RESEARCH SUB-PROGRAM

SUMMARY OF RESULTS FROM GREEN PLAN PROJECTS ON MANURE/NUTRIENT MANAGEMENT AND CLOSED LOOP RECYCLING

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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)

The original level of funding for the research component was $9,700,000 through Mar. 31, 1997. Projects will be carried out by Agriculture and Agri-Food Canada, universities, colleges or private sector agencies including farm groups.

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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The following report, approved by the Research Management Team, is reproduced in its entirety as received from the contractor, designated on the previous page.

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Executive Summary

Many questions about effects on the environment from livestock manures and the nutrients they contain continue to be of prime concern within rural Ontario. Several projects undertaken within The Canada-Ontario Agriculture Green Plan addressed issues related to manure and manure nutrient management and much useful information and experience were obtained. This report was prepared to facilitate the transfer of the results of these studies to extension personnel and the farmers that they serve, to the decision makers within the various levels of government, and to some degree, to the general public.

This report provides a summary of the major observations and conclusions of eight Green Plan research reports, with particular reference to water quality and greenhouse gas issues, along with supplementary information from one project funded through the Land Management Assistance Program and four projects of the Rural Conservation Clubs Program.

Benchmarks

The first project completed within the Green Plan Research Sub-program was the report, *The Current State of the Art on Manure/Nutrient Management* by Goss et al, 1994. It identified and ranked twelve priority areas for research and extension activities, related to manure nutrient management. It also included a literature review summarizing the extent of the knowledge about manure/nutrient management as of 1993 and identified the major gaps in the information base regarding the environmental impact of manure management. Throughout this current report, the report by Goss et al and recommendations made by the committees and sub-committees of the Ontario Agricultural Services Coordinating Committee (OASCC) were used as benchmarks against which to compare the progress made within Green Plan. Results from Green Plan projects are summarized according to the contributions made toward answering specific concerns identified by Goss et al or by OASCC. Unresolved concerns or gaps in the knowledge base and recommendations for future actions, as noted in the individual reports by the respective researchers, are also documented.

Progress In Addressing Identified Needs for Information

Manure use in conservation tillage systems was investigated in on-farm trials. Application of liquid manure was integrated with conservation tillage in an effective and efficient manner, from an operational point of view, although modification of application equipment was sometimes necessary depending on site requirements. If tile drains were flowing at the time of application, side-dressed applications of liquid manure in no-till corn resulted in impairment of the quality of tile drainage water such that water quality guidelines for bacteria, ammonia and phosphorus were exceeded for several hours. This occurred both immediately following the manure application (i.e. within minutes) and after a simulated rainfall event one day later, regardless of the method of liquid manure application. Manure was confirmed as the source of the contamination and macropore pathways contributed to tile flows even under unsaturated soil moisture conditions. Compared to surface application, contamination was generally less when the manure had been injected, especially if the system was modified to till the soil before injection. Guidelines were developed to help reduce contamination of tile drainage water from application of liquid manure in no-till situations.

Corn yields produced with manure-nitrogen applied at rates based on soil N test recommendations were generally equivalent to those from control treatments where inorganic fertilizers were used at equivalent rates.

The availability of manure nitrogen to a crop was most directly related to the ammoniacal nitrogen (NH_4-N) content of the manure. This fraction must be measured and taken into account if manure N is to be used most economically with minimum environmental impact. The release of available N from spring-applied manures with high NH_4-N contents (e.g. liquid swine and cattle manures) was rapid in some years and well in advance of the period of peak N requirement of the corn crop. Solid manures with a low content of NH_4-N and a high C/N ratio (e.g solid beef cattle manure) provided little N to the crop in the year of application. They did not cause a depression in available N in the soil, contrary to expectations.

Determination of the availability of N in the soil early in the growing season was complicated by the apparent disappearance of N. Within a few days after application, the amount of inorganic nitrogen that could be extracted from the soil was always less than the amount of NH_4-N applied in manures or urea. The N in liquid swine manure was generally more available than that in other manures (i.e cattle or poultry). The availability of N in solid beef cattle manure was generally the lowest. Manure N from all sources was less available than N from fertilizer urea.

Manure N dynamics in the soil, related to N mineralization and immobilization, were difficult to assess because of the differences in inorganic N recoveries and variable release rates in the soil. Similar difficulties were experienced in estimating the contribution of available N from the organic N fraction of manures. Nevertheless, there appeared to be little, if any, early-season release of organic N from spring-applied manures. Release of organic N occurred late in the growing season or in subsequent seasons. There was evidence that some of the organic N in fall-applied manure became mineralized in the late summer, twelve months after application. Significant quantities of residual manure N can become available in the year following application. Unfortunately, the soil test for nitrate nitrogen did always not accurately reflect the contribution of nitrogen from previous manure applications and other organic sources of nitrogen such as residues from legume crops or cover crops.

Manure N transformations in moderately acid soils (e.g. mineralization and nitrification) occurred at a slower rate than in neutral or slightly alkaline soils. However, soil acidity had little influence on the extent of N transformations. Liming of these acid soils resulted in an increase in the rate of mineralization and nitrification to near normal levels. Provided that such soils receive lime treatments periodically, soil acidity should not interfere with the availability of manure-N in most circumstances.

The implications for groundwater quality of using liquid manure were found to be similar to those of using mineral N sources at equivalent rates of inorganic N. There was a high risk of nitrate leaching from fall applications of liquid manures with a high NH_4-N content (e.g. liquid swine or liquid dairy cattle manures). This risk existed in the fall immediately after application, in the following spring, and in the next fall period. There appeared to be little risk of water quality impairment from fall-application of composted manures, composted organic wastes or solid manures with relatively low NH_4-N content and substantial bedding content, but these materials also provided little N to the corn crop in the first year.

Fall treatments, designed to immobilize nitrogen, (e.g. seeding of cover crops or adding straw) were not adequate to reduce the risk of nitrate leaching significantly. Cover crops sown after manure application in the fall removed less than 10% of mineral-N applied in liquid cattle manure, and only 10% - 15% of this was transferred to the following corn crop. Much of the N from fall-seeded cover crops did not appear to be become available until late in the following season.

Adjustments in the level and degradability of protein in the diets of dairy cattle were more likely to affect the form of the nitrogen excreted (i.e. urine vs faeces) than the total amount. Feeding a diet with high protein content and degradability to dairy cattle had little effect on the N content of the faeces, but increased excretion of nitrogen in the urine. The major source of available N in cattle manure appears to be derived from the urine. Faeces may even restrict N availability. Dietary changes that increase the proportion of N excreted in the urine could influence N utilization by crops, gaseous losses or leaching.

The fate of nitrogen inputs in six different conventional manure handling systems varied depending on the manure and the system. The amount of N excreted as fresh faeces was consistently 70 - 80% of feed N. As a percentage of N inputs (feed + bedding), final plant available manure NH_4-N amounts ranged between 8% (solid beef) and 40% (liquid swine or liquid dairy). Organic N in the manure varied from 1% (liquid swine) to 45% (solid dairy) of input N. The major pathway of N loss was as ammonia (NH_3) volatilization from fresh manure (22 - 65% of excreted N). Because this loss of N occurred very quickly before the manure was moved into storage, there appear to be few management options for reducing it. In comparison, losses in storage were relatively low for most systems (3 to 23% of manure N). Aerobic conditions in one storage lagoon for liquid swine manure system resulted in high concentrations of NH_4-N in the liquid manure, leading to significant loss of NH_3 during agitation and spreading of the manure. It is also significant to note that the nitrogen contained in runoff from a solid beef manure storage pad represented as much as 25% of the available N in the final manure to be spread.

Greenhouse gas emissions from six conventional manure handling and storage systems were monitored and an extensive database of information was collected. Greenhouse gas losses (except CO_2) were usually negligible with respect to mass balance of C and N. However, the magnitudes of the losses were important from an environmental perspective. The fate of carbon inputs in conventional handling and storage systems varied depending on the manure and the system. The amount of C remaining in the final manure, as a percentage of input C, ranged between 5% (liquid swine) to 39% (liquid dairy). Losses of C in storage ranged as high as 57%.

A comparative benefit-cost assessment of six manure-handling systems, indicated that total annual costs (overhead plus operating) exceeded the value of plant nutrients applied to the soil on five of the six test farms by amounts ranging from $4.13 to $124.28 per tonne of manure applied per year. A small net benefit of $0.06/tonne manure was achieved on one dairy farm.

Soilborne diseases of potatoes can effectively be reduced through the use of manures and other related organic amendments. More than one mechanism is involved and the effects vary depending on the manure, the pathogen, soil type, and soil moisture levels. A rapid and reproducible laboratory bioassay was developed for determining the effect of manures on pathogens in a particular soil. This assay could be used to provide farmers with information as to where certain manures can be safely applied and under what conditions.

Comparison of techniques for composting manures indicated that manures from Ontario livestock operations generally do not have characteristics that minimize the loss of nitrogen or the release of methane (CH_4) during composting. Solid cattle and swine manures had moisture levels significantly above the optimum of 60%. Solid poultry manures were significantly below the optimum. All manures had C/N ratios significantly below the optimum. Similarly, none of the 16 composting techniques tested showed any consistent advantage over the others for reducing losses of nitrogen or production of CH_4. Because anaerobic microsites formed within the composting mass, CH_4 was released during composting in all cases even though pore-space oxygen concentrations were above the 5% level considered adequate. Mixing would appear to be warranted for bacteria, enzyme and substrate distribution (as opposed to overall aeration) and should be carried out using a compost windrow turner, rather than a front-end loader, to minimize heat losses. Nitrogen losses for the sixteen composting processes studied ranged between 8.4% and 52.7%, with the average nitrogen loss being 29.7%. The benefit of a 50% reduction in manure volumes due to composting was typically offset by the value of nitrogen lost during the composting process. The use of wheat straw to optimize the C/N ratio was found to be an uneconomical strategy for reducing nitrogen losses.

Composting generally reduced the potential for leaching of nitrogen, phosphorus and potassium from the finished compost compared to the raw manure. No one process or modification was more advantageous than another in producing compost with a lower potential for leachate losses of these nutrients. The potential for leaching of nutrients from solid beef cattle manure during the composting process was low whether it was done outside or inside, because a hard crust formed on the surface of manure that effectively shed water.

Treatment systems for contaminated water were tested in three Conservation Club projects. . Results from a project to evaluate vegetated filter strips on five cattle farms established that this technology is an environmentally sound treatment system for feedlot and barnyard runoff. Sampling showed no accumulation of nutrients in the soil profile and no change in the quality of ground water samples from preconstruction levels. Two other Conservation Club projects demonstrated that constructed wetlands can be an effective means to treat milkhouse wash water and barnyard runoff without adverse effects on water quality.

Composted organic wastes can be applied at rates in the order of 100 Mg ha^{-1} without adverse effects on the production of corn, soybeans or grass hay. Because composts can inhibit germination of crop seeds to some degree, fall applications may be preferable to spring when higher rates of composted materials are to be applied. Relatively little of the N in these materials was in an inorganic form and it appeared that little or no N from the composts tested was made available to the crops. Thus, normal N application rates should be used in conjunction with the application of composted organic wastes. Composts did contribute significant amounts of phosphorus, potassium, and zinc to the soil, which in time, could be reflected in reduced fertilizer requirements. Three annual additions of composted organic wastes, of 10,000 to 15,000 kg carbon ha^{-1} yr^{-1}, increased organic carbon levels in the soil by almost 33%, relative to where no compost was applied.

Application of composted organic wastes did not adversely affect soil quality in two soils as reflected by soluble salts, metal content or soil microbial biomass. Compost has the potential to increase water holding capacity and improve soil infiltration rates, thereby reducing risks of soil loss due to water erosion. The increased residual water content with the some composts, however, may increase the risk of delayed planting because of wet soil conditions. The impact of compost application on soil pore size distribution needs to be further investigated.

At an application rate of 100 Mg ha^{-1}, the cost of composted urban organic wastes could not be justified on the basis of yield increases and fertilizer benefits. Indeed, these benefits were insufficient to cover the cost of the application. The intangible benefits of organic carbon, improved water characteristics, etc. might be sufficient to justify the cost of applying compost if it were delivered to the farm free of charge.

Unresolved Concerns

Although much useful information and experience related to manure management were gained as a result of Green Plan activities, most of the concerns identified by Goss et al or by OASCC remain to be answered more fully. In an particular, more work is needed to clarify questions related to:

- transformations of manure carbon and nitrogen in the barn, in storage and during application.
- transformations of manure carbon and nitrogen in the soil after application
- the availability of manure N for crop growth.
- the relationship between optimum manure application rates agronomically, economically and environmentally.
- the influence of livestock feeding regimes on manure composition and nutrient availability.
- control or management of odours and gases released from manure.
- economic considerations of manure management systems and of the off-farm effects of manure.

List of Acronyms and Abbreviations

OASCC	Ontario Agricultural Services Coordinating Committee
OMAFRA	Ontario Ministry of Agriculture, Food and Rural Affairs
COESA	Canada-Ontario Environmental Sustainability Accord
CSAMM	*The Current State of the Art on Manure/Nutrient Management,* a Green Plan report by Goss et al

BOD_5	Biochemical Oxygen Demand
C	Carbon
CH_4	Methane
CO_2	Carbon dioxide
DOC	Dissolved Organic Carbon
H_2S	Hydrogen sulphide
K	Potassium
N	Nitrogen
NO_3	Nitrate
NH_3	Ammonia
NH_4-N	Ammoniacal nitrogen
NO_x	Nitrogen oxides
N_2O	Nitrous oxide
O_2	Oxygen
P	Phosphorus

1.0 Introduction

1.1 Rationale

Issues related to the management of manures, and the nutrients they contain, continue to be of prime concern within rural Ontario. Certain sectors of the livestock industry are growing very rapidly in parts of the country, and the size of livestock operations is ever increasing. There is much concern about the potential environmental impact of livestock operations and the manure that they generate. Unfortunately, there has been no clear answer to many of the questions that have been raised about livestock manures and the environment. A number of the projects undertaken with funding from the Research Program of The Canada-Ontario Agriculture Green Plan addressed issues related to manure and manure/nutrient management and much useful information and experience were obtained. To help resolve some of the issues related to management of livestock manures, the findings from these studies need to be transferred to extension personnel and the farmers that they serve, to the decision makers within the various levels of government, and to some degree, to the general public.

1.2 Objectives:

1. To review and summarize the Executive Summaries and major conclusions of eight Green Plan research reports, along with relevant, supplementary information from projects funded through the Land Management Assistance Program or the Rural Conservation Club Program, in the context of a "nutrient-balance utilization" approach to manure nutrient management, with reference to water quality and greenhouse gas issues.
2. To document the progress made within the Green Plan Research Sub-Program relative to manure nutrient management practices and in the understanding of the basic related issues, since completion of *The Current State of the Art on Manure/Nutrient Management* (Goss et al, 1994), with additional reference to Ontario Agricultural Services Coordinating Committee (OASCC) recommendations regarding manure management.
3. To compile unresolved concerns or gaps in the knowledge base and recommendations for future actions, as noted in the individual reports by the respective researchers.

1.3 Background

Canada's Green Plan lists three objectives vital to achieving sustainable agri-food systems:

- to conserve and enhance the natural resources that agriculture uses and shares.
- to be compatible with other environmental resources that are affected by agriculture.
- to be proactive in protecting the agri-food sector from the environmental impacts caused by other sectors and factors, external to agriculture.

The Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) similarly identified the parallel goals of achieving environmental sustainability while maintaining an economically competitive agricultural industry.

The authors of the report, *Phase I Evaluation of the Canada-Ontario Agreement on the Agricultural Component of the Green Plan: Evaluation Assessment*, (Deloitte and Touche Management Consultants and Apogee Research International) state:

> *"The (Treasury Board) approval (for the Green Plan) also specifies that Green Plan effectiveness is to be judged on:*
>
> C *the contribution to the intended reduction in severity of environmental problems;*
>
> C *the related impact on the agricultural productivity and economic viability of the natural resource base for agriculture, and:*
>
> C *the contribution to increased knowledge on the parts of all partners in the sector about environmental sustainability and solutions to current problems"* (page 32)

> *"The ultimate Green Plan goal, stated clearly in the Treasury Board evaluation requirements, is to improve environmental conditions and the viability of the agricultural resource base. These improvements will occur only if farmers change their current practices and adopt the more environmentally sustainable ones being encouraged by the Green Plan activities."* (page 33)

In October of 1991, a group of approximately 50 stakeholders met at the Green Plan Agricultural Stakeholders Forum, held at the Kempenfelt Conference Centre near Barrie Ontario, to identify issues affecting the environmental sustainability of agriculture in Ontario and to suggest strategies for addressing each issue.

From the 30 recommendations crafted at the Stakeholders Forum, the Agreement Management Committee of Green Plan identified nine program areas for Green Plan activities. The Research Sub-Program of Green Plan was comprised of three program areas, one of which was

Manure/Nutrient Management and Utilization of Biodegradable Organic Wastes.

The summary presented here of Green Plan projects related to manure management included eight research projects funded through the Green Plan Research Program, one research project funded through the Land Management Assistance Program and four demonstration projects funded through the

Rural Conservation Clubs program. The Executive Summaries of the research project reports[1] are presented in Appendix A.

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[1] The final reports of the research projects have been published by:
The Southern Crop Protection and Food Research Centre, Research Branch, Agriculture and Agri-Food Canada, 1391 Sandford St., London, Ontario N5V 4T3.

Digital versions of these documents are available for downloading from the "Research Reports" page on the Green Plan Web Site: http://res.agr.ca/lond/gpres/reporlst.html

1.4 Projects Included in this Summary

1.4.1 Green Plan Research Program

Current State of the Art on Manure/Nutrient Management. COESA Report: RES/MAN-001/94

M. J. Goss, J. R. Ogilvie, E. G. Beauchamp, D. P. Stonehouse, M. H. Miller and K. Parris, University of Guelph, Guelph, ON

Nitrogen and Carbon Transformations in Conventionally-Handled Livestock Manures.

COESA Report: RES/MAN-002/97

G. Kachanoski, D. A. J. Barry and D. P. Stonehouse,

Environmental Soil Services[2], Arkell, ON

Manure Composting Techniques: Understanding Nitrogen and Carbon Conservation.

COESA Report: RES/MAN-003/97

R. St. Jean, Ecologistics Ltd, Waterloo, ON

Transformations in Soil: Crop Response to Nitrogen in Manures with Widely Different Characteristics. COESA Report: RES/MAN-004/97

E. G. Beauchamp, J. Buchanan-Smith and M. Goss, University of Guelph, Guelph, ON

The Effects of Livestock Manure Application Methods on Water Quality, Focussing on Nitrogen and Bacteria Transport in Soil. COESA Report: RES/MAN-005/97

G. J. Wall, B. A. Grant, D. J. King, and N. McLaughlin

Agriculture and Agri-Food Canada, Guelph, ON

Application of Composted Organic Waste to Agricultural Land

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[2] The location given is that of the principal contractor/researcher. One or more of the co-authors may be associated with another institution or consultant.

COESA Report: RES/MAN-006/97

V. Alder, R. W. Sheard, R. G. Kachanoski and M. J. Goss ,

Ecological Services For Planning[2], Guelph, ON

Assessment of the Influence of Manures for the Control of Soilborne Pests Including Fungi, Bacteria and Nematodes COESA Report: RES/MAN-010/97

G. Lazarovits and K. Conn, Agriculture and Agri-Food Canada, London, ON

Investigating Methods of Integrating Liquid Manures into a Conservation Tillage Cropping System COESA Report: RES/FARM-002/97

G. Schell and V. Alder, Ecological Services For Planning, Guelph, ON,

in association with R. Samson, REAP Canada and P.-Y. Gasser, AgKnowledge

1.4.2 Land Management Assistance Program

An Investigation into the Management of Manure-Nitrogen to Safeguard the Quality of Groundwater COESA Report: LMAP - 013/95

M. J. Goss, W. E. Curnoe, E.G. Beauchamp, P. S. Smith, B. D. C. Nunn and D. A. J. Barry, University of Guelph, Guelph, ON

1.4.3 Rural Conservation Clubs Program

Constructed Wetland Project, Belle River Conservation Club

Dignard Artificial Wetland, South Nation River Conservation Authority

Evaluation of Vegetative Filter Strips to Treat Beef Feedlot and Dairy Yard Runoff in Ontario, Ontario Cattlemen's Association

2.0 Identified Needs for Information

2.1 Green Plan Agricultural Stakeholders Forum

Recommendations 1 and 2 from the Stakeholders Forum addressed the issue of minimizing the impact of livestock manures on air and water quality, while improving the economic efficiency of farming operations, through more efficient use of manure nutrients.

> **1:** *"Develop alternative manure management systems appropriate for different soil and livestock management combinations."*

> **2:** *"Improve utilization of nutrients by expanded use of soil and manure analyses."*

Recommendation 4 from the Stakeholders Forum addressed the issue of "Closed Loop" recycling of urban or agricultural organic wastes, recognizing that a successful recycling system could turn waste products into useable resources, extend the life of current landfill sites and improve the organic matter content of soils.

> **3:** *"Conduct a pilot project in a small urban community to develop a workable 'closed loop' organic waste recycling system"* (to demonstrate that it can work; to determine the costs and financial benefits; and to identify potential problems or barriers)

2.2 Current State of the Art on Manure/Nutrient Management

The first project completed within the Green Plan Research Sub-program was the report, *The Current State of the Art on Manure/Nutrient Management* by Goss et al, 1994. (Hereafter, referred to as the CSAMM Report.) This project was undertaken to:

> 1: *"identify the various areas of active research related to the management of manure systems and summarize the current knowledge base"*.

2: *"identify areas of research needed to allow the efficient handling, storage, processing and utilization of animal manure on farms in Ontario."*

In preparing their report, Goss et al consulted with The Expert Evaluation Panel for Manure Management, a multi-disciplinary group with producer, government, university and industry representatives. This panel identified and ranked twelve priority areas for research and extension activities, related to manure management. In order of priority, their recommendations were:

1: Develop extension packages to assist farmers in making more effective use of nutrients in manure.

2: Establish a research programme involving engineers, animal scientists, agronomists, soil scientists and economists, to develop a comprehensive framework by which alternative manure management systems can be compared.

3: Establish the relationship between environmentally safe and the most profitable rates of manure application to cropland, taking account of the method and timing of applications. Develop more acceptable manure application methods in conservation tillage systems.

4: Develop the means of predicting the composition of the major types of poultry, pig and cattle manures, based on feeding regimes.

5: Improve nitrogen application recommendations for different crops, based on a soil N test, taking into consideration losses on NH_3 with different times and methods of application.

6: Develop practical, cost-effective methods for managing manure odours from farm systems. This should include seeking means by which the hazard to human or animal health from toxic gases, such as H_2S, can be relieved in different manure systems, and developing better engineered and economic manure management systems, that minimize gaseous losses from manure.

7: Investigate the transformations of manure N following addition to soil to provide more accurate estimates of denitrification, mineralization and immobilization.

8: Investigate and develop the ability to predict the transformations of manure N during storage and/or composting to characterize the impact on availability of N to crops, the potential for nitrate leaching and gaseous losses of NH_3, NO_x, CO_2 and CH_4.

9: Examine the potential for reducing the nutrient content of manures by using improved feeding programmes, including use of feed additives.

10: Assess on-farm economics of different manure management systems in direct association with research on storage, application and utilization of manure.

11: Assess off-farm costs due to environmental impacts, but not solely with respect to manure management. Information on environmental degradation associated with alternative manure management systems must be quantified to allow the costs to be determined.

12: Develop the means by which the deterioration of livestock facility structures by gases produced from manure can be minimized.

Goss et al also conducted three workshops across the province, in March 1993, with representation from a broad cross-section of the agricultural industry. Participants in these workshops were asked to identify the main information needs for farmers and society to address manure issues. The main issues identified in this way are listed below.

- application rates and timing.
- the nutrient content of manure (including manure testing) and its value to crops.
- the economic benefits and environmental costs of manure.
- the relative merits of different manure handling and storage systems.
- methods and equipment to apply manure properly and uniformly.
- alternate uses for manure.

The CSAMM Report included a literature review summarizing the level of knowledge about manure/nutrient management as of 1993. It also identifies the major gaps in the information base or in technology transfer activities, regarding the influence of manure management and environmental conditions on either the utilization of manure nutrients by crops, or on the effect of manure on the environment, or both (summarized in Table 1). Thus, the CSAMM report can be used as a benchmark against which to compare the progress made within Green Plan. The various areas identified in the report which were addressed by specific Green Plan or Supplementary Projects are identified in Table 1. The contributions of Green Plan projects toward addressing specific concerns are summarized in Section 3 of this report.

2.3 Ontario Agricultural Services Coordinating Committee

Within Ontario, responsibility for coordination of agricultural research and services is assigned to the Ontario Agricultural Services Coordinating Committee (OASCC). The eight committees that report to OASCC and their sub-committees (Appendix B) have the responsibility to identify issues for which additional research is required. Several of these committees have identified the need for research or service programs to reduce the impact of livestock production and manure use on the environment. (Their recommendations are listed in Appendix C.) Many of the recommendations made by these committees were generic in nature, calling for additional research directed toward finding affordable and environmentally sustainable methods for managing manures and associated environmental contaminants. More specific recommendations tended to mirror the concerns identified in the CSAMM report. The recommendations made between 1992 and 1997 identified the following areas as being those which should be given priority for additional research.

- affordable systems to minimize contamination of surface and groundwater by livestock wastes.
- effects of livestock housing alternatives on the environment.
- effects of manure handling methods on the environment.
- innovative methods of treating milkhouse washwater and other contaminated water.
- long-term effectiveness of earthen storage structures for liquid manures.
- movement of contaminants from manure through soils into tile drainage water or groundwater.
- reducing, detecting and dealing with hazardous gases associated with livestock operations.
- reducing odours associated with livestock operations.
- protecting steel and concrete from corrosive manure gases.
- reducing the effect of livestock operations through management of livestock feeds.
- nutrient management extension programs.
- integrated management systems for using nutrients from fertilizers, crop residues, manures and organic wastes, in the agro-ecosystem.
- investigating the ability of manure application equipment to apply manure uniformly.
- manure application practices suitable for conservation tillage systems.
- economic analysis of manure handling systems.

Table 1: Green Plan Activities Providing Information Related to Needs Identified in *The Current State of the Art on Manure/Nutrient Management.*

Area of Information Need	**Green Plan Activity Supplying Information:**
Surface Water Quality	
• control and treatment of contaminated water including milkhouse wash water and runoff from barnyards, feedlots or manure storages.	Kachanoski et al St. Jean Rural Conservation Clubs

C runoff from fields after manure application	N. A.[3]
C macropore flow to tile drains	Wall et al
Ground Water Quality	
C leaching from manure storage, processing or treatment	Kachanoski et al St. Jean
C macropore flow or leaching from fields after manure application	St. Jean Beauchamp et al Schell and Alder Goss et al (1995) Alder et al
Air Quality	
C generation of odours and toxic gases in barns, storages and processing	N. A.
C release of odours and toxic gases during application	N. A.
C generation of greenhouse gases in barns, storages or processing and after application	Kachanoski et al St. Jean
C deterioration of structures by corrosive gases released from manure	N. A.

[3] N.A. - Not Addressed by Green Plan Research Projects

Table 1 cont'd: Green Plan Activities Providing Information Related to Needs Identified in *The Current State of the Art on Manure/Nutrient Management*

Nutrient management	
C effects on manure nutrient content and dynamics of livestock species, ration and feeding regime	Beauchamp et al
C carbon & nitrogen transformations in storage, processing or treatment	Kachanoski et al St. Jean
C carbon & nitrogen transformations in soil after application of livestock manures or other organic materials	Beauchamp et al Goss et al (1995) Alder et al Schell and Alder
Other Agronomic Concerns	
C effects of application of manure or other organic materials on crops, soil biota, soil structure, soil compaction, pH, weed populations and plant pathogens	Beauchamp et al Alder et al Lazarovits and Conn Schell and Alder Goss et al (1995) St. Jean Wall et al Rural Conservation Clubs
C practices to minimize environmental effects of the use of manure or other organic materials in conservation tillage systems	Wall et al Schell and Alder Alder et al
Economics	
C on-farm costs and benefits of manure management practices	Kachanoski et al St. Jean Alder et al
C environmental costs and benefits of manure management practices	N. A.

3.0 Progress Made Within Green Plan Towards Addressing Information Needs Related to Manure/Nutrient Management

3.1 Introduction

As outlined in Section 2, OASCC and the CSAMM report identified many areas related to manure management for which there were gaps in the knowledge base. The projects considered in this report provided information on many of these topics. The following sub-sections summarize the key findings of these projects as they relate to the areas listed in Table 1. Because the results are organized by issue area, information from individual projects may be presented in several sub-sections.

3.2 Areas of identified needs not directly addressed by Green Plans projects

- Contamination of surface water by runoff from fields after manure application.
- Generation of odours and toxic gases (other than ammonia) in barns and storage.
- Release of odours and toxic gases (other than ammonia) during spreading.
- Deterioration of structures by corrosive gases released from manure.
- Environmental costs and benefits of manure management practices.

3.3 Control and treatment of contaminated water including milkhouse wash water and runoff from barnyards, feedlots or manure storages

3.3.1 Identified Needs

In 1992 to 1997, inclusive, OASCC annually recommended that research be supported to assess the impact of different manure handling and milkhouse wash water disposal systems on the environment. Although not formally recorded as such, the need for economical ways to manage runoff from solid manure storages has also been frequently expressed.

3.3.2 Summary of Green Plan Research Results

Two research projects provided information related to the control or treatment of contaminated water.

- *Nitrogen & Carbon Transformations in Conventionally-Handled Livestock Manures* (Kachanoski et al)
- *On-Farm Manure Composting Techniques: Understanding Nitrogen and Carbon Conservation* (St. Jean)

Runoff from a storage pad holding solid beef manure system from a cow-calf operation contained 2% of the manure N delivered to the pad (Kachanoski et al). Since this was mostly mineral N, it represented roughly 25% of the final available N. The concentration of NH_4-N in the runoff storage tank averaged 112 mg kg^{-1} in the summer and 256 mg kg^{-1} in the winter.

There is significant loss of moisture from manure by evaporation during composting (St. Jean). Solid beef cattle manure had a net moisture loss of 43.2% when composted outside, and 69.6% for the covered control process. Thus, the process appeared to have potential as a means to treat contaminated water (e.g. barnyard runoff and milkhouse waste water). However, moisture loss from composting processes manipulated for nitrogen conservation was not sufficient to make them suitable for treatment of farm-generated liquids. There was a trend, that was not statistically significant, towards higher nitrogen and organic matter losses as a result of the addition of barnyard runoff to composting manure. (See Section 3.7.3.2)

3.3.3 Observations from Green Plan Rural Conservation Club Demonstration Projects

Three conservation clubs provided information related to the control or treatment of contaminated water.

- *Constructed Wetland Project* (Belle River Conservation Club)
- *Dignard Artificial Wetland* (South Nation River Conservation Authority)
- *Evaluation of Vegetative Filter Strips to Treat Beef Feedlot and Dairy Yard Runoff in Ontario* (Ontario Cattlemen's Association)

3.3.3.1 The Belle River Conservation Club, in conjunction with the Essex Region Conservation Authority, conducted a four year demonstration project to test the feasibility of using a constructed wetland to treat barnyard runoff and milkhouse wash water from a 200 head dairy operation. The treatment system consisted of a storage pond, a serpentine wetland area, in which a variety of native aquatic plants was transplanted, and a polishing pond. Barnyard runoff and milkhouse wastes were directed into a collection tank and then pumped into the storage pond. The system was sized based on average rainfall and evapotranspiration data for the area with additional provision for a 1:100 year storm event. Liquids were held in the storage pond from November through April, and released into the wetland when average water temperatures exceeded 6° C. On average, the operating period was 180 days. The wetland was designed for a retention time of at least 14 days. Excess water from the polishing pond was irrigated on an adjacent pasture when necessary. No water was released into surface watercourses.

On average over the two years, contaminant concentrations in the polishing pond were reduced by 88% to 99%, relative to samples taken at the transfer pump, depending on the parameter (Table 2). Over ninety percent of the removal of E. coli and Biochemical Oxygen Demand (BOD_5) occurred in the storage pond. Sixty percent of the phosphate removal occurred in the wetland complex. Removal of suspended solids was equally divided between the storage pond and wetland area.

Piezometers were installed around the wetland site to monitor ground water quality. Over the two operating years of the project, there was no conclusive evidence of ground water quality impairment.

Additional information about this project can be obtained from The Essex Region Conservation Authority, 360 Fairview Avenue West, Essex, Ontario N8M 1Y6

Table 2 : Artificial Wetland System Treatment Efficiencies, Belle River Conservation Club

Parameter	Concentration at Transfer Pump (mg/L)	Concentration at Polishing Pond (mg/L)	Removal (%)
BOD_5	670.2	17.8	97.3
NH_3-N	45.2	1.7	96.2
Total Phosphate	24.6	25	89.7
Suspended Solids	573.6	75	86.9
E. coli	532254	2393	99.6

3.3.3.2 The South Nation River Conservation Authority conducted a three year demonstration project to evaluate an artificial wetland for the treatment of milkhouse wash water and runoff from a solid manure storage and an exercise yard. The system consisted of a previously existing lagoon in which manure runoff was collected and held temporarily, a stabilization pond, an initial wetland cell, an aerobic pond, a second wetland cell and a vegetated filter strip for overland flow. The wetland system was designed to operate between May 1 and September 30. During the rest of the year, the runoff was stored in the lagoon which was sized to hold the wash water, manure runoff and precipitation from a "wet winter" (amount expected to be exceeded once in ten years).

The stabilization pond was designed to accommodate a BOD_5 loading of 100 kg/ha/day. The wetland was designed for a BOD_5 loading of 75 kg/ha/day and a total nitrogen loading of 3 kg/ha/day. Pollutant concentrations were monitored at each stage of the system. Relative to the concentrations in the lagoon, concentrations at the end of the wetland were reduced by 98.7 % for BOD_5, 97.8 % for nitrogen and 95.3 % for total phosphorus (P). Additional polishing occurred on the vegetated filter strip. Shallow ground water piezometers were installed around the site for the second year. However, because of low soil moisture conditions, there was insufficient water in the sampling tubes for regular monitoring.

Additional information about this project can be obtained from The South Nation River Conservation Authority, Box 69, Berwick, Ontario K0C 1G0

3.3.3.3 The Ontario Cattlemen's Association coordinated demonstration projects on five farms to evaluate vegetative filter strips for the treatment of runoff from beef feedlots and dairy yards. The treatment systems consisted of the following elements:

- a settling area, usually the feedlot or yard, to allow solids to settle and to serve as a holding area in the case of large storm events.
- a filter box to remove debris.
- a gravel spreader to distribute flow over the entire width of the filter strip.
- the vegetative filter strip.

The filter strips were designed such that liquid flowed in a shallow sheet (< 1.3 cm) and infiltrated into the soil. The strips were sized to accommodate a 2-year, 2-hour storm event. The slope of the various strips were between 0.3 to 4.5 percent; lengths were 70 to 180 m.; and widths were 8.0 to 24 m. No event of runoff flowing off the end of any strip was observed. Grab samples were collected for analysis at the point of farthest flow of the liquid. Relative to samples collected from the yard runoff, the system reduced contaminant concentrations by: nitrate - 45.2%, total phosphorus - 31%, total dissolved solids - 29.1%, faecal coliforms - 40.6% and BOD_5 - 51.3%

Results showed no accumulation of nutrients in the soil profile and no change in the quality of ground water samples from preconstruction levels. Surface removal rates, soil profile results, and groundwater monitoring results when taken together, establish that the vegetated filter strip system is an environmentally sound treatment system for feedlot and barnyard runoff.

Additional information about this project can be obtained from The Ontario Cattlemen's Association, 130 Malcolm Road, Guelph, Ontario N1K 1B1

3.4 Contamination of surface water through macropore flow to tile drains

3.4.1 Identified Needs

A 1992 recommendation from OASCC identified the need to "study the movement of bacteria, toxins and nutrients through soil and to examine the quantitative and physical processes involved as well as the development and evaluation of best management systems to reduce the potential for ground water contamination".

A recommendation submitted annually between 1992 and 1996 stressed the need to "investigate management systems to minimize contamination of air, surface and groundwater by nitrogen originating from fertilizers, legumes, manures and other organic sources, and by bacteria from manures and organic wastes applied to soils."

The CSAMM report cited studies documenting the frequent impairment of the quality of tile drainage water from the spreading of liquid manure. The report noted the difficulty of determining an acceptable rate of application of liquid manure due to the numerous factors involved (e.g. manure type and composition, time and method of application, tillage system, soil conditions and weather). The importance of soil macropores for the rapid transport of bacteria to tile drains was highlighted.

3.4.2 Summary of Green Plan Research Results

In the study, *The Effects of Livestock Manure Application Methods on Water Quality, Focussing on Nitrogen and Bacteria Transport in Soil*, Wall et al conducted field scale studies to evaluate liquid manure application technologies in no-till corn cropping systems, in terms of sustainable crop productivity and subsurface water quality (nitrogen, bacteria), and to identify pathways and processes of nutrient and bacteria transport to tile drains and ground water with special consideration to preferential flow.

Side-dressed applications of liquid manure, at the four-leaf stage of corn, resulted in water quality impairments to tile drainage water if tile drains were flowing at the time of application. Water quality guidelines for bacteria, ammonia and phosphorus were exceeded for several hours. Manure was confirmed as the source of this contamination and macropore pathways contributed to tile flows even under unsaturated soil moisture conditions. Simulated rainfall on the day following manure application also resulted in impairment of tile drain water quality. Tile water contamination occurred both immediately following the manure application and after the simulated rainfall event, regardless of the method of liquid manure application. Compared to surface application, contamination was generally less when the manure had been injected, especially if the system was modified to till the soil before injection.

Based on the results of this study, Wall et al offered the following recommendations for the application of liquid manure in no-till cropping systems:

i) Liquid manure nutrient testing is required immediately prior to manure application to establish accurate manure application rates.

ii) Side dress injection or surface application of liquid manure at soil test recommended rates, at the fourth leaf stage, will produce corn yields equivalent to conventional inorganic N fertilization.

iii) Conventional and modified injection equipment are recommended for use on medium to coarse textured soils.

iv) Side dressed injection applications should be considered to reduce impacts on tile water quality relative to surface applications especially on medium and light textured soils.

v) Apply liquid manure to tile drained land when the tile drains are not flowing to reduce impacts on tile water quality.

3.4.3 Additional Information from Specific Studies

3.4.3.1 <u>The Effects of Livestock Manure Application Methods on Water Quality, Focussing on Nitrogen and Bacteria Transport in Soil</u>

Trials were conducted at locations representing the following soil textures: sandy loam, silt loam and silty clay loam. Liquid hog manure was side dressed with a 6,800 L tanker around the fourth leaf stage of corn using surface application and two injection techniques (conventional injection and injection modified by slight tillage in front of the injectors).

Tile flow rate volumes increased within 30 minutes of liquid manure application and returned to base flow conditions within three hours. Flow increases represented <3% of the applied manure on average. The greatest increases in flow rates occurred when the tiles were flowing prior to the manure application. Following simulated rainfall events, one day after manure application, tile flows increased significantly and did not return to base flow rates for several days. Tile drain flow increases represented about 10% of simulated rainfall volumes at the sandy loam and silt loam sites and under 5% at clay loam site.

At all sites, application of liquid manure when the tile drains were flowing usually resulted in water quality impairments to tile drainage water for 2 to 3 hrs following manure application. There was visual evidence (change in turbidity) of tile water contamination within 7 to 30 minutes from the time of application. Although the total volume of manure reaching the tile was small (<2%), water quality guidelines for bacteria, ammonia and phosphorus were exceeded for several hours. The presence of the tracer bacteria and chemicals in the tile water samples after manure application provided verification of manure as the source.

The simulated rainfall events resulted in increased levels of ammonia, tracer bacteria and phosphorus in tile drainage water within 30 minutes. Levels peaked within 60 minutes, but at concentrations lower than those observed on the day of manure application. Loadings, however, were significantly greater due to the larger volumes of water coming through the tile drains. Since the bacteria and chemical tracers were not detected in the tile water a few days after the rainfall event, it appears that the impact of the manure application on the tile water quality is relatively short-lived.

Chemical tracers added to the manure mirrored the bacteria movement to the tile drains both in time and concentration. The percentage of applied non-reactive tracers (bromide, chloride) reaching the tile drains (<2%) was similar to the percentage of the applied manure volume measured in the tile drains. Although <1% of the applied reactive tracer (strontium) was recovered in the tile water, its presence provided evidence that the macropore pathways contribute to tile flows even under the unsaturated soil moisture conditions of the experiment.

Background nitrate (NO_3) levels in the tile water ranged from 7.0 mg/L to 25 mg/L. Liquid manure application did not immediately affect the NO_3 concentration of the tile water since the mineral N in the manure was predominantly present as NH_4-N. Any increase in NO_3 levels of tile water associated with manure application did not occur until 1 to 2 weeks following manure application.

While there was no significant difference between application methods at sandy loam and silt loam sites, the manure injection techniques tended to have less water quality impairment than the surface applied treatment. At the clay loam site, surface applied manure resulted in significantly greater levels of nutrient and bacteria contamination than the injection methods. However, tile water contamination occurred both immediately following the manure application and after the simulated rainfall event, regardless of the method of liquid manure application. In this no-till system, it may only be possible to stop tile water contamination by applying liquid manure during growing season periods when soil moisture content is low and tile drains are not flowing.

The tile drainage model (DRAINMOD 4.0) provided statistically good predictions of tile flow for both years compared to measured flow values. Further study of the water quality components of the model that are currently under development appear warranted.

3.5 Contamination of ground water by nutrients, pathogens or solids from manure through leaching from manure storage, processing or treatment

3.5.1 Identified Needs

The CSAMM report noted concerns related to the leakage or leaching of manure from storage into the soil and hence, into the groundwater. Leakage from concrete storages was thought to be minimal. The greatest concern related to the potential for leaching from improperly sealed earthen storages. Although, it was not identified in CSAMM, similar concerns presumably exist for uncontrolled runoff or leachate from solid manure storages.

3.5.2 Summary of Green Plan Research Results

Two research projects provided information related to the potential for leaching during manure storage, processing or treatment.

- *Nitrogen & Carbon Transformations in Conventionally-Handled Livestock Manures* (Kachanoski et al)
- *On-Farm Manure Composting Techniques: Understanding Nitrogen and Carbon Conservation* (St. Jean)

Kachanoski et al analyzed soil cores taken at various depths and distances from a poultry manure pile on a field site that had been used for several years for manure storage. Soil mineral N concentrations in the top 0.15 m were 88 mg kg^{-1} within 2.5 m of the pile, but averaged around 20 mg kg^{-1} at 5.0 m and farther from the pile. Most of this increase in soil mineral N near the pile was from NO_3, which was also evident at greater depths. While the field storage site did appear to be a point source of NO_3, it was not certain that this NO_3 was contaminating ground water. It may have been denitrified in a saturated zone, perhaps because of soluble C also leaching from the manure.

St. Jean found that the potential for leaching of nutrients from solid beef cattle manure during the composting process was low whether it was done outside or inside. The drying action of the sun caused a hard crust to form on the surface of manure being composted outside. This crust effectively shed water and reduced the potential for N leaching during the process despite the exposure to rainfall.

3.6 Contamination of groundwater through macropore flow or leaching from fields after manure application

3.6.1 Identified Needs

A 1992 recommendation from OASCC identified the need to "study the movement of bacteria, toxins and nutrients through soil and to examine the quantitative and physical processes involved, as well as the development and evaluation of best management systems to reduce the potential for ground water contamination".

A recommendation submitted annually between 1992 and 1996 stressed the need to "investigate management systems to minimize contamination of air, surface and groundwater by nitrogen originating from fertilizers, legumes, manures and other organic sources, and by bacteria from manures and organic wastes applied to soils."

The CSAMM report acknowledged the difficulty in determining the potential for NO_3 to contaminate ground water because of the conversion of NO_3 to nitrogenous gases through denitrification. The report noted that the majority of research had failed to quantify the maximum nutrient loading that could be applied without a negative impact on the environment and that little information was available about the effect of manure application systems on NO_3 leaching. The CSAMM Report also noted that many factors influence the leaching of contaminants into groundwater, including manure type and composition, time and method of manure application, soil physical conditions, weather and soil nutrient levels.

3.6.2 Summary of Green Plan Research Results

Five research projects provided information related to the potential for leaching of NO_3-N after application of livestock manures or composted materials.

- *An Investigation into the Management of Manure-Nitrogen to Safeguard the Quality of Groundwater*. (Goss et al 1995)

- *Transformations in Soil: Crop Response to Nitrogen in Manures with Widely Different Characteristics***.** (Beauchamp et al)
- *Investigating Methods of Integrating Liquid Manures into a Conservation Tillage Cropping System* (Schell and Alder)
- *On-Farm Manure Composting Techniques: Understanding Nitrogen and Carbon Conservation* (St. Jean)
- *Application of Composted Organic Waste to Agricultural Land* (Alder et al)

In the short term the implications for groundwater quality of using liquid manure are similar to those of using mineral N sources at equivalent rates of inorganic N. (Beauchamp et al; Schell and Alder)

Fall application of liquid manures with a high NH_4-N content (e.g. liquid swine or liquid dairy cattle manures) may result in relatively large N losses and low N use efficiency. (Beauchamp et al; Goss et al, 1995) The risk from leaching of NO_3 from fall-applied liquid manure was high in the fall immediately after application, in the following spring, and in the next fall period. Fall treatments, designed to immobilize N, (e.g. seeding of cover crops or adding straw) were not adequate to reduce the risk of NO_3 leaching significantly (Goss et al, 1995). Fall-application of composted manures or of solid manures with relatively a low NH_4-N content and substantial bedding content did not appear to pose a significant hazard to water quality. (Beauchamp et al; Goss et al, 1995; St. Jean)

When manures with a high NH_4-N content (e.g. liquid swine and cattle manures) are applied in the spring, the release of available N can be relatively rapid and well in advance of the period of peak crop requirement for N (Beauchamp et al). Thus, there is the potential for N loss.

Composting generally reduced the potential for N, P and K leaching from the finished compost compared to the raw manure (St. Jean). No one process or modification was more advantageous than another in producing compost with a lower potential for leachate losses of N, P or K. The authors note that their estimates of potential leaching from composts should not be interpreted as being reflective of the behaviour of these nutrients in the soil. Of these three nutrients, only N is regarded as being highly mobile.

Applications of composted organic wastes did not contribute to increased NO_3 levels in the soil solution. (Alder et al)

3.6.3 Additional Information from Specific Studies

3.6.3.1 An Investigation into the Management of Manure-Nitrogen to Safeguard the Quality of Groundwater

This study investigated the fate of N from liquid dairy cattle manure and from composted cattle manure in two field experiments conducted at the Elora Research Station of the Ontario Ministry of Agriculture, Food and Rural Affairs and at the Winchester Research Station of Kemptville College of Agricultural Technology, respectively.

At Winchester, approximately 300 kg total N ha^{-1}, as either liquid dairy cattle manure and as composted cattle manure, was applied in late August on alfalfa sod which had been plowed down. The soil at the time of manure application contained about 80 kg ha^{-1} mineral N. Only 5% of the total N in the composted cattle manure was in the mineral form, as compared to 72% in the liquid manure. By the end of November, there was 55 kg NO_3-N ha^{-1} in un-manured plots, 78 kg NO_3-N ha^{-1} in plots that received composted manure, and 134 kg NO_3-N ha^{-1} in plots treated with liquid manure. However, from analysis of the ^{15}N present in the soil, it appeared that only about 60 kg N ha^{-1} had been derived from the mineral fraction of the liquid cattle manure and that at least 50% of that fraction had already transferred into the organic pool of the soil. (Also see Section 3.10)

The risk from leaching was high in the fall immediately after application, in the following spring, and in the next fall period, especially if cereals were grown in the spring. Total N losses from the liquid manure over two cropping years were estimated at 35% for the spring application and 40% for the fall application. (Some N might have been lost through denitrification rather than by leaching.) Although prevailing weather conditions were not conducive to leaching, about 25% of the N was still lost over winter. (The loss was slightly less where cover crops were grown on land where straw had been incorporated.)

None of the fall treatments designed to immobilize N were adequate to reduce the risk of NO_3 leaching significantly. Cover crops sown after manure application in the fall immobilized N in proportion to the dry matter produced before the first killing frost. Application and incorporation of straw before seeding of the cover crops reduced the amount of N in the cover crops because the growth of these crops was impaired. The cover crops removed less than 10% of mineral-N applied in liquid cattle manure, and only about one tenth of this was transferred to the following corn crop. The main period of N release from the cover crops appeared to occur late in the summer when crop uptake would be minimal.

Evidence from spring barley suggested that the mineralization of organic-N from the fall-applied manure occurred in the following July and thereafter. Much of the NO_3-N that was released would be at risk of leaching after harvest of spring-sown cereals.

Because of its low content of inorganic N, fall application of composted cattle manure did not pose a significant environmental hazard at Winchester. Only 0.46 kg N ha^{-1} from the mineral N in the composted cattle manure was removed in the corn grain. However, in the fall of the following year an average of 85 kg ha^{-1} of mineral N remained in the soil after the harvest of the corn. Nitrate leaching from solid beef manure at Elora was also less than in other treatments during the 1992 growing season.

3.6.3.2 Transformations in Soil: Crop Response to Nitrogen in Manures with Widely Different Characteristics

Beauchamp et al investigated the influence of the characteristics of five different types of manure and of various manure management practices on the release or availability of manure N. The manures used in this study included liquid dairy cattle, solid beef cattle, solid broiler chicken with either wood shavings bedding or straw bedding, and liquid swine manures.

The release of available N from some manures applied in the spring was relatively rapid in some years and well in advance of the period of peak N requirement of the corn crop (e.g. liquid swine and cattle manures). Where substantial available N was released, it was generally related to the amount of NH_4-N applied with the manure.

The efficacy of fall-applied manures and the risk of N loss from them may depend on the characteristics of the specific manure. Crop response to solid manures applied in the fall was similar to the response to manures of the same type applied in the spring. Thus, fall-application of solid manures with relatively low NH_4-N content and substantial bedding content may not result in much N loss.

Fall application of liquid manures with high NH_4-N content (e.g. liquid swine manures) may result in relatively large N losses and low N use efficiency. Response to fall-applied liquid swine manure was lower than to that applied in the spring, suggesting that a significant amount of N was lost to leaching or denitrification during the fall, winter or early spring.

3.6.3.3 Investigating Methods of Integrating Liquid Manures into a Conservation Tillage Cropping System

Schell and Alder concluded that the implications for groundwater quality of using liquid manure in a conservation cropping system are similar to using mineral N sources. Soil NO_3 levels were measured at different times throughout the growing season as an indicator of N availability. There was no clear trend, although there was a suggestion that manure N increased NO_3 readings more quickly than equivalent amounts of N applied in inorganic forms. Residual soil NO_3 levels after harvest varied widely from site to site, and some were high and potentially detrimental to water quality. However, the levels were similar whether the N was from manure or mineral sources. Shallow groundwater NO_3 levels were monitored at two sites. Many of the treatments had NO_3 levels that at least occasionally exceeded the Ontario drinking water quality standards. However, there was no indication that manure N should be managed differently from N from inorganic sources. There were no apparent implications for groundwater quality related to the incorporation of manure.

3.6.3.4 On-Farm Manure Composting Techniques: Understanding Nitrogen and Carbon Conservation

Composting reduced the potential for nitrogen, phosphorus or potassium (K) leaching from the finished compost as compared to the raw manure, in fourteen of the sixteen processes studied (St. Jean). The reduction in leachate losses varied greatly among composts. The N leachate losses observed did not correlate consistently with mineralized N concentrations, and compost leachates were found to contain organic N as well as inorganic mineralized forms of N. This may be a result of the leachate collection procedures followed for comparison purposes and may not be indicative of soil leachate losses.

No one technology or process manipulation factor showed an advantage over the others in producing compost with a lower potential for leachate losses of N, P or K. Specifically:

- Comparison of traditional turned-pile, passive-aeration, and forced-aeration composting processes for solid beef cattle manure did not indicate an advantage for one process over the other in terms of leaching potential.
- There was no evidence that curing solid beef cattle manure compost for an additional period of time of up to 90 days would reduce the potential for N leaching.
- Three different composting processes used by ecological farm operators showed no advantage over conventional farm composting techniques in terms of reduced leachate losses. (*It should be noted, however, that different types of manures were used in the investigations of ecological composting techniques than were used in the conventional composting techniques. The study did not include any manure type by composting technique comparisons.)*

3.6.3.5 Application of Composted Organic Waste on Agricultural Land

Applications of composted urban organic wastes did not contribute to increased NO_3 levels in the soil solution (Alder et al). In the first year of the study (1994), there was a trend towards lower NO_3 levels under compost applications but this was not evident in subsequent years at both sites. In 1995 there was a trend towards lower dissolved organic carbon (DOC) levels under compost applications. However , all solution samples exceeded the Ontario drinking water quality objectives of 5.0 mg L^{-1} of DOC in water, including the controls.

In the compost application rate study, there was no change in the NO_3-N soil test levels as a result of fall application of compost.

3.7 Generation of greenhouse gases in barns, storage or processing and after application

3.7.1 Identified Needs

The CSAMM report recommended that research be conducted to:

> "Investigate and develop the ability to predict the transformations of manure N during storage and/or composting to characterize the impact on availability of N to crops, the potential for nitrate leaching and gaseous losses of NH_3, NO_x, CO_2 and CH_4." (Rec. # 8)

3.7.2 Summary of Green Plan Research Results

Two studies gathered information related to the release of one or more greenhouse gases from manure during storage or composting:

- *Nitrogen & Carbon Transformations in Conventionally-Handled Livestock Manures* (Kachanoski et al)
- *On-Farm Manure Composting Techniques: Understanding Nitrogen and Carbon Conservation* (St. Jean)

Kachanoski et al investigated the release of greenhouse gases and ammonia in six conventional manure storage and handling systems (solid beef, solid poultry, liquid swine - high water use, liquid swine - low water use, solid dairy, and liquid dairy - alley-flush system). Usually the greenhouse gas losses (except CO_2) were negligible with respect to mass balance of C and N. However, the magnitudes of the losses were important from an environmental perspective.

In evaluating sixteen composting processes, St. Jean monitored the moisture, temperature and weight of manure as it composted and the concentrations of NH_3, O_2, CO_2 and CH_4 in the off-gases and pore spaces. No composting technique showed any consistent advantage over the others for reducing the production of CH_4. The author concluded that manures from Ontario livestock operations do not have characteristics that will minimize the production of CH_4 during composting. Solid cattle manures had moisture levels significantly above the optimum of 60%. Solid poultry manures were significantly below the optimum. All manures had C/N ratios significantly below the optimum. Because anaerobic microsites formed within the composting mass, CH_4 was released during composting even though pore-space oxygen concentrations were above the 5% level considered adequate. Mixing would appear to be warranted for bacteria, enzyme and substrate distribution (as opposed to overall aeration) and should be carried out using a compost windrow turner, rather than a front-end loader, to minimize heat losses.

3.7.3 Additional Information from Specific Studies

3.7.3.1 Nitrogen & Carbon Transformations in Conventionally-Handled Livestock Manures

Kachanoski et al collected air samples in the barns on six farms during 24 h periods at various times of the year to determine concentrations of CH_4, CO_2, and N_2O. (The results of spot sampling of the barn air to determine NH_3 concentrations are summarized in Section 3.9.3.) Measurements of greenhouse gas flux rates were made at various stages of the handling systems to rank them for their potential to generate these gases. The results for each of the systems are summarized below.

Solid Beef

The only significant emission of CH_4 occurred from the manure pile in September and March. Rates of CO_2 emission from the stored manure in September were similar to those measured in March and many times greater than that measured from the field soil in October. A similar pattern was observed for N_2O emissions, with no obvious difference between the fall and late winter emission rates from the stored manure.

Solid Poultry (broiler and roaster chickens on wood shavings)

The CO_2 concentration in the barn air was 80% greater in the winter than in summer, but the associated ventilation rate was 2.4 times greater in the summer. The net CO_2-C output in the vented air however was still greater in the summer than in the winter by a factor of 1.25. Concentrations of N_2O in the barn air in the summer and winter were less than normal background air, suggesting a net absorption rather than emission of N_2O in the litter.

Despite higher ventilation rates in the summer, CH_4 concentrations in the barn air were ten times greater in the summer than the winter. Output of C as CH_4 represented about 6% of the total C output of CO_2 + CH_4 during the summer, and 0.3% in the winter. It appeared that CH_4 producing bacteria in the litter were inhibited during the winter crop, possibly by high NH_3 concentrations in the barn air.

Gas flux measurements were conducted on the litter surface in the barn during the winter crop of birds, and on the outdoor pile in March. There was no measurable CH_4 or N_2O emission from the litter surface between the fourth and eighth weeks of growth of the winter crop of birds. The emission rate of CO_2 tripled at eight weeks compared to the rates at four and six weeks of growth. Measurable rates of emission of CH_4, CO_2, and N_2O but not NH_3 occurred from the manure pile in March. The rate of CO_2 emission was comparable to that observed from the litter in the barn at eight weeks.

Liquid Swine - High Water Use

During January and February, concentrations in the exhaust air were 1300 to 2000 ppm for CO_2, 0 to 170 ppm for CH_4, and 0.3 to 0.6 for N_2O.

Gas flux from manure surfaces was determined for the storage lagoons in the summer, late fall, and spring, from the field after manure application in the summer, and from floors and stored manure in the swine building. The rate of CH_4 emission from the lagoons in late summer was at least four times greater than from the other sources measured. No significant CH_4 emission was detected from the soil at 10 to 30 minutes after manure application in August.

Flux of CO_2 was also greatest from the lagoons in late summer compared to all other sources . The rate of CO_2-C emission from the lagoons in August was the same as their rate of CH_4-C emission. The emission rate of CO_2 from the soil was increased by a factor of eight within 10 to 30 minutes after manure application compared to either non-manured soil or to the rate two hours after application.

Flux of N_2O did not show consistent patterns among sources of the same type. The lagoons, slatted floors, and soil showed both emission and absorption of N_2O, although emission rates tended to be greater than absorption rates.

Liquid Swine - Low Water Use

Concentrations of CH_4 in the nursery rooms, gestation room, and farrowing rooms averaged 41 ppm in the summer and 45 ppm in the winter, but the concentrations were much more variable in the summer. The CH_4 concentrations in the feeder barn averaged 43 ppm during the winter. Concentrations of CO_2 in the various rooms averaged 920 ppm during the summer and 2100 ppm during the winter. Concentrations of CO_2 in the feeder barn averaged 1690 ppm in the winter. Concentrations of N_2O did not seem to increase significantly above normal background levels.

The greatest rates of CH_4 emission were 4 to 10 mg CH_4-C m^{-2} min^{-1} measured from the pit below the gestation / farrowing barn and the outdoor cement tank. Surprisingly CH_4 flux from the tank in March was almost as great as in August. The greatest rates of CO_2 emission were 35 to 60 mg CO_2-C m^{-2} min^{-1} from the gestation / farrowing barn pit and the outdoor tank. The greatest rates of N_2O emission were 5 to 15 µg N_2O-N m^{-2} min^{-1} from the earthen lagoon in November, February, and April, and the gestation / farrowing barn pit in October.

Solid Dairy

Concentrations of N_2O in the barn air were at natural background levels (0.33 ppm) during the winter and summer. Concentrations of CO_2 were about two times greater than background (320 ppm) on the two summer sampling dates, and four times greater than background on the winter sampling dates. Concentrations of CH_4 averaged about 60 times greater than normal background concentrations (1.4 ppm) at the winter sampling, and varied from 14 to 80 times greater than background at the summer sampling dates. It is expected that most of the CH_4 originated from the cows rather than from the manure in the barn.

The largest flux of CH_4 occurred from manure in the centre of the covered storage in August. This manure was predominantly cow barn gutter manure, most of which was less than about six weeks old. Much lower rates of CH_4 flux were detected from older manure in the storage in August, and from the stored manure in April. A very small rate of CH_4 flux occurred from newly dumped gutter manure and from the manure pack bedding in the heifer barn in August.

Emissions of CO_2 occurred from all the manure surfaces measured except for the scraped alley in the heifer barn. The greatest emission rates occurred from manure in the covered storage in July and August, regardless of the manure age. Emission rates during the winter from the manure piles and from fresh cow barn gutter manure were about one half the rates measured during the summer. The greatest rates of N_2O emission occurred in August from older manure in covered storage.

Liquid Dairy - Alley-Flush System

Concentrations of CO_2 in the barn air varied from near normal air values to about four times normal during the winter, but stayed at normal background levels during the summer. Concentrations of N_2O remained at normal background air values throughout the winter and summer. Concentrations of CH_4 were about 30 times above normal air values in the spring, and about 10 times greater than normal air levels at the summer sampling.

Gas flux measurements were done at the storage lagoons in the early spring and summer, and at the alley floor in the winter, spring, and summer. In this system, manure is flushed from the alleys directly into a holding tank and pumped to an outside lagoon. This lagoon is passively connected to 3 more lagoons, and the liquid manure level equalizes in each lagoon. The greatest emission rate of CH_4 occurred in August from the crust surface of the third lagoon in the series of four. The rate of CO_2 emission from lagoon #3 in August was ten or more times greater than the rate from the other sources measured. The rate of N_2O emission was more than ten times greater from lagoon #3 in August compared to the other sources measured.

3.7.3.2 On-Farm Manure Composting Techniques: Understanding Nitrogen and Carbon Conservation

In evaluating sixteen composting processes, St. Jean monitored concentrations of NH_3, O_2, CO_2 and CH_4 in the off-gases and pore spaces of the manure as it composted. No composting technique showed any consistent advantage over the others for reducing the production of CH_4. The author concluded that manures from Ontario livestock operations do not have characteristics that will minimize the production of CH_4 during composting. The solid dairy and beef manures sampled during this study had moisture levels in the range of 70% to 80%, significantly above the optimum of 60%. Solid poultry manures averaged 33%. High moisture levels cause manure settling and compaction in windrows, which is believed to reduce the effectiveness of static-pile-forced-aeration and passive-aeration technologies. C/N ratios ranged from 10 for poultry manures to 16 to 17 for dairy and beef, much below the optimum of 30/1.

There was sufficient natural convection through windrows 3 m wide and 1.2 m high to maintain aerobic conditions without enhancements such as forced-aeration, static aeration tubes or mixing. Forced-aeration processes without mixing did not reduce CH_4 concentrations in pore-spaces or off-gases. Because of the non-homogenous nature of manure, anaerobic microsites developed within the composting mass regardless of the technology used. The authors concluded that mixing would help reduce the level of anaerobic microsites. Mixing was observed to stimulate bacterial activity (as indicated by a temperature increase after mixing), even when pore-space oxygen levels were not limiting, probably because of the redistribution of bacteria, enzymes, and substrate. Significantly more heat was lost during mixing when this was done with a tractor loader than with a compost windrow turner. This initial heat loss reduced the rate of natural convection and created a temporary oxygen deficit, increasing the potential for CH_4 production, until the temperature recovered.

3.8 Effects on manure nutrient content and dynamics of livestock species, ration and feeding regime

3.8.1 Identified Needs

A recommendation made repeated through OASCC between 1992 and 1997 identified the need for research "to look for technology that will reduce any negative impact of swine production through the reduction or balancing of the nutrient content and reducing odour associated with swine manure and improved feed utilization".

Other recommendations have identified the need for research into methods of decreasing the amount of nitrogen and phosphorous in manure, especially in relation to poultry manures.

The CSAMM report recommended that research be conducted to:

> "Develop the means of predicting the composition of the major types of poultry, pig and cattle manures, based on feeding regimes." (Rec. # 4) and to
>
> "Examine the potential for reducing the nutrient content of manures by using improved feeding programmes, including use of feed additives." (Rec. # 9)

The report highlighted the need to predict the concentrations of the various nutrients in manures, based on feeding regimes and the composition of feeds, noting that there was opportunity to increase the efficiency of N recovery from feeds thereby reducing the amount in manure. Further investigation was required into the differences in nutrient content of manures, with regards both to composition and availability. There was a need for models to predict available N, which must take account of transformations that occur during both short and long term storage.

3.8.2 Summary of Green Plan Research Results

One phase of the project *Transformations in Soil: Crop Response to Nitrogen in Manures with Widely Different Characteristics* (Beauchamp et al) considered the effects of adjustments in the level and degradability of protein in the diets of dairy cattle on the form and amount of N excreted. The authors concluded that such dietary changes are more likely to affect the form of the nitrogen excreted (i.e. urine vs faeces) than the total amount. Feeding a diet with high protein content and high degradability had little effect on the N content of the faeces of dairy cattle, but increased excretion of nitrogen in the urine. Differences in diet had little influence on extractable inorganic nitrogen from either urine or faeces treated soil. In a soil incubation study, urine nitrogen was transformed to available nitrogen (NH_4 and NO_3) much more rapidly than was faecal N. Relatively low levels of inorganic nitrogen present in the faeces-treated soil tended to decrease during the incubation period probably due to immobilization. Thus it appears that the major source of available nitrogen in cattle manure is derived from the urine and that the faeces may even restrict nitrogen availability. Dietary changes that increase the proportion of N excreted in the urine could influence N utilization by crops, gaseous losses or leaching.

3.9 Carbon and nitrogen transformations in storage, processing or treatment

3.9.1 Identified Needs

An OASCC recommendation in 1997 called for "development of alternative methods of treating livestock and poultry waste that reduce odour, break down settleable solids and stabilize nutrients, especially nitrogen".

The CSAMM report recommended that research was needed to:

> "Investigate and develop the ability to predict the transformations of manure N during storage and/or composting to characterize the impact on availability of N to crops, the potential for nitrate leaching and gaseous losses of NH_3, NO_x, CO_2 and CH_4." (Rec. # 8)

The authors noted that a full assessment of different systems for the handling and storage of manure was needed to determine the extent of ammonia losses from each and to find ways in which these losses may be reduced. The authors noted that little was known about the changes in organic N or mineral N during storage of either liquid or solid manures or about their effect on the availability of manure N. The effects and extent of microbial activity on N dynamics also needed to be researched. Information was needed regarding the effects of storage time and depth on the variability in concentration of N and other nutrients in liquid manure storages.

Similarly, it was noted that little was known about the quantities of C excreted in relation to feed intake of C and that there were gaps in the knowledge about the degradability of C in excreted manure. Further research was needed about C transformations in either short-term or long-term storage and about the processes, magnitude and form (i.e. CO_2 or CH_4) of C losses with different manure storage systems.

The CSAMM report also concluded that the factors involved in the loss of C and N during composting and the extent of these losses need to be investigated.

3.9.2 Summary of Green Plan Research Results

Two studies investigated nitrogen and carbon transformations that occurred in conventional manure storage and handling systems or during composting:

- *Nitrogen & Carbon Transformations in Conventionally-Handled Livestock Manures*, (Kachanoski et al)
- *On-Farm Manure Composting Techniques: Understanding Nitrogen and Carbon Conservation* (St. Jean)

Kachanoski et al tracked the mass balance of C and N from six conventional manure handling systems for a defined set of inputs and outputs. The systems included solid top-loading beef, solid poultry manure, liquid swine (high water use), liquid swine (low water use), solid dairy, and liquid dairy - alley-flush system. The fate of nitrogen inputs varied depending on the manure and the system (Table 3). The amount of N excreted as fresh faeces was consistently 70 - 80% of feed N. As a percentage of N inputs (feed + bedding), final plant available manure NH_4-N amounts ranged between 8% (solid beef) and 40% (liquid swine or liquid dairy). Organic N in the manure varied from 1% (liquid swine) to 45% (solid dairy) of input N. The major pathway of N loss was as NH_3-N volatilization from fresh manure. Because this loss occurred very quickly before the manure was moved into storage, there appear to be few management options for reducing N loss.

Table 3: Fate of Nitrogen from Feed and Bedding for Six Manure Handling and Storage Systems (from Kachanoski et al)

Manure System	% Feed N in Faeces	% Manure N Lost before Storage	% Manure N Lost in Storage	NH_4-N as % of Final Manure N	Final Manure NH_4-N as % of Input N
Solid Beef with Straw	70	65	4	18	8
Solid Poultry with Shavings	75	50	5 - 7	20 - 30	7.5 - 10
Liquid Swine (High water use)	74	23	Trace (but 33% loss during agitation and spreading)	90	38
Liquid Swine (Low water use)	70 - 90	25	3	65	40
Solid Dairy	80	22	4	30	19
Liquid Dairy (Alley Flush)	81	N.A.	21 - 23	90-100 (winter) 50 - 60 (summer)	40

In comparison, losses in storage were relatively low for most systems. However, aerobic conditions in the storage lagoons for the liquid swine manure system with high water usage resulted in high concentrations of NH_4-N in the liquid manure, leading to significant loss of NH_3-N during agitation and spreading of the manure.

The fate of carbon inputs in conventional handling and storage systems varied depending on the manure and the system. Losses of C in storage ranged as high as 57%. The amount of C remaining in the final manure, as a percentage of input C, ranged between 5% (liquid swine) to 39% (liquid dairy). (Information related to emissions of CO_2 and CH_4 is summarized in Section 3.7)

In evaluating sixteen composting processes, St. Jean monitored compost moisture, temperature and weight and the concentrations of NH_3, O_2, CO_2 and CH_4 in the off-gases and pore spaces. (Information related to emissions of CH_4 is summarized in Section 3.7). No composting technique showed any consistent advantage over the others for reducing nitrogen losses. The author concluded that manures from Ontario livestock operations do not have characteristics that will minimize losses of nitrogen during composting. Solid cattle manures sampled had moisture levels significantly above the optimum of 60%. Solid poultry manures were significantly below the optimum. All manures had C/N ratios significantly below the optimum of 30/1. Nitrogen losses for the sixteen composting processes studied ranged between 8.4% and 52.7%, with the average nitrogen loss being 29.7%. None of the processes or modifications investigated showed any advantage over conventional farm composting techniques in terms of nitrogen conservation. The use of wheat straw to optimize the C/N ratio was found to be an uneconomical strategy for reducing nitrogen losses.

3.9.3 Additional Information from Specific Studies

3.9.3.1 Nitrogen & Carbon Transformations in Conventionally-Handled Livestock Manures

This study generated a reference database of the chemical composition of manure from as many components of the different systems as possible. The results for each of the systems are summarized below.

The characterization included aerobic incubation of sand-soil-manure mixtures in the laboratory to measure mineralizable C and N. The report includes full nutrient analysis (N, P, K, C) along with selected analysis of C and N compounds (lignin, acid digestible fibre, volatile fatty acids, etc). Samples of barn air were collected during 24 h periods at various times of the year to determine concentrations of CH_4, CO_2, and N_2O. Spot sampling of the barn air was also done for determination of NH_3 concentrations. Measurements of gas flux rates were made at various stages of the handling systems to rank them for their potential to generate these gases. (Information related to concentrations and emissions of CH_4, CO_2, and N_2O is summarized in Section 3.7)

Solid Beef

Approximately 70% of the N added as feed for a cow-calf operation was excreted as animal faeces. However, the mineral N available in the final manure spread on the field represented only 8% of the N input (feed and straw). Significant rates of NH_3 emission were measured from urine and manure on the alley floor of the barn in September, and a smaller rate was measured from the top-loaded pile in September. Very low rates of NH_3 emission were observed from the manure packs in September, from the packs and pile in March and in the field immediately after manure spreading. An emission rate of NH_3-N in the alley area of 10 mg NH_4-N m^{-2} min^{-1} is equivalent to approximately 7000 kg N per year. This magnitude of N loss is consistent with the estimate of a

57% loss (5800 kg N) of N from fresh faeces within the first day or so of excretion. A total of 57% of the combined excreted and bedding straw C was lost by biological activity (CO_2 loss) during storage on the manure pad. Final manure C was 25% of feed and bedding straw C.

Solid Poultry (broiler and roaster chickens on wood shavings)

Mineral N in the manure was equivalent to roughly 7.5% to 10% of feed N. Approximately 75% of the N added as feed was excreted as faeces. Roughly half of this excreted N was lost to the atmosphere as NH_3-N within a few days after excretion. NH_3 concentrations measured in spot samples of barn air were 43 ppm in the winter compared to 14 ppm in the summer. The difference in NH_3 concentrations was explained by ventilation rates, as net NH_3-N output by ventilation in the summer (38 kg d^{-1}) was similar to that in the winter (43 kg d^{-1}). Changing barn ventilation rates did not influence NH_3-N gas losses. The emission rate of NH_3 was not measured at eight weeks, but at six weeks it averaged about six times greater than at four weeks. There was no measurable emission of NH_3 from the manure pile in March.

Approximately 17% of C from poultry feed ended up in fresh faeces. Chicken respiration losses as CO_2 accounted for 73% of added feed C. Little of the manure C was lost by subsequent biological breakdown of the manure in storage.

Liquid Swine Manure - High Water Use

The farrow to finish operation at the Arkell Research Station uses slatted floors and manure channels that continuously drain to a pumping pit which is emptied weekly into storage towers and lagoons. Final N amounts applied to the soil were 38% of the feed N, almost all as NH_4-N. It was estimated that about 74% of feed N was excreted as fresh faeces. Almost 23% of this excreted N was lost as gaseous NH_3-N in the barn storage areas. During the winter, concentrations of NH_3 in spot samples of barn air ranged from 7 to 12 ppm NH_3.

Losses of N from the manure during storage in the lagoon and towers was negligible, but the N transformed until it was approximately 90% NH_4-N. Because of the high concentration of NH_4-N, agitation and irrigation of the liquid swine manure resulted in a loss of 33% of the manure N from NH_3-N volatilization, mainly during agitation of the lagoon. Losses from agitation were ranked summer >> fall > spring, which was attributed to manure temperature. It would appear that the high water usage resulted in low carbon concentrations in the lagoons, which in turn promoted aerobic mineralization and the high NH_4-N concentrations. Otherwise, the greatest emission rates of NH_3 occurred from the lagoons in August and from the soil within 30 minutes after applying manure in August. A small amount of the loss (3-5% of manure N) was from the irrigation. The loss of NH_4-N from the soil over a 5 hr period amounted to 2 kg N ha^{-1} compared to the 30 to 80 kg N ha^{-1} applied.

When it was pumped to the storage lagoons and towers, C in the manure was only 9% of feed input C. Significant amounts of volatile fatty acids were present in the final manure. Losses of C in the lagoons and towers were approximately 44%. Only 5% of feed C remained in the manure at time of spreading.

Liquid Swine Manure - Low Water Use

In the gestation-farrowing barn, 89% of the feed N was excreted, while 70% of the feed N was excreted in a feeder barn. Gaseous NH_3-N losses in the barns were estimated at 25% of fresh faeces. Concentrations of NH_3 from spot sampling of barn air in various rooms averaged 3.7 ppm during the summer and 9.6 ppm in the winter. The maximum emission rate of NH_3 was 3.5 mg NH_3-N m^{-2} min^{-1} from the solid floor of the gestation barn in late summer. There was evidence of anaerobic conditions in the lagoon for this system and NH_4-N concentrations were lower than at Arkell. Agitation of manure for spreading did not result in significant NH_3-N losses. Losses of N in the earthen lagoon storage were negligible. Only 5% of the C contained in the manure at the time it was pumped into storage was lost in the lagoon.

Solid Dairy Manure

Approximately 80% of feed N was excreted as fresh faeces N. In the milking barn, 18% of the feed N was lost as gaseous N between the milking barn and final storage. Similar losses occurred in the heifer barn. During outside storage on a covered pad, there was a small loss of N as NH_3-N (4% loss of feed and bedding N). Thus, 64% of feed and bedding N was spread as manure N, with 30% of the manure N being present as NH_4-N.

The emission rate of NH_3 was greatest in August from newly dumped cow barn gutter manure in the covered storage, about one third less for gutter manure stored for a few weeks, and about ten times less for the oldest manure in the covered storage. Significant NH_3 emission rates were also detected from recently dumped cow barn gutter manure in March, from the scraped alley and from manure packs in the heifer barn. Losses ranged from 3.5 (new manure) to 0.5 (old manure) mg NH_4-N m^{-2} min^{-1}. An average loss rate of 2.0 mg NH_4-N m^{-2} min^{-1} gives a loss of approximately 400 kg N per year from the manure surface area.

Liquid Dairy Manure - Alley-flush System

In this system, manure is flushed from the alleys directly into a holding tank and pumped to an outside lagoon. This lagoon is passively connected to 3 more lagoons, and the liquid manure level equalizes in each lagoon. Approximately 81% of feed N was excreted in fresh manure. Almost 23% of the N produced in the barn was lost during storage in the lagoon during the winter-spring period. During the summer-fall there appeared to be a 21% loss of manure N in both the storage system and in the pasture. The NH_4-N content of the lagoon manure was 90-100% of total N in the winter-spring compared to 50-60% in the summer-fall. Total N % of the manure was also less in the summer than in the winter. There was also a 50% decrease in volatile fatty acids in the summer compared to the winter.

Emission rates of NH_3 were greatest from the alley before flushing and immediately after flushing in the spring and summer, and from lagoons #1, #2, and #4 during the summer. No emission of NH_3 was detected from lagoon #3, which was crusted over. Significant rates of NH_3 emission were also detected from the alley floor in January and March. The rate of NH_3 volatilization from the various sources during the summer averaged about 1 mg N m^{-2} min^{-1}. Assuming this rate applied to three lagoon surfaces and the barn alleys, the annual N loss as NH_3 would be 1000 kg N.

Manure C transported to the outside storage was 47% of the feed and bedding C. Total C in the manure as spread was 39% of feed and bedding C. Thus, 16% of the manure C moved to outside storage was lost during storage.

3.9.3.2 On-Farm Manure Composting Techniques: Understanding Nitrogen and Carbon Conservation

In evaluating sixteen composting processes, St. Jean monitored compost moisture, temperature and weight and the concentrations of NH_3, O_2, CO_2 and CH_4 in the off-gases and pore spaces. No composting technique showed any consistent advantage over the others for reducing nitrogen losses. The author concluded that manures from Ontario livestock operations do not have characteristics that will minimize losses of nitrogen during composting. The solid dairy and beef manures sampled during this study had moisture levels in the range of 70 to 80%, significantly above the optimum of 60%. Solid poultry manures averaged 33% moisture, significantly below the optimum of 30/1. High moisture levels cause manure settling and compaction in windrows, which is believed to reduce the effectiveness of static-pile-forced-aeration and passive-aeration systems. C/N ratios ranged from 10 for poultry manures to 16 to 17 for dairy and beef, significantly below the optimum of 30/1.

St. Jean tested several techniques for their potential to reduce losses of carbon or nitrogen. (In all cases except the ecological processes, the trials were conducted with solid beef cattle manure.)

- Data collected from three different composting processes used by ecological farm operators did not indicate any advantage for these processes over conventional farm composting techniques in terms of nitrogen conservation. (*It should be noted, however, that different types of manures were used in the investigations of ecological composting techniques than were used in the studies of conventional composting techniques. The study did not include any manure type by composting technique comparisons.)*
- Traditional turned-pile, passive-aeration, and forced-aeration composting were equivalent in terms of carbon or nitrogen conservation.
- 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.
- Outside and inside composting were observed to have similar nitrogen and carbon losses.
- Inoculation of raw manure with composted manure did not demonstrate a conclusive advantage over straight manure composting for nitrogen conservation.
- The value of nitrogen conserved by adjusting C/N ratios to 15, 20, 25 and 30 was found to be approximately 10% of the value of straw added for C/N ratio adjustment.

- Addition of barnyard runoff to composting manure increased losses of nitrogen and organic matter although the trend was 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 loss for the composting process to which barnyard runoff was added was 57.7%, compared to 53.5% for the control. Significant differences in the compost concentrations of mineralized nitrogen were observed as a result of barnyard runoff addition. Compared to raw manures, NO_2-N concentrations in the compost increased by 139 times for the process to which barnyard runoff was added and decreased by 0.69 times for the control process.

3.10 Carbon and nitrogen transformations in soil

3.10.1 Identified Needs

Three recommendations from the CSAMM report identified the need for research on the application and management of manure on cropland to:

> "Establish the relationship between environmentally safe and the most profitable rates of manure application to cropland, taking account of the method and timing of applications, and to develop more acceptable manure application methods in conservation tillage systems." (Rec. #3)
>
> "Improve nitrogen application recommendations for different crops, based on a soil N test, taking into consideration losses on NH_3 with different times and methods of application." (Rec. # 5)
>
> "Investigate the transformations of manure N following addition to soil to provide more accurate estimates of denitrification, mineralization and immobilization." (Rec. # 7)

The report identified the main research needs as involving the investigation of the complex relationships among crop yield, nitrate requirement of crops, the amount of manure applied, and soil physical and chemical properties. Specific gaps in the information that were noted related to:

- the immobilization, mineralization, denitrification and leaching potential of manure N from different types of manure over time following application and how these relate to crop growth and N requirements.
- the effect of manure C and N characteristics, and interactions with different soils, on the extent of C and N transformations, and on the availability of manure N.
- the availability of N from previous applications of manure.
- the agronomic importance of the different forms of N in manure.
- a system or procedure to assist farmers in predicting the nitrogen loss, especially the loss as ammonia, that may occur following application.
- the effect of manure C quality or availability to decomposing organisms in the soil.
- the contribution of manure C to the C in soil.

3.10.2 Summary of Green Plan Research Results

Five research projects considered aspects of the transformations and losses of carbon and nitrogen that occur in the soil following application of manure or composts.

- *Transformations in Soil: Crop Response to Nitrogen in Manures with Widely Different Characteristics* (Beauchamp et al)
- *Nitrogen and Carbon Transformations in Conventionally-Handled Livestock Manures* (Kachanoski et al)

- *An Investigation into the Management of Manure-Nitrogen to Safeguard the Quality of Groundwater* (Goss et al 1995)
- *Investigating Methods of Integrating Liquid Manures into a Conservation Tillage Cropping System* (Schell and Alder)
- *Application of Composted Organic Waste to Agricultural Land* (Alder et al)

Beauchamp et al concluded that the NH_4-N content of manures was the most important factor affecting the availability of manure N to a crop and that this fraction must be measured and taken into account if manure N is to be used most economically with minimum environmental impact.

Determination of the availability of N early in the growing season was complicated by the apparent disappearance of NH_4-N soon after application of manures or urea. Even within a few days following application, the amount of inorganic nitrogen (NH_4 + NO_3) that could be extracted from the soil was always less than the amount of NH_4-N applied in manures or urea. Although it was difficult to make comparisons of available N among different manures, the N in liquid swine manure was generally more available than that in other manures (i.e cattle or poultry). The availability of N in solid beef cattle manure was generally the lowest. Manure N from all sources was less available than N from fertilizer urea. (Beauchamp et al)

The release of available N from some manures applied in the spring was relatively rapid in some years and well in advance of the period of peak N requirement of the corn crop. This was especially true for manures with the higher NH_4-N contents (e.g. liquid swine and cattle manures).

Fall application of liquid manures with high NH_4-N content (e.g. liquid swine and liquid dairy manures) may result in relatively large N losses and low N use efficiency. Response to fall-applied liquid swine manure was lower than that applied in the spring, suggesting that a significant amount of N was lost to leaching or denitrification during the fall, winter or early spring (Beauchamp et al). Much of the mineral N from liquid dairy cattle manure applied in late August could still be accounted for in the soil and plants at the end of November (Goss et al, 1995). From analysis of the ^{15}N present in the soil, it appeared that at least 49% of the labelled mineral-N had been incorporated in the organic-N fraction of the soil. This fraction remineralized very slowly.

The differences in inorganic N recoveries and variable release rates in the soil made it difficult to estimate the contribution of available N from the organic N fraction of manures, or to assess manure N dynamics in the soil involving N mineralization and immobilization (Beauchamp et al). Nevertheless, there did appear to be some release of organic N, especially late in the growing season. Goss et al found no clear evidence that N was released to the crop in the year of application from the organic fraction of spring-applied liquid cattle manure. There was evidence that some of the organic N in fall-applied manure became mineralized in the late summer, twelve months after application. Uptake in the second season was about 5% of the mineral N in the manure at application in both cases (Goss et al, 1995).

Beauchamp observed that significant quantities of residual manure N can become available in the year following application.

Solid manures with a low content of NH_4-N and a high C/N ratio (e.g solid beef cattle manure) did not provide much N to the crop in the year of application, nor did they appear to cause a depression in available N in the soil (Beauchamp et al). Similarly, fall-applied, composted beef cattle manure did not provide much N to the corn crop in the first year, nor did it result in a significant loss of mineral-N.

Cover crops sown after manure application in the fall immobilized N in proportion to the dry matter produced before the first killing frost (Goss et al, 1995). The cover crops removed less than 10% of mineral-N applied in liquid cattle manure, and only 10% - 15% of this was transferred to the following corn crop. Much of the N from the cover crop did not become available until late in the following season.

The rate of manure N transformations (e.g. mineralization and nitrification) was slowed in moderately acid soils (Beauchamp et al). However, soil acidity had little influence on the extent of N transformations. Liming of these acid soils resulted in an increase in the rate of mineralization and nitrification to near normal levels. Provided that such soils receive lime treatments periodically, soil acidity should not interfere with the availability of manure-N in most circumstances.

Normal N application rates should be used in conjunction with the application of composted organic wastes (Alder et al). Relatively little of the N in these materials was in an inorganic form and it appeared that little or no N from the composts tested was made available to the crops. Three annual additions of composted organic wastes, of approximately 10,000 to 15,000 kg carbon ha^{-1} yr^{-1}, increased organic carbon levels in the soil by almost 33%, relative to where no compost was applied.

3.10.3 Additional Information from Specific Studies

3.10.3.1 Transformations in Soil: Crop Response to N in Manures with Widely Different Characteristics

Beauchamp et al investigated the influence of the characteristics of five different types of manure and various management practices on the release or availability of manure N. The manures used in this study included liquid dairy cattle, solid beef cattle, liquid swine manures and solid broiler chicken with either wood shavings bedding or straw bedding.

Levels of available N were closely correlated with grain yields. The authors concluded that the NH_4-N content of manures is the most important factor affecting manure N availability to a crop in the field. This conclusion was supported by both crop yield response and monitoring of soil inorganic N and corn plant seedling N content during the early growing season.

Determination of the availability of N early in the growing season was complicated by the apparent disappearance of NH_4-N soon after application of manures or urea. Even within a few days following application, the amount of inorganic N that could be extracted from the soil was always less than the amount of NH_4-N applied in manures or urea. In some cases, as little as 30 to 40 percent of the applied inorganic N was recovered. An experiment with ^{15}N supported the observation of low recoveries of added NH_4-N. This apparent disappearance was probably due to a combination of ammonia volatilization, fixation by clay and immobilization by soil microbes. A laboratory incubation experiment to determine the nature of this "loss" using ^{15}N produced no clear answer.

Differences in inorganic N recoveries and variable release rates in the soil made it difficult to estimate the contribution to available N from the organic N fraction of manures, or to assess manure N dynamics in the soil involving N mineralization and immobilization. The rates of N release during the first two months of the growing season were inconsistent from year to year, although available N levels generally increased following application. The release of available N from some manures applied in the spring was relatively rapid in some years and well in advance of the period of peak N requirement of the corn crop. This was especially true for manures with the higher NH_4-N contents (e.g. liquid swine and cattle manures).

There appeared to be some release of inorganic N later in the season that may have been partly due to the release of some "lost" N and partly from the organic N applied in the manures. In many cases when corn grain yield was plotted against urea N or manure NH_4-N applications, the latter was apparently more available. This would seem to indicate that available N was being released from the organic N fraction.

Solid beef cattle manure appeared to behave differently than the other manures. Yield responses were generally lowest with the N in this manure. Release of available N from solid cattle manure was very slow during the early part of the growing season. Monitoring of soil inorganic N and plant N uptake in the field, along with a ^{15}N study in the lab, revealed that significant net immobilization of inorganic N from this manure occurred during the early part of the growing season. This is noteworthy because the C/N ratio of the solid beef cattle manure was generally below 20/1, a value below which net mineralization is commonly believed to not occur. Corn grain yields and N composition of mature plants suggested that there was a substantial release of N from the solid beef cattle manure during the latter part of the growing season that was not evident with the other manures.

It had been anticipated that solid beef cattle manure would result in a depression in available N in the soil early in the growing season because of its relatively low NH_4-N content and high C/N ratio. However, this did not appear to be the case. There simply was little or no increase in available N during this period.

The kind of bedding (wood shavings vs straw) in poultry manure had no apparent effect on manure N availability, soil inorganic N concentrations or grain yields, despite wide differences in C/N ratio in the beddings (approx. 280/1 and 65/1, for wood shavings and straw, respectively).

In one experiment, straw or wood shavings were added with liquid dairy cattle and solid beef cattle manures applied in the fall and spring. The effects on grain yield responses from additional bedding materials, either in the fall or spring, were generally small. There was a tendency for added wood shavings to reduce grain yields slightly more than added straw. Both added beddings tended to reduce soil NO_3 concentration after manure application, especially the wood shavings.

The efficacy of fall-applied manures and the risk of N loss from them depend in part on the characteristics of the specific manure. Crop response to solid manures applied in the fall was similar to the response to manures of the same type applied in the spring. Thus, it would appear that fall-application of solid manures with relatively low NH_4-N content and substantial bedding content may not result in much N loss.

Fall application of liquid manures with high NH_4-N content (e.g. liquid swine manures) may result in relatively large N losses and low N use efficiency. Response to fall-applied liquid swine manure was lower than that applied in the spring, suggesting that a significant amount of N was lost to leaching or denitrification during the fall, winter or early spring.

Significant quantities of residual manure N became available in the year following application, depending mostly on the quantity applied. In one of two years of the study, soil N tests reasonably predicted residual N availability. It was anticipated that residual N from solid beef cattle manure might be greater than other manures because it contained more organic N that would be presumably released in later years. This did not appear to be the case.

3.10.3.2 <u>Nitrogen and Carbon Transformations in Conventionally-Handled Livestock Manures</u>.

As discussed in Section 3.7.3.1, there was a very significant loss of ammonia (33% of manure N) during agitation and irrigation of liquid swine manure that had a very high content of NH_4-N. Most of this loss occurred during agitation of the storage lagoons. Spreading rates of liquid swine manure from the gun irrigation system were very uneven. Gaseous NH_3-N losses from the soil immediately after application were quite high, but decreased to negligible levels after 5 hrs. Losses from the soil totalled approximately 3 kg N ha^{-1}, which was 3 to 10% of the applied N (i.e. application rates varied from 30 to 100 kg N ha^{-1}).

3.10.3.3 <u>An Investigation into the Management of Manure-N to Safeguard the Quality of Groundwater</u>

Goss et al (1995) investigated the fate of N from liquid dairy cattle manure and from composted cattle manure in two field experiments conducted at the Elora Research Station of the Ontario Ministry of Agriculture, Food and Rural Affairs and at Winchester Research Station of Kemptville College of Agricultural Technology, respectively.

At Winchester, approximately 300 kg total N ha^{-1}, as either liquid dairy cattle manure or as composted cattle manure, was applied in late August on alfalfa sod which had been plowed down. The soil at the time of manure application contained about 80 kg ha-1 mineral N. Only 5% of the N in the composted cattle manure was present in the mineral form, as compared to 72% in the liquid manure. By the end of November much of the mineral N applied in the manure could still be accounted for in the soil and plants. There was 55 kg NO_3-N ha^{-1} in un-manured plots, 78 kg NO_3-N ha^{-1} in plots that received composted manure, and 134 kg NO_3-N ha^{-1} in plots given liquid manure. From analysis of the ^{15}N present in the soil, however, it appeared that only about 60 kg N ha^{-1} had been derived from the mineral fraction of the liquid cattle manure and that at least 49% of the labelled mineral-N had been incorporated in the organic-N fraction of the soil. A small part of this fraction appeared to be remineralized in early spring. Only small amounts became available even in the second year, as much of the ^{15}N was retained in the soil organic matter.

In the first cropping year, the uptake by corn of N derived from the mineral-N in liquid manure was greater from a spring application (39 kg N ha-1) than from a fall application (31 kg N ha-1). Uptake in the second season was about 5% of the mineral N in the manure at application in both cases. About 32% of the ^{15}N applied was taken up by the two following corn crops at Elora, and almost 21% was found in the two corn crops grown at Winchester. These were equivalent to 47.4 kg N ha^{-1} taken up at Elora, and 42.2 kg N ha^{-1} taken up at Winchester. About 9 kg N ha^{-1} was taken up by the second corn crop. The grain contained 60% of the ^{15}N taken up at Elora and 62% was in the grain at Winchester. In the first year at Winchester, spring barley took up 14% of the ^{15}N applied in liquid cattle manure, equivalent to 28.8 kg N ha^{-1} from the mineral fraction of the manure. Some 52% of the N was in the grain of the spring barley. There was no clear evidence that N was released to the crop from the organic fraction of spring-applied liquid cattle manure in the year of application.

Composted manure did not provide much N to the corn crop in the first year, nor did it result in a significant loss of mineral-N. There was evidence that some of the organic N in fall-applied manure became mineralized in the late summer, twelve months after application.

Cover crops sown after manure application in the fall immobilized N in proportion to the dry matter produced before the first killing frost. Incorporation of additional straw before planting of the cover crop reduced the amount of N incorporated in the cover crops because the growth of these crops was impaired. The cover crops removed less than 10% of mineral-N applied in liquid cattle manure, and only 10% - 15% of this was transferred to the following corn crop. Evidence from crop sampling indicated that much of the N from the cover crop did not become available until late in the season.

N released by ploughing under alfalfa sod at Winchester provided sufficient N for the corn crop. The results indicated that a value of 110 kg N ha^{-1}, currently used in Ontario, was an appropriate credit for the underground residues of the alfalfa hay.

The Ontario soil N test clearly underestimated the amount of mineral N available in the soil on all treatments. The soil N test suggested that the un-manured plots would require some fertilizer N to obtain the maximum economic yield. However, corn yields were unaffected by the treatments imposed despite the indications of the soil N test. Thus, it is clear that adjustments are needed when making fertilizer recommendations based on the test to ensure that the N from crop residues (legumes, straw or cover crop) is included.

At Elora, the growth of the corn crop on the microplots was good in both years, and there was no significant benefit to yield from application of manure compared with control plots in either season. Previously corn had been grown continuously on the site, so the lack of any effect on yield due to manure application in the first season was probably due to residual N from the management of those crops.

Hand-harvested yields of both corn and barley grown at Winchester on land injected with liquid manure were significantly greater than from the control treatments, except where straw had been incorporated or oilseed radish planted. However, there was no difference among treatments in combine-harvested yields.

The spring barley lodged preferentially on the manured plots making the yield results difficult to interpret.

3.10.3.4 Application of Composted Organic Waste to Agricultural Land

Alder et al considered the effects of application of two types of composted organic wastes on the N nutrition of corn and forage grasses. They concluded that normal N application rates should be used in conjunction with the application of composts. The total N content of the two composts ranged between 0.94% and 2.1% on a dry matter basis. The total N application averaged 530 and 628 kg N ha^{-1} yr^{-1} for the two composts, respectively. Relatively little of this N was in an inorganic form. When applied at a rate of 50 Mg dry compost ha^{-1} yr^{-1}, the two composts supplied an average of 12 kg inorganic N ha^{-1} yr^{-1} and 3 kg inorganic N ha^{-1} yr^{-1}, respectively.

When compost was applied at the rate of 100 Mg ha^{-1} yr^{-1}, corn yields on loam soil were higher or near those of the controls, either with or without fertilizer N, and there was adequate N in the ear leaf when measured at silking. There was no indication that compost reduced the availability of the N in the fertilizer. Little or no N appeared to have been made available from the composts.

On the clay loam soil, N fertilizer was applied below the maximum economic rate in both years. The response to the application of compost varied between the two years. In the first year, there was an indication that compost reduced the availability of fertilizer N and hence, yields. In the second year, compost applications did not reduce average yields relative to the controls, either with or without fertilizer-N.

In the comparison of compost-N relations in grass hay, there was no evidence of yield suppression where 170 Mg wet ha^{-1} of compost was applied in the spring. Indeed, where adequate N was applied for optimum yields, the response to N appeared to increase where compost was applied. (This may have been the result of an increase in the amount of moisture retained by the soils treated with compost.)

Dry matter production of the second cut of hay was increased where compost was applied in the absence of N fertilizer. This would suggest that some N became available to the crop from the compost or the soil.

Three annual additions of composted organic wastes, of approximately 10,000 to 15,000 kg carbon ha^{-1} yr^{-1}, increased organic carbon levels in the soil by almost 33%, relative to where no compost was applied. The A horizon carbon content increased from a level of 1.7% for the control to a value of 2.3% for the treated soils. The increases amounted to approximately 17 and 10 tonnes ha^{-1} more total organic carbon in the A horizon of the loam and clay loam soils, respectively, or roughly one third the amount of organic carbon applied as compost over the period.

3.11 Nutrients other than nitrogen

3.11.1 Identified Needs

Goss et al concluded that the current level of knowledge is adequate for management of manure phosphorus. However, some studies provided information related to the effect of the application of manure or other organic materials on the availability of phosphorus and other nutrients.

3.11.2 Summary of Green Plan Research Results

Soil test measurement taken throughout the study *Investigating Methods of Integrating Liquid Manures into a Conservation Tillage Cropping System* (Schell and Alder) demonstrated the tendency for manure use to increase the levels of phosphorus and potassium in the soil.

In the study, *Application of Composted Organic Waste to Agricultural Land,* Alder et al measured the effects on soil nutrient levels of three annual applications of two types of composted organic wastes at the rate of approximately 100 Mg ha ha^{-1} yr^{-1}.

- Total phosphorus additions from the two composts averaged 122 kg P ha^{-1} yr^{-1}, and 82 kg P ha^{-1} yr^{-1}, respectively. Over the three years, soil test P in the loam soil ($NaHCO_3$-extractable phosphorus) increased from 12 mg L^{-1} in the control plot to 30 mg L^{-1} and 20 mg L^{-1}, for the two composts, respectively. On the clay loam soil, soil test P increased from 19 mg L^{-1} in the control plot to 30 mg L^{-1} and 22 mg L^{-1}, respectively.
- The potassium content of the two composts varied annually and ranged between 0.79% and 2.50% for one compost, and between 0.37% and 0.98% for the other. Annual additions of total potassium from compost averaged 752 kg K ha^{-1} yr^{-1} and 300 kg K ha^{-1} yr^{-1}, for the two materials, respectively. Compost additions increased soil test (exchangeable) potassium levels in the loam soil from 64 mg L^{-1} in the control plot to 161 mg L^{-1} and 95 mg L^{-1} for the two treatments, respectively. On the clay loam soil, soil test K increased from 110 mg L^{-1} in the control plot to 156 mg L^{-1} and 129 mg L^{-1}, respectively.
- Annual additions of total zinc from compost averaged 17 and 5 kg ha^{-1} $yr^{-1,}$ respectively. On the loam soil, soil test extractable zinc increased from 0.99 mg L^{-1} in the control plot, to 6.8 mg L^{-1} and 2.9 mg L^{-1}, respectively, for the two composts. On the clay loam soil, soil test zinc increased from 0.78 mg L^{-1} in the control plot to 5.6 mg L^{-1} and 2.6 mg L^{-1}, respectively.

3.12 Effects of application of manure or other organic materials on crops, soil biota, soil structure, soil compaction, pH, weed populations and plant pathogens

3.12.1 Identified Needs

Between 1992 and 1997 OASCC annually recommended that research be undertaken to "investigate the ability of solid manure spreaders to spread manure in a uniform coating on the land."

A 1996 recommendation called for research to "determine optimum rates and application methods of organic amendments (including biosolids and crop residues) in farming systems for the improvement of soil quality."

The CSAMM noted that the influence of microorganisms in manure on soil biology had been overlooked, for the most part. The report also noted that although there are models to estimate the degree of compaction based on axle loads and soil properties, the ability to predict the effect of a given degree of compaction on crop yield is limited.

3.12.2 Summary of Green Plan Research Results

Six research projects and one conservation club project provided some information about agronomic aspects of manure use other than those related to nutrient management.

- *On-Farm Manure Composting Techniques: Understanding Nitrogen and Carbon Conservation* (St. Jean)
- *The Effects of Livestock Manure Application Methods on Water Quality, Focussing on Nitrogen and Bacteria Transport in Soil*. (Wall et al)
- *Application of Composted Organic Waste to Agricultural Land* (Alder et al)
- *Assessment of the Influence of Manures for the Control of Soilborne Pests Including Fungi, Bacteria and Nematodes* (Lazarovits and Conn)
- *Investigating Methods of Integrating Liquid Manures into a Conservation Tillage Cropping System* (Schell and Alder)
- *An Investigation into the Management of Manure-Nitrogen to Safeguard the Quality of Groundwater* (Goss et al, 1995)
- *The Essex Manure Management Club*

Composts made from manures or organic wastes can inhibit seed germination to some degree, even in 50/50 soil/compost mixes. (St. Jean; Alder et al) Where high rates of composted materials are to be applied, fall applications may be preferable to spring.

Application of composted organic wastes did not adversely affect soil quality in two soils as reflected by soluble salts, metal content or soil microbial biomass. (Alder et al)

Use of composted organic wastes often resulted in faster early growth and development of both corn and soybeans (Alder et al). The faster growth and development were usually also reflected in higher yields.

No-till corn yields produced with manure-nitrogen applied at recommended rates based on a soil test were not statistically different from control treatments where inorganic fertilizers were used. (Wall et al; Schell and Alder) However, Wall noted that on heavier soil types, injection of manure as a side-dressed application, reduced corn plant stands because of the disturbance of the soil.

Application of composted organic waste materials resulted in an increase in the total porosity of treated soil as compared to the untreated soil (Alder et al). However, the two materials tested differed in their effect on pore size distribution. One increased the amount of large pore space; the other increased the amount of very small pore space. Infiltration was increased by both composts at the clay loam site and the bulk density decreased.

Use of liquid manure appeared to increase weed pressure under some circumstances, although not to unmanageable levels (Schell and Alder). In one trial of the use of composted organic waste in soybean production, compost applied at the rate of 300 Mg (wet) ha^{-1} acted as a mulch in suppressing weeds (Alder et al). Goss et al (1995) also noted the tendency of composted cattle manure to suppress weed emergence.

Manures and other related organic amendments can be used effectively to reduce soilborne diseases of potatoes (Lazarovits and Conn). More than one mechanism is involved and the effects vary depending on the manure, the pathogen, soil type, and soil moisture levels. Changes in pathogen populations were both qualitative and quantitative. A rapid and reproducible laboratory bioassay was developed for determining the effect of manures on pathogens in a particular soil. This assay could be used to provide farmers with information as to where certain manures can be safely applied and under what conditions.

3.12.3 Additional Information on Specific Concerns

(Note because this section deals with several areas of potential concern, it is organized by topic rather than by research project.)

3.12.3.1 Crop Emergence

Alder et al investigated the effects of two sources of composted organic wastes on the emergence and growth of lettuce, corn and soybeans. In laboratory studies, emergence was delayed if the application rate exceeded 2.5 cm in depth (about 165 Mg (wet) ha^{-1}.) There were also indications in field studies that the rate of emergence of corn was restricted by spring application of high rates of these materials. The restriction was attributed to the high concentration of soluble salts in the material. Application of compost in the fall did not adversely affect crop emergence. In one soybean trial on clay loam, the mulching effect of compost applied in the spring (at 300 Mg (wet) ha^{-1}, a depth of approximately 5 cm.) reduced crusting of the soil surface and substantially increased the proportion of soybeans seeds that emerged.

St. Jean compared 16 composts made from livestock manures for their tendency to inhibit germination of cress seed. All composts inhibited germination to some degree, even in 50/50 soil/compost mixes. In pure compost, germination percentages ranged between 0 and 63.3%, in contrast to control samples with 90 to 100% germination. Germination percentages in 50/50 mixes ranged between 0 and 83.3%. Germination was completely inhibited in finished solid beef manure compost which had been cured for up to 90 additional days, although germination was improved in the soil/compost mix, relative to uncured compost.

3.12.3.2 Growth and Yield

Use of liquid manure as a side-dressed application did not impair crop growth and development. No-till corn yields produced with manure nitrogen applied at soil test recommended rates were not statistically different from control treatments where inorganic fertilizers were used (Wall et al; Schell and Alder).

In the study by Wall et al, there was no significant difference in grain yield between injection and surface manure application methods although both plant populations and grain yields were marginally lower than in control plots in three of the five crop years. On clay loam soil, the manure injection process created problems by tossing large clods onto the corn seedlings, reducing the plant population significantly (6%) compared to the control treatment. Also, manure tended to pond where the clods had been displaced, because of the elevated clay and moisture levels at this site. For successful use on high clay (>30%) soils, the injection equipment used in this study would need to be modified or be used at lower soil moisture conditions.

Use of composted organic wastes often resulted in faster early growth and development of both corn and soybeans (Alder et al). In field trials on two soil types over three years, application of compost either generally either increased the corn yield or had no effect on yield. Compost tended to increase yields when overall yield levels were good and to have no effect when overall yields were low. (One of the composted materials did cause a large reduction in corn yield, relative to the control plot, in one year on clay loam soil.) There was less likelihood of an increase in yield from compost in the absence of commercial N fertilizer than when the crop was grown using normal N fertilizer practices. Soybeans yields were not influenced by compost applications in one trial on clay loam soil, although compost did appear to increase soybean nodule weight per plant.

3.12.3.3 Soil Physical and Hydraulic Properties

Application of composted organic wastes increased total porosity in two soils compared to the untreated soil (Alder et al). However, the two materials differed in their effect on pore size distribution. One compost caused a decrease in the amount of large pores and a very large increase in the residual water content porosity (i.e. very small pores). The amount of fine pore space increased with each year of added compost at both sites. The data suggest that this compost material is either biologically active and results in the organic material being progressively more bound to the clay sized fractions with time, or that the material is very hydrophilic. In contrast, the other compost resulted in a slight increase in the amount of larger pore sizes, along with an overall increase in the total porosity compared to the untreated soil. The influence of this compost on the very small pores was negligible at the loam site and variable at the clay loam site. Infiltration was increased by both composts at the clay loam site and the bulk density decreased. Thus, addition of composts could reduce the risk of soil loss due to water erosion by permitting more rapid infiltration of rainfall into the soil surface. Soil water content usually was not influenced by compost applications.

3.12.3.4 Soil Quality

There was no evidence that application of composted organic wastes diminished soil quality (Alder et al). Soluble salts in two soils remained low after compost applications. Metals in the soil were not significantly elevated. Soil microbial biomass carbon in the soil was not adversely affected.

3.12.3.5 Weed Control

In on-farm trials to investigate methods of integrating liquid manure into conservation cropping systems, use of manure appeared to increase weed pressure under some circumstances (Schell and Alder). However, the farmers cooperating with this study concluded that the additional weeds could be managed through modifications of the overall weed management system, with no serious yield, management or cost concerns.

In one trial of the use of composted organic waste in soybean production, surface application of 300 Mg (wet) ha^{-1} (i.e. to a depth of approximately 5 cm.) acted as a mulch in suppressing weeds (Alder et al). In laboratory experiments, Alder et al measured a significant reduction in seed emergence for corn, soybeans and lettuce and St. Jean observed that composted livestock manures similarly inhibited the germination of cress seed. Application of composted beef cattle manure acted as an effective inhibitor of weed seed germination, and there was no measurable plant development on the treated plots. (Goss et al, 1995) These results would suggest that application of some composts at high rates can suppress germination and emergence of some weeds.

3.12.3.6 Plant Pathogens

Lazarovits and Conn conducted a series of experiments to determine if addition of manures to potato growing fields affected the severity of two major soilborne diseases of potatoes, Verticillium wilt, caused by the fungus *Verticillium dahliae,* and potato scab, caused by *Streptomyces* bacteria. (All of the discussion in this sub-section relates to this project.) In a field experiment, they also looked at the effect of manures on the lesion nematode population and in all experiments they monitored populations of microorganisms other than pathogens to provide some indication of the overall microbial health of the soil. The effect of manures on soil chemistry was also monitored.

The authors concluded that manures and other related organic amendments can be used effectively to reduce soilborne diseases of potatoes. The degree of control depends on the type and condition of the manure used, soil type, and soil moisture levels. Changes in pathogen populations were both qualitative and quantitative.

The most important factor was the manure used. For example, in certain soils fresh chicken and liquid swine manures decreased pathogen populations while solid cattle manure had no measurable effect. The effect of a manure on pathogens was also influenced by the soil to which it is added. The fact that a particular manure reduced disease severity in one location did not ensure that it would do so at another.

Soil moisture also influenced the effect of a manure on pathogens. For example, liquid swine manure decreased the viability of *V. dahliae* in dry soil but not in wet soil.

The impact on pathogens was influenced by the source of manure and how the manure had been handled and stored. Composting chicken manure for one week destroyed its disease suppressive effect on *V. dahliae* and may have increased the potential of potato scab.

Organic amendments had a long lasting effect on soil microbiology. All the amendments tested generally increased the overall microbial population in the soil. There were also changes in the proportions of the types of micro-organisms present. The increase in microbial population along with a decrease in soilborne pathogens is considered to provide a healthier soil. Thus, these organic amendments can be considered as providing a selective fumigation.

There is more than one mechanism by which these amendments reduce the viability of soilborne pathogens. One mechanism is believed to be through the release of ammonia, to which soilborne pathogens are sensitive. The amendments that provided the greatest increase in the overall microbial population and the best overall control of soilborne pathogens were those that contained high amounts of nitrogen (e.g. soymeal, blood meal, meat and bone meal, and chicken manure). These amendments generally also caused the largest increase in soil pH and ammonia levels.

Liquid swine and solid cattle manures did not raise soil pH or ammonia levels but still reduced populations of some soilborne pathogens and disease incidence. There was a correlation between fungal colonization of *V. dahliae* microsclerotia and reduced viability of *V. dahliae*. Thus, one of the mechanisms by which these manures decrease the viability of *V. dahliae* might be through the stimulation of fungal colonization of microsclerotia. This stimulation of biocontrol by these amendments might apply to other soilborne pathogens as well.

The authors developed a rapid and reproducible laboratory assay for determining the effect of manures on pathogens in a particular soil. The assay can be used to provide farmers with information as to where certain manures can be safely applied and under what conditions. The assay is simple and rapid and allows for evaluation of many manure-soil combinations under controlled environmental conditions. It consists of mixing a small amount of manure with soil in test tubes. The mixture is incubated and the effects on pathogen populations determined through plating on selective media. A laboratory assay and field experiments conducted in parallel gave the same results more than 90% of the time.

3.12.3.7 Energy Consumption

Wall et al reported that when the injection equipment for liquid manure was modified to provide a small amount of tillage in front of the injectors points, the power requirement for the modified injection configuration increased relative to conventional injection. The difference was relatively small, however, and the modified injection configuration was considered practical from an energy perspective.

3.12.4 Summary of Results from Rural Conservation Clubs

The Essex Manure Management Club, in conjunction with the Essex Region Conservation Authority, conducted a four year study to determine the feasibility of irrigating liquid swine manure from the third stage of a lagoon system on intensively managed pasture. The lagoon system was associated with a 400 sow farrow-to-finish operation and was sized to provide 365 days storage. Relative to the fresh manure, nutrient concentrations in the liquid contents of the third stage lagoon were reduced by the following percentages:

nitrogen	75%
phosphorus	75%
potassium	25%

The pasture area was divided into four paddocks that were managed on a 28 day rotational cycle from May to September. Manure was applied to a paddock on days 1 and 8 of the cycle for that paddock. Stocker cattle grazed the paddock for a period of 7 days beginning on day 21 of the cycle. No particular problems associated with grazing cattle on irrigated paddocks were reported.
Average daily gains were 1 lb/day in the first year of the study and 2 lb/day in the second. It was noted that extremely hot weather in the first year limited the growth of the cattle.

No tile flow was observed during the sampling periods following irrigation. Soil nutrient levels and ground water quality were not monitored.

Additional information about this project can be obtained from The Essex Region Conservation Authority, 360 Fairview Avenue West, Essex, Ontario N8M 1Y6

3.13 Practices to minimize the environmental impact of the use of manure or other organic materials in conservation tillage systems

3.13.1 Identified Needs

An OASCC recommendation in 1997 stated that research was required "to determine methods of application, rates and effects on soil and plant growth of the application of manure in no-till systems, focussing on maximizing nutrient efficiency".

The CSAMM report recommended that research be conducted to:

> "Establish the relationship between environmentally safe and the most profitable rates of manure application to cropland, taking account of the method and timing of applications, and to develop more acceptable manure application methods in conservation tillage systems." (Rec. # 3)

3.13.2 Summary of Green Plan Research Results

Three research projects provided information about aspects of manure use in conjunction with conservation tillage systems:

- *Investigating Methods of Integrating Liquid Manures into a Conservation Tillage Cropping System* (Schell and Alder)
- *The Effects of Livestock Manure Application Methods on Water Quality, Focussing on Nitrogen and Bacteria Transport in Soil*. (Wall et al)
- *Application of Composted Organic Waste to Agricultural Land* (Alder et al)

Liquid manure application can be integrated with conservation tillage in an effective and efficient manner that will be acceptable to farmers, although modification of application equipment may be necessary depending on site requirements (Schell and Alder). There was no indication that manure nitrogen needed to be managed differently than N from inorganic fertilizers at equivalent rates of available N. Manure application rates should be based on the N content of the manure and the N status of the field as indicated by the soil nitrate test.

Wall et al conducted field scale studies to evaluate liquid manure application technologies in no-till corn cropping systems in terms of sustainable crop productivity and subsurface water quality, with special consideration to preferential flow. The results of this study have been summarized in Section 3.4.

Alder et al concluded that incorporation of composted urban organic wastes was not generally necessary, although the response of corn to incorporation of the compost was variable. On some soils, applying compost without incorporation was beneficial since it acted as a mulch, reducing the adverse effects on emergence from crusting of the soil surface.

3.13.3 Additional Information from Specific Studies

3.13.3.1 Investigating Methods of Integrating Liquid Manures into a Conservation Tillage Cropping System

Schell and Alder conducted experiments on field length plots at six farm sites in southwestern and eastern Ontario in the growing seasons of 1994, 1995 and 1996. The farms sites included two dairy farms, three hog farms and a poultry farm. The conservation cropping systems included three different modified no-till systems, an aeration tillage system using an Aerway™ implement, a chisel tillage system and a ridge tillage system. Treatments included application of 100% of the estimated N requirement from liquid manure, 100% from inorganic fertilizer and a combination of approximately 75% from manure and 25% from inorganic fertilizer. The effect of timing was evaluated through comparisons of pre-plant and side-dress manure applications, and different side-dress application timings. In all cases, the liquid manure was applied with the farmer's liquid manure tanker spreader.

Some difficulties were experienced in applying the required volumes of manure to the field under conservation cropping systems. However, the co-operating farmers were able modify their equipment and refine practices such that the manure was effectively and efficiently applied in most cases. Results varied widely from year to year and from site to site. Difficult weather patterns, weed and pest pressures and changing farmer requirements posed challenges to the conduct of the research and the interpretation of results. However, within the statistical limits of field research, the authors concluded that liquid manure is an effective source of nutrients for corn grown with conservation tillage, with similar implications for water quality as N from mineral fertilizers. Where the total N applied was close to the maximum economic rate (MER) for the field, yields were similar for manure and mineral N sources. Pre-plant broadcast applications and side-dressed applications of manure in emerged corn produced similar yields.

3.13.3.2 Application of Composted Organic Waste to Agricultural Land

Alder et al compared the effects of incorporating preplant applications of composted urban organic wastes against leaving it on the soil surface. For both treatments, crops were planted with a no-till planter. Although the responses of corn and soybeans to incorporation of compost were variable, relative to leaving it on the surface, the authors concluded that incorporation was generally not necessary.

Soil water content measurements in the 0-20 cm soil depth did not indicate that the incorporation of the material changed the rate of drying of the soil. In addition, measurements of erosion loss did not indicate a need for incorporation of compost. On soils prone to surface crusting, compost left without incorporation can serve as a mulch, reducing the risk of poor emergence.

Applications of compost to a mixed species grass hay, where incorporation is not an option, may result in suppression of some species, although species recovery was possible. It is possible that a light harrowing may reduce the smothering of some species.

3.14 On-farm costs and benefits

3.14.1 Identified Needs

The CSAMM Report concluded that research was needed to:

> "Assess on-farm economics of different manure management systems in direct association with research on storage, application and utilization of manure." (Rec # 10), and to
>
> "Establish the relationship between environmentally safe and the most profitable rates of manure application to cropland, taking account of the method and timing of applications." (Rec. # 3)

The report noted that there was a general lack of information regarding the relative on-farm costs and benefits of all manure management practices and that information about the environmental costs of manure management practices was even less available.

3.14.2 Summary of Green Plan Research Results

Three studies collected information related to the costs associated with the manure or waste management practices under investigation:

- *Nitrogen and Carbon Transformations in Conventionally-Handled Livestock Manures* (Kachanoski et al)
- *On-Farm Manure Composting Techniques: Understanding Nitrogen and Carbon Conservation* (St. Jean)
- *Application of Composted Organic Waste to Agricultural Land* (Alder et al)

Kachanoski et al conducted a comparative benefit-cost assessment of six manure-handling systems. Total annual costs (overhead plus operating) exceeded the value of plant nutrients applied to the soil on five of the six test farms by amounts ranging from $4.13 to $124.28 per tonne of manure applied per year. A small net benefit of $0.06/tonne manure was achieved on one dairy farm.

St. Jean reported that the benefit of a 50% reduction in manure volumes due to composting was typically offset by the value of nitrogen lost during the composting process.

At an application rate of 100 Mg ha^{-1}, the cost of composted urban organic wastes ($45 Mg^{-1}, delivered) could not be justified based on yield increases and fertilizer benefits (Alder et al). Indeed, these benefits were insufficient to cover the cost of the application. The intangible benefits of organic carbon, improved water characteristics, etc. might be sufficient to justify the cost applying compost if it were delivered to the farm free of charge.

3.14.3 Additional Information from Specific Studies

3.14.3.1 Nitrogen and Carbon Transformations in Conventionally-Handled Livestock Manures
Kachanoski et al compared the benefits and costs associated with the six manure-handling systems used in the study of N and C transformations in storage and handling (Sections 3.7 and 3.9). The manure systems included solid beef, solid poultry, liquid swine with high water usage, liquid swine with low water usage, solid dairy and liquid dairy from an alley-flush system. A questionnaire was designed for collection of bio-physical and economic data from farmers. A spreadsheet system was developed to analyse the farm data and produce a profile of total annual manure production, total capital investment in manure-handling facilities and equipment, annual costs of ownership and operation of manure-handling, economic benefits from manure, and total net costs or benefits from manure operations (Table 4).

Table 4: Summary of Costs and Benefits for Six Manure Handling Systems

System	Capital Invested	Annual Ownership Costs	Annual Operating Costs	Annual Economic Benefits	Annual Net Benefits (Costs) of Manure	Net Cost/t Manure Applied / yr
	$	$	$	$	$	$/t
Poultry (Solid)	128,700	31,067	4,718	16,027	(19,758)	(43.13)
Swine (low water use)	181,308	42,778	8,966	25,369	(26,374)	(4.23)
Beef (Solid)	410,591	138,175	17,057	11,566	(143,666)	(124.28)
Swine (high water use)	393,062	95,395	31,280	15,931	(110,745)	(16.65)
Dairy (Solid)	200,203	51,450	30,771	12,188	(70,033)	(19.27)
Dairy (Liquid)	50,383	12,060	3,072	15,465	333	0.06

Capital investments in manure-handling facilities and equipment were substantial, especially in the case of the three research stations (Elora - solid beef; Arkell - liquid swine with high water use and Ponsonby - solid dairy). Ownership costs (depreciation, interest, repairs, insurance) were substantially higher than operating costs (energy and labour) in all cases. Total annual costs exceeded the economic benefits (opportunity cost value of plant nutrients at field application stage) in the case of five of the six test farms by amounts ranging from $4.13 to $124.28 per tonne of manure applied per year. A small net benefit of $0.06/tonne manure was achieved on the dairy farm which used the alley-flush system.

The net costs, and in the one case small net benefits, reflect only the direct, measurable economic benefits and costs of manure-handling operations. Omitted from the calculations were:

- any on-farm benefits from the long-term soil structural and productivity improvements conferred by infusions of organic matter in livestock manures;
- any on-farm costs of soil compaction, farm water supply contamination or aerial pollution associated with manure-handling techniques; and
- any costs in the form of off-site environmental damage due to gaseous emissions and surface or ground water pollution from nitrate, phosphorus or bacteria leachates.

3.14.3.2 On-Farm Manure Composting Techniques: Understanding Nitrogen and Carbon Conservation

St. Jean observed that:

- Composting of beef cattle manure reduced the weight of manure to be spread by 57.1% and spreading costs by $1.71/T (wet) of manure (based on a nitrogen fertilizer cost of $0.814/kg of actual nitrogen). Nitrogen losses during composting for beef cattle manure were equivalent in value to the reduced spreading costs.

- Composting reduced the weight of poultry manure to be spread by 51.0% for a reduction in spreading costs of $1.53/T (wet) of manure. The cost of the nitrogen loss from poultry manure exceeded the reduction in spreading costs by $5.10/T (wet).

- Composting of dairy cattle manure reduced the weight of manure to be spread by 58.0%, reducing land spreading costs by $1.74/T (wet) of manure. The reduced spreading costs for composted dairy cattle manure yielded a net benefit of $0.41/T (wet) manure after N losses were accounted for.

4.0 Recommendations for Additional Research

4.1 Introduction

Four of the research project reports contained recommendations for additional research. These recommendations are listed below as presented by the authors of the respective reports.

4.2 Manure Composting Techniques: Understanding Nitrogen and Carbon Conservation.

- The results of the study indicate that there 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.

- 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.

- 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.

- 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.

4.3 The Effects of Livestock Manure Application Methods on Water Quality, Focussing on Nitrogen and Bacteria Transport in Soil

- The tile drainage model (DRAINMOD 4.0) provided statistically good predictions of tile flow for both years at Sites 1 and 2 compared to measured flow values. Further study of the water quality components of the model that are currently under development may be warranted.

4.4 Application of Composted Organic Waste to Agricultural Land

(Note: The authors of this report presented a list of thirteen "Conclusions and Recommendations". Only those statements that identified the need for additional research are presented here. The conclusions have been incorporated into the discussion in preceding sections.)

- Further information is needed to assess the contribution of N mineralized from the composts over time to establish whether a nitrogen credit may be warranted.

- Compost has the potential to increase water holding capacity and improve soil infiltration rates, thereby reducing risks of soil loss due to water erosion. The impact of compost application on soil pore size distribution needs to be further investigated.

- The bench marked field sites provide an opportunity to obtain additional data on soil test levels. It would be useful to monitor the soil test levels at these sites in the future thereby establishing the fertility value of the compost applications to the farmer. To further evaluate the long term effects of the currently imposed treatments, continuation of the existing trials for an additional three years is recommended.

- Further understanding of the physical and chemical properties of the compost and corresponding impacts on the physical, chemical, and biological characteristics of soil when the compost is applied is needed to allow farmers to decide on the suitability of using a particular compost for a specific soil.

4.5 Assessment of the Influence of Manures for the Control of Soilborne Pests Including Fungi, Bacteria and Nematodes

- Despite all that we have learned about why some manures are effective against pathogens and others are not, and why a manure can be effective in one soil but not another, there remains significant gaps in our knowledge. Manures and soils differ significantly in their chemical and biological properties and thus different manure-soil mixtures affect soil microorganisms in different ways. More research needs to be done so we can understand more about such interactions. Manures should not be looked upon as waste materials but rather as under utilized energy sources that can benefit soil microbial diversity.

- Potato growers should pretest manures with their soils to determine the impact on disease incidence. This can be done on a small section of their field or with our laboratory assay.

- Methods for manure handling, storage, and application need to be reevaluated to maximize the potential benefit of these products.

4.6 Investigating Methods of Integrating Liquid Manures into a Conservation Tillage Cropping System

Based on the results of this on-farm research program, and general considerations of the other concurrent Green Plan studies, the following recommendations are made:

- All relevant Green Plan research into manure management and nutrient dynamics should integrated into a comprehensive set of revised manure management recommendations built on, or complementary to OMAFRA Publication 296.

- The program of field research and farm cooperator involvement in conservation tillage and manure management should continue.

- A series of manure management conservation tillage demonstration sites should be established to show the general farm population the wide range of manure management options in conservation tillage and demonstrate the flexibility and adaptability possible within a conservation tillage approach.

- Equipment manufacturers should be encouraged to conduct research and development in side-dress applications of liquid manure to allow a broader range of farmers to use this technique without having to make their own equipment modifications.

- The interaction between agricultural nitrogen use and rural groundwater quality should continue to be the focus of research and broad surveys, regardless of the source on nitrogen.

Schell and Alder also noted that the major drawback with on-farm research is the lack of experimental control and rigour. The main challenges encountered in their experiments were:

- A tendency of farmer cooperators to change experimental parameters. (However, the ability of farmer cooperators to identify and respond to limitations in the practices being studies was noted as being one of the strengths of on-farm research that should not be eliminated.)
- The demands placed upon the researcher when projects are spread out geographically. Because experimental procedures must be carried out simultaneously at several locations, the protocol must be implemented by different individuals. This can lead to inconsistency in experimental design and measurement. Tight, simple, experimental designs and good communication among all participants are essential.

A major benefit of this form of research was that farmers were able to evaluate the technologies being assessed and to provide immediate feedback.

5.0 Unresolved Concerns

Introduction

As discussed in Section 2.2, the report, *The Current State of the Art on Manure/Nutrient Management*, by Goss et al, included twelve priority areas for research or extension activities related to manure/nutrient management. The following sub-sections each contain a brief summary of the contributions of Green Plan Research activities toward addressing these priorities and an assessment of the issues that remain unresolved.

It should be noted that the tone of this section may seem negative because of the emphasis on unresolved questions. In fairness, these questions are very complex and it would not be reasonable to expect them all to be answered through only eight projects. As outlined earlier in this report, all of the projects made very real contributions to the level of understanding of these questions. Nevertheless, much more work needs to be done to answer the crucial questions that still remain.

1: Develop extension packages to assist farmers in making more effective use of nutrients in manure.

Development of extension packages was not part of the mandate of the Research Program. Significant contributions in this regard were made through other components of Green Plan, specifically, the Best Management Practices books, the Environmental Farm Plan and some Rural Conservation Clubs.

2: Establish a research programme involving engineers, animal scientists, agronomists, soil scientists and economists, to develop a comprehensive framework by which alternative manure management systems can be compared.

The need for such a comprehensive system to evaluate manure systems remains high. As illustrated by a number of the Green Plan projects, management changes that lessen the effects of manure on one aspect of environmental quality often result in a worsening of the effects on other parameters. No Green Plan project undertook to develop the means to comprehensively compare alternative manure management systems. However, results from a number of Green Plan Research Projects are being used as input into the development of a decision-support system through a project initiated by the Manure Systems Group of the University of Guelph, entitled *Development of a Comprehensive Expert System for Animal Manure Management*. The Manure Systems Group is an inter-disciplinary team, under the leadership of M. J. Goss and D. P. Stonehouse.

3: Establish the relationship between environmentally safe and the most profitable rates of manure application to cropland, taking account of the method and timing of

applications. Develop more acceptable manure application methods in conservation tillage systems.

Studies demonstrated the importance of the NH_4-N fraction of manure as the key indicator of the value of manure as a source of N for crop production and of the potential for N losses after application. The results also confirmed the importance of timing the application of manures with high NH_4-N content to coincide with the period of peak crop N demand in order to reduce the risk of N losses to the environment.

Because of the difficulty in tracking the fate in the soil of inorganic N from manure, it was not was possible to measure or predict the transformations of either inorganic or organic N in the soil. Thus, it was also not possible to establish the relationship between the most economical rate of application and environmental safety. Additional work is required to determine if these difficulties can be overcome.

The potential for contamination of tile drainage water through macro-pore flow of liquid manure after application in no-till systems was clearly demonstrated. Although contamination was reduced when the manure was injected into the soil, as compared to surface application, none of the application systems reduced contamination to a level below surface water quality guidelines, except in the driest conditions. Further work is needed to establish the combinations of application rates, methods and timing that would be suitable for use with the wide range of soil and environmental conditions experienced on Ontario farms.

An on-farm study of manure application methods demonstrated the feasibility of applying liquid manure in no-till situations from an operational point of view. However, this study provided little information about the environmental effects of applying manure using the application techniques that were being tested.

None of the Green Plan projects investigated the use of solid manures in conservation tillage systems.

Because of the limited duration of all the Green Plan projects, none was able to fully investigate the effects of regular manure applications to cropland over the long-term. More information is required about the effects of historical patterns of manure use on N transformations and on the levels of inorganic N in soil, from the perspective of both crop nutrition and the potential for leaching of nitrate to groundwater. Information is also required about the agronomic and environmental implications of continual elevation of soil levels of crop available phosphorus and potassium.

4: Develop the means of predicting the composition of the major types of poultry, pig and cattle manures, based on feeding regimes.

Adjustments in the level and degradability of protein in the diet of dairy cattle were found to be more likely to affect the form of the nitrogen excreted (i.e. urine vs. faeces) than the total amount. It would appear that dietary changes that increase the proportion of manure N excreted as urine could influence N utilization by crops, gaseous losses or leaching. More work is required before it will be possible to predict manure composition based on feeding regimes.

5: Improve nitrogen application recommendations for different crops, based on a soil N test, taking into consideration losses on NH_3 with different times and methods of application.

NH_3 losses during application were estimated as part of one study. These data add to the database of information relating to N losses and in time, will contribution to the development of predictive tools.

Crop response to manure N, applied at rates based on soil NO_3-N test recommendations, was measured in several studies. In most cases, the soil test accurately predicted the optimum rate of N, but there were inconsistencies indicating the need for further work. In particular, the results confirmed the limitations of the soil NO_3-N test for predicting the release of N from the organic fraction of previous applications of manure or from crop residues.

6: Develop practical, cost-effective methods for managing manure odours from farm systems. This should include seeking means by which the hazard to human or animal health from toxic gases, such as H_2S, can be relieved in different manure systems, and developing better engineered and economic manure management systems, that minimize gaseous losses from manure.

None of the projects investigated techniques to reduce or manage odours from livestock manures. One study did monitor gaseous losses of carbon and nitrogen from manures during handling, storage and applications. An extensive database of information was collected that, with further analysis of the data, may indicate possible strategies to pursue for controlling gaseous losses. However, it should be noted that the authors of that study concluded that because the majority of the N losses occur in the barn soon after excretion, the potential to reduce gaseous losses of N would appear to be quite limited.

7: Investigate the transformations of manure N following addition to soil to provide more accurate estimates of denitrification, mineralization and immobilization.

In a study to determine the extent and rate of the transformations of manure N in soil, denitrification, mineralization and immobilization proved to be impossible to quantify accurately because of the apparent disappearance of NH_4-N from the soil solution soon after application of either manure or urea. Because it was impossible to establish a base level of inorganic N in the soil, it was also impossible to determine the source of inorganic N in the soil or in the crop at later stages of the growing season. Additional work is required to see if the difficulties encountered in this project can be overcome.

Similar difficulties were experienced in estimating the contribution of available N from the organic N fraction of manures. In general, there appeared to be little early-season release of organic N from spring-applied manures. Release of organic N appeared to occur late in the growing season or in subsequent years.

8: ***Investigate and develop the ability to predict the transformations of manure N during storage and/or composting to characterize the impact on availability of N to crops, the potential for nitrate leaching and gaseous losses of NH_3, NO_x, CO_2 and CH_4.***

One study monitored the losses of carbon and nitrogen from manures during handling, storage and application in six distinct systems. The compositions of the manures at each stage of the system were also determined, as much as possible. An extensive database of information was collected that, with further analysis of the data, should provide insights into the transformations that occur and into their potential effect on nutrient availability.

Transformations in manure carbon and nitrogen during composting were monitored for 16 composting processes. The results of this study suggest that composting cannot be viewed as an effective means of conserving manure nitrogen nor as a cost-effective means to reduce the amount of material to be spread.

9: ***Examine the potential for reducing the nutrient content of manures by using improved feeding programmes, including use of feed additives.***

Adjustments in the level and degradability of protein in the diet of dairy cattle were found to be more likely to affect the form of the nitrogen excreted (i.e. urine vs. faeces) than the total amount. However, this area continues to appear to be worthy of further investigation, especially for monogastrate species.

10: ***Assess on-farm economics of different manure management systems in direct association with research on storage, application and utilization of manure.***

In one study, all costs and direct agronomic benefits associated with six distinct manure handling and storage systems were monitored in detail. However, because of the wide range of options available to farmers in designing and operating manure systems, much more data of this nature would be required to enable the prediction of the costs and benefits of alternative manure handling, storage and application systems.

11: *Assess off-farm costs due to environmental impacts, but not solely with respect to manure management. Information on environmental degradation associated with alternative manure management systems must be quantified to allow the costs to be determined*.

None of the Green Plan projects attempted to estimate the economic impact of the off-farm environmental effects of manure management.

12: *Develop the means by which the deterioration of livestock facility structures by gases produced from manure can be minimized.*

None of the Green Plan projects investigated means to minimize the deterioration of livestock facilities by gases released from manures.

Appendix A: Green Plan Research Report Executive Summaries

Current State of the Art on Manure/Nutrient Management

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COESA Report No.: RES/MAN-001/94

Executive Summary

This report has been prepared to determine the current state of the art of manure management in Ontario in relation to concerns in the farm community and amongst the general public. It is intended to serve as a guide for coordination of the research, extension and implementation programs needed to overcome current problems in manure management. A draft report was reviewed by Agriculture Canada, and this final version takes account of their comments. This version also includes the results of the assessment of priorities for research made by the University of Guelph Expert Evaluation Panel for Manure Management on 17 September 1993

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Following an introductory chapter, a detailed assessment of current knowledge is presented using a framework that follows manure from the point of excretion to the point of utilization in crops.

The third chapter presents areas of actual or recently completed research in Canada. The fourth chapter is a review of three manure systems workshops held at Woodstock, Port Perry and Kemptville. The workshops were intended to gather information on the views of the agricultural community on the perceived problems associated with manure management, and to solicit solutions.

The current knowledge base, together with the on-going research projects and the input from the agricultural community, provides the basis for identifying priority needs for research and extension. A priorized assessment of these needs is presented in Chapter five. Twelve key objectives were identified for research and extension needs on manure management in Ontario over the next five years:

1. Develop extension packages to assist farmers in making more effective use of nutrients in manure.

2. Establish a research programme involving engineers, animal scientists, agronomists, soil scientists and economists to develop a comprehensive framework by which alternative manure management systems can be compared.

3. Establish the relation between environmentally safe and most profitable rates of manure application to cropland, taking account of the method and timing of applications. This also requires the development of more acceptable manure application methods in conservation tillage systems.

4. Develop the means of predicting the composition of the major types of poultry, pig and cattle manures, based on feeding regimes.

5. Improve nitrogen application recommendations for different crops based on a soil N test, taking into consideration the losses of NH_3 with different times and methods of manure application.

6. Develop practical cost-effective methods for managing manure odours from farm systems. This should include seeking means by which the hazard to human or animal health from toxic gases, such as H_2S, can be relieved in different manure systems, and developing better engineered and economic manure management systems that minimize gaseous losses from manure.

7. Investigate the transformations of manure N following addition to soil to provide more accurate estimates of the denitrification ($N0_X$ gas losses), mineralization and immobilization processes that are agronomically and environmentally important.

8. Investigate and develop the ability to predict the transformations of manure N during storage and/or composting to characterize the impact on availability of N to crops, the potential for nitrate leaching, and gaseous losses of NH_3 and $N0_X$, together with $C0_2$ and CH_4.

9. Examine the potential for reducing the nutrient content of manures using improved feeding programmes, including use of feed additives.

10. Assess on-farm economics of different manure management systems in direct association with research on storage, application and utilization of manure.

11. There is a need to assess off-farm costs due to environmental impacts, but this should not be developed solely with respect to manure management. However, the information on environmental degradation associated with alternative manure management systems must be quantified to allow the costs to be determined.

12. Develop the means by which the deterioration of livestock facility structures by gases produced from manure can be minimized.

Nitrogen & Carbon Transformations in Conventionally-Handled Livestock Manures

R. G. Kachanoski, D. A. J. Barry, D. P. Stonehouse and E. G. Beauchamp

Environmental Soil Services, 605 Arkell Rd., Arkell, ON

COESA Report No.: RES/MAN-002/97

Interpretive Summary

One objective of this project was to investigate various manure storage and handling systems with respect to nitrogen (N) and carbon (C) changes during storage and handling. A literature review found few definitive studies done specifically on this topic. These transformations determine the nutrient content and losses from the handling system. Thus, a primary goal of the project was to measure C and N of the animal feed, fresh faeces, and the various states of transformation of the manure as it moved through the handling system. The magnitudes of the various losses of C and N between the handling stages were also measured. Thus, methods of estimating the mass balance had to be devised. Since the economics of the systems also had to be assessed the study was done on "operational sized units".

Six manure handling systems were chosen to track the mass balance of C and N for a defined set of inputs and outputs. The systems included; (1) solid poultry manure, (2) solid top-loading beef, (3) liquid swine (high water use), (4) liquid swine (low water use), (5) solid dairy, and (6) liquid alley-flush dairy. The study allocated considerable resources to chemical analysis, to form a reference database of chemical composition of manure from as many components of the different systems as possible. This characterization included aerobic incubation of sand-soil-manure mixtures in the laboratory to measure mineralizable C and N. Full nutrient analysis (N, P, K, C) are given along with selected analysis of C and N compounds (lignin, acid digestible fibre, volatile fatty acids, etc). The data given are average values for major time periods (fall, winter, etc), but sampling was usually done on a weekly or bi-weekly basis. Measurements of greenhouse gas flux rates were made to rank stages of the handling system with respect to their potential to generate these gases. Usually the greenhouse gas losses (except CO_2) were negligible with respect to mass balance of C and N. However, the magnitudes of the losses are important from an environmental perspective.

The fate of the C and N inputs varied depending on the manure, but there were also many similarities. The amount of N excreted as fresh faeces was consistently 70-80% of applied feed N. Final plant available manure NH_4-N amounts as a percentage of N inputs were (1) solid poultry manure = 7.5 to 10%, (2) solid top-loading beef = 8%, (3) liquid swine (high water use) = 38%, (4) liquid swine (low water use) = 40%, (5) solid dairy = 19%, and (6) liquid alley-flush dairy = 40%. Additional amounts of organic N were in the manure, but it varied from 1% (liquid swine) to 45%(solid dairy) of input N. Gaseous loss of N from NH_3-N volatilization was the major pathway of N loss. The loss occurred very quickly from fresh manure leaving few management options for reducing N loss.

A second major objective of this research was to provide a comparative benefit-cost assessment of the six manure-handling systems. A questionnaire was designed for collection of bio-physical and economic data from farmers, through on-farm interviews or mailing out. A spreadsheet system was developed to analyse the farm data and produce a profile of total annual manure production, total capital investment in manure-handling facilities and equipment, annual costs of ownership and operation of manure-handling, economic benefits from manure, and total net costs or benefits from manure operations. Five of the six farms displayed net costs of manure operations (i.e. costs exceeded benefits) ranging from $4.13 to $124.28 per tonne of manure applied per year. The sixth farm showed a net benefit of $0.06 per tonne of manure applied per year. These results concurred with previous research results, which typically showed a net cost for manure operations.

Results from this study are being used by a manure systems team at the University of Guelph to aid in development of an expert system for managing animal waste. The final manure generated from the different systems was used in a different study evaluating plant uptake of the manure nutrients. This study is a separate AAFC Green Plan report (Principle Investigator, Dr. E. Beauchamp, Univ. of Guelph), but the combination of the studies gives a complete summary of the fate of C and N and other nutrients.

On-Farm Manure Composting Techniques:
Understanding Nitrogen and Carbon Conservation

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COESA Report No.: RES/MAN-003/97

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 shed 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).

Transformations in Soil: Crop Response to Nitrogen in Manures with Widely Different Characteristics

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Executive Summary

A three-year field and laboratory study was undertaken to obtain a better understanding of the availability of N in manures that vary substantially in several important characteristics.

The manure characteristics focussed on in this study included kinds of manure (animal species), ammoniacal and total N contents, and kind of bedding. A major objective was to determine how these characteristics affect the release or availability of manure N especially during the early season in synchrony with corn crop N requirement. Also studied were fall vs spring applications of manures, the influence of soil acidity on N availability with different manures, and the effects protein level and degradability in the diet of dairy cows on manure N availability.

The research was conducted in five phases briefly as follows.

- corn crop response to fall- and spring-applied manures on the farms on which they were produced.
- corn crop response to fall- and spring-applied manures to compare rates of manure N and bedding additions of several manures at the Elora Research Station.
- corn crop response to residual N from manure and urea applied the previous year
- a laboratory study to determine the effects of soil acidity and liming on N transformations with several manures
- a laboratory study to determine the characteristics and availability of N in urine and faeces of dairy cows fed diets varying with respect to protein content and degradability.

The manures studied varied widely with respect to ammoniacal N content and included liquid dairy cattle (LC), solid beef cattle (SC), solid broiler chicken with wood shavings bedding (Pw), solid broiler chicken with straw bedding (Ps), and liquid swine (LS) manures. These manures represent the range of manures commonly produced on livestock farms in Ontario. Different rates of these manures were compared with different rates of urea in field experiments.

It was anticipated that manures with relatively low ammoniacal N content and high C/N ratio (e.g. SC manure) would result in a depression in available soil and manure N early in the growing season. Instead there was little or no increase in available N during this period. With LS manure having a relatively high ammoniacal N content, release of available N occurred well in advance of the major period of N uptake by the corn crop.

The ammoniacal N content of manures was the major determinant of N availability after application. The relative importance of the organic N fraction compared with ammoniacal N in manures could not be ascertained. It was observed that extractable soil inorganic N (nitrate and ammonium) was always less than ammoniacal N applied in manures or urea even within a few days following application in the spring. In some cases, as little as 30 to 40 percent recovery was obtained. This apparent disappearance was probably due to ammonia volatilization, fixation by clay and immobilization by soil microbes. The rates of release of some of this N during the first two months of the growing season were inconsistent from year to year. Where substantial available N was released, it was generally related to ammoniacal N applied with the manure. These differences in inorganic N recoveries coupled with variable release rates in the soil from year to year made it difficult to estimate the contribution of available N from the organic N fraction of manures, or to assess manure N dynamics in the soil involving N mineralization/immobilization.

In spite of difficulties in comparing different manures, it appeared that the SC manure behaved differently than the others. Monitoring of soil inorganic N and plant N uptake in the field along with a 15N study in the lab revealed that significant net immobilization of inorganic N occurred during the early part of the growing season. Furthermore, corn grain yields and N composition of mature plants suggested that there was a substantial release of N with the SC manure during the latter part of the growing season that was not evident with the other manures.

There was no clear indication that fall application of solid manures significantly reduced corn crop response compared with spring-applied manures. However, crop response to fall-applied swine manure was decidedly lower than spring-applied manure in two field experiments. Thus, it appears that the efficacy of fall-applied manures may depend on manure characteristics.

The kind of bedding (wood shavings vs straw) in the Pw and Ps manures or the additions of these beddings to SC and LC manures appeared to have relatively little influence on manure N availability.

The rate of nitrification (ammonium to nitrate) was slower in acid soils but increased to a near normal rate when these soils were limed. Other than slowing nitrification rate, soil acidity did not appear to exert any other influence.

The feeding of a diet with high protein content and degradability to dairy cattle resulted in a higher portion of excreted N present in the urine, but with little change in the faeces. Differences in diet had little influence on extractable inorganic N from either urine or faeces treated soil. Virtually all of the urine N was converted to ammonium and eventually to nitrate in soil whereas only a small fraction of faeces N was recovered as inorganic N. There was evidence that the concentrations of extractable inorganic N with the faeces treatment actually decreased during the incubation period. This indicated that the urine fraction of cattle manure contains almost all of the N immediately available to a crop.

It is anticipated that the findings of this study will be used to revise the manure application recommendations for crop production.

This project is related to another project entitled "Nitrogen and Carbon Transformations in Conventionally-Handled Livestock Manures" done by Environmental Soil Services. Various C and N characteristics of the manures are examined to a greater extent in that study.

The Effects of Livestock Manure Application Methods on Water Quality, Focussing on Nitrogen and Bacteria Transport in Soil

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COESA Report No.: RES/MAN-005/97

Executive Summary

In a joint effort between Agriculture and Agri-Food Canada, the Upper Thames River Conservation Authority and the Ontario Ministry of Agriculture Food, and Rural Affairs, a study was conducted with the following objectives:

1) Conduct field scale studies of liquid manure application technologies for different soil/climatic conditions;
2) Evaluate application technologies in no-till corn cropping systems in terms of sustainable crop productivity and subsurface water quality (nitrogen, bacteria);
3) Identify pathways and processes of nutrient and bacteria transport to tile drains and ground water with special consideration to preferential flow;
4) Validate tile drainage water quality model (DRAINMOD) with field scale data and use models to identify scenarios in which water quality standards are likely exceeded;
5) Develop liquid manure application recommendations for environmentally sustainable no-till corn crop production.

Three (two ha) field sites were selected in the Mixedwood Plains ecozone with contrasting soil textures (Site 1(medium)-silt loam, Site 2 (light)- sandy loam and Site 3 (heavy)- silty clay loam), systematic tile drainage and a history of no-till corn crop management. A no-till corn crop was planted in May at each field site by the farm cooperator using commercial no-till planters outfitted with various coulter and trash whipper arrangements to manage the corn residue. Starter fertilizer was applied with the planting units according to the farm cooperators preference with rates ranging from 5-36 kg N/ha, 6-14 kg P/ha, and 0-26 kg K/ha. Control plots were fertilized at the time of planting according to soil test recommendations. Soil and manure nutrient analysis conducted in about the 3rd week of June was used to compute the manure application rates that would be required to meet the crop N requirements according to soil test recommendations. The required liquid manure application rates ranged from about 56,165 to 71,890 L/ha. Crop performance (plant populations, time to silking, leaf tissue analysis, weed pressure, lodging, grain moisture and yield) was monitored from the time of emergence to harvest. The cost effectiveness of the manure application equipment in terms of draft and fuel consumption was measured with an instrumented research tractor from Agriculture and Agri-Food Canada.

The liquid hog manure was side dressed with a 6,800 L tanker around the fourth leaf stage by surface application and two injection techniques (conventional injection and injection modified by slight tillage in front of the injectors). Before application of the manure, bacteria tracer and strontium chloride (StCl) and potassium bromide(KBr) were added to the manure. The area being drained by each of 12 tiles (7 m by 100 m) was treated as an individual plot. Three treatments (surface applied, conventional injection, modified injection) and a control (inorganic fertilizer) were replicated three times, and crop and water quality response to the liquid manure application was monitored. On the day following the manure application, rainfall was simulated using a travelling gun irrigation system to apply about two to three cm of water to the plots over a 20 to 30 minute period.

Water quality samples were taken weekly throughout the growing season while the tiles were flowing. On the days of manure application and the simulated rainfall event, tile water quality samples were taken at 15 min to three hour intervals. An automated meterological station at each study site provided temperature, relative humidity, wind speed/direction, and 15 minute precipitation data. Soil and hydrologic data from the study sites were used to evaluate a tile flow prediction model (DRAINMOD 4.0). Two years of data were obtained for Sites 1 and 2 while a single year of data was collected at Site 3.

Agronomic results showed that the use of liquid manure at side dress did not impair performance of crop growth and development. The combination of side dressed manure N and the starter fertilizer N when applied at soil test recommended rates provided no-till corn yields that were not statistically different from the control treatments where inorganic fertilizers were used. There was also no significant difference in grain yield between the injection and surface manure application methods, although both plant populations and grain yields were marginally lower than the control plots in three of the five crop years. The tractor energy consumption data clearly showed the extra power required for the modified injection configuration over the conventional injection, however, the difference was relatively small and the modified injection configuration was considered practical from an energy consumption perspective.

Liquid manure application for all treatments resulted in increased rates of tile flow volumes within 30 minutes of application and returned to base flow conditions within three hours. Flow rate increases were greatest when the tiles were flowing prior to the manure application. The simulated rainfall event increased tile flows significantly by approximately 20 L/min at Sites 1 and 2 and by 7 L/min at Site 3 and did not return to base flows for several days. Flow increases in the tile drains after liquid manure application represent less than 3% of the applied manure, while tile drain flow increases after the simulated rainfall represent about 10% of rainfall volumes at Sites 1 and 2 and less than 5% at Site 3.

Tile water quality impairment was observed through increased turbidity and measured through the presence of bacteria and ammonium, for all manure application treatments within 7 to 30 minutes of application and continued for two to three hours. While the total volume of applied manure reaching the tile was small(<2%), water quality guidelines for bacteria, ammonium and phosphorus were exceeded for several hours. The presence of the bacteria tracer and chemicals in the tile water samples after manure application provided verification that manure was the source of contamination. The simulated rainfall event resulted in increased levels (but at lower concentrations then following manure application) of ammonia, bacteria tracer and phosphorus within 30 minutes and peaked within 60 minutes. Since the bacteria and chemical tracers were not detected in the tile water a few days after the rainfall event it appears that the impact of the manure application on the tile water quality is relatively short-lived.

The movement of the tracers strontium, bromide and chloride mirrored the bacteria movement to the tile drains both in time and concentration. The percentage of the applied non-reactive tracers bromide and chloride reaching the tile drains was found to approximate the percentage of liquid manure reaching the tile drains (<2% of applied). While <1% of the applied reactive tracer (strontium) was recovered in the tile water, it provides evidence that the macropore pathways are contributing to tile flows even under the unsaturated soil moisture conditions of the experiment.

Regardless of the method of liquid manure application, tile water contamination occurred both immediately following the manure application and the simulated rainfall event. In this no-till system, it may only be possible to stop tile water contamination by applying liquid manure during the growing season periods when soil moisture content is low and tile drains are not flowing.

The tile drainage model (DRAINMOD 4.0) provided statistically good predictions of tile flow for both years at Sites 1 and 2 compared to measured flow values. Further study of the water quality components of the model that are currently under development may be warranted.

Study results have led to the following recommendations for the application of liquid manure in no-till cropping systems:

i) Liquid manure nutrient testing is required immediately prior to manure application to establish accurate manure application rates.

ii) Side dress injection or surface application, at the fourth leaf stage, of liquid manure at soil test recommended rates will produce corn yields equivalent to conventional inorganic N fertilization.

iii) Conventional and modified injection equipment tested are recommended for use on medium to light textured soils.

iv) Side dressed injection applications should be considered to reduce impacts on tile water quality relative to surface applications especially on medium and light textured soils.

v) Apply liquid manure to tile drained land when the tile drains are not flowing to reduce impacts on tile water quality.

Application of Composted Organic Waste to Agricultural Land

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Executive Summary

The application of composted organic waste to agricultural lands has the potential to benefit agriculture in terms of improving soil quality, but information on the environmental and agronomic aspects of the use of compost is needed to allow farmers to assess the risks and benefits of its use. The purpose of this study was to evaluate the impact of composted organic waste applications to farmland on soil quality, crop growth and yield, and water quality in addition to assessing the economics of its application.

A series of laboratory and field experiments were conducted over a four year period to determine the feasibility of applying urban generated compost to farmland for crop production. Sites for the field trials were established on loam and clay loam soils on farms near Campbellville, Ontario. The finished composts used in the trials were a mixture of food, wood, paper and yard waste sources, and were obtained from two private composting facilities.

The yields of corn, soybeans, and all-grass hay were not generally depressed by the addition of compost. In fact, in some cases significant increases in production were attributed to compost. Incorporation of the compost was not demonstrated to be necessary.

Clear evidence of altered nitrogen availability was not demonstrated and it appeared that normal nitrogen application rates would be required in conjunction with the compost applications. The contribution of nitrogen mineralized from compost was not significant in this study.

Lettuce seed germination in sand-compost mixes in the lab indicated that high concentrations of compost in the mix and pure composts were not suitable for seed germination. Mixes containing less than 25% compost by weight were unlikely to inhibit germination provided that the composts were relatively biologically stable, or 'finished'. Such a phytotoxic effect of the composts may explain the clear

preference for fall applications of compost by both corn and soybeans which was evident in a single year trial comparing rates and time of application. However, the effect was most noticeable at rates of greater than or equal to 150 Mg (wet) compost ha^{-1}. The spring applications of compost in other trials in this study often improved crop success over that where no compost was applied.

Compost improved soil quality by raising the soil test index, thus reducing the requirement for phosphorus, potassium, and zinc. However, the two compost sources varied in their ability to elevate soil test levels in relation to the amount of total P they contained. Substantial increases in the organic carbon content of the soil were evident after only three years of applying the compost on both soils.

The higher organic carbon level in the soil, in turn, was related to a decrease in soil density with a corresponding increase in total porosity. A greater infiltration rate resulted from the increased porosity. A higher residual pore volume and increased water retention was observed for one of the composts.

After three successive years of compost application the metal content of the surface soil was not increased to levels of potential concern. Evidence of potential nitrate nitrogen contamination of ground water supplies was not found. Only sporadic indications of a few metals (Cu, Mn, Ni, Zn) in the water percolating through the soil profile were observed. Where they appeared they were not always associated with a compost treatment.

Some of the parameters measured were influenced to varying degrees by the source of the compost; a result of differing analysis of the two materials used in the experiments.

An economic analysis of the use of urban compost on agricultural land indicated that the value to the producer through yield and enhanced soil fertility would barely cover the application costs if the compost were delivered to the farm site at no cost. However, since benefits of compost application to the soil have been demonstrated which were intangible, such as organic carbon and increased porosity, a farmer could justify the cost of applying the material if it were delivered free to the farm site.

Assessment of the Influence of Manures for the Control of Soilborne Pests Including Fungi, Bacteria, and Nematodes

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COESA Report No.: RES/MAN-010/97

Executive Summary

The objective of this project was to determine if addition of manures to potato growing fields effects the severity of soilborne diseases. Two major soilborne diseases on potatoes in Ontario are Verticillium wilt caused by the fungus Verticillium dahliae and potato scab caused by Streptomyces bacteria. We used these two diseases as model systems to study the effects of manures on soilborne pathogens.

Results and conclusions:

1. We developed a rapid and reproducible laboratory assay for determining the effect of manures on pathogens in a particular soil. The assay consists of mixing a small amount of manure with soil in test tubes. The mixture is incubated and the effects on pathogen populations determined by making serial dilutions of the soil onto semi-selective media. This assay gave the same results as field experiments more than 90% of the time. This assay is simple and rapid and allows for evaluation of many manure-soil combinations. This will enable us to provide farmers with information as to where certain manures can be safely applied and under what conditions.

2. The effect of a manure on pathogens is determined by the soil to which it is added. Example: Chicken manure reduced the pathogen population in three out of four soils we tested. Thus, the fact that a particular manure reduces disease severity in one location does not guarantee it will do so at another location.

3. Soil moisture can influence the effect of a manure on pathogens. Example: Liquid swine manure decreased the viability of V. dahliae in dry but not in wet soil.

4. The most important factor that impacts on pathogens is the manure used. Example: In certain soils we found that fresh chicken and liquid swine manures decreased pathogen populations while solid cattle manure had no measurable effect. Wetting and aerobically incubating this chicken manure for one week destroyed its disease suppressive effect and may have increased the potential of potato scab. Thus, the impact on pathogens is determined by the source of manure and how the manure has been handled and stored.

Recommendations:

1. Despite all that we have learned about why some manures are effective against pathogens and others are not, and why a manure can be effective in one soil but not another, there remains significant gaps in our knowledge. Manures and soils differ significantly in their chemical and biological properties and thus different manure-soil mixtures affect soil microorganisms in different ways. More research needs to be done so we can understand more about such interactions. Manures should not be looked upon as waste materials but rather as under utilized energy sources that can benefit soil microbial diversity.

2. Potato growers should pretest manures with their soils to determine the impact on disease incidence. This can be done on a small section of their field or with our laboratory assay.

3. Methods for manure handling, storage, and application need to be reevaluated to maximize the potential benefit of these products.

Investigating Methods of Integrating Liquid Manure into a Conservation Tillage Cropping System

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COESA Report No.: RES/FARM-002/97

Executive Summary

This research project was funded by the Canada-Ontario Green Plan. Green Plan research activities were designed to promote environmentally sustainable agriculture within the farming community. The objectives of this project were established by the Green Plan Agreement Management Committee and included:

- **Objective A** - to determine the influence of the source (cattle, swine, poultry), amount and method of manure application on the nutrient status in the soil and availability to crop growth in a conservation tillage system; and

- **Objective B** - to investigate techniques of retaining the nutritive value of manure within the rooting zone in a conservation cropping system.

While the objectives of the project were focused on an investigation of methods of integrating manure management in a conservation tillage system, an important secondary goal was to produce information which would be directly relevant and of immediate use to a wide range of farmers. This was the underlying purpose behind conducting on farm research. The direct and significant involvement of farmers in designing, implementing and interpreting the research was seen as key to wider application of results and significant impact on the goals of the Green Plan.

Research experiments were conducted on field length plots at six farm sites in southwestern and eastern Ontario in the growing seasons of 1994, 1995 and 1996. The farms sites included two dairy farms, three hog farms and a poultry farm, which provided a range of manure types. The conservation cropping

systems in place at the six farms included three different modified no-till systems, an aeration tillage system using an Aerway™ implement, a chisel tillage system and a ridge tillage system. This broad range of tillage activities provided wide scope for testing manure application practices under a range of field conditions and timing requirements.

The experimental treatments included the application of 100% of the estimated nitrogen requirement from manure, 100% from inorganic fertilizer and a combination of approximately 75% of the nitrogen requirement from manure and 25% from inorganic fertilizer. The effect of the timing of manure application was evaluated through comparisons of treatments involving pre-plant and side-dress manure applications, and different side-dress application timings.

The effect of the treatments on the nutrient status of the soil was evaluated through soil fertility and soil N tests in spring and fall. The effect of the treatments on agronomic and crop productivity was evaluated using corn yield and weed counts at some of the sites. The effect of the treatments on farm management activities was evaluated by the farmer co-operators. Farmer impressions and comments were used extensively to evaluate the operational and economic feasibility of treatments.

As would be expected in a broad ranging field research program, results varied widely from year to year and from site to site. Difficult weather patterns, weed and pest pressures and changing farmer requirements posed challenges to the conduct of the research and the interpretation of results. However, within the statistical limits of field research, several conclusions were reached.

First, the research confirmed that liquid manure is an effective substitute for inorganic fertilizer in conservation tillage corn production. Manure application rates should be based on the nitrogen content of the manure and the nitrogen response of the field as indicated by the nitrate soil test. A wide range of manure volumes (2000 to 9000 gallons per acre) and total N applications (100 to 200 kg/ha) were evaluated. Where the total N applied was close to the maximum economic rate (MER) for the field, yields were similar for manure and mineral N sources. Calculating manure application rates was a straight forward matter based on manure analysis and soil nitrate. Delivering the required volumes of manure to the field under conservation cropping systems was not always straight forward. However, with typical farmer ingenuity, equipment was modified, practices were refined such that the manure was effectively and efficiently applied in most cases. Highly concentrated poultry manure and highly dilute dairy manure were extreme situations that tested farmer ingenuity and equipment flexibility. Yet even in these challenging situations, methods were developed to deliver the volume of manure necessary to provide the appropriate nitrogen amount to the corn.

Second, the research demonstrated that there is flexibility in the timing of the application of manure under conservation tillage. Pre-plant broadcast of manure and application of substantial volumes of manure to standing corn crops were both shown to produce similar yields as mineral N sources, with no un-surmountable operational difficulties. Once again equipment modification and farmer ingenuity played an important role in getting the manure nutrients to the crop at the right time and without crop damage.

Third, the research suggests that the groundwater implications of using manure in a conservation cropping system are similar to using mineral N sources. Residual soil nitrate levels after harvest were measured as an indicator of nitrate volumes potentially available to leach to groundwater. The results of these measurements varied widely from site to site, and some high, and potentially detrimental, levels were detected. However, the levels were similar whether the nitrogen was from manure or mineral sources. Based on the reasonable assumption that conservation tillage provides water quality benefits beyond conventional tillage, the use of manure in conservation systems is as environmentally sound as the use of mineral nitrogen, and seems to offer water quality benefits over the use of manure in conventional systems.

Fourth, the research showed conclusively that manure can be integrated in to conservation tillage in an effective and efficient manner that will be acceptable to farmers. All the farmers involved in the research were able to solve their problems and develop a manure management/conservation tillage system that worked for them. Based on their own whole farm accounting, taking into account all the costs and benefits specific to their own situation, 5 of the 6 farmers saw reasons to invest time and money in the systems. One farmer abandoned conservation tillage during the course of the experiment, but this decision seems to have been based on a wide range of issues not specifically related to difficulties with manure applications. Following three seasons of data collection, it is evident that no single system of manure application tested was the most efficient in terms of corn yield and minimizing residual N left in the soil profile in the fall. Conditions vary from farm to farm and it is essential that the manure application system be tailored to the requirements at each site. Ongoing on farm research and demonstration sites should be used to promote the concept of conservation tillage to a wider group of livestock producers.

An Investigation into the Management of Manure-Nitrogen to Safeguard the Quality of Groundwater

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COESA Report No.: LMAP-013/95

Executive Summary

In this study the fate of nitrogen from liquid dairy cattle manure and from composted cattle manure was investigated in two field experiments. These were conducted at the Elora Research Station of the Ontario Ministry of Agriculture, Food and Rural Affairs in collaboration with Drs. D.L Burton, E.G. Beauchamp and R.G Kachanoski, and at Winchester Research Station of Kemptville College of Agricultural Technology in collaboration with W.E. Curnoe.

In the first experiment carried out at Elora in 1991-1992, the soil was a Conestogo silt loam (Gleyed Melanic Brunisol). The particle size fraction of the Ap horizon consisted of sand (0.26), silt (0.55), clay (0.18); the organic matter fraction was 0.056, and the pH was 7.0. A sub-programme of a larger investigation was established with the objective of evaluating the risk of nitrate leaching from spring-applied manure, and identify how much of the mineral N from the liquid cattle manure (LCM) was incorporated into a corn crop. The contribution to N in the crop due to mineralization of soil organic matter was also investigated. Liquid cattle manure was applied in spring before planting corn on a randomized complete block design with fourfold replication. Corn was also planted in 1992.

In the second experiment carried out at Winchester in 1991-1993, the soil was a Dalhousie clay loam (Humic Gleysol). The particle size fraction of the Ap horizon consisted of sand (0.20), silt (0.52), clay (0.28); the organic matter fraction was 0.037, and pH was 6.3. Both liquid manure from dairy cattle and composted cattle manure were applied to ploughed-down alfalfa forage during late summer. The liquid cattle manure was injected, and the solid manure applied with a conventional spreader. The objective of the programme was to evaluate the risk of nitrate leaching over the fall, winter and spring from fall-applied manure, and evaluate whether this could be alleviated by timely agronomic practices without impairing the productivity of the land. The following ten experimental treatments were replicated fourfold in 4 randomized blocks, and test crops planted:

1. Alfalfa ploughed in; grass (Timothy); no manure; corn (Control)
2. Alfalfa ploughed in; grass (Timothy); 172 x 103 L ha-1 liquid cattle manure; corn (manure control - LCM)
3. Alfalfa ploughed in; 54 t ha-1 composted cattle manure; corn (CCM)
4. Alfalfa ploughed in; liquid manure; barley ; wheat (LCM + barley)
5. Alfalfa ploughed in; liquid manure; oilseed radish cover crop; corn (LCM + OSR)
6. Alfalfa ploughed in; liquid manure; 3.8 t ha-1 straw (dry weight) incorporated; corn (LCM+straw)
7. Alfalfa ploughed in; liquid manure, straw; oilseed radish cover crop; corn (LCM + straw + OSR)
8. Alfalfa ploughed in; liquid manure; winter wheat, corn (LCM + winter wheat)
9. Alfalfa ploughed in; winter wheat, corn (Control + winter wheat)
10. Alfalfa ploughed in; barley; wheat. (Control + barley)

Winter wheat was sown in the fall of 1992 on the plots where spring barley had been grown. In the spring of 1993 all plots not growing winter wheat were planted with corn.

The soil, soil water, and plant material was sampled to assess the availability of the nitrogen to crops, determine the presence of mineral nitrogen, including nitrate, in the soil, and determine the magnitude of the fluxes of nitrogen. 15N was used to trace the fate of the nitrogen present in the mineral fraction of the manures at both experimental sites. Tracer was also applied directly to the soil to identify the fate of mineral nitrogen produced by mineralization of soil organic matter prior to the application of manure, and to help identify potential sources of the nitrogen mineralized after manure application.

From 15N tracing, it was shown that the loss of mineral nitrogen from manure was greater during surface spreading and mechanical incorporation in spring than after early fall application to recently cultivated land followed immediately by hand-digging.

At Winchester, the soil at the time of manure application contained about 80 kg ha-1 mineral nitrogen. Only 16 kg ha-1 of mineral nitrogen was present in the 320 kg N ha-1 from the composted cattle manure, but of the 301 kg N ha-1 applied in the liquid manure 216 kg N ha-1 was mineral nitrogen. The volumetric water content of the top 100 mm of soil was approximately 0.15 at the time the manure was applied at the end of August. This was ideal for injection, but severely impaired the establishment of the grass. Growth of the winter wheat, oilseed radish was good in the fall of 1991. There was considerable growth of volunteer oats from seeds present in the incorporated straw, and wild mustard weeds grew on plots where liquid cattle manure was applied but no crop was planted in the fall. The uptake of mineral nitrogen (y, kg N ha-1) by all crops in the fall was directly related to the dry matter produced (x, t ha-1) according to the equation: $y = 43x - 10.2$ ($p < 0.001$). However, less than 10% of mineral-N applied in the liquid cattle manure was taken up by the sown cover crop. By the end of November much of the mineral nitrogen applied in the manure could be accounted for in the soil and plants. In un-manured plots there was 55 kg NO3-N ha-1, 78 kg NO3-N ha-1 in plots that received composted manure, and 134 kg NO3-N ha-1 in plots given liquid manure. All this nitrogen was at risk of leaching. However, from analysis of the 15N present in the soil it appeared that only about 60 kg N ha-1 had been derived from the mineral fraction of the liquid cattle manure, at least 50% of that fraction had already transferred into the organic pool of the soil. Remineralization of a small part of this fraction appeared to take place in early spring. But much of the 15N was still retained in the soil organic matter after two years. Only small amounts became available even in the second year.

The winter was cold and the snow cover was ended by heavy rain on 14 January, after which the temperature dropped sharply and killed the winter wheat crop.

There was little through drainage in the early spring of 1992, and all plots contained at least as much mineral nitrogen at planting in May than in November. Nonetheless, loss of 15N over this period was consistent with about 50 kg N ha-1 of the nitrogen present in the mineral fraction of the liquid cattle manure being lost from the soil over winter. The loss was about 25%; less where cover crops were grown and straw had been incorporated. Two further periods of leaching were identified in late spring and early summer. The maximum concentration of nitrate-N recorded in the water draining from the rooting zone for all treatments exceeded the Ontario Drinking Water Objective of 10 mg L-1 during one or both periods.

Growth of the corn crop on the microplots at Elora was good in both years, and there was no significant benefit to yield from application of manure compared with control plots in either season. Previously corn had been grown continuously on the site, so the lack of any effect on yield due to manure application in the first season was probably due to residual nitrogen from the management of those crops. The crops at Winchester grown on land injected with liquid manure produced significantly greater grain yields than the Control treatment when harvested by hand, except where straw had been incorporated or oilseed radish planted, but this was not converted into significantly more combinable yield. The yield of barley was influenced by the lodging that took place preferentially on the manured plots. Although earlier in the season nitrogen uptake by barley was greater on manured plots than on plots that received no manure, there was no significant difference at harvest. In the first cropping year the uptake by corn of nitrogen derived from the mineral-N in manure was greater from a spring application (39 kg N ha-1) than from a fall application (31 kg N ha-1). Uptake in the second season was about 5% of the mineral nitrogen in the manure at application in both cases. Only 16% of the nitrogen in the cover crop was transferred to the following corn crop. Evidence from crop sampling indicated that much of the nitrogen from the cover crop did not become available until after 20 August. This was also true for nitrogen from the organic fraction of the manure. There was no clear evidence that nitrogen was released from the organic fraction of the liquid cattle manure to the crop planted after the spring application. There was evidence that some of the organic nitrogen in manure became mineralized in the late summer, twelve months after application, when it was at risk to leaching over winter.

Nitrogen released by the ploughing of the soil under alfalfa-hay at Winchester provided sufficient nitrogen for the corn crop. The total nitrogen in the control treatment at harvest was 150 kg N ha-1. The crop on land injected with liquid manure contained 225 kg N ha-1, but this was not converted into significantly more combinable yield. About half of the additional nitrogen was present in the grain, but the remainder was in the harvest residues that contribute to the organic matter pool of the soil and therefore could be remineralized in the future. The results indicated that a value of 110 kg N ha-1, currently used in Ontario, was an appropriate credit for the underground residues of the alfalfa hay.

The Ontario soil nitrogen test suggested that the un-manured plots would require some fertilizer nitrogen to obtain the maximum economic yield, but all manured plots contained sufficient nitrogen. Since yields of corn were unaffected by the treatments imposed despite the indications of the soil nitrogen test, it is clear that adjustments are needed when making fertilizer recommendations based on the test to ensure that the nitrogen from crop residues (straw or cover crop) is included. The soil N test, which only takes account of nitrate-N, clearly underestimated the amount of mineral nitrogen available in the soil on all treatments.

Total loss over two cropping years, estimated as 15N not present in soil or crop, were 35% for the spring application and 40% for the fall application. The potential for leaching loss to occur in the period following the fall application was considerable. The application of manure in the early fall resulted in a large amount of mineral nitrogen in the soil, much of it in the nitrate form. In that experiment, the prevailing weather conditions were not conducive to leaching, but incorporating composted cattle manure at the same time of year did not have a significant impact on the soil pool of mineral nitrogen.

The study strongly indicated that applying liquid manure in the fall was potentially hazardous to water resources. The risk from leaching was high in the fall immediately after application, in the following spring, and in the next fall period, especially if cereals were grown in the spring. None of the fall treatments designed to immobilize nitrogen were adequate to reduce the risk significantly.

Combining straw incorporation and growing a cover crop that would be removed for forage in late fall appeared to offer the best solution to minimize loss of nitrogen from manure applied in early fall. However, in a wet fall the impact of this treatment might not be as great as the results for a relatively dry fall. Furthermore, smaller yields may also result.

Appendix B: Committees and Sub-committees Within the OASCC System.

Agricultural Economics

- Farm Management & Production Economics
- Marketing
- Resources Development
- Rural community Development

Agriculture and Food Engineering

- Food Engineering
- On-farm Energy and Processing
- Power and Machinery
- Rural Environment Engineering
- Structures and Buildings

Animal

- Aquaculture
- Beef
- Dairy
- Deer
- Equine
- Fur-bearing
- Goat
- Pork
- Poultry
- Sheep

Field Crops

- Cereal Crops
- Corn
- Forage Crop
- Oil and Protein Seed Crop
- Pulse
- Tobacco

Food Processing

Dairy Products and Processing

Fruit/vegetable Products and Processing

Grain/oilseed Products and Processing

Meat Products and Processing

Horticultural Crops

Agroforestry

Apiculture and Pollination

Berry Crops

Crucifer Crops

Ginseng

Grape and Wine

Greenhouse Flowers

Greenhouse and Protected Crops

Low Acreage and Specialty Crops

Marketing

Muck Crops

Nursery/Landscape and Turf

Pome Fruits

Potatoes

Stone Fruit

Tomatoes

Pest Management

Crop Protection

Livestock and Poutltry Pest Control

Weed

Soil, Water and Air

Agrometeorology

Soil Management

Soil Survey and Land Use

Water Management

Appendix C: Recommendations Relating to Manure/Nutrient Management Made by OASCC Committees Between 1992 and 1997.

Recommendations (by Committee and Sub-committee)	**Year of Recommendation**					
	97	96	95	94	93	92
Animal: Beef Sub-committee						
Seek solutions to environmental issues that recognize the economic and production realities of the farmer. Specifically, investigate novel approaches to livestock interactions with watercourses and management approaches that allow riparian areas to be used for production while minimizing environmental impacts. Also investigate novel approaches to manure management which recognize financial and operational concerns of the farmer while maintaining water quality.	X	X	X			
Animal: Dairy Sub-committee						
To support research into the assessment of different housing alternatives and their effects on animal welfare, profitability, producer welfare and the environment.	X	X	X	X	X	X
Animal: Swine Sub-committee						
To support research which assesses the impact of different manure handling and milking washwater disposal systems on the environment.	X	X	X	X	X	X
To evaluate the impact that swine production has on the environment in the areas of alternative manure storage, manure application, disposal (value added) and dead animal disposal and its effect on soil and water pollution.	X	X	X	X	X	X
To look for technology that will reduce any negative impact of swine production through the reduction or balancing of the nutrient content and reducing odour associated with swine manure and improved feed utilization.	X	X	X		X	X
To determine optimum of siting swine barns for odours management, disease transmission and the acceptance by the community.	X	X	X		X	
To conduct economic analysis on specific technical swine research ranging from breeding programs, herd health practices, manure handling systems, nutritional programs, etc.				X	X	X

Recommendations (by Committee and Sub-committee)	**Year of Recommendation**					
	97	96	95	94	93	92
Animal: Poultry Sub-committee						
Research to maintain environmental integrity and lower feed input costs, by reduction of nitrogen and phosphorous excretion through improvement of nutrient availability, better recycling of waste materials and better or alternate methods of manure disposal. (Broilers)	X	X	X	X	X	X
Research into decreasing the amount of nitrogen and phosphorous in poultry manure. (Layers)	X	X	X	X	X	X
Methods to reduce faecal output of nitrogen and phosphorous. (Turkeys)				X	X	X
Soil, Water and Air						
To determine methods of application, rates and effects on soil and plant growth of the application of manure in no-till systems, focussing on maximizing nutrient efficiency.	X					
Initiate research on the dispersion and diffusion of odours from livestock wastes to minimize rural/urban conflicts.	X					
Development of alternative methods of treating livestock and poultry waste that reduce odour, breakdown settleable solids and stabilize nutrients, especially nitrogen.	X					
Develop integrated management systems for nitrogen from fertilizer, legumes, manure and organic wastes in the agri-ecosystem.	X					
To develop an integrated approach for the management of water quality and nutrient for environmentally sustainable use of farm manure, green manure and agro-chemicals.	X					
Develop feasible methods and techniques to evaluate the effects of pollution control and remediation measures in agricultural/rural watersheds.		X				
Develop improved technical means and methods to properly interface the use of fertilizers in conjunction with livestock manures within the farm system.		X			X	
Determine optimum rates and application methods of organic amendments (including biosolids and crop residues) in farming systems for the improvement of soil quality.		X				

Recommendations (by Committee and Sub-committee)	**Year of Recommendation**					
	97	96	95	94	93	92
Investigate management systems to minimize contamination of air, surface and groundwater by nitrogen originating from fertilizers, legumes, manures and other organic sources, and by bacteria from manures and organic wastes applied to soils.		X	X	X	X	X
Study the movement of bacteria, toxins an nutrients through soil. Examine the quantitative and physical processes involved as well as the development and evaluation of best management systems to reduce the potential for ground water contamination.						X
Engineering						
Investigate the ability of solid manure spreaders to spread manure in a uniform coating on the land in order to: a) determine if equipment design allows for the uniform spreading of solid manure (not a recommendation in 1996) b) acquire information that can be used to determine the application rates. c) identify future research needs in the design of solid and liquid manure applicators	X	X	X	X	X	X
To evaluate and quantify the potential impact of large livestock operations on the rural environment.	X	X	X			
To investigate and develop methods of handling and disposal of large volumes of manure.	X					
Research on air quality in livestock building: Develop an economical warning device or devices to alert farm personnel that a hazardous gas is at a dangerous level; evaluate devices and develop procedures for dealing with gas hazards; examine in more depth the chronic effects of sub-lethal gas levels and evaluate the extent of this aspect of the problem.	X	X	X	X		
Determine the extent of metal corrosion problems in farm structures and develop a recommended course of action. An intensive survey of farm structures would be helpful in meeting this objective.	X	X	X	X	X	

	Year of Recommendation					
Recommendations (by Committee and Sub-committee)	97	96	95	94	93	92
To determine the feasibility of using: a) steel coating and/or concrete additives to inhibit the corrosion of reinforcing steel in such adverse situations as slatted floors, silos and manure storages. b) concrete sealants and coatings that may reduce concrete deterioration which in turn will protect the reinforcing steel.						X
To determine the relationship between various wood preservatives and the amount of corrosion occurring on the metal fasteners connecting these members in a typical farm building.						X
Encourage researchers to work on: a) the establishment of Threshold Limit Values (TLV) for the combination of air pollutant encountered inside farm buildings b) the development of Codes of Practices and/or Standards for indoor air quality and working environments.					X	X