RESEARCH SUB-PROGRAM

Current State of the Art
on
Manure/Nutrient Management

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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.

Current State of the Art on Manure/Nutrient Management

- Summary of Current Knowledge-base
- Information gaps and Concerns
- Areas of Active Research in Ontario
- Areas needing Research
- Summary of Manure Systems Workshops with Farmers

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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.

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.

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1 INTRODUCTION

1.1 Purpose

To determine the current state of the art of Manure/Nutrient Management in Ontario:with reference to literature from other areas of North America and Europe. To determine, with the farming community, their manure related concerns through a series of workshops.

1.2 Objectives

The objectives of this report are two fold. Firstly there is a need to identify the various areas of active research related to the management of manure systems and summarize the current knowledge base. The second objective is to identify areas of research needed to allow the efficient handling, storage, processing and utilization of animal manure on farms in Ontario.

These goals provide the basis for coordinating the research, extension, and implementation needed to overcome current problems in manure management. The ultimate aim should be a broader review that would furbish a detailed set of guidelines for farmers, through which responsible and educated decisions can be made with respect to the handling of manure.

1.3 Procedures

A data-base of relevant papers published available to the authors was compiled. A literature review was conducted by various means to determine recent knowledge in the topic. Earlier comprehensive studies were reviewed. The basis for classification is shown in Figures 1a, 1b, and 1c. This chart traces the handling of manure from the moment it is released by the animal until it is incorporated into the soil and used by crops. Areas where knowledge was considered satisfactory were marked. The effort was then focused on the perceived gaps in the literature. These gaps were also viewed against research needs identified by various organisations.

Information was sought from the scientific literature, the so-called grey literature, experience and consensus among experts in the field and the experience of farmers and their advisors. This included the Expert Evaluation Panel for Manure Management established at the University of Guelph. They provided practical input and helped evaluate recommendations. The membership of the panel is given in Appendix 1.

A series of workshops were held, in conjunction with the Ontario Ministry of Agriculture and Food, at Woodstock, Port Perry and Kemptville. Members of the agricultural community were invited to discuss problems in manure management and their solution. Representative farm operators presented information on their present manure management systems. A summary report of the workshops is included as part of this report.

Table 1a. The framework used to identify the engineering and agronomic facets of manure management

	ENGINEERING	AGRONOMY					
	Engineering	Nutrient management				Soil biology	Soil fabric
		Carbon	Nitrogen	Phosphorus	Others	Biological Components	Soil structure
EXCRETION	2.1.1	2.2.1.1.1	2.2.1.1.2				
INITIAL HANDLING & SHORT-TERM STORAGE	2.1.1	2.2.2.1.1	2.2.2.1.2				
LONG-TERM STORAGE	2.1.2	2.2.3.1.1	2.2.3.1.2				
PROCESSING TREATMENT	2.1.3	2.2.4.1.1	2.2.4.1.2	2.2.4.1.3	2.2.4.1.3		
TRANSPORT	2.1.4	2.2.5.1.1	2.2.5.1.2				
FIELD APPLICATION	2.1.5	2.2.6.1.1	2.2.6.1.2	2.2.6.1.3	2.2.6.1.3	2.2.6.2.1	2.2.6.3..1
UTILIZATION	2.1.6	2.2.7.1.1	2.2.7.1.2			2.2.7.2.1	

The numbers in the grids indicate the sections in the report where information on the respective topics can be found. Blank grids indicate areas where there is considered to be sufficient information.

Table 1b. The framework used to identify the environmental facets of manure management

	ENVIRONMENTAL CONCERNS						
	Water Quality				Air Quality		
	Carbon (BOD)	Nitrogen	Phosphorus	Bacteria	NO_x	CH_4	C
EXCRETION					2.3.1.2.1		
INITIAL HANDLING & SHORT-TERM STORAGE							
LONG-TERM STORAGE		2.3.2..1.1		2.3.2.1.3	2.3.2.2.1		2.3.2.2.2
PROCESSING TREATMENT					2.3.3.1.3	2.3.3.1.1	2.3.3.1.2
TRANSPORT							
FIELD APPLICATION		2.3.4.1.1	2.3.4.1.2	2.3.4.1.3	2.3.4.2.1		2.3.4.2.2
UTILIZATION							

The numbers in the grids indicate the sections in the report where information on the respective topics can be found. Blank grids indicate areas where there is considered to be sufficient information.

Table 1c. The framework used to identify the economic facets of manure management

	ECONOMIC CONCERNS			
	BENEFITS		COSTS	
	ON FARM	OFF FARM	ON FARM	OFF FARM
EXCRETION				
INITIAL HANDLING & SHORT-TERM STORAGE			2.4.2	
LONG-TERM STORAGE			2.4.2	
PROCESSING TREATMENT			2.4.2	
TRANSPORT	2.4.3		2.4.2	
FIELD APPLICATION	2.4.3		2.4.2	
UTILIZATION	2.4.3	2.4.5		2.4.4

The numbers in the grids indicate the sections in the report where information on the respective topics can be found. Blank grids indicate areas where there is considered to be sufficient information.

1.4 Background and Approach

As the world demand for animal protein shows an increase so too do the problems associated with the handling of the manure byproduct by the livestock industry, especially the quantity of manure produced in intensive production units. The handling of these large volumes of manure is of major concern today because of the potential for environmental contamination (Baldwin 1981; Lampkin 1990; Webber and Lane 1969; Webber and Elrick 1968 and Webber 1971).

Gaseous losses lead to enhanced concentration of ammonia and oxides of nitrogen in the atmosphere (McGarthy and Rajoratham 1972; King 1973; Kresge and Satchell 1960; Martin and Chapman 1952; Ryan *et al.* 1973 and Ryan and Keeney 1975). Ammonia release to the atmosphere has importance because it contributes to acidification of soils . Nitrous oxide is a potent "greenhouse" gas. Both groups of gases are soluble, and ammonia can be returned in precipitation and, together with NO_2, in dry deposition, thus adding to the soil mineral nitrogen fraction in an uncontrolled manner. For housed animals, there can also be problems associated with the comfort and health of human operators working in an atmosphere with heavy loads of irritant or noxious gases. There is also the possibility of adverse impacts on animal health and performance. This can obviously affect the profitability of an enterprise, and the need for careful design of barns to prevent the build-up of gases requires both an economic and an engineering approach to the handling of manure (Patni and Jui 1984).

Manure has to be stored for part of the year at least, and there are two basic approaches to storage: first is to keep the manure as dry as possible and store as solid or semi-solid material; second is to add cleaning water and produce a slurry which can be handled as a liquid. There are different implications for engineering and economics with these two systems (Barrington and Piché 1992; Paul *et al.* 1992). The possibilities for treating the manure during storage also differs markedly between the solid and liquid handling. Solid manure can be composted during storage, or simply allowed to break down (Goldstien 1991; Guidi and Poggio 1987). There can be major changes in the composition and the form of the nutrient fractions as a result (Baldwin 1981; Ngoody *et al.* 1971 and Wild 1988). Liquid manure can also undergo transformations, particularly resulting in the release of gaseous products (Webber and Lane 1969).

On most livestock farms the manure is applied to land, particularly cropped land (Baldwin 1981). Solid manure only lends itself to surface spreading which then requires a second tillage operations to incorporate. Liquid manure may be spread from a tanker, applied by irrigation, or injected using hollow tines linked directly to a tank or indirectly through a flexible hose. The application of liquid adds manure plus water; the latter increases the water content of the soil and may even result in flow through tile drains. Solid manure may not change soil water content.

Farm manure is a potentially valuable source of nitrogen, phosphorus and potassium and other inorganic nutrients, as well as a source of organic matter that can enhance soil properties when applied to the land (Kirchmann and Witter 1992; Krogdahl and Dahlsgard 1981; Lanyon and Beegle 1989; Stevenson 1982; Wild 1988; Zubriski and Zimmerman 1974). In some instances the addition of bulk organic matter through manure can be advantageous. Organic carbon compounds in manure can be transformed by microbial activity to form materials which are effective as binding agents in the soil (Patni and Jui 1987). Organic compounds in manure also enter the nutrient cycles within the soil in which plant nutrients are mineralized into forms which are readily available to plants. Leaching of soluble nutrients, such as nitrate, present within the manure or those released by mineralization can lead to the contamination of water resources that are used as potable water supplies, commercial fishing or for sport and recreation (Edwards and Daniel 1992).

Nitrate is of concern in potable water because of methaemoglobinaemia. Methaemoglobin is an oxidized form of haemoglobin which is incapable of reversibly binding oxygen in the blood. The irreversible binding of oxygen to haemoglobin results in a cyanosis, which mainly affects newly born infants (Fraser and Chilvers 1981; Rajagopal and Tobin 1989; Terblanche 1991).

From the brief account of manure given above it is obvious that manure management is multifaceted in that there are both direct and indirect impacts of the manure, and these operate at nearly all stages in the process. Preparing a literature review requires that all facets be considered. The economic and educational aspects impact on every area of manure management (Kelland and Stonehouse 1984; Narayanan and Stonehouse 1981). Due to the overwhelming volumes of literature available and the time constraints, considerable selectivity was exercised when writing this report.

2 CURRENT KNOWLEDGE BASE ON MANURE/NUTRIENT MANAGEMENT

2.1 Engineering

The engineering approach to manure/nutrient management is driven by goals similar to those for other sciences. Each discipline manipulates the operations, designs and practices to obtain the optimal solution. A list of current issues facing engineers and others was given by Fleming (personal communication, May, 1993) as:

- odours in barn, from storage and at spreading
- leaching of nitrate - N to ground water over time
- losses of NH_3 and bacteria to surface water at spreading of liquid manure
- soil compaction during spreading
- nutrient management - making most economical efficient use of nutrients while minimizing environmental impact

2.2 Excretion/ short-term storage

The purpose is to capture manure and transfer it to short term storage as quickly as possible. Fresh wet manure lying on an exposed floor leads to odour production. Such odours, vented through the ventilation system, irritate workers and neighbours alike. The odour is a complex mixture of chemicals, part of which are the nitrogenous compounds. Nutrients are conserved best when the manure is captured under a slatted floor. Barn ventilation does not then strip ammonia as much as can occur when manure is captured on flat floors.

The current information available through the Canada Plan Service (CPS) represents the latest in design for slatted floors and short term storage. The internal arrangements of pens, ventilation, animal walk alleys, feeders and waterers are all aimed at locating the defecation area to as small an area as possible. The design of slatted floors no longer present problems.

The complex organic matter on the floor as well as the corrosive gases derived from organic acids, bases and sulphur compounds can cause rapid decay in animal housing compared to other farm building structures (Mathiasson *et al.*, 1991).

Other gases are evolved from manure stored in pits under the barn floor. Low amounts of hydrogen sulphide (H_2S) gas are constantly evolved and high levels are generated upon mixing the pit contents. The major concerns are related to the evolution of hydrogen sulphide gas, when emptying the short-term storage, as it is toxic. Hayward and MacDonald, (1990) have identified these concerns and a sensor for H_2S has been developed as a warning device. Methane (CH_4) is also generated and expelled from the pit on mixing. Both H_2S and CH_4 are dangerous, the first to human and animal health and the second because of its explosive nature.

2.3 Long-term storage

Plans are available through the CPS for liquid and solid storage units. Various types of liquid storage are popular in Ontario with emphasis on open top storage. This is considered to be the most economical of construction. However, such storages collect rain and snow, while allowing free volatilization of ammonia.

Cracks in liquid manure storage can lead to ground water pollution although Barrington *et al.* (1991) show this to be small. The work documented by Barrington *et al.* (1987a, 1987b) showed that while clean water infiltrated through unsealed cracks in concrete storages from high water tables, the reverse flow was not so severe. When manure, at 10% solids, was in the tank the exfiltration was greatly reduced (by more than 10:1). In other work Barrington *et al.* (1991) stated that even though exfiltration was slow the products remained in the soil through which they flowed. Once all the soil surrounding a well became contaminated it was not possible to clean up. Jofriet (1992) has developed new plans for the Ontario Ministry of Agriculture and Food (OMAF) which attempt to present best practice in the design and construction of concrete underground storage. Open topped earthen storages being used. Unless properly constructed using impervious liners, manure liquids can leak into the sub-soil (Barrington *et al.*, 1991)

Liquid manure losses to ground water are the main concern. Placing a storage above ground is not really a solution because of cost, difficulty of filling and agitation. Earthen storage, in areas with shallow bedrock, pervious soils and/or shallow water table also endanger water supplies. Some townships require soils engineering to determine the depth of suitable soil otherwise artificial liners of various types are needed. Too small long-term storage (capacity less than 180 days) also require the spreading of manure on partly frozen ground and risk endangering surface water supplies.

The computer program M-CLONE (Fleming and Ogilvie, 1989a, 1989b; Fleming 1988) is available to assist in the choice of methods from defecation through to long-term storage and application. This knowledge-based program connects the user's preferences with stored knowledge on cost, labour use, odours, nutrient losses and potential environmental impact. The program runs on a personal computer (PC) and provides estimates of the ranking of the chosen system on a scale of 1 to 10. The user is able to change the weighting of the determining factors and obtain a new ranking based on these changes. The program is currently limited to liquid manure for swine production. A companion program integrates soil test information to determine nutrient needs for various crops in Ontario.

The perception of air quality is the single most important consideration in determining the location of manure storage systems according to Larson (1991). In Saskatchewan , the Research Council has determined practical separation distances in the absence of a precise definition of air stability and source strength of odour . It is generally felt that all the methods chosen to store manure and remove manure from the facility are determined by the initial capital needed to be invested in both time and labour. The Agricultural Code of Practice (1976) still governs the siting of storages in Ontario.

2.3.1 Processing & treatment

Little has been done in this area for the last 7-8 years. Prior to this, subsidies were available and methane was produced by several pilot plants including one at the Univ. of Guelph (Pos *et al.*, 1979, 1980, 1981, 1985, 1985). Treatment by aerobic means was done in the early 1970's but abandoned due to power costs. Such treatment resulted in a loss of both carbon and ammonia but reduced odours.

Composting of solid manure is being practised on Ontario farms (Fleming, 1993). While the basic requirements for composting are known, many on-farm operations do not achieve complete stabilization. Various recipes exist to mix the various carbon and nitrogen contributing materials.

Although some studies indicate that aeration of liquid manure is not worthwhile, there is no work on micro-aeration systems which introduce oxygen slowly (House 1993).

2.3.2 Transport

Transport of liquid manure is via pipelines, tanker-trailers and custom truck spreaders. The technology is well advanced but the larger tankers have caused problems with compaction. Equipment manufacturers seem willing to increase tanker size to meet market demands. Custom spreaders, with wide tires, prevent much compaction, but are not the first choice of spreading method for farmers due to cost and availability.

Safety of operators and compaction of fields are the main concerns. The mass of the tanker and contents often exceeds the capacity of the tractor brakes to stop a fully loaded unit. Semi-solid manure is not easily transported resulting in on-road deposition.

Fleming, (1990) analyzed the costs associated with commercial transport and placement of manure.

2.3.3 Field application

Application methods are via broadcast (of solid, semi-solid and liquid manure), irrigation and injection (of liquid manure). They are well developed and little, if any research is on-going, except perhaps by manufacturers in improving their spreaders. There is a need to provide injectors with more rapid throughput capacity. Broadcast without incorporation and irrigation, two very popular methods, have high losses of ammonia from spread manure. Injection is being recommended to reduce the losses but reduces the amount which can be applied per hour. The small window of time available to most farmers in the spring often mitigates against use of this method. Poor distribution patterns result from all types of manure spreaders due largely to the nature of the material. Problems have also been associated with the use of injection on rolling topography. Fleming (1991 1992a, 1992b) identified macropore flow of manure liquids into subsurface drains on spreading. Pre-tillage is being incorporated into new machine to prevent macropore flow (Houle Mfg. and Husky Mfg.). Compaction from spreading equipment, always a problem, is being reduced by new machine design as well (tankers with tracks now being made by Husky Mfg.).

2.3.4 Utilization

Except as crop nutrient material, and/or biogas generation feedstock, there has been little work by engineers on utilization of manure. Biogas generation, of course, only uses part of the raw material, reducing the carbonaceous material by 50%. The remainder of the solids must still be spread on crop land.

	-Floors	-Concrete (solid system) -Dirt (Solid system) -Paved (Solid system) -Slatted (Liquid system)
Collection-	-Scrapings	-Scrapers, gutter cleaner, front-end loader, cable scraper
	-Lot Run off	-Drainage design, storage
Transport to Storage-	Stacker, front-end loader, pumping	
	-Liquid	-Concrete -Steel -Earthen
Storage-	-Solid- Stack	-Roofed -Unroofed
	Pit	-Concrete -Earthen
Solid Separation-	-Sedimentation, centrifuging, screening and filtering	
	-Liquid and Slurries	-Chopper/open impeller pump, piston pump, helical rotor, submerged centrifugal pump, positive displacement gear type pump (for transport), paddle wheels with vertical shaft, inclined auger, vacuum tanker (agitation equipment), tank wagon with injectors, terrogator, irrigation systems (for spreading.
Transport and Spreading	-Solid	-Box spreader, open tank spreader, dump truck, earth mover or wagon, terrogator.

Figure 1 Engineering alternatives in manure handling.

2.4 Agronomy

There is a huge volume of information on the agronomic value of manures although it is only in recent years that greater attention has been given to the value of the various nitrogen components in manure. Richards and Martel, (1991) included a short review of manure and agronomic research done in Canada, including that involving nitrogen. Other recent reviews have been done by Paul (1991) and Paul *et al*. (1990) including pertinent research done in Ontario and Quebec along with other research on manure done elsewhere. Only selected references will be mentioned below with respect to nitrogen, to provide some idea of current knowledge and research requirements.

Although carbon is not a plant nutrient derived from the soil, it is important as a component of the soil organic matter and the many attributes it contributes to soils. The role of manures in soil organic matter levels has been well covered (Johnston *et al*. 1989). Much of the information on carbon contributions and dynamics in livestock farm systems was reviewed by Beauchamp and Voroney (1993) so that many of the comments presented below are based on perceptions from this study. A short review of waste carbon cycling was presented by Gilmour *et al.,* (1977).

There are no agronomic issues involving nutrients other than nitrogen associated with excretion, storage, or transport of manure. Phosphorus, potassium and nutrients other than nitrogen are not lost by volatilization so the content in manure will not change provided there is no loss of bulk material.

2.4.1 Excretion

2.4.1.1 Nutrient management

As the quest for more efficient nutrient management continues we need to be able to predict the concentration of the various nutrients in manure (nutrients of main concern are nitrogen in mineral - NH_4^+ - and organic forms; phosphorus, potassium and carbon). By knowing the nitrogen content of the animal feed, it is possible to predict the quantity of nitrogen excreted for some groups of animals at least (Kirchmann and Witter, 1992). The total of manure N may be calculated by apportioning the N in the feed between N assimilated by the animal and that excreted.

2.4.1.1.1 Carbon

Not much is known about the quantities of C excreted in relation to feed C intake. Beauchamp and Voroney, (1993) estimated that from 15 to 50% of the feed C may be excreted depending largely on the kind of feed, livestock and feed quality (digestibility). The degradability of excreted manure C depends on the bedding with which the faeces and urine may come into contact. For example, wood shavings are much less readily degradable than straw. The degradability of manures is not well understood especially as it relates to N release dynamics when applied in the field.

2.4.1.1.2 Nitrogen

Nitrogen is excreted both in faeces and urine and occurs in a large number of forms ranging from urea or uric acid to complex cellular constituents. The major form of N in urine is urea (uric acid in birds) although Whitehead *et al*. (1989) and Thomas *et al*. (1988) have shown that up to 35 percent may be present in other forms such as allantoin, hippuric acid, and creatinine. In general, it is estimated that 40 to 70% of the N in poultry manure is in the form of uric acid while about 50% is in the form of urea (Krogdahl and Dahlsgard, 1981). The relative agronomic importance of these different forms of N is unknown. It is believed that soon after excretion urea or uric acid is rapidly transformed to ammonium which is considered to be the form readily available to crops. The remainder of the manure N is considered to be slowly available over years.

Depending on the type of livestock and feeding regime, the recovery of feed N in manure ranges from 72 to 89 percent (Azevedo and Stout, 1974). Thus it would seem that there is some latitude for increasing the efficiency of N recovery thereby resulting in less N in wastes. It has been suggested (Paul and Beauchamp, paper in preparation) that improvement in animal use efficiency of N is more desirable than increased efficiency of manure N recovery by crops, because less N is released into the environment. Further research is needed in this area.

Further investigation into the differences in nutrient content of manures is needed. Table 2, illustrates that the composition of manure varies between species, and values are known to be dependent on diet. The lignin-protein complexes and hemicellulose content between ruminants and non ruminants will vary due to the ability of the former to break down cellulose, sugars and complex starches within the animal (Maclean *et al*. 1983). Thus the manure of non-ruminants will tend to be higher in cellulose than that of ruminants, which have a high bacterial content. In addition to species and feed, the nitrogen concentrations in different manures depends on the health of the animals, the bedding content, and the amount of water added (Beauchamp, 1983). Models for prediction of the available N are required, and these must take account of the transformations that occur during short and long term storage. The consistency of manure depends on the type of livestock as well as the contents of the feed.

Table 3 shows the range of nutrient content in compost.

Table 2. Characteristics of different types of manure.

Type of dung	pH (H_2O)	% of nutrient		
		N	P	K
Cattle (solid) (liquid)	7.4	0.21-1.00 0.04-0.61	0.02-0.34 0.01-0.15	0.14-1.44 0.02-0.58
Pig (solid) (liquid)	6.5	0.13-1.35 0.01-0.78	0.01-0.62 0.01-0.33	0.10-0.75 0.01-0.49
Poultry (solid) (liquid)	5.9	0.19-5.55 0.42-0.90	0.02-2.10 0.07-0.48	0.09-2.30 0.13-0.39

Sources: Beauchamp,1983; Fraser, 1985; Kirchmann and Witter 1992.

Table 3. Typical nutrient content of finished compost.

Nutrient content	
Nutrient	**Content** (% dry weight)
Nitrogen	<1 - 4.5
Potassium	0.5 - 1
Phosphorus	0.8 - 1
Calcium	2 - 3
Magnesium	2 - 3

Source: MAFF, 1993.

2.4.2 Initial handling and short term storage

2.4.2.1 Nutrient management

2.4.2.1.1 Carbon

It is expected that microbial degradation processes continue following the voiding of faeces and urine but little is known about the C transformations that occur in the short term. For example, the differences between liquid and solid manure are not known although it is known that liquid manures contain more readily decomposable C compounds (Paul, 1991). These readily decomposable C compounds are presumably rapidly decomposed in "aerobic" solid manure systems. The C dynamics in different manures have not been studied.

2.4.2.1.2 Nitrogen

The transformation of urea and possibly other compounds to ammonium occurs relatively rapidly. This was evident in the study by Burton and Beauchamp (1986) where substantial quantities of ammonia were lost in swine barns before the manure reached storage. The loss varied from 5 to 27% of the excreted N, depending on the duration of the residence period in the barn, the temperature and the extent of ventilation (Beauchamp and Burton, 1985). A full assessment of different manure systems is needed to determine the extent of ammonia losses for each, and ways in which these losses may be reduced.

2.4.3 Long-term storage

2.4.3.1 Nutrient management

2.4.3.1.1 Carbon

It has been observed that about one-quarter to one-third of manure C may be lost as CO_2 or CH_4 during normal storage periods (Patni and Jui, 1987; Vanerp and Vandiyk, 1992). Thus C transformations are obviously occurring but there is little understanding of the processes. The aeration of the manure is an important factor in determining carbon loss (Table 4). Further research is needed to determine the magnitudes of C losses with different manure storage systems. Moreover, whether C losses occur as CO_2 or CH_4 is extremely relevant question in relation to greenhouse gas emissions and global warming.

Table 4. Organic matter, nitrogen and carbon losses during incubation of animal dung at 25EC for 7 months.

Type of dung	Organic Matter Losses (%)	C Losses (%)	N Losses (%)
Cattle			
Fresh	0	0	0
Anaerobic	15.4	19.5	0†
Aerobic	26.6	27.9	0.1
Pig			
Fresh	0	0	0
Anaerobic	16.9	25.8	0†
Aerobic	47.1	51.4	23.4
Poultry			
Fresh	0	0	0
Anaerobic	40.1	43.7	7.5
Aerobic	57.9	58.0	76.5

†Recovered amounts of N were larger than initially present, which may be due to non-symbiotic N_2 fixation. Source: Kirchmann and Witter 1992.

2.4.3.1.2 Nitrogen

With respect to ammonia losses, many of the comments in section 2.2.2.1.2 also pertain to this section. In general, the extent of ammonia loss depends on the aeration of the manure, and is proportional to exposure of the manure to the atmosphere (Table 4). Thus covers or crusting of liquid manures or toploading vs bottom loading of solid manure storages or surface to volume ratio will influence the losses of ammonia. The extent of these losses is unknown, or not easily predictable, so that further research is needed. Some loss of manure N, especially ammonium, may occur by leaching from earthen storages (Miller *et al.*,1990) but this is not considered to require further research.

N transformations that occur during storage are not well understood. The effects and extent of microbial activity on N dynamics need to be researched. Little is known about the changes in organic

N or mineral N during storage of liquid or solid manures. Yet, as was noted earlier, significant losses of manure C may occur as CO_2 or CH_4. The accompanying N transformations in different manures, and how they affect availability of manure N, are not known.

Data collected on the variability in the concentration of nitrogen and other nutrients in animal slurry stored in farm tanks would be more useful if the following were more closely monitored:

(1) the concentration variability with storage time and

(2) the concentration variability at varying depths within the tanks. For example, slurry depths of less than 1m had consistently lower concentrations than that at greater depths (Patni and Jui, 1987).

The information would then allow a better understanding of the various biochemical changes taking place, and for the controlling factors to be better quantified.

2.4.4 Processing & treatment

2.4.4.1 Nutrient management

2.4.4.1.1 Carbon

The most common treatment that manures may undergo is composting. It is commonly believed that up to 50% of the manure C may be lost during the composting process. It is not clear what factors are involved in C loss or associated N losses and the extent of their effects. In any case it is believed that it is better to apply raw (fresh or non-composted) manure to soil and allow decomposition to occur in the soil. Besides stimulating the microbial population, this should improve soil structure development and stability.

2.4.4.1.2 Nitrogen

The process of greatest concern currently is composting of manure. It has been amply demonstrated by Paul (1991) that the availability of N in cattle manure compost is much lower than in the raw manure, although release of N appears to continue for several years to a greater extent. Although manure composting may be a questionable means for managing manure, there is a need for a better understanding of the reasons for reduced N availability. It is evident that N transformations and ammonia losses occur during the composting process. It is not clear how composting conditions and the composting mixture affect these transformations and hence N availability to crops. It is believed that significant N losses may occur if the C/N ratio is too low (e.g. 20-30) but the optimum is not known. During composting about 50% of the organic matter 20-30% of the nitrogen, and 40% of the potassium content of manure can be lost if manure is windrowed without covering (Vogtmann and Besson, 1978; Lampkin, 1990).

Composting is often cited as a way of stabilizing the nitrogen in manure and improving its handling characteristics, but the loss of N in the process may outweigh the potential benefits. Nonetheless, harmful bacteria and unwanted weed seeds will be killed. There is also a major reduction in the bulk volume for economy of transporting manure over greater distances.

Another option for processing manure is biogas production. In this process, much of the manure N is converted to the ammonium form and may be applied in the residues. Alternatively, the residues may be fed to livestock to provide "single cell" protein. This has been found to be an inefficient source. Further comments will not be made because this process is currently not economically feasible.

In the past, much effort was made employing aerobic treatments to reduce manure odours (e.g. Pos *et al.* , 1971). Besides being costly, N losses are enhanced by ammonia stripping or denitrification of nitrate formed by nitrifiers in liquid manures. This loss of N is agronomically important. If, in the future, aerobic treatment is reconsidered as a feasible option, research will be needed to develop a means to conserve N.

From time to time, special concoctions have been promoted as ways to "stabilize" N in manures during storage. There is no scientific evidence to show that such products are effective to any significant extent for any suggested purpose.

2.4.4.1.3 Phosphorus and Other Nutrients

The availability of phosphorus and other nutrients may change during composting or other processing. There is little information available to address this issue but the change is not likely to be nearly as great as that for nitrogen.

2.4.5 Transport

2.4.5.1 Nutrient management

2.4.5.1.1 Carbon

There is nothing especially relevant about manure C and transport except the quantities involved. The quantities of manure to be transported would depend on the proportion of feed C emitted and the extent of gaseous losses that occur during storage.

2.4.5.1.2 Nitrogen

There is little concern about manure N with respect to transport from livestock facilities to the field. Some thought is being given to pumping manure to earthen storages but this is mainly of engineering and economic concerns.

2.4.6 Field application

There are two basic systems for applying liquid manure to arable land. First is surface spreading using irrigation guns or distribution from a tanker. Best management practices require that the manure be incorporated within 24 h of application (Taylor *et al*., 1993). The second system is direct injection. The manure is placed below the soil surface using a hollow tine preceded by a coulter to cut through the residues. The injector system can be mounted directly behind a tanker, or set on a tool bar connected to the three-point hitch of a tractor and linked to a stationary tanker via a flexible hose. The availability of nutrients, particularly nitrogen, differs between the two basic systems for manure application, mainly because of differences in the potential for gaseous losses (Beauchamp, 1986).

There is also interest in the fate of micro-organisms that are present in manure, especially pathogens, when the material is applied to the land.

Application methods are of critical importance in conservation tillage systems, particularly for no-till. Conservation tillage, which does not involve soil inversion and leaves 30% residue cover on the soil, is practised on about 19% of cropped land in Ontario (Lammers Helps, H., 1991, personal communication). About 5% of crops are grown using no-till. Although adoption of no-till is not extensive, manure management in conservation tillage systems poses particular problems which will be discussed in detail in the following sections.

2.4.6.1 Nutrient management

2.4.6.1.1 <u>Carbon</u>

Aside from the quantities of manure C applied, there is the question of manure C quality or availability to decomposing organisms in the soil. The contribution of manure C to the C (organic matter) in the soil may not be as great as commonly perceived although it is nevertheless important in the C economy of a livestock farm (Beauchamp and Voroney, 1993). The soluble carbon content of calcareous soils increased due to the application of pig slurry. The increase varied between soils, but tended to be greater for larger slurry additions (Bernal, 1991).

2.4.6.1.2 Nitrogen

Paul *et al.* (1990) reported on N budgets at two research stations, and indicated that approximately one-third of the total N input was lost. The agronomic activities on these two stations were considered typical of those on most livestock farms in Ontario. Most of the N loss occurred from ammonia volatilization either from livestock facilities or from manure following application in the field. Significant ammonia losses were reported by Beauchamp *et al.* (1982) as well as in many other studies in Europe and North America (Paul *et al.* , 1990). These studies have suggested that up to 100 percent of the ammonia present in applied manures may be lost within a few days to a few weeks. The three most important variables which influence volatilization appear to be temperature, soil pH and soil texture. The relative humidity and the initial soil moisture also affect volatilization to a lesser extent.

Ammonia can be readily lost from surface applications by volatilization (Beauchamp, 1983; Thompson *et al.* 1987). In contrast, the gaseous losses from manure after injection mainly result from denitrification (Thompson *et al.* 1987). Overall the total nitrogen available to crops is generally greater after injection than after surface spreading (Paul, 1991). The loss of nitrogen by volatilization is considered more fully in Section 2.3.

There are marked differences between methods of manure application in the loss of ammoniacal nitrogen to the air (Table 5). However, as indicated in Section 2.3., these losses are extremely variable. There are considerable problems associated with deciding the appropriate time to apply manure. These include assessing the risks from soil compaction, likelihood of run-off, and volatilization.

The timing of manure applications is critical both for the availability of nitrogen to crops, and on the potential for environmental impacts. As manure storage on many farms is limited, the common periods for application are the fall, winter and spring. In spring applications may be as a pre-plant fertilization or as a side- or top-dressing. The experimental evidence shows that compared with spring applications, manuring land in fall or winter results in lower recovery of applied nitrogen by the crops, and greater risk of leaching and denitrification (Table 6). There does not appear to be any major interaction between application systems and timing. The development of future strategies for manure management should therefore concentrate on spring applications.

Tillage practices are also likely to influence the nitrogen losses at the time of application. All the evidence points to less porosity, particularly less air-filled porosity, under conservation tillage (Douglas and Goss, 1987). In some cases this is offset by greater continuity of larger pores so that infiltration rates may be little changed compared with conventional tillage. However, the smaller volume of pores under no-till results in less potential for the temporary storage of water in the topsoil, and this may shorten the time to ponding and induce more surface runoff compared with conventional tillage (Kachanoski *et al.*, 1992). As a result, heavy rain shortly after manure is spread may result in more nitrogen being lost under reduced tillage than under conventional tillage.

There are rapid methods to measure the ammonia content of manures in storage (R. Fleming, personal communication), but the ability to predict losses following application is far from complete. This is important because it has been determined that the ammonia-N fraction in manures is considered to be readily available to crops, but the remaining organic N fraction may be only marginally available in the year of application (Beauchamp, 1986; Paul, 1991). Immediate incorporation or injection of manures are considered necessary to minimize these losses. Nevertheless, this is not always possible. A system or procedure needs to be developed to assist farmers in predicting the ammonia loss that may occur following application.

Table 5. Comparison of different methods of manure application on the losses by volatilization of ammonia (% of applied nitrogen).

Method of Application	Type of Waste	% Nitrogen Lost 0-7 days
Broadcast	Solid Liquid	15-30 10-27
Broadcast with immediate cultivation	Solid Liquid	1-5 1-8
Injection	Liquid	1-5
Sprinkler irrigation	Liquid	14-37

Source: Fleming, 1988; Meisinger and Randall 1991; Van der Molen 1990a.

Table 6. Sinks for N following application of slurry in three treatments to grassland in winter and spring in the UK: results corrected for the appropriate control plots. Values in parentheses are the amounts of N expressed as % of the total N applied. Data from Thompson *et al*. (1987).

	Nitrogen Sinks†			
Application	Apparent Recovery in Herbage	NH_3 Volatiliz. Loss	Denitrific. Loss	G Sinks
Winter Experiment	S)))))))))Q kg N ha^{-1} (%) S)))))))))Q			
Surface spread slurry	49.0 (19.8)	77.1 (30.8)	29.9 (12.1)	156.1 (62.9)
Injected slurry	82.7 (33.4)	2.1 (0.9)	52.7 (21.3)	137.5 (55.4)
Injected slurry † nitrapyrin	90.1 (36.3)	2.1 (0.9)	22.7 (9.2)	114.9 (46.3)
CV‡	17.0% -	25.3% -	98.2% (42.6%)	--
Spring Experiment				
Surface spread slurry	66.9 (25.5)	53.0 (20.2)	4.5 (1.7)	124.4 (47.5)
Injected slurry	93.9 (35.5)	2.4 (0.9)	17.7 (6.8)	114.0 (43.5)
Injected slurry † nitrapyrin	109.9 (42.0)	2.4 (0.9)	14.0 (5.3)	126.3 (48.2)
CV‡	13.8% -	21.1% -	182% (74.8%)	--

† In both experiments leaching losses from all treatments were negligible

‡ Coefficients of variation determined as follows:

Apparent recovery: from the total apparent recoveries for each of the four plots for the three treatments in each experiment.

NH_3 volatilization: from the total NH_3 loss determined for each of the three tunnels used for the surface application treatment.

Denitrification: the average coefficient of variation for all denitrification measurements in each experiment. In parenthesis the average for values greater than 0.10 kg N ha^{-1} d^{-1}

2.4.6.1.3 Phosphorus and other nutrients

Increasing the amount of cattle manure applied to soils in Alberta over a period of 11 years increased the total phosphorus content of the soil and the available phosphorus (Chang *et al.* 1991). From agronomic considerations, one would want to apply only as much phosphorus, either as manure or fertilizer, as is required for most economic crop production. Current recommendations (OMAF Publication 296) assume that 40% of the phosphorus in manure is as available in the year of application as commercial fertilizer. This assumption has not been tested thoroughly but is probably adequate for the purpose.

In many cases, if not most, where there has been a history of manure application, the phosphorus available in the soil will be adequate for production of field crops, so no additional phosphorus would be needed. No economic benefit should be attached to the phosphorus in the manure in these cases. Addition of manure will further increase the phosphorus level in the soil which may be undesirable from an environmental standpoint. Thus there may be an economic disadvantage to manure application. These aspects are site specific, depending on the soil available phosphorus.

Current information is adequate for management of manure phosphorus.

Manure also contains significant amounts of micronutrients and heavy metals. The zinc content of the soil increased in proportion to the amount of manure applied, but copper did not accumulate (Chang *et al.*, 1991). Soil pH also decreased due to the application of cattle manure (Chang *et al.*, 1991), and pig slurry (Bernal *et al.*, 1992). Long-term application of pig slurry to grassland was investigated to establish the impact that metals such as copper and zinc from feed additives might have on the soil content of potentially toxic metals (Christie, 1990). Soil total nickel or the lead content were not increased by slurry application. However the copper and zinc content of the soil increased, and the availability of the metal to the herbage was enhanced. The application of 200 m^3 ha^{-1} y^{-1} pig slurry acidified the soil which would tend to reduce the soil microbial biomass, but the increase in copper could have the same effect. Effects of cattle manure were much smaller. Verloo and Willaert (1990) concluded that the actual impact of slurry on heavy metal accumulation in soils and the crops growing on them depended on pH. Continued application at high rates may result in toxic levels of copper in the long-term (Meeus-Verdinne *et al.* 1980) but this is not likely to occur on neutral to alkaline soils (Anderson *et al.* 1991).

2.4.6.2 Soil biology

2.4.6.2.1 Biological components

Evidence from the Ausable-Bayfield Conservation Authority indicates that bacteriological contamination from tile drains can be greater after injection than after surface spreading (Foran and Dean, 1991). There were 20-40 times more Bacillus spores present on manured crops than on un-manured crops, and numbers remained constant with time to harvest (Östling and Lindgren, 1991). However, numbers of Clostridium spores, some coliforms and E. coli all declined with time after manure application.

Pathogenic bacteria associated with animal manures may not accumulate in soils containing earthworms. After 48 h the population of Salmonella bacteria introduced to soil containing earthworms were reduced by a factor of four compared with that of a worm-free soil. Earthworms also caused a small reduction in the population of the normal bacteria.

One of the concerns about applying liquid manure is the development of anaerobic zones. This can have a detrimental effect on the larger soil fauna, such as earthworms (Edwards and Lofty, 1977) which are known to be sensitive to soil pH and oxygen status (Wild, 1988).

2.4.6.3 Soil fabric

2.4.6.3.1 Soil structure

The beneficial effects of livestock manure on soil physical properties have been recognized for many decades (Sweeten and Mathers, 1985). Manure application resulted in increased stability of soil aggregates to slaking due to an increase in organic matter content (Mbagwu and Piccolo,1990; N'Dayegamiye and Angers, 1990). We do not have, however, data to permit an estimation of either the degree to which soil structure is improved nor the effect of the improved soil structure on crop yield. Thus we are not able to include this benefit of manure in an economic analysis with a reasonable degree of confidence. In general, soil structure is not a major problem on soils with a history of manure application. On these soils, continued application would maintain but not further improve the soil physical properties. Manure application could result in significant improvement in soil physical properties of soils which have been cropped without manure application. The magnitude of this improvement would be site specific depending on the soil texture and the degree of structural degradation. The impact of manure may depend on type and treatment. Stabilized carbon compounds in compost are not as beneficial to soil structure improvement as those in manure since they may be too stable to be utilized by the soil microbes (Richards and Martel, 1991).

Although there are significant gaps in knowledge on this aspect of manure management, the complexity of the issue would require a long-term, intensive research program. It is questionable that such a program can be justified in view of other issues of greater potential benefit. We can continue to apply our subjective knowledge on this issue in situations where more quantitative analyses are not able to distinguish clearly between alternative management systems.

Manure application systems may cause compaction of surface and subsurface soil due to excessive wheel loading. There are models available that give reasonable estimates of the degree of compaction based on axile load and soil properties (Koolen *et al.*,1992). Soil moisture content at time of spreading is a major factor. Thus the effect is both site and time specific. Our ability to predict the effect of a given degree of compaction on crop yield is very limited. This effect will also be site and weather dependent.

Given these uncertainties, it is not feasible to incorporate this aspect of manure management into an economic analysis. The most appropriate approach is to recommend only those practices that we are confident will not result in compaction and hence have no impact on crop production.

2.4.7 Utilization

The main objective of utilising manure in land spreading is to optimise the nutrient uptake for crop production while disposing of manure without contributing to environmental pollution. The main research need involves investigating the complex relationship between crop yield, nitrate requirement of crops, the amount of manure applied, and the soil physical and chemical properties (Edwards and Daniel,1992).

2.4.7.1 Nutrient management

2.4.7.1.1 Carbon

The decomposability of manures and manure C dynamics in soils are important with respect to N availability dynamics that will be covered in section 2.2.7.1.2 on manure nitrogen.

Although Beauchamp and Voroney (1993) were able to predict the quantities of manure C eventually applied to the soil, there were uncertainties that need to be further researched including the magnitudes of most of the factors mentioned above. The dynamics of manure C compound decomposition in the soil are not well understood. Some of the C compounds present in liquid cattle manure are readily available to denitrifiers (Paul and Beauchamp, 1989).

2.4.7.1.2 Nitrogen

There is considerable uncertainty about the availability of manure N once incorporated in the soil. For example, Beauchamp (1986) found that about three-quarters of the ammonium-N fraction was as available as equivalent fertilizer N. It was reasoned that immobilization and denitrification may account for this difference. Research is needed, however, to identify whether manure C and N characteristics, and interactions with different soils, are important in determining the extent of availability of manure N, i.e. the immobilization of ammonium N and the rate of release of the organic N fraction (Beauchamp and Paul, 1989). In this regard, a major research need is to determine the immobilization and mineralization of manure N (and soil N) over time following application, and how this relates to crop growth and N requirements. It is expected that manure C and N characteristics as well as soil characteristics will determine the dynamics of N immobilization and mineralization. In conventionally cultivated soil, the recovery of nitrogen by corn in grain yield was similar for manure incorporated at pre-plant, and as a side-dressed application (Beauchamp, 1983). However, the possibility exists that in conservation tillage systems better recovery of nitrogen may result from a later application at side-dressing than earlier at pre-planting because of the presence of more crop residues at the soil surface, and the greater soil density associated with conservation tillage systems can cause cooler soil temperatures in the early spring (Johnson and Lowery, 1985).

The greater continuity of pores under reduced tillage can increase soil anisotropy (De Jong *et al*. 1983). This in turn can increase the potential for anaerobic zones to develop and for denitrification to occur (Goss *et al.* 1993b), so lowering the efficiency with which fertilizer nitrogen is used (Paul 1991). However, the concentration of drainage into a smaller number of continuous pores may result in less leaching of nitrate-nitrogen derived from mineralization of soil organic matter (Goss *et al*., 1988).

Occasionally, there have been reports of manure actually restricting crop growth and depressing yields. For example, Beauchamp (1986) observed a corn yield depression with low application rates of solid beef manure. This was attributed to N immobilization by soil microbes competing for available soil N. Some other factor probably caused depression of corn yields reported by Beauchamp (1991) when high rates of liquid dairy cattle manure were applied. Nitrification was apparently depressed. Ammonia toxicity from manure may also depress corn growth.

The residual N from manure applications may be considerable (Beauchamp, 1987) but could be estimated by a soil test for corn (and possibly barley in the near future) (Kachanoski and Beauchamp, 1991). The test measures the amount of NO_3-N (N-TEST is expressed in terms of kg N ha^{-1}) in the top 60 cm of the soil at the time of planting. The economic rate of fertilizer (MERN) is calculated from the equation below, where a and b depend on the ratio between the kilogram price of fertilizer and corn grain.

$$MERN = a - b * N\text{-}TEST$$

Values for 'a' are around 220 kg N ha^{-1} and for 'b' range from about 1.4 to 2. For full management capability a nitrogen response curve is required, but a two point calibration can be used for continued monitoring (Kachanoski, 1993, private communication). The prediction of availability of N from manure applied in the previous summer or fall (or winter though not recommended) remains difficult although some research is now ongoing, and there is evidence that the mineral nitrogen content of soil rather than the nitrate component can give a better prediction of the fertilizer requirements under those conditions (Goss *et al.*, 1993a).

Estimates of nutrient availability from manure are normally based on the total content. For nitrogen, part is present in inorganic form and part as organic. In liquid manures at least half the nitrogen is in the inorganic ammoniacal fraction. More of the nitrogen in liquid poultry manure is present in mineral form than is that in liquid dairy manure (Beauchamp, 1986). Because of losses by leaching and in gaseous form, less than 20% of the total nitrogen applied to the soil may be recovered in the crop (Paul, 1991), but results suggest that most of the nitrogen recovered in the first year after application comes from the mineral component. The availability of the mineral fraction may be between 75 and 80% as available to a crop as urea fertilizer. Injection can reduce the gaseous losses considerably compared with spreading, thus increasing the availability of nitrogen (Thompson *et al.*, 1987). However, there is evidence that by assuming typical values for gaseous losses, the available nitrogen can be predicted from the mineral nitrogen component of the manure.

There is not a lot of information on the relationship between the rate of mineralization and the type of manure. In particular it is not established whether differences in carbon content of manures can influence rates of mineralization. Mineralization rates vary from season to season, and the possible interactions with the ability of different crops to intercept nitrogen need to be identified.

The amount of manure present on the field at the time of a rain event will determine the magnitude of the nitrate concentrations in the soil solution (Gerhart, 1986). High concentrations of nitrogen in the soil resulting from manure applications may result in:

1. negative feedback with legumes as nitrates may have an inhibitory effect on both nodulation and nitrogen fixation (Paul and Clarke, 1989)
2) potential for groundwater contamination, as excess nitrate can leach with excess precipitation (Goss *et al.*, 1993)
3) soil acidification during the conversion of ammonia-N to nitrate-N (Hausenbuiller, 1985)
4) increased emissions of ammonia and nitrous oxide via the process of volatilization and denitrification respectively (Hatch *et al.*, 1991; Jarvis *et al.*, 1991; Petersen; 1992).

Douglas and Magdoff (1991) showed in laboratory studies that the nitrogen released into the Walkley-Black acid-dichromate digest was well correlated with the amount of N mineralized during incubation (r^2 = 0.89 and also with the fraction of organic nitrogen mineralized (r^2 = 0.82).

2.4.7.2 Soil biology

2.4.7.2.1 Biological components

The influence of microorganisms in manure on soil biology has, for the most part, been overlooked. There have been studies done on pathogenic organisms (NRC, 1983) in manures but none on strictly agronomic aspects. Sutton (see NRC, 1983) reviewed some aspects of transmission of phytopathogens and weed seeds in manures that may have agronomic implication. Whether research is needed on this aspect at this time is debatable. It is known that composting of manure will suppress phytopathogens (Hoitink *et al.*, 1993).

The activities of micro-organisms in C and N transformations in different kinds of manures and the subsequent effect on N release is not known. It is likely that there are different microbial populations in solid and liquid manures, aerobic and anaerobic manures. Anaerobic bacteria dominate in untreated-liquid manures, resulting in the synthesis of fatty acids that are likely to influence N immobilization once applied to the soil (Kirchmann and Lundvall, 1993).

2.5 Environment

Miller *et al*. (1990), Miller (1991) reviewed the current knowledge related to the impacts of livestock manure on water quality in Ontario. They concluded that disposal of manure rather than efficient utilization had become common, and this had resulted in an increased potential for contamination of surface and groundwater. They also concluded that the pollutant of major concern was nitrate, which was the greatest threat to groundwater because of its mobility. They considered that phosphorus was of major concern in overland flow to surface water. They argued that the contributions of ammonium, organic carbon, and bacteria to surface water were of lesser concern because they could be controlled by managing the timing of manure applications.

There were five specific research needs identified by Miller *et al*. (1990). These were:

1. Establishment of the relation between environmentally safe and most profitable rates of nitrogen application to crop land.
2. Establishment of a system for predicting environmentally safe rates of manure, sub-projects to include:
   - nitrogen transformations and losses during storage and handling
   - prediction of denitrification of manure nitrogen after incorporation into the soil
   - mineralization/immobilization of manure nitrogen after incorporation into the soil
   - effect of hydrological factors on the transport of nitrogen to groundwater
   - validation of predictive models for nitrogen transport
3. Macropore transport of dissolved and particulate pollutants.
4. Methods for manure application in no-till systems.
5. Potential leaching of phosphorus to groundwater from long-term intensive manure applications.

The concerns for air quality due to manure management were identified for the United Kingdom (MAFF, 1992). Odour problems were highlighted. The spreading of animal slurries was responsible for 44% of 1400 justified complaints about odour from agriculture. Slurry or manure stores were responsible for 21% of the justified complaints. Livestock production was identified as the major source of ammonia in the atmosphere. The ammonia mainly came from livestock buildings (35%), manure stores, and from land application of manure (35%). Concerns derived from the release of ammonia focused on soil acidification and nitrogen enrichment of heath lands subsequent to its deposition from the atmosphere (see also ApSimon *et al.*, 1987).

Minimizing odour production from buildings relied on maintaining cleanliness, which can be encouraged by appropriate structural designs, and reducing the amount of drinking water that can mix with excreta.

Engineering solutions are readily available to minimize odour production in confined storage. It is important that poultry manure is kept dry because addition of water can release odours. If manure is stored in the open, piles should be designed to shed rain and prevent the manure from becoming too wet. Keeping the manure well aerated by turning will help to minimize odour production.

Treatment of manures can be used to reduce odours. Mechanical separation of coarse solids from slurry results in a material that can be stacked and composted. The liquid can be stored more readily because there is less of a problem of crusts and solid settlement. Such liquids can be aerated in storage to reduce odour release during land application.

Odours and volatilization of ammonia can be greatly reduced during manure application by adoption of appropriate equipment. Band spreading reduces odours by 50% compared with splash plates, and injection can reduce ammonia volatilization by 85-95% compared with surface spreading. Where solid manure has to be applied, or surface spreading is carried out, the material should be turned under as soon as possible after application.

It was concluded that animal production, including manure management, made a significant contribution to the release of greenhouse gases. Possibly 30% of methane released in the UK comes from animals and stored slurry. Nitrous oxide release to the atmosphere from anaerobic slurry or soil was considered to be a major contributor that could be reduced (MAFF, 1992). Ruminants are important for methane release into the atmosphere (74 Tg y^{-1}), and about 2% of the nitrogen in animal manures may contribute to emissions of NO_x from soil (Bouwman, 1990).

In Ontario, about 18 kg N ha^{-1} is deposited in wet and dry deposition, of which about 6 kg N ha^{-1} is ammoniacal nitrogen (Barry *et al*., 1993). The considerable variation between monitoring sites observed in studies of deposition may be due to the impact of ammonia volatilization from livestock operations (Barry *et al*., 1993).

While the above documents describe the concerns for water and air quality related to manure management, there are no comparable documents that indicate concerns related to soil, and its potential for sustainable use when animal manures are applied intensively over long periods.

The following sections consider information and developments not covered in these position documents. As odour is mostly associated with organic compounds, information on this topic is considered under the carbon sub-heading of sections dealing with air quality air quality.

2.5.1 Excretion

One of the major limitations that exists is the prediction of the nutrient content of animal excreta. Charles, (1984) developed a model which correlates the food intake of hens to the numbers of eggs produced. The model includes environmental and nutritional factors of greatest impact. The food intake is determined and from the nutrient available, egg production is predicted. Manure nutrient content is the difference between the nutrient from feed intake and that from egg production. At present, there is an effort within Europe to develop such models for other animal groups.

The feed industry can play a major role in changing the product characteristics of manure. Some of the potential impacts of improving feed management are indicated in Table 7.

Table 7. Feed related measures contributing to the reduction in pollution caused by animal production.

Changes in feeding regime	Reduction in manure content (%)	
SUPPLEMENTS	Nitrogen	Phosphorus
Increase use of supplementary amino acids and related compound combined with reduced levels of protein in foods.	20 - 25	-
Enzymes Cellulase	5	-
Phylases	-	25-30
Growth promoting substances	5	5
SYSTEMS		
Precise feed formulation to animal needs	10 - 15	10 - 15
Phase feeding	10	10
Increased use of highly digestible raw materials	5	5

Source: Personal communication, Peter Williams 1993.

Some concerns relate to water quality, but mainly to air quality.

2.5.1.1 Water quality

The initial stage of manure management deals with the waste products produced by the livestock. In Ontario, there is usually no impact upon water quality as most farmers do not permit defecation into rivers.

2.5.1.2 Air quality

2.5.1.2.1 Nitrogen

The air quality is affected due to volatilization, especially in confined areas, such as in the barn, where the ammonia present may be greater than the allowable amounts (Gadd, 1987). Lung disease in pigs is extremely common throughout Canada (C.M. Williams, 1993 personal communication). Up to 23% of ammonia emitted from agriculture may come from urine from animals (Pain *et al*., 1991). In the UK, it has been calculated that for cattle up to 11 times more nitrogen is lost by volatilization from within housing and from the slurry produced (Jarvis, 1990). Impacts on soil are also minimized because intensive grazing is not the norm in Ontario. Ammonia volatilization from grazed grassland was greater from cattle than from sheep operations (Jarvis *et al*. 1989a,b; 1991). Some problems could be associated with uncovered yards where manure is not removed frequently, and these will be the same as when manure is applied to the land.

2.5.2 Long-term storage

The major concerns are for water and air quality.

2.5.2.1 Water quality

2.5.2.1.1 Nitrogen

Particular concern for groundwater quality relates to clay-lined lagoon storage units located on sandy loam or loamy sand soils with shallow water tables (Ritter and Chirnside, 1990). If cracks develop in the walls of the liner after the lagoon has been emptied, newly added manure can seep out before solids can effect a reseal. Similarly leaks can develop if plant roots are allowed to penetrate the liner. Once manure has leaked out, ammoniacal nitrogen can be nitrified and organic nitrogen mineralized, resulting in nitrate that can move to the groundwater.

2.5.2.1.2 Other mineral nutrients

Patni and Jui, (1984) concluded the following from their investigation of mineral content of dairy cattle liquid manure during anaerobic storage:

1. The total solids concentration in slurry can decrease during prolonged storage due to volatilization of some organic matter.

2. There is an increase in dry ash and macronutrient concentrations due to a decrease of total solids in the absence of dilution. The dry mineral concentrations will therefore vary as a function of age and the loss of total solids.

3. Concentrations of P, K, Ca and Mg on a dry weight basis have a strong negative correlation with total solids in slurry.

4. About 40 % of slurry ash consists of P,K Ca and Mg.

2.5.2.1.3 Bacteria

The microbiological population in excreta undergoes considerable change during storage. Nodar *et al.* (1990) concluded that poultry excreta contained a high density of micro-organisms, and was similar to cattle slurry in this respect. However, numbers were an order of magnitude greater than those found in pig slurry. At the beginning of slurry storage, the population of viable organisms in most microbial groups abruptly declined (Nodar *et al.*, 1992). Denitrifying and sulphate reducing microbes, together with algae, were the groups that increased at this time. Thereafter, the total population multiplied rapidly, becoming five-fold greater than the initial value after 14 weeks. The increase was mainly attributed to anaerobic bacteria (proteolytic, ammonific, amylolytic, anaerobic-cellulytic and anaerobic-nitrogen fixing species) ; aerobic heterotrophic bacteria, actinomycetes and fungi showed little change.

2.5.2.2 Air quality

2.5.2.2.1 Nitrogen

Gaseous loss of ammonia from slurry over 180 days of storage, calculated on the basis of the ash content of slurry, ranged from 17 to 54% (Dewes *et al*., 1990). The variation may be due to differences in the pH of the slurry (Dewes *et al*., 1990). Slurry composition tends to change in storage due to fermentation. The extent of the change depends on several factors including the conditions and duration of the storage. Patni and Jui (1991) determined that the concentration of N in both the slurry and its liquid fraction tends to be lower in the top meter depth than at greater depths after prolonged undisturbed storage of slurry in farm tanks. They concluded that nitrogen loss cannot be avoided even in an undisturbed covered tank.

2.5.2.2.2 Carbon

For convenience, problems associated with odours are considered in terms of the carbon component of manures. Odours from pig slurry are of particular concern. The sources of odour are organic compounds produced by anaerobic processes taking place within the stored material (Sneath and Williams, 1990).

In part, anaerobic conditions develop because of separation of materials during storage. Patni and Jui (1987) investigated changes in solid and carbon content in dairy cattle slurry in farm tanks. In the top 1 meter of slurry in a store, substantial spatial and temporal variation occurred in the concentration of slurry expressed as total solid by weight (TS_w), total solid by volume (TS_v), fixed solids (FS) or volatile solids (VS).

2.5.3 Processing & treatment

Processing treatments commonly affect odour formation, or gas production, including the volatilization of ammonia.

2.5.3.1 Air quality

2.5.3.1.1 Methane

Methane production has been studied in an anaerobic lagoon of dairy slurry with solids separated (Safley and Westermann, 1992). Methane concentration in the gas evolved (P) was dependent on the temperature (TEC) of the slurry according to the equation:

$$P = 89.514.e^{-0.00381T}$$

2.5.3.1.2 Carbon

Slurry from hog units has been extensively studied. Williams (1984) demonstrated that the offensiveness of the odour from such slurry can be correlated with the volatile fatty acid concentration. Thorough aeration of the slurry removed odour completely (Sneath and Williams, 1990). Sphagnum peat moss at levels of 4-8% by weight added to hog slurry also reduced the offensiveness of the odour by preventing the release of 1,2-ethanediamine, N-methyl methenamine, 3-methyl 2-butanamine, methyl hydrazine, ethanethioic acid and methanethiol (Al-Kanani *et al.*, 1992). A combination of 1% sphagnum moss and 2% calcium carbonate was also very effective. Reducing the dry matter content to less than 1.5% prevented the development of offensive odour for more than a year, as could continued aeration (Sneath and Williams, 1990). Even the aeration caused by wind movement prevented odour development for 180 days after a full aeration treatment (Sneath and Williams, 1990). Acidification of the liquid manure had only a trivial effect on reducing odour, 4% monocalcium phosphate monohydrate (MCPM) and elemental sulphur had no effect on odour (Al-Kanani *et al.*, 1992). MCPM did reduce odour offensiveness.

Aeration at a rate of 2.4 to 4.8 L $h^{-1}kg^{-1}$ volatile matter was also recommended for optimizing the composting of solid hog manure (Lau *et al.*, 1992).

2.5.3.1.3 Nitrogen

Considerable effort has gone into treating slurry to reduce ammonia volatilization. Separation of solids by passing through a mesh screen can have a significant effect, but for cattle slurry the solids would need to be separated using a 0.1mm mesh to reduce ammonia volatilization by 50% (Frost *et al.*, 1990). Acidification of the same slurry to pH 5.5 decreased volatilization by about 85%.

2.5.4 Field application

The concern is for water and air quality.

2.5.4.1 Water quality

2.5.4.1.1 Nitrogen

The potential for nitrate to contaminate ground water is difficult to determine due to the conversion of NO_3^- to gaseous nitrous oxide and nitrogen gas. This denitrification process occurs more readily with organic nitrogen sources such as livestock manure. The amount of subsurface denitrification is a function of manure type, soil type, time of application and depth to ground water (Burton *et al.*, 1991). The Ontario Farm Groundwater Quality Survey found that on farms where manure was spread there was a significantly smaller proportion of wells contaminated with nitrate than where only mineral fertilizers were used. Soil type was important in this result, and on sandy and sandy loam soils more wells were contaminated where manure was spread than where it was not (Rudolph and Goss, 1993). However, the impact of soil type was only significant at a probability of 0.06.

The majority of research to date has failed to quantify the maximum nutrient loading before a negative environmental impact occurs. An application of 36,000 L ha^{-1} of manure had a more deleterious impact on water quality than did an application of 140,700 L ha^{-1} (Dean and Foran, 1991).

There is little information available on the impact of the manure application system on nitrate leaching. However, the potential for surface runoff to occur immediately after application is greater with surface spreading than injection.

The timing of manure applications is critical both for the availability of nitrogen to crops, and on the potential for environmental impacts. As manure storage on many farms is limited, the common periods for application are the fall, winter and spring. In spring applications may be as a pre-plant fertilization or as a side- or top-dressing. The experimental evidence shows that compared with spring applications, manuring land in fall or winter results in lower recovery of applied nitrogen by the crops, and greater risk of leaching and denitrification (Table 6). There does not appear to be any major interaction between application systems and timing.

The changes in soil structure resulting from reduced tillage may modify significantly the impacts of agricultural practices on the environment. In particular the consequences for manure application need to be considered. The reduction in air-filled porosity can limit the volume of liquid manure that could be applied without inducing drain flow because of transport through macropores. Consequently the potential for nitrate contamination of groundwater and bacterial contamination of rivers could increase (Dean and Foran, 1991). However, Beven and Germann (1982) suggested that macropores do not always increase infiltration rates because additional surfaces are made available for infiltration into the matrix at depth.

Nitrate leaching from land where animal manure was applied was greater than that from where mineral fertilizer was applied because no account was made of the mineralization of the organic nitrogen in the slurry (Thomsen *et al.*, 1993). Many models have been developed and used to predict the nitrate concentration in water leaving the rooting zone of crops, and the impact or risk of contamination from agricultural practices (eg Shaffer *et al.*, 1991, Ahuja *et al.*, 1993). The NLEAP model (Shaffer *et al.*, 1991) will predict the risk of groundwater contamination for applications of manure. However, the prediction of nitrogen mineralization from manure, and of gaseous losses lacks validation for Ontario.

2.5.4.1.2 Phosphorus

Phosphorus contribution to surface water in runoff from agricultural land was the major focus of the Soil and Water Environmental Enhancement Program (SWEEP). Studies under the Pollution from Land Use Reference Group (PLUARG) of the International Joint Commission (IJC), established during the 1970's that runoff from agricultural land was responsible for about 70% of the phosphorus reaching Lake Erie from the tributaries in Ontario (Miller *et al.* 1982). About 20% of this amount or 15% of the total was estimated to be due to direct inputs from livestock operations including runoff from storage areas and surface runoff from manure applied close to streams and not incorporated. The remainder was due largely to phosphorus associated with eroded sediment. Manure application would have two opposing effects on this latter contribution. Manure application would increase the phosphorus content of the soil and hence the concentration on the eroded sediment; on the other hand manure would tend to improve soil structure and hence reduce erosion.

One aspect of phosphorus in runoff that is quite poorly understood is the bioavailablity of the different forms of phosphorus (Sharpley, 1992). While manure application may not increase the total phosphorus in runoff, it is more likely to increase the amount of bioavailable phosphorus.

2.5.4.1.3 Bacteria

The Ontario Farm Groundwater Quality Survey found that on farms where manure was spread there was a significantly greater proportion of wells contaminated with bacteria than where only mineral fertilizers were used. Soil type was important in this result, and no difference was found on coarse, gravelly soils or fine-textured soils (Rudolph and Goss, 1993). Liquid manure adversely affected tile water quality when applied to the land following the current farming guidelines. Seventy-five percent of the manure spreading events investigated resulted in water quality impairment (Dean and Foran, 1991). The difficulty of determining an acceptable rate of application of liquid manure due to the numerous factors which affect the contamination of water courses is apparent (Dean and Foran 1993). The importance of soil macropores for the rapid transport of bacteria to tile drains was highlighted in their studies. Strains of *Clostridium perfringens* in manure (both pig and cattle) were found to have a high resistance to antibiotics, and their spread through the environment was related to land application of livestock waste (Van Stappen *et al.*, 1990).

Bacteriological contamination from tile drains can be greater after injection than after surface spreading (Foran and Dean, 1991).

2.5.4.2 Air quality

2.5.4.2.1 Nitrogen

Much research has been devoted to examining the loss of ammonia to the atmosphere due to volatilization after surface applications of manure. Loss from bare soil is less than losses from grassland (Thompson *et al.*,1990) or arable land with surface residues or growing crops (Bless *et al.*, 1991).

Additional factors that influence the volatilization from surface-applied slurries are wind speed, temperature, the pH at the surface of the slurry, and its dry matter content (Van den Abbeel *et al.*, 1990; Sommer *et al.*, 1991). After adjusting for pH and temperature, Sommer and Olsen (1991) found a sigmoid relationship between the cumulative loss of ammonia and the dry matter content, such that the loss was greatest for dry a matter content between 4% and 12%.

Incorporation of manure reduced ammonia volatilization from 32% of total ammoniacal nitrogen to about 16% (Van der Molen *et al.*,1990a).

A transfer model was developed by Van der Molen *et al.* (1990b) that related the rate of ammonia volatilization to the concentration of the gas at the surface of a layer of slurry and the background concentration in the atmosphere. The model takes account of the depth of soil in which slurry is distributed. It also takes account of evaporation of soil water, and infiltration of rain. The model needs to be extended to predict pH at the volatilizing surface.

The impact of mechanical separation of particulate organic matter from slurry applied to grassland has been examined. Thompson *et al.* (1990) found that in the initial 5 h the rate of volatilization was slower from cattle slurry pressed through a 3mm mesh than from unseparated slurry. Later the relative rates were reversed, so that the losses from the two treatments over 6 days were 35% and 38% respectively. Stevens *et al.* (1992a) investigated particle separation, manure acidification and dilution, and a washing treatment for cattle slurry applied to grassland. A 50% reduction in volatilization compared with untreated slurry could be obtained by removing solids using a 0.4mm mesh, or using a 10 mm mesh and diluting the strained material with 86% by volume of water, or by using a 2mm mesh and washing with a 53% volume of water after manure application. A 90% decrease in volatilization was achieved by acidification to pH 6, acidification to pH 6.5 and dilution with a 50% volume of water, or by acidification to 6.5 after pressing through a 0.4 mm mesh. Adding 10M nitric acid to the slurry to 1.4% by volume reduced volatilization by 75% compared with the unamended slurry, and increased the nitrogen content of the slurry by 2 g N L^{-1}. The acidified slurry had a superior balance of N P and K for fertilizing grass. Stevens (1992b) showed that for acidified whole-slurry the efficiency of nitrogen use was only 54% of that for mineral fertilizer. However, after separation through a 1.1 mm mesh and acidification the efficiency of nitrogen use from the slurry was 88%. The lower efficiency of the whole slurry was attributed to enhanced denitrification and contamination of plant leaves.

Acidification of cattle slurry to pH 5.5 reduced volatilization by 14 to 57% (Pain *et al.*, 1990). Anaerobic digestion had no significant effect on the volatilization of ammonia from pig slurry applied to grassland (Pain *et al.*, 1990). Acidification of pig slurry, including the addition of sphagnum peat moss, also decreased ammonia volatilization by at least 74.6% (Al-Kanani *et al.*, 1990b). Elemental sulphur and calcium carbonate increased the volatilization. While acidification did not reduce the effectiveness of the slurry nitrogen for wheat growth, the combination of 1% sphagnum moss and calcium carbonate impaired plant growth.

The total nitrogen available to crops is generally greater after injection than after surface spreading (Paul, 1991). There is also less of an odour problem with injection.

Ammonia loss during sprinkler irrigation of pig manure ranged from 14-37% of total Kjeldahl nitrogen present in the slurry (Safley *et al.*, 1992). The pH of the slurry also increased, which would promote greater volatilization once the manure reached the soil.

The organic material in cattle manure provides additional carbon substrate for denitrifying bacteria in soil which can stimulate denitrification for long periods after slurry applications. The emission of gases such as N_20, NO and NO_2 due to denitrification are likely to be greater than that from soils receiving mineral nitrogen fertilizers (Thompson and Pain, 1990). Effects of the application of unamended cow slurry to grassland was tested by Burford *et al.* (1976). The soil atmosphere under slurry was found to contain up to 680 ppm of nitrous oxide (N_2O). The actual gaseous loss of nitrogen was not determined, but was deemed significant. It was suggested that further work be carried out investigating gaseous transfer. Burford *et al.* (1976) demonstrated that after a heavy application of slurry to light textured soil a significant amount could not be accounted for in the soil or drainage water. The nitrate in the drainage water was less than 1% of total N applied. Paul *et al.* (1993) showed that manure amended soil produced N_2O and NO due to nitrification and denitrification processes. Production of the gases was greater when the manure applied was slurry than when it was compost. As a minimum water content of the soil was important for denitrification losses from manure (Nugruho and Kuwatsuka, 1992), the additional water applied could have been an important factor in generating losses from the slurry.

Pain *et al.,* (1990) observed a rate of 0.91 kg N ha^{-1} day^{-1} for denitrification a few weeks after slurry application to a freely drained loam soil in the fall. The total losses were about 29% of the ammoniacal-nitrogen applied, but acidification of the manure increased the loss to 41% of the applied ammonium-nitrogen. The nitrification inhibitor, dicyandiamide, reduced denitrification to an extent depending on the concentration applied in the slurry. Another nitrification inhibitor, nitrapyrin, had little effect on the rate of denitrification. Denitrification after a spring application was much less than that after a fall application on this soil, and little took place from a poorly drained loam after applying manure at either time. Surface application of manure in summer was associated with smaller losses of nitrogen by denitrification (Van den Abbeel *et al.* 1990).

Gaseous losses from manure after injection mainly resulted from denitrification (Thompson *et al.*, 1987). The denitrification loss appeared to be associated with the region immediately around the slit, and were apparently coupled with the production of nitrate in the soil (Petersen, 1992).

Few researchers have reported losses of nitrous oxide from cropped land fertilized with manure, but losses under corn were comparable with losses from grassland given much greater nitrogen applications (Eichner, 1990).

2.5.4.2.2 Carbon

The impact of anaerobic digestion of pig slurry on odour release during application to grassland was investigated by Pain *et al*. (1990). Anaerobic digestion reduced odour emission by 70-80% over the first 6 h after application. Odour intensity was also reduced, but offensiveness at a given intensity was unaltered.

2.6 Economics

2.6.1 Introduction

There are a variety of approaches that may be employed in manure management (Figure 2). The environment is the ultimate factor that will determine the most economically efficient farming system, by virtue of the critical potential impacts of farming on the natural resource base and ecological systems. The problem arises from an apparent divergence between society's perspective and the individual farmer's perspective on economically efficient farming systems in general, and economically efficient manure management systems in particular. Society takes account of all financial gains and losses, both on and off the farm. The farm operator generally only considers the on-farm gains and losses. Furthermore, the most cost-effective system for a farmer, assisted by modern technology, does not necessarily have to be based on a traditional mixed livestock-cropping system.

Specialization and economic efficiency in agriculture have broken the traditional link between animal and crop production, leaving the manure unutilized or under-utilized (Narayanan and Stonehouse 1981). It is the job of the economist to determine the financial gains or losses which may be attributed to the aforementioned scenarios. The financial balances need to be determined from both the perspective of the individual farm operator, and the perspective of society as a whole, because the latter takes account of a much broader range of criteria. Differences in the net financial balance would then establish the degree of divergence between the two perspectives. These differences may in turn provide a basis for developing new manure management guidelines and policies, such as regulation and subsidization of farmers.

There is a significant gap in the literature which quantifies the benefit and cost characteristics of manure. Such information is vital for the economist to develop useful models which can accurately determine both the on-farm and off-farm costs and benefits on behalf of society as a whole. The same information is vital for farmers interested in basing manure equipment purchases on-farm benefits and costs.

2.6.2 On-farm Costs

In order for economists to obtain realistic estimates of on-farm costs, account needs to be taken of capital costs of manure-handling equipment; labour requirements and costs for equipment maintenance and operation; fuel, repairs and other operating costs for manure-handling equipment, along with equipment operating rates (tonnes solid manure handled per hour, or litres liquid manure handled per hour); expected useful life of manure-handling equipment and estimated salvage value at the end of that useful life; the cost of capital, whether from own private or borrowed sources, or annual amortization rates for manure handling equipment.

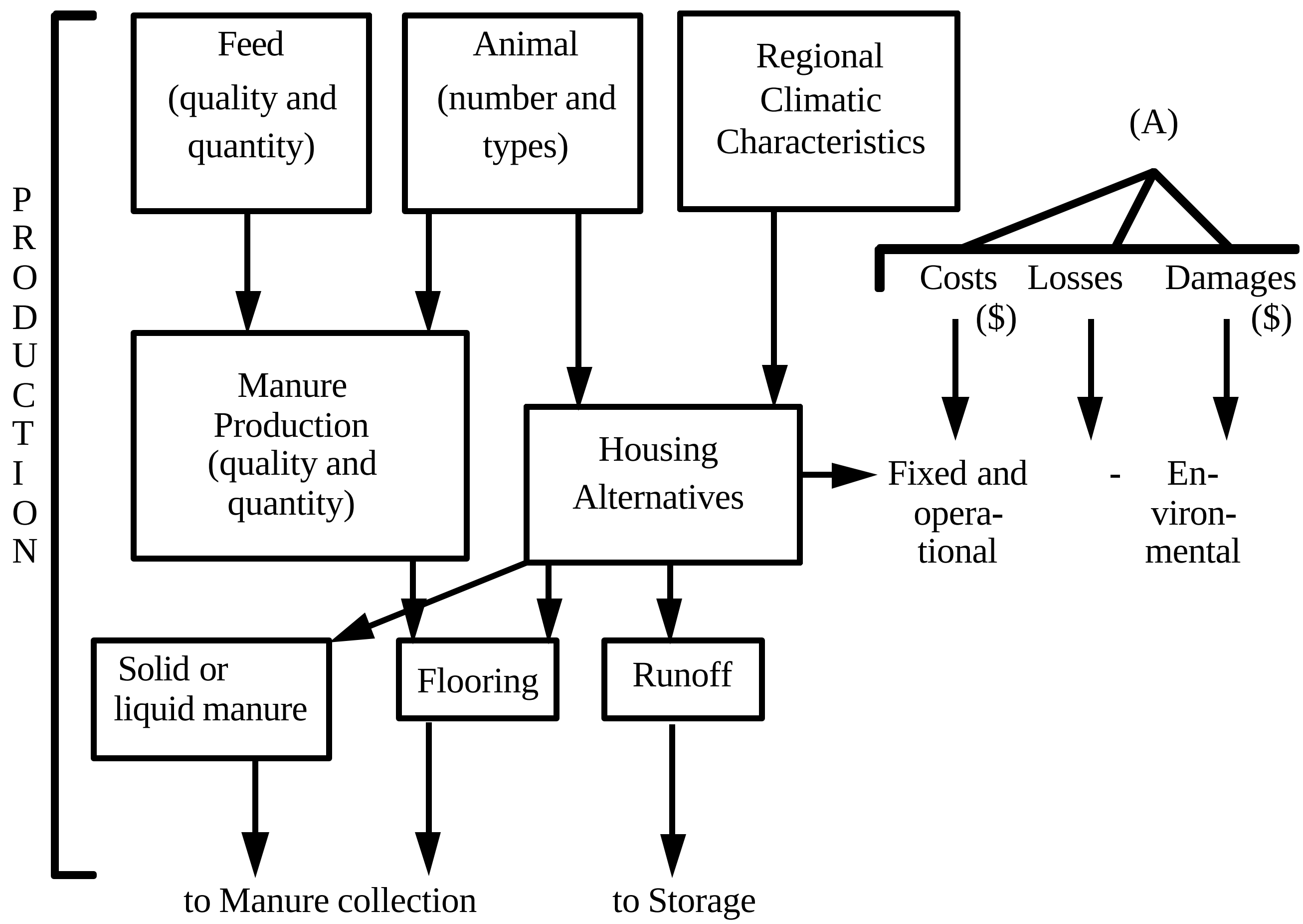

Figure 2. Flow of activities and costs in livestock manure management. (after Narayanan and Stonehouse, 1981).

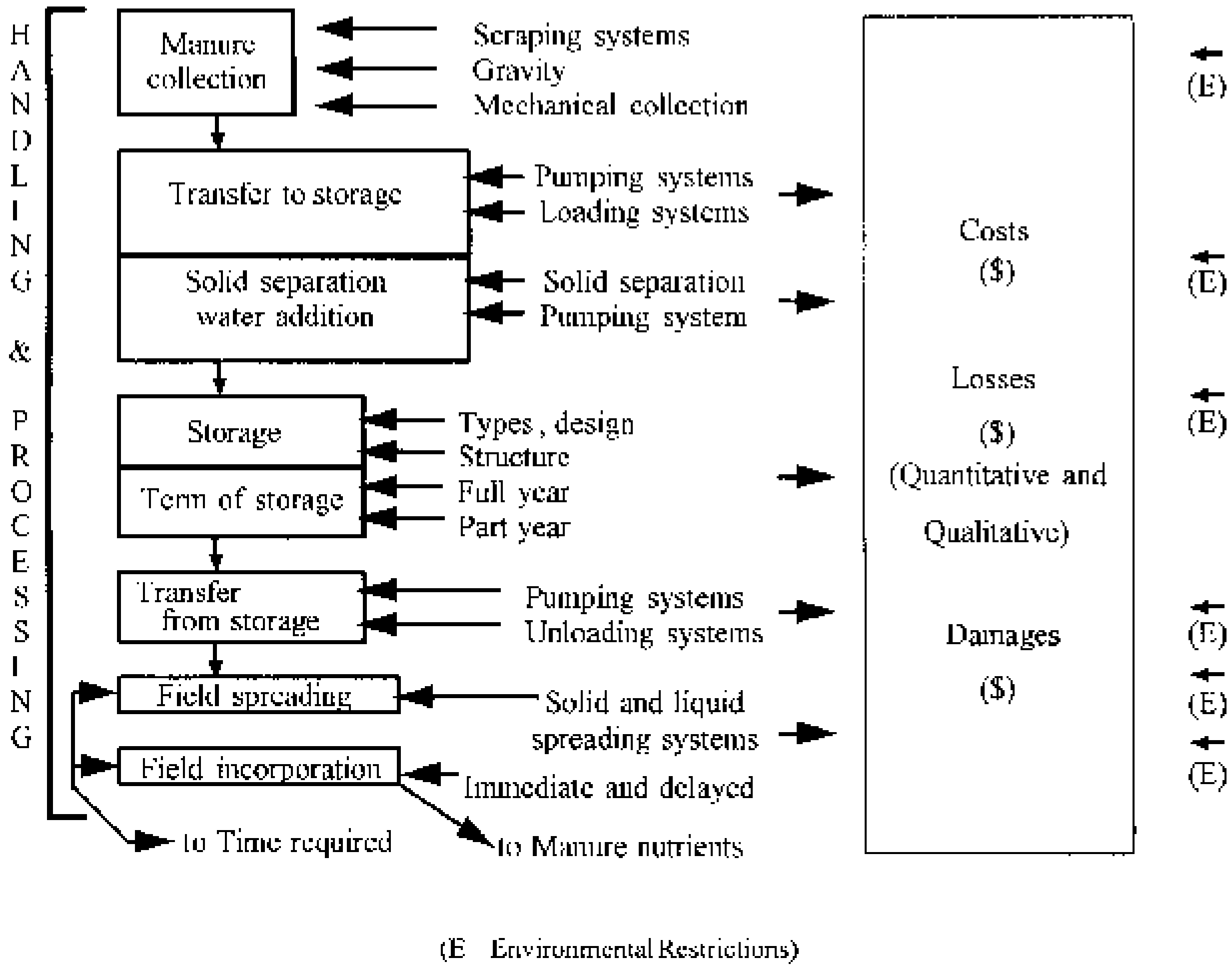

Figure 2. (cont'd.)

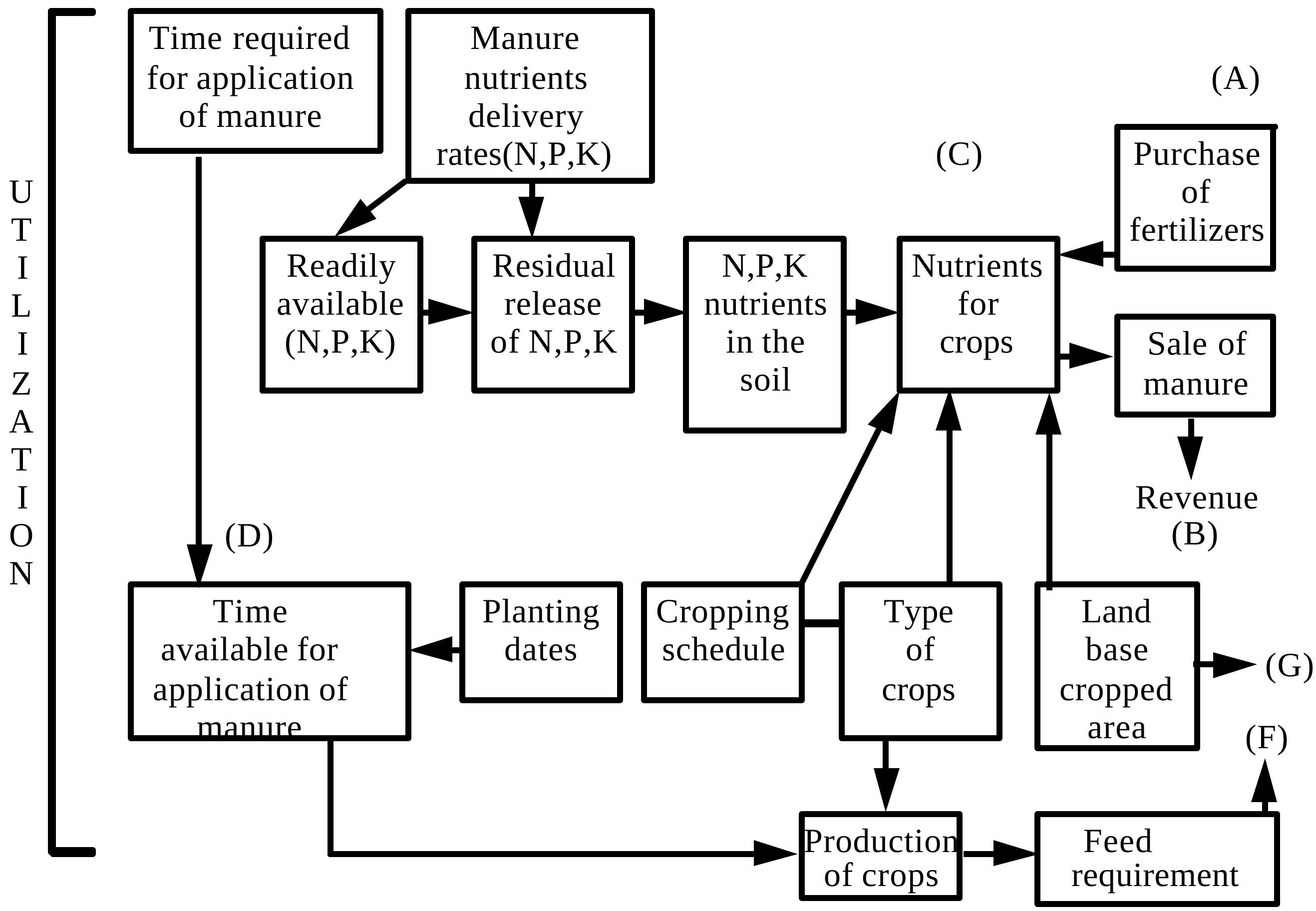

Figure 2. (cont'd.)

Although considerable work has been done in the area of on-farm manure-handling costs (e.g. Huang, 1979; Ogilvie *et al.*, 1975; Narayanan and Stonehouse, 1981; Christensen *et al.*, 1981; Kelland and Stonehouse, 1984; Fleming and Ogilvie, 1989a), such cost estimates need to be continually up-dated and expanded as new manure-handling systems and equipment emerge. Work is also needed to estimate such indirect or concealed costs as reduced soil productivity resulting from soil compaction due to on-land manure operations when conditions are not appropriate; for example the work of Raghavan *et al.*, (1978), needs to be extended specifically to manure operations on land.

2.6.3 On-farm Benefits

For realistic estimates of on-farm benefits of manure, economists require agronomists, soil scientists, biologists and others to provide improved data on plant nutrient retention/loss rates and availabilities, and their available ratio for plants for alternative ways of handling manure. It is only through nutrients retained, both macro (N, P, and K) and micro (Mn, Zn, Cu, B, etc.), that manure has any inherent value for crop production purposes. Economic benefits can be attached to these inherent values through reference to synthetic fertilizer replacement costs. Although considerable research work has been done on plant nutrient retention/loss rates (e.g. Tiarks *et al.*, 1974; Burton *et al.*, 1984; Fachowsky and Hennig, 1990, Stephenson *et al.*, 1990) much more work is required before economic benefit estimates for various manure-handling systems are to be considered completely accurate and reliable (Kelland and Stonehouse, 1984; Stonehouse, 1991).

Additional economic benefits may be conferred by the organic matter fraction in manure, in terms of soil humus replenishment or enhancement and the associated soil-conservation, drought-resistance and other properties. To provide estimates of economic benefits that are more realistic and reliable (Stonehouse, 1991), more research work would be needed to augment earlier work on organic matter retention/loss rates and the associated soil physical benefits (e.g. Hafez, 1974; Tiarks et. al., 1974). There have been some attempts to characterize the nitrogen (Beauchamp 1986) and organic matter content (Nambu and Germar 1980; Sommerfeldt and Chang, 1985; Paul *et al.*, 1991; Bernal and Kirchman, 1992). Measurements for elements such as P and K, which are equally important, are often ignored by researchers. In addition, research work is needed to establish the benefits and costs of composting manures. The work of Freeze *et al.* (1993) in determining economical transportation distances for solid or liquid manures on the prairies, needs to be repeated for Eastern Canada.

2.6.4 Off-farm Costs

Off-farm costs occur in the form of damage perpetrated on the environment and ecological systems adjacent to the farm in question due to inappropriate manure-handling procedures such as spillage into watercourses, excessive field application rates, seepage of plant nutrients and bacteria into groundwater, open livestock access to watercourses with pollution from defecation, etc. Such procedures may not impose any cost on the farmer - in fact, some inappropriate handling procedures may help reduce on-farm costs. Off the farm, however, such procedures can and do lead to downstream watercourse pollution with adverse consequences in terms of reduced availability of drinking water, fish habitat, recreational facilities, irrigation and industrial water. Alternative water resources may be obtainable, but only at additional (collection and transportation) costs to society. The polluted waters can be remedied, but again only at a cost to society. These external costs (or so-called negative externalities) are measurable, and should be incorporated into any economic assessments of manure-handling alternatives (Stonehouse *et al.*, 1990).

2.6.5 Off-farm Benefits

Similarly, off-farm benefits (or positive externalities) should be accounted for in manure economics assessments. Again, very little work has been done in the area of benefits from manure to the general public, in such forms as potential improvement in food security through physical benefits conferred upon the soil. Examples of past research in this area found that livestock manurial sources of plant nutrients were superior to synthetic fertilizer sources in an energy efficiency context (Kelland and Stonehouse, 1984), but that for manurial sources to be superior in an economic efficiency context would require fertilizer prices to be at their early 1980's peaks (Stonehouse and Narayanan, 1984). In both studies, however, negative externalities were neglected.

2.6.6 Overall Economic Impacts

Economists cannot effectively analyze the overall economic impacts jointly to farmers and the public (the so-called net social welfare impact) of manure management without the help of technical scientists. To date, economists have worked with very poor estimates of both off-farm benefits and off-farm costs; that is, they do not have legitimate, concrete figures relating the downstream/off-farm benefits and costs of manure to soil enhancement and downstream watercourse pollution rates, respectively.

Farmers are increasingly concerned about the economic impact on their businesses of the government trend towards restricting practices such as reducing chemical herbicides use, and prescribing specific manure-handling techniques. Dollars motivate farmers and they will not go broke for the good of humankind (Anon 1993). The scientific community needs to assist farmers by establishing the net positive or negative effects of the degradation, or stewardship of the environment due to alternative farming systems and management practices.

The aforementioned impacts will ultimately affect the profitability of farms and thus determine the viability of business (Stonehouse *et al.*, 1993).

Sustainable agriculture is emphasised by MoE, OMAF and other government institutions. Through the 1980's, this has been of less concern to the farmer than it was to the population (Stonehouse *et al.*, 1993). In the 1990's, however, farmer concerns are also growing. The concern for the environment by the population is likely to increase farmers awareness of environmental damage and the need for remedial measures. (Clansy 1986; Coleman 1985; Crosson and Ostrov 1988; Crosson 1989; Douglas 1985).

Information focusing on manure-handling system alternatives should prove extremely helpful to farmers attempting to make decisions about manure systems selections with economics, energy efficiency, and environmental care in mind. Any one or a combination of several procedures could be followed to provide such information. First, surveys of practising farmers would reveal what manure handling procedures are being used, what problems they face, what is effective and what is not, and what their specific information needs are. Second, simple budgeting techniques could be used to develop profiles of a) plant nutrient retention rates, b) organic matter fates, c) economic benefits and costs attached to different manure-handling systems, using all the latest technical and financial data available. Third, more intensive, longer-term research into alternative manure systems could establish more accurate figures on nutrient and organic matter retention rates, surface and groundwater leaching rates, and the off-farm as well as on-farm economics picture.

While one is aware of the multi-faceted nature of manure management there is a need to develop quantifiable economic guidelines. These guidelines need to aid the farmer in maximizing the efficiency of resource use for his farm while minimizing cost. Invariably the information collated may be misleading (Scott 1968).

3 AREAS OF ACTIVE RESEARCH IN CANADA

3.1 Ontario

The following list contains a brief description of some of the projects currently under way, which examine manure management in Ontario.

1. Manure N availability to corn
Beauchamp E G (project leader)
University of Guelph, Ontario Agricultural College, Guelph, Ontario

Started: 89.08.28; End: 92.04.01

Objectives:
To determine the response of corn to liquid dairy cattle manure N applied in the fall as compared to a spring application. To study the affect of incorporation of manure and urea applications in the fall.

Tests indicated that there was no difference in crop response to fall vs. Spring application nor to incorporation of the manure or urea in the fall. Analyses of uptake of N have not yet been completed. 1991 Data confirm previous observations that the residual N carryover of manure or fertilizer does not last beyond one growing season. This part of the project ended in 1992. Second part of this project, dealing with the fate of manure N at the Elora and Arkell stations, was completed. A final report on this aspect of the research indicates 17-20 percent of N was exported as meat, milk or eggs. Eventual recommendations from this study will be included in revisions of the OMAF publication 296.

2. Application of liquid manure on water quality moving from tile drains.
Ausable-Bayfield Conservation Authority.

Previous results revealed that land application of liquid manure under normal farming practices could increase nutrient and microbial content of water leaving tile drains. Bacteria could appear in water leaving the tiles within 20 min of application if soils were at or above field capacity.
In spring/summer 1991 liquid pig manure was studied on a clay loam soil with tile drains at 15 m spacing. Comparisons included application by irrigation gun compared with soil injection; recently disturbed (8 cm) compared with soil undisturbed since fall ploughing.
Effects of soil disturbance were studied in May. The `undisturbed' plots were heavily cracked (0.5 - 3 mm width) and there were numerous pores < 0.5 mm diameter, and some pores > md diameter. There was about 10 % surface residue cover.
Effects of the type of applicator were investigated in June.

3. **Nitrate in drainage from a mixed farm operation.**
Patni N K (project leader)
Agriculture Canada, Research Branch, Centre for Food and Animal Research, Central Experimental Farm, Ottawa, Ontario

This work is an Ag Can project under its environmental quality programme. The study involves three areas on the Central Experimental Farm in Ottawa. There are two major watersheds involved and a unit of 3 fields. Data were collected on water quality changes in the creek water from the start to the end of its course through the monitored areas.

4. **Effect of livestock manure application and management on surface water quality.**
Wall G (project leader)
Agricultural Canada, 70 Fountain St. Guelph . Ontario

Research into controlling the overland movement of manure nutrients and bacteria is taking place in the Kintore watershed (Oxford County), using rainfall simulation and natural collection troughs. Liquid hog and solid cow manure are being used in five tillage systems: no-till, mouldboard incorporated, mouldboard top spread, chisel incorporated and chisel top spread.
No-till and mouldboard incorporated seem more effective in controlling nutrient and bacteria losses in surface runoff. Low fall and winter contamination levels increased with warm temperatures in spring. Top spread mouldboard plough plots produced higher levels of nutrients and bacteria, from fall until spring. Not enough data has been collected from plots, to determine the effectiveness of chisel ploughing.

5. **Nitrogen Management - A Budgetary Approach**
Goss M.(project leader)
University of Guelph, Ontario Agricultural College, Guelph, Ontario

In Ontario intensification of agricultural production has resulted in the development of specialization of enterprises. In consequence there are arable farms with soils having depleted organic matter where only mineral fertilizers are available. Equally there are some animal enterprises producing more manure than can safely be applied to the associated land base. However, within the main geographic regions some mixed farming is also practised, and speciality crops are grown in a wide range of locations. This makes it difficult to evaluate directly the consequences of different management practices on the environment at a regional scale.
One method for predicting regional losses of nitrate from agriculture to groundwater is to calculate the nitrogen balance for a whole farm, taking account of animals and crops. The resultant N-budget can be formulated so that a positive balance indicates the amount of N potentially available for leaching. This amount for typical farming systems could then be combined with hydrological

information and climatic data using a Geographic Information System to predict maximum nitrate-N concentrations moving to groundwater from farming in the region.

6. **Design and development of agricultural equipment**
John Deere Welland Works
Welland, Ontario

Farm loaders; farm wagons; manure spreaders; rear blades; rotary cutters; utility vehicle

7. **Movement of agricultural and domestic waste water bacteria through soils**
Lee H (project leader)
University of Guelph, Ontario Agricultural College, Guelph, Ontario

Started: 91.12.03; End: 94.12.31

Objective:
1) confirm in laboratory studies the suitability of using nalidixic acid-resistant E. Coli under test conditions.
2) Laboratory study of the influence of soil types, soil conditions, application rates, and reworked layer on the transport characteristics of bacteria through soils.
3) Determine, through field monitoring: a) the level of bacterial contamination of surface receiving waters from the spreading of agricultural wastes on tile drained fields; and b) the movement of bacteria from septic tank leaching beds into the saturated zones where they may be transported to surrounding shallow wells.
4) Develop a mathematical models of bacterial transport through soils, suitable for use over a range of soil and environmental conditions;

8. **The study of bacterial movement through agricultural soils**
Lee H (project leader)
University of Guelph, Ontario Agricultural College, Guelph, Ontario

Started: 91.04.16; End: 93.04.01

Objective: to develop a mathematical model relating the pollution potential of agricultural waste spreading and the various parameters and independent variables.
A literature review was completed in 1992. Site samples will be collected and analyzed for the review. This research will investigate the mechanisms of bacterial contamination of receiving waters by the discharge of liquid agricultural wastes or septic tank effluents. The results should contribute to improved guidelines with respect to agricultural waste discharge and design of septic tank tile drain systems.

9. Nitrate concentrations in shallow groundwater as influenced by application rates of nitrogen

Whiteley H R (project leader)
University of Guelph, College of Physical and Engineering Science, Guelph, Ontario

Started: 90.02.06; End: 93.04.01

Objectives:
1) to measure the seasonal variation in amounts and concentrations of nitrate-nitrogen leached to below the water table
2) to assess the effect of variation in application rates of nitrogen on the amount and concentration levels.
Data was collected during 1990 at the elora research station on flowrates and nitrate-n concentrations in outflow from the buried pipe drains and from overland runoff. The data will be used in part for the calculation of a nitrogen budget for the elora site. To provide information to meet the need for careful and skilful management of nitrogen applications in agriculture in ways that produce the greatest possible net benefit for producers while preserving groundwater quality. This will help to ensure that management regulations and practices for nitrogen applications are well-founded and sensible.

10. Sources of contamination in outflow from tile drains

Whiteley H R (project leader)
University of Guelph, College of Physical and Engineering Science, Guelph, Ontario

Started: 90.02.06; End: 93.04.01

Objectives:
1) To review previous field studies of water quality in water discharging from buried pipe drains to establish what situations and land-use practices give rise to problem concentration of contaminants, with special attention to sources and pathways.
2) To identify instances where corrective measures have been taken and the success of the corrective measure.

Information on the impact of improper direct connection of pollution sources to buried pipe drains has been conveyed to the Ontario Agricultural and Food Engineering Committee of OASCC. Extremely high bacterial counts and phosphorus concentrations have been observed at some locations where improper milk house drainage connections occur.

To assist in finding and correcting sources of contamination and thus lead to measurable improvement in water quality in streams and municipal drains.

11. Hydrogen sulphide monitor for swine facilities

Hayward G L (project leader)
University of Guelph, College of Physical and Engineering Science, Guelph, Ontario

Started: 90.01.0; End: 93.04.01

Objectives:
To construct and calibrate several prototype barn monitors to measure hydrogen sulphide levels above manure pits.
An H_2S detector was built and calibrated. Data showed that the concentration of hydrogen sulphide in a manure pit exhaust plenum rose very quickly when the manure is agitated. A steady level of about 50 ppm was reached within 30 seconds after the agitation was started. This level was maintained for 100 minutes. When the agitation was stopped, the concentration dropped to 10 ppm in about 8 minutes. Very little hydrogen sulphide was observed in the barn above the slats. A warning sensor placed in the barn can prevent the build up of hydrogen sulphide. A loud alarm sounding when the gas reaches critical concentration would allow the operator to shutdown the agitator. A ventilation system would then reduce the gas levels within the barn. Continued research is required into the safety and reliability of a semiconductor sensor.

12. Residual nitrogen from various sources

Rowsell J G (project leader)
Ontario Ministry of Agriculture and Food, New Liskeard College of
Agricultural Technology, New Liskeard, Ontario

Started: 90.05.01; End: 95.06.01

Objectives:
To determine the yield response of barley to residual nitrogen applied to preceding barley crops in the form of dairy cattle manure and urea.
Higher residual amounts of N from manure applied the previous year then from fertilizer. Nitrogen rates applied at recommended levels had negligible impact on left-over nitrate-nitrogen quantities.

Impact: current nitrogen recommendations for spring cereals are not based upon soil testing and the soil test being developed will be impractical for spring cereals in ontario. This trial will determine how much nitrogen is left over for succeeding crops from 2 sources so that nitrogen applications may be reduced and ground water contamination minimized.

13. An investigation of the transient nature of hazardous conditions in swine barns due to manure gases released during slurry mixing and removal

Clarke S (project leader)
Ontario Ministry of Agriculture and Food, Kemptville College of

Agricultural Technology, Kemptville, Ontario

Started: 89.06.01; End: 92.04.30

Objectives:
To establish protective measures directed at humans and animals in confined swine operations. The danger arises from the potential of being poisoned by dangerously high concentrations of manure gases. Field work done; working on final report.

Impact:
Reduced potential for accident and injury as a result of dangerous or lethal levels of manure gas release during slurry agitation. Better understanding of the factors and conditions that affect gas formation and release.

14. Flow of manure through soil macropores

Fleming R (project leader)
Ontario Ministry of Agriculture and Food, Centralia College of
Agricultural Technology, Huron Park, Ontario

Started: 90.05.22; End: 90.11.02

Objectives:
1) To determine to what extent flow of manure through soil macropores occurs under typical conditions.
2) To compare macropore flow from different manure spreading methods.

15. Methane and carbon dioxide emissions from farm animals and manure.

Jackson H A (project leader)
Agriculture Canada, Research Branch, Centre for Food and Animal Research, Central Experimental Farm, Ottawa, Ontario

Started: 92.04.01; End: 97.03.31

Objectives:
1. To accurately determine the amounts of greenhouse gas emissions produced by farm animals and manure.
2. To evaluate the effectiveness, under field conditions, of existing techniques to reduce greenhouse gas emissions from farm animals.
3. To reduce methane emissions from farm animals by developing and/or evaluating new methane emission reduction techniques.

The study will establish representative methane emission values for dairy cattle by measuring methane produced within a barn housing a typical milking herd. It will measure the greenhouse gas released from slurry storage tanks and investigate the feasibility of reducing emissions by capturing these gases for enhanced biogas production and utilization as an energy source.
Emissions from a CFAR dairy barn will be correlated to other barn sites (including beef, swine, and poultry barns) in order to extend these measurements to a national scale. The study will measure the effectiveness of rumen methane emission reduction techniques such as strategic feed supplementation, physiological manipulation of the rumen, and control of rumen microorganisms.

16. Effectiveness of manure additives.

Patni N K (project leader)
Agriculture Canada, Research Branch, Centre for Food and Animal Research, Central Experimental Farm, Ottawa, Ontario

Started: 90.12.27; End: 92.12.31

Objectives:
To evaluate the effectiveness of selected manure additives for their ability to control the production of odour-producing chemicals, to reduce solids content, and to retain nitrogen and organic matter in stored swine manure and dairy cattle manure slurry.
1. The test system was installed in an isolated barn and the field work was completed. Eight products were tested for their effectiveness using swine manure.
2. An interim contract research report was submitted to OPPMB.

17. The use of jerusalem artichoke fructooligosaccharide-rich flour in animal diet

Farnworth E R (project leader)
Agriculture Canada, Research Branch, Centre for Food and Animal Research, Central Experimental Farm, Ottawa, Ontario

Started: 87.11.01; End: 93.12.31

Objectives:
1. To determine the effects on normal production parameters of adding jerusalem artichoke flour to animal diets.
2. To verify the beneficial effects of adding jerusalem artichoke powder to animal diets, in particular, effects on manure smell, incidence and severity of diarrhea and feed efficiency.
3. To determine what effects the ingestion of jerusalem artichoke has on intestinal microflora populations.
4. To compare the performance of animals consuming diets containing jerusalem artichoke flour to those eating tubers at various stages of processing.

a. Proximate analysis of the jerusalem artichoke/corn meal product has been completed. At the present time, the analysis of the complex carbohydrates is being carried out using high pressure liquid chromatography techniques.
b. The feeding trial has been completed. Samples of manure are now being analyzed for dry matter content, volatile fatty acid content and microbiological profile.
Two experiments have now been completed using processed tuber material, and have shown that: - such a product can be incorporated easily into a swine diet; the additive is acceptable to swine; changes are occurring in the digesta/manure of these animals.
c. The crop was planted and harvested and processed into meal that will be used in upcoming animal feeding trials. An efficient way of processing raw tubers is now in use.
d. An additional experiment was completed, in which raw jerusalem artichokes were fed to weaner pigs.

18. Manure Management to Sustain Water Quality

Goss M.(project leader)
University of Guelph, Ontario Agricultural College, Guelph, Ontario

Started: 91.07.08; End: 93.01.31

This is an Ag Can NSCP project. In this experimental programme, the fate of the mineral and organic N in applied cattle manure and from alfalfa residues was investigated. Conservation of N from fall-applied manures or fall-ploughed alfalfa hay by incorporation into a cover crop,or immobilized in straw residues, was studied. Cover crops did not take up sufficient nitrogen to have significant impact on the nitrogen in the soil that was available for leaching over the fall and spring.

19. Managing Cover Crops and Tillage to Conserve Nitrogen Following Manure Applications

Vyn T.(project leader)
University of Guelph, Ontario Agricultural College, Guelph, Ontario

This is a Land Stewardship II project. In this experimental programme, the ability of different cover crops to absorb nitrate-nitrogen from fall applications of manure is being investigated. Cover crops studied included red clover, oilseed radish and oats. Corn will be sown by no-till or after seedbed preparation following fall ploughing.

20. Trace gas analysis methodology

Thurtell G (project leader)
University of Guelph, Ontario Agricultural College, Guelph, Ontario

Objectives:

A trace gas analyzer system (TGAS) has been developed using new laser technology for the measurement of trace gases in the natural environment. The instrument has a highly accurate and fast response sensor which will measure low concentrations of gases such as NO_x, CO, CH_4 and NH_3. The instrument is designed for continuous field use. It is suitable for measurement of gaseous losses from manure fields, from animal housing and from manure storage areas.

3.2 Quebec

1. Improvement of the N and P fertilizer efficiencies of liquid hog manure using organic waste products of the pulp and paper industry.

Jones W (project leader)
Macdonald Campus of McGill University, Faculty of Agricultural and
Environmental Sciences, 21-111 Lakeshore Road, Ste-Anne-de-Bellevue, Quebec

Started: 91.04.01; End: 94.03.31

The objectives of this research are to evaluate the effects of lignosulphonate additions to liquid hog manure on:
1) ammonia volatilization from liquid hog manure during storage and after field application;
2) the forms and distribution of phosphorus within the liquid hog manure and soil receiving manure additions, and
3) nutrient (N and P) availability to plants, plant growth and yield.

The project is in the initial stages with preliminary tests of lignosulphonate-manure mixtures in the laboratory. Studies have indicated that ammonia volatilization is reduced with applications of lignosulphonate to the manure. Field studies are now being conducted to evaluate the influence of this treatment on corn growth and nutrient uptake.

This project is part of an ongoing research thrust dealing with the improvement of the fertilizer value of manures. Current management practices may lead to volatilization losses of up to 100% of the ammonia nitrogen in animal manures, creating a serious air and surface water pollution hazard. These losses result in less efficient nitrogen nutrient cycling within the farm system. Decreasing or eliminating these losses during storage and when the manure is applied to the soil, could result in the savings of millions of dollars in nitrogen fertilizer costs and environmental damage.

2. Effect of ice in the development of cracks in reinforced concrete liquid manure storage tanks.

Masse D I (project leader)
Agriculture Canada, Research Branch, Centre for Food and Animal Research, Central
Experimental Farm, Ottawa, Ontario

Started: 88.12.31; End: 92.12.31

Objectives:
1. To develop and transfer designs, management information, and related technology to improve the function, safety, and economy of animal housing.
2. To determine the pressure exerted by ice caps that develop in cold weather in concrete manure storage tanks. To propose new design criteria for these structures for inclusion in construction standards and codes. The new criteria will increase the expected life of the storage structure and reduce the risk o environmental hazard due to leakage or structural failure.
Data continues to be collected and analyzed by Laval University under a Canada-Quebec program.

Tests on scale models have shown that the stresses and pressures exerted by ice caps in swine liquid manure storages were influenced by dry matter content but not by liquid filling method. The pressure due to frozen manure was 2 to 5 times greater than the hydraulic pressure. If full-scale results agree with the scale-model results, it would appear that storages in the field are underdesigned.

3.3 Prince Edward Island

1. **Manure application strategies for environmental safety and efficient crop production.**
Campbell A J (project leader)
Agriculture Canada, Research Branch, Charlottetown Research Station
P.O. Box 1210, Charlottetown, Prince Edward Island

Started: 91.05.01; End: 94.05.01

Objectives:
To examine the effect of manure application strategies on environmental safety and efficient crop production.
This project was approved in early august 1991. The equipment was purchased. After calibration, the first three applications of manure were made in the fall.

3.4 Nova Scotia

1. **Laboratory and field evaluation of high land application of manure**
Ghaly A E (project leader)
Technical University of Nova Scotia, Halifax, Nova Scotia

Started: 85.04.01

2. **Composted chicken manure and fresh effects on grass-legume**
   Warman P R (project leader)
   Nova Scotia Agricultural College, Truro, Nova Scotia

   Started: 91.04.01; End: 93.03.31

   Objectives:
   To determine if there will be a significant difference between treatments of a forage crop fertilized with composted chicken manure versus fresh chicken manure at the same rate.

3.5 British Columbia

1. **Nitrogen and manure use in sustainable agriculture management**
   Chipperfield K (project leader)
   Agriculture Canada, Research Branch, Agassiz Research Station, P.O. Box 1000, Agassiz, British Columbia

   Started: 91.01.01; End: 95.12.31

   Objectives:
   To develop cost-effective strategies to minimize the environmental impact of the agricultural use of nitrogen and other selected agricultural chemicals.

   Broccoli field trials completed. Technology transfer to producers by technical report, oral presentations and field tours.
   Completed second year of field trials.

   The research results will be used to assist in land use planning and policy decisions with respect to the use of agricultural chemicals and manure, and to assist in the development of management recommendations for the use of manure and inorganic nitrogen fertilizers. This information will increase the sustainability of agricultural production through more efficient on-farm use of resources and will decrease the potential of environmental impact of current agricultural practices.

3.6 Alberta

1. **Water movement and nutrient management model for southern Alberta**
   Chang C (project leader)

Agriculture Canada, Research Branch, Lethbridge Research Station, Lethbridge, Alberta
Started: 79.01.01; End: 96.03.31

Objectives:
Develop a model to guide the application of nutrients (quantity and timing) to soils for increasing crop nutrient use efficiency, and to predict the transport of water and transport and transformation of nutrients and other salts in the environment.
The impact on groundwater quality of long-term annual application of manure at rates of up to three times the maximum recommended rate was minimal under nonirrigated conditions. However, the nitrate content in the soil increased with increasing rates of manure application, and the accumulated total amount of manure applied has the potential to cause groundwater contamination in year with above normal precipitation. Under irrigation, the leaching losses of nitrate ranged from 41 to 50 kg/ha/yr at the maximum recommended rate after 1978. The nitrate content in the groundwater could reach as high as 19.6 Mmol/l during the growing season from 6.04 Mmol/l.
Compaction treatment had significant effects ($p < 0.05$) On bulk density down to 25 cm. However, in 1989 and 1990 the grain yields were not significantly different among the treatments.

2. Restoring productivity to exposed dark brown chernozemic subsoil under dryland conditions

Dormaar J F (project leader)
Agriculture Canada, Research Branch, Lethbridge Research Station, Lethbridge, Alberta
Started: 65.01.01; End: 94.03.31

Objectives:
To determine the role of feedlot manure, cereal straw, inorganic fertilizer, and topsoil applications in a continuous cropping rotation for the recovery of eroded land and the effect of eroded soil on the quality of wheat.

Long-term research has illustrated that restoring the productivity to a severely eroded soil can be a long-term and expensive proposition. Dryland field studies have demonstrated that moderately high applications of feedlot manure (15 t/ha) are much more effective than high rates of chemical fertilizers.
Ongoing efforts to restore productivity of artificially eroded soil include the application of manure, commercial fertilizer, fertilizer plus straw, and topsoil addition. To clarify the processes involved and help characterize the relationship between soil quality and productivity, various analyses of soil physical and chemical properties are being conducted. In addition, analysis of wheat samples are being conducted to determine chemical and baking properties.

4 WORKSHOP REVIEW

4.1 Introduction

To develop sustainable agriculture it is important to balance the increased demands for animal protein and other products with the manure and other waste which is a by product of animal production. For any management programme to be successful it must be both economically viable as well as applicable to each particular operation. Improving manure management applications through recommendations, requires handling the manure in a cost effective and environmentally sound system.

A series of three meetings were held across the province of Ontario. The purpose of these meetings was to gather information on the views of the agricultural community on the perceived problems and solutions associated with manure management. The participants of the workshop represented a broad cross-section from the farming industry. Participants were chosen from a list of names supplied by the OMAF Agricultural officers based on their involvement in the agricultural industry. The participants at each workshop were given an agenda, and divided into smaller groups of about 6 - 8 people. Within each group the members had a leader and a recorder. The groups were divided so as to evenly distribute the varied expertise. The members were encouraged to be direct and open about their views and ideas. The members first introduced themselves and describe their interest and concerns. Producers were asked to describe their operations. The groups were then assigned to discuss a group of questions and report as a group at the end of the exercise. These activities were completed during the morning session, and the group broke for lunch. In the afternoon session the solutions to the issues raised in the morning were addressed. A summary discussion on "where do we go from here?" wrapped up the workshops. A copy of the full report of the workshop is included as a separate document, and key points are summarized below.

4.2 Issues and solutions

4.2.1 Feed

There was some recognition that feed could be modified to affect odour, but no comments that suggested an awareness that nutrient supply could also be managed to reduce their excretion. Most of the interest was in reducing the drinking water mixing with excrement in the barn.

There was a noticeable change to long-cut hay in eastern Ontario, associated with the farmers' desire to increase their flexibility over timing for manure applications.

4.2.2 Barn design

Barn design was a major factor that limited farmers changing their manure handling practices. Most farmers inevitably had some liquid and some solid manure to handle, and for them semi-solid systems would be ideal. However, the engineers consider semi-solid materials the most difficult for which to produce effective machinery.

4.2.3 Storage units for manure

There was usually a trade-off between having easy access to the storage for spreader and tankers, and the distance from the barn. As a ready supply of water was a major factor in locating a barn, many storages were located close to water resources that were at risk if leaks developed.

4.2.4 Processing manure

Many felt that composting manure might have some benefits, particularly for reducing odours and the volume needed to be applied to the land. However, the general view was expressed that treatment increased the cost, either capital or labour.

4.2.5 Transport

The cost effective distances that manures could be transported was identified as about 1 mile, except for solid poultry manure, which because of its nutrient content was found to be about 6 miles. That was a factor in generating overload on fields close to the barn.

The consequences of meeting road-traffic laws, especially those related to spills, were cited as reasons why manure purchases are resisted by farmers.

4.2.6 Application

The greatest problem was the absence of appropriate methods for applying manure to no-till crops. The next most important concern was the difficulty of applying manure uniformly.

Farmers were concerned about soil compaction due to heavy equipment, and this caused many to adopt irrigation. However, drift was recognized as a significant problem for this system.

Injection machinery was considered to be expensive, and it was felt that it was unproven as a technique for rolling topography. Consequently many were dubious about adoption.

Farmers who had tested the manure from their storages did not find that there was much change in the test results, so nutrient content they felt could be assumed. The most favoured approach to nutrient management was soil testing to identify what applications were required.

4.2.7 Utilization

Farmers considered that there were real advantages to applying manure to the land beyond its fertilizer value. Many were convinced of better soil structure where manure was applied, and this resulted in improved yields. Crop rotation became an essential feature where manure was applied, and this was considered also to have advantages.

There were clearly defined disadvantages. Weeds were considered to be a greater problem where manure was applied. Farmers lacked confidence in the recommendations for manure application, and felt that there was no guarantee of sufficient nitrogen being available to corn crops.

4.2.8 Environmental concerns

Everyone was concerned about contamination of water resources.

There was considerable discussion about the importance that odour had as a factor in manure management decisions. Volatilization of ammonia was also recognized as a problem, although its value as a fertilizer was of more concern.

Direct contamination of water, land and property by irrigation drift was a significant problem.

4.2.9 Farmer needs

Farmers demanded improved advice on the amount and timing of manure applications. They felt that on-farm testing of manure might help in this regard.

There needs to be better information for farmers on the relative merits of manure systems for minimizing the impacts of manure on the environment.

Most farmers believed that there was considerable research information available to help solve many of these problems, but more effort was needed in providing the extension for this knowledge and in educating practitioners and the public alike.

5 ASSESSMENT OF PRIORITY RESEARCH AND EXTENSION NEEDS RELATED TO MANURE MANAGEMENT

Section 2 of this report presented a survey of current knowledge on manure management using a detailed framework to ensure that all facets of the system were included. Section 3 presented a summary of active or recently completed research projects in Canada and Section 4 presented a review of workshops held to obtain input from farm operators. The information in these sections provides the necessary background for establishing priority research and extension needs. Once current research is completed, information obtained will need to reviewed against the gaps noted in Section 2. In this section we present an assessment of the needs for Ontario. These have been established in collaboration with the Expert Evaluation Panel for Manure Management, the membership of which is listed in Appendix 1.

5.1 Methodology

Eighteen discrete proposals were identified from the review, and these were divided into four groups based on topic discipline. The Expert Panel then added a further proposal related to odour control. The full list is presented in Table 8.

The Panel divided into four disciplinary sub-groups, and reviewed the priority within the four groups of proposals, although each disciplinary sub-group made a more thorough assessment of the proposals within its area of expertise.

The priority for proposals within the topic groups were presented by the relevant sub-group of the Panel and reviewed by the whole Expert Panel, any major differences in views being resolved by discussion.

The sub-groups then reconvened to establish their assessment of overall priorities. These assessments were presented to the whole Panel, and any points of disagreement were solved by discussion. In the course of discussions it became clear that a number of proposals could be combined for simplicity, and a final list of twelve recommendations resulted.

5.2 Results and Conclusions

The divergence of views of the priories within the disciplinary groups of proposals was generally not great, and the possibilities for linking proposals permitted consensus.

There was full agreement on the selection of the most urgent tasks. These were to develop extension packages to assist farmers in making more effective use of nutrients in manure, and the establishment of 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 (Table 9). It was the view of all the Panel that the farming community cannot wait for all the information to be fully available before an extension initiative was put in place. Furthermore, the framework for future research and extension needs to be established rapidly to prevent wasted effort and ensure the most effective use of limited funding.

Very high priority was given to establishing the relation between environmentally safe and most profitable rates of manure application to cropland. The Panel saw this as including the development of more acceptable manure application methods in conservation tillage systems.

Table 8. Initial list of proposals for research and extension needs, related to manure management, that were presented to the Expert Panel.

A. Animal management and environment

1. Examine the potential for reducing the nutrient content of manures using improved feeding programmes.

2. Investigate the long-term effects of feed additives on manure management.

3. Develop the means of predicting the composition of the major types of poultry, pig and cattle manures, together with the availability of macronutrients to plants, and establish the changes occurring during storage.

4. Establish the relation between environmentally safe and most profitable rates of manure application to cropland, taking account of the method and timing of applications.

5. 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.

B. Engineering

6. Seek means by which the hazard to human or animal health from toxic gases, such as H_2S, can be relieved in different manure systems.

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

8. Develop better engineered and economic manure management systems that minimize gaseous losses from manure.

9. Develop more acceptable manure application methods in conservation tillage systems, particularly on rolling topography.

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

C. Field utilization

11. Improve nitrogen application recommendations to take into consideration the losses of NH_3 with different times and methods of manure application.

12. Investigate the relation between time of manure application, the soil N test and nitrogen requirement of crops.

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

14. 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.

D. Gaseous losses

15. Determine precisely the magnitude of losses of $C0_2$, CH_4, NH_3 and $N0_x$ from different manure handling systems.

16. Determine the processes involved and quantify the losses of $N0_x$ gases following manure application and incorporation in the field.

17. Investigate 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 $N0_x$.

18. 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.

19. Develop practical cost-effective methods for managing manure odours from farm systems.

Table 9. Prioritised listing of research and extension needs for 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.

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APPENDIX 1 Membership of the University of Guelph Expert Evaluation Panel for Manure Management

Producer (Organizations)	Government	University
Richard Hiscock (Farmer)	Ron Fleming (OMAF)	Michael Goss
Bob Hunsberger (Farmer)	Don Hilborn (OMAF)	Murray Miller
Harold Rudy (OSCIA)	Barb Lovell (OMAF)	Eric Beauchamp
Peter Doris (OCA)	John Schleihauf (OMAF)	Peter Stonehouse
Elbert Vandonkersgoed (CFO)	Chris Brown (OMAF)	Ann Clark
Walter Grose (Ag Machinery)	Tom Prout (Ausable-Bayfield Conservation Authority)	John Ogilvie
Ray Grose (Ag Machinery)	Naveen Patni (Ag Can)	Jock Buchanan-Smith
Tom Sawyer (TFIO)	Gregory Wall (Ag Can)	
Heiko Oegema (Farmer)		
John Benham (Farmer)		

APPENDIX II Summary Proceedings of the Manure Systems Workshop.

SUMMARY PROCEEDINGS

OF THE

MANURE SYSTEMS WORKSHOPS

HELD

March 3, 1993 - Woodstock

March 4, 1993 - Port Perry

March 5, 1993 - Kemptville

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ORGANIZING COMMITTEE

Dr. Mike Goss, Land Stewardship Chair, University of Guelph

Mr. Don Hilborn, Ontario Ministry of Agriculture & Food, Woodstock

Ms. Kathy Parris, University of Guelph

Mr. Tom Prout, Ausable Bayfield Conservation Authority

Mr. John Schleihauf, Ontario Ministry of Agriculture & Food, Guelph

Dr. Peter Stonehouse, Agricultural Economics and Business, University of Guelph

MANURE SYSTEMS WORKSHOPS

This summary is aimed to act as a source of information on the views of the agricultural community today.

To develop a sustainable agriculture it is important to balance the increased demands for animal protein and other products with the manure and other waste which is a by product of animal production. For any management programme to be successful it must be both economically viable as well as applicable to each particular operation. Improving manure management applications through recommendations, requires handling the manure in a cost effective and environmentally sound system.

A series of three meetings were held across the province of Ontario. The purpose of these meetings was to gather information on the views of the agricultural community on the perceived problems and solutions associated with manure management. The participants of the workshop represented a broad cross-section from the farming industry. Participants were chosen from a list of names supplied by OMAF offices based on their involvement in the agricultural industry (Appendix 1). The participants at each workshop were given an agenda (Appendix 2), and divided into smaller groups of about 6 - 8 people. Within each group the members had a leader and a recorder. The groups were divided so as to evenly distribute the varied expertise. The members were encouraged to be direct and open about their views and ideas. The members first introduced themselves and describe their interest and concerns. Producers were asked to describe their operations. The groups were then assigned to discuss a group of questions and report as a group at the end of the exercise. These activities were completed during the morning session, and the group broke for lunch. In the afternoon session the solutions to the issues raised in the morning were addressed. A summary discussion on "where do we go from here?" wrapped up the workshops.

QUESTIONS

Prior to the first workshop, a list of eight questions was drawn up to stimulate discussion around the main activities associated with livestock units and the handling of manure. The following section details the key points gathered from the discussion at all three workshops.

1.	Considering your experience, does the changing of livestock feed influence the quality and quantity of manure produced?

It was generally agreed that feed influences manure. In Eastern Ontario there has been a shift to long cut hay which has influenced manure management, including manure applications. Much of the manure is now applied to forages. Farmers main priority when considering feed conversion is its conversion to animal protein. Some opportunities were identified in hog and poultry operations to influence the manure through the type of feed. This has lead to a reduction in the volume of (hog) manure and has ensured that the dry manure is really dry in poultry production units.

Odour reducing additives were too costly, but farmers might use them if work is done to improve them so that they have greater impact on the problem.

2.	How important is the design of your barn/animal housing for handling manure? What are

The design of the barn and associated facilities restricts the flexibility for changing manure handling systems.

The ease of handling manure is becoming more important in the design of new facilities.

The scale of an operation is a significant factor in the design of barns and the type of manure handling system that can possibly be introduced.
Most livestock producers have to contend with both solid and liquid manure in the barn or in the yard. Outside pads (earth or concrete) intercept a lot of water that needs to be considered within the total design criteria of the barn system.
Production of dirty water is a mixed problem depending on the requirements of manure handling.

Some systems result in too much liquid so production of dirty water is to be avoided. Other systems need the addition of water to help make the manure manageable.

Practical solutions to the production of unwanted dirty water are **eaves troughs** in which can be used to divert water away from manure storage. **Berms** are sometimes used to prevent barn yard runoff. **Vegetated buffer strips** can be used to prevent contamination of streams or ponds.

Animal welfare, manure handling and the preferred method of application all need to be considered together in the design of new barns.

Clean water use with manure handling is not considered by many farmers to be a problem as it ultimately provides additional water to crops in summer, and helps encourage infiltration of manure during application. Animal comfort **is taken into account** in the barn and this certainly influences manure management requirements. For example it may mean that calves are kept on hard pack which gives a solid manure source whereas the main barn is on a liquid system.

3. How important is convenience in the storage of manure on the farm? What factors are important in influencing the decision of where to locate the storage?

Convenience was identified as the most vital aspect of storage. Labour resources were important in locating storage. Recognition of the total system is the key to manure storage. For maximum convenience the location of the manure storage unit:

- must not interfere with other farming operations
- allow access for spreaders, tanks etc.
- recognize there are limits to how far it is possible to separate barn and storage area.

It was recognized that environmental concerns are important to farmers when considering the location of manure storage. Zoning of buildings is an important factor in deciding on the location of storage units. Storage units need to be located where they will not contaminate water resources. There was a need for technical support on this issue because easy access to drinking water supplies for the barn was often important in locating the farm buildings in the first place.

A final comment on manure handling and storage was, "The general population must recognize that if sewage treatment regulations were applied to agriculture, treatment plants of the size associated with a small town would be needed on each livestock farm".

4. What are your thoughts about treating, processing, or using gases from your manure while it is in storage (eg. composting, aeration)?

Most manure treatment increases the costs, and products such as biogas or compost give inadequate financial returns so they may not be viable. Also considerable technical expertise is required in some cases (eg biogas) to carry out the treatment.

"Farmers won't go broke for the good of mankind" was indicative of the feelings about manure processing.

Composting was thought to have many advantages for the environment:

- odour control
- less problem to environment because composting results in a good balance of C:N in the final product
- low capital investment required
- heat production might be exploitable, but gaseous losses of N are increased.

Nonetheless, while there is a populist view that composting is a viable option, many farmers see composting as not being practical, mostly because it is capital and labour intensive.

Getting value added into manure through sales to urban or commercial outlets is viewed as costly and inconvenient and only at best a niche market item.
Aeration was not considered practical without improvement in design.

5.	How far is it reasonable to transport manure to apply it to the land? What are the problems and advantages of spreading manure on all parts of your farm? Does

General agreement that irrigation system can only be used up to 1 mile from the storage unit.

Tanks and spreader transportation could be further but many felt that the cost effectiveness declined markedly after 1 mile.

The major exception is solid chicken manure which because its high nutrient value may get transported up to 6 miles from the barn.

Many concerns were expressed about manure application.

Close to barn spreading creates problems of nutrient overload. Water quality issues cause concern for farmers. These raised questions such as, "How much manure should be spread and how can the window of time available for spreading be increased?" There was a recognition of the need to exploit the nutrients - "get them back where they came from".

Farmers needed to know the total system demand for nutrients, and it was recognized that manure application should reflect this demand.
Farmers would like to increase the distance manure can be transported cost-effectively so that they can increase the land use available for animal manure to include their whole farm.

A number of limitations to selling manure were raised.

Liquid manure is difficult to sell because of the road traffic laws - especially with the possibility of spills.

There is also farmers resistance to purchasing manure because of:

- weeds
- the nutrients value of manure is not adequately demonstrated
- soil compaction from handling and spreading is a problem
- the trend towards no-till, where appropriate application methods are considered to be problematic

6.	How do you apply manure on your farm? Is the design of the equipment adequate?

Farmers apply manure as liquid and solid.

Liquid application is by Irrigation, Injection, Tanker Spread, Solid application is by spreaders.

Irrigation and injection give concerns on rolling land. There is a significant need for good advice. Many farmers were concerned about environmental impacts.
Irrigation also creates problems because of drift.

Machinery and equipment is improving but it is costly to change to new (liquid application) systems and solid spreaders.

Current guidelines used by farmers when applying manure:

1. The amount of land available for application and the mass of manure present.

2. Nutrient requirements.

Farmers need better support in this area.

Testing of manure is not done: some have in the past but it generally showed little variation so they asked "why bother to continue?"

Many felt that soil testing a better way to go.

Semi-solid application would be of interest to farmers but engineers see this as a particularly difficult material to handle.

7. What are the advantages and disadvantages when using manure to fertilize crops? Do you have any indication of long-term benefits (eg. for soil structure or protection from erosion) or problems for your crop production, utilizing the manure you produce?

Advantages of manure application

Manure allows reduction of commercial fertilizer.

Manure has more than fertilizer values:

- many perceived soil structural improvements, especially better soil tilth.
- increased yield with manure especially in drier years.
- allows crop rotation which has additional benefits over monoculture.

Disadvantages of manure

- It is costly for farmer to apply manure- tractor fuel requirement increases.
- Compaction - can be solved with equipment and better management practices.
- Weeds
- Losses of nitrogen to air and water resources.
- Excess application gives yield losses.
- Odour problems
- Reduced tillage systems are not very compatible with manure application.

8. Are you aware of any problems or concerns from neighbours about the manure storage and application to land that might be considered an environmental hazard or nuisance?

The problems reported included:

- Odour problems
- Drift problem from liquid irrigation
- Spills and spreading close to road
- Noise when spreading at night
- Neighbours and passers-by don't always recognize the need for some tolerance of manure smells etc.
- Farmers are increasingly being made aware of concerns about the well water quality of their neighbours. There are problems of contamination from the outlet from tile drains, to water source. There are problems are associated with both liquid and solid applications.

SOLUTIONS

The answers to the questions on manure management were reviewed by the workshop moderators, and questions then drawn up for consideration of solutions. The following section details the questions posed and the key points raised from the discussions at all three workshops.

1.	How can we best address the odour and other environmental concerns about manure?

There is a need to develop a public relations information plan that provides for education of the general public and new neighbours of livestock farmers.

Dealing with odours:

<u>Odour at the time of application</u> can be reduced if incorporation is carried out rapidly after application.

Possible additional solutions include injection and low-level irrigation nozzles.
The success of reducing odour emissions really depends on the operator because it was felt that there is adequate technology. The greatest problem is handling manure in the no-till systems where incorporation is not considered an option.

<u>Odour around the barn and manure storage</u>

Zoning of barns and manure storage has been a successful means of reducing complaints.

Possible solutions include:

! Reduce the time manure is present in the barn.
! Have filters on barn ventilation systems - possibly encourage vertical stacks (but this was thought not to be appropriate in Ontario). It was believed to be useful to screen manure storage units with trees.
! Prevent leakage from manure storage lagoons by better design and management.
! Educate producers about environmental protection through:

  •Improved advice on time of application
  •Matching nutrient supply to crop requirements
  •Provide practical on farm manure testing

•The relative merits of solid and liquid systems for the environment

Special concern was expressed about reaching hobby farmers to educate them about manure management and environmental concerns.

2.	How can we improve manure management so that the farmer can make better use of the nutrients and minimize environmental contamination?

A key comment was that farmers should be encouraged to regard manure as a resource not a waste. Manure should be incorporated where possible. Farmers were concerned about what can be done about manure in no-till system. Also some incompatibility also exists with applying manure to forage and permanent pastures. A plea was made for farmers to plan manure application just the same way as if applying fertilizer. Particularly it was urged that farmers needed to plan ahead.

There is a need to provide tests to establish the value of the manure. The use of the soil N test and other soil tests should be used to help achieve applications that are appropriate to crop requirements.

Keeping records on the rate of application should be encouraged. Operators can use manufacturers specifications on pump rate etc. to obtain detailed application information.
There is a need for a wide range of equipment that can be used under different climate conditions and soil types.

There is a need to improve equipment that would give better distribution of solid manure.

Keep liquid levels down in solid systems.

How can the window of opportunity for application be increased?

This information was provided by a participant as an example of an on farm test.

The Effectiveness of Manure as a source of Nutrients to second year corn out of barley and clover

Treatment	Plant Population	Corn Yield (Pioneer 3925)/bu/acre
No manure (Control)	26 000	88
	28 000	93
Irrigated Manure Pre-Plant	25 000	119
(5 000 gals/acre hog manure)	30 000	121
Irrigated Manure Post-Plant	28 000	132
(5 000 gals/acre hog manure)	29 000	164
	30 000	167
Commercial fertilizer only		
160N 50P 90K	30 000	132
190N 50P 90K	29 000	130
190N	30 000	166
160N	27 000	129
120N	27 000	129
90N	26 000	134

NB. Soil Test on experiment site: P=26 (high), K=156 V.High, pH=7.8.

3. How can we best develop guidelines and regulations for managing manure that are sensible and practical? Whose problem is manure anyway?

Manure was seen to be the problem of both the farmer and society. However the view was expressed that "We don't want their garbage, they don't want our manure". But there was a regional variation as to how much responsibility the farmer should accept. The role of society was seen to be the more important from the west to the east of the province.

There should be one lead ministry for policy on manure.

There is great distrust of the MOE in their understanding of the farmers difficulties. It was suggested that an MOE officer be stationed in OMAF to develop a concept of a community relations officer (c.f. Ontario Provincial Police). Society must help the farmer to ensure that agriculture does not lose its competitive position when meeting environmental requirements.

Concern was expressed about the support given by government. Low interest loans should be introduced for government assistance programs rather than grants. Grants tend to help people who can afford to get them rather than those who need help.

It was generally accepted that guidelines were the appropriate means of compliance.

The advantages of guidelines were that they:

- provide for farmer input leading to practical solutions.
- allow the farming community to be proactive and avoid confrontations.
- allow farmers to respond to peer pressure
- allow development and incorporation of new information from other jurisdictions from innovative farmers.

It was suggested that a certification process could be adopted to increase compliance to guidelines. This should be mandatory for contractors and custom operators but voluntary for farmers.

Regulations were viewed only as a last resort to deal with people who "just do not care".

Current knowledge does not permit a zero tolerance regulation to be introduced now, which is what many city people want. Further research is necessary to achieve that goal and introduction of sensible regulations would therefore be delayed.

Regulations have a high cost of enforcement. They can be abused by vindictive neighbours and there must be sensitivity and common sense applied to the problems of manure.

4. What are best techniques for manure testing and application?

This question missed the mark and the comments made did not really address the issue.

The pertinent comments were:

- Use common sense.
- Techniques need to be practical and achievable using normal management techniques.

5. What are the main information needs for farmers and society to address the manure issue?

It was noted that farmers require information on:

- the quality of manure especially to nutrient content
- the quantity of manure to apply
- the value of the manure applied - including field variation due to uneven application

Farmers need convincing that the manure will provide an adequate supply of nutrients for their main cash-producing crops.

All information needs to be given in terms of the economic benefits and the environmental costs of manure application.

There is a need for on farm demonstration plots to highlight the value of manure, and provide some practical solutions to problems, such as those produced by innovative farmers.

Custom applicators need educating on the correct approach to manure application.
Research Information is required on:

- possibilities for processing of manure, eg. composting, aeration, separation - liquid from solid elements, digestion
- alternative systems for collection and storage

- research should consider labour requirements, cost, and the small amount of time available from the farmers for supervision.
- research needs should not have to wait for information to come from work in Ontario. Farmers expressed the view that some risks in adopting research from other jurisdictions such as Europe and the US was justified and there was no need to "reinvent the wheel" in Ontario.

Society needs reassurance that farmers are responsible being and are doing their best with the information available.

The environmental farm plan would be one method of accomplishing this.
Targeting of information recipients is required so that local officials, councils, politicians and the press are told about manure issues by appropriate packages. Real-estate agents could help ensure that new rural residents understand what farming practices involve.

Odour needs to be presented as the 'smell of livestock farming' . "As with any other industry agriculture has its background odours such as manure".

Issues such as the flow of manure through soil (eg tile system) requires additional information for both society and farmers.

Society also needs to be educated about the following aspects of manure:

Manure :lowers the use of commercial fertilizer

:improves soil quality

:improves the sustainability of the rural economy

:recycles

One solution suggested that to reduce conflict between farmers and the rural residents was to zone land as agricultural and include a condition on title deeds that domestic use must be linked to a recognition of others "right to farm".

6.	What is the best approach to making manure more valuable to the farmer, eg. what processing is possible?

Best approach is to improve storage capacity so that it can be applied at the proper time.

Manure is a nutrient resource.

Improve value if the nutrient value is known.

Separation of the solid and liquid component of manure would help to improve utilization.

Pelleting manure was a possibility for a niche market.

Lowering the cost of manure equipment increases the value of the manure. This can be achieved by sharing or renting equipment.

Any processing of manure really has to be simple and workable.

Processing will improve the odour problem

- drying also helps in this aspect
- composting was believed to reduce odours and stabilize nutrients

WHERE DO WE GO FROM HERE?

When this question was raised the general view was that farmers preferred to be involved with small workshops where they could exchange information rather than have a large provincial conference that only involved invited speakers.

A greater demand for technical information from experts on manure management systems was noted, as the workshops proceeded from Woodstock to Kemptville.

APPENDIX 1

LIST OF PARTICIPANTS

Kemptville

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John Spanjer,

APPENDIX 2
AGENDA

MANURE SYSTEMS WORKSHOPS AGENDA

9:30 a.m. Introductions: John Schleihauf
Dr. Michael Goss

9:45 a.m. Table Introductions

In 3-5 minutes, within the table group, describe your farming operation or involvement in manure issues, so that others at the table can share your experiences. The recorder will summarize your remarks.

10:30 a.m. What is the current state of the art in manure systems in Ontario? Discuss the following questions and report as a group at the end of the exercise.

1. Considering your experience, does the changing of livestock feed influence the quality and quantity of manure produced?

2. How important is the design of your barn/animal housing for handling manure? What are the main advantages and disadvantages of the design? How should dirty water from the barn or yard be dealt with?

3. How important is convenience in the storage of manure on the farm? What factors are important in influencing the decision of where to locate the storage?

4. What are your thoughts about treating, processing, or using gases from your manure while it is in storage (eg. composting, aeration)?

5. How far is it reasonable to transport manure to apply it to the land? What are the problems and advantages of spreading manure on all parts of your farm? Does transportation limit sales of manure to other farms?

6. How do you apply manure on your farm? Is the design of the equipment adequate? What guidelines do you use to determine the amount to apply? Do you test the manure before application?

7. What are the advantages and disadvantages when using manure to fertilize crops? Do you have any indication of long-term benefits (eg. for soil structure or protection from erosion) or problems for your crop production, utilizing the manure you produce?

8. Are you aware of any problems or concerns from neighbours about the manure storage and application to land that might be considered an environmental hazard or nuisance?

11:20 a.m.	Table reports
12:00 noon	Lunch
1:00 p.m.	From the issues raised in the morning discussion, what are some possible solutions?
2:00 p.m.	Table reports on the solutions
2:45 p.m.	Summary discussion: "Where do we go from here?"
3:00 p.m.	Adjournment

CANDID COMMENTS

"We won't go broke for the good of mankind".

"Manure is the cost of doing business".

"Just like any other industry manure has its odours, who are we to say that smog is better than manure's odour".

"There is a blockage in the bureaucratic bureaucracy.. the system is constipated, remove the blockage!"

"Farming is a business and dollars motivate".

"Let's get those nutrients back where they came from".

".... the right to farm".

"Don't reinvent the wheel in Ontario".

"Image of the farmer important as is the food produced".

"Manure is a resource- we paid to produce it".

"This is not S.W. Ontario..settlement was near watercourse, soils are shallow, costs are different, especially if bedrock is blasted".

"Manure is an asset, not a liability".