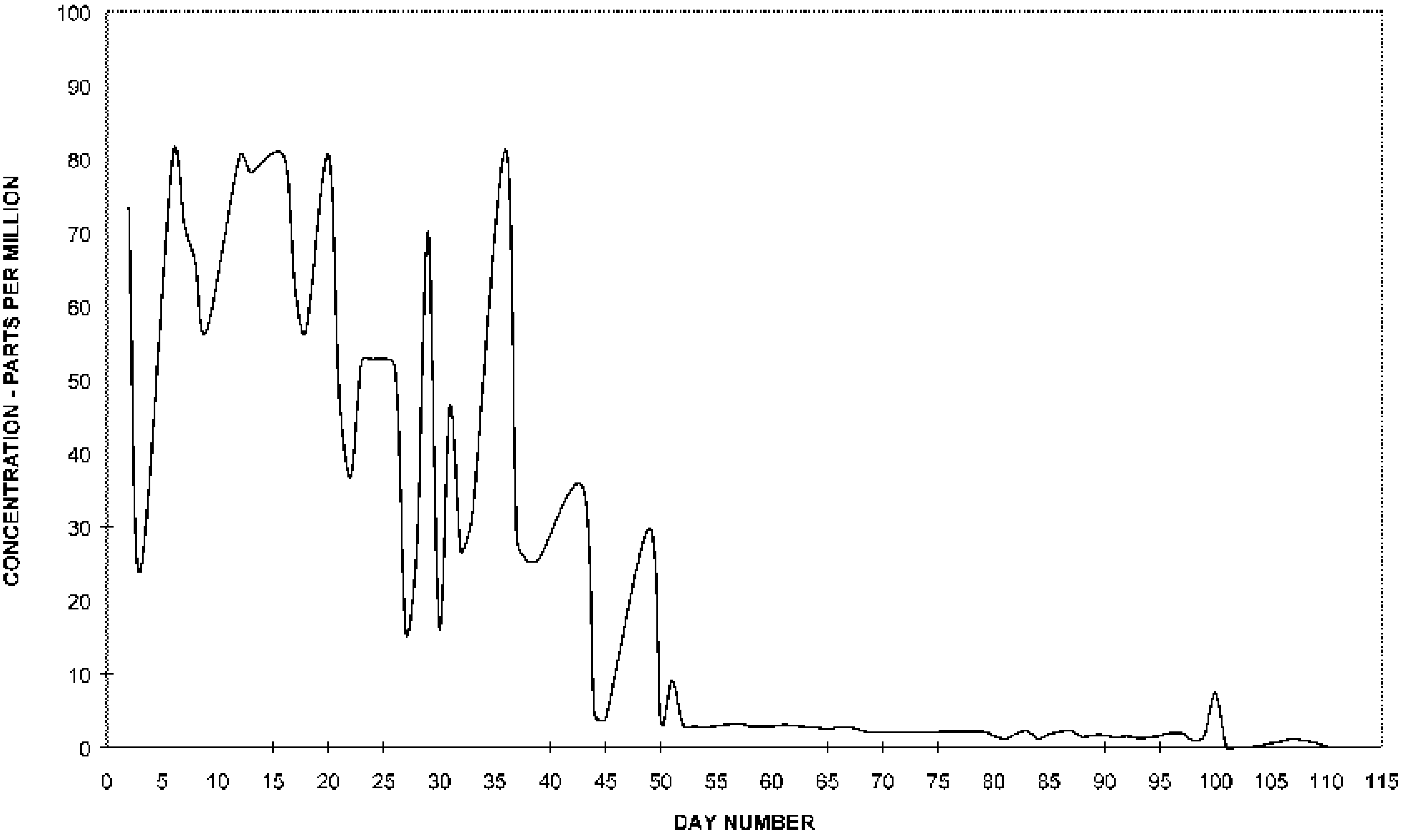


FIGURE 5.22. OFF-GAS METHANE CONCENTRATION - TURNED PILE COMPOSTING INSIDE - THIRD YEAR EXPERIMENT

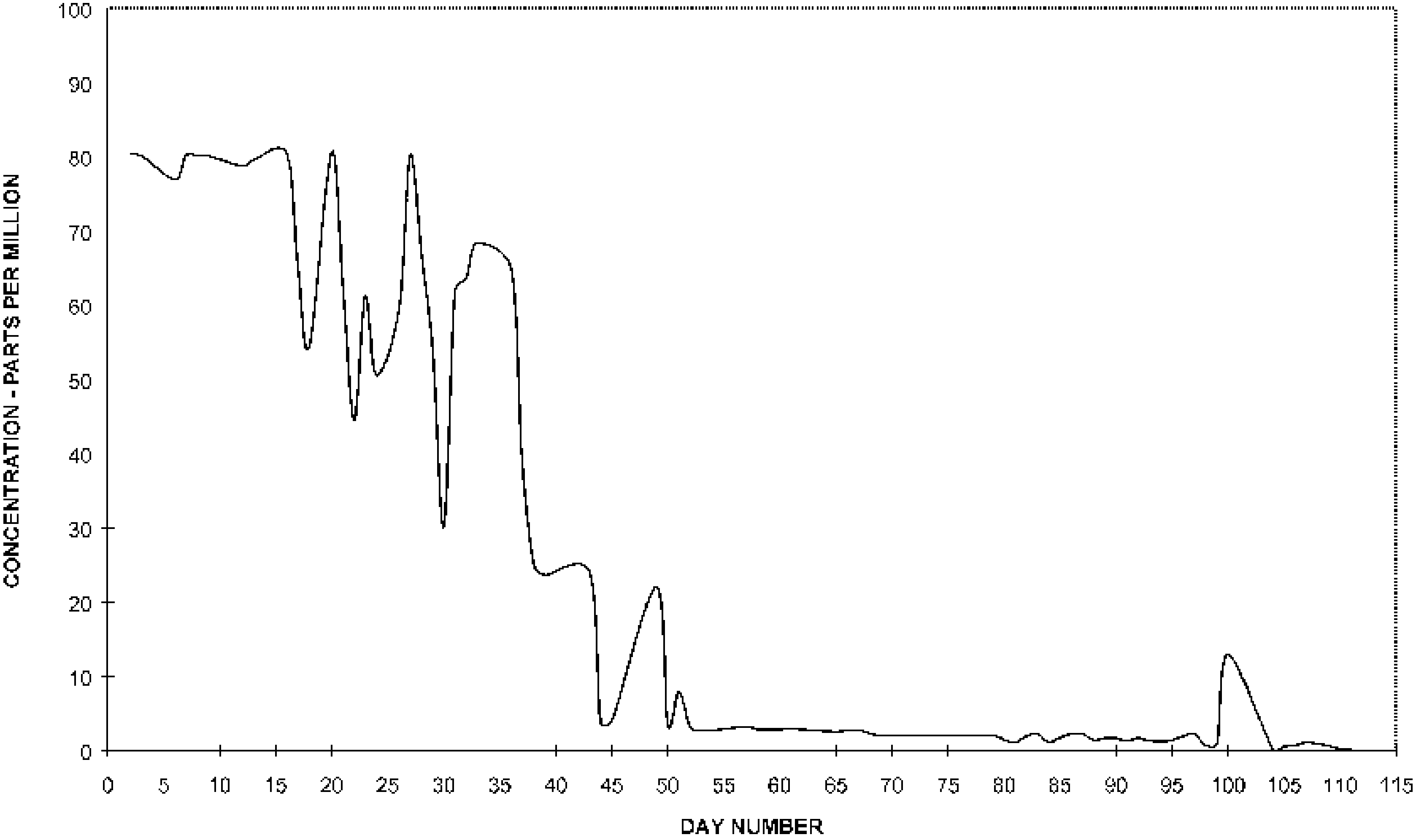


FIGURE 5.23. OFF-GAS METHANE CONCENTRATION - PASSIVE AERATION COMPOSTING - AERATION TUBES OPEN FOR FULL DURATION OF COMPOSTING PROCESS

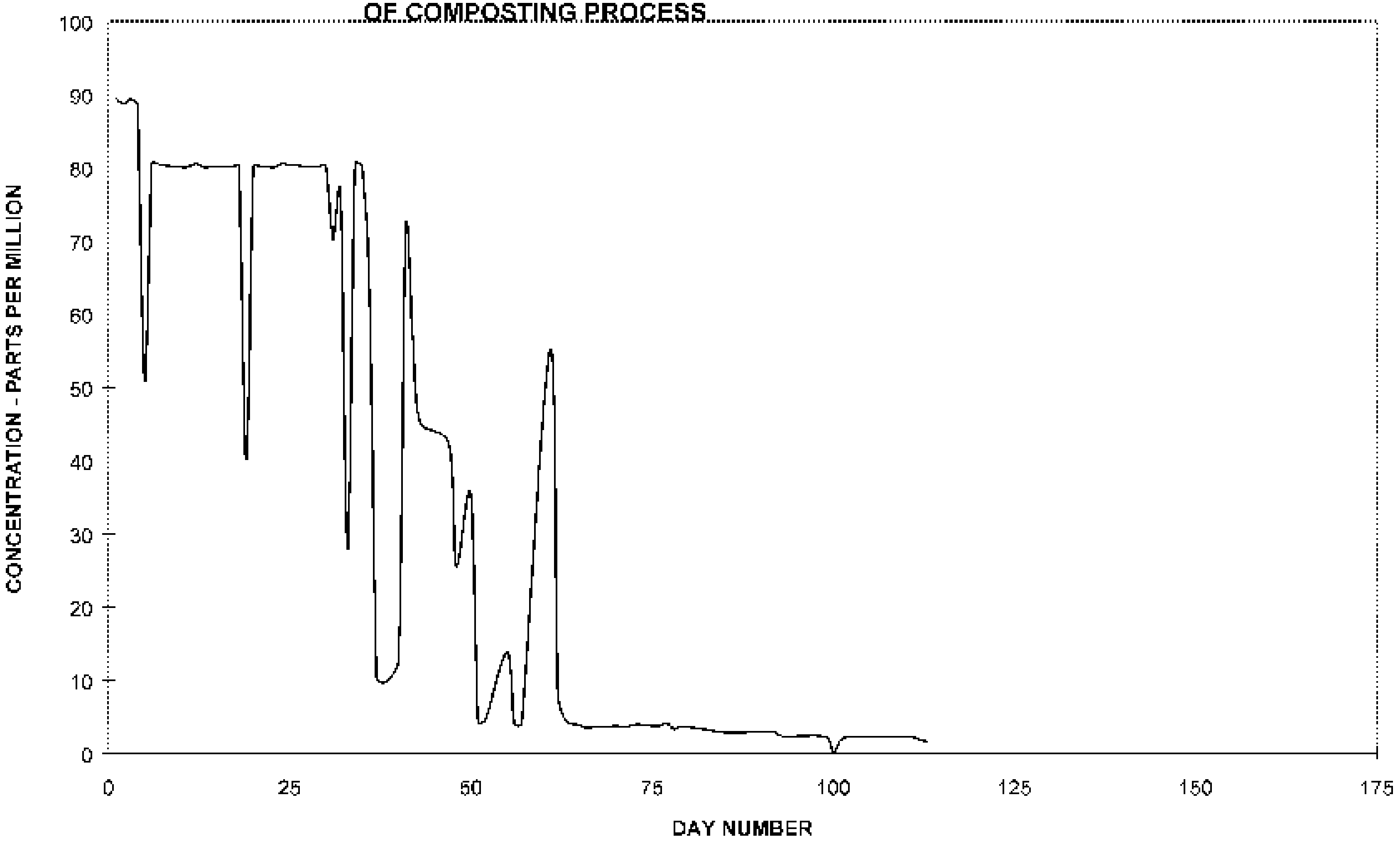


FIGURE 5.24. OFF-GAS METHANE CONCENTRATION - PASSIVE AERATION COMPOSTING - AERATION TUBES SEALED FOR 21 DAYS AFTER WINDROW FORMATION

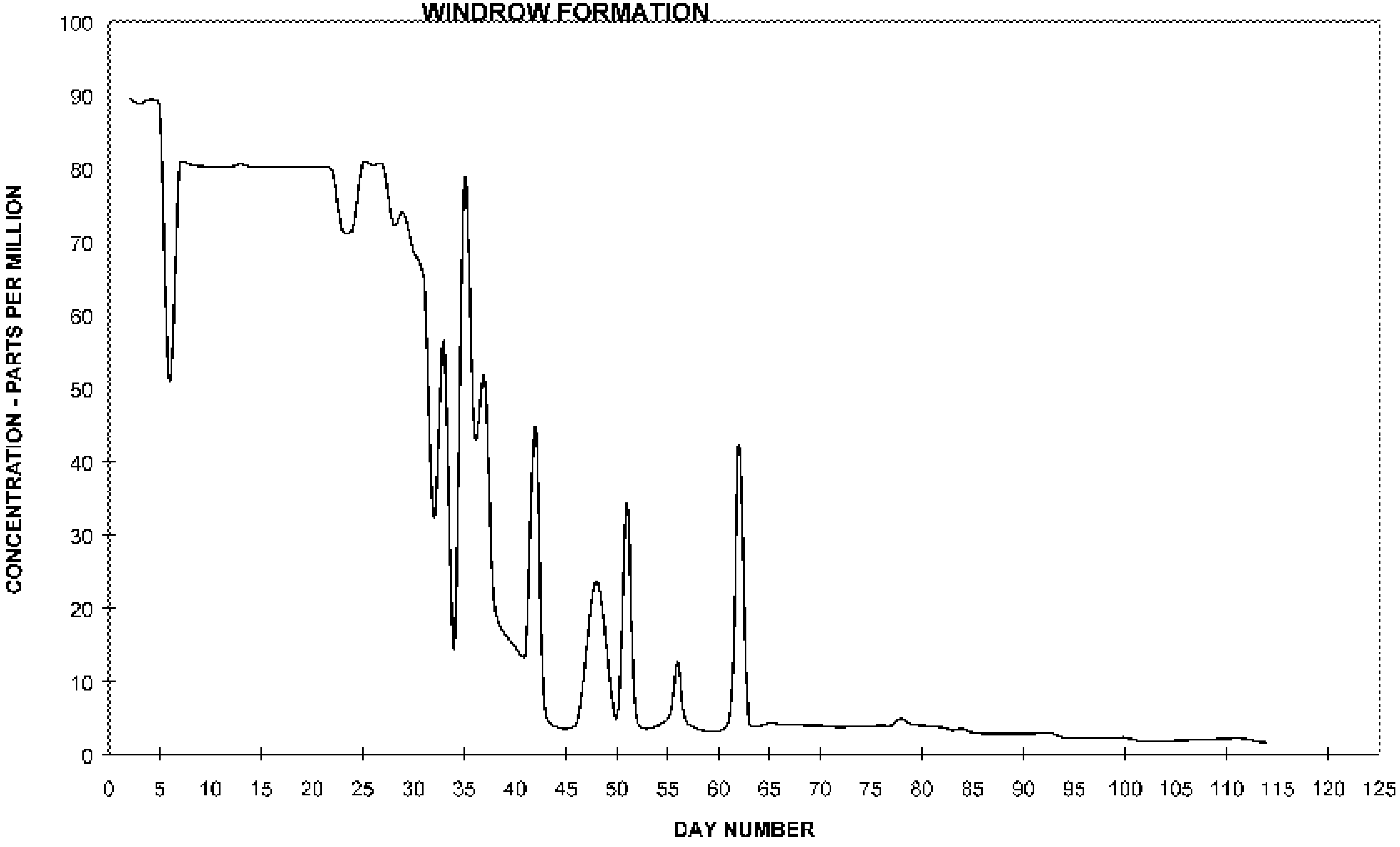
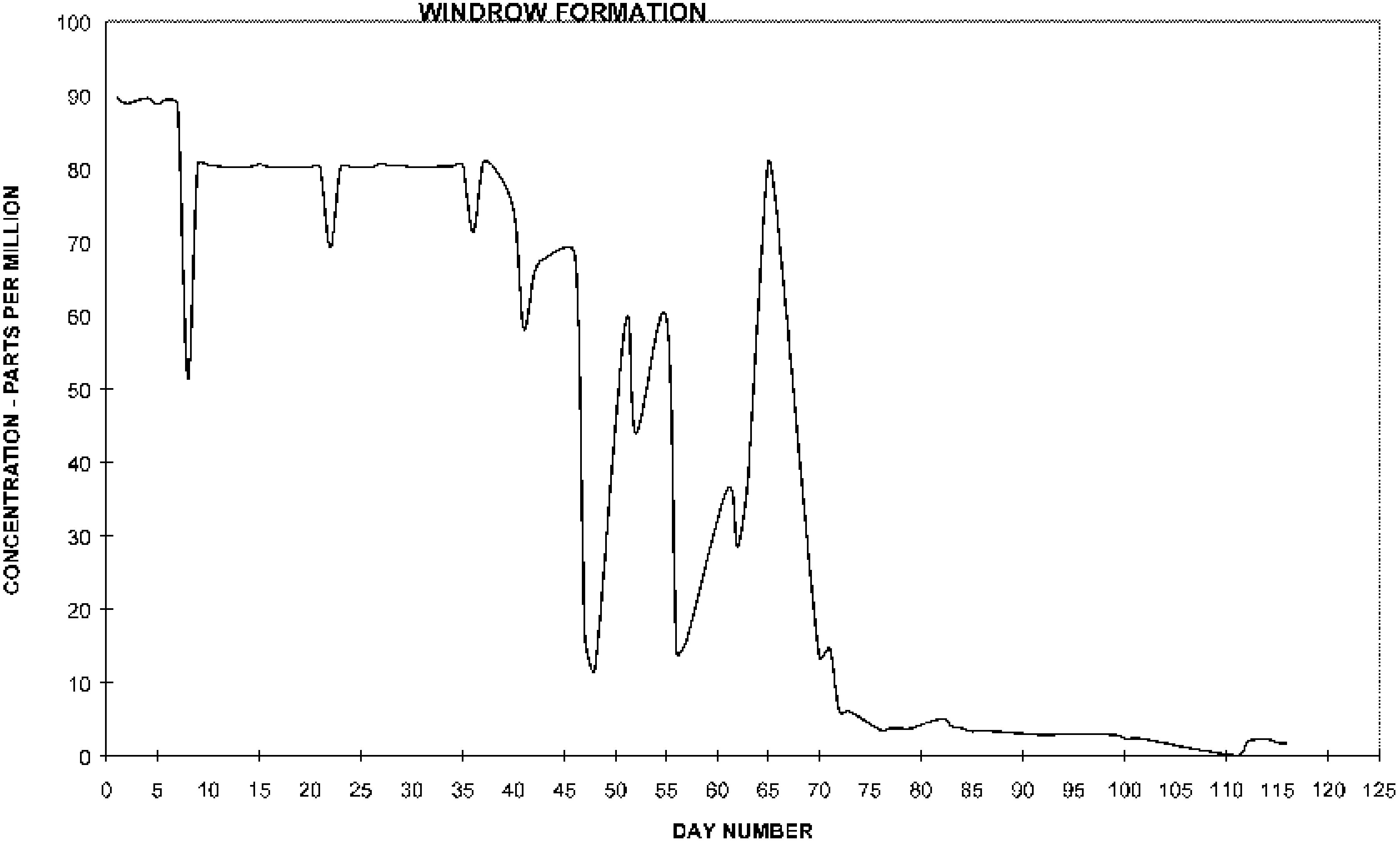
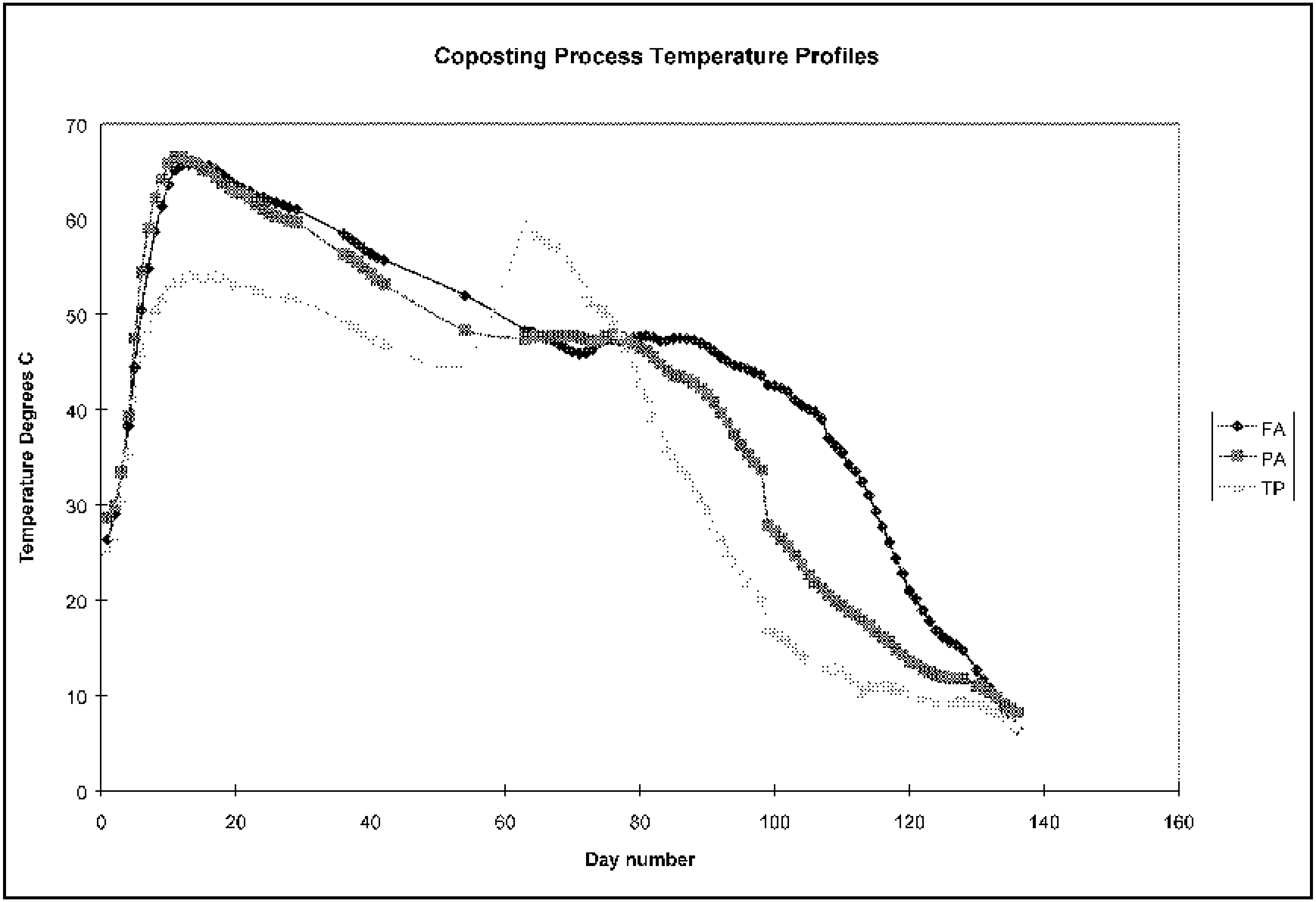


FIGURE 5.25. OFF-GAS METHANE CONCENTRATION - CONTINUOUS FORCED AERATION COMPOSTING - AERATION STARTED 21 DAYS AFTER WINDROW FORMATION



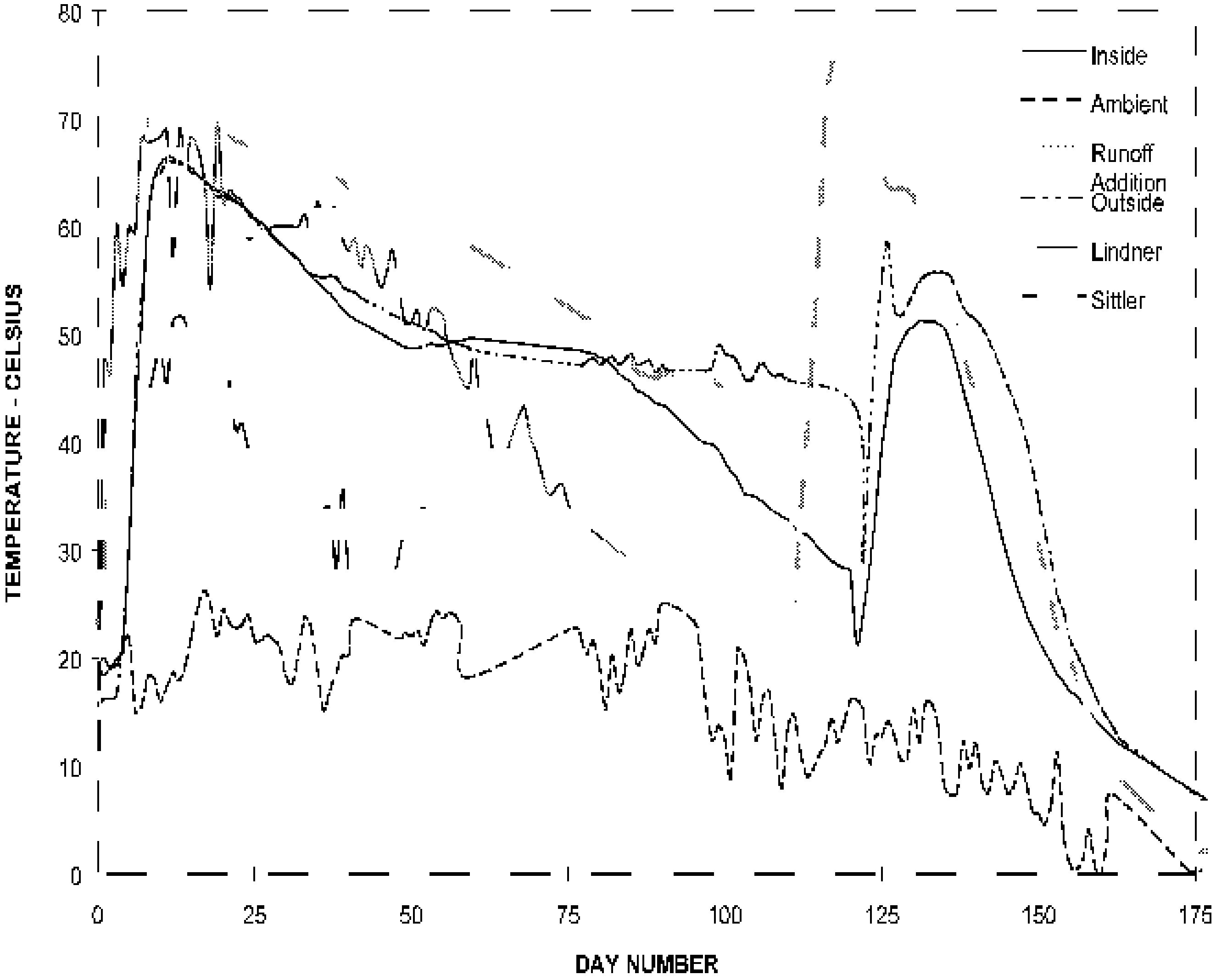

Coposting Process Temperature Profiles
Temperature Degrees C
0
10
20
30
40
50
60
70
Day number
0
20
40
60
80
100
120
140
160
FA
PA
TP

composting and intermittent-forced-aeration composting. The temperature curves all follow the same general profile. The forced-aeration process temperatures remained slightly higher than those of the passive-aeration process or the turned-pile process for the duration of the processes. The turned-pile process temperature remained consistently below that of the forced-aeration and passive-aeration process except after turning (Figure 5.26). The turned-pile process was mixed only twice. After the first mixing a marked increase in temperature was noted but the same response did not result from the second mixing and subsequent mixings were not warranted, based on pore-space O_2 concentrations.

Figure 5.27 shows temperature profiles for the second year composting trials. Included in Figure 5.27 are temperature profiles for the Sittler-turned-pile-Luptke process, the Lindner-field-windrow process, which are both ecological farm processes, and the three turned-pile processes conducted at the main research site during the second year of experiments. The temperature curves in Figure 5.27 all follow a somewhat similar profile of early peaking temperatures and a gradual decline over time. The three processes conducted at the main research site showed a more pronounced temperature peak with a more consistent and steady temperature decline. This is most likely because the base site temperature data was collected with an on-line data collection system gathering data 24 hr a day compared to cooperator sites where temperatures were taken manually with a three foot temperature probe (described in Section 4.4.4), once daily. The Lindner-field-windrow process had consistently lower temperatures than the other processes, throughout the composting period. This is believed to be because of the high moisture content (80.18%) in the raw manure and finished compost (82.31%). High manure moisture content results in increased natural settling and compaction of composting manure which in turn impairs air movement through manure windrows during composting and reduces aerobic biological activity.

The turned-pile processes carried out at the main research site each exhibited a temperature peak after mixing, not evident in the Sittler-turned-pile-Luptke process. Mixing criteria for the turned-pile processes at the base site were originally based on maintaining pore-space O_2 levels above 5%, assuming this would result in optimized bacterial activity. A minimum pore-space O_2 concentration of 5% is required to prevent composting process inhibition from O_2 deficiency (R. Rynk 1992). This criteria proved unacceptable as a means of optimizing process microbial activity because the O_2 concentrations did not drop below the 5% target level for any extended period. However mixing was observed to increase microbial activity as indicated by an increase in CO_2 levels following mixing. This increase in CO_2 levels after mixing is assumed to be the result of mixing bacterial populations and enzymes released by the bacteria, throughout the substrate.

FIGURE 5.27. TEMPERATURE PROFILES - YEAR 2 EXPERIMENTS

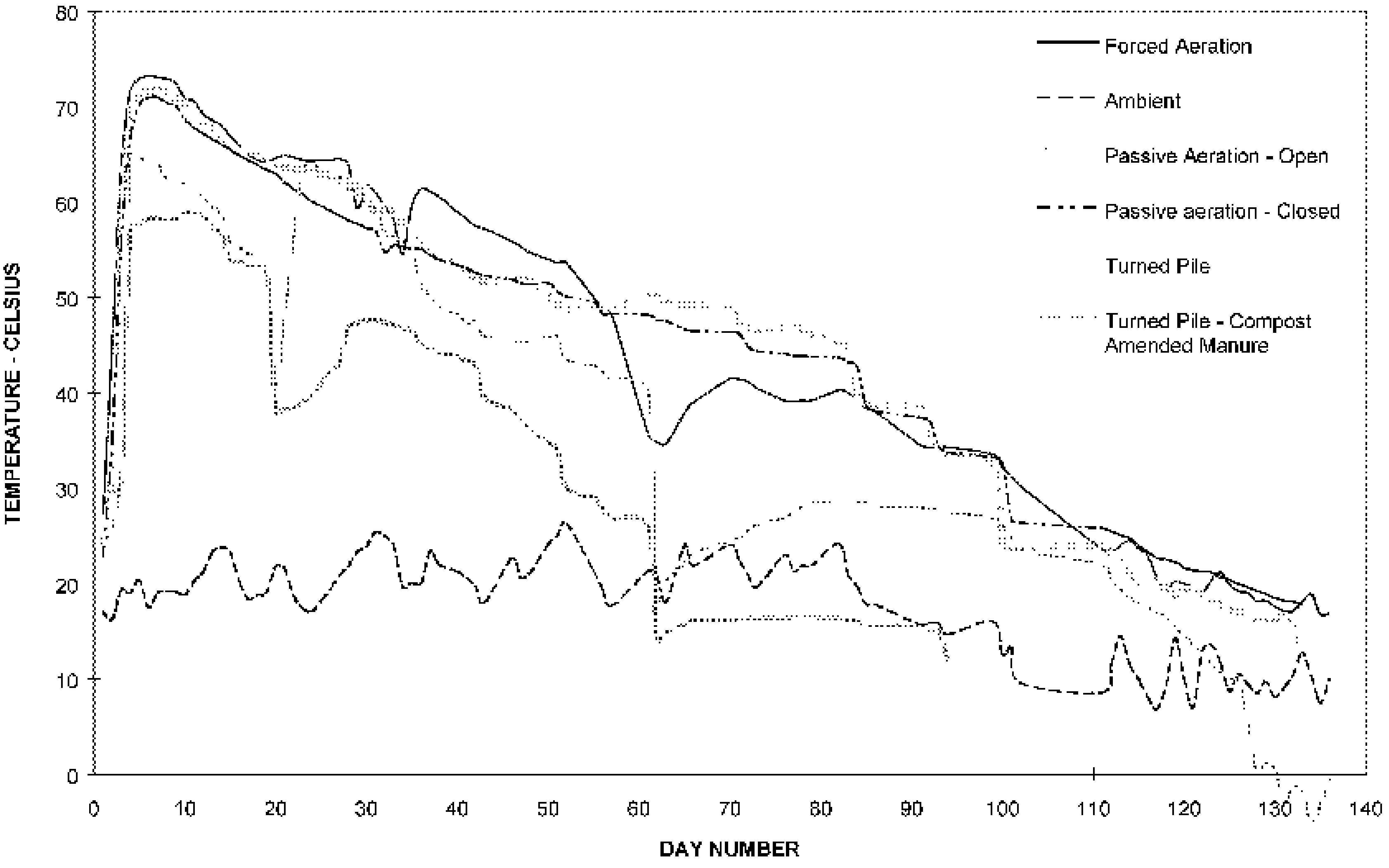


The first mixing was carried out to facilitate runoff addition. In order to make valid process comparisons between the turned-pile process factors being studied, the three processes were mixed at the same time. The process to which barnyard runoff was added reached a significantly higher peak temperature after mixing than the other two processes and maintained a higher temperature for the remainder of the equivalent composting periods. This is believed to be because the runoff addition enhanced the distribution of bacteria and enzymes responsible for organic matter decomposition resulting in slightly higher bacterial activity as shown by the slightly higher pore-space CO_2 levels and higher temperatures. Since pore-space O_2 concentrations were consistently above the 5% level at which O_2 becomes a limiting factor, it was assumed that other benefits of mixing were responsible for the increased biological activity.

Figure 5.28 shows temperature profiles for the composting processes conducted during the third year experiments. Temperature profiles are presented in Figure 5.28 for turned-pile composting of raw manure, turned-pile composting of raw manure amended with compost at a rate of 40% by volume, passive-aeration manure composting, modified-passive-aeration manure composting in which aeration tubes were closed for the first 21 days and forced-continuous-aeration manure composting.

The temperature curves in Figure 5.28 all reached their highest levels within the first 10 days of the experiment. All but the turned-pile processes showed a general trend of decreasing temperatures after this initial 10 day period. The turned-pile process temperatures typically dropped significantly following each mixing event before recovering or stabilizing to also yield a gradually declining temperature profile for the remainder of the undisturbed period. The passive-aeration process and modified-passive-aeration process which had the aeration tubes sealed for the first 21 days both followed very similar patterns with an early peak temperature and a gradual temperature decline. The temperature decline between day 15 and day 30 was greater for the passive-aeration process with the tubes closed for the first 21 days than the control passive-aeration process. Based on the pore-space O_2 concentrations (Figure 5.13 and Figure 5.14) this was not the result of limiting concentrations of O_2. The modified passive-aeration process exhibited slightly lower temperatures for the majority of the composting period. The temperature profiles do not show an increase in temperature after opening the aeration tubes at day 21 as was expected.

FIGURE 5.28. TEMPERATURE PROFILES - YEAR THREE EXPERIMENTS



Pore-space O_2 concentrations were approximately 17% on day 21 for both passive-aeration processes and it is believed that no temperature increase was exhibited after tube opening because O_2 was not a limiting factor in the level of bacterial activity.

The continuous-forced-aeration process was aerated starting at day 21 and a temperature pattern change and temperature increase was observed for approximately 30 days after the commencement of aeration. Pore-space O_2 levels were approximately 12% at the time aeration was started which was sufficiently high that O_2 concentration was not a limiting factor in microbial activity. The temperature increase however indicates that there was an increase in microbial activity as a result of aeration.

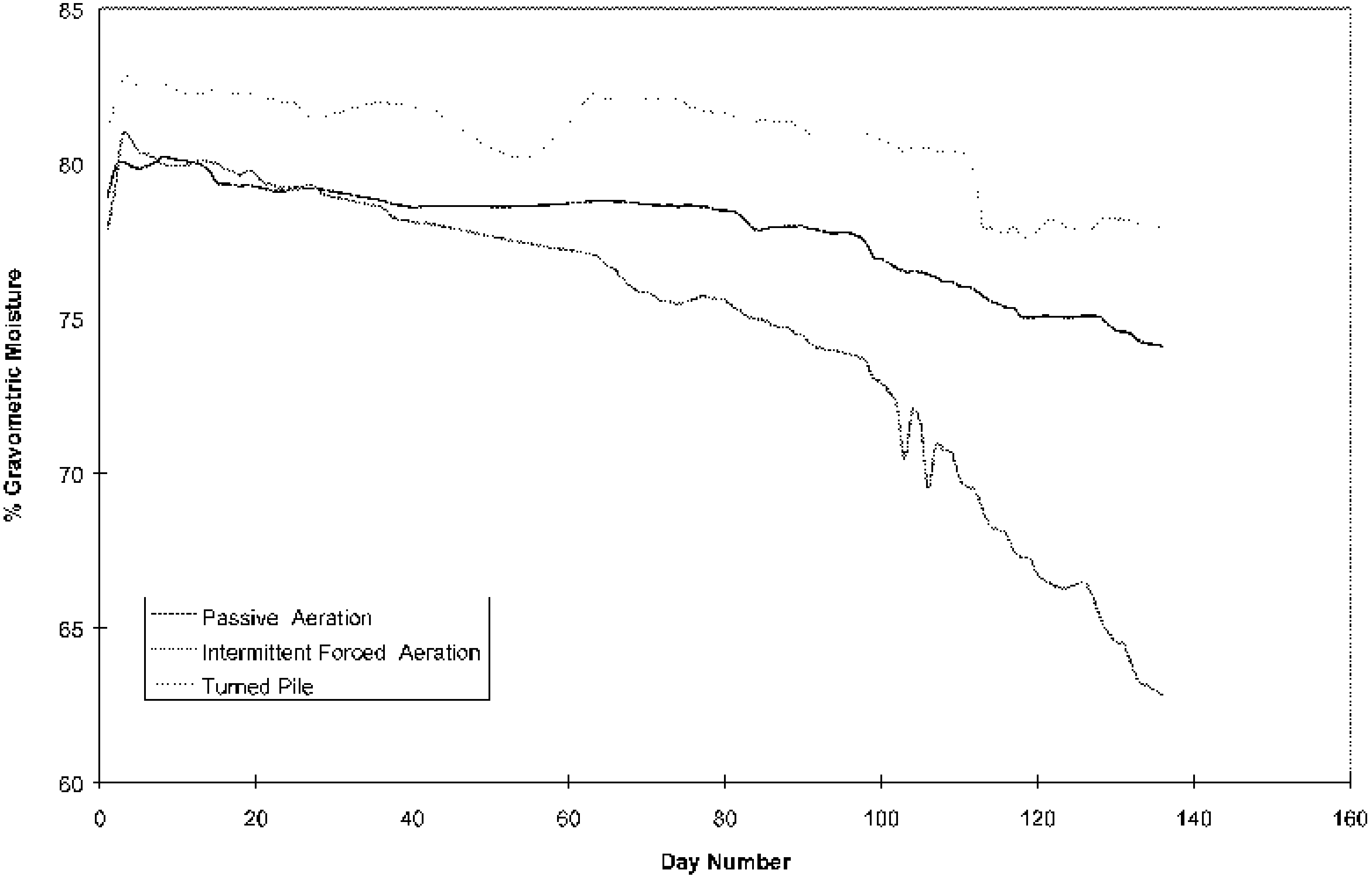
The temperature profiles for the turned-pile process and turned-pile process conducted with manure amended with compost were similarly shaped. However, the turned-pile process conducted with the manure amended with compost had consistently lower temperatures for the duration of the composting processes. The smaller quantity of fresh substrate in the compost manure mix for bacterial decomposition is believed to have resulted in the lower temperature.

5.7 Compost Moisture Monitoring

Gravimetric moisture data collected on-line was substantiated by comparison of bulk analysis results with respect to raw manure and compost moisture levels. The moisture levels of the manure composting trials conducted at the base site were monitored on-line to determine if moisture levels were a limiting factor in the composting processes studied. The continuous-forced-aeration process (process #10) had the lowest final moisture content at completion of composting with 54.6% and the Lindner-field-windrow process (process #9) had the highest final moisture level at the completion of composting with a moisture content of 82.3%. Moisture does not become limiting until it approaches the 40% range (R. Rynk 1992) and data collected for the 16 composting trials indicates that moisture was not a limiting factor in any of the 16 composting trials conducted.

Figure 5.29 shows moisture profiles for the intermittent-forced-aeration process (process #1), the passive-aeration process (process #2), and the turned-pile composting process (process #3).

FIGURE 5.29 MOISTURE PROFILES



The three profiles are somewhat different although the overall trend is that of a slight and slow decline. Dry matter loss through the oxidation of organic matter occurred at a rate similar to the moisture loss for all composting processes. Because of this, the moisture levels remained relatively stable with a very slow decline for the duration of all processes studied.

The moisture probes used for the study (Described in Section 4.4.5) were observed to respond to some degree to changes in compaction and for this reason the moisture level readings were observed to jump after mixing. The moisture probes also tended to record somewhat high compared to bulk analysis results.

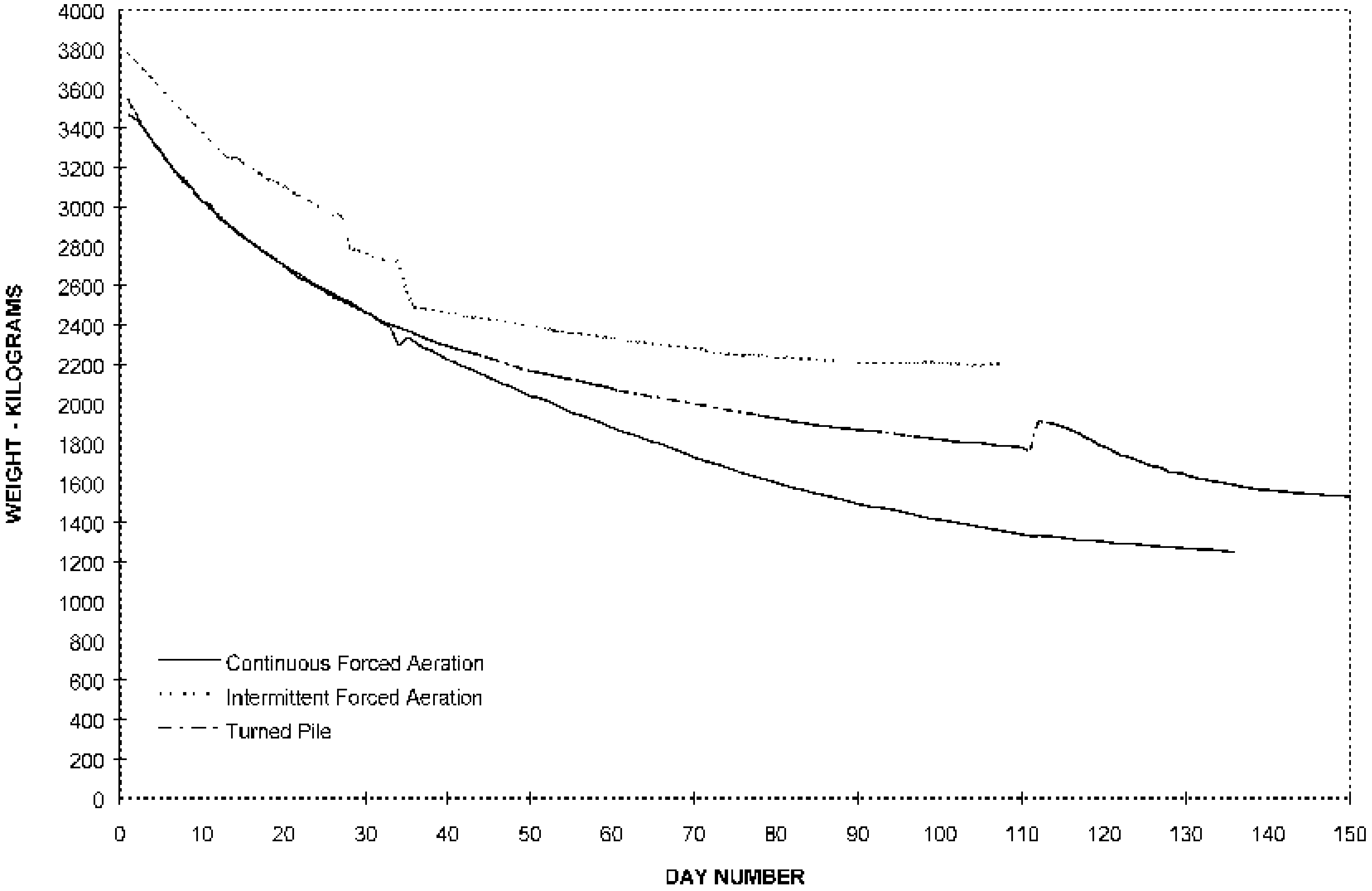
Discussions with the manufacturer of the moisture probes indicated that the high temperature of the composting manure would not affect the performance of the probes. During our studies we found the probe life expectancy to be highly variable. In the first year 4 probes malfunctioned and were replaced. By the end of the project 13 out of the original 18 moisture probes purchased failed and it appears that the units are presently not an appropriate low-cost technology for on-farm compost moisture monitoring. We believe the high composting temperatures combined with the corrosive nature of raw manure, is responsible for the failures.

5.8 Compost Process Weight Monitoring Results

Figure 5.30 shows a graph of the daily weights for the intermittent-forced-aeration composting process (process #1), the turned-pile process with barnyard runoff addition (process #4), and the continuous-forced-aeration process (process #10). The weight losses, measured using the method described in Section 4.4.6, followed an asymptotic curve with an average total weight loss of 41.7% for the intermittent-forced-aeration process, 57.5% for the turned-pile process with runoff addition and 64.4% for the continuous-forced-aeration process.

Weight loss occurs during composting as a result of a combination of moisture loss and oxidation of organic matter through bacterial degradation. The turned-pile process experienced dry matter losses of 46.6% compared to 48.2% for the intermittent-forced-aeration process which were not statistically different and 44.1% for the continuous-forced-aeration process. The raw manure dry matters were 24.2% (intermittent-forced-aeration),

FIGURE 5.30. WEIGHT LOSS PROFILES



27.6% (turned-pile) and 30.5% (continuous-forced-aeration). The final compost dry matters were 30.2% (intermittent-forced-aeration), 42.7% (turned-pile) and 45.37% (continuous-forced-aeration). The dry matter loss data indicate that forced-aeration of static-piles with windrow dimensions of 3 meters wide by 1.2 meters high does not result in higher organic matter losses which would suggest a higher degree of decomposition and more stable organic material.

Moisture losses for the turned-pile process were 65.5% which was statistically different from the 55.8% for the intermittent-forced-aeration process and 69.4% for the continuous-forced-aeration-process. This indicates that moisture loss did not increase as a result of intermittent-aeration of the static-pile composting material. The continuous-forced-aeration process exhibited a higher moisture loss of 69.3%, which was the primary reason for the difference in weight change as the dry matter loss was 44.1%. The static-pile continuous-forced-aeration processes did not exhibit an advantage over turned-pile processes in terms of increasing dry matter losses which suggests an increase in biological activity and organic matter degradation. An increase in biological activity would have resulted in an increase in dry matter loss.

5.9 Compost Seed Germination Results

Seed germination tests were conducted using cress seed to determine if there was any detectable difference in the process composts evaluated in terms of maturity as indicated by level of seed germination inhibition. Table 5.14 shows the results of the germination tests. A commercial potting soil was used as a control to determine the seed viability. Seed viability, based on observations made on the control pots, ranged from 90 to 100%. The germination test results show that all composts, regardless of process method used to produce the compost, exhibited seed germination inhibition. Even when the composts were mixed at a 50/50 ratio by volume with potting soil, all composts exhibited some degree of seed germination inhibition. The results are somewhat surprising and do not seem to follow a predictable pattern. For instance the static-pile-continuous-forced-aeration process had 0.0% germination rate for the pure compost and 50/50 soil/compost mediums. It was assumed initially that continuous-forced-aeration would yield a well-matured compost compared to passive-aeration processes, but germination tests do not substantiate this. It was also most mature and exhibit the lowest seed germination inhibition. The seed germination results do

Table 5.14. Compost Germination Test Results

Composting Process	Germination Medium		
	Compost Seed Germination	50/50 Compost/Potting Soil Mix Seed Germination	Potting Soil Seed Germination
Intermittent-Forced-Aeration Process #1	0%	30%	90%
Passive-Aeration Process #2	0%	40%	90%
Turned-Pile Process #3	0%	66.7%	90%
Turned-Pile - Barnyard Runoff Addition Process #4	0%	10%	93.3%
Turned-Pile-Outside Process #5	23.3%	76.7%	93.3%
Turned-Pile-Inside Process #6	34.8%	83.3%	93.3%
Sittler-Turned-Pile Luptke Method Process #7	16.7%	40%	93.3%
Zettle-Modified-Static-Pile Process #8	0%	36.6%	93.3%
Lindner-Field-Windrow Process #9	63.3%	70%	93.3%
Forced-Aeration Continuous Aeration Process #10	0%	0%	100%
Passive-Aeration Tubes Closed 21 days Process # 11	0%	0%	100%
Passive-Aeration Process #12	0%	0%	100%
Turned-Pile Manure/Compost Mix Process #13	0%	83.3%	100%
Turned-Pile Turned after 21 days Process #14	0%	20%	100%

not substantiate this assumption. The Lindner-field-windrow composting process had the lowest organic matter loss at 36.9% and actually exhibited one of the lowest levels of seed germination inhibition. Seed germination inhibition in finished composts does not appear to be related to the process used for producing the compost or the level of organic matter loss which has occurred during the composting process. The germination tests did not identify the superiority of one process over another in terms of compost maturity level at the end of the heating phase of composting processes. Based on the seed germination tests all the compost materials produced require additional curing time to allow low temperature biological activity and chemical reactions to remove inhibitory chemicals present in the compost.

5.10 Compost Curing Study Results

Compost curing studies were undertaken to determine the effect of curing on carbon losses, nutrient leaching and seed germination inhibition. Table 5.15 shows the characterization data for the two passive-aeration process composts used for the curing experiments. Composts produced using conventional passive-aeration (process #12), and modified-passive-aeration where the aeration tubes are closed for the first 21 days (process #11), were used for the curing experiments. The average moisture content during the curing period for the composts from process #11 were 62.4% and 64.8% for the compost from process #12. Table 5.15 contains characterization data for the composts after 30, 60 and 90 days of curing.

Organic matter levels remained relatively constant and no significant difference in organic matter levels was observed between the fresh compost and the compost materials cured for 30, 60 and 90 days. This indicates that continued biological degradation was very slow and any net change was below detection capabilities of current laboratory procedures. This also indicates that curing does not contribute significantly to further carbon losses.

Nitrogen levels on a percent dry matter basis for fresh compost and composts allowed to continue curing for 30, 60 and 90 days, were not statistically different although a trend of slightly higher nitrogen levels after curing was observed, which can result from organic matter losses exceeding nitrogen losses. Nitrate levels were found to vary significantly between the different compost materials. Nitrate levels were higher after curing but did not increase continually with increased curing time but rather increased and then decreased. The

Table 5.15. Characterization Data for Cured Compost

Process Description	% N D.M. Basis	NH_4-N mg/kg D.M. Basis	NO_3-N mg/kg D.M. Basis	NO_2-N mg/kg D.M. Basis	O.M % D.M. Basis
Passive-Aeration Process #12	2.92	98.27	1125	7.37	71.12
Passive-Aeration Process #15 Cured 30 days	3.18	98.3	1761	3.91	71.39
Passive-Aeration Process #15 Cured 60 days	3.31	97.69	1343	3.73	69.60
Passive-Aeration Process #15 Cured 90 Days	3.38	97.91	1668	5.88	69.92
Passive-Aeration Tubes Closed 21 days Process # 11	2.96	63.73	1110	5.01	71.41
Passive-Aeration Tubes Closed 21 days Process # 16 Cured 30 Days	3.31	56.75	1538	1.86	71.75
Passive-Aeration Tubes Closed 21 days Process # 16 Cured 60 Days	3.11	92.22	2888	6.82	70.63
Passive-Aeration Tubes Closed 21 days Process # 16 Cured 90 Days	3.29	82.10	1897	9.71	69.25

decrease may be the result of denitrification occurring in anaerobic microsites as the curing process proceeded.

Table 5.16 shows nitrogen, phosphorus and potassium leachate losses for fresh compost and compost cured 30, 60, and 90 days. Curing did not have a significant effect on total nitrogen leaching. Total nitrogen leaching losses were not reduced after 90 days of curing. This is not surprising in light of the bulk analysis results which indicate that there was little change in the amount of nitrogen present in mineral form, the form susceptible to leaching, with increased curing time. Phosphorus leaching losses varied over the 90 day curing period and followed a trend of increasing concentration and then decreasing concentration. Phosphorus leaching was not consistently higher after curing. In the curing experiment using compost from process #11, phosphorus leaching losses were not statistically different after curing 30, 60 or 90 days. In the curing experiment using compost from process #12, leaching losses increased significantly after 30 days of curing and then decreased to levels which were not statistically different from fresh compost for compost cured 60 and 90 days. Potassium leaching losses were not significantly changed as a result of curing.

The results of germination tests are presented in Table 5.17. Seed inhibition in the fresh compost and compost cured 30, 60 and 90 days remained high enough in the pure compost material to be 100% inhibitory to seed germination. At a 50/50 soil-compost mix, a decrease in seed germination inhibition was observed as a result of curing. Seed germination inhibition for the two curing experiments did not follow a consistent trend of decreased inhibition as curing time increased. Rather inhibition decreased after 30 days increased again after 60 days and then decreased again after 90 days. However, the increased seed germination inhibition observed in the 50/50 soil-compost mix tests using compost cured 60 days were not higher than that observed in the 50/50 soil-compost mix tests using uncured compost.

The results indicate that curing does reduce seed gemination inhibition, but, 90 days is not sufficient time to observe a germination inhibition decrease in the compost when used as a pure germination medium.

Table 5.16. Compost Curing Study Leachate Losses

Composting Process	N % Loss	P % Loss	K % Loss
Passive-Aeration Process #12	15.37%	10.08%	41.26%
Passive-Aeration Process #15 Cured 30 days	19.51%	19.23%	56.60%
Passive-Aeration Process #15 Cured 60 days	15.66%	11.76%	45.19%
Passive-Aeration Process #15 Cured 90 Days	19.67%	12.59%	44.48%
Passive-Aeration Tubes Closed 21 days Process # 11	18.4%	12.92%	42.43%
Passive-Aeration Tubes Closed 21 days Process # 16 Cured 30 Days	14.77%	16.62%	47.45%
Passive-Aeration Tubes Closed 21 days Process # 16 Cured 60 Days	18.65%	12.65%	49.32%
Passive-Aeration Tubes Closed 21 days Process # 16 Cured 90 Days	24.01%	15.00%	47.21%

Table 5.17. Germination Test Results for Cured Compost

Composting Process	Germination Medium		
	Compost Seed Germination	50/50 Compost/Potting Soil Mix Seed Germination	Potting Soil Seed Germination
Passive-Aeration Process #12	0%	0%	100%
Passive-Aeration Process #15 Cured 30 days	0%	66.7%	100%
Passive-Aeration Process #15 Cured 60 days	0%	23.3%	100%
Passive-Aeration Process #15 Cured 90 Days	0%	86.7%	100%
Passive-Aeration Tubes Closed 21 days Process # 11	0%	0%	100%
Passive-Aeration Tubes Closed 21 days Process # 16 Cured 30 Days	0%	66.7%	100%
Passive-Aeration Tubes Closed 21 days Process # 16 Cured 60 Days	0%	16.7%	100%
Passive-Aeration Tubes Closed 21 days Process # 16 Cured 90 Days	0%	66.7%	100%

duration of the three composting processes. Mass balances prepared using conservation of ash principles were based on total ash, and the phosphorus and potassium sum component of ash.

Laboratory analyses of manures use relatively small quantities of sample for analysis purposes. This makes it more difficult to obtain representative analysis results. N, P, and K analysis are performed on 2.5 gram samples. Analysis for total nitrogen, phosphorus and potassium originate from one laboratory analysis procedure. For this reason the phosphorus and potassium portion of total ash was used for mass balance comparisons of total nitrogen, ammoniacal nitrogen, NO_3-nitrogen, and NO_2-nitrogen to determine if this is an appropriate method of calculating nitrogen losses. Table 5.18 shows loss data based on conservation of ash principles and on actual weight loss data.

The mass balances calculated using conservation of ash principles and calculated using weight loss data match closely for the continuous-forced-aeration process (process #10). The weight-based mass balance results had means similar to those calculated using conservation of ash principles. The means for both methods were within the standard deviation of the other. The nitrogen mass balances based on the sum of phosphorus and potassium had means closest to those calculated based on weight losses. The measured weight loss mass balance results and conservation of ash mass balance results, when compared for the intermittent-forced-aeration process (process #1) and the turned-pile process with runoff addition (process #4), had means which were substantially different but primarily within the standard deviation of each other.

The mass balance means calculated using the sum of phosphorus and potassium and based on conservation of ash principles were closest to the mass balance results based on actual weight loss data. The relative magnitude between process means was similar for both the P+K and total ash methods of mass balance calculations.

The results confirm that conservation of ash principles are a valid mass balance technique. The results also indicate that the use of the sum of phosphorus and potassium provides nitrogen loss results similar to nitrogen loss results based on weight loss.

It should be noted that manures are not homogeneous. On a per tonne basis, manure from a single source will contain similar characteristics. However, small samplings are highly prone

Table 5.18. Comparison of Mass Balance Results Based on Conservation of Ash Principles and Actual Weight Loss Data

Process Description	Mass Balance Basis		Statistic	N % Loss	NH_4-N % Loss	NO_3-N % Increase	NO_2-N % Loss	O.M. % Loss	H2O % Loss	Ash Balance (Wt. Loss Basis Only)	D.M. % Loss
Intermittent-Forced-Aeration Process #1	Conservation of Ash Principles	Based on Ash	Mean	38.91	99.48	6,143	78.24	58.16	55.75	NOT APPLICABLE	48.22
			Std.Dev.	3.62	0.29	1,013	9.96	4.75	2.39		2.85
		Based on P+K	Mean	19.12	99.31	8141	71.19	42.01	49.51		31.39
			Std.Dev.	4.3	0.36	1184	13.17	3.67	2.72		4.3
	Actual Measured Weight Loss Basis		Mean	10.74	99.39	7620	79.64	40.80	46.29	+ 40.38%	27.21
			Std.Dev.	6.32	0.36	965	9.90	2.10	0.77	12.32	3.80
Turned-Pile With Runoff Addition Process #4	Conservation of Ash Principles	Based on Ash	Mean	36.24	56.49	1035	13922	57.73	76.20	NOT APPLICABLE	64.58
			Std.Dev.	11.89	3.54	538	8388	1.72	3.39		7.96
		Based on P+K	Mean	32.23	53.72	1136	-14726	54.98	74.77		47.34
			Std.Dev.	12.19	2.86	664	8667	2.12	2.59		2.58
	Actual Measured Weight Loss Basis		Mean	16.85	41.97	1489	-20292	43.64	68.09	+ 33.91%	34.43
			Std.Dev.	14.05	7.46	971	10828	6.09	2.03	18.86	4.60
Continuous-Forced-Aeration Process #10	Conservation of Ash Principles	Based on Ash	Mean	26.98	98.62	8383	-1600	52.46	69.35	NOT APPLICABLE	44.07
			Std.Dev.	21.88	.67	2053	1214	7.75	7.79		6.51
		Based on P+K	Mean	31.34	98.63	8214	-1459	38.95	70.98		45.34
			Std.Dev.	10.30	.74	2564	1122	12.56	6.02		10.55
	Actual Measured Weight Loss Basis			31.36	98.69	8095	-1395	55.36	72.06	- 2.89%	46.96
				16.23	0.60	2524	1019	5.35	2.57	23.69	8.30

to variations in characteristics. This is evident in the mass balance results for ash based on actual weight data. Ash increases of 30% to 40% between the raw manure and the compost were observed. Since ash is conserved during composting, the discrepancy is the result of sample variability, small sample sizes, and laboratory analysis procedures.

A minimum of 10 grab samples were used for each sample taken for this project and 12 samples were analyzed for each process for comparison. Laboratory analysis procedures, however, use very small sub-samples of manure for analysis; less than 5 grams. It is therefore important that sufficient samples be analyzed to account for the natural variability in small samples of manure, if conservation of ash principles are to be used for mass balance calculations. It is also suggested that, to improve results, each sample submitted for analysis should undergo replicated tests for each lab procedure and the results averaged to give a good indication of the manure sample or compost sample characteristics.

5.11 Limitations of C/N Ratio Optimization

In order to assess the suitability of Ontario beef, dairy and poultry manure for composting in terms of C/N ratio and moisture content, manure from four typical beef, dairy and broiler-poultry farms were sampled and analyzed for total nitrogen, total carbon and dry matter.
Table 5.19 shows the results of the manure analysis.

Acceptable moisture levels for composting range from 40% to 65% (Rynk, R., *et al*. 1992) with the optimum range between 50% and 60% (Midwest Plan Service 1985). Moisture levels for the beef and dairy manures sampled and shown in Table 5.19 were above the acceptable range for composting and averaged 73.2% and 79.5% respectively. Manure moisture levels above the recommended upper range of 65% can result in low manure porosity. The excess moisture occupies pore-spaces and increases the tendency of the manure to settle and compact, reducing the potential for air exchange through the composting material. Altered management practices, such as changes in feed rations and greater use of bedding, could potentially help to lower the initial moisture content of the manures collected on-farm.

The optimum C/N ratio for nitrogen conservation during composting is 30:1 (Mathur, S. 1992). Poultry manure C/N ratios were the lowest with a mean of 10:1. Beef and dairy

Table 5.19. Manure Characteristics for Beef, Dairy and Poultry

Manure Type	Statistic	Total Nitrogen % Dry Matter Basis	Total Carbon % Dry Matter Basis	Dry Matter % As Is Basis	Moisture % As Is Basis	C/N Ratio
Beef	Mean	2.71	45.73	26.80	73.20	16.95
	Std.Dev.	0.19	1.34	1.57	1.57	1.29
	Var.	0.03	1.80	2.47	2.47	1.66
	# Samples	4	4	4	4	4
Poultry	Mean	4.24	42.53	66.88	33.12	10.17
	Std.Dev.	0.67	1.03	1.76	1.76	1.27
	Var.	0.45	1.07	3.10	3.10	1.61
	# Samples	4	4	4	4	4
Dairy	Mean	2.89	44.45	20.47	79.53	16.02
	Std.Dev.	0.59	1.02	3.35	3.35	4.09
	Var.	0.35	1.05	11.24	11.24	16.77
	# Samples	4	4	4	4	4

manures had similar C/N ratios of 16.3 and 16.0 respectively. All C/N ratios were significantly below the optimum.

Table 5.20 shows the quantities of straw required for poultry, beef and dairy manures to adjust the C/N ratio to 15:1, 20:1, 25:1 and 30:1. The table also shows the resulting moisture level, increase in volume, increase in weight and estimated cost based on using wheat straw. Straw addition costs were calculated based on a straw value of $0.022 per kilogram.

A straw density of 164.3 kg/m^3 (Rynk, *et al*. 1992) was used for the calculations. It was assumed that the volume increase from straw addition would be 50% of the dry bulk volume. Reductions in nitrogen loss are based on a C/N ratio to nitrogen loss relationship developed from data collected during this project. Nitrogen losses used for the analysis of nitrogen loss reductions due to straw addition for C/N ratio adjustment are as follows: for a C/N ratio of 15, nitrogen losses of 33.6% were used, for C/N ratios of 20, nitrogen losses of 29.6% were used, for C/N ratios of 25, nitrogen losses of 25.6% were used and for C/N ratios of 30, nitrogen losses of 21.6% were used. The value of the conserved nitrogen is based on nitrogen costs of $0.814/kg of actual nitrogen.

The value of nitrogen conserved as a result of C/N ratio adjustment using straw was approximately 10% of the cost of the added straw on a consistent basis. From an economic stand point straw addition for nitrogen conservation is not economical. There are however other benefits to adding straw to manures for composting. Adding extra straw to the manure provides increased organic matter for land application. Additional straw also increases manure porosity which will reduce the tendency for anaerobic microsites and reduce the production of CH_4, a greenhouse gas of concern.

The addition of straw for C/N ratio optimization has other economic implications beyond the cost of the straw. The additional straw results in an increased amount of material that has to be handled. Solid manure spreading costs in Ontario are $3.00/tonne (Hilborn 1997). A weight increase of 27.74% and 24.27% was calculated for the beef and dairy cattle manures respectively. The additional straw required to achieve the optimum C/N ratio of 30 will result in manures having a reduced bulk density. The reduced bulk density in turn will reduce the manure tonnage capacity of bulk manure spreaders.

Table 5.20. Summary of C/N Ratio Optimization For Composting

Manure Type		Carbon to Nitrogen Ratio			
		Adjusted C/N Ratio of 15	Adjusted C/N Ratio of 20	Adjusted C/N Ratio of 25	Adjusted C/N Ratio of 30
Beef Manure	Straw Required kg/T manure	N/A	58.81	162.74	277.38
	Straw Cost $/T manure	N/A	$1.30	$3.59	$6.12
	Volume Increase %	N/A	15.48	42.83	73.00
	Weight Increase %	N/A	5.88	16.27	27.74
	Adjusted Moisture %	N/A	69.8	64.6	59.9
	Nitrogen Conserved kg/T manure	N/A	0.177	0.467	0.757
	Value of Conserved N N/T manure	N/A	$0.14	$0.38	$0.62
Poultry Manure	Straw Required kg/T manure	347.22	740.06	1171	1647
	Straw Cost $/T manure	$7.66	$16.32	$25.82	$36.31
	Volume Increase %	91.39	194.78	308.31	433.54
	Weight Increase %	34.72	74.01	117.4	164.7
	Adjusted Moisture %	27.68	24.14	21.73	19.98
	Nitrogen Conserved kg/T manure	0.955	2.09	3.22	4.36
	Value of Conserved N N/T manure	$0.78	$1.70	$2.62	$3.55
Dairy Manure	Straw Required kg/T manure	N/A	62.51	147.89	242.06
	Straw cost $/T manure	N/A	$1.38	$3.26	$5.34
	Volume Increase %	N/A	16.45	38.92	63.71
	Weight Increase %	N/A	6.25	14.79	24.21
	Adjusted Moisture %	N/A	75.55	70.83	66.37
	Nitrogen Conserved kg/T manure	N/A	0.184	0.415	0.646
	Value of Conserved N N/T manure	N/A	$0.15	$0.34	$0.53

Straw addition for C/N ratio optimization did not bring moisture levels of the blended manure to the optimum range of 50% to 60% for the dairy cattle manures. At a C/N ratio target of 30, the dairy cattle manure moisture level was calculated to be 66.4%. At a target C/N ratio of 30, the beef cattle manure was calculated to have a moisture content of 59.9% which is at the upper limit of the optimum moisture level. At a target C/N ratio of 30 for the poultry manure, the moisture level was calculated to be 19.98% which is below acceptable moisture levels. Moisture would have to be added to the poultry manure to bring the moisture level up to the optimum range of 50% to 60%. The moisture levels of broiler manure are relatively low compared to cattle manure and have a high nitrogen content compared to cattle manure. As a result, larger quantities of straw are required for C/N ratio optimization, resulting in a significant lowering of the moisture level. Adding moisture would be another cost associated with optimizing the C/N ratio for poultry manures.

5.12 Economic Comparison of Composting Processes

The intent of this section is to compare labour and energy costs associated with the composting processes studied in this project.

The process technologies compared in this section include passive-aeration composting, static-pile-forced-aeration composting using intermittent aeration, turned-pile composting using a loader tractor, and turned-pile composting using a commercial windrow turner. Labour, and energy requirements are based on a combination of project experience and published information on composting costs. Assumptions and basis for associated costs are indicated where appropriate. Energy costs for hydro are based on \$0.0767/kwh. Fuel costs for tractor operation are based on diesel fuel priced at \$0.407/L. A 65 hp loader tractor with a 0.76 m^3 bucket was used for comparison purposes. Tractor fuel consumption of 15.9 L/hr was used for the analysis. It was assumed the loader tractor was used for bucket mixing and pulling the Sittler windrow turner model 510 that requires 65 hp to operate.

The bulk density of manures can be variable between farms depending on the amount and type of bedding used, and will affect the composting costs on a per tonne basis. For the purposes of this comparison, dairy cattle manures were used with an assumed bulk density of 865 kg/m^3 (Rynk R. 1992). All references to manure tonnage are on a wet basis for the economic analysis.

Labour requirements to transport manure from barns to the composting site are assumed equal and have not been included in the comparison. Additional labour requirements to build windrows have been included, and is over and above that which would be experienced just stacking manure in the yard. Labour has been included for placement of aeration piping. Energy costs have also been included for placement of aeration pipes because it has been assumed that the loader tractor will remain running during placement of the pipes. Aeration pipes are assumed to have a life expectancy of two processes based on experience, due to heating deformation and breakage during removal.

All process windrow dimensions were similar for comparison and are approximately 3 m wide and 1.2 m high unless otherwise noted. These dimensions result in windrows which contain approximately 2.60 m^3 manure/m of windrow length and 2.246 T/m of windrow length. Energy costs for the turned-pile method, assume that at commercial farm scale, turning frequency would not exceed three mixes. Data collected during this project indicates that mixing is required more for substrate distribution and the breaking up of anaerobic microsites than for aeration, at the windrow sizes studied. Pore-space O_2 levels for composting processes monitored during this study remained above the minimum acceptable composting pore-space concentration of 5% (R. Rynke 1992), without mixing. Natural convection through composting manure occurs as a result of the high temperatures attained during manure composting, and has been observed during this study to provide sufficient air exchange to maintain aerobic conditions.

Capital costs for concrete composting pads have been included in Table 5.21. These are estimates only based on conceptual designs and should be considered in the range of -25% to +40%, customary for estimates based on conceptual designs. All facility capital costs are based on providing composting capacity for 150 tonnes of manure.

Table 5.21 summarizes the costs associated with the various types of composting processes studied during this project.

The Lindner-field-windrow process had the lowest labour and energy requirements, at 0.012 hr/T of manure composted, and energy costs of $0.081/T of manure composted. Passive-aeration composting energy and labour requirements were slightly higher than those for the Zettle-modified-static-pile process, which did not use aeration tubes. Labour requirements for the Zettle process were 0.036 hr/T of manure composted, and energy costs were

Table 5.21. Economic Comparison of Composting Methods

Composting Technology	Component	Labour hr/T	Labour hr/m^3	Energy $/T	Energy $/m^3	Misc. $/T	Misc. $/m^3	Capital Costs
Passive-Aeration	Form Windrow	0.024	0.021	$0.155	$0.134			
	Place Aeration Pipes	0.019	0.016	$0.123	$0.106			
	Total	0.0427	0.037	$0.278	$0.240			
	Aeration Pipes					$4.67	$4.03	
	Concrete Pad and Runoff Collection System							$22,150
Turned-Pile Loader Tractor	Form Windrow	0.012	0.010	$0.077	$0.066			
	One Mix	0.049	0.042	$0.317	$0.274			
	Three Mixes	0.147	0.127	$0.951	$0.823			
	Concrete Pad and Runoff Collection System							$22,150
Sittler-Turned-Pile-Luptke Process Windrow Turner	Form Windrow	0.0768	0.0679	$0.439	$0.380			
	One Mix	0.00162	0.00140	$0.010	$0.0086			
	15 Mixes	0.0243	0.0209	$0.157	$0.136			
	Total	0.103	0.0902	$0.606	$0.525			
	Straw					$1.21	$1.05	
	Hay					$1.91	$1.65	
	Clay					$0.51	$0.44	
	Rock Dust					$1.49	$1.28	
	Windrow Cover Material					$0.50	$0.432	
	Total					$5.62	$5.30	
	Windrow Turning Machine							$11,500
	Concrete Pad and Runoff Collection System							$22,150
Forced-Aeration Intermittent	Form Windrow	0.024	0.021	$0.015	$0.134			
	Place Aeration Piping	0.019	0.016	$0.123	$0.106			
	Aeration - 2 min/hr - 1 m^3/hr/dry T manure			$0.517	$0.446			
	Total	0.043	0.037	$0.655	$0.686			
	Aeration Piping					$0.767	$0.663	
	Aeration Blower Installed							$6,950
	Concrete Pad and Runoff Collection System							$22,150
Lindner-Field-Windrow	Form Windrow	0.012	0.010	$0.081	$0.070			
Zettle-Modified-Passive-Aeration	Form Temporary Pile	0.024	0.021	$0.163	$0.141			
	Form Windrow	0.012	0.010	$0.081	$0.070			
	Total	0.036	0.031	$0.244	$0.211			

$0.244/T. This is very similar to the cost for the conventional static-pile-passive-aeration process using aeration tubes that had energy costs of $0.278/T of manure composted.

Turning compost with a windrow turner was much more efficient than loader tractor turning. Labour and energy requirements for mixing with a windrow turner were one thirtieth the labour and energy costs for loader tractor turning. Table 5.21 provides a cost of $11,500 for a windrow turner. The windrow turner has a width capacity of 3.5 meters and operates at a forward speed of 4.5 m/min, which equates to mixing approximately 600 tonnes of manure with a bulk density of 865 kg/m^3 in an hour in a windrow 3 m wide and 1.2 m high.

The Sittler-turned-pile-Luptke process had the highest costs associated with it due to the amendments which were added to the manure. The manure amendments cost $5.62/T of manure composted. Even though the materials in the Sittler process were mixed 15 times it had lower energy costs than the turned-pile process which was turned only three times with a loader tractor.

Energy requirements for intermittent-forced-aeration composting were slightly higher than loader tractor turned-pile composting energy costs.

Nitrogen losses were lowest for the Lindner-field-windrow process which also had the lowest labour and energy costs. The Sittler-turned-pile-Luptke process had the highest nitrogen losses and the highest composting costs associated with the process. Based on the parameters examined as part of this study, there is no justification for the extra expenses over other processes.

The Zettle-turned-pile process had the second lowest energy and labour costs and did not demonstrate any advantage in terms of carbon and nitrogen conservation over other processes. Field spreading costs for solid manure currently average $3.00/tonne in Ontario (Hilborn 1997). Composting can significantly reduce the tonnage of manures which require land spreading and thus reduce land spreading costs. The average dry matter loss for all composting processes conducted in this study was 46.0%. The average moisture loss was 61.2%. Based on these averages, composting of beef cattle manure has the potential of reducing the tonnage of manure requiring spreading by 57.1% which represents a reduction in land spreading costs of $1.71/T (wet) of manure. Composting has the potential of reducing the tonnage of poultry manure requiring land spreading by 51.0% which represents a reduction in land spreading costs of $1.53. Composting of dairy cattle manure has the potential of reducing the tonnage of manure requiring land spreading by 58.0% which represents a reduction in land spreading costs of $1.74 per wet tonne of manure.

Nitrogen losses occur during manure composting primarily as a result of NH_3 volatilization. The average nitrogen loss for all composting processes studied during this project was 29.7%. Based on a nitrogen fertilizer cost of $0.814/kg of actual nitrogen, composting of beef, dairy and poultry manure has the potential of reducing manure nitrogen values by $1.75, $6.63/T (wet) and $1.43/T (wet) respectively. Nitrogen losses due to composting have the potential to exceed the benefit value of reduced tonnage in the case of poultry manure. In the case of beef cattle manure the value of lost nitrogen has the potential to be equivalent to the benefit value of decreased land spreading costs. Composting of dairy cattle manure has the potential to provide a benefit of $0.41/T (wet), in terms of tonnage reduction when nitrogen losses are figured in. Actual composting costs have not been included in these cost/benefit values as they vary depending on the process used.

6.0 SUMMARY OF FINDINGS AND CONCLUSIONS

The findings and conclusions arising from this on-farm evaluation of composting processes are presented below under the following headings:

6.1. Composting process technologies and process manipulation factors.
6.2. Manure characteristics and their significance to composting.
6.3. Composting aeration.
6.4. Ammonia volatilization during composting.
6.5. Compost and raw manure leachate losses.
6.6. Nitrogen losses during composting.
6.7. Moisture losses during composting.
6.8. Compost mixing.
6.9. Methane production during aerobic composting.
6.10. Compost curing effects.
6.11. Manure C/N ratio optimization.
6.12. Economic aspects of composting.

The study objective which each point refers to is also identified below each statement made.

6.1 Comparison of Composting Process Technologies and Process Manipulation Factors

a. Based on the results of the experiments conducted during this project, composting processes conducted at ecological farming enterprises (field-windrow, modified-passive-aeration, and the Sittler-turned-pile-Luptke processes) did not have any advantage over traditional turned-pile, passive-aeration or static-pile-forced-aeration composting processes. The Sittler-turned-pile-Luptke process, the most unique of the ecological processes studied, had the highest nitrogen loss (54%) of all the composting processes studied. (Study Objective 5.)

b. Comparison of traditional turned-pile, passive-aeration and forced-aeration processes with similar windrow dimensions of 3 m wide and 1.2 m high, did not indicate that one process was advantageous over the other in terms of nitrogen or carbon conservation. (Study Objective 1.)

c. Compost inoculation of raw manure with composted manure did not demonstrate a conclusive advantage over straight manure composting as a process manipulation factor for nitrogen conservation. (Study Objective 6.)

6.2 Manure Characteristics and Their Significance to Composting

a. The manures generated on Ontario farms have moisture levels in the 70% to 80% range based on project samplings, which is significantly above the optimum composting level of 60%. The relatively high moisture levels causes manure settling and compaction in windrows, which is believed to reduce the effectiveness of static-pile-forced-aeration and passive-aeration technologies. (Study Objective 8.)

b. Poultry, beef and dairy cattle manures sampled as part of this project all had C/N ratios significantly below the optimum of 30/1 (S. Mathur 1992). Sampled poultry, beef and dairy manures had C/N ratios 10.1:1, 16.3:1 and 16.0:1, respectively. (Study Objectives 2 and 8.)

c. Moisture levels for the beef and dairy manures sampled as part of this project were above the acceptable range for composting and averaged 73.2% and 79.5% respectively. Acceptable moisture levels for composting range from 40% to 65% (Rynk, R., *et al*. 1992) with the optimum range between 50% and 60% (Midwest Plan Service 1985). (Study Objectives 2 and 4.)

d. The raw manure data collected during this study indicates that Ontario manures do not have characteristics which will minimize nitrogen losses or minimize the production of CH_4 from anaerobic microsites within the aerobic composting mass. The manures typically have low C/N ratios and high moisture content. The tendency of high moisture manures to have a higher CH_4 release can be countered through the use of compost mixing. (Study Objectives 2 and 8.)

6.3 Composting Aeration

a. The pore-space O_2 concentrations observed during the study indicate that windrows with a width of 3 m and a height of 1.2 m achieve sufficient air exchange due to the high temperature of the composting manure and natural convection through the windrow to maintain O_2 concentrations above the minimum acceptable composting concentration of 5%. (Study Objectives 1 and 8.)

b. Pore-space O_2 concentration data indicated that natural convection in static-pile composting processes, due to the heat gradient between composting manure and ambient air, is sufficient to maintain aerobic conditions without any technology enhancements such as forced-aeration, the addition of static aeration tubes or mixing. (Study Objectives 1 and 8.)

c. Intermittent-forced-aeration did not result in a lower nitrogen or organic matter loss compared to continuous-static-pile-forced-aeration. This is believed to be the result of natural manure settling and compaction in the static-pile windrow which reduced the effectiveness of forced-aeration. (Study Objectives 1 and 8.)

d. Data collected indicates that mixing actually results in a short-term O_2 draw-down in the composting manure due to the temperature drop that occurs as a result of loader tractor mixing. The high temperature of the composting manure is the primary force which creates the natural air convection through the windrow. When the temperature was reduced in composting manure due to mixing, the O_2 concentration actually decreased immediately after mixing rather than increasing as expected. (Study Objectives 1 and 8.)

6.4 Ammonia Volatilization During Composting

a. Experiments conducted to determine the effect of restricting air exchange potential during the first 21 days of composting (the period of highest NH_3 production) did not reduce the total nitrogen losses and data did not substantiate any advantage to this process manipulation factor in terms of nitrogen conservation. (Study Objectives 1 and 8.)

6.5 Compost and Raw Manure Leachate Losses

a. No significant difference in nitrogen or organic matter losses between composting inside and outside was observed. Any nitrogen leaching that occurred during outside composting due to precipitation was not of sufficient magnitude to be observed in bulk sampling analysis results. (Study Objectives 1, 4 and 8.)

b. Nitrogen, phosphorus and potassium leachate losses were observed to be reduced as a result of composting compared to raw manure leachate losses. Fourteen out of 16 processes studied showed a reduction in nitrogen, phosphorus and potassium leaching losses as a result of composting when compared to raw manure. The level of reduction in leachate losses between composts were highly variable. No trend was evident which would suggest one technology or process manipulation factor was more advantageous over another in producing compost with a lower potential for leachate losses. Differences in nitrogen leachate losses between raw manures and composts ranged from a 0.4% decrease for turned-pile compost to a decrease of 72.9% for the Zettle-modified-static-pile compost. (Study Objectives 1, 4 and 8.)

c. The nitrogen leachate losses observed did not correlate consistently with mineralized nitrogen concentrations, and compost leachates were found to contain organic nitrogen as well as inorganic mineralized forms of nitrogen. This may be a result of the leachate collection procedures followed for comparison purposes and may not be indicative of soil leachate losses. Leachate laboratory analysis procedures can be found in Appendix A. (Study Objective 4.)

d. Reductions in phosphorus and potassium leachate losses, as a result of composting compared to raw manure levels, were variable and showed no trend which would indicate one process factor as being responsible for a more favourable reduction. Compost maturity as indicated by relative seed germination inhibition did not indicate that one compost was more mature compared to another and leachate loss differences could not be attributed to level of maturity or organic matter loss. (Study Objectives 1, 4 and 8.)

6.6 Nitrogen Losses During Composting

a. A trend of higher nitrogen losses and organic matter losses, as a result of addition of barnyard runoff to composting manure, was evident, though not statistically significant. The composting process to which barnyard runoff was added had a nitrogen loss of 36.2% compared to 22.4% for the control process. Organic matter losses were 57.7% for the composting process to which barnyard runoff was added compared to 53.5% for the control and were not statistically different. (Study Objectives 3 and 8.)

b. Significant differences in the compost concentrations of mineralized nitrogen were observed as a result of barnyard runoff addition. NO_2 nitrogen concentrations increased by 139 times in the compost from the process to which barnyard runoff was added and decreased by 0.69 times for the control process, compared to the raw manures. High levels of NO_2 generally indicate a less stabilized organic material. The organic matter losses however did not substantiate that the compost produced with runoff addition was less decomposed. (Study Objectives 3 and 8.)

6.7 Moisture Losses During Composting

a. Moisture losses observed during inside and outside composting were significantly different. The outside turned-pile process had a net moisture loss of 43.2% compared to a 69.6% moisture loss for the process conducted inside. (Study Objective 3.)

b. Based on the on-line moisture monitoring data collected and bulk analysis of finished compost, moisture losses from processes manipulated for nitrogen conservation and aeration optimization are not sufficient to make the processes effective for treatment of farm- generated organic liquids. Composting processes manipulated to maximize moisture loss, however, as opposed to nitrogen conservation do have potential as a treatment process for farm-generated organic liquids. Further study is required in this aspect of composting. (Study Objectives 3 and 8.)

6.8 Compost Mixing

a. Mixing was found to enhance bacterial activity as observed by increases in CO_2 concentrations, a draw-down of O_2 concentrations and a gradual elevation in compost temperature. (Study Objectives 1 and 8.)

b. Mixing in windrows 3 m wide and 1.2 m high was found to be advantageous in terms of substrate distribution and in the breaking up of anaerobic microsites within the windrow, but was not found to be necessary to maintain overall aerobic conditions. (Study Objectives 1, 7 and 8.)

c. The CH_4 data collected indicates that thorough mixing of manures prior to composting and at several times during composting are warranted to break up anaerobic microsites and enhance the percentage of composting mass which is aerobic. (Study Objectives 1, 7 and 8.)

d. Mixing is warranted to redistribute manure substrate, bacterial colonies and associated enzymes responsible for aerobic degradation, even when pore-space O_2 concentrations are adequate for aerobic decomposition. (Study Objectives 1 and 8.)

6.9 Methane Production During Aerobic Composting

a. Off-gas CH_4 concentration data did not indicate that one process technology or process manipulation factor was more advantageous over another in reducing CH_4 production. All composting processes studied emitted CH_4 during the composting process even though pore-space O_2 concentrations were above the 5% level considered adequate for aerobic composting (Rynk 1992). The data indicates that anaerobic microsites exist even when static-pile-forced-aeration technology is used for composting. (Study Objectives 1, 7 and 8.)

6.10 Compost curing effects

a. Organic matter levels remained relatively constant during curing and no significant difference in organic matter levels were observed between the fresh compost and the compost materials cured for 30, 60 and 90 days. This indicates that continued biological degradation during curing was very slow and any net change was below detection capabilities of current laboratory procedures. (Study Objectives 1 and 8.)

b. Compost curing does not contribute significantly to further carbon losses. (Study Objectives 1 and 8.)

c. Total nitrogen levels on a dry matter basis for fresh compost and composts allowed to continue curing for 30, 60 and 90 days were not statistically different although a trend of slightly higher nitrogen levels after curing was observed, which can result from organic matter losses which exceed nitrogen losses. (Study Objectives 1 and 8.)

d. Nitrate levels were found to increase as a result of curing. Nitrate levels were higher after curing but did not increase continually with increased curing time but rather increased and then decreased. The decrease may be the result of denitrification occurring in anaerobic microsites as the curing process proceeded. (Study Objectives 1 and 8.)

e. Nitrogen leaching losses from compost were not reduced by curing the compost for up to 90 days. This is not surprising in light of the bulk analysis results which indicate that nitrogen present in mineral form, susceptible to leaching, did not decrease with increased curing time. (Study Objective 4.)

f. Phosphorus leaching losses varied over the 90 day curing period and followed a trend of increasing concentration and then decreasing concentration. Phosphorus leaching was not consistently higher after curing. In the one curing experiment, phosphorus leaching losses were not statistically different after curing 30, 60 or 90 days. In a second curing experiment, leaching losses increased significantly after 30 days of curing and then decreased to levels statistically the same as the fresh compost for compost cured 60 and 90 days. The experiment shows that potassium leaching losses are not significantly changed as a result of curing. (Study Objective 4.)

g. Seed germination inhibition in compost at the end of the high temperature degradation phase of composting and compost cured 30, 60 and 90 days was found to remain high enough to be 100% inhibitory to seed germination, when only compost was used as a seed germination medium. At a 50/50 soil compost mix, a decrease in seed germination inhibition was observed as a result of curing. (Study Objective 8.)

h. Seed germination inhibition observed when a 50/50 soil compost mix was used as the germination medium did not follow a consistent trend of decreased inhibition as compost curing time increased. Rather, inhibition decreased for the soil and 30 day cured compost germination medium mixture, increased for the soil and 60 day cured compost germination medium mixture and then decreased again for the soil and 90 day cured compost germination medium mixture. The increased seed germination inhibition observed in the tests using a 50/50 soil and 60 day cured-compost mix medium were not, however, higher than that observed in the 50/50 soil and uncured-compost mix germination medium. (Study Objective 8.)

i. The seed germination test results indicate that curing does reduce seed germination inhibition, but, curing 90 days is not sufficient time to observe a decrease when only compost is used as a seed germination medium. (Study Objective 8.)

6.11 Manure C/N Ratio Optimization

a. The use of wheat straw for optimization of C/N ratio as a strategy for reducing nitrogen losses was found to be uneconomical. The value of nitrogen conserved by adjusting C/N ratios to 15, 20, 25 and 30 was found to be consistently below the value of the straw required to adjust the C/N ratio. The value of conserved nitrogen was approximately 10% of the value of straw added for C/N ratio adjustment. However, the addition of straw to manures for composting provides other benefits as well as reduced nitrogen losses. These include increased organic matter for land application, reduced moisture concentrations bringing the moisture content of manures closer to levels considered optimum for composting and increased manure porosity which reduces the tendency for anaerobic microsites in composting manure windrows, reducing CH_4 emissions. (Study Objectives 2 and 8.)

6.12 Economic Aspects of Composting

a. The Lindner-field-windrow process had the lowest labour and energy requirements, at 0.012 hr/T of manure composted, and energy costs of $0.081/T of manure composted. Passive-aeration composting energy and labour requirements were slightly higher than those for the Zettle-modified-static-pile process, which did not use aeration tubes. Labour requirements for the Zettle process were 0.036 hr/T of manure composted, and energy costs were $0.244/T. These values are very similar to those for the conventional static-pile-passive-aeration process with aeration tubes, which had energy costs of $0.278/T of manure composted. (Study Objectives 5 and 8.)

b. Turning compost with a windrow turner was found to be more efficient than loader tractor turning. Labour and energy requirements for mixing with a windrow turner were one thirtieth the labour and energy costs for loader tractor turning. (Study Objectives 5 and 8.)

c. The Sittler-turned-pile-Luptke process conducted at the Sittler farm had the highest costs associated with it due to the amendments which were added to the manure. The manure amendments cost $5.62/T of manure composted. Even though the Sittler process was mixed 15 times it had lower energy costs than the turned-pile process which was turned only three times with a loader tractor. (Study Objectives 5 and 8.)

d. Energy requirements for intermittent-forced-aeration composting were found to be slightly higher than loader tractor mixed turned-pile composting energy costs. (Study Objectives 5 and 8.)

e. Nitrogen losses were lowest for the Lindner-field-windrow process which also had the lowest labour and energy costs. The Sittler-turned-pile-Luptke process conducted at the Sittler farm had the highest nitrogen losses and the highest composting costs associated with the process. Based on the parameters examined as part of this study, there is no justification for the extra expenses incurred with this process over other processes. The Zettle-modified-static-pile process had the second lowest energy and labour costs and did not demonstrate any advantage in terms of carbon and nitrogen conservation over other processes. (Study Objectives 5 and 8.)

f. Field spreading costs for solid manure currently average \$3.00/T in Ontario (Hilborn 1997). Composting can significantly reduce the tonnage of manures which require land spreading and thus reduce land spreading costs. The average dry matter loss for all composting processes conducted in this study was 46.0%. The average moisture loss was 61.2%. Based on these averages, composting of beef cattle manure has the potential of reducing the tonnage of manure requiring spreading by 57.1% which represents a reduction in land spreading costs of \$1.71/T (wet) of manure. Composting has the potential of reducing the tonnage of poultry manure requiring land spreading by 51.0% which represents a reduction in land spreading costs of \$1.53/T (wet) of manure. Composting of dairy cattle manure has the potential of reducing the tonnage of manure requiring land spreading by 58.0% which represents a reduction in land spreading costs of \$1.74/T (wet) of manure. The reduction in land spreading costs are, however, offset by the value of nitrogen lost during composting as presented in finding 6.12 g and the labour and energy costs associated with composting. Turned pile composting costs using a 65 horsepower tractor with a 0.76 m^3 bucket are estimated to be \$2.19/T based on labour and energy costs to form the compost windrow and mix the windrow three times with the loader tractor. Even though composting has higher direct costs than direct economic benefits, other benefits more difficult to assess economically do result. These include the benefit of timeliness during manure spreading periods, the benefits of reduced field leachate losses from applying composted manures compared to raw livestock manures, and the ability to spread compost more evenly than raw manure due to the finer drier nature of composted manure compared to raw manure. (Study Objective 8.)

g. The average nitrogen loss for all composting processes studied during this project were found to be 29.7%. Based on a nitrogen fertilizer cost of \$0.814/kg of actual nitrogen, composting of beef, dairy and poultry manure has the potential of reducing manure nitrogen values by \$1.75/T, \$6.63/T and \$1.43/T respectively on a wet weight basis. Nitrogen losses due to composting have the potential to exceed the benefit value of reduced tonnage in the case of poultry manure. In the case of beef cattle manure the cost associated with the value of lost nitrogen has the potential to be equivalent to the benefit value of decreased land spreading costs. Composting of dairy cattle manure has the potential to provide a benefit of \$0.41/T (wet), in terms of tonnage reduction when nitrogen losses are considered. Actual composting costs have not been included in this assessment as they vary depending on the process used. (Study Objective 8.)

7.0 IMPLICATIONS OF THE STUDY RESULTS FOR ON FARM COMPOSTING

The results of this project can only be applied confidently to on farm composting processes involving compost windrow formations which fall within windrow dimensions used during this project (approximately 3 meters wide at the base and 1.2 meters high). The windrow dimensions can have an effect on aeration patterns through the composting manure mass and therefore comparisons of processes involving windrows with significantly different dimensions are not valid.

In general the study found that their was no justification for enhanced aeration technologies for windrows with a base width of approximately 3 m and a height of 1.2 m. Natural convection through the composting manure was found to be sufficient to maintain overall aerobic conditions within the pore spaces of the composting mass.

Mixing of composting windrows was found to be advantageous more for the redistribution of bacteria, manure substrates and bacterial enzymes responsible for organic matter degradation, than for increasing pore space oxygen concentrations. Mixing of composting manures was also observed to help break up larger manure clumps. The large manure clumps contain anaerobic micro-sites responsible for methane production, even though the composting mass is predominantly aerobic. The farmer should experiment and use compost temperature as an indication of the effect of mixing. A rise in average daily temperature after mixing indicates a positive effect. An initial temperature drop due to heat loss during mixing will be observed but the compost temperature should increase above the preceding daily average if mixing was warranted for redistribution of substrates, bacteria and enzymes.

Compost mixing using a front-end loader tractor was found to cool the composting manure significantly during the mixing process, particularly during cooler weather. This cooling effect reduces the heat gradient between the composting manure and ambient air, which in turn results in reduced air exchange through the composting mass. Experiments carried out during this study indicated that mixing performed to improve pore space oxygen content actually resulted in a short term (several days) decrease in pore space oxygen content because of the heat loss, and resulting reduced heat gradient which drives the convective air movement through composting manures. During warm summer months the heat loss is not so great, but during cold weather composting it is very significant. As a result farmers should use caution when mixing during cold weather. Compost mixing using a windrow turner results in lower heat losses during the mixing process compared to loader tractor mixing. This is because small masses of manure are not exposed to cooler ambient air for as great a period as with loader mixing and the windrow remains in the same location during mixing with a windrow turner, thus there is no significant heat loss due to the windrow being placed on a cold surface, as occurs with loader tractor mixing.

The study did not find differences in nutrient losses between composting outside and composting indoors. This was concluded to be the result of the pyramid shape of the windrows and the hard outer surface which forms from air and sun drying. Both factors tend to help shed water, preventing it from penetrating the windrow. To reduce leachate losses it is important to have a pyramid shape to the windrow so rain water is shed off. The potential for nutrient leachate losses from compost were also found to be less than the potential
for nutrient leachate losses from raw manure.

The study did not provide evidence that one process or manipulation factor produced a more mature or superior compost material compared to another based on maturity, as established by the degree of seed germination inhibition. All compost materials were inhibitory to seed germination to approximately the same degree. Therefore farmers wishing to compost should choose the least expensive method of composting for their particular operation.

Compost curing is a secondary composting step during which chemical and biological transformations continue at a much slower rate. Curing is accomplished by allowing the compost material to sit in windrows. This provides time for the slower secondary transformations, which eliminate seed germination inhibition in compost, to occur. Germination inhibition tests indicated that the inhibitory effect observed in pure compost germination media was reduced when the compost media was diluted using a 50/50 by volume soil compost mix. Although germination tests were not conducted at soil/compost mixtures equivalent to possible field spreading rates it is believed that at these rates seed inhibition would be negligible. For horticultural applications containing a high percentage of compost material as the germination media, seed germination inhibition is a more important factor. Curing periods of 30, 60 and 90 days were examined as part of the study. Seed germination inhibition was still observed to be significant after 90 days of curing, indicating that curing periods required to eliminate seed germination inhibition are extensive. Farmers should experiment using their own germination tests to determine the appropriate curing time for their compost material, relative to the intended compost use.

The seed germination inhibition characteristic of uncured compost can be beneficial if the compost is used as a mulch to control weeds. So the need for curing is dependant on the end use of the compost material.

Ontario manures analyzed as part of this project contained relatively low C/N ratios (17% and less) and high moisture levels (70% and greater) compared to composting optimums of 30 for C/N ratio and 60% for moisture. Based on these findings Ontario manures would benefit from additional dry sources of carbon to reduce moisture levels and increase the C/N ratios, if they are going to be composted. However, the study found that optimizing C/N ratios using wheat straw, as a means to retain nitrogen, was not economically viable. The cost of the wheat straw was greater than the value of the conserved nitrogen. There may be other benefits to the use of increased bedding in the form of improved animal health, and increased organic matter for field incorporation which should be considered.

Turned pile composting costs using a 65 horsepower tractor with a 0.76 m^3 bucket were estimated to be $2.19/T based on labour and energy costs to form the compost windrow and mix the windrow three times with the loader tractor.

Composting of beef cattle manure has the potential of reducing the tonnage of manure requiring spreading by 57.1% which represents a reduction in land spreading costs of $1.71/T (wet) of manure. Composting has the potential of reducing the tonnage of poultry manure requiring land spreading by 51.0% which represents a reduction in land spreading costs of $1.53/T (wet) of manure. Composting of dairy cattle manure has the potential of reducing the tonnage of manure requiring land spreading by 58.0% which represents a reduction in land spreading costs of $1.74/T (wet) of manure. The reduction in land spreading costs are, however, offset by the value of nitrogen lost during composting and the labour and energy costs associated with composting.

The average nitrogen loss for all composting processes studied during this project were found to be 29.7%. Based on a nitrogen fertilizer cost of $0.814/kg of actual nitrogen, composting of beef, dairy and poultry manure has the potential of reducing manure nitrogen values by $1.75/T, $6.63/T and $1.43/T respectively on a wet weight basis.

Even though composting has higher direct costs than direct economic benefits, other benefits more difficult to assess economically do result. These include the benefit of timeliness, because of the reduced volumes during manure spreading periods, the benefits of reduced field leachate losses from applying composted manures compared to raw livestock manures, and the ability to spread compost more evenly than raw manure due to the finer drier nature of composted manure compared to raw manure.

This study indicates that composting can be carried out effectively using simple turned pile techniques as compared to many more sophisticated techniques. However, farmers must evaluate their reasons for composting and assess all direct and indirect benefits prior to integrating composting into their manure management program.

8.0 RESEARCH RECOMMENDATIONS

1. The results of the study indicate that their is a need for additional research on the role of compost mixing in smaller dimension windrows, which remain aerobic through natural convection. Mixing of compost windrows is a significant cost. Research is required to confirm the optimum frequency, timing and benefit.

2. Curing of compost materials intended for field applications is an area which requires further study. There is no question that compost material at the end of the rapid high temperature degradation phase has seed germination inhibition properties. The effect that this property has on field crops at varied application rates, and varied application timing schedules should be examined further. Application timing may be an effective means of weed control in some crops.

3. Further studies are warranted to determine if frequency of mixing or the initial particle size distribution of manures intended for composting can be manipulated to reduce the production of methane, a green house gas of concern. It may be beneficial to pass the raw manure through a modified manure spreader to produce a relatively fine manure texture which would should reduce the potential for anaerobic clumps.

4. Studies to examine the effect of blending raw manures with finished compost to reduce nitrogen losses and possibly decrease the degree of anaerobic conditions in the composting mass warrants further study. During this project one such experiment was carried out which indicated that this strategy has some merit for nitrogen retention and modified bacterial activity.

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APPENDIX A

LABORATORY ANALYSIS PROCEDURES

Manure and Compost
Leachate Analysis Procedures

Bulk Manure and Compost
Laboratory Analysis Procedures