EFFECTS OF LIVESTOCK MANURE DISPOSAL ON NITRATE ACCUMULATION IN A CLAY SOIL

by

Glen Carl Bergson

A dissertation submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

ABSTRACT

GLEN CARL BERGSON

THE UNIVERSITY OF MANITOBA

OCTOBER 1975

Mankind is currently experiencing a period of increased ecological awareness. Agriculture is being affected by this concern partly because of the potential contribution of livestock wastes to environmental pollution. In the fall of 1971 the Departments of Agricultural Engineering and Plant Science undertook a groundwater and runoff water quality manure management experiment at the University of Manitoba Glenlea Research Station.

Approximately 3.2 ha were subdivided into 140, 7.6 m by 30.5 m plots. Five crops, alfalfa, barley, corn, reed canary grass, and a mixture of meadow fescue, brome, and alfalfa were seeded. Swine, beef, and dairy cattle manure were selectively applied at levels of 33.5, 67.0, and 201.0 kg ha^{-1} of N in the spring, fall, and winter. Inorganic fertilizer at levels of 67.0 and 201.0 kg ha^{-1} of N and a bulk application of sewage sludge were applied. Selected plots were monitored for percent nitrogen uptake and chemical analysis of soil samples was performed for these plots. Analysis of the runoff from selected plots was also included in the experiment. The data were analyzed statistically using a split-plot design.

Runoff from agricultural land can pose a serious threat to the environmental ecosystem. Nitrate and phosphate concentrations well in excess of the recommended standard critical values were recorded. The chemical oxygen demand (COD) of the runoff was, in some cases, recorded greater than that of domestic sewage.

Nitrate leaching and buildup of nitrate-nitrogen in the soil profile was not a serious problem at the manure application rates tested. A statistical analysis indicated a differential nitrogen uptake ability between alfalfa, barley, corn, and reed canary grass. Reed canary grass demonstrated the highest percent nitrogen uptake ability on a dry matter basis. There was no nitrate accumulation in the soil profile of the manured plots. Control and pre-treatment (1972) plots had greater nitrate concentrations in the surface layer than at any depth after manure treatment.

As part of the thesis the entire research project was assessed. Lack of a proper statistical design may be evidence enough to warrant discontinuation of the project on a long term basis. Consideration should be given to dividing the experiment into smaller and more controllable (statistically and operationally) projects.

Livestock wastes definitely can contribute to pollution of the environment if adequate management techniques are not developed. There is a need for on-going research in the area of agriculture and the environment.

ACKNOWLEDGEMENTS

I wish to express my sincere thanks to the chairman of my committee, Dr. D. D. Schulte. I am appreciative of the guidance, encouragement, direction, understanding, and friendship I received. Thanks are due to Dr. F. Penkava for his work in capacity of departmental advisor. He, too, provided understanding and encouragement. I am appreciative of the work of Dr. G. Racz (Department of Soil Science) in the capacity of external examiner.

There are others -- professors, technicians, graduate and undergraduate students, and friends -- each in his own way making a significant contribution to my thesis and graduate work. These people, although often taken for granted, were appreciated. Thank you ...

I am indebted to the entire educational system for providing me with the opportunity to acquire professional skills, a graduate school education, many friends and experiences, and an exciting future.

Last, but most important, I love my wife, Carol, and family; they showed understanding and patience; they provided guidance and encouragement; and, they gave me the desire to push on when my enthusiasm was at a low ebb.

Thank you ...

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Mankind is currently experiencing a period of increased ecological awareness. In the past, industrial wastes were discharged as cheaply as possible. Very often this involved discharge of raw wastes (chemicals, metals, liquids, solids) into the air, soil or water. In many cases the wastes were assimilated by the environment through processes such as mineralization, diffusion, or dispersion. However, as industrialization has progressed, discharge of environmentally degrading emissions (emissions that are so intense that assimilation is not possible and permanent or continuing damage results) into common property natural resources has become unfavourable. Concerned citizens realized that continued dumping of environmentally degrading emissions could not persist if mankind was to survive. It follows that many facets of human endeavour, including agriculture, have been influenced by this newly founded ecological revolution.

Agriculture is experiencing a period of rapid increased demand for its products. While the "green revolution" has supplied more food to the world's exploding population than ever before, a tremendous strain on agri-business to supply considerably more food still exists. Mechanization, advancements in chemical technology, developments in plant and animal genetics, and more intensive farming methods coincident with the "green revolution" are being employed to meet demands for food. Despite the significance of improved technology, production techniques, and the "green revolution" Barkley and Seckler (1972) believe that severe economic and environmental problems will result from these recent trends.

The Manitoba Institute of Agrologists in a 1973 publication, Agriculture and the Environment, indicated that present and future pollution hazards can be associated with fertilizers, pesticides, and livestock wastes. When dealing with livestock wastes, it is important to realize that animal manure contains valuable ingredients for crops and soils -- fertilizer and organic matter. Manure, when applied to a soil-crop regime, is a source of essential plant nutrients such as nitrogen, phosphorous, and potassium as well as micro-nutrients such as boron, manganese, copper, and zinc. Moreover, addition of manure to the soil contributes to the amount of organic matter which is important to soil structure and to the reservoir of potentially mineralizable plant nutrients. However, animal wastes (and by-products associated with the storage and decomposition of manure) may result in pollution of the air, soil, and water. Some related factors in environmental pollution from livestock wastes are quality and quantity of manure, frequency of disposal of manure, soil type and topography, land use or cropping practice, and urban-rural conflicts.

Allred (1969) indicated that there is a trend toward more concentrated and confined livestock production enterprises; and, increased amounts of manure produced in fewer locations would have an adverse effect on the quality of the environment. It has been stated that land disposal is the most feasible and most economic method of manure disposal (Manitoba Institute of Agrologists - 1973). In spite of the positive effect that the addition of manure can have on the crop and the soil, problems may be associated with the application of manure where the nutrient values of the manure applied exceed the crop utilization rate. This, for example, can result in an increased presence of nitrate-nitrogen in the soil and in the groundwater. An acceptable level of nitrate-nitrogen (NO_3^--N) in the ground water is 10 mg l^{-1} (Canadian Drinking Water Standards and Objectives - 1968) and concentrations above this level may be related to infantile methemoglobinemia. Surface runoff from areas where manure has been applied may transport particulate and soluble forms of manure nutrients and pathogens (for example, salmonella bacteria, entamoeba histolytica parasite, and infectious hepatitis virus, Bauer - 1969) into waterways adjacent to farm land in concentrations harmful to aquatic life and human health. Eutrophication of these waters may be increased as a result of carbon, nitrogen, phosphorus, or micro-nutrients which are associated with runoff from manured fields. Land application of manure may be offensive to individuals in nearby communities. Ammonia, hydrogen sulfide, indoles, skatols, mercaptans and other amine gases may be released to the atmosphere when manure that has existed in an anaerobic state is applied to the land; and, the environmental problem is the perception of these gases.

Essentially, the environmental problem in livestock production are a conflict between an ever-increasing demand for food and the handling of an undesirable by-product - animal manure. Research has been initiated to define and alleviate some of these conflicts in Manitoba. Crop response to the application of various types and rates of manure, soil profile and plant tissue analysis, and nutrient concentrations in runoff are being studied under the direction of the Department of Agricultural Engineering at the University of Manitoba.

The objective of this thesis, as a part of the research project, is to more clearly define the basis on which the experiment was established and to examine the results in hope of contributing to the understanding of some of the environmental aspects of manure management using soils and crops as a disposal media. Specifically, the objectives of this thesis are:

1. To assemble a complete background and analysis of the experimental design of the manure disposal experiment at the University of Manitoba Glenlea Research Station.
2. To interpret, where possible:
   a) the accumulation of nitrogen from manures, commercial fertilizers, and sewage sludge in the soil profile of the experimental plots at the Glenlea Research Station.
   b) the concentration of nutrients in the spring and summer runoff from selected plots at the Glenlea Research Station.
   c) the effectiveness of control techniques such as scheduling for the application of manure for Manitoba conditions.
   d) the uptake of nitrogen by those crops sampled in 1973.

CHAPTER 2

REVIEW OF LITERATURE

2.1 The Manure Problem in Manitoba

Heald and Loehr (1971) indicated that prior to the 1950's agricultural wastes could be disposed of without any consequence to the environment. During the 1950's, however, clear signs developed showing that the environment was being damaged by agricultural, industrial, and municipal wastes disposed of in the land and air. Heald and Loehr (1971) also suggested that the agricultural complex (production and processing of agricultural products) was the largest single source of pollution in the United States. Bayley (1971) indicated that the number one research priority should be the return of agricultural organic wastes, in particular manure, to the land. Similar trends have developed in Manitoba. On farms in Manitoba, livestock manure has traditionally been returned to the land; but, as livestock production facilities have increased in size, livestock manure has become a serious contaminant in the soil, air, and water (Buchanan - 1971). Hudek (1971) outlined the potential livestock pollution problem in Manitoba with a comparison to a human population equivalent in terms of biochemical oxygen demand (BOD) contained in the livestock wastes (Tables 2.1, 2.2). The livestock population equivalent in Manitoba in 1969 was approximately equivalent to three-fourths of the total Canadian population in terms of BOD equivalence.

Buchanan (1971) considered land application of animal manure as the most economic and feasible method of manure disposal subject to limitations

TABLE 2.1 Livestock Waste Quantities for Animals of Average Weights*

Animal	Wet Manure (Kg/Day)	Dry Manure (Kg/Day)	Population Equivalent
Cattle	29	4.54	11
Hogs	3.17	0.5	3
Chickens	.12	.03	1/12
Turkeys	.34	.09	1/4
Man	-	-	1

TABLE 2.2 June 1969 D.B.S. (Dominion Bureau of Statistics) Numbers of Livestock in Manitoba and Population Equivalent*

Animal	Livestock Numbers	Population Equivalent
Cattle	1,019,000	11,209,000
Hogs	612,000	1,836,000
Sheep	41,000	120,000
Hens	5,440,000	453,500
Turkeys	825,000	206,250
Horses	36,000	360,000
		14,184,750

* Hudek, E. P. 1971. Waste management problems in the primary agricultural industry, Unpublished report (seminar), Dept. of Agr. Eng., University of Manitoba, Winnipeg, Canada.

such as air pollution, ground and surface water quality, and crop utilization rates of nitrogen. Disposal of manure onto farm land has advantages as a source of nutrients and organic matter and is probably the most practical final placement for the manure (Klausner et al - 1971). Loehr et al (1973) also considered land application of farm animal manure as the most practical method of manure disposal and utilization if adequate management of methods was provided.

To this point, manure has been referred to in general terms. The 1973 edition of the Agricultural Engineers Yearbook defines manure as follows:

> "Manure is the fecal and urinary defecations of livestock and poultry. Manure may often contain some spilled feed, bedding, or litter".

However, quality and quantity characteristics of the manure vary between animal species. Similarily, amounts of spilled feed, bedding, and litter, spilled drinking water and washing water, and milk house wastes vary depending on the management practices of the particular farmer. Feed rations contain carbohydrates, proteins, fats, lignin, and inorganic nutrients such as nitrogen, phosphorous, potassium, and micronutrients; but, may vary from season to season, farm to farm, and region to region resulting in a variation in manure characteristics. For example, most farmers in the Nebraska region of the United States feed corn whereas the farmers of Manitoba are more likely to feed barley. Since the chemical characteristics of the manure depend primarily upon the chemical properties of the feed processed by the animal (McKinney - 1970) a variation in feed input (for example, a difference between corn feed and barley feed) will change the characteristics of the manure.

McCalla et al (1970) suggested that approximately 90% of the dry matter in manure is organic waste material from animal digestion of feeds; and, that manure retains about 60 to 70% digestible materials. As well, McCalla et al (1970) indicated that animal waste is more concentrated than the feed in lignin and minerals upon deposition in the feedlot or confinement and less concentrated in carbohydrates. If, as McKinney (1970) suggests, 70% of the feed consumed is excreted in the form of urine and manure, perhaps there is a case for re-feeding of manure to livestock.

It is a fact that the inherent variability in manure must be recognized when examining the implications of disposal of animal manure onto farm lands. Previously referenced, Buchanan (1971), Klausner et al (1971) and Loehr et al (1973), indicated that manure should be returned to the farm land provided that precautions ensured proper management techniques. When manure is applied to the soil (Figure 2.1) it may:

1. be mineralized by the soil biosphere ,
2. be washed away by runoff or be leached into the hydrosphere ,
3. volatilized into the atmosphere.

Regardless of the fate of the manure after land disposal, each of the aforementioned receptor media are unique in their relationship with the manure; and, each will be further discussed as soil biosphere, hydrosphere, and atmosphere.

2.2 Soil Biosphere

The intended final placement of manure during land application is the soil biosphere -- the soil and crop. Manure, as previously discussed,

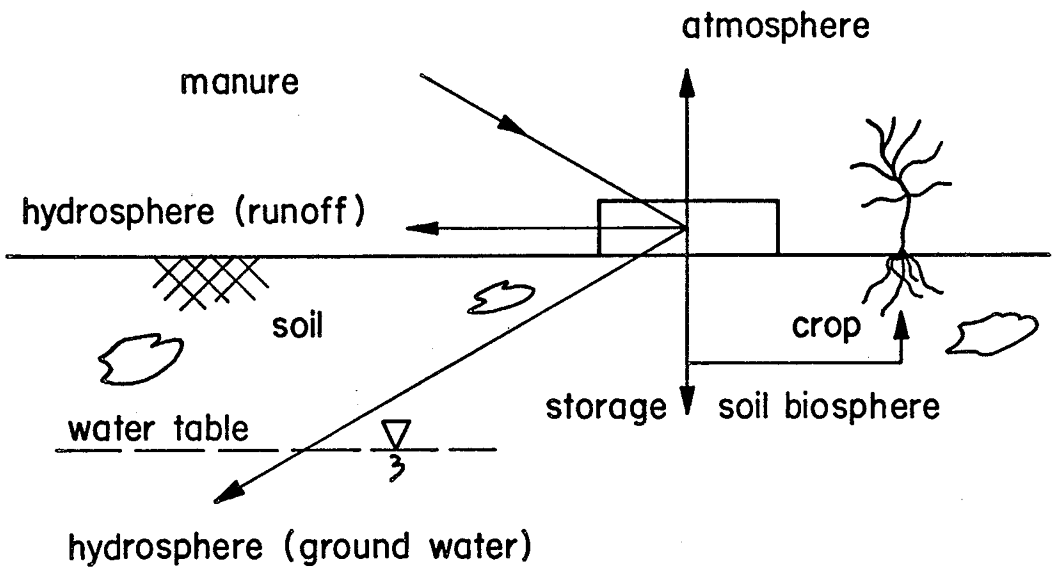

Fig. 2.1 Manure Applied to Farm Land

is a complex commodity in the crop-soil-manure regime. The soil is equally variable. Complex physical, chemical and biological properties are inherent to the many types of soil. Climate, parent material, living organisms, local topography, and time are factors that determine the kind of soil produced (Berger - 1972a). There are, for example, more than 500 types of soils recognized and mapped in Manitoba (Beke et al - 1971). Upon formation, there are four components of soil that warrant consideration. Soil is a mixture of mineral matter, organic matter, water, and air. Although variable, an ideal combination of the four components for plant growth is approximately 45% mineral matter, 5% organic matter, 25% water, and 25% air (Foth and Turk - 1972a). Physical variability of soil relates to the proportioning of these four soil components with respect to flow and storage of water, movement of air, particle size, and structural aggregating ability (Berger - 1972b). Chemical variability is primarily due to the proportioning of the mineral materials (Berger - 1972c). Biologically, the soil supports innumerable forms of plant and animal life; from single celled organisms to large burrowing animals (Foth and Turk - 1972b). In fact, some soil microbiologists consider soil as a living tissue because of the heavy population of living organisms (Robinson - 1972).

Additions of manure to soil greatly increase the biological activity of the soil. The growth of bacteria, fungi, and actinomycetes is stimulated. by addition of manure; and aerobic cellulose metabolizing bacteria are more numerous in manured fields (McCalla et al - 1970). Not only does the manure add organic matter to the soil, the manure stimulates the biological activity which contributes to the decomposition of the organic matter in the soil (i.e. mineralization of the soil organic matter). Robinson (1972) supports McCalla et al (1970) by indicating that many properties of soil, particularly those important to the decomposition of manure, are properties of the soil microflora. The ultimate disposition of manure, that is, the mineralization of the organic matter rendering the inorganic fraction available for storage in the soil and for crop utilization, depends on the interactions of the biological, chemical, and physical characteristics of the soil system with the surrounding soil environment.

Application of animal manure on to the soil surface or incorporation into the soil is followed by manure decomposition. Decomposition can be aerobic, anaerobic, or facultative. The factors contributing to the decomposition of the manure (i.e. organic matter) or the proliferation of micro-organisms favourable to decomposition are physical variables such as moisture content, clay content and type (Robinson - 1972), and oxygen, temperature, and micro-organisms already abundant in the soil (McCalla et al - 1970).

Like the organic matter in crop residues the manure organic matter (fats, carbohydrates, proteins, lignin) must be decomposed before the inorganic nutrients become readily available. The soil organisms that regulate decomposition have similar nutrient-element-physical requirements to that of the higher forms of life (Foth and Turk - 1972c). For example, temperature regulates some of the chemical and biological changes in the soil. Biological reaction rates increase two to three fold for every $10^{o}C$ temperature increase to a rough upper limit of $80^{o}C$ with the optimum temperature range around 35°C (Foth and Turk - 1972c). Autotrophic bacteria, which are capable of oxidizing ammonia, nitrite, sulfur, manganese, hydrogen, carbon monoxide, and methane, function within a temperature range of 5-55°C with production of nitrates greatest at 37°C (Donahue - 1965a). Moisture influences the numbers and activities of soil micro-organisms. The optimum amount of moisture for most soil organisms is between 50 and 70 percent of the water holding capacity of the soil (Foth and Turk - 1972c). Soil aeration is primarily governed by fluctuations in water content and is considered the inverse of moisture content. Aeration, therefore, increases with a decreasing water content; and, an increase in water content leads to the development of anaerobic conditions. Aeration may be reflected by the soil texture (Robinson - 1972). Texture refers to the fineness or coarseness of the soil and is determined by the relative proportions of sand, silt, and clay. Rates and extents of physical and chemical reactions are governed by texture because it determines the amount of surface area on which reactions can occur (Foth and Turk - 1972c). Concentration and rate of supply of gases affects the soils' micro-organisms (Foth and Turk - 1972c). Oxygen is used in the oxidation process; carbon dioxide as a source of carbon for autotropic organisms; and, nitrogen gas for the nitrogen fixing bacteria. Abundant oxygen will favour nitrite and nitrate formers, nitrogen fixers, fungi, and actinomyces which oxidize organic matter (Foth and Turk - 1972c). Initial populations have a decided influence on microbial activity. If numbers are small the mineralization process will be slower in commencing. If the aforementioned physical factors are conducive to soil microbial activity then the specific mineralization process may commence immediately (Robinson - 1972).

The conversion of nutrients in organic matter to the mineral inorganic form (i.e. decomposition) is termed mineralization. Mineralization of animal manure in the soil yields nitrogen, phosphorous, potassium, and micro-nutrients such as boron, copper, manganese, cobalt, zinc, and moylbdenum (McCalla et al - 1970). One of the factors affecting the ability of the soil to behave as a medium for the disposal of farm animal waste is the ability of the plants (cropping practice) to utilize the mineralized nutrients. The cropping procedure in this sense must be included as part of the soil biosphere since plants require sixteen essential nutrients for growth (Donahue - 1965b). Excessive mineralization of animal manure in the soil may lead to nutrient leaching into groundwater or nutrient loss (runoff) into ditches, streams, and lakes (McCalla et al - 1970). Runoff and leaching and problems associated with each are discussed in Section 2.3 - Hydrosphere. Excessive mineralization may result in the accumulation of nutrients in the soil or plant system. This accumulation may result in an unhealthy environment for the plants or possibly toxic concentrations for the plant consumers.

Yields of corn (for silage) were depressed by heavy applications of solid beef feedlot manure beyond a certain upper limit of between 556,000 and 740,000 kg ha^{-1} of manure. These depressed yields were attributed to the accumulation of soluble salts in the soil from large manure treatments. Toxic ammonium concentrations in the soil to a depth of 30 cm were partially responsible for poor germination and poor seedling vigor. Sodium and potassium accumulations in the soil were associated with poor yields (Murphy et al - 1972). However, Hensler et al (1971) suggested that for most soils, nutrients in manure (including N, P, K, Ca, Mg, S, Zn, Cu, Mn, Fe and B) can be used in crop production with little danger of plant toxicity; but, nutrient utilization efficiency decreases with increasing application rates thereby creating a pollution potential. Overman et al (1971) determined that oats grown with dairy manure measure up to those grown with commercial inorganic fertilizer in chemical composition, palatability, and digestibility. O'Callaghan et al (1973) suggested that animal manure spread on grazed areas may cause a health hazard to grazing animals. Nitrate poisoning where forages contain an excess of (0.4 - 0.5)% nitrate-nitrogen is also a possibility. Ukrainetz (1969) indicates that nitrate poisoning due to the accumulation of nitrates from nitrogen fertilizers may occur at levels as low as 0.14% nitrate-nitrogen. Over application of manure or under estimation of nutrient quantity associated with manure mineralization may result in conditions that are hazardous to the livestock or detrimental to the crops that have been manured.

2.3 Hydrosphere

Although the intended final placement of the animal manure during land application is the soil biosphere, the possibility of manure deposition in the hydrosphere exists. There are two distinct, but not separate, modes and locations by which the hydrosphere may become contaminated. Runoff from sloping fields may affect surface water courses and lakes. Leaching of nutrients may contaminate ground water reservoirs, surface water courses and lakes.

When precipitation, snowmelt, irrigation, or the like supplies water to a sloping surface at a rate exceeding the infiltration rate of water into the soil, runoff occurs (Holt - 1969). If infiltration is inhibited (for example, by an impervious layer or frost conditions) then runoff becomes an even more critical problem. Allred (1969) indicates that a large portion of stream and lake pollution that occurs during spring thaw is thought to have originated from fields where farmers have spread manure during the previous winter months. When manure is spread on frozen or snow covered fields, or when heavy rainfall occurs subsequent to land application of manure, considerable runoff resulting in nutrient loss is possible. Nitrogen losses may be as high as 3.34 - 4.45 kg ha^{-1} to over 25.6 kg ha^{-1} (Miner and Willrich - 1970). Klausner et al (1971) indicated that on a frozen grass sod field with a 20% slope, 16.15 kg ha^{-1} of nitrogen (expressed in N) and 4.65 kg ha^{-1} of phosphorus (expressed in P_2O_5) were lost.

Leaching can be associated with groundwater seepage or percolation (Armstrong and Rohlich - 1970). If the rate (total yearly rate in a bulk application) of fertilizer (manure) nitrogen does not exceed the nutrient requirements of the crop there should be little likelihood of nitrate-nitrogen leaching because of the lack of accumulation of nitrate-nitrogen (Power - 1970). A nitrate-nitrogen pollution potential