Generic Environmental Impact Statement on Animal Agriculture:

A Summary of the Literature Related to Soils (I)

Prepared for the Environmental Quality Board

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ENVIRONMENTAL QUALITY BOARD

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To Interested Minnesotans:

The GEIS on Animal Agriculture is a statewide study authorized and funded by the 1998 Minnesota Legislature and ordered by the EQB. The Legislature directs the EQB to "...examine the long-term effects of the livestock industry as it exists and as it is changing on the economy, environment and way of life of Minnesota and its citizens."

The intent of the GEIS is twofold: 1) to provide balanced, objective information on the effects of animal agriculture to future policymakers; and 2) to provide recommendations on future options for animal agriculture in the state. The success of the GEIS on Animal Agriculture will be measured by how well it educates and informs government officials, project proposers, and the public on animal agriculture, and the extent to which the information is reflected in future decisions and policy initiatives, made or enacted by Minnesota state and local governments.

The GEIS consists of three phases during the period summer 1998 through summer 2001: scoping the study; studying and analyzing the 12 scoped topics; and drafting and finalizing the GEIS. The EQB has established a 24-member Advisory Committee to provide advise to EQB during all phases of the GEIS. The scoping phase of the GEIS was completed in December of 1998.

This literature summary is the first step in the second phase aimed at study and analysis of the 12 key topics. This summary is intended to inform the Environmental Quality Board (EQB) members, EQB staff, and the Advisory Committee on the "Feedlot GEIS" scoping questions and research needed for adequate completion of the GEIS. The EQB would like to acknowledge the time and effort of the Advisory Committee members who provided invaluable input in the development of this "tool" for use throughout the GEIS process.

The literature summary is formatted to address the 12 topics of concern and 56 study questions outlined in the Feedlot GEIS Scoping Document (www.mnplan.state.mn.us). Any conclusions or inferences contained in this report are those of the authors and do not necessarily reflect the positions of the EQB or the Feedlot GEIS Advisory Committee.

The EQB would like to make this literature summary available to others interested in the effects of animal agriculture. Copies of this literature summary will be available for use in the Minnesota Planning/EQB Library: 300 Centennial Building, 658 Cedar Street, St. Paul. The Library will also house copies of the key literature review articles and the searchable database compiled as part of this literature review. A limited number of copies of this literature summary will be printed for distribution at cost.

For further information on the GEIS or this literature summary please contact the EQB at 651-296-9535.

Sincerely,

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TABLE OF CONTENTS

Executive summary....................I–1
Introduction....................I–5
Review of Literature....................I–20
Knowledge gaps....................I–36
Literature cited....................I–38
Attachments....................I–46

EXECUTIVE SUMMARY

The impact of animal agriculture on Minnesota soils depends both on manure applications and on the type of feed crops grown. Both manure and the perennial forages used to feed animals improve soil quality and productivity. The structure of animal agriculture determines where manure is applied and whether soil-enhancing crop rotations are used.

In the past, animal and crop production were closely linked. As these two operations are increasingly separated from one another, manure is not returned to the cropland that fed the animals. This means that nutrients are exported from cropland, and fewer acres receive the soil quality benefits of manure application. As manure is concentrated in smaller areas, it becomes more difficult to handle as a nutrient source and its pollution potential increases.

The effect of animal agriculture on soil depends on

- how much manure is applied,
- whether manure is applied with minimum nutrient losses
- whether manure is applied when soil is dry enough to avoid soil compaction,
- what crop rotation is used to feed the animals. Perennials or densely-rooted forages that generate high residue improve soil quality.

These factors are not necessarily linked to operations of a particular size.

RESEARCH RESULTS

Studies of the effects of manure applications often compare manure application to the application of a comparable level of inorganic fertilizer nutrients. Thus, the effects summarized below usually represent the effects of manure in contrast to commercial fertilizers. These results are summarized in the table at the end of the executive summary.

Agronomic rates of manure application are based on the soil nutrient test levels and crop needs. Disposal rates of manure application are amounts greater than agronomic rates. The issues involved in the calculation of agronomic rates are addressed in the Manure and Crop Nutrients Report.

Manure generally has positive effects on soil physical and biological properties when it is applied at agronomic rates. Research into the effects of disposal rates of manure have generated mixed results. It is likely that environmental problems such as movement of nitrates to ground water and phosphorous pollution of surface waters will occur before soil physical properties are adversely affected.

Physical Properties

Soil productivity and environmental quality depend on several related soil physical properties: soil structure, aggregation, density, water holding capacity, infiltration, and aeration. These properties are impacted to varying degrees by management practices, including manure application and cropping system practices (i.e. crop rotation, tillage).

Livestock systems that promote the rotation of sod or hay crops reduce tillage frequency, stimulate soil microbial activity, provide protective cover and dense root growth, and improve soil physical properties relative to continuous row cropping. Improvements in soil physical properties are also seen in reduced tillage systems.

Manure application improves soil physical properties by building soil organic matter content and improving soil structure, which in turn reduce erosion. The organic matter aids in stabilizing soil structure, reducing soil density, and increasing water holding capacity. Generally soil physical properties improve with increased rates of manure application, and this applies to all types of manure. Organic matter enhancement from manure application can increase water holding capacity but may not increase the amount of water available to plants. The improvements in soil physical properties from manure application are not achieved with mineral fertilizers.

Manure applied at very high rates results in short term degradation of soil tilth, due to changes in soil properties, such as infiltration rate. However, these are overcome with time and the manure application usually results in net soil tilth improvements.

Perennial pastures grown for rotational grazing can improve soil structure. However, animal traffic can contribute to compaction and may reduce infiltration rates depending on the soil type, soil fertility practices, climate, indigenous soil properties, the cropping/pasture system, and how the animals are managed on the pasture. In grazing systems, pasture management is critical. In addition, efficient use of recycled manure nutrients can contribute to more uniform pasture fertility, and improvements of soil properties.

Management practices that reduce erosion are critical for Minnesota. To protect water quality, erosion control is especially important where and when manure is applied to soil. Manure application reduces soil erosion by improving infiltration rates and structural stability. Cropping systems that include hay or sod crops reduce erosion by providing protective soil cover, compared to continuous row crop production. In some cases, the use of conservation tillage in row crop production can minimize these differences.

Nutrients

The nutrient loading of high manure applications generally does not have a negative impact on soil productivity. However, with high loading, nitrogen and phosphorus from manure can have negative environmental impacts.

Salts

Manure application at agronomic rates is unlikely to create salt problems in Minnesota. The exception may be the long-term application of manure in highly localized areas where salts are already a problem. Such areas can be found on some prairie soils with restricted drainage, such as the heavy soils of the Red River Valley. However, in the Red River Valley, the current density of animal operations is not high.

Weeds

Under some conditions manure can be a source of weeds but in general this is not a problem for farmers.

Biological Attributes

Soil biological activity is impacted by animal agriculture. Manure additions build organic matter and improve soil physical properties, both of which result in increased biological activity. However, the degree and direction of manure's effect depends on a number of factors: the type of soil to which it is applied, method of incorporation, the degree of compaction caused by application, carbon-to-nitrogen ratio of the manure, and decomposability of the manure. Manure can also have beneficial effects for disease and pest control.

Cropping systems which include perennial forages and grasses promote soil biological activity compared to row crops. Animal grazing also can increase soil biological activity when stocking rates, animal traffic and forage removal are well managed.

Some potential problems of manure application include: stimulation of denitrification which results in nitrogen losses; contribution to selection of antibiotic-resistant bacteria in the environment; and fecal coliform contamination of soil and water.

KNOWLEDGE GAPS

The authors recommend the following studies to improve understanding of the effect of animal agriculture on Minnesota's soil resources.

- Estimations of the inputs, outputs, and recycling of nutrients in livestock systems of Minnesota.

- Examination of erosion potential for different types of livestock and cash-grain farms in Minnesota.

- A geographical and historical analysis of Minnesota crop and livestock farming.

- The effects of antibiotic feed additives on microbial activity in soils.

- Investigations of the long-term effects of grazing management systems and their impacts on soil quality.

- The value of manure applications for renovating degraded soils.

- The benefits to soil quality of various types of manure amendments versus crop diversity through rotations, green manures, and cover crops.

EFFECTS OF ANIMAL AGRICULTURE IN MINNESOTA ON SOIL CHARACTERISTICS COMPARED TO INORGANIC FERTILIZER

	Manure applied at agronomic rates	Manure applied at disposal rates	Animal treading	Forage crops
Biological Characteristics				
Biological Activity	↑	↕	↕	↑
Earthworms and Arthropods	↑	↕	↕	↑
Soil Organic Matter Levels	↑	↑	↔	↑
Pests and Disease	↓	↕	↔	↓
Bacterial Contamination	↔	↑	↔	↔
Physical Characteristics				
Aggregate stability	↑	↑	↔	↑
Bulk density	↓	↓	↑	↓
Infiltration	↑	↕	↕	↑
Water holding capacity	↑	↑	↔	↑
Erosion potential	↓	↓	↕	↓
Soil Aeration	↑	↑	↓	↑
Soil Tilth	↑	↑	↔	↑
Salts	↔	↔	↔	↔
Weeds	↕	↔	↕	↕

↕ = may increase or decrease this characteristic

↔ = has little or no effect

INTRODUCTION

A Soil Primer

Our agricultural economy, and our lives, depend on the soil beneath our feet. It provides the food we eat, cleans the water we drink, and supports the diverse biological habitats around us.

Soil is not a static pile of crushed rock, but a structured mix of minerals, organic matter, air, water, and living organisms. Thousands of years are needed for rock to develop into soil, and hundreds of years for rich organic surface layers to develop. Soil is formed when parent material, such as weathered rock, alluvial stream deposits, or glacial deposits, are subjected to climatic and biological forces. Each soil is unique because of its particular developmental history.

Soil is a dynamic body. Gases and water move into and out of the soil. Organic matter is transformed among many different forms. Soil structure is continually being formed, strengthened, or weakened. Living organisms, including microbes, roots, and insects change the physical and chemical environment of the soil. All of these processes occur simultaneously.

Healthy soil performs several functions. It gives us bountiful crops and forests, diverse wildlife, beautiful landscapes, and clean air and water. Soil does each of these by performing five essential functions:

- Regulate water. Soil regulates and partitions the flow of water and solutes into and over the land.

- Sustain plant and animal life. Soil sustains biological activity, diversity, and productivity.

- Decompose and filter pollutants. Soil filters, buffers, degrades, immobilizes, and detoxifies organic and inorganic materials, including industrial and municipal by-products and atmospheric deposition.

- Cycle nutrients. Soil stores and cycles carbon, nitrogen, phosphorus, sulfur, and other nutrients and elements within the earth's biosphere.

- Support structures. Soil supports socioeconomic structures and protects archeological treasures associated with human habitation.

Six soil processes will be discussed below. Many terms used in Part II are explained in this section.

- Formation of soil structure
- Soil water movement
- Gas exchange
- Nutrient cycles
- Biological processes
- Organic matter dynamics

Formation of soil structure

Soil particles (sand, silt, and clay) range in size from gritty sand particles as large as 2mm (1/16 inch) down to microscopic clay particles 1000 times smaller. The relative amount of sand, silt, and clay is called soil texture. These particles rarely exist separately in the soil. They are normally combined into clumps called aggregates or peds. A few particles bind into tiny microaggregates. Microaggregates, in turn, combine to form larger aggregates. Ideally, soil will have a wide range of aggregate sizes and pore sizes. Soil texture and the organic matter content of a soil control the degree of aggregation that is possible.

Aggregates form as a result of physical, chemical, and biological processes. Physical and chemical processes are especially important in the formation of smaller aggregates. Particles are physically pushed closer together by freezing and thawing, wetting and drying, roots pushing through the soil, and the burrowing of earthworms and other organisms. At the molecular level, electrochemical charges bond clay particles together and organic matter then binds with the clay particles.

Biological processes are very important in the formation of soil aggregates. Humus and compounds produced by soil organisms help bind soil particles together. Fungal strands and fine roots surround aggregates and help stabilize them. Plant residue is food for the fungi and bacteria that help form and stabilize soil aggregates. All of these processes explain why plant residue, manure, and other forms of organic matter improve soil structure.

Larger organisms, such as insects and earthworms, enhance soil structure when they burrow through the soil and deposit fecal pellets that become stable soil aggregates.

The structure of agricultural soils is generally measured and compared in terms of the size and strength of the soil aggregates. Aggregate stability is the strength of soil aggregates to withstand chemical and physical forces, such as tillage or rain. Aggregates in healthy soil will vary in size and will have high aggregate stability. Soils with poor aggregate stability are susceptible to formation of surface crusts when rain drops hit aggregates and detach soil particles. Then fine clay particles clog the spaces between aggregates and form a crust on the soil. Biological activity and organic matter (such as from manure and crop roots) help stabilize aggregates and prevent erosion and the formation of surface crusts.

Soil structure is the arrangement and stability of aggregates (clusters of soil particles) and pore spaces in soil. The pore size and shapes affect the ability of a soil to transmit water and air. This impacts root and plant development. Soils with good structural development are more porous and less dense than poorly structured soils.

Soil density, usually called bulk density, is a measure of the proportion of solids and voids in a volume of soil. Soils with good structural development are more porous and less dense than poorly structured soils. Soil bulk density is dependent upon the soil texture, with sandy soils having higher density than fine textured soils. Degradation in soil structure due to depletion of organic matter or other factors can increase bulk density over the long term. Compaction from wheel traffic or grazing can increase soil bulk density.

Soil water movement

Soils store water that can be utilized by plants and other organisms. Like animals, plants need large amounts of water every day. Yet, too much water deprives roots of air and makes soil susceptible to compaction. Water management is basic to erosion and pollution control.

Several soil properties that affect soil water movement are:

- Available water holding capacity— the amount of water soil can hold against gravity's pull, and that is readily available to plant roots. The plant available water is the difference between the amount of water stored when the soil is wet to field capacity and the permanent wilting point—the amount remaining in the soil when plant roots can no longer extract water. The amount of stored water that is available for plant uptake is controlled by organic matter content and soil type.

- Infiltration rate—the rate at which rain, irrigation, or snowmelt gets through the surface and into the soil. Water that does not infiltrate, generally becomes runoff. Infiltration rate depends on factors such as structure, aggregate stability, and density. Living crop vegetation and decaying crop residues on the soil surface protect soil from rain drop impact and slow runoff, resulting in higher infiltration. Rough soil surfaces increase infiltration by creating depressional areas where water can pond and not runoff.

- Hydraulic conductivity—a measure of water transmission through soil and is often used to assess effects of management. Hydraulic conductivity is generally measured by assessing the flow of ponded water through a volume of soil. Hydraulic conductivity is a good assessment of soil structural changes; however, it does not include the effect of soil particle detachment caused by raindrop impact on soil and crusting. Thus, hydraulic conductivity measurements assess soil structure and porosity, while infiltration rates measured with simulated or natural rain assess hydraulic conductivity in combination with soil surface conditions.

- Drainage or percolation— the excess water that soil cannot hold that moves out of the rooting zone so that roots and organisms can get air. Soil texture, soil structure, and landscape position determine how much water percolates through the soil.

Gas exchange

Plant roots and other soil organisms get essential gases from soil air. Gaseous exchange with the atmosphere is required in order to maintain an adequate supply of oxygen and to avoid excess accumulation of the carbon dioxide generated by biological respiration. Aeration refers to the volume of air in the soil as well as the exchange of air at the soil surface. The air-filled porosity is controlled by the total amount of pore space and the volume of the pores occupied by water.

The factor that exerts the most change on soil aeration is the soil water content. Constant changes in water content due to precipitation, evapotranspiration, and drainage result in simultaneous changes in soil air content.

The development of soil macropores can be important for soil aeration. Macropores are large pores generated from root channels, earthworm burrows, cracks, or fissures. When a soil is saturated, the macropores are the first pores to drain and fill with air. Management practices that promote development of macropores include limited tillage, high surface residue, perennial forage and hay crops, and organic matter additions, such as animal and green manure.

Nutrient cycles

Soil is the storehouse for the nutrients that plants need. It is a dynamic environment in which soil biological, chemical, and physical processes are continually changing the form of plant nutrients.

Soil particles and plant residue are made of large quantities of nutrients that are unavailable to plants. Through chemical and biological activity, some mineral particles weather into mineral ions or form clay minerals made of sheets only several atoms thick. Plant residue may also decompose into mineral ions or may be transformed into humus. Mineralization is the conversion of organic compounds by soil organisms into inorganic compounds. Immobilization is the reverse process--plants and soil organisms convert inorganic compounds to organic form in their tissues.

Clay and humus are not absorbed by plants, but they hold nutrients on their surfaces. The amount of places available on clay and humus to hold nutrients is called the "exchange capacity" of the soil. Cation exchange capacity is the sum of exchangeable cations that a soil can hold, or the number of places available for positively charged ions, including calcium, magnesium, sodium, potassium, copper, zinc, manganese and iron ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cu^{2+}, Zn^{2+}, Mn^{2+}, and Fe^{2+}). Nutrient ions attached to the exchange sites on clay and humus are released into the soil solution for use by plants and soil organisms such as bacteria and fungi.

Plant roots draw most of the nutrients they need from the soil solution—the water and dissolved minerals in soil pores. The amount of nutrients in the soil solution at any one time is just a fraction of those needed by plants over the course of their life cycle. The soil solution must be continually replenished from the store of nutrients in minerals and organic matter. As plants draw nutrients out of the soil solution, more may be released into solution from exchange sites on clay or released from the organic fraction due to mineralization. Many farmers also contribute nutrients to the soil solution by adding chemical fertilizers each year. Fertilizers added to soil do not remain unchanged, waiting to be used by plants. Like minerals from other sources, either they become attached to exchange sites, or are used by microorganisms and transformed into other forms.

Soil fertility is not just a measure of the amount of nutrients, but whether plants can get the nutrients when they need them. To thrive and use soil nutrients, plants need deep, crumbly soil for good root growth, adequate water holding capacity, appropriate pH, adequate organic matter levels, and a healthy biological community to cycle nutrients, enhance plant growth, and control pathogens.

Biological processes

Soil organisms were mentioned in connection with all of the previous soil processes. Their life cycles are an integral part of the soil formation process, development of soil structure, and nutrient cycles. Their activity is highly dependent on the air and water status of soil, temperature, food supply, and pH.

The food web of organisms that live underground is at least as diverse and complex as the ecosystem of plants and animals living above ground. Practically all the energy for the food web comes from the sun. Plants and other photosynthesizers convert the sun's energy and carbon dioxide into the carbon compounds used by other organisms. Plant-eaters create compounds that other organisms need. As bacteria, fungi, earthworms, microscopic insects, and other organisms consume and transform carbon compounds, they release carbon dioxide back into the atmosphere and make nutrients available to plants.

Measuring biological characteristics

Soil biological activity is evaluated by measuring a number of soil processes, including some related to organic matter cycling.

- Total organic carbon and nitrogen, or total organic matter
- Microbial biomass— the quantity of soil microbes, including mostly fungi and bacteria, as well as protozoa, algae, nematodes and very small animals (mites, insects, etc.)
- Mineralizable carbon and nitrogen— the fraction of organic matter that can be decomposed by microbes. Laboratory measures of respiration rate (CO_2 released from the soil) reflect mineralizable carbon. Mineralizable nitrogen is the ammonium or nitrate nitrogen released during decomposition.
- The 'active' or readily decomposable fractions of organic matter
- Enzyme activities
- The activity of indicator organisms such as earthworms and specific groups of nematodes

These factors tend to be useful tools for evaluating soil quality because most of them respond fairly quickly to management changes, so they can serve as early indicators of improvement or degradation.

The importance of soil organic matter

The amount and type of organic matter in the soil plays a central role in how well soil performs functions such as producing crops and protecting water quality. The effect of animal agriculture on soil quality is largely related to its effect on soil organic matter.

Organic matter is the vast array of carbon compounds in soil. For simplicity, organic matter can be divided into two major categories: stabilized organic matter and biologically active organic matter.

The stabilized organic matter fraction can increase the amount of water and nutrients stored in soil. Stabilized organic matter are compounds that have been decomposed and transformed into forms that organisms cannot readily use. Thus, nutrients cannot be released from these compounds, though nutrient ions may be associated with the surface of these substances, as described in the Nutrient Cycles section above. Some stabilized organic matter may be decades or centuries old.

Biologically active organic matter is continually used and transformed by soil organisms. It is a source of nutrients for the soil organisms as it decomposes.

High levels of organic matter in the soil can either be maintained by continual additions of large amounts of plant residue or other organic inputs, or by maintaining soil environmental conditions that reduce decomposition. For example, intensive stirring of soil by tillage increases decomposition and thereby reduces organic matter levels. On the other hand, the wet conditions in poorly drained soils, which may not benefit the crop, will reduce decomposition rates and thereby increase soil organic matter.

SOIL QUALITY

What is soil quality?

Soil quality is how well soil does what we want it to do. More specifically, soil quality is the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Karlen et al., 1997). In short, soil quality is the capacity of the soil to function.

- People have different ideas of what a quality soil is. For example:
- for people active in production agriculture, it may mean highly productive land, sustaining or enhancing productivity, maximizing profits, or maintaining the soil resource for future generations;
- for consumers, it may mean plentiful, healthful, and inexpensive food for present and future generations;
- for naturalists, it may mean soil in harmony with the landscape and its surroundings;
- for the environmentalist, it may mean soil functioning at its potential in an ecosystem with respect to maintenance or enhancement of biodiversity, water quality, nutrient cycling, and biomass production.

Key soil quality concepts

Soil quality has an inherent and a dynamic component.

Dynamic soil quality is how soil's changes in response to management. This is the focus of current soil quality discussions. Each soil type also ---has an inherent ability to perform its functions. For example, fine-textured soil will usually hold more water and nutrients than coarse, sandy soil. For practical purposes, the texture of soil does not change. Land capability classifications are based on inherent soil quality.

Soil quality is an assessment of multiple functions

In addition to bountiful crops, agricultural land provides clean air and water, healthy forests, wildlife habitat, and beautiful landscapes. "Soil quality" refers to how well soil performs all of these functions simultaneously. A single measure such as crop yield or water infiltration is not an adequate assessment of soil quality.

The definition of soil quality depends on use and soil type

Is 72 beats/minute a healthy heart rate for a person? The answer depends on the individual's genetics, age, and desired level of physical activity. Similarly, the parameters of a healthy soil depend on the inherent characteristics of the soil and on how it is used. A healthy sandy soil should have higher water infiltration than a healthy clayey soil. Undisturbed prairie soil will have a higher level of soil organic matter than healthy agricultural soil.

Soil quality is inextricably linked to sustainability.

A quality soil is one that functions well without degrading over time. It must be resilient and recover its ability to function after stresses such as flooding, fire, or ordinary agricultural practices such as tillage. Changes in soil quality measurements over time indicate whether land management practices are sustainable.

Assessing soil quality

Like human health, soil quality is too broad a concept to measure directly and must be inferred by evaluating indicators. Indicators are measurable properties of soil or plants that provide clues about how well the soil is functioning.

Useful indicators:

- are easy to measure,
- measure changes in soil functions,
- encompass chemical, biological, and physical properties,
- are accessible to many users and applicable to field conditions,
- respond to variations in climate and management.

Indicators are usually measures of soil characteristics, such as bulk density or organic matter properties, but assessments may also include measures of soil functions, such as crop yield or erosion rates. Measurements that are commonly used as indicators in soil quality research are listed in Table 1 (Lewandowski and Zumwinkle, 1999).

Table 1: Commonly Studied Soil Quality Indicators

Scale of indicators

Chemical measurements:	**Physical measurements:**	**Biological measurements:**
Biologically active organic matter	Water infiltration	Microbial biomass

Organic C and N	Aggregate stability	Potentially mineralizable N
Cation exchange capacity	Rooting depth	Basal respiration
Extractable bases	Penetration resistance	Earthworms
pH	Water holding capacity	Enzyme activity
Electrical conductivity		
Sodium adsorbtion ratio		

The indicators in Table 1 describe soil properties at a single point in time and space. Other indicators that summarize soil characteristics over larger areas or time spans may be more useful in assessing soil resources at larger scales (Tables 2 and 3).

Table 2: Potential field-, farm-, or watershed-scale indicators of soil quality (From Karlen et al., 1998)

Biological	**Chemical**	**Physical**
Crop yeild	Organic matter changes	Topsoil thickness
Crop appearance	pH changes	Soil color
Weed pressure	Available P & K	Subsoil exposure
Disease pressure	Cation levels	Compaction
Nutrient deficiencies	N availability	Crusting
Earthworms	Heavy metals	Ponding (infiltration)
Decomposition rates	Salinity	Runoff
Root growth pattern	Nutrient loss in streams	Rill and gully erosion
	Nutrient loss to groundwater	Poor plant emergence
		Ease of tillage
		Soil structure

Table 3: Potential regional-, national-, or international-scale indicators of soil quality (From Karlen et al., 1998)

Biological	**Chemical**	**Physical**
Productivity (yield stability)	OM trends	Desertification
Taxonomic diversity at the Group level	Acidification	Loss of vegetative cover
Species richness, diversity	Salinization	Water erosion
Keystone species & ecosystem engineers	Water quality	Wind erosion
Biomass, density & abundance		

Farmers' Assessments of Soil Quality

Understanding and managing soil quality is a site-specific endeavor. It is about reading soil characteristics and selecting optimum practices for each unique situation. For this reason, soil quality research is enhanced by long-term, systems-oriented studies, and by the local observations of farmers and those who work with farmers.

Planners, researchers, and farm managers each observe soil differently, and communicate soil characteristics differently. The Wisconsin Soil Health Program has done extensive work with farmers to learn their priorities with regard to soil health. The goal of their project has been to integrate farmers' observational knowledge with scientists' analytical expertise (Garlynd et al., 1994; Harris and Bezdicek, 1994; and Romig et al., 1995).

Based on the Wisconsin work with farmers, the Natural Resources Conservation Service has written a protocol for developing locally-based, qualitative soil health assessment cards for use by farmers. Several different soil health cards have been created in regions around the country to help farmers track changes in soil quality. (For example, see the Willamette Valley Soil Quality Card, 1998.)

Table 4 ranks the soil properties used by farmers to assess soil health, as identified by the Wisconsin project. Although expressed somewhat differently, farmers identified many of the same priorities as soil scientists. Romig and his colleges noted that farmers tend to have a stronger temporal perspective of their soil than do scientists. They can observe how a given field responds to different kinds of storms, or how crops respond to a variety of climatic extremes, and they have a feel for how soil aggrades or degrades over long periods of time. Farmers do not separate management and measurement of soil health. In fact, they seemed to focus more on the processes they believe create or destroy soil health than on the soil properties themselves (Romig et al., 1995).

Table 4: Soil Properties Used Most Often by Farmers to Assess Soil Health (Romig et al. 1995)

1. organic matter	8. pH	15. water retention	22. growth rate
2. crop appearance	9. soil test	16. phosphorus	23. weeds
3. earthworms	10. yield	17. nutrient deficiency	24. fertility
4. erosion	11. compaction	18. decomposition	25. feel
5. tillage ease	12. infiltration	19. potassium	26. chemicals in groundwater
6. drainage	13. color	20. roots	27. surface cover
7. structure	14. nitrogen	21. mature crop	28. surface crust

Managing for soil quality

Many combinations of management practices can be beneficial to soil quality. Generally, systems with good soil quality are those that maintain or increase the amount and quality of organic matter in the soil. Organic matter and the organisms that feed on it are central to nutrient cycling, the formation of soil structure, and water dynamics. Organic matter increases the soil’s capacity to hold water and nutrients. It improves soil structure and reduces the effects of compaction.

The practices that affect soil quality (either positively or negatively) can be discussed in five groups.

1. Organic matter additions—Organic matter must be regularly added to the soil to maintain a healthy soil biological community and to maintain or increase the level of organic matter in the soil. Manure can contribute significant amounts of high quality organic matter to the soil, though organic matter from crop residues and cover crops sometimes can be more desirable.

2. Cropping patterns—The choice of cropping system has a substantial effect on soil quality. Generally, a longer rotation with diverse crops contributes a variety of organic residues to the soil, and supports a healthy biological community. In particular, perennials and sod crops with dense root systems are beneficial to soil quality. Some animal production systems improve soil quality because they make it economically possible for farmers to grow perennial forages and pastures.
3. Tillage—Tillage is useful for mixing organic matter into the soil and preparing a seed bed, but it also increases the decomposition and loss of soil organic matter, reduces soil aggregation, and destroys the habitats of some important organisms by burying surface residue.

   A wide variety of tillage systems are used in Minnesota, ranging from frequent and intensive turning of the soil, to no-till systems in which only a narrow furrow is cut to plant seeds into last season's crop residue.

   Reduced tillage is attractive in some large scale cropping systems, because it requires less labor than conventional tillage, can reduce erosion rates, and prevents the rapid decomposition of soil organic matter that occurs when soil is aerated. In some reduced tillage systems, more herbicides are used compared to conventional tillage.

   One type of reduced tillage used in Minnesota is ridge tillage. It has several advantages, especially on cold poorly drained soils, including improvement of infiltration, and reduction of runoff, and compaction. Residues left on the soil surface prevent wind and water erosion.
4. Amendments—Amendments which increase crop production, such as fertilizer and irrigation, may increase the amount of organic residue contributed to the soil. Some amendments, such as high-salt fertilizers, may at least temporarily reduce some biological activity. Some pesticides reduce biological activity. The use of manure can reduce the need for some fertilizers and pesticides.
5. Traffic—Heavy or frequent traffic can compact soil, especially when soil is wet. Heavy liquid manure tanks can create deep soil compaction that is difficult to remedy. Even large animals are light compared to tractors, but they can cause surface compaction where they concentrate in small areas or graze on wet soils with insufficient cover.

ANIMAL AGRICULTURE AND SOIL QUALITY

Manure in soil

Soil quality is the ability of soil to sustain productivity and maintain environmental quality. In contrast to inorganic fertilizers, regular manure application can protect soil quality because it enhances biological activity and soil structure.

Manure has several effects when added to the soil.

Supplies nutrients immediately. Manure contains nitrogen (as ammonium), phosphorus, potassium, and micronutrients (e.g. Cu and Zn) that can be used directly by plants. This is the most commonly recognized value of manure.

Supplies nutrients over time. Other nutrient pools in manure are part of organic (carbon-containing) compounds. These compounds trigger biological activity which ultimately makes nutrients in the manure available to plants.

Lowers pH. Regular manure application generally lowers soil pH. The acidifying effect of nitrogen added as manure is less than that of nitrogen added as anhydrous ammonia or urea.

Salt and ammonia toxicity. Manure contains high levels of salts that will burn leaves if applied to growing plants. Salts are usually not a concern in Minnesota because they are quickly leached by rain. High levels of ammonia or ammonium in fresh manure can be detrimental to germinating seeds.

Improves soil structure. The increased biological activity and organic matter content improve soil structure by helping to bind soil particles into aggregates. In some situations, manure can serve as a protective mulch on soils that are vulnerable to erosion.

Enhances biological activity and diversity.

Manure is known to affect the mix of organisms in soil, but these changes are poorly studied. Manure may affect pest and nutrient cycles by changing the diversity of soil organisms.

Soil and management of grazing animals

Grazing animals are a key to a dynamic recycling process for pasture ecosystems. An understanding of pasture management and uniform distribution of manure nutrients is critical.

Permanent pastures often have low productivity. Rotational or short-duration grazing can often double forage production and lengthen the grazing season.

Classic work in Missouri has demonstrated the importance of pasture design and management to minimize nutrient losses and reduce the potential of severe soil compaction. The researchers demonstrated that excretion patterns by grazing livestock are influenced by placing of water troughs, location of shade and the topography of the land. Phosphorus and potassium concentrations are likely to build-up where animals congregate. Nitrogen losses will vary by pasture design and lane access. It was noted that sheep tend to defecate and urinate in a more uniform pattern than cattle (Peterson and Gerrish, 1994).

The longer the rotation period between pastures, the greater opportunity for manure to concentrate in certain areas. For example, a 12-paddock system for a beef cow/calf herd, with water access in the paddocks less than 600-800 ft from the grazing herd, is more efficient than a 3-paddock system in terms of spatial distribution of manure nutrients where water may or may not be as accessible. Short rotation periods between paddocks are better if shade trees are located in paddocks. Square paddocks with minimal landscape variation within paddocks are recommended.

The Link Between Soil Quality And Water Quality

One soil function is to regulate and partition the flow of water. The structure of soil partially determines how much water flows overland to streams and lakes, and how much enters the soil and flows through it to become groundwater.

The biological, physical, and chemical characteristics of soil are responsible for filtering water. Soil generates clean groundwater by adsorption, decomposition, and buffering of potential pollutants.

Phosphorus is concentrated in the topsoil on manured fields, and can be carried in runoff along with sediments to surface water. Thus it is especially important to protect high-phosphorus soils from erosion. Nitrate leaching can result in potential groundwater degradation. Because of these effects, manure application at high rates on some soils could impair water quality (See the Manure and Crop Nutrient report, section on the Economic Liability of Manure for more information).

The Link Between Soil Quality And Air Quality

Another function of soil is regulation and partitioning of gas emission. Volatilization of ammonia from manure into the atmosphere can be expected with manure handling. Nitrification and denitrification of manure applied to soil can also lead to formation of nitrous oxide (N_2O). Nitrous oxide is a “greenhouse” gas and can contribute to ozone layer depletion if the manure is not handled correctly. Other air quality problems include emission of volatile sulfur and organic compounds which are discussed in the Air Quality and Odor report.

ANIMAL AGRICULTURE AND SOIL QUALITY

Critique of the Study Questions

The authors of this report were asked to answer the following question.

How are the following properties of soils affected by manure application and livestock production systems?

- Moisture holding capacity
- Soil tilth
- Air incorporation
- Erosion potential
- Biological activity
- Structure and density
- Weed content
- Productivity

Because the properties specified by the question are properties used in the assessment of soil quality, the Soils team chose to rephrase the question in terms of the effect of manure and livestock production on soil quality. The following changes were made to the study question.

- Items were grouped into physical, biological, and chemical categories.

■ Nutrients and nutrient cycling cannot be separated from other soil properties, and are discussed briefly in this report. For a more complete discussion of soil nutrients, see the Manure and Crop Nutrients report.

■ Water infiltration was added to the report because of its importance to productivity and soil and water quality.

■ Soil aeration was substituted for air incorporation.

■ Soil erosion potential and soil productivity are only touched on briefly. The characteristics of farming systems that determine erosion rates and productivity go beyond factors directly related to animal agriculture.

How Animal Agriculture Affects Soil

Farming specialization

One of the most dramatic transformations of the Midwestern agricultural landscape resulted from the shift from mixed crop-and-livestock farming to specialized cash-grain farming over the past 50 years (Hart, 1986). Before WWII most farms had a small number of animals. Now, animals are concentrated on fewer farms that often purchase much of their feed. Many other farmers specialize in cash grains to be sold to other regions.

Specialization in either animal or crop production has two effects on soil. First, nutrients are becoming more unevenly distributed over the land. Most of the nutrients fed to livestock pass through animals and accumulate in the manure— most notably, nitrogen, phosphorus and potassium. If feed and animals are raised in the same area, most of the phosphorus and potassium and some of the nitrogen removed in growing forage and feed grain can be returned to the soil as manure. However, nutrients removed from the soil during crop producton are often shipped to another county, state, or country, fed to animals, and concentrated in manure far from the feed source (DeLuca and DeLuca, 1997). The cost of transporting manure prevents it from being shipped back to the land where the feed came from.

Second, specialized farming can result in the loss of perennial forages from crop rotations. Before WWII a typical Minnesota farm had pigs, chickens, and cattle. Cattle are ruminants that can utilize forages such as alfalfa or grasses. With increased specialization, most farms do not have ruminant animals and have no need for forages. Forages and pastures are difficult to incorporate into cash grain operations.

Size of animal operations

The size of an animal operation is not associated in a simple way with soil quality. Both small and large operations without manure management plans can have negative soil quality impacts. However, good or bad management on a large operation can affect a larger area.

There is one direct link between animal operation size and soil quality. The size of an animal operation is related to the amount of acreage available for spreading manure. Generally, larger operations are expected to have more difficulty finding adequate crop acres to apply manure economically. The availability of land is a separate issue from whether the manure is applied appropriately.

Rotational grazing

Rotational grazing is an operation in which animals get most of their feed by grazing a small paddock for a short period and then moving to a new paddock. The short grazing periods allow the pasture to recover for multiple grazings during the growing season.

Because most feed comes from pastures, the farmland is planted mostly to soil-building and soil-protecting perennials. As animals harvest much of their feed, they spread manure over the same land that produced their feed. These soil quality benefits of rotational grazing depend on proper management of animal traffic and pasture plants.

What determines the effect of an animal operation?

The effect of a particular animal operation on soil quality depends on the interaction of many aspects of the operation. The effect of an operation can be estimated by asking three questions:

1. How is the manure handled? Is it being applied at agronomic rates? (Section Manure Handling)
2. What is being fed and how is it grown? Does the diet support the production of perennials, other dense-rooted and soil covering crops? (Section Cropping Systems)
3. Does the operation as a whole support soil quality? (Section Whole Farm Effect on Soil Quality)

With answers to these questions, the research reviewed in Part C will support an educated guess of whether an operation is having a positive or negative impact on soil quality. However, in most cases the research will not support a calculation of the degree of the positive or negative effect.

Manure handling

Three factors determine whether manure will have a positive or negative effect on soil.

1) Rate of application.
Manure generally has a positive effect on soil if it is applied at agronomic rates. Agronomic rates are levels calculated to match the crop needs and to minimize nutrient overloading.
Disposal rates are high levels applied to dispose of the manure rather than to enhance crop production. Any rate higher than an agronomic rate can be considered a disposal rate.
Application of manure at disposal rates can have negative effects on soil quality due to deterioration in physical properties, and toxicity for plant growth and microbial activity.

Calculating agronomic rates: Land managers must decide whether to base manure application rates on crop nitrogen needs or soil phosphorus levels. Currently in Minnesota, agronomic rates are usually computed to meet the nitrogen needs of crops. Nitrogen is more valuable to the farmer, but, in terms of crop needs, manure typically contains far more phosphorus than nitrogen. Thus, if manure is applied based on crop nitrogen needs, soil phosphorus levels will rise.

The Manure and Crop Nutrients report includes a discussion of how agronomic rates can be calculated and the difficulty of applying predetermined rates. Agronomic rates vary, but are less than 20 tons of dry matter per acre. Because some animal operations have insufficient land close by to apply all the manure at agronomic rates, cropland has been used as a disposal site for manure.

Interpreting application rates for manure is difficult because of the different ways manure data are reported. Applications of liquid manure can be reported in tons or gallons of wet manure slurry or as the oven dry equivalent. Solid manure application rates are most often reported as tons of wet weight.

2) Application method

Application methods can make a great difference in contribution of manure to soil quality. For example, manure injection can reduce potential environmental impacts. Application on the soil surface without immediate tillage to incorporate manure into the soil can result in significant losses of nitrogen (Schmitt, 1999). See the Manure and Crop Nutrient report for more information about nutrient losses with different application methods.

Heavy liquid manure tanks on wet soil can cause deep soil compaction.

3) Type of manure

Manure from each animal species has characteristic levels of salts, pH, and nutrients. Even within species, manure characteristics vary depending on feed content and how the manure is handled and stored.

The levels of nutrients and additives in feed will be reflected in the manure composition. Innovations in feeding practices may have dramatic effects on the nutrient value of manure. For example, the use of phytase enzymes in feed and the use of a genetically improved, low phytate corn variety can improve animal use efficiency of phosphorus and can reduce the phosphorus concentrations in manure (Bosch et al., 1998; Spencer et al., 1998).

There are many different types of manure handling systems discussed by the Manure and Crop Nutrients team. Some generate solid manure that include bedding. Other systems generate liquid manure that can be pumped and injected into the soil. A variety of storage systems are available. These variations have some impact on the nutrients in manure and each system puts limitations on how the manure can be handled. Different systems may have different effects on water quality (see Water Quality report). However, with any of the major systems, it is possible to use the manure in a way that enhances soil quality.

Composting of manure has several effects that could change the impact of manure on soil quality. It substantially reduces the bulk of manure, making it cheaper to transport. Weed seeds, fly eggs, and pathogens can be reduced when high temperatures are generated during the composting process.

Cropping systems

Two aspects of cropping systems determine their effect on soils.

1. *Inclusion of perennial forages, sod crops, legumes, or high residue crops.*
   Dense-rooted perennials such as alfalfa, grasses, and some other forages, are better (by some standards) for soil quality than row crops that leave the ground bare of living cover much of the year, and take a long time to generate a root system and canopy that will protect the soil. The dense root structure of perennials improves soil structure and contributes high-quality organic matter to the soil. Perennials and cover crops provide food and habitat for soil organisms that would otherwise die back during an annual fallow period, and they protect the soil from wind and water erosion.
   Pasture systems for raising animals allow farmers to produce these soil-enhancing crops. Forages are more expensive to transport than grains, so markets for forages depend on the distribution of animals over the landscape.
2. *Length and diversity of crop rotation.*
   By rotating among several crops, a farmer can increase the diversity of organic matter that is added to the soil, and the types of tillage that are used. This increases the diversity of organisms in the soil and reduces pest infestation and weed populations.

Whole-farm effect on soil quality

The section on managing soil quality in the Introduction section of this report describes the components of farming systems that affect soil quality. Practices that are valuable for protecting soil quality include organic matter additions, rotating row crops with perennials and other densely-rooted crops, keeping the ground covered with plants, and preventing erosion.

RESEARCH RESULTS: THE IMPACT OF MANURE AND CROPPING SYSTEMS

Soil organic matter

Soil organic matter may be the single most important indicator of soil quality and productivity. Additions of organic matter, whether animal manure, green manure, organic sludges and wastes, or crop residues, can be beneficial to the biological and physical properties of the soil. However, appropriate amounts and timing of application are important to ensure that soils do not become degraded by compaction, crusting, accumulation of salts and other processes. The increase in biological activity and plant health due to manure application is both a result of additional food sources for the soil organisms, as well as improved soil structure, which allows for better air exchange and moisture holding capacity.

Research examining the effects of manure and cropping systems on soil organic matter are part of many of the studies described in this report. See Section on Biological Activity, for more research comparing the effects of various cropping systems and manure applications on the different types of soil organic matter.

Particularly informative for understanding organic matter dynamics is the Farming Systems Trial at the Rodale Research Center in Pennsylvania. This trial is a set of long-term plots fertilized with either animal manure, conventional fertilizers, or a cover crop nitrogen source. In spite of similar carbon and nitrogen inputs, the manure treatment sequestered significantly more carbon in the soil than the conventional treatment (Drinkwater et al., 1998). In another study of the Farming Systems Trial, the authors suggest that long-term manure amendments increase short-term carbon pools (which decompose more rapidly), while cover crops may increase the soil's ability to store carbon long term (Wander et al., 1994). The manure amended plots had greater carbon and nitrogen mineralization rates and higher soluble carbon contents. This implies that the most biologically active soil organic matter fraction was relatively increased compared to other soils in the Farming Systems Trial. On the other hand, the soils under the organic cover crop treatment showed a greater accumulation and retention of total carbon, particulate organic matter, and a reduced soluble carbon content. The amount and proportion of the less active, but still labile, organic matter was higher than that for the manure or inorganic fertilizer treatment. These findings suggest that higher carbon to nitrogen ratios, or more resistant forms of carbon, (which are higher in green manures than in animal manures) may be more beneficial for long-term organic matter buildup and soil quality.

Effects of manure on long-term buildup of organic matter depend partly on soil texture. Long-term trials in Denmark (the Askov experiments initiated in 1894) and England (Rothamsted Classical Experiments, begun in 1843) have shown that the lighter-textured, sandy loam soils in the Askov trials require much higher animal manure inputs to maintain or increase soil organic matter than the medium-textured soils at the Rothamsted Experiment Station (Christensen and Johnston, 1997).

Soil physical properties

This section will discuss the impacts of manure application and of the cropping systems used to feed and bed animals on individual physical parameters. For some soil quality parameters, elements of specific livestock systems are important, e.g. the impact of grazing on soil compaction. For others the differences among livestock systems are not as important.

Soil structure and density

The impact of manure on soil structure is closely related to porosity and other soil properties such as infiltration rate, hydraulic conductivity, air permeability, compaction, crusting, and erodibility. Management practices, including manure additions, have a significant impact on soil structure and bulk density. Incorporation of organic matter usually improves structure and lowers bulk density. Tillage decreases bulk density in the plow layer in the short term.

Impacts of Livestock Production on Soil Structure and Density

Livestock and cropping systems that maintain soil organic matter content will result in larger and more stable soil aggregates than systems that deplete soil organic matter. Increasing tillage intensity, decreasing the frequency of perennial forage crops, and decreasing manure applications can decrease aggregate stability.

Results of a study of cropping systems in Iowa showed that aggregate stability differs with farming system. One cropping system based on a diverse rotation (including corn, soybeans, oat, and hay), manure applications, and conservation tillage resulted in higher soil organic matter content and higher aggregate stability than that of the same soil managed in a corn and soybean rotation, without additions of manure (Jordahl and Karlen, 1993). Cropping systems studies with regular organic matter additions in Ohio (Jackson, 1988) and in the Netherlands (Droogers and Bouma, 1996) showed similar differences in soil physical properties.

Each of these cropping systems included multiple elements that impact soil quality (tillage practice, rotation, manure additions) and the relative impacts of individual management factors are difficult to separate. In general, management systems that maintain or build soil organic matter and stimulate microbial activity are associated with increased structural development in soils. In each case, livestock production was part of the system that gave the best aggregate stability.

1) Cropping System Impacts. Crop species and crop rotation sequence impact soil structure. Grass and perennial forage crops improve aggregation and aggregate stability. This is due to protection of the soil surface from rain drop impact, the root distribution and architecture of perennial forages and grasses, and the stimulation of biological activity in the soil. Livestock systems that support crop rotations including perennial forages are expected to result in improvements in soil physical properties compared to continuous row crop systems (Curtin et al., 1994). In Minnesota, the most common perennial forage crop is alfalfa. Alfalfa in a crop rotation improves soil aggregation and these impacts often exist for years after the alfalfa crop (Neher, 1950; Meek et al, 1990). Other forages such as clover, reed canary grass, orchardgrass, etc. have effects similar to alfalfa on aggregate stability. These effects have been attributed to the high density of roots of forage crops (Dexter, 1991; Drury et al., 1991).

Other management practices can be used to improve soil structure when rotations do not include hay or sod crops. In southern and central Minnesota, the most common cropping system is the corn-soybean rotation. Soil aggregates break down more during cropping with soybeans than for corn (Stauffer, 1946; Alberts and Wendt, 1985). High amounts of crop residue from corn production result in higher soil organic matter content than for soybean production and these residues are responsible for the observed increase in aggregate stability (Havlin et al., 1990). Similarly, reduced tillage systems generally have higher organic matter content and higher aggregate stability than conventional tillage approaches (Lal et al., 1994).

2) Manure Impacts. The impact of manure application on soil physical properties has been the subject of considerable research. In general, the research has evaluated changes in physical properties by comparing one or more rates of manure application to a control treatment with no manure applied. Manure application decreases soil bulk density and increases aggregate stability. The magnitude of these changes increases with increasing rates of manure (Sommerfeldt and Chang, 1985; Mathers and Stewart, 1984; Tiarks et al., 1974; Unger and Stewart, 1974). An example of this kind of research is a study in Virginia, where annual poultry manure applications decreased bulk density and increased aggregate stability in a clay loam soil. These changes increased with increasing rates of manure. Infiltration rates were also much greater for soil with manure additions, but the effect did not appear until several months after manure application (Weil and Kroontje, 1979). Long-term application (up to 14 years) of modest rates of solid dairy manure resulted in lower density and higher hydraulic conductivity than soils without manure (Mathers and Stewart, 1984).

Manure addition changes soil properties due to both the organic matter addition and increased crop growth. A stimulus in crop growth increases root penetration, crop residue, and microbial activity. Stimulation of crop growth from addition of mineral fertilizers to soils has been shown to improve soil physical properties relative to unfertilized soil, but not to the same extent as from manure addition (Wood and Hattey, 1995; Biederbeck et al., 1984).

Soil structure and density improvements have been observed with manure from varying livestock species including beef and dairy cattle, hogs, and poultry. Similar improvements in soils have been observed for manure from both solid and liquid manure, although most research has been conducted with solid manure.

3) Grazing. Grazing systems increase the amount of perennial forages grown. Grazing (as opposed to harvesting the forage) does not substantially alter soil aggregation or eliminate the benefits of forages on soil structure. In some cases, however, grazing animals can compact the soil surface (Alderfer and Robinson, 1947). Studies that have evaluated changes in bulk density due to grazing have yielded inconsistent results, since compaction due to grazing is highly dependent upon soil type, soil moisture content at the time of grazing, stocking rate and stocking frequency. No comparisons have been made to determine the relative importance of compaction due to grazing verses compaction from tillage or harvesting equipment. Compaction damage due to light equipment (and presumably animals) is generally limited to surface soil.

A 5-year North Dakota study compared light (37% pasture use), moderate (47% pasture use), and heavy (93% pasture use) grazing intensity on reclaimed cool-season pasture. Soil compaction increased with grazing intensity (Hofmann and Ries, 1988).

In the southern plains of the U.S., comparisons of soil compaction by grazing cattle showed increased bulk density and soil strength for silt loam and sandy loam. The sandy loam was more sensitive to compaction than the silt loam. It was noted that tillage practices in these areas could not eliminate the compaction from cattle grazing pastures (Krenzer et al., 1989).

Field studies in the United Kingdom, on sandy-loam cattle pastures, showed increased soil bulk density and cone penetrometer resistance in the 3-4 inches depth, due to soil compaction caused by trampling. These dense areas impeded drainage and caused soil structural and hydrological changes (Mulholland and Fullen, 1991). Simulation experiments verified that on saturated pasture soil the most severe structural damage occurs on initial impact.

Soil moisture holding capacity

Soils store water that can be utilized by plants and other organisms. The capacity of soils to hold water depends upon the soil texture, soil structure, porosity, and organic matter content. Management factors impact water holding capacity by altering structure and porosity as well as organic matter content. Highly eroded soils may lose water holding capacity due to a reduction in the topsoil depth.

Impacts of Livestock Production on Soil Moisture Holding Capacity

Crop and livestock production systems that maintain soil organic matter content can result in higher moisture holding capacity than systems that deplete organic matter. The increase in moisture holding capacity with increasing organic matter content is greatest for sandy soils (Bauer and Black, 1992). Although water holding capacity may increase with increasing organic matter, the amount of plant available water may not. In some cases, increasing organic matter content may decrease the amount of plant available water (Bauer and Black, 1992; Sommerfeldt and Chang, 1987). Manure application to a Canadian soil increased water holding capacity, but did not increase the plant available moisture. In the Netherlands, a soil with regular manure additions over several decades had only slightly higher available water holding capacity than a soil without manure addition (Droogers and Bouma, 1996).

Application of animal manure to Texas soils increased moisture holding capacity and decreased evaporation rates (Unger and Stewart, 1974). Compacted, poorly structured soils hold less moisture than similar soils with good structure and lower density. Comparison of summertime soil moisture contents in Washington under contrasting management systems showed that moisture content was consistently higher when the soil was managed with a legume green manure crop in rotation with wheat and pea, compared to wheat and pea without the green manure (Reganold, 1988).

Perhaps more important than the moisture holding capacity of a soil is the soil's ability to transmit water. Infiltration rate is an important soil quality indicator because it integrates numerous elements of soil quality, including density, structure, susceptibility to crusting, etc. Infiltration and hydraulic conductivity of soils are discussed in the next section.

Infiltration

The rate of water infiltration into a soil is an excellent indicator of soil quality. Soils with poor aggregate stability are susceptible to formation of surface crusts due to detachment of soil particles by rain drops.

Impacts of Livestock Systems on Infiltration

1) Cropping System Impacts. Cropping systems that protect the soil surface with a crop canopy, or allow the accumulation of crop residue on the surface, promote infiltration. Perennial forage crops are especially effective in promoting infiltration. In a long term study in Pennsylvania, infiltration rates were measured for soils cropped to corn in differing crop rotations. Including a hay crop in rotation with corn and soybeans increased infiltration rates (Radke and Berry, 1993). These differences were due to changes in soil structure, since tillage and residue cover were similar in both cases.

For row crops, conservation tillage approaches that leave residue at the soil surface result in higher infiltration rates than when crop residues are incorporated into the soil (Ginting et al., 1998; Dick et al., 1991).

Reduced tillage approaches result in higher infiltration rates due to the presence of residue cover at the soil surface, improved soil structure, and an increased presence of macropores (Radke and Berry, 1993). With both crop cover and conservation tillage, the protective cover prevents formation of a surface seal and allows for greater infiltration rates. Residue cover has a more important impact on infiltration than differences in soil structure or density due to differences in tillage (Zuzel et al., 1990).

2) Manure Impacts. Manure application generally increases hydraulic conductivity and infiltration rates of soils, especially when soil structure is improved (Albrecht and Sosne, 1944; Tiarks et al., 1974; Mathers et al., 1977). Infiltration rates, inferred from differences in runoff, were higher in soils with manure than for soils without manure, regardless of the type of tillage, in both Minnesota (Ginting et al., 1998) and Wisconsin (Mueller et al., 1984). However, infiltration

rates of soils that already have good structural stability might not be further improved with manure (Sommerfeldt and Chang, 1985). For crop production in areas where water is a factor that limits crop production, increasing infiltration allows for greater capture and storage of water for crop uptake. Likewise, higher rates of infiltration reduce runoff and the associated losses of sediment and nutrients.

Manure applied at heavy (disposal) rates can reduce infiltration in the short term. In one study, high application rates of poultry manure restricted infiltration initially and resulted in much higher runoff after several months. The initial decrease in infiltration was suspected to be due to hydrophobicity (non-wettability) of the partially decomposed manure (Weil and Kroontje, 1979). However, these high application rates resulted in substantially higher infiltration than conventionally fertilized plots at the end of one growing season.

Soils are effectively sealed by clogging soil pores at or near the surface when relatively concentrated feed yard runoff is applied (Lehman and Clark, 1975). However, infiltration rates increase if the surface soil is disturbed.

3) Grazing. Grazing influences infiltration rate but not in a consistent manner. A comparison of different grazing management approaches in Wyoming, showed that infiltration rates are lower with higher animal stocking rates (Abdel-Magid et al., 1987). A similar study in Pennsylvania showed that compaction of the soil surface due to heavy grazing reduced infiltration rates, while moderate grazing did not (Alderfer and Robinson, 1947).

A Western Australian study examined the effects of sheep stocking rates (a normal stocking rate, 3 sheep/acre; low stocking rate, 1.5 sheep/acre, and no sheep), and trampling of the pasture after winter rains. This work showed that the magnitude of soil structural damage was affected by initial condition of the soil and stocking rate. The topsoil was damaged by sheep trampling. The lower stocking rate reduced the degree of soil structural damage. Growth and decay of pasture roots, disruption of a surface crust, and soil compaction, all contributed to differences in infiltration rates between grazed and ungrazed pastures (Proffitt et al., 1995).

Erosion potential

Erosion is of major importance in Minnesota and worldwide. The loss of topsoil to erosion results in reduced productivity and sustainability of the soil resource. Erosion is also responsible for degradation of surface water quality. Measures to reduce erosion rates are critical to Minnesota.

The susceptibility of a soil to erosion is closely related to the aggregate stability of the soil. Well-aggregated soils are less prone to dispersion by raindrops, surface sealing, and erosion. Furthermore, higher infiltration rates generate less runoff. Thus, much of the discussion on aggregate stability and infiltration rate applies also to the erodibility of the soil.

Impacts of Livestock Production on Erosion

1) Cropping System Impacts. Pasture or hay crops substantially reduce the susceptibility of soil to erosion (Curtin et al., 1994; Smith and Hallam, 1990). Livestock systems that include these crops in rotation, especially on highly erodible soils, will substantially reduce erosion. In Washington, a soil managed since 1908 with a green manure crop (alfalfa-wheatgrass) in rotation

with wheat had 16 cm more topsoil than a similar soil managed without the green manure crop. The differences were due to erosion (Reganold, 1988). Tillage practices also impact erosion rates. Reduced tillage systems that maintain crop residues on the soil surface are effective in reducing soil erosion (Dickey et al., 1985; Ginting et al., 1998). Erosion may be less for continuous corn than for a corn-soybean rotation because of higher levels of residue from the continuous corn system (VanDoren et al., 1984).

2) Manure Impacts. Manure application has been shown to reduce the erodibility of soils (Mueller et al., 1984; Ginting et al., 1998). This is due to increased aggregate stability and infiltration rates and decreased bulk density. Although both runoff and erosion can be reduced by heavy manure applications, the losses of nutrients may not be reduced because of the higher concentrations in heavily manured soils. By contrast, some researchers have speculated that continuous application rates of manure slurries could increase erodibility of soils by increasing the concentration of the potassium or sodium salts and the degradation of soil structure. Although this has been shown to be true in the laboratory at very high rates of manure application, fields with long histories of slurry manure applications have not been shown to be more dispersive or susceptible to erosion (Auerswald et al., 1996). In field studies the degradation of soil structure due to salts is seen only where disposal rates of manure are applied and not when agronomic rates are applied (see Section on Salts in Manure).

The erosion reduction due to manure application is most notable when the structure of the soil at the surface is stabilized. Thus, plowing down or injecting manure below the soil surface will not have an immediate impact on erodibility of soil. However, in subsequent years following tillage, the organic matter applied with manure will be mixed and brought to the surface (Ginting et al., 1998).

Soil aeration

The pore space of a volume of soil is occupied at any one time by either water or air. Aeration is critical to the quality of a soil to provide essential gases to plants and soil organisms. Plants differ in their tolerance to wet, poorly aerated soils. Although alfalfa requires a well-drained soil, many perennial forage species such as alsike and ladino clover are more tolerant of poor aeration.

Impacts of Livestock Production on Aeration

1) Manure Impacts. Manure application reduces bulk density and thus increases pore space and the potential for better air entry (Sommerfeldt and Chang, 1985; Mathers and Stewart, 1984; Tiarks et al., 1974; Unger and Stewart, 1974). Soil structure and aggregate stability also influence the density, porosity, and aeration of a soil. Practices that improve these properties by maintaining organic matter content have a beneficial effect on soil aeration (Curtin et al., 1994; Neher, 1950; Meek et al, 1990).

2) Grazing. Management factors that impact soil aeration are factors that alter soil density and porosity, such as compaction. A potential compacting force can change soil mass-porosity, and pore-size distribution, (Freitag, 1971).

A long-term (>30 years) study in New South Wales in Australia, indicated that grazed pastures had lower porosity, in the top 2 inches, than ungrazed pastures. After 30 years, pastures grazed at

4, 8 or 12 sheep/acre had similar soil properties. Maintenance of pasture cover was considered more of a priority than stocking rate for long term management (Greenwood et al., 1997).

Soil tilth

Soil tilth is a qualitative description relating the physical condition of the soil to plant growth. There is no single measure of tilth, but it is the combined result of numerous other properties such as bulk density, soil strength, aggregate size and stability, moisture content, and aeration. Tilth generally refers to ease of tillage, fitness as a seedbed, and suitability for root penetration and seedling emergence. An index was developed in Minnesota and Iowa for quantifying soil tilth based on five soil physical properties (Singh et al., 1992). For soils in a corn-soybean rotation, values of the tilth index changed significantly during the year. Farmers use tillage equipment, in large part, to promote good soil tilth. The effects of livestock systems on specific properties that influence soil tilth were discussed in the preceding sections. In this section only a few studies that directly comment on soil tilth will be discussed.

In a comparison of the effects of different long-term management systems on a silt loam soil in Washington, tilth was better when a green manure crop was included in the rotation. This was due to better structure and higher organic matter content (Reganold, 1988). In Minnesota, rotations that include a perennial forage such as alfalfa, would be the most common system similar to the green manure system in Washington.

A long-term study in Alberta, Canada compared physical properties of a soil with and without manure addition under several different tillage practices. Manure application improved soil tilth, as indicated by a decrease in the tractor drawbar draft (power requirement) for tillage equipment at higher manure application rates. The study also suggested that the decreased energy required for tillage involved more than a simple reduction in bulk density. There was also a change in soil consistence (Sommerfeldt and Chang, 1985). However, in the same study, manure applied at three times the agronomic rate resulted in poor seedbed conditions and poor germination for the first year, but not in subsequent years. Other work has shown short-term degradation of soil tilth with heavy manure application rates, followed by long term improvements (Weil and Kroontje, 1979).

Recent Dutch research compared the effect on soil physical properties of five farm management systems--high input cropping; integrated lower input (a reduced N- fertilizer, herbicides, insecticides and shallower soil tillage); minimum tillage just initiated (3 inch plowing depth); minimum tillage over the previous 18 years; and permanent pasture. Soil water retention, hydraulic conductivity, air-filled porosity and workability were some of the factors examined. Pasture and the old minimum tillage system had the most favorable soil properties for growing crops due to improved soil structure and increased biological activity. The conventional and integrated system had the least favorable tilth. They found that systems that stimulated the presence and activities of structure-forming soil fauna would also stimulate more favorable soil properties such as better aeration and more workable days in a growing season (Vos and Kooistra, 1994).

Nutrients

The nitrogen, phosphorus, and potassium added to soil in manure contribute to soil productivity. Manure added to soils can provide the high fertility needed for high-yield production. This is discussed in detail in the Manure and Crop Nutrient report. Manure addition can especially contribute to long-term increases in N and P fertility. Nitrogen accumulates in soil organic matter, which is a slow-release source of N. Phosphorus accumulates in soils by adsorption on soil particles or by formation of low solubility precipitates with iron, aluminum, and calcium. With long-term heavy applications of manure, P fertility can become much greater than that needed by crops. While this is not detrimental for crop growth, it can have negative impacts on nearby surface waters.

Copper and zinc are nutrient elements that are often added to feeds and can accumulate in manure. With very long-term additions of manures high in these elements, the lifetime loading limit set by USEPA for sewage sludge can be exceeded. With application at agronomic rates the life-time limit for these elements will not be exceeded for more than 350 years (see Manure and Crop Nutrient report).

Salts in manure

Animal manures contain salts of ammonium, potassium, and sodium which in arid and semiarid regions can accumulate in sufficient concentrations to inhibit plant growth (Mathers and Stewart, 1974). In soils, ammonium is converted into nitrate by microbes and nitrate salts can accumulate. In western Minnesota the climate is sub-humid, which is dry enough for some salt problems to occur. Salts in soils can impair the ability of plants to absorb water, and in alkaline pH soils can cause the dispersion of soil particles and degradation of soil structure. Many of the soils in western Minnesota are alkaline and have pH values greater than 7.0. Generally, the rainfall in western Minnesota is sufficient to leach salts. Salt accumulation does not occur except at low spots where drainage is poor and natural and/or added salts accumulate, causing problems for crop production. Accumulation of natural salts is commonly observed in soils of the Red River Valley.

Manure applied at disposal rates can have a very significant impact on salts in soils, especially in dry climates. Studies in California, Arizona, Texas, and Nebraska demonstrated that salt build-up from heavy application of liquid and solid manure can deteriorate soil structure, reduce permeability, contaminate groundwater, and reduce crop yields (Adriano et al., 1971; Amoozegar-Fard et al., 1980; Mathers and Stewart, 1974; Tiarks et al., 1974).

More interesting for understanding the effect of manure on soils in Minnesota are the results of an Indiana study on liquid swine manure. Manure was applied to corn at rates varying from approximately an agronomic rate (based on N need) to four times the agronomic rate. The experiment was conducted on three sites, including prairie silt loam and clay loam soils not greatly different from soils found in western Minnesota. Over the three years of the experiment, levels of soil sodium, potassium, phosphorus and nitrate increased, especially at the highest application rate. However, sufficient leaching and uptake of sodium, potassium, and nitrate occurred such that salt toxicity did not occur at the agronomic rate, and the increase in salts was small. Measurable increases in sodium and potassium content were obtained at the disposal rates. Greater dietary sodium resulted in greater sodium content of the manure (Sutton et al., 1984).

Similar results were obtained in a four year study of manure application on corn at the West Central Experiment Station in Morris, Minnesota. About 30 dry tons per acre (disposal rate) of solid and liquid beef manure, and liquid hog manure were applied for two consecutive years, and the residual effects of manure application were monitored for an additional two years. Greater accumulations of sodium and potassium were measured at Morris than in Indiana, because the rate of application was greater and leaching intensity is less in Morris. During both years of manure application, corn in plots receiving liquid beef manure showed signs of wilting, in localized areas early in the season, due to elevated salt levels. Measurable increases in salt content with depth were found for all three manure treatments. Sodium levels increased in all manure treated plots. Yield results showed that salt levels were not high enough to decrease yields below those from inorganically fertilized plots. The authors speculated that continuous application of manure to corn, at disposal rates, would eventually lead to yield reductions due to salt accumulation (Evans et al., 1977).

Manure as a source of weeds

Wild birds and animals excrete plant seeds and are important agents of seed dispersal. Livestock feed is often a source of weed seeds that will survive the trip through the gut of animals and into manure. Manure can be a source of weeds if animals spend at least part of their time on a weedy pasture, are fed weedy hay, or are fed course ground feed containing weeds (Muenscher, 1987). Silage is not a source of weeds because weed seeds do not survive in a silo. Composted manure does not contain high counts of viable weed seeds (Crafts and Robbins, 1987). The high temperatures generated by some composting systems can greatly decrease weed seed survival.

Few studies have been conducted to quantify the contribution of manure to weeds on farms under modern management conditions. Most of the research on weed seeds in manure dates from before World War II. Recently, researchers in New York studied dairy manure from 26 farms as a source of weeds. They found that the seed contributed by manure was not an important source for weeds compared to the seed density already in the soil. The researchers did stress that if soil weed seed density is low and manure weed seed density is high, manure could be a relatively important source of weed seeds (Mt. Pleasant and Schlather, 1994).

Researchers in Canada found no evidence that liquid dairy manure compared to commercial fertilizer altered weed density or species diversity. The results suggest that the amount of weeds introduced with liquid dairy manure was negligible and that the species composition of introduced weed seeds from liquid dairy manure was similar to those that already existed at the site (Stevenson, et al., 1997).

Biological activity

As for other soil properties, the effects of animal agriculture on biological activity depend on the response to manure additions as well as the types of cropping and/or grazing systems employed. The effects of agricultural systems on biological activity largely depend on the type and amount of organic matter added to the soil. Thus studies of the effect of manure and cropping systems on biological activity often include measurements of changes in soil organic matter quality and quantity.

Manure impacts on soil biology

Manure Applications Increase Biological Activity

Many studies have confirmed that animal manures applied at agronomic rates increase soil biological activity compared to commercial fertilizer. In one study in Quebec, researchers evaluated effects of 14 years (1977-1991) of manure and inorganic fertilizer applied at recommended rates. They found significantly higher soil earthworm abundance and diversity, greater biological activity as measured by rate of carbon dioxide production (respiration rate), a higher organic matter content, and greater soil aggregate stability (Estevez et al., 1996). In another study at a different site, N'Dayegamiye and Angers (1990) found that manure application improved soil structure and increased fungal and bacterial populations.

Studies on long-term plots in eastern Oregon showed that soils with a long history of organic amendments maintain higher levels of microbial biomass, total carbon and nitrogen, and relatively more carbon and nitrogen in the bodies of living organisms. Soil enzyme activities are also higher (Fauci and Dick, 1994). Researchers in California also found that animal manures, as well as green manures and crop residues added to soils increase enzyme activities within a few weeks, compared to unamended soils (Martens et al., 1992).

The increase in biological activity in response to manure application often can be explained by the increase in soil organic carbon. In a Nebraska study comparing organic farming methods and conventional management, (in a four year crop rotation of oat/clover-corn-soybean-corn), soil bacterial and fungal numbers, dehydrogenase enzyme activity, and soil biomass were highest in manure-amended soils. These soils had better water status. The total carbon, nitrogen and potentially mineralizable nitrogen in the surface 3" of soil were 20-40% greater for manured soil than for soils receiving the same nutrients as conventional fertilizer. These factors promoted greater soil biological activity, and increases in the microbial populations paralleled the increases in soil organic carbon content (Fraser et al., 1988). In an Oregon study of pasture soils with and without dairy manure additions, researchers found 50% more total bacteria and fungi in spring and winter, and twice as many in the fall where manure had been applied (Entry and Emmingham,1995).

Manure also affects larger soil organisms. A field experiment in a pasture in South Australia showed that manure promoted reproduction and local aggregations of earthworms (Hughes et al., 1994). In another Australian study, the presence and distribution of sheep manure changed the vertical and horizontal distribution of burrows and the amount of burrowing activity of two earthworm species. The earthworms tended to concentrate under dung patches. One species concentrated more near the soil surface in response to the presence of sheep manure. The earthworms burrowed less actively when manure was present and resources were not scarce (Hughes et al., 1996).

While application of manure generally increases soil biological activity, compaction from heavy equipment used to spread manure can have the opposite effect. On a dairy farm in Norway converting from conventional to organic practices, different cattle manure treatments, fertilization levels and soil compaction were studied over six years. Increasing the manure rate from 80 to 160 lbs N/acre increased yields of a mixed pasture from 2.8 to 3.1 tons dry matter/acre. However, the soil compaction from tractor applied manure decreased yields from 4 to 3 tons dry matter/acre. Soil compaction reduced air-filled pore space and the number of earthworms (Hansen, 1995).

Nitrogen mineralization was also decreased by compaction, presumably because organic materials and microbial biomass were protected from attack by nematodes (Breland and Hansen,1996).

Differences in Quality and Types of Manure

As described in the section on soil organic matter, research at the Rodale Research Center in Pennsylvania suggest that amendments with higher carbon-to-nitrogen ratios, (such as in green manures as opposed to animal manures) may be more beneficial for long-term organic matter buildup and soil quality.

Similarly, manure amendments with lower nitrogen contents (higher carbon to nitrogen ratios) may be preferable for maintaining soil organic matter levels, and improving soil structure and biological activity. In a study comparing long-term application of solid beef manure, with a carbon to nitrogen ratio of about 20, versus pig slurry with a carbon to nitrogen ratio of 6, researchers found that relatively greater amounts of the native soil organic matter were mineralized where the pig slurry had been applied. They suggested that long term pig slurry applications in soils with low carbon to nitrogen ratios could result in enhanced mineralization of the existing soil organic matter to the extent that soil organic matter would be depleted (N'Dayegamiye and Cote, 1989). In long-term plots in Oregon, as well, researchers found that beef manure increased microbial biomass more than poultry manure, in proportion to the amounts of carbon added for an equivalent amount of nitrogen input. Because the beef manure is lower in nitrogen, more organic carbon was added for the same addition of nitrogen. Both microbial biomass and enzyme activity for all the treatments correlated with the total amounts of organic carbon added over time (Collins et al., 1992).

Other studies have examined effects of manure on bacterial and fungal feeding nematodes, since they play such a crucial role in the turnover of soil biomass and the mineralization of nutrients. Researchers at Ohio State University showed that additions of organic inputs, whether legume cover-crop or cow manure, led to significant increases in populations of fungivorous (fungi-eating) and bacterivorous (bacteria-eating) nematode groups. Interestingly, there were relatively more bacterivores in the manure treatment and fungivores in the legume cover crop treatment, probably because of the difference in the quality of the organic matter (Bohlen and Edwards, 1994). The more resistant compounds in cover crop plant material compared to animal manure are more likely to encourage fungal growth. These results are consistent with the differences observed in the distribution of different forms of soil carbon in the Rodale Farming Systems Trial mentioned above, where the researchers found that manure apparently increased the short-term carbon pools and the legume cover crop seemed to affect longer-term pools. In a Scottish study, addition of cattle manure had no effect on different types of nematode populations, but poultry manure increased numbers of bacterial feeders (Griffiths et al., 1994).

Manure Applications Can Increase the Loss of Nitrogen

So far, we have reported the benefits to soil biological activity associated with the application of manure. However, the concomitant addition of carbon with manure nitrogen can stimulate losses of nitrogen to the atmosphere through microbial denitrification. In denitrification, nitrate nitrogen is transformed to nitrous oxide gas or dinitrogen gas, and nitrogen is lost from the soil. This occurs in zones in soils that are anaerobic (without oxygen) where there is decomposable organic matter. In a manure-treated soil this process is concentrated at the interface between wet manure and soil, where readily decomposable organic matter in the manure consumes oxygen, and nitrate from the soil can encounter the denitrifying bacteria. In one Swedish study, nitrogen loss due to denitrification was 14-fold higher with fresh manure than with anaerobically-digested manure although amounts of dissolved carbon differed only by a factor of 3 (Petersen et al., 1996). Losses are not always significant. In Ontario, accumulated nitrous oxide losses from the soil surface of manured plots was equal to only 1% of the potentially mineralizable N. Two thirds of the total nitrous oxide loss occurred in the first 7 weeks after application (Lessard et al., 1996).

Manure Affects Community Structure

Little work has been done to determine the changes in microbial community structure in response to manure addition. One laboratory study using phospholipid fatty acid analysis (PLFA) showed that community structure was altered within a few millimeters of the manure/soil boundary, mostly due to diffusion of dissolved organic carbon from the manure. However, after 3 days, PLFA composition gradually became more like the bulk soil again (Frostegard et al., 1997).

Manure Affects Crop Diseases and Pests

There is evidence that manure additions can have beneficial effects by reducing the incidence of diseases and pests. One study examined diseases of winter wheat in three different rotation patterns in western Oregon. It was found that the disease pathogens were collectively least prevalent where N, in a wheat-fallow rotation, was supplied as manure or pea vines (green manure) rather than as inorganic fertilizer (Smiley et al., 1996). In another case, germination of the pathogenic fungus (*Fusarium oxysporum)* was significantly higher in a soil amended with chemical fertilizer than in soil amended with farmyard manure (Toyota and Kimura, 1992). Average emergence rates of western corn rootworm were reduced by 45% in manured plots compared with nonmanured plots, during one year of the study, and in the other year were not different. Thus manure applications do not lead to increased western corn rootworm populations as had been proposed, and may in some years reduce them (Allee and Davis, 1996).

Plant parasitic nematode (*Meloidogyne incognita*) populations in cotton-cropped land decreased linearly with increasing rates of poultry manure addition (Riegel et al., 1996). In a study with squash and cotton in South Carolina, poultry manure and litter reduced root-knot nematode infection while bacterial- and fungal-feeding nematodes increased (Fortnum, 1994). In greenhouse and field trials with tomato, total numbers of plant parasitic nematodes in the roots, and numbers of nematode eggs decreased with increased rates of chicken litter (Kaplan and Noe, 1993).

Manure Can Contribute to Selection of Antibiotic-resistant Bacteria

Antibiotic use in subtherapeutic doses as feed additives for animal production is a common practice in the U.S. and throughout the world. This practice can lead to selection of resistant microbial populations (including pathogens) in both the animal's native microbial community and in the local environment due to shedding in fecal material (Kelley et al., 1998). Normally, about 2% of a 'wild-type' bacterial population are resistant to any given antibiotic. However, up to 10% of bacterial populations from animals regularly exposed to antibiotics have been found to be resistant (Novick, 1981). A very high percentage (80-100%) of the isolated bacterial populations from poultry litter, suitable for soil application, were multiple-antibiotic resistant (Kelley et al., 1998). No reports on this topic were found for cattle or swine manure.

Manure Can be a Source of Bacterial Contamination

Fecal bacteria are present in manure and may move down through the soil profile into springs or wells, or with surface runoff and sediment into streams and waterways. Constructed wetlands can help to reduce fecal coliform concentrations in runoff from confined livestock operations (Cooper and Lipe, 1992). These issues are discussed in the Water Quality report.

Manure Can Contribute to Toxic Levels of Elements

In some manure amendments, such as from pigs fed high copper rations, high (disposal) rates of manure application can result in significant reductions in soil biological activity due to copper toxicity (Huysman et al., 1994). This is discussed in more detail in the Manure and Crop Nutrient report (Section on carrying capacity for nutrient and toxic substances).

Cropping system impacts

Growth of perennial grass or alfalfa in an animal production system is an excellent way to improve soil structure. Depending on the type of perennial forage, benefits can be realized in one cropping season (Angers and Mehuys, 1988; Stone and Buttery, 1989). Extensive, fibrous grass root systems can improve soil structure by:

1. Binding larger soil aggregates with fine roots and mycorrhizal hyphae, and
2. Feeding soil bacteria, that help bind microaggregates with adhesive metabolic products.

Thus, forages increase both microbial biomass and aggregate stability, which are often well-correlated (Drury et al., 1991; Huggins et al., unpublished).

In Ontario, Canada, reed canary grass increased aggregate stability and improved microbial biomass more than alfalfa, orchard grass, or red clover, possibly because fungal growth is favored by the higher carbon-to-nitrogen ratio in reed canary grass. However, all these crops had significantly higher aggregate stability than corn and soybeans (Drury et al., 1991). Microbial biomass was greater for reed canary grass than all other crops tested, except alfalfa at the first and last sampling dates. The legumes (alfalfa and clover) tended to favor bacterial biomass, and the grasses increased fungal biomass. In a cropping system comparison in Maryland, researchers showed that total and labile carbon were significantly higher under grass, and lower under conventionally tilled (CT) corn. Grass resulted in twice as much soil metabolic activity compared to CT continuous corn. Less tillage and more grass also improved other soil biologicalactivity indicators, including nitrogen mineralization, earthworm (*Lumbricidae*) populations, microbial respiration, and extractable organic carbon (Weil et al., 1993).

In one Ohio study, researchers found better aggregation, lower bulk densities and greater organic carbon in continuous corn and a corn-soybean rotation than in a corn-oat-meadow rotation. They suggested that this unexpected result might be due to a number of factors including relatively low crop residue, poor soil cover, and excessive vehicular traffic for harvesting forage, resulting in poor soil structure and low aggregation (Lal et al., 1994).

Grazing impacts

Well-managed grazing systems generally enhance soil biological activity, while high stocking rates or grazing when soils are too wet causes compaction and degrades structure—resulting in less biological activity.

A number of studies have confirmed that compaction can reduce biological activity. A UK study compared a permanent pasture, with high organic carbon content, to a continuous cereal (28 years) with low organic carbon. Compaction was simulated using five tractor passes each of 10,736 lbs to selected plot sites. Compaction reduced net nitrogen mineralization in the pasture, but not on the cropped site. Respiration decreased with compaction on both sites (Jensen et al., 1996). These researchers concluded that soil biological factors, such as soil respiration and nitrogen mineralization, may be more sensitive to heavy traffic than physical properties (Jensen et al., 1996).

Soil compaction under grazing animals depends on the type of livestock grazed. In a grazing experiment in Vermont, compaction was found to be greater under cattle than sheep. Microbial respiration rates, soil nematode numbers, and average earthworm numbers were all higher in sheep-grazed than cattle-grazed treatments and were inversely related to the degree of soil compaction (Murphy et al., 1995). Depending on soil texture and moisture, these researchers concluded that low stocking densities with continuous grazing or long paddock occupations of several days in a rotational grazing system can potentially cause serious compaction problems. They suggested that periodic soil aeration might benefit pasture production under cattle grazing.

Other biological processes affected by compaction include earthworm activity and cycling of nitrogen. In a study of cattle grazing on permanent pasture, trampling cattle destroyed earthworm burrows at the 1 inch soil depth. At the 9 inch depth, castings by earthworms rather than trampling were the most important source of burrow disintegration (Ligthart, 1997).

Welsh studies with compacted grassland soil have shown that simultaneous nitrification and denitrification at shallow soil depths resulted in nitrogen losses (Abbasi and Adams, 1998).

In a two year study in North Dakota, moderate grazing (45% removal of plant growth) resulted in higher decomposition and soil nitrogen mineralization rates, and lower nitrogen release from litter and root decomposition, than in the heavily grazed (77% plant removal) or long term ungrazed treatments (Shariff et al., 1994). These increases in net soil nitrogen mineralization with moderate grazing appeared to contribute to the higher levels of plant production and nitrogen uptake found in this treatment. They suggest that moderate grazing may also contribute to conservation of nitrogen due to greater retention of nitrogen in plant litter and roots.

A field experiment in South Wales, UK demonstrated the benefits of grazing for soil biological activity. Researchers found that when sheep-grazing intensity was reduced or removed completely, total soil microbial biomass was dramatically reduced and bacterial/fungal ratios changed significantly (Bardgett and Leemans, 1995). In laboratory microcosm studies on these same soils, continuous defoliation (as would occur with grazing) caused increases in microbial biomass either as a result of increased soluble nutrients exuded from live roots or nutrients released from dead and decomposing roots (Mawdsley and Bardgett, 1997).

Another effect of grazing is the tendency for nutrients to become unevenly distributed, and this in turn can affect biological activity and productivity. One study showed potassium accumulation in "camping zones" near water, the mineral feeder and shade, and depletions in non-camping zones (Wilkinson et al., 1989). Sheep manure tends to be more uniformly deposited than cattle manure, so sheep pastures are less likely to manifest this problem (Murphy et al., 1995).

KNOWLEDGE GAPS

Significant gaps exist in the knowledge of how livestock management impacts soil quality in Minnesota. Most of the research discussed in this report examines the effects of single practices, or a small set of practices, on specific soil characteristics. From this research we get a picture of the effect of some farm practices on soil quality, but we do not have complete understanding of how crop and livestock management interact on real farms in Minnesota. We propose the following research topics to fill the knowledge gaps.

A. STUDIES THAT COULD BE ACCOMPLISHED IN 18 MONTHS OR LESS IF ADEQUATELY FUNDED INCLUDE:

Nutrient balances (inputs, outputs, and recycling) for livestock systems in Minnesota.

Data obtained from farms representing different sizes and types of livestock operations on different soils could be obtained and estimates of the nutrient balances could be made.

The nutrient balance calculations combined with information on the capacity of soils to retain nutrients are needed to define the number of animals per area of available cropland that is environmentally sustainable, assuming manure nutrients are not exported from the area. Additionally, the calculations could be used to estimate where, and at what rate, nutrients are concentrated on or exported from cropland.

Examination of the erosion potential for different types of livestock and cash-grain farms in Minnesota.

Estimates of the effects of different types of livestock and grain farming operations could be generated using computer simulation models for individual operations, local watersheds, and regions of the state. This could include estimation of the effects of reduced tillage versus conventional tillage and the effects of different grazing systems.

Although computer model calculations provide imperfect estimates of actual erosion losses they can generate valid rankings of the erosion potential for different livestock and cropping systems.

A geographical and historical analysis of Minnesota crop and livestock farming.

An analysis of animal agriculture systems would allow interpretation of the significance of the soil quality research presented in this report and gained from other research investigations.

Some questions that might be addressed are: Where, and in what situations, are perennial forages grown? How has this changed over the last 50 years? To what extent are productivity and sustainability affected where forages are not grown? How far can farmers economically transport manure? Where do markets exist that transfer manure from livestock to cropping operations? What are the regional conditions that encourage the return of manure to cropland? What are trends in soil quality and soil erosion around the state? Can they be linked to differences in animal agricultural systems?

The effects of antibiotic feed additives on microbial activity in soils.

This research would examine the long-term potential for selection of antibiotic resistant bacteria and any possible negative effects on soil quality, as well as human and animal health. Soil microbial activity could be compared on farms with long-term application of manure with and without antibiotics. Sites where there has been a recent change in antibiotic use could be used to evaluate how quickly microbial populations respond.

B. STUDIES THAT WOULD REQUIRE GREATER THAN 18 MONTHS INCLUDE:

Investigations of the long-term effects of grazing management systems and their impacts on soil quality.

This research would provide information on concerns related to the effects of grazing management. For example, soil compaction research in Minnesota has traditionally focused on continuous cropping systems and compaction related to mechanical forces. However, there are a number of specific questions to be answered regarding recognition and control of soil compaction by grazing livestock in Minnesota. Other concerns in grazing systems are with the potential for nitrate leaching from urine spots, and spatial variation of nutrients in soil.

The value of manure applications for renovating degraded soils.

Repeated manure application can increase the organic matter in soils and increase crop productivity of soils that have been degraded by erosion. Systematic data on the use of manure to renovate degraded soils in Minnesota are not available.

Results of this study could be used to develop site-specific recommendations for the renovation of degraded fields, as well as degraded areas within fields.

The benefits to soil quality of various types of manure amendments versus crop diversity through rotations, green manures, and cover crops.

Manure can have important positive effects on soil quality. Perennial forages in crop rotations, as well as green manures and cover crops, also have positive effects on soil quality. The relative advantages and disadvantages of these different practices are not well understood for Minnesota conditions. This research will address the question of how to achieve maximum benefit to soil quality on livestock farms: Should manure be applied mainly to annual crops? Must perennial forages be included in crop rotations, regardless of manure inputs? Is it best to apply manure to perennial forages to achieve the largest, most persistent gains in soil quality?

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ATTACHMENTS

ONGOING RESEARCH

Title of Study	Investigators
■ Integrated approaches to manure management and biological control of plant diseases.	Hoitink, HAJ, WA Dick, and TL Loudon
■ Use of phytase enzymes and low phytate corn in Delaware's poultry grain agriculture: Assessing the agronomic, animal nutrition, and environmental impacts.	T. Sims
■ Long-term manure application and phosphorus transport in poorly drained soils.	R. Simard, S. Beauchemin
■ Phosphorus requirements for dairy cows.	L.D. Satter
■ Reducing non-point phosphorus runoff and ammonia emissions from animal manure with alum.	P.A. Moore
■ Evaluation of Alternative Crops in Dryland Multi-Crop Rotations on Farms in the North Eastern Colorado Region.	James M. Krall
■ Land application of liquid hog manure at environmental vs. agronomic rates.	Neil Hansen, Peter Gessel, John Moncrief
■ Beef Cattle Feedlot Manure for Site Specific Application.	Bahman Eghbal
■ Impact of accelerated erosion on soil properties and productivity.	Larry Cihacek, K.A. Ringwall, R. Carcoana
■ Managing dairy manure nutrients in a recycling compost program within the Le Sueur River watershed.	Chester-Jones, Peters, Busch, Busman, Norm and Sallie Volkmann

Investigators: T. Sims

Institution or Affiliation: University of Delaware, Department of Plant and Soil Science

Title of Study: Use of phytase enzymes and low phytate corn in Delaware's poultry grain agriculture: Assessing the agronomic, animal nutrition, and environmental impacts

Funding Agency: State of Delaware Research Partnership, BASF

Duration of Study: 1997-1999

Objectives: Assess agronomic, animal nutrition, and environmental impacts of low phytate corn.

Key Words: poultry, phytase, low phytate corn

Location (or Locations) of Study: Sussex County, DE

Type (or types) of Soil Used: Sandy loam

Climate: Warm, humid.

Approach: This study was primarily conducted in the laboratory. Phosphorus content of poultry manure from animals fed low phytate corn was analyzed phosphorus. Corn in the feed was also analyzed for supplying adequate phosphorus for animal nutrition.

Progress: on-going. Data collected, approximately 300 acres of low phytic acid corn planted

Potential Implications: Produce low phytate corn for use in animal feed which supplies the necessary P levels for animal nutrition while at the same time reducing total P in animal manure. If successful this approach to reducing P in animal manures would be environmentally beneficial for reducing P inputs in to the soil.

Publications: In progress

Other Comments: Interview done with Dr. April Leytem.

Further related research by Dr. Sims is listed at the following web site: http://bluehen.ags.udel.edu/envsoil/projects/default.htm#projects

Investigators: R. Simard, S. Beauchemin

Institution or Affiliation: Agriculture and Agrifood Canada

Title of Study: Long-term manure application and phosphorus transport in poorly drained soils

Funding Agency: Internal and external

Duration of Study: 1992 - ongoing

Objectives: Long term impact of swine manure on P.

Key Words: redox, swine, dairy manure, compost, poorly drained soils

Location (or Locations) of Study: Quebec, Canada

Type (or types) of Soil Used: Sandy loam to heavy clay in poorly drained soils

Climate: Cool, humid.

Approach: Evaluate long-term manure application to poorly drained soils, evaluate phosphorus pools (partitioning) using field scale studies, evaluate runoff and drainage water for nutrients primarily P, measure the degree of P saturation, in response to manure application rates, for Canadian soils with a variety of textures.

Progress: on-going

Potential Implications: The results of this study will be beneficial for making recommendations pertaining to the implications of long-term manure application on soil P saturation levels. This study may also characterize process of movement of P through soils in a management system of long-term manure applications.

Publications: Soil Science Society, Canadian Journal of Soil Science

Other Comments:

Investigators: L.D. Satter

Institution or Affiliation: USDA-ARS Dairy Forage Research Unit

Title of Study: Phosphorus requirements for dairy cows

Funding Agency: USDA-NRI

Duration of Study: 1996-2002

Objectives: Reduce amount of P in manure..

Key Words: dairy, phosphorus, nitrogen

Location (or Locations) of Study: Prairie du Sac, Wisconsin

Type (or types) of Soil Used: Silt loam intermixed sandy, glaciated terrain

Climate: humid.

Approach: Farm management of manure through mass balance of phosphorus for crop production and environmental protection while maintaining animal nutrition requirements is the approach being used in this study. Experimental procedures include analyzing dietary phosphorus requirements for dairy cattle and then if possible reduce dietary consumption through reduced phosphorus in livestock feed and consequently animal manure.

Progress: Submitting publications to journals of Dietary P. in process of collecting data on cropping systems

Potential Implications: This study may provide need information regarding phosphorus budgets for whole farm management. This research may lead to recommendations for dietary P which may lead to further research on reduced P in animal feeds as well as reduced P in animal manures and the effects on the environmental fate of P from live stock manure. This study may also lead to reduced energy requirements for the manufacture of N and for management of N from manure supplemented with commercial fertilizers plus N credits from other crops.

Publications: Journal of Dairy Science – 2 publications
Nutrition conference plus manuscripts.

Other Comments:

Investigators: P.A. Moore

Institution or Affiliation: USDA-ARS Poultry Production and Product Safety Research Unit

Title of Study: Reducing non-point phosphorus runoff and ammonia emissions from animal manure with alum.

Funding Agency: Internal (USDA), External (US Poultry Assoc.), EPA

Duration of Study: 20 year study beginning in 1994

Objectives: Reduce P in runoff of surface applied manure, decrease ammonia volatilization, improve animal productivity

Key Words: Alum, aluminum sulfate, precipitate P, ammonia volatilization, poultry litter, P runoff, pasture, soluble P

Location (or Locations) of Study: Northwest , Arkansas

Type (or types) of Soil Used: silt loam

Climate: warm, humid.

Approach: Initial lab studies and small plot field trials of P movement through soils with Alum and non-Alum treated poultry litter. Poultry house research was conducted on ammonia volatilization, animal health, and human health. Watershed scale experiments comparing Alum treated litter with non-Alum treated litter showed P in runoff was reduced by 75%. Alum treatment poultry litter has reduced heavy metal runoff (Cu, Zn, As) by 50%.

Progress: Found success using Alum to treat poultry litter to reduce P movement through and across soils

Potential Implications: Reduced environmental quality degradation by reducing P in runoff, improved poultry production, and improvements in human and animal health.

Publications: JEQ

Other Comments: Other on-going long-term studies related to manure applications (rates, treatments)
–Also looking at other manures (swine)
–estrodial – estrogen compound reduced in

Investigators: James M. Krall

Institution or Affiliation: University of Wyoming

Title of Study: Evaluation of Alternative Crops in Dryland Multi-Crop Rotations on Farms in the North Eastern Colorado Region

Funding Agency: USDA - SARE

Duration of Study: 1995-1999

Objectives: Compare a winter-pea/winter-wheat rotation with the conventional winter wheat/fallow system.

Key Words: dry land, grazing

Location (or Locations) of Study: southeast Wyoming, northeast Colorado

Type (or types) of Soil Used:

Climate: dryland

Approach: An alternative, livestock-based, crop rotation is compared to the conventional wheat-fallow rotation for dry land production. The alternative rotation involves fall-sown winter pea. The pea is grazed in spring, disked in summer and followed by winter wheat.

Progress: Will assess soil quality indices this fall after 4 complete rotation cycles. Yield data suggest improved soil condition with inter pea in rotation.

Potential Implications: including winter pea and grazing systems in rotation with wheat may promote soil quality.

Publications:

Other Comments:

Investigators: Hoitink, HAJ, WA Dick, and TL Loudon

Institution or Affiliation: Ohio State University, Plant Pathology Dept

Title of Study: Integrated approaches to manure management and biological control of plant diseases

Funding Agency: USDA Cooperative Research NRI Competitive Grants

Duration of Study: 01 April 1998 - 31 Mar 2000

Objectives: 1) Develop and demonstrate best management practices for on-farm composting capitalizing on natural convective gaseous transfer to minimize turning and reduce labor and odor problems; 2) Improve disease control in no-till crop production utilizing manures and composted manures; and 3) Develop and demonstrate novel procedures for biological control of soilborne diseases of nursery crops utilizing composted manures.

Key Words: manure management, biological control, on-farm composting

Location (or Locations) of Study: several locations all over the state of Ohio

Type (or types) of Soil Used: numerous including Wooster silt loam and Hoytville clay

Climate: humid, temperate

Approach: 1) Compost windrow conditions will be simulated in a pilot-scale chamber utilizing existing in-vessel gas transfer models. Field scale windrow data will be used to validate the most promising model. This model will be used to develop BMPs for on-farm composting. 2) A four-replicate complete factorial experiment will be conducted on two soils, one well-drained and the other poorly-drained. Variables will include organic amendments (manure and composted manures), rates (four levels), and tillage (reduced and plow-tillage). Data collected will include climatic information, agronomic practices, yield, disease severity, and soil quality (chemical and biological properties). 3) Natural and biocontrol agent-fortified container media amended with composted manures will be evaluated for suppressiveness to Rhizoctonia crown and root rot, Pythium and Phytophthora root rot and Verticillium wilt of nursery crops. The most suppressive systems will be demonstrated in cooperating nurseries.

Progress: A commercial scale hog-finishing facility has produced 2 crops of 1000 hogs each with manure produced under the slatted floor in a dry form and no liquid by-products at all. This manure has just completed the composting process and will be sold as potting mix and for field application. Fifteen new finishing facilities at various locations are under construction at this time, one of which will have capacity for 8000 hogs at a time. Under objective two, these researchers are in the second year of a study where large amounts of dairy manure and/or compost are applied and worked in to the top 1-2 inches of soil to try to convert fields from conventional to minimum tillage in one year, with yields and soil properties comparable to a long term no-till field. Finally, Dr. Hoitink has shown, with a number of students over the last 25 years, that composted or aged manure can impart systemic-induced (broad spectrum) resistance to plants. On the other hand, fresh manure or too much manure can actually activate plant diseases. Mechanisms for this include: too much free nutrient availability in fresh manure, so plant and animal pathogens are stimulated and there is no competition from suppressive organisms. There is no parasitism or antibody production in very nutrient rich soils. Thus, a certain stability of organic matter is required before systemic induced resistance occurs.

Potential Implications: According to Dr. Hoitink, the technology exists to avoid any problems with manure handling in chicken broiler and layer, hog and beef production. Only for dairy production is the volume of water too great to be handled with the present technology, but this is being worked on at present at Ohio State. These systems completely bypass all liquids so leakage and pollution are not concerns. Ammonia levels are maintained within safe bounds, and the ammonia is trapped and converted to nitrate. Odor problems are also solved with this technology. The problem is how to convert existing facilities, and those still being constructed without this manure handling feature.

Publications:

Hoitink, H.A.J. and M.J. Boehm, 1999. Biocontrol within the context of soil microbial communities: A substrate-dependent phenomenon. Annual Reviews in Phytopathology 37: 427-446. In press.

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Hoitink, H.A.J. 1998. Control of nuisance and detrimental molds (fungi) in mulches and composts. Fact Sheet HYG-3304-98. Ohio State University Extension, Wooster, OH 44691.

Hoitink, H.A.J., W. Zhang, D.Y. Han, A.G. Stone, M.S. Krause and W.A. Dick, 1998. How to optimize disease control with composts. Pg 50-65 In Ornamental Plants, Special Circular #157. 117 pages. Ohio Agricultural Research and Development Center, Wooster, OH 44691.

Other Comments: Manure and erosion: By composting manure, applications can be made to 25-40% slopes without erosion. Fresh dairy manure applied on slopes is a disaster. For egg production, on-site composting has been incorporated into the facilities for henhouses as large as two million hens, with a guaranteed composition of 4.5% nitrogen, ammonia is trapped out, and there is no odor problem except from the hens themselves. This composting procedure results in no net loss and sometimes a slight profit on the production of the manure. For broiler production, it has been shown that manure can be rototilled in and kept moist on the floor of the broiler house for up to 10 crops of broilers; the manure can then be taken off and marketed directly without composting. This aged manure has beneficial effects on the birds, with the worst disease losses occurring in the first flock and the least in the tenth flock.

Investigators: Neil Hansen, Peter Gessel, John Moncrief

Institution or Affiliation: University of Minnesota

Title of Study: Land application of liquid hog manure at environmental vs. agronomic rates.

Funding Agency: University of Minnesota graduate school

Duration of Study: 1999 - 2001

Objectives: Evaluate impact of variable rates of land applied, liquid hog manure on soil and water quality

Key Words: runoff, manure, aggregation

Location (or Locations) of Study: Morris, MN

Type (or types) of Soil Used: Barnes loam

Climate:

Approach: 12 runoff plots are used to replicate 4 rates of liquid hog manure application which range from environmental (p-based) rates to agronomic (N-based) rates. Natural runoff is measured as well as soil quality parameters.

Progress: First manure application made in fall of 1998.

Potential Implications: Determine “ideal” application rates that consider minimizing water quality problems and maximizing crop response.

Publications:

Other Comments:

Investigators: Bahman Eghbal

Institution or Affiliation: USDA Lincoln Nebraska

Title of Study: Beef Cattle Feedlot Manure for Site Specific Application

Funding Agency: USDA

Duration of Study: 1999-2004

Key Words: Site specific, precision agriculture, beef manure, soil quality,

Location (or Locations) of Study: Central Nebraska, near Grand Island (irrigated corn) and the Nebraska Northeast Experiment Station

Type (or types) of Soil Used: Mollisols

Climate: 25 in of rain, wet-dry sub humid. The Central Nebraska site is irrigated.

Approach: Manure is applied in a site-specific manner only to areas with soil carbon less that 1.5%, to meet N needs of the crop. One objective is to see if organic C in the low organic matter areas can be increased to the organic matter content in the remainder of the areas on the study sites. Greenhouse gas emissions (methane, CO_2 and N_2O) will be measured where manure is applied.

Progress: The initial data from 1998 show that in the low organic matter soils manure increases yield of corn over commercial fertilizer by 15 bu/ac. The organic C contents increased by 0.15%.

Potential Implications: Manure is a valuable resource for the renovation of degraded soils. This study will determine the time frame for renovation and the improvements in crop yields and soil quality.

Publications: None

Other Comments:

Investigators: Larry Cihacek, K.A. Ringwall, R. Carcoana

Institution or Affiliation: North Dakota State University, Department of Soil Science

Title of Study: Impact of accelerated erosion on soil properties and productivity

Funding Agency: USDA – NCR committee 174

Duration of Study: 1992-1999

Objectives: Evaluate the use of feedlot manure for restoring the productivity of severely eroded soil.

Key Words: manure, productivity, erosion

Location (or Locations) of Study: Manning, SD

Type (or types) of Soil Used: severely eroded Cabba and Chena soils, formed in siltstone

Climate:

Approach: Variable manure application rates and frequencies. 50 tons of manure/acre either 1 of 3 years, 2 of 3 years, or 3 of 3 years. Assess production, soil aggregation, and tilth.

Progress: Manured soils have increased in productivity and soil quality. These changes were not noted until after about 4 years of manure treatment.

Potential Implications: Manure is a valuable resource, but more frequently is treated as a waste.

Publications:

Other Comments:

Investigators: Chester-Jones, Peters, Busch, Busman, Norm and Sallie Volkmann (dairy producers)

Institution or Affiliation: University of Minnesota and commercial dairy producers

Title of Study: Managing dairy manure nutrients in a recycling compost program within the Le Sueur River watershed

Funding Agency: Minnesota Dept of Ag

Duration of Study: March 1998 to March 2000

Objectives: 1. To monitor manure nutrient flow from a 600-cow dairy through a solid/liquid separator and evaluate nutrient recycling of manure solids through composting used as bedding or land application for forage crops; 2. Monitor the effect of composted manure nutrient availability when land applied at varying rates to corn land to be harvested as corn silage.

Key Words: dairy manure; compost; nutrient recycling; bedding; land application

Location (or Locations) of Study: Dairyfield farm, Janesville MN

Type (or types) of Soil Used: Webster clay-loam

Climate:

Approach: The farm is one of 6 dairy units that have been used for a nutrient profile project. The approach is to take frequent samples of the liquid and solid stream on a 600-cow freestall barn. The solid stream in monitored from the compost pile through the compost windrows. Compost temperatures and nutrient composition are taken frequently. Compost is recycled with addition of woodchips as a bedding source for freestalls. A 10 x 1/3 acre plot area has been established to evaluate the spring and fall application of 30 vs. 45 tons/acre of compost or raw dairy manure vs. urea and zero N application. All plots are planted to the same corn variety. All plots received 50 lbs. of a 34-10 starter fertilizer. Each plot has a corresponding control. Soil samples are taken twice/yr; corn silage yields are taken/plot. MN Dept of Ag are using a rain simulator to look at run-off effects within each plot. The project will contribute to the whole-farm nutrient balance

Progress: First year of spring compost application to the plots completed; second year of fall compost application to same plots well under way.

Potential Implications: Implications of improving the recycling of the waste stream on a dairy using composting; project will allow for more efficient accountability of manure nutrients; project will provide information on the availability of compost nutrients to support forage crops growth and the effect on soil fertility and organic matter base. Overall impact of refining crop and soil fertility program and reduce purchased fertilizer costs on a dairy farm within a sensitive environmental river watershed area.

Publications:

Other Comments: The above farm is 1 of 6 Waseca County farms that are being used for nutrient profile project. This latter project is not funded from an outside source. Soil, manure and feed analyses have been supported by my internal gifts account which has now run dry. We have been turned down for 3 external grants to date to support the study. Hopefully GEIS research needs can utilize these farms which offer a microcosm of the Minnesota dairy industry