Generic Environmental Impact Statement on Animal Agriculture:

A Summary of the Literature Related to Manure and Crop Nutrients (J)

Prepared for the Minnesota Environmental Quality Board

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September, 1999

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,

Gene Hugoson, Commissioner, Minnesota Department of Agriculture and Chair, Minnesota Environmental Quality Board
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EXECUTIVE SUMMARY

This topic covers: current manure storage and application practices, the environmental and economic benefits and risks of manure in comparison to other sources of crop nutrients, and the carrying capacity of soils to absorb nutrients and heavy metals. We grouped the Scoping Document questions into the following three categories: I. Storage and Handling, II. Value and Environmental Impacts, and III. Inventory of nutrient sources and soil levels. A fourth category, recommended research, is also presented.

STORAGE AND HANDLING

SCOPING QUESTION 1. WHAT MANURE STORAGE AND APPLICATION PRACTICES ARE IN CURRENT USE IN MINNESOTA AND HOW DO THEY COMPARE TO THE PRACTICES IN USE IN THE PAST? TO WHAT EXTENT DO THE CURRENT PRACTICES ADHERE TO EXISTING REQUIREMENTS?

We have presented a detailed description of current storage and application practices. There is no data base that provides an inventory of storage and application practices for Minnesota. The Minnesota Pollution Control Agency has data on a subset of animal operations. Their database represents only about 25% of the total and the sample is weighted heavily toward large operations and those that have received complaints. In this report, we offer an inventory based on the collective opinion of faculty that have knowledge in this area. This question could be answered by using a statistical sampling approach or a complete tally (similar to the census issue). It would be limited by resources, and by cooperation from property owners.

SCOPING QUESTION 5. WHICH MANAGEMENT, CONSTRUCTION, STORAGE, AND APPLICATION TECHNIQUES IN MINNESOTA AND OTHER PLACES MAXIMIZE THE POSITIVE AND MINIMIZE THE NEGATIVE IMPACTS OF MANURE?

Environmentally sound storage and application requires good management. It also requires investment in well constructed storage facilities and investment in the proper handling and application equipment. There is no single manure storage, handling, and application system that can be recommended as best, because the physical nature of livestock manures, available labor and time, management skills, soil properties, and weather conditions vary spatially and temporally in Minnesota.

VALUE AND ENVIRONMENTAL IMPACTS

SCOPING QUESTION 2. TO WHAT EXTENT IS MANURE AN ASSET OR LIABILITY TO THE ENVIRONMENT, COMMUNITY, AND THE ECONOMY? WHAT ARE THE COMPARATIVE BENEFITS AND RISKS OF MANURE COMPARED TO COMMERCIAL FERTILIZER AND OTHER SOURCES OF FERTILITY (SUCH AS LEGUMES AND SEWAGE SLUDGE) INCLUDING COMPARATIVE ENERGY USE, AND HOW DOES THE COMPARISON VARY ACCORDING TO GEOGRAPHY AND GEOLOGY AND BY MANURE MANAGEMENT METHOD?
Manure can have value in several respects. The first obvious one is the direct nutrient value. The value depends on the site-specific soil nutrient levels and nutrient concentrations of manure. In some areas of Minnesota soil levels of phosphorus and potassium and most micronutrients are already at adequate levels. Therefore, the value of these constituents in certain cases may be questionable. Manure also imparts biological and physical properties to the soil that make it more productive and less erosive. It is difficult to put a dollar figure on this benefit. The cost of manure includes those associated with storage, handling, and application. There can be also an environmental cost.

If manure is over-applied, applied at the wrong time in the growth cycle, applied unevenly, allowed to experience losses in storage, handling, and application, then it can degrade water and/or air quality. Depending on the manure source, varying levels of part of its nitrogen can be present in a slow release form that is very beneficial environmentally. Part of the nitrogen is similar to commercial fertilizer in a soil system. This is an advantage of manure. Commercial nitrogen is relatively cheap. It can be applied very uniformly, precisely, and at ideal times to maximize crop uptake. In contrast, manure will often behave like other organic nutrient sources such as sewage sludge and compost in soil.

The most sensitive environmental regions in Minnesota are the deep glacial outwash sands in the central part of the state with surficial aquifers and the karst area in southeastern Minnesota where fractured limestone bedrock provides for entry of nitrogen and other mobile contaminants directly into the aquifer. The relatively impermeable glacial till and glacial lakebed sediments pose a risk of nitrate loss to surface waters through tile drainage. These landscapes also pose the greatest risk of losses of pollutants from runoff.

Surface runoff losses of phosphorus, and oxygen demanding materials are a major concern in Minnesota. Manure applications near water bodies, surface applied without incorporation, applied at excessive rates, and applied on frozen or snow covered ground pose a greater risk. The erosion potential of the site is an important consideration. The use of conservation tillage has been shown to reduce total P losses. Increased P concentration near the soil surface and contributions from plant residues with these systems needs further evaluation. Set backs, buffer strips, and sand filters at surface tile inlets also need further research.

Most nitrogen fertilizers are produced by combining nitrogen from the air with natural gas. The price of nitrogen fertilizer is linked to energy prices. A potential by-product from manure is energy, produced by methane generation or by burning manure directly, but these usually are not competitive with coal or other energy sources.

**INVENTORY OF NUTRIENT SOURCES AND SOIL LEVELS**

**SCOPING QUESTION 3. WHAT IS THE CARRYING CAPACITY OF THE SOILS IN THE AGRICULTURAL AREAS OF MINNESOTA FOR THE NUTRIENTS AND TOXIC SUBSTANCES CONTAINED IN MANURES? WHAT ARE THE CURRENT LEVELS OF THOSE SUBSTANCES IN THE**
SOILS IN AGRICULTURAL AREAS OF MINNESOTA (INCLUDING PHOSPHORUS AND TRACE METALS)?

Soils vary in the amount of nutrients they can hold. Many nutrients are held tightly by soil unless very high concentrations are present. Other nutrients are not held tightly by soil and move with soil water. Nutrient forms can change after entering the soil and become more or less mobile. Generally, the finer the soil texture (that is, the higher the silt and especially clay content), the more water and nutrients it can hold.

Some farmers and other land managers have soil analyzed for nutrient levels. Generally, soil tests have increased to high levels in the last several decades. As was mentioned earlier, some soils are natively high in certain nutrients.

SCOPING QUESTION 4. WHAT IS THE TOTAL AMOUNT AND PROPORTION OF PLANT NUTRIENTS APPLIED TO SOILS IN MINNESOTA FROM: A) ANIMAL MANURES, B) COMMERCIAL FERTILIZERS, C) LEGUMES, D) PLANT DECOMPOSITION, E) SEWAGE SLUDGE, AND F) ATMOSPHERIC DEPOSITION?

It is difficult to answer certain aspects of this question. There are records on the amounts of commercial fertilizer sold. One can infer the amount of manure that is generated by the numbers of animals, but there are good databases on some species and not on others. Legumes can take nitrogen gas from the atmosphere and convert it to plant-available forms. If there is nitrogen present from other sources (manure, fertilizer, plant residues, soil organic matter release, atmospheric deposition, etc.), then legumes will "fix" less atmospheric nitrogen, and take up what is available. Therefore, it is hard to estimate nitrogen fixation by legumes. Plant decomposition is a nutrient cycling process, rather than an input of new nutrients. There are fairly good records on sewage sludge application. There is also a national network of monitoring sites for atmospheric deposition of various forms of nitrogen. This is a small part of the total. Very important to the whole farm nutrient balance is the purchase of feeds, which contain large amounts of nutrients. These nutrients are added to soils when manure is applied.

RECOMMENDED RESEARCH

Recommended research is organized into two broad categories: environmental protection and improved crop production which follow. Quantify benefits of manure in addition to the nutrient content, including erosion control, increased water holding capacity, and in the case of composts-weed control and disease suppression. Evaluate the extent to which nitrate leaching and phosphorus runoff losses from Minnesota animal agriculture can be reduced. Characterize and evaluate whole-farm nutrient balances for different classes of livestock. Develop initial P application guidelines to protect surface water quality. Identify the best manure strategy when applying to land with surface tile inlets? Determine the impact of winter application on runoff losses from snowmelt and rainfall runoff under Minnesota conditions? Conduct a manure survey to determine the metal content by species and investigate their transport in soil systems.
Enhance manure’s value as a resource by better assessment of the nutrient release patterns for different types of manure. Evaluate synchronicity of nutrient release with crop demand by blending synthetic fertilizers with manure. Develop new application equipment designed to evenly and efficiently distribute manure. Evaluation of real-time nutrient analysis coupled with precision application. Estimate how much the transportability and value of manure is enhanced by dewatering and composting?
CRITIQUE OF SCOPING DOCUMENT QUESTIONS

SCOPING QUESTION 1. WHAT MANURE STORAGE AND APPLICATION PRACTICES ARE IN CURRENT USE IN MINNESOTA AND HOW DO THEY COMPARE TO THE PRACTICES IN USE IN THE PAST? TO WHAT EXTENT DO THE CURRENT PRACTICES ADHERE TO EXISTING REQUIREMENTS?

There is no database that provides an inventory of storage and application practices for Minnesota. The Minnesota Pollution Control Agency has data on a subset of animal operations. Their data base represents only about 25% of the total and the sample is weighted heavily toward large operations and those that have received complaints. This question could be answered (at least present practices) by using a statistical sampling approach or a complete tally (similar to the census issue). It would be limited by resources, and by cooperation from property owners.

SCOPING QUESTION 2. TO WHAT EXTENT IS MANURE AN ASSET OR LIABILITY TO THE ENVIRONMENT, COMMUNITY, AND THE ECONOMY? WHAT ARE THE COMPARATIVE BENEFITS AND RISKS OF MANURE COMPARED TO COMMERCIAL FERTILIZER AND OTHER SOURCES OF FERTILITY (SUCH AS LEGUMES AND SEWAGE SLUDGE) INCLUDING COMPARATIVE ENERGY USE, AND HOW DOES THE COMPARISON VARY ACCORDING TO GEOGRAPHY AND GEOLOGY AND BY MANURE MANAGEMENT METHOD?

We saw this question as being much too broad. It literally covers the entire GEIS in scope. In an effort to narrow the scope we focused on manure viewed as an asset or environmental liability with discussion on geologically sensitive areas and management techniques. We did not address manure effects on communities. Nor did we pursue a complex economic analysis of manure generating enterprises but did offer some simple value estimates. We felt that these issues would be found in other topic areas. Some aspects of this question are presented from published research but research is needed to answer other aspects.

SCOPING QUESTION 3. WHAT IS THE CARRYING CAPACITY OF THE SOILS IN THE AGRICULTURAL AREAS OF MINNESOTA FOR THE NUTRIENTS AND TOXIC SUBSTANCES CONTAINED IN MANURES? WHAT ARE THE CURRENT LEVELS OF THOSE SUBSTANCES IN THE SOILS IN AGRICULTURAL AREAS OF MINNESOTA (INCLUDING PHOSPHORUS AND TRACE METALS)?

We interpreted “carrying capacity of soils” in the context of how much of the different constituents found in manure can be held by various soils before losses are excessive. To evaluate current levels we gathered data from the University of Minnesota and North Dakota State University Soil Testing Laboratories. By adding data from private laboratories (who do most of the soil tests in Minnesota) we could get a much better
picture. A state-wide survey of manure content of micronutrients and toxic compounds would also be helpful.

**Scoping Question 4. What is the total amount and proportion of plant nutrients applied to soils in Minnesota from: a) animal manures, b) commercial fertilizers, c) legumes, d) plant decomposition, e) sewage sludge, and f) atmospheric deposition?**

It is difficult to answer certain aspects of this question. There are records on the amounts of commercial fertilizer sold. One can infer the amount of manure that is generated by the numbers of animals, but there are good databases on some species and not on others. Legumes can take nitrogen gas from the atmosphere and convert it to plant-available forms. If there is nitrogen present from other sources (manure, fertilizer, plant residues, soil organic matter release, atmospheric deposition, etc.), then legumes will "fix" less atmospheric nitrogen, and take up what is available. Therefore, it is hard to estimate nitrogen fixation by legumes. Plant decomposition is a nutrient cycling process, rather than an input of new nutrients. There are fairly good records on sewage sludge application. There is also a national network of monitoring sites for atmospheric deposition of various forms of nitrogen. This is a small part of the total. Very important to the whole farm nutrient balance is the purchase of feeds, which contain large amounts of nutrients. These nutrients are added to soils when manure is applied. Whole farm nutrient budgets would help answer this question.

**Scoping Question 5. Which management, construction, storage, and application techniques in Minnesota and other places maximize the positive and minimize the negative impacts of manure?**

Environmentally sound storage and application requires good management. It also requires investment in well constructed storage facilities and investment in the proper handling and application equipment. There is no single manure storage, handling, and application system that can be recommended as best, because the physical nature of livestock manures, available labor and time, management skills, soil properties, and weather conditions all vary across time and from farm to farm. In the literature review presented here the pros and cons of various storage and handling techniques commonly found in Minnesota are presented.
MANURE AND CROP NUTRIENT PRIMER

BACKGROUND

Historically, livestock manure was a primary source of plant nutrients. Its value for maintaining and improving the productivity of the soil has been recognized from antiquity (Nowak, et al., 1998). Fertilizing crops with livestock manure nutrients began several millennia ago and is mentioned in the Old Testament of the Bible and other ancient documents.

Before the advent of commercial fertilizer production, access to manure was considered necessary for the long-term sustainability of farming systems. Results from long-term cropping system trials confirm this in every case where commercial fertilizers have not been added. For example, after 40 years of cropping without manure, crop yields were only 20% as large as those where manure was applied annually.

In the middle of this century, commercial fertilizer production changed crop nutrient management in the USA and other countries. This technology affected the structure of American agriculture, and eventually made possible the concentration of livestock production we see today.

For example, in 1996 the combined value of all livestock and poultry on Minnesota farms was over $2.1 billion. Animal agriculture in Minnesota is predominated by pork, dairy, and poultry production and is mostly concentrated in south, south central, and southwestern parts of the state (Minnesota Agricultural Statistical Service, 1997). The manure associated with these animals presents some unique challenges and opportunities. Manure can be recycled for uses such as potting soil, compost for gardens, and other off farm uses.

VALUE OF MANURE

The fundamental reason for input of nutrients into agroecosystems is the need to produce high crop yields, whether or not the crop have relatively low value and low marginal return. In modern cropping systems crop nutrient needs are achieved through addition of inorganic and organic nutrient sources. Inorganic nutrient sources, such as fertilizers, are excellent sources of crop nutrients and are usually readily available. Organic nutrient sources such as animal manures, biosolids and various agricultural and industrial byproducts, also can effectively supply crop nutrients. Essential elements in manure have been shown to contribute to the effects of commercial ammonium-nitrate on corn yield (Durieux, et al., 1995). Manure nutrient effects on wheat and corn yield are comparable to commercial fertilizer (Weidemann, 1943).

The value of manure is largely viewed in terms of its nutrient content. Nutrient value can range widely. The concentration of nutrients depends on dilution with wash water and barnyard runoff as well as losses. The biggest influence is probably water content. As an
example, data from survey of poultry manure showed that manure value ranging from about 5 to 80 dollars per ton for N, P, and K only (Moncrief, et al., 1991).

There are other beneficial effects of manure associated with less tangible economic returns. Manure can improve soil physical and biological properties improvement because of its content of humus, and organic constituents. Soil physical and biological improvement results in a more favorable medium for plant growth and reduced runoff losses of pollutants. For decades researchers have noted the benefits of manure additions to soil, from renovating eroded sites (Latham, 1940) to improving soil physical properties and fertility following centuries of manuring (DeLuca and DeLuca, 1997; Sandor and Eash, 1991). Manure additions to sandy soil improves water holding capacity and improves structure (Hornick, 1988). Other researchers indicated that manure additions can tolerance to corn rootworm, possibly by maintaining higher soil nutrient levels (Allee and Davis, 1996). These have been more thoroughly discussed in the Soil Literature Review.

The cost associated with manure is the storage, handling, and application costs. Generally these costs are smallest closer to the source, with economical storage construction, and when manure is applied without soil injection. If animal manure is concentrated and relatively dry it can be economically transported greater distances.

**STORAGE AND HANDLING**

Manure can be stored on a daily or an annual basis. Increased storage allows more flexibility in timing the application to coincide with crop demand. This generally reduces environmental losses. Liquid or gaseous losses of nutrients and pollutants can occur during storage and handling or after land application. Generally as storage capacity increases allowing for more flexibility in timing applications costs also increase. There are many different methods of storing and handling manure. A brief summary of many common methods is presented in the first section of the literature review.

**ENVIRONMENTAL IMPACT**

Manure can have a positive or negative impact on the environment depending on the management. If applied at too high a rate, too far in advance of plant recovery of nutrients, on an environmentally sensitive area, using an improper application method, or without regard to soil levels environmental damage can result. The main constituents of manure that are important from an environmental standpoint are nitrogen, phosphorus, and oxygen demanding materials. Nitrate nitrogen can result in “Blue Baby” syndrome or be toxic to livestock in high enough concentrations. Ammonium-ammonia nitrogen will be partitioned into both species depending largely on water pH. Ammonia is a very toxic biocide and in high enough concentrations is lethal to aquatic and terrestrial plants and animals. Oxygen demanding materials are reduced compounds that consume oxygen that is dissolved in water when they are converted to oxidized states, largely by microorganisms which derive energy from the conversion. This can be organic compounds or inorganic compounds such as ammonium. When dissolved oxygen levels are reduced fish become stressed and/or die and unpleasant odors develop. Phosphorus is
important because algae growth in most freshwater lakes is limited by this essential nutrient. When algae are allowed to grow they convert carbon dioxide to reduced organic carbon with energy from the Sun. When they die and decompose this carbon becomes a source of dissolved oxygen demand.

When manure is applied to the soil and its constituents are not lost by runoff or leached to groundwater these same characteristics have a positive impact on soil quality as a growth medium for plants.

Besides nutrients essential for plant growth, Animal manure also contains certain metals (trace elements), pathogens, small quantities of biocides and growth hormones (Eck and Stewart, 1995; Edwards and Daniel, 1992; Hansen, 1996; Sims and D.C. Wolf, 1994). Elements of potential environmental concern added to soil by land application of animal manure include nitrogen (N), phosphorus (P), copper (Cu), zinc (Zn), chromium (Cr), and arsenic (As) (Bouldin and Klausner, 1998; Brumm, 1998; Mikkelsen, 1997; Sims, 1997; VanHorn and Hall, 1997). Excessive input of N and P from animal manure is a potential threat to surface and/or ground water quality. Environmental concern over metals stems from their potential toxicity to plants and their biological magnification through the ecological food chain. Environmental impacts of these elements are discussed in other sections of the report.

**SOIL PROPERTIES AND RETENTION OF NUTRIENTS AND METALS**

In Minnesota, as in other states, land application is the most cost effective and widely used method of animal manure management. As a result, nutrients and additives excreted by animals eventually end up in agricultural soils. Chemical composition of manure is dependent on the type of animal, animal diet, and pre application treatment practices. Typical amounts of nutrients in manure from five species of livestock are presented in Table 1.

Once animal manure is applied to soil, the fate of its constituents is determined by the nature of the individual constituent and by an array of complex chemical reactions and physical processes. Soil chemical and physical properties such as pH, organic matter, amount of clay, and moisture profoundly influence many of these reactions. Soil microorganisms are driving forces for many other reactions.

Chemically speaking, clays and organic matter are the most active fractions of soil solids. Clay particles are very small (< 2 micron) and are primarily made up of aluminum (Al), silicon (Si), oxygen (O), and iron (Fe) arranged in an orderly crystalline structure. The organic fraction in soil is the byproduct of breakdown and alteration of plants, animals, and microorganisms and is often termed 'humus.' In general, the dominant electrical charge on soil clay and humus is negative. Thus, clay and humus impart a net negative charge to soil and can retain positively charged ions. Positively charged ions are called cations and negatively charged ions are called anions. Cations in soil include the metallic cations, potassium (K⁺), copper (Cu²⁺), zinc (Zn²⁺) etc, as well as ammonium (NH₄⁺). Nitrate (NO₃⁻), phosphate (PO₄³⁻), and arsenate (AsO₄³⁻) are three anions of potential environmental concern.
The cations have different abilities to bind with the soil minerals, due to variation in their binding strength (a function of their charge) and concentration in soil water (National Research Council, 1989). As a result, cations dissolved in the soil water can displace other cations attached to the soil, through a process called cation exchange. Cation exchange plays an important role in retention of the ammonium form of nitrogen and metals. Cation exchange capacity is a quantitative measure of the number of cation binding sites available per unit weight of soil (National Research Council, 1989). The unit for expressing cation exchange capacity is centimole of positive charge per kilogram of soil (cmol/kg). Thus, if a soil has a cation exchange capacity of 20 cmol/kg, one kg (2.2 lb) of that soil is capable of adsorbing (holding onto) up to 20 cmol of potassium ions (K⁺), because (K⁺) has a positive charge of 1. The same soil can adsorb only 10 cmol of calcium ion (Ca⁺²), because (Ca⁺²) has a positive charge of 2. If no other cations were present in this soil, it could hold up to 8 tons of K⁺ or about 4 tons of Ca⁺² per acre in the top 6 to 8 inches (the plow layer). A typical Minnesota prairie soil with a cation exchange capacity of 18 cmol/kg contains, 5600 pounds of Ca, 720 pounds of Mg, and 780 pounds of K, and much smaller amounts of other cations per acre in the plow layer. This calculation is based on the assumption that there was 14 cmol/kg of exchangeable Ca, 3 cmol/kg of exchangeable Mg, 1 cmol/kg of exchangeable K.

Table 1. Typical range of nutrients in manure from five species of livestock.a
Composition of manure varies widely with diet, animal age, lactation, and other factors.

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<th>Type Waste</th>
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<td>Cattle (steer)</td>
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<td><strong>Elements</strong></td>
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<tr>
<td>CP</td>
</tr>
<tr>
<td>N</td>
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<tr>
<td>Ash</td>
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<td>Zn</td>
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<tr>
<td>Se</td>
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<td>Mo</td>
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a Mineral composition of animal wastes, dry matter basis; Adapted from National Research Council (1983); Fontenot, 1981; ASAE standards, 1990, and Fontenot et al., 1996.

The negative charge associated with humus is pH dependent. Under very acid conditions the negative charge is not very high, however, under neutral to alkaline conditions the
charge associated with humus can exceed the charge of crystalline clays. In general, soils with high clay content retain nutrients better than soils with high sand content, and soils with a high silt content are between clay and sandy soils.

Similar to positively charged ions, negatively charged ions (anions), such as nitrate (NO$_3^-$), phosphate (PO$_4^{3-}$), and arsenate (AsO$_4^{3-}$) may also be adsorbed on some soil clay or humus. This is called anion exchange. Although adsorption of anions is not nearly as great as that of cations, it is nonetheless an important mechanism for retaining negatively charged ions. Many anions, (for example, phosphate and arsenate) can also be retained by forming insoluble compounds.

SOIL TESTING AND NUTRIENT RECOMMENDATIONS

Plants obtain fourteen elements essential for their growth from the soil. These elements are present in soil in water soluble and insoluble forms. The soluble fraction of nutrients are readily available for plant uptake, but only a fraction of the insoluble form of various elements is available for plant uptake.

The task of measuring the amount of water insoluble elements that can potentially become available for plant growth has been an area of intensive research. Soil scientists have developed chemical reagents to extract a fraction of the insoluble elements that is related to the amount that becomes available for plant uptake during a growing season. These measurements are used in conjunction with information from field and laboratory data to issue fertilizer recommendations for crop production.

OTHER NUTRIENT SOURCES

Meeting the challenge of nutrient management for animal based agriculture requires information on various input and outputs of nutrients on a regional scale such as:

- animal manures
- commercial fertilizers,
- legumes
- plant decomposition
- sewage sludge
- atmospheric deposition.
- Purchased feeds

Sewage sludge, for example, is a small source of nutrients on a state-wide scale, but may be quite significant for a particular farm. Similarly, one could consider livestock manure to be an input in both-large scale and field-scale analysis, whereas within an individual farm, manure serves as a temporary storage pool for nutrients that entered the farm in other sources. A number of researchers have developed nutrient budgets on state and/or national scales {National Research Council 1993 #526}

Nutrients are introduced into an agroecosystem from a number of sources. Quantification of the contribution of various sources represents a challenge to the agricultural scientists

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due to the complexity of the processes involved. A number of complex and often mutually exclusive processes are often involved. Utilization of nutrients contained in various organic fertilizers is accomplished through microbial conversion. Soil bacteria and fungi are important organisms in converting plant residues and manures into usable crop nutrients. These transformations include conversion of nitrogen-containing compounds into ammonium followed by conversion to nitrite and nitrate. Breakdown of organic nutrient sources takes considerable time with only a fraction of the applied nitrogen being available the first year. As a very broad generalization, approximately 50% of the total nitrogen applied will be available the first year with approximately half of the remainder available the next year. Actual mineralization rates are difficult to determine given the fact that this is a biological process that is sensitive to temperature and moisture ranges in the soil system. Estimates of nitrogen and phosphorus mineralization rates are needed to accurately determine application rates of organic nutrient sources (Gilmour, et al., 1996) as well as determining the availability of heavy metals that may be contained in the manure (Berti and L.W. Jacobs, 1996). The topic of nitrogen mineralization is addressed in more detail in other sections of this report.

An estimate of nutrients from fertilizer can be obtained from fertilizer sale data. The assumption is that fertilizers purchased in Minnesota are applied in the state. In this analysis we have estimated nutrients produced from animal manure in Minnesota by using the data on the number and species of animals. Chemical composition and storage aspect of animal manure has been addressed in the other sections of this report. No losses have been calculated for nutrients contained in manure, as data are not available on the proportion of various manure held in the various storage type. We assumed that volatilization of ammonia from manure likely re-enters the system (plants and soil) within state border, and assigned the source as manure. This assumption could be checked in future research.

Another important source of nitrogen for cropping systems in Minnesota is fixation of atmospheric nitrogen gas by legumes. A discussion on dynamics of legume fixation in Minnesota is presented here due to its ecological and economical significance in crop production in Minnesota.

**SYMBIOTIC NITROGEN FIXATION**

**Basic Concepts**

Legumes are the second largest family of seed plants in the world. Soybean, an annual grain crop, and alfalfa, a perennial forage crop, are the most widely grown legumes in Minnesota. Red clover, birdsfoot trefoil, and white clover are also grown for hay and pasture, while field peas, edible beans, and lupin are grown for grain. Legumes are noted for the production of grain and forage that contain significantly more protein than grasses (such as corn, wheat, oats, and other cereals, and forage grasses). Legumes also are appreciated for their ability to grow in the absence of nitrogen fertilizer inputs.

Legumes can convert atmospheric nitrogen gas (N₂) into protein for plant growth through a symbiotic process involving the plant and a specific bacterial partner. The plant
provides food energy generated by photosynthesis to bacteria that are located inside specialized root structures called nodules. In return, the bacteria convert atmospheric N$_2$ into inorganic nitrogen, which the plant converts to organic forms such as amino acids and proteins.

Legume species require specific bacteria for effective N$_2$ fixation and N production. For example, the bacteria nodulating alfalfa are *Sinorhizobium meliloti*, whereas *Bradyrhizobium japonicum* nodulates soybean. Therefore, a recommended management practice is to add the appropriate bacteria to legume seed before planting. In fields where the same legume species have been grown within 5 years, inoculation is not required because previously applied bacteria can survive for several years. However, with some environmental conditions, such as very low soil pH, addition of new bacteria is required with each legume planting.

Under optimum conditions, biological nitrogen fixation can provide the total nitrogen need of the plant and, in addition, can provide a net input into cropping systems. However, legumes typically also obtain nitrogen from the mineralized soil organic matter and fertilizer residues, so that the percentage of nitrogen in the plant derived from fixation usually ranges from 50 to 80%, depending on stand age, species, and soil nitrogen levels (Figure 1).

The diagram also shows that legume add new organic N from atmospheric nitrogen fixation to the soil during growth, the amount being regulated in part by available soil N supply.

**Legume Nitrogen Contribution**

What is the actual amount of N$_2$ fixation by legumes? This amount often is estimated using only the harvested forage or seed. Because both of these plant tissues usually have high nitrogen (protein) concentrations, much of the nitrogen in the plant is removed from the field. Typical numbers from the scientific literature are shown in Table 2. Differences in N$_2$ fixation among legumes are related to differences in biomass production, biomass nitrogen concentration, effectiveness of the symbiosis, and environmental factors, such as nitrogen supply from the soil, fertilizer, or manure.

These estimates are based on a variety of experiments using different techniques. There is a need to develop a better understanding of atmospheric N fixation by legumes in Minnesota with respect to the varying amounts of available N in the soil.

Harvested forage and seed often are used on the farm as feed for livestock. Thus, the fixed nitrogen is partly used to produce animal products and much of this feed nitrogen is excreted in manure. This manure is spread on the fields, returning some of the fixed nitrogen to the soil.

However, legumes also have direct effects on the amount of soil nitrogen present on the farm. Several factors influence the potential level of legume nitrogen contribution to soil nitrogen reserves:
The $N_2$ fixation capacity of the legume species (Table 2).

![Figure 1](image.png)

**Figure 1.** Schematic showing how the amount of soil nitrogen available to a grass crop (G) regulate growth and total N in the crop, whereas it simply alters the amount of fix vs. soil N in a legume crop (L), with little effect on yield or total N uptake.

Table 2: Typical amount of reported $N$ fixation by legumes in Minnesota and surrounding states.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Fixation (lb/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa</td>
<td>130 - 200</td>
</tr>
<tr>
<td>White clover</td>
<td>115</td>
</tr>
<tr>
<td>Red clover</td>
<td>75 - 132</td>
</tr>
<tr>
<td>Birdsfoot trefoil</td>
<td>50 - 115</td>
</tr>
<tr>
<td>Soybean</td>
<td>68 - 135</td>
</tr>
</tbody>
</table>

The quantity of legume residues remaining in the soil. Only a portion of the nitrogen in legumes typically remains in the soil, after harvest of forage or grain. Roots and other plant parts that are not harvested remain in the field, as are plant parts that die during the year.

The nitrogen concentration in plant residues. Crowns and thick roots of legumes like alfalfa contain lower nitrogen concentrations that the foliage, whereas the small diameter roots have similar nitrogen concentrations as foliage (Dubach and Russelle, 1994)

The proportion of symbiotically fixed $N_2$ in the residues. An equal or lower proportion of fixed nitrogen is found in roots than in foliage of legumes like alfalfa and its relatives (Lory, et al., 1992; Zhu, et al., 1991; Zhu, et al., 1998).

**Quantifying the Nitrogen Contribution by Alfalfa and Soybean**
With normal alfalfa production, most of the foliage is removed in three or four harvests per year. Given a yield of 3.8 tons of forage per acre with 18% crude protein concentration, about 188 pounds of nitrogen are removed from each acre. Based on Minnesota research, about 60 to 80% of this nitrogen comes from the atmosphere (112 to 150 pounds per acre); the remainder (38 to 76 pounds per acre) is absorbed from the soil. Leaf loss during growth and harvest is often 20% or more per year, and alfalfa also loses and then replaces 30 to 50% of its small roots per year (Dubach and Russelle, 1994; Goins and Russelle, 1996). Both of these tissues contribute nitrogen to the soil, with some of that being re-absorb by the alfalfa crop itself. For alfalfa grown in climates like we have in Minnesota, this contribution results in a net buildup of 50 lbs of nitrogen per acre each year of alfalfa growth (Peterson and Russelle, 1991).

If soil nitrogen content increases by 50 pounds per acre and between 38 and 76 pounds of soil nitrogen are removed in alfalfa forage, then alfalfa must add 88 to 126 pounds of nitrogen from the atmosphere to the soil each year. This means that total biological nitrogen fixation by alfalfa must be at least equal to the fixed nitrogen removed in foliage plus the amount of fixed nitrogen added to the soil 238 pounds per acre in this example. The amount of fixed nitrogen added to the soil can be greatly increased if part of the foliage is incorporated before growing the next crop.

**Figure 2.** Schematic diagram of the annual amount of fixed N contributed by alfalfa to Minnesota soils (Peterson and Russelle, 1991). Each number represents millions of pounds (for e.g., 20 million pounds of N originally fixed by alfalfa or in the milk produced by Minnesota dairy cows.

Alfalfa is grown on about 1.4 million acres in Minnesota with a production of about 5.3 million tons of forage (assuming an average yield of 3.8 tons per acre). In an analysis conducted by (Peterson and Russelle, 1991), alfalfa fixed over 400 million pounds of
nitrogen annually, and resulted in a net annual increase of soil nitrogen of about 174 million pounds. In addition, they concluded that about 220 million pounds of fixed nitrogen was returned to the soil via manure. A critical assumption in their calculation is the estimation of 50 pounds of fixed N being added each year of alfalfa when a stand is maintained about 3.5 years. There is relatively little data in the literature to support this assumption, and it is not known how different amounts of available N in soil alters net nitrogen fixation by alfalfa or other legumes (Figure 2).

In contrast, growth and harvest of a soybean crop may actually result in a decline in soil nitrogen. When 35 bushels of soybean per acre are harvested, the export of soil-derived nitrogen in the seed may substantially exceed that of the symbiotically-derived nitrogen in the residue that is returned to the soil (Heichel and Barnes, 1984). On a high organic matter soil in Minnesota, when soybeans obtained about 40% of the nitrogen from symbiosis and 60% from the soil, a nitrogen deficit of about 80 pounds per acre resulted from growing this crop. While the proportion of grain and herbage nitrogen derived from symbiosis may increase on soils with low or medium organic matter concentration, it is apparent that on many soils soybeans do not contribute a significant amount of fixed nitrogen to the soil, other than indirectly when they are fed and the manure is spread on the field.

**Legume N Contributions to Crop Rotations**

Legumes like alfalfa traditionally have been used to supply nitrogen for cereal crops in crop rotations. For example a traditional 5-year rotation involving alfalfa would consist of alfalfa seeded with oats in year 1, 2 years of alfalfa, and then 2 years of corn. In this system, the alfalfa would be harvested or grazed for livestock feed and the corn crops utilize the residual nitrogen in the fourth and fifth year. Very little fertilizer nitrogen is needed in this cropping system. A commonly used rotation in western and southern Minnesota is to alternate corn and soybean each year. Soybean is not very efficient in fixing nitrogen from the air, so nitrogen fertilizer requirements for corn are higher in this case.

The contribution of nitrogen that legume crops make to subsequent crops is usually expressed in terms of the 'nitrogen fertilizer replacement value' or 'nitrogen credit.' This credit is the amount of fertilizer nitrogen that the farmer can withhold and still produce optimum yields of the non-legume. In Minnesota, fertilizer replacement values the first year after alfalfa range up to 150 pounds per acre, while soybean usually can replace 40 pounds. If the alfalfa stand was very good before rotating to another crop, a second year credit of up to 75 pounds of nitrogen per acre can be taken.

Although nitrogen fertilizer replacement value is used in adjusting recommended nitrogen fertilization rates, it does not accurately reflect the actual nitrogen addition legumes make. To illustrate this, consider that a small grain crop, such as wheat, also is given a nitrogen fertilizer credit under typical conditions. If the stubble was tilled in during the summer before corn is grown, about 40 pounds less nitrogen is needed per acre of corn, because the nitrogen released from soil organic matter after the small grain harvest is available to the next crop.
In conclusion, legumes make a very high contribution of nitrogen to Minnesota. If about 30% of the alfalfa is rotated to corn each year and a modest nitrogen fertilizer credit of 100 pounds per acre were taken the first year, then alfalfa reduces the need for nitrogen fertilizer by about 36,000 tons and saves farmers over $15 million dollars. It is well documented by surveys conducted by the Minnesota Department of Agriculture and other studies that farmers and their advisors do not credit legumes as much as they should. The same is true for manure, despite long-standing efforts to educate both groups. This is one area that may require enhanced means of motivating a change in behavior.
The main source of this section are the Glossary of Soil Science Terms (SSSA, 1997), the Resource Conservation Glossary (NRCS, 1982), and the Manure Management Practices for the Minnesota Pork Industry (Schmidt and Jacobson, 1994).

**Aerobic**- Occurring in the presence of molecular oxygen (said of chemical or biochemical processes such as aerobic decomposition)

**Ammonia**- the nitrogen component of the gas (NH₃) released by the microbiological decay of plant and animal proteins. Loss of ammonia to the atmosphere is commonly referred as “ammonia volatilization”.

**Ammonium**- ion (NH₄⁺) form when ammonia gas comes in contact with water. Ammonium binds tightly to soil particles and is not typically leached into the ground water.

**Anaerobic**- occurring in the absence of free oxygen (such as biochemical process).

**Broadcast**- the spreading of manure on top of soil surface.

**Chelates**- Organic compounds that can bind with metals to increase the soluble fraction of some metals.

**Composting**- a controlled biological process, which converts organic constituents, usually wastes, into humus like material, inert, safe and suitable for use as soil amendments or organic fertilizer.

**Deep pit**- a deep (6-8 feet) storage area directly below an animal confinement building.

**Denitrification**- the chemical or biological process in which nitrate or nitrite is reduced to gaseous nitrogen.

**Earthen basin**- a large hole dug in the ground, typically lined with clay or some synthetic material, in which manure is stored. The basin is emptied at least once per year.

**Facultative**- having or occurring in the presence or absence of free oxygen.

**Fertilizer**- any organic or inorganic material of natural or synthetic origin that is added to a soil to supply one or more plant nutrients essential for the growth of plants.

**Flushing system**- a flushing system is a manure collection system that uses large volumes of water flowing down shallow gutters to scour and clean the dung area several times per day. The shallow gutters can be open gutters or gutters under open flooring.

**Gravity drain**- a system where manure is temporarily collected in shallow gutters under a
slotted floor. The gutters are drained on occasion by means of a plug or valve. Manure then drains or is pumped to a long-term storage area.

**Ground water**—the supply of fresh water that forms a natural reservoir under the earth’s surface.

**Immobilization**—the conversion of an element (e.g. nitrogen, phosphorus, etc.) from the inorganic form to various organic compounds in microbial or plant.

**Incorporation**—the tilling of the soil after the broadcasting of the manure to move the manure from the surface of the soil to under the soil surface.

**Injection**—the application of manure underneath the soil surface.

**Inorganic nitrogen**—nitrogen in the form of ammonia, ammonium, nitrate, nitrites, nitrogen gas or nitrogen oxides.

**Lagoon**—a treatment structure, typically earthen, for agricultural wastes. A lagoon can be aerobic, anaerobic, or facultative depending on the loading and design. Lagoon can be one stage or multi-staged. An anaerobic lagoon is different from earthen storage in that the lagoon is managed to allow for treatment of the manure. Anaerobic lagoons are only partially pumped each year (approximately one third of the total volume) whereas earthen storages are emptied once or twice a year.

**Leaching**—the removal of soluble materials, such as nitrates or chlorides, from soils or other material via water movements.

**Manure**—manure is the fecal and urinary excretion of livestock and poultry. Often referred to as livestock manure, this material may also contain bedding, spilled feed, water or soil. It may also include wastes not associated with livestock excreta, such as milking center wastewater, contaminated milk, hair, feathers, or other debris (ASAE, 1998). Manure is stored until it is recycled to cropland or treated so it may be recycled for uses such as potting soil, compost for gardens, and other off farm uses.

**Nitrate (NO$_3^-$)**—the nitrogen component of the final decomposition product of the organic nitrogen compounds. Nitrate is extremely water-soluble and is negative charge excludes it from adsorption on to soil particles. This characteristic renders it highly susceptible to leaching.

**Nitrification**—the biological oxidation of ammonium to nitrite and nitrate.

**Nitrite (NO$_2^-$)**—nitrite is an intermediate product in the conversion of ammonium to nitrate. Nitrite is extremely unstable (nearly immediately converting to nitrate) and therefore is rarely detected in groundwater.

**Nitrogen cycle**—the succession of biochemical reactions that nitrogen undergoes as it is converted to organic or available nitrogen from the elemental form. Organic nitrogen in waste is oxidized by bacteria into ammonia (NH$_3$). If oxygen is present, ammonia is
bacterially oxidized, first into nitrite (NO$_2^-$) and then into nitrate (NO$_3^-$). If oxygen is not present, nitrate and nitrite are bacterially reduced to nitrogen gas, completing the cycle.

**Nutrients**- elements or compounds essential as raw material for organism growth and development. For plant growth, seventeen elements have been found to be universally essential, three mostly from air and water (carbon, hydrogen, oxygen) and fourteen from soil solids (nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, manganese, boron, molybdenum, copper, zinc, chlorine, and cobalt)(Brady, 1984). Six of the fourteen (nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur) are used in relatively large amounts by plants and so called **macronutrients**. The other eight, even though as just essential as the macronutrients, are required in such a small quantities, thus so called **micronutrients**

**Odor**- foul scent or aroma. Most odors emanating from manure are due to decomposing manure.

**Organic matter**- the organic fraction of plant, animal, and microorganisms at various stages of decomposition.

**Organic nitrogen**- nitrogen in the form of urea, protein, or amino acids.

**Phosphorus**- one of the primary nutrients required for the growth of plants. Phosphorus is often delimiting nutrient for the growth of aquatic plants or algae in lakes and rivers.

**Pollutant** - any introduced substance that limits a resource use for a specific purpose.

**Pollution** - the condition caused by the presence in the environment of substances of such character and in such quantities that the quality of the environment is impaired or rendered offensive to life.

**Eutrophication**- a means of aging of lakes whereby aquatic plants are abundant and waters are deficient in oxygen. The process is usually accelerated by enrichment of water with surface runoff containing nitrogen and phosphorus.

**Runoff**- the portion of precipitation or irrigation water on an area that does not infiltrate, but instead is discharged from the area by flows across land surface or subsurface and eventually appeared in streams and other water-bodies.

**Scraper system**- a system of removing manure from a shallow gutter by means of blades scraping the gutter surface.

**Settling basins**- a concrete or earth bottom settling structure where the solid in runoff or the waste settles out.

**Slotted floor**- floor in a facility that has open spaces to allow manure and other waste material to pass through.

**Stock pile**- long term solid manure storage.
LITERATURE REVIEW

MANURE STORAGE AND HANDLING

The main source of this review on manure storage and handling (from on Animal Manure Production and Characteristics to section on Manure Storage) is the Mid West Plan Service (MWPS) Publication No. 18, Livestock Waste Facilities Handbook MWPS (1985). This section is intended to provide background on basic storage and handling techniques for readers without farming familiarity. MWPS is sponsored by the 12 land grant universities in the North Central Region to produce extension educational materials addressing a range of engineering issues related to agriculture that are common to the 12 states. Materials are intended for producers, consultants, extension educators, contractors, and equipment suppliers. MWPS No. 18 Livestock Waste Facilities Handbook is the most recent comprehensive summary of current technologies in use or applicable to Minnesota. Basic handling and storage techniques have not changed since 1985. Comments on specific Minnesota circumstances are based on the expert opinion of the storage and handling subgroup that prepared this document.

Animal manure utilization technology is subject to regulation (local, state, and federal). In Minnesota, the feedlot ordinance is administered by the Minnesota Pollution Control Agency (MPCA). In the ordinance, the MPCA is to regulate proper collection, storage, and land application of manure (MPCA, 1998a).

Besides regulations, manure utilization technology is also influenced by factors such as

- farm (size, soil type, typography, crops);
- operation (size and type, capital, mechanization level, owner preferences);
- climate (precipitation, temperature norms, prevailing winds);
- livestock management;
- animal (species and ration);
- manure characteristics; and
- local changes in human population and land use.

System selection is based on economics, engineering, public reaction and regulation, and numerous factors related to agriculture and the operation.

Manure can be handled and stored as a solid, a semi-solid, or liquid. The amount of bedding or dilution water influences the form. In turn, besides the quantity and properties of manure, manure form influences the selection of collection and spreading equipment and the choice of storage type.

Animal Manure Production and Characteristics

The properties of manure depend on several factors:

- animal species;
ration digestibility;
- ration protein and fiber content;
- animal age;
- environment; and
- animal productivity.

An overview of fresh manure properties (physical properties, nutrients, heavy metals, and bacteria) across animal species by a common unit of livestock mass/day is shown in Table 3. The standard deviation of manure output and nutrient composition indicates the challenges of defining standard manure properties as they can be influenced by many factors. Production and nutrient content of manure by subsets of animal size within species are shown in Table 4, focusing on N, P, and K output. This table describes manure production in units that can be applied to nutrient management and for sizing manure storage systems. A large portion of N, P and K from feed is excreted in the manure, which is then available for whole-farm nutrient recycling through the soil, plant, and animals. The range of N, P, and K in excreted manure expressed as a percentage of input are generally 70-80% N, 60-85% P, and 80-90% K of that fed to animals are excreted in the manure (Moore and M.J. Gamroth., 1993).

In addition, whatever system is in place, a key fact is that 100% of excreted manure is seldom recovered due to physical losses on the farm. A recent survey (NRCS, 1995) of Midwest confinement livestock farms, NRCS indicated that percentages of manure (feces and urine) recovered the highest in cage layers and broiler units (95%). Eighty percent was recovered in lactating dairy cow units, but only 60% from other units on the dairy farm. In beef feeder units, 75% of the manure was recovered. Confined swine and turkey units had 70% recovery rates. Only 35% was recovered from sheep units.

Grazing animals will distribute the majority of their manure within the pasture system, so recovery for field application is not necessary, but some manure may be recoverable inside loafing barns, milking barns, and feeding areas. One of the major factors contributing to animal manure output and composition is the feeding regimen and digestibility of the feed nutrients. A good example would be the changes in a typical lactation of a dairy cow. Daily and annual excretion estimates of various fractions and nutrients by Holstein dairy cows are shown in Table 5 (Van Horn, et al., 1996). This example represents a cow producing 18,150 lbs. milk per lactation which is close to the average level found in Minnesota herds that are on the Dairy Herd Improvement Association (DHIA) program, and also close to the average production reported by dairy farmers in a Minnesota survey (Russelle, 1999). As milk production increases the total amount of manure and the ratio of urine to feces increases. The digestibility of the feed averages 62% in this example with 38% of the dry matter intake (DMI) excreted. The example shows the effect of feeding varying dietary protein, P, K, Ca, and Mg levels. It also shows typical outputs of Na and Cl.

Efforts are underway to find ways of improving the efficiency of utilization of dietary nutrients and reduce manure excretion rates in all animal systems. Feeding 0.6% vs. 0.4%
Table 3. Fresh manure production and characteristics per 1000 kg (2200 lb) live animal mass per day.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units~</th>
<th>Animal Types</th>
<th>Dairy</th>
<th>Beef</th>
<th>Veal</th>
<th>Swine</th>
<th>Sheep</th>
<th>Goat</th>
<th>Horse</th>
<th>Layer</th>
<th>Broiler</th>
<th>Turkey</th>
<th>Duck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Manure *</td>
<td>kg</td>
<td>Mean SD</td>
<td>86</td>
<td>58</td>
<td>84</td>
<td>24</td>
<td>40</td>
<td>41</td>
<td>51</td>
<td>64</td>
<td>85</td>
<td>47</td>
<td>110</td>
</tr>
<tr>
<td>Urine</td>
<td>kg</td>
<td>Mean SD</td>
<td>26</td>
<td>18</td>
<td>39</td>
<td>**</td>
<td>15</td>
<td>**</td>
<td>10</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Density</td>
<td>kg m⁻³</td>
<td>Mean SD</td>
<td>990</td>
<td>100</td>
<td>0.13</td>
<td>0.052</td>
<td>0.010</td>
<td>0.16</td>
<td>0.24</td>
<td>0.45</td>
<td>2.7</td>
<td>1.3</td>
<td>15</td>
</tr>
<tr>
<td>Volatile Solids</td>
<td>kg</td>
<td>Mean SD</td>
<td>12</td>
<td>2.7</td>
<td>3.2</td>
<td>2.6</td>
<td>5.2</td>
<td>2.1</td>
<td>11</td>
<td>3.5</td>
<td>1.0</td>
<td>1.4</td>
<td>12</td>
</tr>
<tr>
<td>Biochemical oxygen demand, 5-day</td>
<td>kg</td>
<td>Mean SD</td>
<td>1.6</td>
<td>0.75</td>
<td>1.7</td>
<td>1.7</td>
<td>3.1</td>
<td>**</td>
<td>1.2</td>
<td>**</td>
<td>1.7</td>
<td>**</td>
<td>2.1</td>
</tr>
<tr>
<td>Chemical oxygen demand</td>
<td>kg</td>
<td>Mean SD</td>
<td>11</td>
<td>2.4</td>
<td>3.7</td>
<td>2.7</td>
<td>5.3</td>
<td>**</td>
<td>2.5</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>pH</td>
<td>kg</td>
<td>Mean SD</td>
<td>7.0</td>
<td>0.45</td>
<td>8.1</td>
<td>7.0</td>
<td>7.5</td>
<td>**</td>
<td>**</td>
<td>**</td>
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<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Total Kjedahl Nitrogen&lt;</td>
<td>kg</td>
<td>Mean SD</td>
<td>0.45</td>
<td>0.096</td>
<td>0.034</td>
<td>0.073</td>
<td>0.045</td>
<td>0.021</td>
<td>0.11</td>
<td>0.12</td>
<td>0.016</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Ammonia Nitrogen</td>
<td>kg</td>
<td>Mean SD</td>
<td>0.079</td>
<td>0.083</td>
<td>0.12</td>
<td>**</td>
<td>0.27</td>
<td>**</td>
<td>0.45</td>
<td>0.45</td>
<td>0.063</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Total Phosphorus</td>
<td>kg</td>
<td>Mean SD</td>
<td>0.094</td>
<td>0.024</td>
<td>0.16</td>
<td>0.052</td>
<td>0.066</td>
<td>0.18</td>
<td>0.071</td>
<td>0.071</td>
<td>0.081</td>
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<td>**</td>
</tr>
<tr>
<td>Orthophosphorus</td>
<td>kg</td>
<td>Mean SD</td>
<td>0.061</td>
<td>0.058</td>
<td>0.12</td>
<td>0.030</td>
<td>0.032</td>
<td>**</td>
<td>0.019</td>
<td>0.016</td>
<td>0.032</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Potassium</td>
<td>kg</td>
<td>Mean SD</td>
<td>0.29</td>
<td>0.27</td>
<td>0.32</td>
<td>0.15</td>
<td>0.32</td>
<td>**</td>
<td>0.25</td>
<td>0.18</td>
<td>0.091</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Calcium</td>
<td>kg</td>
<td>Mean SD</td>
<td>0.16</td>
<td>0.11</td>
<td>0.33</td>
<td>0.33</td>
<td>0.28</td>
<td>**</td>
<td>0.29</td>
<td>0.14</td>
<td>0.04</td>
<td>0.036</td>
<td>**</td>
</tr>
<tr>
<td>Magnesium</td>
<td>kg</td>
<td>Mean SD</td>
<td>0.071</td>
<td>0.016</td>
<td>0.37</td>
<td>0.047</td>
<td>0.072</td>
<td>**</td>
<td>0.057</td>
<td>0.016</td>
<td>0.064</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Sulfur</td>
<td>kg</td>
<td>Mean SD</td>
<td>0.051</td>
<td>0.005</td>
<td>0.044</td>
<td>0.043</td>
<td>0.055</td>
<td>**</td>
<td>0.022</td>
<td>0.14</td>
<td>0.057</td>
<td>0.085</td>
<td>**</td>
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<tr>
<td>Sodium</td>
<td>kg</td>
<td>Mean SD</td>
<td>0.052</td>
<td>0.026</td>
<td>0.030</td>
<td>0.067</td>
<td>0.078</td>
<td>**</td>
<td>0.036</td>
<td>0.010</td>
<td>0.036</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Chloride</td>
<td>kg</td>
<td>Mean SD</td>
<td>0.13</td>
<td>0.039</td>
<td>0.26</td>
<td>0.052</td>
<td>0.089</td>
<td>**</td>
<td>0.056</td>
<td>0.064</td>
<td>0.051</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Iron</td>
<td>g</td>
<td>Mean SD</td>
<td>12</td>
<td>6.6</td>
<td>8.1</td>
<td>9.7</td>
<td>16</td>
<td>**</td>
<td>8.1</td>
<td>4.8</td>
<td>4.2</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Manganese</td>
<td>g</td>
<td>Mean SD</td>
<td>1.9</td>
<td>0.75</td>
<td>1.4</td>
<td>1.4</td>
<td>2.8</td>
<td>**</td>
<td>2.1</td>
<td>1.8</td>
<td>2.2</td>
<td>2.1</td>
<td>**</td>
</tr>
<tr>
<td>Boron</td>
<td>g</td>
<td>Mean SD</td>
<td>0.71</td>
<td>0.35</td>
<td>0.61</td>
<td>0.30</td>
<td>1.2</td>
<td>**</td>
<td>1.8</td>
<td>**</td>
<td>1.7</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Molybdenium</td>
<td>g</td>
<td>Mean SD</td>
<td>0.074</td>
<td>0.012</td>
<td>0.028</td>
<td>0.030</td>
<td>0.083</td>
<td>**</td>
<td>0.033</td>
<td>0.057</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
</tbody>
</table>
Table 3. Continued

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units~</th>
<th>Animal Types</th>
<th>Dairy</th>
<th>Beef</th>
<th>Veal</th>
<th>Swine</th>
<th>Sheep</th>
<th>Goat</th>
<th>Horse</th>
<th>Layer</th>
<th>Broiler</th>
<th>Turkey</th>
<th>Duck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc</td>
<td>g</td>
<td>Mean SD</td>
<td>1.8</td>
<td>1.1</td>
<td>13</td>
<td>5.0</td>
<td>1.6</td>
<td>**</td>
<td>2.2</td>
<td>19</td>
<td>3.6</td>
<td>15</td>
<td>**</td>
</tr>
<tr>
<td>Copper</td>
<td>g</td>
<td>Mean SD</td>
<td>0.45</td>
<td>0.31</td>
<td>0.12</td>
<td>0.048</td>
<td>0.22</td>
<td>**</td>
<td>0.53</td>
<td>0.83</td>
<td>0.98</td>
<td>0.71</td>
<td>**</td>
</tr>
<tr>
<td>Cadmium</td>
<td>g</td>
<td>Mean SD</td>
<td>0.0030</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>0.0072</td>
<td>**</td>
<td>0.0051</td>
<td>0.038</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Nickel</td>
<td>g</td>
<td>Mean SD</td>
<td>0.28</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>0.62</td>
<td>0.25</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Lead</td>
<td>g</td>
<td>Mean SD</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>0.084</td>
<td>**</td>
<td>0.74</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Total coliform</td>
<td>colonies</td>
<td>Mean SD</td>
<td>1100</td>
<td>63</td>
<td>36</td>
<td>20</td>
<td>20</td>
<td>**</td>
<td>490</td>
<td>110</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Fecal coliform</td>
<td>colonies</td>
<td>Mean SD</td>
<td>16</td>
<td>28</td>
<td>27</td>
<td>18</td>
<td>12</td>
<td>**</td>
<td>0.092</td>
<td>7.5</td>
<td>**</td>
<td>1.4</td>
<td>**</td>
</tr>
<tr>
<td>Fecal streptococcus bacteria</td>
<td>colonies</td>
<td>Mean SD</td>
<td>92</td>
<td>31</td>
<td>28</td>
<td>530</td>
<td>58</td>
<td>**</td>
<td>59</td>
<td>16</td>
<td>**</td>
<td>590</td>
<td>**</td>
</tr>
</tbody>
</table>

Source: [ASAE 1998]

~All values wet basis; 1 kg = 2.2 lb; 454 g = 1 lb.
**Data not found.

*Differences within species according to usage exist, but sufficient fresh manure data to list these differences was not found. Typical live animal masses for which manure values represent are: dairy, 640 kg; beef, 360 kg; veal, 91 kg; swine, 61 kg; sheep, 27 kg; goat, 64 kg; horse, 450 kg; layer, 1.8 kg; broiler, 0.9 kg; turkey, 6.8 kg; and duck, 4.8 kg.
* Feces and Urine was voided.

{ Parameter means within each animal species are comprised of varying populations of data. Maximum numbers of data for each species are: dairy, 85; beef, 50; veal, 5; swine, 58; sheep, 39; goat, 3; horse, 31; layer, 74; broiler, 14; turkey, 18 and duck, 6.

< All nutrients and metals are given in elemental form.

# Mean bacteria colonies per 1000 kg animal mass multiplied by 10<sup>10</sup>. Colonies per 1000 kg animal mass divided by kg total manure per 1000 kg animal mass multiplied by density kg/m<sup>3</sup> equals colonies per m<sup>3</sup> of manure

P in the diet will require an additional acre of land per cow to dispose of manure and prevent potential P accumulation effects on the environment (Linn, 1994). Reduction of dietary P in dairy cow diets is becoming well accepted, and a dietary level of only 0.38% P appears to be adequate (Satter and Wu, 1999). At this level of phosphorus in the dairy cow diet, farmers have a better chance at avoiding P buildup in their soil (Powell, 1999). Proper balancing of total dietary protein and digestibility of protein for dairy cows at different production levels will help in controlling N excretion rates as indicated in Table 5. The amount of K excreted is becoming more critical from an animal health viewpoint, as high levels of K in manure are taken up by the plant and are returned in the forage fed...
to cattle. High K affects availability of other minerals, such as Mg and Ca, which can cause metabolic problems during the calving period.

Dairy farming in the Netherlands has seen some dramatic improvements of nutrient use as nutrient flow in soils, crops, forage, cattle and manure has been characterized the main components (Aarts, et al., 1992). This has continued throughout the decade. In beef, cattle, swine, and poultry much research in the last 5 years has been focused on nutrient management strategies to reduce nutrient excretion rates. More discussion of dietary effects can be found in the section on Manure Nutrient Accountability and Whole-Farm Balance.

Table 4. Production and nutrient content of manure from various farm animals

<table>
<thead>
<tr>
<th>Animal Species</th>
<th>Animal size, lb</th>
<th>Manure lb/day</th>
<th>Manure cu ft/day</th>
<th>Manure Gal/day</th>
<th>N lb/day</th>
<th>P lb/day</th>
<th>K lb/day</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dairy cattle</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>13</td>
<td>0.19</td>
<td>1.5</td>
<td>0.06</td>
<td>0.011</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td>250</td>
<td>22</td>
<td>0.32</td>
<td>2.4</td>
<td>0.11</td>
<td>0.023</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>43</td>
<td>0.66</td>
<td>5.0</td>
<td>0.22</td>
<td>0.047</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>89</td>
<td>1.32</td>
<td>9.9</td>
<td>0.45</td>
<td>0.094</td>
<td>0.29</td>
<td></td>
</tr>
<tr>
<td>1400</td>
<td>120</td>
<td>1.85</td>
<td>13.9</td>
<td>0.59</td>
<td>0.131</td>
<td>0.41</td>
<td></td>
</tr>
<tr>
<td><strong>Beef cattle</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>30</td>
<td>0.50</td>
<td>3.8</td>
<td>0.17</td>
<td>0.051</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>750</td>
<td>45</td>
<td>0.75</td>
<td>5.6</td>
<td>0.26</td>
<td>0.079</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>60</td>
<td>1.0</td>
<td>7.5</td>
<td>0.34</td>
<td>0.109</td>
<td>0.24</td>
<td></td>
</tr>
<tr>
<td>1250</td>
<td>65</td>
<td>1.2</td>
<td>9.4</td>
<td>0.43</td>
<td>0.12</td>
<td>0.31</td>
<td></td>
</tr>
<tr>
<td><strong>Beef cow</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>63</td>
<td>1.05</td>
<td>7.9</td>
<td>0.36</td>
<td>0.11</td>
<td>0.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Nursery pig</strong></td>
<td>35</td>
<td>2.9</td>
<td>0.038</td>
<td>0.27</td>
<td>0.018</td>
<td>0.0052</td>
<td>0.01</td>
</tr>
<tr>
<td>Growing pig</td>
<td>65</td>
<td>5.3</td>
<td>0.070</td>
<td>0.48</td>
<td>0.034</td>
<td>0.0099</td>
<td>0.02</td>
</tr>
<tr>
<td>Finishing pig</td>
<td>150</td>
<td>12.4</td>
<td>0.16</td>
<td>1.13</td>
<td>0.078</td>
<td>0.023</td>
<td>0.045</td>
</tr>
<tr>
<td>200</td>
<td>16.6</td>
<td>0.22</td>
<td>1.5</td>
<td>0.104</td>
<td>0.036</td>
<td>0.059</td>
<td></td>
</tr>
<tr>
<td>Gestating sow</td>
<td>275</td>
<td>11.3</td>
<td>0.15</td>
<td>1.1</td>
<td>0.069</td>
<td>0.023</td>
<td>0.04</td>
</tr>
<tr>
<td>Sow &amp; Litter</td>
<td>375</td>
<td>15.0</td>
<td>0.21</td>
<td>1.4</td>
<td>0.1</td>
<td>0.031</td>
<td>0.054</td>
</tr>
<tr>
<td>Boar</td>
<td>350</td>
<td>14</td>
<td>0.19</td>
<td>1.4</td>
<td>0.081</td>
<td>0.023</td>
<td>0.051</td>
</tr>
<tr>
<td>Sheep</td>
<td>100</td>
<td>4</td>
<td>0.062</td>
<td>0.46</td>
<td>0.045</td>
<td>0.0066</td>
<td>0.032</td>
</tr>
<tr>
<td>Poultry-layers</td>
<td>4</td>
<td>0.26</td>
<td>0.0035</td>
<td>0.027</td>
<td>0.0034</td>
<td>0.0012</td>
<td>0.0012</td>
</tr>
<tr>
<td>Poultry-broilers</td>
<td>2</td>
<td>0.17</td>
<td>0.0024</td>
<td>0.018</td>
<td>0.0024</td>
<td>0.0006</td>
<td>0.0008</td>
</tr>
<tr>
<td>Horse</td>
<td>1000</td>
<td>51</td>
<td>0.75</td>
<td>5.6</td>
<td>0.31</td>
<td>0.072</td>
<td>0.25</td>
</tr>
</tbody>
</table>

*Adapted from (Moore and M. J. Gamroth, 1993)*

**Manure Collection**

Selection of a collection system depends on

- type of facility;
- labor requirements;
- investment; and
- manure handling system.
### Table 5. Daily and yearly excretion estimates of various fractions and nutrients by Holstein cows.

<table>
<thead>
<tr>
<th>Daily milk and dry feed intake for:</th>
<th>Total for</th>
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<tbody>
<tr>
<td>0-30 days</td>
<td>31-70 days</td>
</tr>
<tr>
<td>71-205 days</td>
<td>206-365 days</td>
</tr>
<tr>
<td>Milk, lb/cow</td>
<td>Year</td>
</tr>
<tr>
<td>100</td>
<td>18,150</td>
</tr>
<tr>
<td>70</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Dry</td>
<td>14,462</td>
</tr>
<tr>
<td>Dry feed intake, lb/cow</td>
<td></td>
</tr>
<tr>
<td>55.8</td>
<td></td>
</tr>
<tr>
<td>46.3</td>
<td></td>
</tr>
<tr>
<td>39.2</td>
<td></td>
</tr>
<tr>
<td>25.2</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fraction or Nutrient</th>
<th>Excretion for cow described in column above</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lb/day</td>
</tr>
<tr>
<td></td>
<td>lb/day</td>
</tr>
<tr>
<td></td>
<td>lb/day</td>
</tr>
<tr>
<td></td>
<td>lb/day</td>
</tr>
<tr>
<td></td>
<td>lb/yr/cow</td>
</tr>
<tr>
<td>Raw manure (feces + urine)</td>
<td></td>
</tr>
<tr>
<td>195.0</td>
<td>160.0</td>
</tr>
<tr>
<td>125.0</td>
<td>100.0</td>
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<tr>
<td>70.0</td>
<td>60.0</td>
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<tr>
<td>21.2</td>
<td>17.6</td>
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<tr>
<td>17.7</td>
<td>14.7</td>
</tr>
<tr>
<td>0.899</td>
<td>0.727</td>
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<tr>
<td>1.030</td>
<td>0.846</td>
</tr>
<tr>
<td>0.408</td>
<td>0.308</td>
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<td>0.500</td>
<td>0.391</td>
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<tr>
<td>0.123</td>
<td>0.115</td>
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<tr>
<td>0.151</td>
<td>0.138</td>
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<td>0.235</td>
<td>0.208</td>
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<tr>
<td>0.296</td>
<td>0.265</td>
</tr>
<tr>
<td>0.242</td>
<td>0.217</td>
</tr>
<tr>
<td>0.382</td>
<td>0.333</td>
</tr>
<tr>
<td>0.102</td>
<td>0.086</td>
</tr>
<tr>
<td>0.185</td>
<td>0.155</td>
</tr>
<tr>
<td>0.145</td>
<td>0.127</td>
</tr>
<tr>
<td>0.197</td>
<td>0.178</td>
</tr>
<tr>
<td>Total N (NRC, low)(^1)</td>
<td></td>
</tr>
<tr>
<td>0.601</td>
<td>0.601</td>
</tr>
<tr>
<td>0.698</td>
<td>0.698</td>
</tr>
<tr>
<td>0.729</td>
<td>0.729</td>
</tr>
<tr>
<td>0.860</td>
<td>0.860</td>
</tr>
<tr>
<td>0.101</td>
<td>0.101</td>
</tr>
<tr>
<td>0.138</td>
<td>0.138</td>
</tr>
<tr>
<td>0.151</td>
<td>0.151</td>
</tr>
<tr>
<td>0.201</td>
<td>0.201</td>
</tr>
<tr>
<td>0.227</td>
<td>0.227</td>
</tr>
<tr>
<td>0.302</td>
<td>0.302</td>
</tr>
<tr>
<td>0.164</td>
<td>0.164</td>
</tr>
<tr>
<td>0.108</td>
<td>0.108</td>
</tr>
<tr>
<td>0.050</td>
<td>0.050</td>
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<tr>
<td>0.088</td>
<td>0.088</td>
</tr>
<tr>
<td>0.088</td>
<td>0.088</td>
</tr>
<tr>
<td>0.138</td>
<td>0.138</td>
</tr>
</tbody>
</table>

\(^1\) Adapted from (Van Horn, et al., 1996). Crude protein percent of total diet dry matter used in calculations for cows producing 100, 70, 50, and dry cows for “NRC (National Research Council -nutrient requirements for dairy cattle, 1989), low diets” were 16.0, 14.8, 13.8, and 11.0%, respectively. Respective crude protein percents for “NRC, high diets” were 17.5, 16.4, 15.3, and 12.0% of total diet dry matter.

Some systems combine collection and storage functions, such as built-up manure pack or slotted floors over a liquid tank. Slotted flooring refers to slats and perforated or mesh flooring. Slotted flooring rapidly separates an animal from its manure. Slotted flooring materials, spacing, and width depend on the manure properties and animal responses such as slipping and foot injury.
Manure collection depends on manure forms. Solid and semi-solid manure can be collected with tractor scrapers, front-end loaders, or mechanical scrapers. Liquid manure can be collected with scrapers, flushing systems, manure gutter, gravity flow channel, slotted floors, or recirculation flush pits.

For smaller operations, shallow manual gutters work well behind dairy stalls or under cantilever swine farrowing stalls. Manure is hand scraped from the gutter directly outside or into a sump or deep narrow collection gutter at the end. Mechanical scrapers can reduce manual labor depending on the storage method and the degree of cleanliness. Scrapers remove manure regularly, so building and livestock cleanliness are easier to maintain. These buildings have fewer odors than buildings with pits under slats because of frequent manure removal (at least once a day), but some ammonia is still released from the wet gutter surface. Types of scrapers are tractor-mounted blades, barn cleaners, underslat scrapers, and front-end loaders.

In a flush system, a large volume of water flows down a sloped, shallow gutter or alley. Deep narrow gutters were popular in the 1960s because they are usually self-cleaning. Thus odors are reduced because the manure is removed from the building before malodorous anaerobic bacteria have a chance to multiply. Gravity drain gutters are commonly installed in swine buildings under raised farrowing stalls and nursery decks with totally slotted floors. Recirculation flush pits are a modification of the gutter flushing concept to help alleviate pit odor problems in remodeled buildings, but they are also being installed in new swine, beef, and dairy buildings. Gravity flow channels are rectangular shaped channels with a flat, level bottom and a 6”-8” high dam at the outflow end. The main application has been tie stall and free stall dairy barns.

**Manure Transfer to Storage**

Transferring system selection depends on individual farm’s:

- manure characteristics;
- housing system;
- bedding practices;
- labor availability; and
- manure storage system.

Manure is transferred from an animal facility to storage with a large piston pump, pneumatic pump, centrifugal pump, gravity flow, or reception pit and pump. Mechanical pump transfer is very reliable. The success of a system depends on the careful matching of pump capabilities to manure characteristics. Gravity flow transfer uses the hydraulic head exerted by the relatively liquid manure to force the manure to flow. Little or no bedding should be in the manure. Reception pit and pump method refer to collection of manure in a small concrete pit and then pump it to an outside storage with a centrifugal chopper pump.
Manure Storage

Stored manure (a mixture of unused feed, bedding, water, feces, and urine) is usually kept in some sort of enclosure or container for a period of time. Fresh manure has less objectionable odor (Miner, 1975). During manure storage, however, significant odor is generated by anaerobic decomposition. The longer the manure is stored the greater the potential for gases and odors to become a problem. In Minnesota, storage of manure is almost always in the anaerobic state (Goodrich, 1999) and storage time is limited by Minnesota Pollution Control Agency regulations to a maximum of one year (MPCA, 1998b).

Cover

Storage may be covered or not covered. A cover may be a rigid structure: for example the building and roof that is constructed over a manure pit beneath a swine building. The rigid roof constructed of "T" beams on top of a liquid manure pit used to flush a swine building is another example of a covered storage. An impermeable membrane made of rubber, reinforced plastic, or even fiberglass may cover an above ground liquid manure storage. Examples of temporary covers on storage ponds are those using blankets of wheat straw, clay balls, or floating plastic (Jacobson, et al., 1998).

The decision to cover a storage is usually based on

- economics;
- siting requirements; and
- preference of the owner.

A covered tank will reduce odors around the farmstead. It will also reduce the amount of precipitation entering the tank resulting in a 15% to 20% reduction in volume to handle. However, a concrete cover may double the construction cost compared to an open top tank (Hilborn, 1995).

The liquid manure storage can be located directly under the barn or outside the barn. A fully slatted, storage under the barn is generally not recommended due to ventilation concerns and gas problems when agitating. To address this, many swine operations construct storage under the barn with a solid roof. On top of this roof, a 2’ deep fully slatted pit is constructed. The small pit is periodically emptied into the larger storage by opening a valve. This effectively avoids ventilation and gas problems associated with long term storage under the barn (Hilborn, 1995).

Uncovered storage examples are open storage ponds, open slurry tanks, mounds on feedlots, manure piles, and open manure pits. Wind moving across the surface will move more odors to the neighbors from uncovered than from covered manure, as a general rule (Zahn, et al., 1997). The drying effect on solid manure is sometimes a benefit, but rainfall usually offsets this advantage, given Minnesota conditions of equal evaporation and rainfall.
Considerations Prior to Building Storage

Storage design varies by state and locality because of climate, pollution control regulations, and decisions made by local jurisdictions.

A number of considerations must be addressed prior to building storage facilities. A person must evaluate site and soil conditions carefully to avoid contaminating ground and surface waters. Unlined storage should not be located over shallow fractured bedrock or below the water table. If shallow bedrock is present, a registered professional engineer or board of health should be contacted. Obviously, the site should be checked for buried utilities and drainage tiles. Storage basins in sandy or gravelly soils or other areas where serious leakage can cause groundwater pollution should also be avoided. The soil characteristics to a depth of at least 3' below the proposed storage bottom needs to be considered. A soil survey is helpful in evaluating a site. County extension personnel or NRCS staffs are qualified to help in site evaluation.

Storage facility location should consider all farmstead operations, building locations, and prevailing winds. At least 100 feet should be allowed between a water supply and the nearest part of storage. Dairy operators need to check with milk and health authorities for minimum spacing requirements between manure storage and milking facilities. Manure storage should be located, sized, and constructed for convenient filling and emptying, all weather access, and to keep out surface runoff.

Required storage capacity depends on

- regulations;
- number and size of animals;
- amount of dilution by spilled and cleaning water;
- amount of stored runoff; and
- desired length of time between emptying.

The designer should provide enough storage to spread manure only when field conditions, labor availability, weather and local regulations permit.

Handling large volumes of manure can delay other farm activities. Large manure storage facilities require many hours, usually over a period of several days, to remove material from storage and apply it to land. This job often comes at prime times for fieldwork. If spring application is required, the land is often not ready for manure spreader traffic before it is time to till and plant. Post-harvest spreading saves time during busy spring planting activities. It also provides a chance for winter freezing and thawing to lessen effects of soil compaction from the spreading operation. However, manure spreading in fall is not a best management practice in many areas of Minnesota, because of the increased risk of nitrate leaching loss.

Storage Design
We discuss storage design of liquid manure first, then solid manure, and finally semi-solid manure. This approximates the importance, and approximate volume of manure that exists in Minnesota at the present time (Goodrich, 1999).

**Liquid Manure**

**Liquid Manure Pits**

Liquid manure has become the most prevalent way of handling and storing manure for swine and dairy. Some chicken manure is stored as a liquid. The ability to use pumps to move the material and the reduction in volume of bedding used are two reasons that this has occurred in Minnesota (Goodrich, 1999).

For this discussion, liquid manure pits have vertical side-walls are lined, and are below grade. They may be either in a building under slats or solid floors or outside and usually separated from the building. Below ground storage can be used for semi-solid and liquid manure. Manure with up to about 15% solids can be agitated and pumped. Storage depth may be limited by soil mantle depth over bedrock, water table elevation, and possibly, effective pump lift.

Typical storage periods range from 5 to 12 months. The designer needs to provide capacity for dilution water, rain, snow, and milking center waste. Pits must be designed to withstand all anticipated earth, hydrostatic, and live loads, plus uplift if a high water table exists.

It is often necessary to dilute manure to aid pumping. Frozen manure, long fibrous material, and debris may require special pumping equipment. Sand and gravel cannot be pumped.

Liquid manure pits are used for storing swine manure beneath barns, swine manure outside of barns, liquid dairy manure beneath barns, liquid dairy manure outside barns, poultry manure beneath barns, and poultry manure outside barns. Liquid manure pits are sometimes also used beneath slatted beef barns. The pits outside of barns may or may not have covers.

Pits are sized to contain the manure for various sizes of animal units. Therefore they are really size independent. There are some economies of scale in that the cost per unit volume decreases as size goes up, but the cost per unit of storage is higher than earth basins. When the storage is beneath the building, a cover is on the pit, and the pit is used as the foundation for the structure, saving some cost.

However there is a large liability in having the mass of decaying material generating gases and odors that move into the building housing the animals and into the area where workers must be present for long periods of time. Severe safety problems can occur during agitation and cleaning of the pits that are located beneath buildings (Goodrich, 1999, Hilborn, 1995).
Ventilation problems occur when the pits get too full, when the mechanical ventilation systems fail, or the curtain systems fail to open properly. Even micro-bursts of gases from the decaying material in the pits may cause serious problems for the animals, which are located small distances above the bubbling anaerobic mass.

**Earth Storage Basins**

Earth basins are earth-walled structures formed by excavation and earth berm, so they are generally partly above and partly below grade. They may or may not be lined. Earth basins can extend the capacity of indoor pits or provide total storage needs. Earth basins provide long-term storage at low to moderate investment. They are designed and constructed to prevent ground and surface water contamination. They also eliminate the problem of hazardous gas entrapment and reduce the potential of fatalities. It is important to thoroughly evaluate site suitability, dike construction, and bottom sealing for any earthen basin.

Earth basin design is key to having a suitable storage that is environmentally sound. The design must keep the bottom of the storage at least 3’ above bedrock and at least 2’ above the water table, depending on local pollution control regulations. Soil characteristics must be studied to determine basin wall sideslope design. The contractor must follow accepted construction methods for sealing, building dikes, and bank seeding. In general, steeper inside banks conserve space, reduce rainfall runoff entering the basin, and leave less manure on banks as the basin is emptied. Inside bank slopes of 2:1 to 3:1 (run: rise) are common for most soils. The outside sideslopes should be no steeper than 3:1 for easier maintenance. The embankment should be wide enough (at least 12’) to mow and to get a tractor on for agitation. The engineer will determine the basin depth after considering the site, storage volume needed, groundwater conditions, and emptying equipment. A deeper basin requires less area for the same capacity as a shallow basin.

When placing concrete access ramps, a slope no steeper than 10:1 should be used for tanker or spreader access. A 5:1 slope is acceptable for tractor and pump access. Provide a rough surface for improved traction when wet. Deep groves or ridges (1” deep or more) across the ramp will assist traction.

Basins are either top- or bottom-loaded. Top-loaded solids pile up around the loading point, because the manure does not flow away, particularly in cold weather. Bottom loading pushes solids away from the inlet and distributes them evenly. Top loading methods usually are used on dairy farms and a barn cleaner extension is located so it can empty into the storage next to the barn. Freezing of manure machinery can be a problem. A shroud or an extension of the barn is often built over the extension to reduce the problems associated with the cold Minnesota winters.

A tractor scraper or loader can be used to push the manure out to the storage and into the storage. Sometimes there is a pileup at the push point and that can be a problem in freezing weather.
Bottom loading methods can be used with both liquid manure and semi-solid manure. Chopper-type liquid manure pumps may be used. A small sump and a chopper pump transport the manure to the storage basin. The pump chops long bedding material for easier pump-out later. If the sump is outdoors, pump freezing can be a problem.

Piston manure pumps can move manure through 10”-15” diameter PVC or steel pipe. The pump is usually in the barn and the storage may be up to 300’ from the barn. Pneumatic manure pumps use compressed air injected into a sealed tank to force manure through 12” diameter PVC pipe to the storage. Centrifugal and other liquid pumps can be used in manure characteristics allow. Liquids from milk houses, barn floor washing, etc. can be pumped into the storage, because it is a convenient way to store that material and dilutes the manure so that pumping to the field is easier.

Gravity loading storage below the level of barn does not need any pumps for loading. Manure is worked down into the storage by the animal hooves as they move about on slats. Slats are individual supports made of wood, plastic, or concrete. They have spaces between them, which allow the manure to pass into the pit below.

Liquid manure basins are used for storing swine manure outside of barns, liquid dairy manure outside barns, and poultry manure outside barns. Runoff from outside dairy and beef lots is often stored in basins and this is usually very dilute material. The pits outside of barns may or may not have covers. Those that have covers are much less likely to contribute strongly to odor problems.

The term "lagoon" is often used, but this is an incorrect term for these manure storage facilities. A lagoon is an earthen facility for the biological treatment of wastewater. It can be aerobic, artificially aerated, anaerobic or facultative depending on the loading rate, design and type of organisms present (ASAE, 1998).

Minnesota winter conditions slow biological treatment to such low levels for months. Therefore the term lagoon does not describe animal manure storage basins in Minnesota.

**Aboveground Manure Tanks**

Aboveground manure tanks are circular silo types or rectangular structures. They are more expensive than earth basins and are usually not used to store runoff or dilute manure. They are an excellent alternative where basins cannot be used due to site limitations, such as space constraints, shallow fractured bedrock, or where earth basins are not acceptable.

Aboveground tanks work well for enclosed buildings, but they are difficult to use for open lots because of the variation in manure consistency. In addition, an aboveground tank is too expensive to be used for runoff water from feedlots, which must be handled separately.
Construction options for aboveground tanks include concrete stave similar to that used for silo storage. The diameter of this type of construction is limited because of the shape of the staves and the strength of the steel bands used to hold staves in place.

Reinforced monolithic concrete structures are very durable. Lap or butt joint coated steel has been marketed by a number of companies and these have worked well for storage. Spiral-wound coated steel has not had good success in Minnesota because the coatings have not been durable.

The joint between the foundation and the sidewall can be a problem if improperly constructed. The reliability of the dealer and construction crew is as important as the tank material in assuring satisfaction. These tanks must have special safety devices to prevent back flow from the tank from escaping if there is a rupture in a valve or a malfunction of the pump system.

The engineer must size aboveground tanks for the manure volume, intercepted rainfall, and either milking center wastewater, if included, or added dilution water. The desired storage period should be determined based on when land and labor is available for land application. Next, the volume of manure that will accumulate over the storage period is calculated to determine the volume needed.

Some tanks are loaded with a large piston or a pneumatic manure pump through a large diameter underground pipe. Piston and pneumatic manure pumps can move material into storage that may be difficult to remove. With aboveground tanks, the operator should use little bedding or use only chopped bedding, and add extra dilution water to reduce agitation problems. Providing a water faucet at the pump will allow addition of dilution water during loading.

Aboveground liquid tanks are used for storing swine manure outside of barns, liquid dairy manure outside barns, and poultry manure outside barns. The tanks outside of barns may or may not have covers. Those that do have covers are much less likely to contribute strongly to odor problems.

The cost per unit of storage is slightly higher for aboveground tanks when compared with concrete below ground tanks. The additional pumping equipment needed to transfer from the barn to the tank is considerable and is somewhat expensive. Maintenance is an additional cost.

Pre engineered solutions are available for different sizes of storage. Covers are rather expensive and more difficult to apply and maintain because of the elevation above ground. European standards often require these types of storage for most operations, but they are not common in Minnesota except on dairy operations.

**Semi-solid Manure Storage**

Semi-solid manure is manure with excess liquids drained off and some bedding added to increase solids content. Solid manure has relatively large amounts of bedding added to
give it a stackable consistency. Both semi-solid and solid manure can be handled with equipment already present on many farms. Thus, semi-solid manure storage allows waste from many sources to be stored in one facility and handled with the same set of equipment. For example, dairy stanchion barns, calf pens, maternity pens, and young stock housing produce various consistencies of manure that can be handled in one semi-solid storage. Semi-solid storages can be an outside facility with picket dams to drain off rainwater or may be roofed structures.

The hauling schedule from a semi-solid storage facility is flexible. Storage can be designed for any period of storage, from a few days to several months. Whenever time allows, farmers can haul a few loads of manure without planning ahead to agitate the storage facility, as is required with liquid manure. Also less total material is hauled from storage, because no water is added.

If rainwater is drained from an uncovered storage, manure with semi-solid characteristics can be handled with loaders and endgate or flail-type spreaders. These drained storages allow a producer to deposit semi-solid manure in an uncovered storage and maintain semi-solid handling characteristics by draining off rainwater. All excess water (runoff from roofs, pads, etc.) must be kept out of the manure storage. A picket dam removes only rainwater that falls on the storage; it does not reduce the water content of the manure. Farmers should not expect to put slurry in and get a solid out. Dimensions of drained storages should be limited to 100 feet to enhance drainage.

The structure should allow rainwater to drain from the storage regardless of the manure level. A picket-type structure with continuous vertical slots about 3/4 inch wide between standing planks (pickets) holds manure solids back but allows liquids to drain through. Vertical slots work much better than horizontal slots. The storage should be loaded using a stacker, a piston pump of a type that does not require the addition of water during pumping, or a tractor push-off ramp.

Picket dams may be in earth storages, or in the walls of bunker-type storages having concrete or post-and-plank walls. The manure surface is highest at the loading point and slopes toward the surrounding earth walls. A channel for runoff water forms where the manure meets the earth dike. When a drainage structure is properly located, rain water runs off the crusted surface of the manure, flows around the edge along the channel formed between the manure and earth bank, and runs through the vertical slots of the structure. A channel should be maintained behind the picket for the liquids to drain away. It is critical to locate a picket dam anywhere water will accumulate. Dam length is not as important as location. One picket dam must extend 2/3 of the way up the ramp to drain water from the ramp.

These drained storages require that some bedding be added to the manure for convenient handling with spreaders having endgates. This storage method should not be used for sand-bedded free stalls.

The drainage water from the manure storage is polluted with microorganisms and nutrients and must be directed to a holding pond, a lagoon, or an infiltration area.
Semi-solid manure also can be stored in a roofed structure. The aboveground roofed storage system was developed for dairy comfort stall barns in high rainfall areas where large amounts of bedding are mixed with manure. However, some dairy producers are now building them for free stall barn manure, because new equipment designed for handling semi-solid manure is now available. The roof protects stored manure from rainwater to keep it as dry as possible. Manure in the storage crusts over, reducing odor and fly breeding problems. This system provides an aesthetically pleasing structure that appears to be another building on the farmstead. These storages are typically bottom-loaded using a large diameter piston pump. A hoist on a beam above the doorway lifts the planks from a bulkhead in one end of the building. Manure then flows over the bulkhead onto a cone slab where a front-end loader is used to fill a spreader. When all planks are removed, the loader can go inside the structure to remove the remaining contents. This type of storage is for dairy barns.

**SOLID MANURE STORAGE**

Solid manure storage is used where manure dries sufficiently or where enough bedding is added make it a stackable solid. This is a very popular type of storage for turkey growers and for chicken farmers, who have high rise buildings with superior ventilation rates, which dries the manure. Stacking systems for dairy manure also are observed frequently in Minnesota. Problems with flies are reported with stacking methods. The stacks are not usually covered in Minnesota and therefore are subject to rain and snow, adding considerably to the volume that must be handled at the end of the storage period.

**Positive and Negative Aspects of Current Storage Practices**

**Liquid Manure Pits**

How do current practices compare to past practices?

The modern reinforced concrete tanks with sufficient capacity for one-year storage are almost always installed in new construction of swine facilities. This contrasts strongly with former practices of shallow pits, which had limited storage capacity. These reinforced concrete tanks also have sufficient strength in the walls to properly withstand the soil and equipment pressures because they are designed by engineers and are installed by properly trained contractors.

The Minnesota State Auditor stated that the MPCA has adequate design standards for structures that store manure (MN State Auditor, 1999). This contrasts with former practice of untrained contractors installing what they thought was correct, with little design provided. An old practice used a clay soil to form the bottom of the tank.

Do current practices meet existing requirements?

Current engineered concrete tanks do meet the storage and water protection requirements. Proper drainage is also supplied to ensure that the tanks do not float. They are adequately sealed and located.
Which storage maximizes the positive aspects and minimizes the negative impacts of manure?

The use of reinforced concrete tanks gives the strongest and most leak proof storage. The larger storage volume however may increase the odor emissions since the manure is stored for a longer time than when the pits were smaller. The tanks reduce the amount of rainfall, which dilutes the manure and increases the volume needed to be applied to soil. The location of the large proportion of these tanks beneath buildings imposes additional hazards on the animals and workers in the buildings when they are agitated to remove the manure. As a result of this hazard, many tanks are not adequately agitated and solids accumulate from year to year and reduce the storage space.

**Earth Storage Basins**

How do current practices compare to past practices?

In the past (1970-1990) there were only a few outside storage basins and most of those were for runoff from beef lots and dairy lots. In the 1990s larger hog operations were built with some outside storage basins. Parker et al. (1999a) reported that seepage had exceeded the 6.1-m sampled depth under an unlined feedlot runoff pond. The seepage also exceeded the allowable Nebraska seepage rate following a rainfall event on a dry bottom pond.

Do current practices meet existing requirements?

A review of current state regulations from 17 states (not including Minnesota) showed a wide range of requirements for limiting seepage from storage basins (Parker, et al., 1999a). They further recommended that a risk based regulatory system be developed to answer the question "how much seepage is too much?"

The Minnesota State Auditor stated that the MPCA is monitoring about a dozen earthen basins constructed since the agency has toughened its standards in 1993 to gather information on the long-term adequacy of these basins. MPCA is also considering alternative ways of addressing concerns about potential leakage from unlined earthen basins installed before the standard were changed (MN State Auditor 1999).

Which storage maximizes the positive aspects and minimizes the negative impacts of manure?

Outside storage basins really have few positive aspects other than low initial construction costs. Maintenance costs are not minimal and they pose risk of groundwater and odor pollution (Parker, et al., 1999b). The negatives include collecting additional rainwater, increasing odors, reducing the amount of solids that can be recycled and being a hazard to safety of animals and persons.
Above-Ground Manure Tanks

How do current practices compare to past practices?

The above ground tank is a replacement for solid manure storage which had no containment and often was of insufficient size. The limited footprint and open top storage replace a much larger area and reduce the amount of rainfall that mixes with the manure.

Do current practices meet existing requirements?

The above ground tanks are engineered and meet requirements if sized sufficiently. There is protection against groundwater contamination and spillage if proper construction and operational schedules are maintained.

Which storage maximizes the positive aspects and minimizes the negative impacts of manure?

Above ground storage maximizes the storage volume per perimeter length. The rainfall collected is minimized. The cleaning out process is well mechanized. Sealing is done well and groundwater is protected. The limited and elevated surface layer may hold down the emissions of gases and odors. The manure is hidden in a structure, which is reasonably pleasing to see and thus may reduce complaints from people who pass, by the operation. Due to the head pressure created by having the liquid manure storage above ground, a leak in the piping at the bottom of the tank can cause the entire storage volume to be released in a very short period of time causing an environmental event. Adequate safeguards and inspections are needed to prevent such occurrences.

Semi-Solid Manure Storage

How do current practices compare to past practices?

The old way of storing semisolid manure outside of barns is much poorer than using the newer methods of semisolid storage. The newer methods provide a method to drain away liquids to separate storage areas and make the whole situation much better for the environment.

Do current practices meet existing requirements?

The newer methods do meet requirements for protection of groundwater. Stacking pads of concrete and structures to control and collect runoff contain the contaminated material and protect the water and soil.

Which storage maximizes the positive aspects and minimizes the negative impacts of manure?

Separation of liquids and solids make handling much easier and cleaner. The areas create less odors and environmental damage from excess nutrients and runoff into areas where the nutrients can cause damage.
Solid Manure Storage

How do current practices compare to past practices?

The old way of storing solid manure outside of barns on soil or near fields was much poorer than using the newer methods of solid storage. The newer solid slabs lower seepage and reduce potential pollution.

Do current practices meet existing requirements?

The newer methods do meet requirements for protection of groundwater. Stacking pads of concrete and structures to control and collect runoff contain the contaminated material and protect the water and soil.

Which storage maximizes the positive aspects and minimizes the negative impacts of manure?

Solid storage under roof, screened from view on a sealed floor maximizes the collection of nutrients and reduces the negative impacts of runoff.

MANURE HANDLING

Manure with 20%-25% solids content (75%-80% moisture content) can usually be handled as a solid, i.e. it can be stacked and can be picked up with a fork loader. Liquids need to be drained and the manure dried or bedding added to get solid manure. In the 10%-20% solids content, handling characteristics vary depending on the type of solids present. In this range, the percent solids content does not necessarily define handling characteristics. Manure with 4%-10% solids content can usually be handled as a liquid, but may need special pumps. Manure with 0%-4% solids content is handled as a liquid with irrigation or flushing consistency. Liquids, which have larger solids settled or filtered out or manure with dilution water added may have 4% or less solids. Manure that can be handled as a liquid are referred to as slurries.

Solid Manure-20% or more solids

Manure with 20% or more solids can usually be handled as a solid. Solid manure characteristics vary with the animal, ration, amount and type of bedding, time of year, and the amount of liquids separated from the solids. Manure collected in a settling basin can contain soil and debris.

Most solid manure spreaders are box-type. Others include flail-type spreaders, dump trucks, earth movers, or wagons. A spreader should distribute manure uniformly. Front-end loaders, scrapers and blades and several mechanical systems transport solid manures but are not usually used for spreading. Box-type spreaders are tractor-pulled or mounted on trucks. Spreader boxes are steel or wood and need to be watertight for road transport. Spreader mechanisms include paddles, flails, and augers. The feed apron, which moves
the manure to the spreader, is often variable speed. Some spreaders have moving front-end gates that push the manures to the spreading mechanism.

Flail-type spreaders are tanks with open tops and usually have a shaft mounted near the open top and parallel to the main axis of the tank. Chain flails on the shaft throw the manure out the side of the spreader as the shaft turns. Large spreader capacity reduces the number of trips to the field but can increase soil compaction.

**Semi-Solids-4% to 15% Solids**

Semi-solids with up to about 15% solids can be pumped. Solids and liquids separate in storage so agitate manure before pumping. Big gun sprinklers can spread manure with high solids content. Pipeline design is similar to that for dilute manure, except that each component is selected to handle more solids. Big guns handle any consistency up to that of thick milk. Manure solids can coat crop leaves, reducing photosynthesis and causing salt burns on leaves. Also, over application of semi-solid manure or manure draining from the pipe when detached can kill the crop in that area. Avoid applying semi-solid manure to a growing crop. If it is necessary to apply manure during crop growth, apply at minimal rates unless fresh water is also applied. For alfalfa, apply after hay cutting. For corn, do not apply when the plant is very young or during silking.

**Liquid Manure- <4% solids**

Manures with up to about 4% solids can be handled as a liquid. Liquids are spread on fields with tank wagons, or are pumped through large hoses to injectors mounted on toolbars where it is applied below the surface of the soil. Tractors pull these injectors. Fibrous materials, such as bedding, hair, or feed, can hinder pumping. If large quantities are handled, a pipeline may be preferred over tank wagons for transport. Prevent large solids such as ID tags, containers, lids, teeth, and hair from passing through the pump. Settle out solids if possible. For irrigation, provide a chopper ahead of the pump intake. Required pump capacity is influenced by amount of manures; time, labor, and power source available; labor and equipment costs; and for cropland disposal, the rate at which soil and crops can receive water. A small capacity pump is less expensive but may require more labor.

Liquid manure can be applied with irrigation system. Irrigation equipment land applies manure and also adds water and fertilizer to crops. Improved crop production from the water and the fertilizer value of manure can help pay for the manure land application system. For relatively large amounts of effluents, irrigation systems are economical and labor saving. As with any manure management system, there are potential problems.

- Odor problems can be severe, depending on the manure and management.
- Application of strong manures to crops may adversely affect plant growth or utilization.
- Fine-textured and tight soils may not have enough permeability to receive liquids rapidly.
Irrigation methods used are surface and sprinkler irrigation system. Surface spreading is an effective method of manure disposal. Manure water is delivered to the field through portable or stationary pipe and spread on fields with gated irrigation pipe or through an open ditch with siphon tubes or turnout gates. Surface irrigation is low cost and has low power requirements and few mechanical parts. However, it requires a high degree of management skill, is inflexible with respect to land area, and requires a moderate amount of labor. Surface systems require good design and management to avoid runoff and to get uniform distribution. Do not use them on land with greater than 2% slope. Before attempting surface spreading, contact a soil and water engineer to inspect the site and help you decide. Dissolved nutrients enter the soil with the liquids, but solids tend to settle out or be filtered out by grass near the inlet to the field. More nutrients and somewhat more liquid are absorbed at the high end of the slope.

Sprinklers allow land application on rolling and irregular land. Types of sprinkler systems are hand-move sprinkler, towline, stationary big gun, towed big gun, traveling big gun, center pivot system, sideroll system, and solid set system. Each system has its own advantage and disadvantages. Although initial and operating costs are generally higher for sprinklers than for surface systems, labor requirements are reduced, some systems can be automated, and application can be more uniform. Odors from sprinkled manure can create nuisances. Avoid sprinkling on days with high humidity or when wind blows odors to areas of concern. Select sprinklers and spacing to avoid runoff for the particular soil type, topography, crop, and application time. Select equipment to handle anticipated manure particle sizes with minimum plugging and maintenance. There is also data that suggests that air borne pathogens can also be a problem (NRAES, 1994 and 1996).

**Nutrient Losses During Collection, Storage, and Land Application**

The percentage of the original manure nutrient content retained in various storage systems by species is summarized in Table 6. The cost:benefit ratio of optimizing retention of manure nutrients under different storage structures or manure handling should be considered when upgrading or adding new facilities.

Bedding and water dilute manure, resulting in less nutrient value per pound. Much nitrogen can be lost to the air as ammonia. Runoff and leaching in open lots can remove nitrogen. There is much less nitrogen loss from compost pits, liquid storage systems, or roofed feeding areas. Nitrogen losses between excretion and land application are presented in Table 7.
Table 6. Percentage of original manure nutrient content retained in various storage systems

| Method          | Dairy |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
|-----------------|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Daily spread    | 80   | 90 | 90 | 65   | 90 | 90 | 75   | 90 | 90 | 75   | 90 | 90 | 75   | 90 | 90 | 75   | 90 | 90 | 75   | 90 | 90 | 75   | 90 | 90 |
| Dry + roof      | 70   | 90 | 90 | 60   | 90 | 90 | 65   | 90 | 90 | 60   | 90 | 90 | 65   | 90 | 90 | 60   | 90 | 90 | 65   | 90 | 90 | 60   | 90 | 90 |
| Earthen Storage | 55   | 60 | 70 | 65   | 80 | 85 | 60   | 70 | 65 | 60   | 70 | 65 | 60   | 70 | 65 | 60   | 70 | 65 | 60   | 70 | 65 | 60   | 70 | 65 |
| Lagoon /flush   | 30   | 40 | 60 | 65   | 80 | 85 | 25   | 40 | 60 | 30   | 40 | 60 | 30   | 40 | 60 | 30   | 40 | 60 | 30   | 40 | 60 | 30   | 40 | 60 |
| Open lot        | 60   | 70 | 65 | 60   | 70 | 60 | 60   | 70 | 65 | 60   | 70 | 60 | 60   | 70 | 65 | 60   | 70 | 65 | 60   | 70 | 65 | 60   | 70 | 65 |
| Pits + slats    | 75   | 95 | 95 | 75   | 95 | 95 | 70   | 95 | 95 | 75   | 95 | 95 | 75   | 95 | 95 | 75   | 95 | 95 | 75   | 95 | 95 | 75   | 95 | 95 |
| Scrape/storage  | 70   | 90 | 90 | 70   | 85 | 90 | 70   | 85 | 90 | 70   | 85 | 90 | 70   | 85 | 90 | 70   | 85 | 90 | 70   | 85 | 90 | 70   | 85 | 90 |

*a Adapted from Moore and Gamroth (1993 - National Data base)

Table 7. Typical losses between excretion and land application adjusted for dilution in the various systems. These values are in addition to land application losses.

<table>
<thead>
<tr>
<th>System</th>
<th>% Nitrogen lost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid</td>
<td></td>
</tr>
<tr>
<td>Daily scrape and haul</td>
<td>15-35</td>
</tr>
<tr>
<td>Manure pack</td>
<td>20-40</td>
</tr>
<tr>
<td>Open lot</td>
<td>40-60</td>
</tr>
<tr>
<td>Deep pit (poultry)</td>
<td>15-35</td>
</tr>
<tr>
<td>Liquid</td>
<td></td>
</tr>
<tr>
<td>Anaerobic pit</td>
<td>15-30</td>
</tr>
<tr>
<td>Above-ground storage</td>
<td>10-30</td>
</tr>
<tr>
<td>Earth storage</td>
<td>20-40</td>
</tr>
<tr>
<td>Lagoon</td>
<td>70-80</td>
</tr>
</tbody>
</table>

Adapted from MWPS (1985)

Table 8. Average nitrogen losses by method of application and manure type.

<table>
<thead>
<tr>
<th>Application method</th>
<th>Type of waste</th>
<th>% Nitrogen lost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadcast</td>
<td>Solid</td>
<td>15-30</td>
</tr>
<tr>
<td>Broadcast</td>
<td>Liquid</td>
<td>10-25</td>
</tr>
<tr>
<td>Broadcast with immediate</td>
<td>Solid</td>
<td>1-5</td>
</tr>
<tr>
<td>cultivation</td>
<td>Liquid</td>
<td>1-5</td>
</tr>
<tr>
<td>Knifing</td>
<td>Liquid</td>
<td>0-2</td>
</tr>
<tr>
<td>Sprinkler irrigation</td>
<td>Liquid</td>
<td>15-35</td>
</tr>
</tbody>
</table>

*a Adapted from MWPS (1985)
Phosphorus and potassium losses are negligible except for open lots or storage basins. About 20%-40% of the phosphorus and 30%-50% of the potassium can be lost by runoff and leaching in open lots. However, much of the P and K can be recovered by runoff control systems such as settling basins and holding ponds. Up to 80% of the phosphorus in storage basins can accumulate in bottom sludge and is not applied to land unless the sludge is removed.

Methods of application of manure are: broadcast (top dressed) with plow-down or disk ing, broadcast without plow-down or disk ing, knifed (injected under the soil surface), and Irrigated. The effects of manure application method and type of manure is shown in Table 8.

The greatest nitrogen response follows land application and immediate incorporation into the soil. Plow down solid manure as soon as possible to minimize nitrogen loss and to begin release of nutrients for plant use. Most losses occur in the first 24 hours after application, so incorporate manure into the soil as soon as possible. Injecting, chiseling, or knifing liquids into the soil minimizes odors and nutrient losses to the air and/or to runoff. Nitrogen loss as ammonia from land is greater during dry, warm, windy days than during humid or cold days. Ammonia loss is generally greater during the spring and summer months.

Poultry and veal calf manures are highly alkaline, so ammonia losses are greater than from other manures. It is especially important that poultry and veal calf manure be incorporated into the soil as soon as possible. Uniform application prevents local concentrations of ammonium or inorganic salts that can reduce seed germination and yields. Apply manure as near planting date as possible so more nutrients will be available to plants, especially in areas of high rainfall and with soils in which nitrate is lost by leaching or denitrification. Lowered germination and reduced seedling growth could occur, however, if planting takes place immediately after heavy manure applications because of high salt concentrations near the soil surface.

As an alternative, late fall or winter applications may be desirable because of greater labor availability and better soil trafficability. Even though fall-winter applications may result in a 25%-50% total nitrogen loss (from leaching and denitrification), fall applications allow soil microorganisms's time to more fully decompose manure and release nutrients for the following crop season. This is especially advantageous for solid manure, which contains high levels of organic matter.

**Minnesota Producers Using Manure Storage and Handling Systems**

The percentages of Minnesota producers using various manure systems are presented in Table 9. The table was developed by a panel from the Department of Biosystems and Agricultural Engineering, University of Minnesota with expertise in manure management systems. The process included a meeting to discuss the various systems and components within the systems. The percentages are represented in a range as this is the opinion of the panel without any scientific or survey data to verify these ranges.
Species of horse, sheep, goat, veal, and duck are not included. Percentages are by production units, not animal numbers. Percentages sum within each major category however may exceed 100% due to multiple systems within a production unit, e.g. outdoor lots with animal shelters which use both liquid and solid manure systems. All blank cells indicate less than one percent.

**Manure Management Handling and Storage Trends**

The following are manure management handling and storage trends in the last couple of years:

Collection

- Increased dietary refinement to decrease total manure voided and decrease nutrients in the manure.
- Increased use of water saving devices in washing and cleaning to decrease total manure-water output.
- Increased use of deep pits.
- Decreased use of gravity drain and high volume flush systems.
- Increased of solid flooring with increase use of straw bedding.
- Change in feeding systems to reduce feed wastage and to use less water.

Transfer Systems

- Decrease in manure moisture content to reduce cost of hauling for increased hauling distance.

Liquid – Solids Separation

Increase in handling liquids and solids separately, with the liquids being applied close to the source and the solids being transported further distances from the source.

Increase opportunity to reduce phosphorus application on near by fields by applying it at a further distance from the source.

Increased use of separation is limited by flow, separation efficiency, and costs.

Storage

- Increased covered storage either by deep pits under the barn or (naturally or artificially) covering of outdoor storage.
- Increased windbreak and landscaping use.
- Increased storage capacity to meet MPCA requirements and allow more flexibility for land application.

Treatment

- Increased interest in composting and handling as a solid.
Increased treatment is limited by the additional costs.

**Land Application**

- Increased injection and incorporation.
- Increased custom (commercial) manure applications.

Change cropping practices to accommodate increased usage of manure and improve timeliness of application.

Table 9. Estimated percentages of Minnesota producers using various manure systems, based on judgement of faculty who are experts in the field. No comprehensive survey of manure storage facilities is available for Minnesota.

<table>
<thead>
<tr>
<th>Collection</th>
<th>Dairy</th>
<th>Swine</th>
<th>Beef&lt;sup&gt;i&lt;/sup&gt;</th>
<th>Turkey&lt;sup&gt;j&lt;/sup&gt; Broiler</th>
<th>Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slotted flooring</td>
<td>3 - 10</td>
<td>60 - 85</td>
<td>1 - 3</td>
<td>&gt;99</td>
<td></td>
</tr>
<tr>
<td>Solid floors/manure pack</td>
<td>70 - 90</td>
<td>2 - 10</td>
<td>70 - 80</td>
<td>&gt;99</td>
<td></td>
</tr>
<tr>
<td>Manual scrape</td>
<td>20 - 40</td>
<td>1 - 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automatic scrape</td>
<td>50 - 60</td>
<td>1 - 4</td>
<td></td>
<td>&gt;99</td>
<td></td>
</tr>
<tr>
<td>Flushing (high volume)</td>
<td>1 - 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravity drain</td>
<td>5 - 15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pit-recharge</td>
<td>1 - 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unpaved lot runoff</td>
<td>20 - 40</td>
<td>1 - 4</td>
<td>70 - 90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paved lot runoff</td>
<td>20 - 30</td>
<td>2 - 10</td>
<td>20 - 30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transfer system to storage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slotted flooring to pit</td>
<td>3 - 10</td>
<td>60 - 86</td>
<td>1 - 3</td>
<td>&gt;99</td>
<td></td>
</tr>
<tr>
<td>Solid floor/manure pack</td>
<td>70 - 90</td>
<td>10 - 20</td>
<td>70 - 80</td>
<td>&gt;99</td>
<td></td>
</tr>
<tr>
<td>Reception pit and pump</td>
<td>45 - 60</td>
<td>5 - 15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravity drain - pipe</td>
<td>2 - 5</td>
<td>15 - 25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravity drain - surface</td>
<td>50 - 60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressure vessel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vacuum tank wagon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loader/skid steer</td>
<td>25 - 40</td>
<td></td>
<td></td>
<td>&gt;99</td>
<td></td>
</tr>
<tr>
<td>Liquid - Solids separation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>96 - 98</td>
<td>95 - 99</td>
<td>85 - 95</td>
<td>&gt;99</td>
<td>&gt;99</td>
</tr>
<tr>
<td>Settling tank</td>
<td>2 - 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Settling basin</td>
<td>1 - 2</td>
<td>1 - 2</td>
<td>5 - 15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Settling channel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical separation</td>
<td>1 - 2</td>
<td>1 - 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaporation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage</td>
<td>Dairy</td>
<td>Swine</td>
<td>Beef</td>
<td>Turkey Broiler</td>
<td>Layer</td>
</tr>
<tr>
<td>None/Minimal&lt;sup&gt;j&lt;/sup&gt;</td>
<td>20 - 40</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liquid</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pits</td>
<td>2 - 8</td>
<td>65 - 85</td>
<td>1 - 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Earthen basin</td>
<td>45 - 60</td>
<td>65 - 85</td>
<td>80 - 90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Above ground</td>
<td>2 - 8</td>
<td>1 - 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Semi-solid</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The Economic Liability of Manure Storage and Handling

The Minnesota feedlot ordinance requires every farm with at least 10 animal units to have an operating permit. There are over 40,000 farms requiring a permit, and each will need a
land application plan for manure as part of the permitting process (Levins, et al., 1996). The required proper storage, collection, and land application has reduced the economic value of manure. The economic value of manure is assumed to be the value of commercial fertilizer it could replace, minus storage, hauling, and application costs.

Farms need to have sufficient manure storage capacity to allow maximum flexibility in timing manure applications. When storage is inadequate, applications must be made without due consideration to likely losses or other adverse effects, such as soil compaction. Manure costs are largely tied to the costs of storage, which are directly related to storage capacity. As the capacity increases, costs also increase. Application costs increase with distance from the source, as well as total acres covered. This economic pressure (and the typically distasteful nature of manure handling) encourages application of higher manure rates closer to the farmstead. As animal concentrations increase, the distance from the source over which manure must be transported increases. This is the cost that ultimately limits the size of animal operations (Fleming, et al., 1998).

Thus far, agronomically-determined manure application rates generally have been designed to supply nitrogen to the following crop. There is increasing impetus to base the rate on crop phosphorus need, instead, at least for fields where runoff to surface water is a concern, and this typically doubles the amount of land required for manure application. Therefore, economic forces are sometimes at odds with the best environmental strategy.

The dis-economies of scale and disincentives for environmentally sound manure application are particularly problematic for dilute liquid manures, such as storage basin liquids, where large quantities of dilution water must also be transported to the field (Fleming, et al., 1998). Transportation costs are much less of an issue for solid manures where there is less water and thus less weight. Poultry manure, separated solids from dairy manure, and bedded manures such as swine manure from hoop structures all have a relatively high nutrient densities, and can thus be economically transported greater distances. Composting such manures reduces moisture, weight, and volume even more.

Addressing the disincentives to environmentally sound manure management does not come without costs, and the balance between benefits and cost is a major factor in on-farm manure management decisions. The greatest differences among manure management system alternatives are related to costs for manure storage, machinery, fuel, labor, and timeliness of operations (Harrigan, et al., 1996). Some of these costs, manure storages, represent significant capital investments that set the pattern for other manure management decisions, sometimes for a period of several decades, while others are more adaptable to evolving policy and economic incentives.

Example of costs associated with storage structure and storage capacity are presented in Table 10. Based on a summary of data from dairy farms in Wisconsin, (Frame, 1998) concluded that the cost of manure storage construction and barnyard improvements was about $65,000 per farm. He concluded that this unacceptably high cost was a barrier to farmers moving from daily haul systems.
Table 10. Comparison of costs for manure storage (MN NRCS, 1993, personal communication)

<table>
<thead>
<tr>
<th>Types of Storage Structure</th>
<th>Approximate cost/1000 gallon of storage capacity $^{\dag}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unlined (natural) earthen basin</td>
<td>36</td>
</tr>
<tr>
<td>Clay-lined earthen basin using clay on site</td>
<td>70</td>
</tr>
<tr>
<td>Clay-lined earthen basin using clay from an off-farm borrow site (varies with haul distance)</td>
<td>88</td>
</tr>
<tr>
<td>Earthen basin lined with plastic liner (geosynthetic membrane)</td>
<td>76</td>
</tr>
<tr>
<td>Earthen basin lined with concrete</td>
<td>88</td>
</tr>
<tr>
<td>Above-ground tank constructed with precast concrete</td>
<td>141</td>
</tr>
<tr>
<td>Round, above-ground tank constructed of poured in place concrete</td>
<td>163</td>
</tr>
<tr>
<td>Above-ground, glass-lined tank</td>
<td>198</td>
</tr>
</tbody>
</table>

$^{\dag}$ Cost estimates based on 50,000 gallon storage capacity. Cost per 1000 gallon will decrease significantly for larger storages.

The lowest cost of manure handling equipment is associated with daily hauling and the highest cost is associated with slurry injection. According to (Harrigan, et al., 1996), the highest net return is associated with short-term manure storage and frequent hauling; the lowest with long-term storage and slurry injection. Compared to slurry injection, net return on the 150-herd cow farm increased about $20, $28, and $78/cow-yr for slurry spreading, irrigation, and daily hauling, respectively. When odor is a concern, injection of the slurry car reduce odors, but increases handling costs (fuel, maintenance, and labor). According to this analysis, fuel use was greatest for slurry injection and the least for daily hauling with a V-tank spreader. Slurry injection and slurry spreading concentrated labor in the spring and fall, which caused delay in both tillage and planting and led to lower corn yield and higher feed costs. As might be expected, therefore, a recent survey of Minnesota dairy farmers (Russelle, 1999) indicated that most depend on daily or frequent manure hauling as their primary strategy for manure application, while liquid storage systems are of secondary importance.

Nearly 30 years ago, researchers at Cornell University (Casler and LaDue, 1972) concluded that conversion from daily hauling to a 6-month liquid manure slurry storage system would result in increased costs for the farmer, higher odor impacts during manure application, and uncertain reductions in water contamination. They recognized that many of the benefits from such storage systems are public rather than private. This realization has resulted in cost-sharing that is available to farmers from state and federal...
governments to support construction of manure storage facilities and physical barnyard improvements to prevent runoff.

Although most analyses have concluded that costs of manure storage and handling exceed the economic benefits, some have not. For example, considering dry manure from beef feedlots in Idaho, which involve minimal storage costs (Araji and Stodick, 1990) concluded that the cost of manure application was only 20 to 35% that of commercial fertilizer. Clearly, evaluations must be made on the basis of the livestock involved, storage system being considered, and mode of manure transportation that is available.

VALUE AND ENVIRONMENTAL IMPACTS

**Crediting Manure Nutrients: An Asset**

As commercial fertilizer has reduced the need for manure, the economic benefit of manure has been increasingly viewed only in terms of the direct benefit associated with the essential nutrients for crop growth. This typically is measured in terms of the fertilizer replacement value. For example, an application of 10 tons of solid beef manure to an acre of land reduces fertilizer nitrogen requirements by about 40 lbs. during the next cropping year, which would save the farmer about $10 per acre at present fertilizer prices, disregarding the cost of manure application. Such a calculation ignores other tangible benefits of manure.

Utilization of manure applied to land is accomplished through microbial conversion of plant residues and wastes into usable crop nutrients. Breakdown of organic nutrient sources takes considerable time with only a fraction of the applied nitrogen being available the first year. Actual mineralization rates are difficult to determine given the fact that this is a biological process that is sensitive to temperature and moisture conditions found in the soil system. Information on nitrogen mineralization rates is needed to accurately determine application rates of organic nutrient sources (Gilmour, et al., 1996). In manure, N is mostly organic and ammonium nitrogen. Organic N is a slow release N source. Ammonium N is equivalent to commercial fertilizer and, except for that lost to the air, can be used by plants in the application year. Organic nitrogen must be converted to inorganic form before plants can use it. Variable amounts of organic nitrogen are released in a plant-available form during the first cropping year after application (Table 11). Organic N released during the second, third, and fourth cropping years after initial application is usually about 50%, 25%, and 12.5%, respectively of that mineralized during the first cropping season (MWPS, 1985).
Table 11. Amount of organic nitrogen mineralized (released to crops) during the first cropping season after application of animal manure (MWPS, 1985).

<table>
<thead>
<tr>
<th>Manure Type</th>
<th>Manure Handling</th>
<th>Mineralization Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swine</td>
<td>Fresh</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>Anaerobic liquid</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>Aerobic liquid</td>
<td>0.30</td>
</tr>
<tr>
<td>Beef</td>
<td>Solid without bedding</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>Solid with bedding</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Anaerobic liquid</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>Aerobic liquid</td>
<td>0.25</td>
</tr>
<tr>
<td>Dairy</td>
<td>Solid without bedding</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>Solid with bedding</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Anaerobic liquid</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>Aerobic liquid</td>
<td>0.25</td>
</tr>
<tr>
<td>Sheep</td>
<td>Solid</td>
<td>0.25</td>
</tr>
<tr>
<td>Poultry</td>
<td>Deep pit</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>Solid with litter</td>
<td>0.30</td>
</tr>
<tr>
<td></td>
<td>Solid without litter</td>
<td>0.35</td>
</tr>
<tr>
<td>Horses</td>
<td>Solid with bedding</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Nearly all of the phosphorus and potassium in animal wastes are available for plant use the year of application.

The availability of manure nutrients to crops varies with manure storage and application. For example, nitrogen losses by ammonia volatilization can be large when slurry is not incorporated soon after spreading. Thus, the "book value" for swine manure is 28 lb of nitrogen per thousand gallons of slurry when it is incorporated within three days, but only 22 lb per thousand gallons when it is not.

Crop rotations, addition of organic materials, and presence of legumes can all cause changes in N availability to succeeding crops. It is of utmost importance that the "N credit" (that is, the reduction in N fertilizer required to produce optimum yield) for these effects be determined using the correct method. Most published studies where N credits were determined have been based on a method that does not account for improved yield potential in crop rotations compared with continuous cropping of one species or in manured fields compared with those that do not receive manure.

When this yield advantage is present, the best way to determine true N fertilizer need is to use several rates of N on the crop of interest both with and without the effect one wants to measure. For example, different rates of N fertilizer should be applied to both continuous corn, and corn grown after soybean. The difference in optimum rates is the N credit. The same method can be used with and without application of manure, sewage sludge, or other amendment, and with other crop rotations. At Waseca, corn grown after wheat shows the same effective N benefit as corn grown after wheat with underseeded alfalfa (Randall, 1980). The economic N rate in continuous corn was 173 lb N/acre and was 145 lb N/acre in both rotations with wheat. Thus, the N credits for wheat or wheat plus alfalfa before corn was 28 lb N/acre in that study (Lory, et al., 1995).
Corn rarely responds to fertilizer N the first year after alfalfa at some Minnesota locations and has limited N fertilizer response at others (Lory, et al., 1995). Further analysis of data collected in that research concluded that simple adjustments using an N credit approach may not be accurate and reliable at all Minnesota locations (Lory, et al., 1995). That research concluded by recommending more careful study of N credits under different Minnesota soil and weather conditions. This discussion of N credits is very important, because the risk of leaching or other losses of N increase as fertilizer N rate exceeds that needed for optimum yield.

Robust estimates of N credits for various crop systems are needed to provide environmentally sound recommendations. University of Minnesota recommendations typically are well supported and kept up-to-date by research on crop yield and environmental impact. Special recommendations can be made of particular situations, such as is being done as part of a current LCMR project in southwest Minnesota. It is largely fertilizer dealers and independent consultants on whom Minnesota dairy farmers rely for fertilizer recommendations (Russelle, 1999). The key, then, is to assure that farmers and their advisors use the appropriate recommendations, especially on fields where the environmental impacts of excess nitrate may be large.

Surveys by the Minnesota Department of Agriculture show that farmers typically are applying N fertilizer within 10 to 30 lb N/acre of the University of Minnesota recommendations when their crop rotations are simple soybean and corn (Bruening, 1998). However, fertilizer N applications apparently are much in excess of the University recommendations when rotations are more complex or when livestock manure is being used. Presumably this over-application results when farmers or their advisors (fertilizer dealers, independent consultants, etc.) do not credit manure, legumes and other crops in the rotation for the N they effectively contribute to the system, a recognized problem in many states (Lory, et al., 1995; Peterson and Russelle, 1991).

Nitrogen recovery by plants receiving topdressed (surface-applied and not incorporated) manure slurry is relatively low, primarily because of ammonia volatilization losses. Current guidelines in Minnesota suggest that about 20% of the slurry N applied in this way will be absorbed by a crop (Schmitt and Rehm, 1998b), and this matches recent experimental results with dairy manure slurry on reed canarygrass (Russelle, et al., 1997). These ammonia losses can have significant downwind effects when large concentrations are released or large areas serve as the source. At the same time, losses by other mechanisms, such as leaching, are reduced. Thus, the relative impact of various pathways of N loss can be assessed in each situation to determine what management is desirable.

By using livestock manure on the fields from which feed was harvested, a variable and often very large fraction of the harvested nutrients are returned to the soil. Thus, manure collection and application helps recycle nutrients on the farm. This recycling helps improve agricultural sustainability.

An interesting contrast is provided by our systems of handling livestock manure and human manure. Livestock manure typically is used to recycle nutrients on cropland, whereas human wastes are not. In municipalities, human wastes are treated, which results
in large losses of nitrogen gases. The solid fraction is either landfilled or applied to land near the town and much of the liquid fraction, which contains significant amounts of phosphorus, is disposed of in rivers. In septic tank systems, some nutrients accumulate in the sludge, which generally is landfilled, while those in the liquid fraction infiltrate into a relatively small volume of soil on the property. In terms of potential and likely environmental benefit, then, livestock manure use is considerably more beneficial to sustainable crop production than is our current system of human waste treatment.

This discussion leads to an important concept. Within a farm that produces most of its own livestock feed, manure should not be considered a source of new nutrients, but rather a temporary storage pool for nutrients. Where purchased feeds comprise a large proportion of the livestock diet on a given farm; nutrients in this imported feed will comprise a similarly large proportion of manure nutrients. In this case, manure will contain "new" nutrients for the farm. On a whole farm basis, when nutrient imports (feed, fertilizer, symbiotic N\textsubscript{2} fixation, etc.) exceed exports in products (milk, meat, wool, eggs, hay, etc.), nutrient accumulation or losses, or both, will increase. Manure handling and application play a significant role in managing where and when nutrients are used, and can therefore strongly influence the environmental impacts.

In addition to the obvious economic value, manure also improves the physical and biological soil properties that are important for soil quality and crop production, but it is not as easy to estimate a dollar value for this positive aspect of manure utilization. Research has consistently shown that manure applied at agronomic rates can reduce water runoff and the concentrations of soil and associated pollutants by increasing water infiltration into the soil. In Minnesota, researchers observed that a one-time manure application on a landscape with 12% slope reduced rainfall runoff by 0.4 inch in 1993 and 0.13 inch in 1994, which thereby reduced sediment loss 1.1 and 0.1 ton/acre, in moldboard and ridge till cropping system, respectively (Ginting, et al., 1998). The authors also concluded that when manure was applied with proper residue management, they were effective in minimizing runoff and sediment losses during intense rainfall.

As discussed in other sections of this report, livestock manure provides benefits that are difficult to assess economically. A good example is the improvement in soil quality that accrues with long-term manure addition. However, the main economic value of manure usually is associated with the nutrients it recycles on the farm. Regardless of the advantages obtained in recycling the nutrients in livestock manure by using it on cropland, the costs of manure storage and handling typically outweigh the direct economic benefits of reduced commercial fertilizer requirements.

**Manure Nutrient Accountability And Whole-Farm Balance**

As animal agriculture faces the increasing intensity of environmental challenges, more emphasis is being placed on reduction of nutrient excretion, utilization of nutrient budgets to account for manure nutrients as an economic asset to an operation, and developing nutrient profiles that contribute to effectively managing whole-farm nutrient balances as presented in Figure 3 (Koelsch and Lesoing, 1998;Chandler, 1996;Coffey,
Factors affecting the whole-farm nutrient budget include nutrient excretion rates, nutrient removal by plants, nutrient binding capacity of the soil, and loss of nutrients in the system (Van Horn, et al., 1996). Controlling nutrient losses are particularly prevalent in the Netherlands where mandated target goals for the next decade have intensified the emphasis to maintain a farm nutrient balance that includes the profiles of energy, N, P, K, emission of ammonia, carbon dioxide and methane (De Boer, et al., 1977; Mandersloot, et al., 1993; Tamminga, 1996).

The question of whole-farm nutrient balance does not mean that intensive farming necessarily results in "leaky" conditions. Surveys of 1550 Dutch dairy farms in 1992 showed that the best farms with high milk production had N losses no worse than the farms with poorest balance and low milk production (de Vries, 1994). This De Marke experimental farm in the Netherlands has demonstrated that much improved nutrient cycling is achievable in concert with high milk production, if all aspects of the inputs, losses, and recycling of nutrients are addressed.

Losses still occur on the De Marke farm, but at drastically reduced rates than on commercial dairy farms (de Vries, 1994). Due to inherent and, to some extent, inescapable inefficiencies of the food chain, losses must be expected in systems that are more productive than natural ecosystems (O'Connor, 1974).

Dairy and poultry production has very high nutrient use efficiencies, compared to beef and pork production. For example, milk N produced per unit N consumed is generally between 0.2 and 0.3, whereas the ratio for meat N production is closer to 0.1 or 0.15 (Van Vuuren and Meijs, 1987; Worthington and Danks, 1992). That is to say, 70 to 80% of the N eaten by a high producing dairy cow is excreted as urine and dung, whereas growing
steer excretes about 90%. Adult humans are extremely inefficient in nutrient use, because we excrete about as much as we eat.

Improvements in N use efficiency by dairy cattle can be achieved with nutritional management or ionophoreses (which selectively suppress bacteria in the rumen that produce ammonia) (Broderick and Shaver, 1994). Dutch researchers suggest that the maximum N use efficiency may be about 0.43 (Van Vuuren and Meijs, 1987), although it is very unlikely such high efficiency could be achieved on farms, due to the wide variety of factors that influence animal productivity, including temperature stress, incomplete feed digestion, variable feed quality, etc. Recent research in Wisconsin has suggested that dairy rations could contain 0.38% P, rather than the currently recommended 0.48% P, which would decrease P excretion in manure by 25 to 30% without reducing milk production or reproductive efficiency (Satter and Wu, 1999).

Thus, it is reasonable to expect that Minnesota dairy farms should be able to achieve acceptable whole-farm balances for these and perhaps other nutrients, with good control of the dairy rations, best use of on-farm crops to limit import (purchase) of supplements, and excellent herd and crop management. This statement is predicated on the availability of sufficient land on which to apply manure.

Phytate is the major storage compound of phosphate in plants. It is poorly available to most monogastric (single stomach) animals, like swine and poultry, and 80 to 90 percent of dietary phytate is excreted in manure. As the result, producers have to add more P to diets of monogastric animals.

Although swine and poultry manure comprises only 18% of total manure in the USA, they account for about one-third of all phosphorus excreted by livestock (Cromwell and Coffey, 1991). In addition, phytate chelates trace nutrients, such as copper and zinc, and reduces their availability (Ravindran, et al., 1995), requiring higher supplementation of these metals in the diets, with higher subsequent excretion.

Two ways of reducing P excretion in monogastric animals are to feed plants with less phytate (for example, low phytate corn grain) or to add phytase to the diet. Phytase is an enzyme that releases phosphate from the phytate molecules. Either approach appears to be effective (Cromwell, et al., 1992;Ertl, et al., 1998).

In livestock operations, the differences between the amount of total feed intake (DM basis) and nutrient composition minus total outputs (amount and composition of milk, meat, eggs, etc weight gain) closely predicts the amount excreted in the urine and feces (Powers and Van Horn, 1998;Van Horn, et al., 1996;Van Horn, et al., 1996). Typically, the feed DM consumed by livestock may be between 60 and 70% digestible, which will result in between 30 and 40% of DM excreted in feces and urine. Predicted total manure (feces and urine) DM excretion for a livestock unit can be estimated by knowing the feed DM intake and estimates for digestibility (Van Horn et al., 1996ab).

A Florida example using an N budget per 2.5-acre units on a dairy operation is shown below (Van Horn et al., 1996):
N-budget:

**INPUTS:**

2.5 acre harvested crops provide 1258 lb N in feed, and 2024 lb N in purchased feed are imported to the farm = total of 3288 lb N, enough to support 10.4 cows

**OUTPUT:**

Milk = 970 lb N; New calves born plus their weight gain = 31 lb N; total of 1001 lb N;

**DIFFERENCE (INPUTS - OUTPUTS)**

2287 lb N in the manure

In this system the manure is flushed into a screen separator. The effluent is stored in a storage basin or pond then sprayed on to cropland with irrigation equipment. The solids are used for compost and sold off the farm. Prior to irrigation 158 lb of manure N is lost in composted solids. Forty-eight lb N are volatilized before flushing and 198 lb N volatilized in the storage basin or pond. A total of 82.3% of the original manure N (1882 lb N) will go into the irrigation system. During irrigation 282 lb N are volatilized. Once applied a further 246 lb N are lost in the soil, 51 lb N to the groundwater, but 37 lb of N are gained from rainfall. A total of 1340 lb of manure N can be utilized for crops or 71%. In the same scenario, 96% of the manure P would be returned to the crop fields with only 4% P loss to the compost solids, 2 lb P loss to surface run-off (P environmentally balanced in this case), and 2 lb P gain from rainfall. Ninety-eight percent of total manure K output was accounted for on the irrigation spray fields with 1.3% loss to the compost solids. The cropland received 101 lb of K, 5% of manure K was lost to the ground water and 9 lb K to surface run-off but a 2 lb K gain from rainfall. Over 98% of the manure K was returned to the cropland. Accounting for nutrient losses in Minnesota will be more challenging than in Florida, where it is mandated to document total nutrient flow and this is made easier by use of volume meters on the spray irrigation equipment.

A detailed accounting of nutrient flow was conducted on a Florida grazing dairy operation (Boettcher, 1995). The research found that 23% of the feed N and P was accounted for in milk outputs leaving 77% of feed nutrients excreted. Approximately 24% of manure N and P were excreted in the milking area where 5% of manure N was lost. In the feeding area 28% of the manure N was excreted. The remaining manure N and P were excreted in the pasture and lanes to and from the pasture. A further 45% of the manure N was volatilized but all of the P was available.

Work by (Peterson and Gerrish, 1996) emphasized the importance of designing a cattle grazing system to optimize the distribution of manure nutrients on the pasture and prevent build-up of nutrient concentrations under shade or by water and feeding stations. Placement of water within 600 to 800 ft walking distance of the cattle, design of square paddocks, minimize landscape variation within paddocks, limit time cattle have access to
'comfort' areas and preference for a 12 paddock system were critical criteria. Manure nutrient loss in the pasture access lanes ranged from 13 to 22%.

Table 12. Compositional analyses of manure (feces and urine) by manure storage and handling system on six Waseca County dairy farms, 1997-1998.

<table>
<thead>
<tr>
<th></th>
<th>DM</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>N</th>
<th>P</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% DM basis</td>
<td></td>
<td></td>
<td></td>
<td>lbs/ton*</td>
<td>1000 gal**</td>
<td></td>
</tr>
<tr>
<td><strong>Farm A</strong>: (40 cows tie-stall/summer grazing)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manure from barn cleaner</td>
<td>13.0</td>
<td>2.8</td>
<td>.78</td>
<td>1.24</td>
<td>7.3*</td>
<td>2.0</td>
<td>3.2</td>
</tr>
<tr>
<td><strong>Farm B</strong>: (50 cows tie-stall – partial grazing)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lagoon from barn and milk house</td>
<td>8.7</td>
<td>5.5</td>
<td>1.0</td>
<td>4.9</td>
<td>40.0**</td>
<td>7.3</td>
<td>35.6</td>
</tr>
<tr>
<td><strong>Farm C</strong>: (600 cows free stall/flush)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flush water (150,000 gal/day)</td>
<td>0.8</td>
<td>11.3</td>
<td>3.8</td>
<td>10.0</td>
<td>7.6**</td>
<td>2.5</td>
<td>6.7</td>
</tr>
<tr>
<td>Flush water + manure effluent</td>
<td>1.25</td>
<td>9.6</td>
<td>4.0</td>
<td>6.4</td>
<td>10.0**</td>
<td>4.2</td>
<td>6.7</td>
</tr>
<tr>
<td>Separated solids (to be composted)</td>
<td>25.5</td>
<td>1.7</td>
<td>.47</td>
<td>.67</td>
<td>8.7*</td>
<td>2.4</td>
<td>3.4</td>
</tr>
<tr>
<td>Separated liquids to lagoon</td>
<td>1.0</td>
<td>14.0</td>
<td>2.0</td>
<td>10.0</td>
<td>11.7**</td>
<td>1.7</td>
<td>8.4</td>
</tr>
<tr>
<td><strong>Farm D</strong>: (500 cows free stall/flush)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st Stage lagoon</td>
<td>5.2</td>
<td>6.4</td>
<td>1.4</td>
<td>3.3</td>
<td>27.8**</td>
<td>6.1</td>
<td>14.3</td>
</tr>
<tr>
<td>2nd Stage lagoon</td>
<td>2.5</td>
<td>8.6</td>
<td>1.6</td>
<td>1.6</td>
<td>17.6**</td>
<td>3.3</td>
<td>3.3</td>
</tr>
<tr>
<td><strong>Farm E</strong>: (30 cows, tie-stall)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lagoon from barn and milk house</td>
<td>2.9</td>
<td>7.2</td>
<td>3.4</td>
<td>1.4</td>
<td>17.6**</td>
<td>8.3</td>
<td>3.4</td>
</tr>
<tr>
<td><strong>Farm F</strong>: (180 cows free stall/scrape)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7-day storage pit</td>
<td>21.0</td>
<td>2.5</td>
<td>.61</td>
<td>1.7</td>
<td>10.5*</td>
<td>2.6</td>
<td>7.1</td>
</tr>
</tbody>
</table>

The concepts of nutrient balance is currently being applied in Minnesota at 6 Waseca County dairy farms varying in herd size and manure handling and storage systems (Chester-Jones, 1997). Information on manure composition in storage systems at these farms is presented in Table 12.

Farm A represents a 40-cow tie stall unit where manure is collected from a barn cleaner directly to a manure spreader. Cows are housed inside during the winter and only housed inside during milking throughout the grazing season. Farm B has a 50-cow tie-stall barn where manure is directly pumped to a storage basin (that also holds milk house washings) which is emptied twice a year. Cows are housed inside during the winter and partially grazed from the late spring to early fall. Cows are fed from a feed bunk outside daily. Farm E similarly has a tie-stall barn with manure and milk house washings pumped to a storage basin pumped once per year. The 30 cows in this herd are housed inside year round, but are also fed outside daily.
The other three farms have free stall housing units for their lactating herds. Farm C has a 600-cow free-stall and flush unit. Flush water from a storage basin is pumped to storage tanks. Free-stall areas are flushed with 150,000 gallons from the storage basin daily. The flush water and manure effluent is pumped into a solid/liquid separator. The liquids return to the storage basin. The solids are stacked on a concrete pad next to the separator where composting process begins. Stacks will be moved into 200 cu yard windrows. After completion of the composting process, the compost is blended with wood chips and used as bedding in the free-stall barn.

Farm D is a 500-cow free stall with a similar flush system but all the flush water and manure effluent are pumped into a primary stage storage basin. The effluent from this storage basin is collected into a secondary stage storage basin used for recycling as flush water. A portion of manure nutrients are recycled continuously through both flush systems. Farm F is a free stall barn that is scraped daily into a short-term storage pit at the end of the barn. The composition of manure in this system closely resembles that of fresh cow manure. Manure is land applied by a side-slinging manure spreader weekly. Storage basins on the other farms are emptied either through an irrigation pipe system or injected beneath the soil surface from a manure tank.

Typical feed, milk, manure, and urine nutrient composition from cows on these 6 farms are summarized in Table 13.

N, P and K Budget

A detailed accountability for nutrient flow was conducted on a Florida grazing dairy operation (Boettcher, 1995). The research found that 23% of the feed N and P was accounted for in milk outputs leaving 77% of feed nutrients excreted. Approximately 24% of manure N and P were excreted in the milking area where 5% of manure N was lost. In the feeding area 28% of the manure N was excreted. The remaining manure N and P were excreted in the pasture and in the lanes leading to and from the pasture. A further 45% of the manure N was volatilized but all of the P was available. For estimating a nutrient budget using concepts previously described, data from 600-cow herd free stall with a flush system (Farm C in Table10) in Waseca County is given below

- **INPUTS**
  Feed averaged 54 lb of DM/cow daily containing 1.5 lb N, 0.27 lb P, and 0.69 lb K/day.

- **OUTPUT**
  Milk averaged 68 lb/day contained 0.32 lb N, 0.068 lb P and 0.109 lb K
  Cow body weight gain/day @ 0.2 lb/day which contain 0.002 lb N, 0.001 lb P, and 0.004 lb K;
  TOTAL OUPUT 0.322 lb N, 0.069 lb P, and 0.1094 lb K

- **DIFFERENCE (INPUT - OUTPUT)**
Manure nutrients excreted/cow daily = 1.18 lb N, 0.2 lb P, 0.58 lb K
Manure nutrients excreted /600 cows daily = 708 lb N, 120 lb P, 348 lb K.

Using Florida research, the digestibility of the DM fed to Farm C cows is 65%. Then 35% of DM is excreted (30% in feces and 5% in urine) providing 18.9 lb of manure DM excreted daily/cow. The manure averaged 83% moisture. Each cow would excrete just over 111 lb of wet manure daily. This excretion rate will change with dietary nutrient concentration, milk production and stage of lactation as shown in Table 5.

The manure from the herd is flushed daily from the free stall barns. The flush water effluent contains 10.2 lb N, 1.8 lb P, and 6.5 lb K/1000 gallons, which is pumped into a solids/liquid separator. The solid manure is piled on a concrete pad next to the separator. This manure averaged 8 lb N, 0.9 lb P, and 2.5 lb K/ton at 74.5% moisture. The liquid effluent returns to a storage basin, which is recycled flush water. The storage basin is pumped twice a year. Over 50% of N, 40% of P, and over 65% of the K is recycled into the flush water storage basin. The solids are composted and blended with wood chips then used for bedding the free stalls. Records of nutrients in harvested crops, land-applied storage basin effluent, and any purchased fertilizer used will be applied to the budget to estimate losses and account for retained nutrients on the farm. The farms used in this project have a high soil fertility base and optimizing the available manure nutrients to maintain the fertility will preclude the necessity of purchasing fertilizers. The goals of a nutrient budget are to maintain a balance within the limitation of the land base available.

Table 13. Compositional analyses of feed, milk, manure and urine averaged across 6 dairy farms in Waseca County, MN representing 1400 cows, 1997-98.a

<table>
<thead>
<tr>
<th></th>
<th>Dry Matter DM</th>
<th>CP</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Feed, % DM basis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total mixed rations</td>
<td>49.0</td>
<td>16.9</td>
<td>2.71</td>
<td>0.47</td>
<td>1.44</td>
<td>0.93</td>
<td>0.29</td>
</tr>
<tr>
<td>TMR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pastures (1 farm)</td>
<td>20.0</td>
<td>20.4</td>
<td>3.26</td>
<td>0.48</td>
<td>3.00</td>
<td>0.58</td>
<td>0.22</td>
</tr>
<tr>
<td>B. Manure, % DM basis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(individual cow composites)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Confined cows</td>
<td>19.0</td>
<td>15.1</td>
<td>2.41</td>
<td>0.76</td>
<td>0.75</td>
<td>1.90</td>
<td>0.57</td>
</tr>
<tr>
<td>Pastured cows</td>
<td>15.5</td>
<td>13.1</td>
<td>2.10</td>
<td>0.86</td>
<td>0.64</td>
<td>2.95</td>
<td>0.74</td>
</tr>
<tr>
<td>C. Urine, % as is (Individual cow composites)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Confined cows</td>
<td>-</td>
<td>4.0</td>
<td>0.62</td>
<td>0.02</td>
<td>0.78</td>
<td>0.002</td>
<td>0.03</td>
</tr>
<tr>
<td>Pastured cows</td>
<td>-</td>
<td>2.65</td>
<td>0.41</td>
<td>0.05</td>
<td>0.81</td>
<td>0.001</td>
<td>0.02</td>
</tr>
<tr>
<td>Milk (Bulk tank composites)</td>
<td>-</td>
<td>3.03</td>
<td>0.47</td>
<td>0.10</td>
<td>0.16</td>
<td>0.14</td>
<td>0.01</td>
</tr>
</tbody>
</table>

a Current on-going project; six farms ranging from 30 to 600 cows with varying manure storage and handling facilities; one rotational grazing herd.
Not Fully Crediting Manure: An Environmental Liability

The negative side of the manure nutrient ledger occurs when manure is over applied, applied at inappropriate times of the year, or unevenly applied. Under these conditions, environmental impacts can be large and the benefit of the nutrients lost for crop growth. The challenges to manage manure so as to maximize the economic benefit and minimize any negative environmental impacts are many. Composition of manure can change during handling and storage and is affected by diet. Therefore, estimating the nutrient content from published values can introduce large errors. A representative sample is necessary at the time of application, but this is difficult to obtain and the analysis may not be available to determine an application rate. However, these analyses will help the farmer determine the appropriate fertilizer rate needed in manured fields.

The next challenge is to get manure uniformly applied. This can be difficult due to applicator limitations, weather conditions, and lapses of time between applications. After manure is applied the amount of nutrients that are in organic forms that need to be released to become available to crops is largely driven by weather (temperature and moisture). In cool dry years crops can run short and in warm wet years there can be an overabundance of nutrients. There can also be release of nutrients in warm autumns or springs when crops are not present to take them up.

Causes of Excessive Manure Application

Excessive application of manure is often due to economic pressures and uncertainties described above. This results in a manure disposal rather than a manure utilization strategy. Also, the advent of economical commercial fertilizers a few decades ago resulted in the trend of less reliance on manure nutrients for meeting crop demand. The use of commercial fertilizers, rather than manure, was appealing to crop producers because the application rate, nutrient density, and application uniformity were perceived to be far superior for commercial fertilizer. On-farm tests confirm that manure application is often quite nonuniform, in part because of equipment limitations and in part due to human error. As a consequence, many producers do not fully credit manure for the nutrients it contributes to their cropping system. As a result, on many integrated livestock and crop farms, there is an excess of nutrients applied to crops because of insufficient reductions in fertilizer nutrient additions on manured fields.

Uncertainty due to weather plays a significant role on lack of manure crediting. Weather can limit timely applications, cause nutrient losses, and reduce nutrient availability to crops. So the uncertainties that farmers face include:

- Am I sure of my rate?
- Am I confident in the nutrient content?
- Is manure applied uniformly?
- Will the weather result in nutrient losses or reduced release?
- Is my storage sufficient to allow optimum timing of my application?
All of these uncertainties result in farmers often reducing the amount of nutrient credit they take from applied manure and in some cases also in over application and environmental degradation.

A combination of short-term manure storage and daily hauling is chosen for many herds due to its low cost (Harrigan, et al., 1996). But when manure is hauled daily, nutrient concentration and uniformity of distribution can be highly variable. Also, delays of manure incorporation can lead to volatilization of N or nutrient loss in runoff water. With this system farmers are often reluctant to reduce commercial fertilizer use because losses are not quantified and they recognize the lack of uniformity in application rate.

The reasons for manure nutrient crediting problems are mainly that too many assumptions were being made that were not true regarding crediting (Schmitt, et al., 1996). These researchers stated that the most important decision manure applicators make is nutrient application rate, which includes knowing the manure application rate, manure nutrient content, and manure nutrient availability index. A comprehensive survey provided strong evidence that very few crop producers had adequate information on their farm to properly credit manure nutrients(Schmitt, et al., 1996).

As a result of improper crediting of manure, excess nutrients on livestock producer’s fields have led to numerous environmental concerns. These environmental concerns have recently led to regulatory issues sweeping the state and country, and it is this regulation, either existing or proposed, that is the major driving force behind producers changing their manure nutrient management practices (Schmitt, et al., 1999). These authors also reported that manure testing and application calibration are high educational priorities, yet the most accepted nutrient management strategy being implemented was the development of nutrient management plans.

Nutrient (manure) management plans require each livestock producer to detail--on a field by field (crop by crop) basis--the rate, time, and method of manure application as well as any additional commercial fertilizer that is added to a field. The ultimate objective of each farm’s nutrient management plan is to have a set of management practices that meet the agronomic needs of the crop, minimize any environmental liabilities, and provide economic optimization for the whole system.

An article has been written describing a software program developed in Minnesota that meets the overall objectives of nutrient management planning(Schmitt, et al., 1994). An important concept presented in this paper is that there are three major areas of input needed for optimum plans: manure supply, crop nutrient demand in each field, and economic information. While manure supply and economic information are relatively static for an enterprise, the field demand section is somewhat dynamic depending on which crops are selected to be grown in each field and fertilized with manure.

**Environmental Liability of Manure**

The environmental liability of manure has been associated with degradation of water and air quality. Water degradation is due to influx of manure-derived nutrients, biologically
decomposable material, and certain microorganisms. Air quality problems arise due to disagreeable odors and presence of harmful gases. We do not address direct human health impacts due to gases in this section, as this is discussed elsewhere in the GEIS.

Manure has been a liability in several instances because of poor manure application practices, disposal of manure at high application rates, greater concentrations of animals associated with modern livestock production systems, or uncontrolled access of livestock to surface water. The application of manure rates beyond the N and P removal by crops can result in excessively high soil N and P test. Soils in Oklahoma and Texas had high P (85 to 419 ppm Mehlich-3 P) due to application of beef feedlot, poultry, or swine manure (Sharpley, 1996). Repeated application of manure, even at recommended rates for one nutrient, can result in excessive accumulations of other nutrients. The ratio of available nitrogen to phosphorus is often lower in manure than crops require. In addition, because nitrogen can be lost by a numerous pathways, nitrogen losses are often more likely than phosphorus losses. As a result, even at agronomically acceptable manure rates based on crop nitrogen need, excessively high soil phosphorus accumulations can change manure from being a net asset to becoming a net environmental liability.

In addition, with increasing encroachment of suburban development on farms and the development of highly concentrated animal feeding operations, odor has become a widely recognized problem. These water and air quality concerns of manure have resulted in regulations, including the federal Clean Water and Air Acts. However, many scientists now recognize that high soil test levels does not necessarily imply high environmental liability. The question is, “What are the measures for the environmental liability of manure?”

**Risk as a Measure of Environmental Liability**

The liability of manure to the environment should be considered in terms of risk. The environmental risks from manure management include several types. Much of the press emphasis is on catastrophic/accidental failures, especially large manure spills that kill fish in streams, but there are also impacts from runoff and leaching from manure application to soil that can be more gradual and difficult to detect (Richard and Hinrichs, 1998). Risks related to storage facilities can be minimized by facility design, construction, and management.

Risk of adverse effects on surface water from manure application is related to rate of manure application, thoroughness of incorporation into the soil, slope and soil condition (e.g., water infiltration rate), the rate and intensity of rainfall or snowmelt, proximity to surface water, presence of vegetated buffer strips between the manure soil and surface water, and many other factors. For example, frozen soils allow little water to infiltrate, so the risk of runoff is higher than on non frozen soil, other things being equal. Similarly, properly designed and managed vegetated buffer strips can effectively filter out particulate material in runoff and allow infiltration of some of the dissolved nutrients and suspended microorganisms. On the other hand, unless infiltration is high enough to stop water movement across a vegetated buffer strip, dissolved nutrients are not completely
removed, so managing soil nutrient levels in the field is a critical issue affecting risk of surface water impacts.

As with surface runoff, the risk of adverse impacts of manure on ground water are greatly dependent on many variables such as precipitation, geology, landscape, depth to water, and the characteristics of the potential pollutant. Nitrate is highly mobile in soils, whereas phosphorus typically is not. Of course, the environmental risk is not the same over the whole state. The risk of nitrate entering shallow aquifers is highest in the deep glacial outwash sands in the central part of the state, the fractured limestone aquifers in the southeast, and in shallow aquifers throughout the state, such as those in southwest Minnesota. These risks have been taken into account in developing best management practices recommended for various regions of the state, but need to be considered in each field where manure is to be applied.

Once the soil test is very high, the risk for higher P concentration in water is greater although P loss in water may not be the case. There have been many efforts to relate soil P test with dissolved phosphorus concentration in runoff. In a laboratory study or under rainfall simulation an increase of Mehlich-3 P from 100 to 500 ppm, resulted in increasing dissolved P from 0.2 to 1.9 ppm (Pote, et al., 1996). However, desorption of P is not only dependent on soil P test but also on the duration of contact time between water and the soil and the ratio between water and soil (Sharpley, et al., 1981). Therefore, concentration of dissolved P is greatly dependent on runoff and rainfall intensity. This indicates, that high soil P test did not necessarily means higher dissolved P loss although P concentration in runoff is higher due to higher soil test. The low rainfall runoff from manured soils can cancel out the effects of higher soil P test (Ginting, et al., 1998). Dairy manure application under a chisel plow system did not result in greater molybdate reactive P loss even though concentrations of molybdate reactive P were greater due to incomplete incorporation of manure into soil (Mueller, et al., 1984). These findings emphasize that the hazard of high nutrients is dependent on many variables.

**Comparative Risk of Manure and Other Source of Nutrients/Fertility**

**Water Quality**

Inherently, quantity and quality of elements in commercial fertilizer are controlled. In manure however, quality and quantity of elements vary with many factors, such as feed, storage, handling, and many other manure management decisions. Due to its organic nature, manure will have greater environmental risks in term of soluble or particulate organic elements, such as organic nitrogen, organic phosphorus, and oxygen-demanding compounds. Elements in animal feed and organisms from animal digestive tracts caused manure to present a greater risk for water contamination from heavy metal, hormones, and pathogens than commercial fertilizers. Water contamination by manure can occur directly from storage facilities or unprotected animal confinement areas, as a result of land application of stored manure, and as a result of direct deposition on soil or in water by the livestock (Morse, 1996).
As with any other nutrient source, excessive application of commercial fertilizer and manure will increase soil nutrient status, thereby increase risk of losses (King, et al., 1990; Vellidis, et al., 1996). Once the nutrients from both inorganic fertilizer or sources are in the same form and quantity, the risk of losses of nutrient of interest will be the same provided other factors are the same.

**Nitrogen Leaching**

Nitrate-N leaching from application of commercial fertilizer or manure has generated water quality concerns. There are cases showing that nitrate-N concentrations measured in soil percolate at 3-ft depth on the 2% slope were higher under commercial fertilizer (8.3 ppm) than 8 ton/acre broiler litter treatments (4.8 ppm) (Wood, et al., 1996).

Nitrate in the subsurface tile drain system is a good indicator that nitrate-N leached is a major concern for groundwater quality. Depending on the amount of water draining, large nitrate-N losses from commercial N fertilizer may occur (Baker and Johnson, 1981; Baker, et al., 1975; Randall, et al., 1997; Randall and Iragavarapu, 1995). In Iowa, averaged across the 4-yr period, mean annual nitrate-N losses were 35 lbs/a (Baker, et al., 1975). Nitrate-N concentrations and losses from continuous corn crops increased with increasing rate of commercial fertilizer N application. Nitrate-N losses were very high when the commercial fertilizer-N application rate exceeded recommendations (Gast, et al., 1978). Annual NO$_3$-N losses from moldboard plowed continuous corn fertilized with 178 lbs/a N ranged from 1.1 to 156 lbs/a during an 11-yr period in Minnesota (Randall and Iragavarapu, 1995). Even with best management practices, however, nitrate losses can be relatively high, because leaching is the product of the volume of water flowing through the soil and the concentration of nitrate. Minnesota research showed that annual row crop systems (continuous corn or corn/soybean rotation) had much greater losses in tile drainage than did a Conservation Reserve Program planting or alfalfa (Randall, et al., 1997).

Nitrate leaching losses are generally small when fertilizers or manure are applied at recommended times and rates. British researchers found that N-rich manures should not be applied in the fall but should instead be applied in the spring as a top dressing to growing crops otherwise nutrient loss will occur and be more pronounced on coarser textured soils (Smith and B.J. Chambers, 1993). Once the rate exceeds plant demand for high yield, or if application time results in high nitrate supply during times of low crop demand, nitrate losses increase. Some research has shown that over application of poultry manure results in high nitrate in soil solution (Kingery, et al., 1993), groundwater (Adams, et al., 1994), and wells (Ritter and Chirnside, 1982).

Nitrate leaching losses generally are quite low when manure is surface applied to established perennial forages. This is due in part to the higher ammonia volatilization that occurs with surface application, in part to the high nitrogen demand of the crop, and in part to the lack of water movement below the root zone. Perennial crops use water and nitrogen over a longer period than annuals, and therefore nitrate leaching losses are lower than in annual crop systems. This conclusion, of course, is tempered by soil texture. For example, no accumulation of nitrate in a fine textured soil was measured when a grass
hay crop received either high rates of manure slurry or nitrogen fertilizer, however, soil water nitrate concentrations did increase on a sandy soil when nitrogen rates of either source exceeded about 200 lb/a (Russelle, et al., 1997).

**Phosphorus Leaching**

Phosphorus has been considered immobile in soil (Brady, 1984). The most prevalent form of plant-available phosphorus, the phosphate ion, interacts chemically with calcium, iron, and aluminum in soils, and only negligible amounts of P are usually transported to subsurface tile lines (Kladivko, et al., 1991). Phosphorus losses in subsurface tile drainage from soils receiving commercial P fertilizers range widely depending on various soil properties. Average soluble P concentrations were 0.63 ppm during spring to fall and 0.42 ppm during fall to spring on a sandy soil used for citrus production in Florida (Calvert, 1975). In Ontario, phosphate-phosphorus concentrations and losses from intensively cropped sandy and silty clay soils ranged from 0.015 to 0.072 ppm and 0.03 to 0.27 lb/a, respectively (Miller, 1979). On organic soils in the same study, phosphate-phosphorus concentrations and losses were much higher, ranging from 1 to 18 ppm and 1.8 to 41 lbs./a, respectively. A 3-yr study on a silty clay soil showed a mean soluble inorganic P concentration of 0.04 ppm and annual losses of 0.39 lb/ac (Bottcher, et al., 1981).

Preferential flow has been cited as greatly affecting P losses in some soils. Phosphate-P concentrations and losses from a clay loam soil with extensive cracking averaged 0.24 ppm and 0.42 lb/acre/year or 3% of the total fertilizer P added (Gaynor and Findlay, 1995). In Quebec, total P concentrations ranged from 0.01 to 1.17 ppm in tile drainage with higher P concentrations related to samples taken immediately after extended dry periods when soil cracking could have enhanced preferential flow (Beauchemin, et al., 1998; Sims, et al., 1998)

Research documenting P losses in subsurface tile drainage from soils receiving manure is limited. In New York, annual application of dairy manure at rates of 0, 16, and 89 ton/acre (wet) to a calcareous, glacial till, silt loam soil resulted in 3-year average inorganic P concentration of 0.011, 0.014, and 0.218 ppm, respectively (Hergert, et al., 1981). The initial Olson P soil test was 11 ppm and after 3 year was unchanged with the 16 ton/acre manure rate but was increased to 35 ppm by the 89 ton/acre.

Recent research has indicated that phosphorus losses via leaching are higher with organic phosphorus sources than with inorganic sources (Eghball, et al., 1996). Suspended or dissolved organic phosphorus forms may move through the soil without being influenced by chemical precipitation. Thus, it appears that the risk of phosphorus leaching to ground water or to surface water through tile drains may be somewhat higher with manure than with commercial fertilizer. However, there are little data at present to indicate that these impacts are ecologically significant or are occurring in Minnesota soils.

**Leaching of Pathogens**
Manure poses a greater risk of pathogen impacts in the environment than commercial fertilizer because manure contains pathogens associated with fecal material. Storage conditions can either increase or decrease viable pathogen concentrations in manure. Coliform bacteria movement through the soil profile and into drainage water has been associated with flow through large pores (macropores), which reduces the soils ability to retain bacteria and viruses (Smith, et al., 1972). Well-structured soils allowed rapid downward movement of coliform bacteria when accompanied by high water addition rates (Smith, et al., 1985).

Rapid downward movement of pathogens associated with manure can occur within hours of manure application. For example, 30- to 900-fold increases in fecal bacterial concentrations in drain tile out flow from a pasture on sandy loam soil occurred within 2 hours of spreading liquid manure (Evans and Owens, 1972). In Ontario, sandy loam, silt loam, and clay loam soils, water quality degradation from bacterial contamination occurred within 20 minutes to 6 hours of liquid manure spreading at 8 of 12 sites (Dean and Foran, 1992). A field that was tilled just prior to manure application had insignificant microbial contamination. Shearing of the macropores by tillage appeared to limit microbial transport (Dean and Foran, 1992), and may dramatically attenuate bacterial concentrations in leachate water (Smith, et al., 1985). In Kentucky, the potential for ground water contamination by fecal coliform bacteria depended more on soil structure and water flow than the mortality rate within 2 months after a manure application (Smith, et al., 1985). Thus, the risk of pathogen impacts on ground water that manure application poses is strongly site-dependent, and clearly related to soil structure and disturbance.

**Nitrogen in Runoff Water**

Soil nitrogen from both commercial fertilizer and manure is subject to loss in runoff water. Runoff losses of nitrogen are lower when manure is incorporated in the soil, applied at lower rates, applied at proper timing. In a simulated rainfall runoff study 7 days after fertilizer and manure application, the concentration of nitrate-N, ammonium-N, total N, were higher from plots that received inorganic fertilizer than those receiving manure (Edwards and Daniel, 1994). Poultry litter application increased mean concentrations of total N in runoff during the following 16 weeks in both no-till (15.4 ppm) and tilled treatments (16.7ppm)(Heathman, et al., 1995). More important in terms of aquatic life is the concentration of ammonium-N. A study evaluated the effects of fertilizer rate, hog manure rate and time of application on ammonium-N losses in surface runoff. Plots receiving chemical fertilizer plus hog manure had a significant increase in ammonium-N losses as compared with the plots receiving fertilizer only (Gangbazo, et al., 1995). Due to the fall manure effect, NH4+-N loads increased by three-fold after the first year, 1.46 times between the first and the second year, and 1.14 times between the second and the third year for corn when compared with the treatment that received only fertilizer.

**Phosphorus in Runoff Water**

Phosphorus is a primary nutrient that limits growth of undesirable aquatic plants in lakes, so phosphorus runoff has long been a topic of concern in Minnesota. Concern over
phosphorus losses from commercial fertilizer or manure is primarily related to off-site transport of surface runoff, erosion and associated phosphorus-enriched sediment entering streams and lakes. Livestock operations can have a significant effect on total phosphorus runoff. Streams in watersheds with high livestock population had a 50-fold total phosphorus loss compared to forested watersheds (Duda and Finan, 1983).

The concentration of phosphate-phosphorus and total phosphorus of plots receiving inorganic P fertilizer can be higher than the plots that received manure (Edwards and Daniel, 1994). Phosphorus concentrations in runoff from fields that have been recently fertilized with commercial fertilizer and manure are often very high and decrease with time (Edwards and Daniel, 1994). The longer inorganic phosphorus is in contact with soil, the more likely it will form compounds that are less soluble, and become essentially immobile. (Shreve, et al., 1995)

Due to phosphorus immobility in the soil and lack of incorporation manure application results in accumulation of phosphorus at the soil surface (Ginting, et al., 1998; Kingery, et al., 1993). There have been many efforts to relate soil phosphorus test levels with dissolved phosphorus concentrations in runoff. In one study, an increase of Mehlich-3 phosphorus (one of many typical soil test methods used in the USA) from 100 to 500 ppm, resulted in dissolved phosphorus increasing from 0.2 to 1.9 ppm (Pote, et al., 1996). Poultry litter application increased concentrations of total phosphorus in runoff during the 16-week study with no-till (5.8 ppm) and tilled treatments (6.1 ppm) (Heathman, et al., 1995). However, desorption of phosphorus is not only dependent on soil phosphorus test, but also on the duration of contact time between water and soil and on the ratio between water and soil (Sharpley, et al., 1981). Therefore, concentration of dissolved phosphorus is greatly dependent on runoff and rainfall intensity. High soil phosphorus tests do not necessarily mean higher dissolved phosphorus losses. Because manuring can improve water infiltration rates, low rainfall runoff from manured soils can cancel out the effects of higher soil phosphorus test (Ginting, et al., 1998; Mueller, et al., 1984).

These interacting effects have been combined recently into a phosphorus risk index, which is being promoted in some states (Lemenyon and R.G. Gilbert, 1993). This index takes into account the soil phosphorus test, slope, proximity to surface water, and all the other relevant management and site characteristics to produce a numerical index that indicates risk of surface water damage. Thus, a flat field with very high soil test phosphorus may have a low risk index, because water runoff is unlikely, unless it is quite near to surface water. Land Conservation personnel from Trempealeau County, Wisconsin, indicate that farmers apparently understand and accept this index, which is being used to develop manure management plans on those farms.

**Carbon in Runoff Water**

Soluble and particulate organic constituents in manure or sewage sludge results in greater risk loss of carbon in surface water quality than commercial fertilizer. Loss of carbon will increase chemical oxygen demand and biological oxygen demand of water, reducing oxygen for fish and other aquatic organisms. In a rainfall simulation study, highest concentrations of chemical oxygen demand (COD) occurred in runoff from plots treated
Pathogens in Runoff Water

Manure poses a greater risk of pathogen impacts on surface water than commercial fertilizer because manure contains pathogens associated with fecal material. Poultry manure contains pathogens related to human diseases (Bhattacharya and J.C. Taylor, 1975; Fontenot and Webb Jr, 1975; McCaskey and Anthony, 1979). Poultry manure application on pasture increased the amount of fecal coliform in runoff water (Giddens and Barnet, 1980). In a watershed in eastern Nebraska, variation of fecal bacteria has been related to livestock management and manure handling practices (Baxter-Potter and W.W. Gilliland, 1988). Virus has also been reported in poultry litter (Sims and D.C. Wolf, 1994). Due to virus small size and weak interaction with clay and organic matter, virus can be potentially leached through soil, into ground water, and surface water. Bacteria leached to less extent due to its larger sizes and its interaction with soil particles (Angle, 1994).

The pathogenic hazard of manure and sewage sludge is greatly dependent on the persistence of pathogens in soil. The approximate survival time of pathogens in soil (Kowal, 1986) is:

- fecal coliform ranged 8 – 55 days
- Enterovirus ranged 70-170 days
- Poliovirus ranged 70-90 days
- Helminth eggs >1000 days

Using source tracing techniques based on differences in antibiotic resistance of bacteria in manure from different types of livestock, the relative contribution of different livestock to bacteria in streams is separated. See Section on Comparison of Causes of Impaired Rivers and Streams for Various Land Uses in the Water Resources report for more description.

Animal manure contains substances that protect virus from inactivation, so viruses may persist for prolonged periods of time if stored under non-aerated conditions. At times of land application, this may lead to environmental contamination with pathogens (Pesaro, et al., 1995). On the other hand, the persistence of hepatitis A virus was inactivated more rapidly in the presence of cattle manure slurry and with swine manure slurry (Deng and Cliver, 1995). Sewage sludge may need decontamination prior to agricultural use by raising pH (Ghiglietti, et al., 1997). Treating sewage sludge with lime increases pH and exothermic reactions, which further reduces pathogens (Sloan and Basta, 1995). Treated biosolids can be safely applied to land with minimal off-side impacts to surface waters (Harris-Pierce R.L., et al., 1995). Would similar treatment of livestock manure be economic and effective? There clearly is a need for more research on the presence,
pathogenicity, persistence, impact, and management of microorganisms in livestock manure.

**Heavy metals**

Like sewage sludge, manure poses a risk to soil and water contamination with heavy metals. The poultry industry adds compounds with arsenic, cobalt, copper, iron, manganese, selenium, and zinc to poultry feed (Tufft and Nockels, 1991). Copper has been used as a growth promoting additive in pig diets (Braude and Hosking, 1975; Prince, et al., 1979). Chromium is used for growing-finishing pigs (Page, et al., 1993) and zinc at the pharmacological level is used to improve pig performance (Hahn and Baker, 1993). Swine fed with 250 ppm copper produced manure containing 61 ppm copper (Brumm and Sutton, 1979). Application of poultry manure resulted in elevated levels of Cu and Zn in soils (Kingery, et al., 1993).

Metal uptake by plants is dependent on solubility and exchangeability of the element. Plant available heavy metals that may be contained in the waste need to be determined (Berti and L.W. Jacobs, 1996). Solubility and exchangeability of calcium, magnesium, iron and manganese in soils treated with sewage sludge were not significantly different from those treated with cowpea green manure or chicken manure (Li, et al., 1997). Heavy metals such as copper could function as a bactericide in soil. Addition of sludge with low or high content of heavy metals (chromium, silver, copper, mercury, and lead) and organic pollutants reduced atmospheric nitrogen fixation activity (Martensson and Torstensson, 1996).

**Other Aspects**

Sewage sludge may result in phytotoxicity to germination and seedling growth, although some researchers have shown otherwise (Warman and Termeer, 1996). Application of composted cow manure or activated sewage sludge also resulted in significant increases of grubs (Green June beetles) in 1 of 2 years studied (Potter, et al., 1996).

**Air Quality**

Manure poses greater risk for air pollution than commercial fertilizer, especially with regard to volatile organic substances and odor. Air quality concerns related with manure are the volatilization of ammonia, volatile organic compounds, and reactive organic compounds from decomposition of manure and bedding (Morse, 1996). Other gasses produced from manure include sulfur compounds, methane, and nitrous oxide (Kuroda, et al., 1996).

Odors can be generated on livestock production farms from three major source areas: production facilities; manure treatment systems; and fields where manure is applied (Westerman and Zhang, 1997). Under anaerobic conditions, bacteria break down the manure into simple organic acids and finally produce methane, other gases, and foul smelling odors (Day and Funk, 1998). From a swine production facilities, 40 organic compound were identified in liquid and gas samples, of which 27 volatile organic
compounds were confirmed to contribute to decreased air quality in the vicinity of the facility (Zahn, et al., 1997).

Odors and noxious gases can be a major problem during land application of stored manure. Storage method and presence of a cover, animal diet, application method, weather conditions, and other factors affect the concentration and dispersion of gases. The odor issue is treated in much more detail in the Manure and Odor Topic area.

Maximize the Positive and Minimize the Negative Impacts of Manure

Improving Livestock Manure Storage and Treatment Facilities

A treatment system is designed and operated for biodegradation — converting organic matter (feed, bedding, and body byproducts) in animal manure to more stable end products.

Anaerobic Lagoons

In Minnesota, true lagoons are not common. Earth basins (which are storages, not lagoons) are more common for swine, dairy, and beef operations even those using flushing and recirculation.

Anaerobic lagoons handle high loading rates but give off some septic odors. Well designed and managed lagoons have a musty odor. Foul odors indicate malfunction. Aeration of the top few inches of a lagoon may start aerobic conditions and reduce odors but can be costly and difficult. Mineral buildup, resulting from water evaporation leaving dissolved salts behind, requires periodic dilution and pumping. Water from roof drains and other sources are often added to a lagoon.

Anaerobic lagoons liquefy and break down manure solids, but not all manures added are completely degradable. Sludge accumulation depends on management, environment, manure characteristics, and loading rate. After about 2 years, sludge buildup rate in a properly functioning lagoon may decrease. Because complete treatment is not practical, the sludge is periodically pumped or drained to cropland. Enough land area must be available to land apply lagoon effluent and sludge.

Methane can be produced during anaerobic digestion. This process converts the biodegradable organic portion of animal manure into biogas (a combination of methane and carbon dioxide). The remaining semi-solid is relatively odor free but still contains all the nitrogen, phosphorus, and potassium originally present in the animal manure. However, half of the nitrogen can be lost after 72 days of storage in a holding pond. The solid portion of the semi-solid can be separated and used as bedding.

Anaerobic digestion is a stable and reliable process, as long as the digester is loaded daily with a uniform quantity of manure, digester temperature does not fluctuate widely, and antibiotics in the manure do not slow biological activity. Major problems with digestors include manure handling, pumping, grinding, mixing, and screening miscellaneous
debris. Gas leakage (methane is explosive at 5%-15% in air) and pipe and valve corrosion have also been problems. To reduce these problems, obtain competent engineering design and purchase quality materials.

Advantages

- In addition to labor savings from removing liquid manure from buildings, labor can also be saved by using irrigation to dispose of liquids.
- Long storage times permit pumping flexibility while bacteria break down solids.
- The high degree of stabilization can reduce odors during spreading.
- High nitrogen reduction is an advantage if manure used must be on small areas.

Disadvantages

- Odors are produced if environmental or management changes reduce biological activity. Lagoons are sensitive to sudden changes in temperature and loading rates.
- Where winter water temperatures are near or below freezing, lagoons experience spring and fall turnover (bottom water rises and top water drops). After a winter of little bacterial action due to low temperatures, odorous material from the lagoon bottom rises to the surface. Higher spring water temperatures increase microbial action, and foul odors are generated during the bacterial buildup stages.
- Because higher temperatures improve manure decomposition, anaerobic lagoons work best in summer and in areas without cold winters.
- Fertilizer value reduction is a disadvantage if lagoon effluent is used to fertilize crops. Up to 80% of the nitrogen is lost in a lagoon. Phosphorous may precipitate to the bottom but can be recovered when sludge is removed.

Aerobic Systems

The aerobic treatment process requires that free oxygen be made available to microorganisms in the manure through mechanical or natural aeration. The systems available to producers are naturally aerated lagoons, mechanically aerated lagoons, oxidation ditches and composting.

Advantages

- The major advantages of aerobic treatment systems are:
- Relatively odor-free operation.
- Fast rate of biological growth.
- Rapid adjustment to changes in loading and temperature.
- Elevated temperatures are not required.

Disadvantages:

- Oxygen is required.
- High production of biological sludge.
Relatively high space, maintenance, management and energy requirements for artificial oxygenation.
Shallow depths require large surface area.

Currently, the aerobic process is considered uneconomical for livestock operations. But with the advantage of odor control, aeration may become more popular.

**Composting**

Composting is a biological process in which organic matter (volatile solids) is degraded to a relatively stable humus-like material. Composting reduces manure volume. A study showed that approximately 50% of the carbon was lost from microbial respiration, which contributed to the overall volume reduction associated with composting (Eghball, et al., 1997). Manure composting can be either anaerobic or aerobic, but modern composting is usually limited to aerobic systems.

- Objectives of composting are to:
  - Stabilize putrescible organic matter.
  - Kill pathogens and weed seeds.
  - Conserve the nitrogen, phosphorus, potash, and resistant organic matter found in the raw material.
  - Produce uniform, sterile, and relatively dry end produce, which free from odors.
  - Conduct the process free from insects, rodents, and odors, and as inexpensively and dependably as possible.
  - Produce a valuable fertilizer and soil conditioner.

Composting is a biological process, so environmental factors influence organism activity and determine the speed and extent of the composting cycle. The most important factors are material particle size, moisture content, aeration, temperature, and initial carbon-nitrogen ratio. Ideally, the smaller particles, the greater the surface area, and the more access for the degrading organisms. Particle size may need to be reduced by grinding, such as crop residues like corn stalks.

The moisture content for optimum composting is 50%-60%, depending on particle size and aeration. If aeration is maintained, the moisture content can be above 60%. At high moisture content, voids fill up with liquids, and aeration is hindered. Low moisture levels retard or stop microbial activity, although some composting occurs with moisture as low as 25%.

If adequate aeration can be maintained despite high moisture content, fresh animal manure can be composted directly because of favorable particle size. Over-aeration has no advantage and tends to reduce temperatures. Aeration can be accomplished by forced air or turning.

High rate composting in a large rotating drum is another common method. Forced air is supplied to drums up to 12’ in diameter and 8’ long. The material rolls in these drums for 2 to 10 days.
High temperatures are sustained long enough in most operations to destroy pathogens, weed seeds, and insect eggs and larvae. Generally, the interiors of compost piles reach these elevated temperatures but not the outer surfaces. Turning the pile mixes the two areas.

Composting also depends on microbe food and nutrient supplies. Mineral content of livestock manures is usually adequate. Carbon is an energy source, and with nitrogen also builds protoplasm. More carbon than nitrogen is required, but activity decreases with too much carbon. The proportion of carbon to nitrogen is the C/N ratio. A C/N ratio of 30:1 is about optimum for rapid composting. With C/N ratios lower than 20, nitrogen is lost during composting and escapes as ammonia. In animal manure, the C/N ratio is usually 10-15:1. Composting animal manure with bedding or other plant wastes, or with municipal wastes containing large amounts of paper, has been successful. If the pile does not reheat after turning, the process is complete. Finished compost is dark brown to black in color, practically insoluble in water, has a slightly earthy to musty odor, and has a loose friable texture.

Composting, though sometimes expensive, degrades organic material to inert humus with some fertilizer value. Usually composted livestock manure contains 0.5% nitrogen, 0.4% phosphorus, and 0.2% potassium. While not rich in fertilizer value, the material is odorless, sterile, and weed free. Adding compost improves soil moisture retention of light soils and pore volume of heavy soils. Compost-improved soils have a relatively stable structure and are erosion resistant.

**Addressing Constraints and Strategies in Sustainable Manure Management**

If manure nutrients are to be more efficiently used in agricultural crop production, some or all of the constraints must be addressed. Table 14 summarizes those constraints and suggests some possible remedies (Richard, 1998). The challenges of specialization and scale in livestock production become a constraint when individual livestock farms are unable to economically utilize the nutrients in their manure. However, these same challenges can be transformed into opportunities. Concentrated sources of manure tend to generate environmental, social, or political problems, which often help clarify for producers the need to create and market manure products for off-farm uses. There are also economies of scale in some of the treatment and processing technologies, which reduce the costs of those technologies for larger operations. Groups of smaller farms can also achieve similar economies of scale by cooperative manure management efforts, as currently occurs in the U.S.A.

Nutrient density is a particular problem when liquid manure must be hauled over a distance. For highly dilute systems, pipeline delivery via umbilical cords or buried lines reduces application costs considerably. Nutrient concentration can also be increased through design of collection systems, by minimizing use of flush water in liquid systems and bedding in solid manure handling systems. A particularly effective nutrient concentration technique for swine manure is the fecal-urine separation developed in Japan, that concentrates 55% of the N and 95% of the P in the fecal matter, which represents only 27% of the total mass (Person, 1997). Further concentration of nutrients
in this and more conventional solid manure collection systems, along with homogenization to promote uniformity and stabilization to facilitate storage and handling can be accomplished through such established technologies as composting and pelletization.

Table 14. Constraints and strategies to increase sustainable manure management.

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<tr>
<th>Constraints</th>
<th>Strategies</th>
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<tr>
<td>Specialization</td>
<td>Promote integrated crop and livestock farming.</td>
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<td></td>
<td>Market manure products to specialized crop farmers.</td>
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<tr>
<td>Scale</td>
<td>Decentralize livestock production facilities.</td>
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<td></td>
<td>Utilize scale (for large farms or aggregations of smaller farms) to</td>
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<td></td>
<td>capitalize manure treatment and processing facilities.</td>
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<tr>
<td>Low nutrient density</td>
<td>Concentrate nutrients using solid manure collection, liquid/solid</td>
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<td></td>
<td>separation, composting, drying and/or pelletization.</td>
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<tr>
<td>Spatial variability</td>
<td>Install pipelines for efficient transport of liquid manure.</td>
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<tr>
<td>Temporal variability</td>
<td>Homogenize during processing, treatment, and application.</td>
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<tr>
<td></td>
<td>Stabilize nutrients in organic forms using composting, anaerobic digestion,</td>
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<td></td>
<td>drying and/or pelletization.</td>
</tr>
<tr>
<td>Application variability</td>
<td>Characterize bioavailability for different processes and products.</td>
</tr>
<tr>
<td></td>
<td>Develop improved application technologies.</td>
</tr>
</tbody>
</table>

Source: (Richard, 1998)

These later approaches, while they facilitate efficient nutrient utilization on an integrated crop and livestock farm, they can also provide an attractive way to market manure from livestock farms to specialized crop farms or even non-agricultural markets. Compost is already being marketed this way by a number of facilities. The value of this product-as a fertilizer and soil amendment for horticulture-is well established. Specially processed compost is now also being used as a pesticide substitute, providing plant pathogen suppression equal or better than chemical pesticides for several common soil borne diseases (Hoitink and Fahy, 1986; Hoitink and Grebus, 1994), while compost extracts are being used for foliar fungal disease control (Brinton, et al., 1996; Weltzhien, 1992).

Composting has proven very attractive for livestock producers for a variety of reasons, including the ready availability of proven technology (Richard, 1992; Richard and Walker, 1990), the high value and ready acceptance of the product, and the ease of adaptation to many different sizes and types of livestock operation (Rynk, et al., 1992). The primary disadvantage to traditional batch composting is the high cost of a dry, carbonaceous bulking amendment, such as sawdust or straw, to absorb excess moisture present in the manure. Liquid - solid separation technologies can aid with this problem, particularly with dairy and cattle manures where the solids fraction has a relatively large particle size (Zhang and Westerman, 1997). Bio-drying systems use the heat generated by composting to allow sequential additions of manure, effectively recycling the bulking amendment for multiple batches of manure (Richard, 1998; Richard and Choi, 1996).

The other potential concern with composting is the possibility of market saturation, as the high price currently received for the product may drop as many more compost production facilities are built. Market development, especially for such added value characteristics as pathogen suppression, will prove important for this technology's future success.
Another option for turning manure into a marketable product is through drying, with or without pelletization. Pelletization has seen increasing use in the U.S.A. for sewage sludge, and has received good farmer acceptance. In the Netherlands, where pollution from excess manure nutrients is also a serious concern, a government initiated program is pelleting manure for both domestic and export markets (Voorburg, 1993, cited in (Gassman and Bouzaher, 1995). Pellets are easy to store and can be applied with fertilizer equipment. The disadvantages to this method are the high energy costs associated with drying the manure, and the need for large centralized facilities to achieve economies of scale.

Research, Development, and Demonstration

To further minimize the negative impacts of manure storage, handling, and storage, further research, development and demonstration are necessary. Some research aspects are:

- Research dietary manipulation to reduce total mass and nutrients (increased retention) and odor control or adjustments.
- Determine sulfur mass balance where inputs could be reduced in order to reduce hydrogen sulfide emissions.
- Develop handling and separation methods to reduce phosphorus in the manure.
- Research seepage from storage units including concrete and earthen basins and both liquid and solid storage units.
- Test effects of tile placement around concrete and earthen storage units and their longevity, sizing, effectiveness, and construction techniques.
- Develop low cost treatment system for reducing biological oxygen demand/chemical oxygen demand and/or odor control.
- Develop storage agitation techniques to increase the uniformity of manure for land application.
- Develop easy calibration methods for land application equipment.
- Develop land application equipment with more uniform application to decrease the volume.
- Determine nutrient availability during the first cropping season after application and the amount carried over to next cropping season.
- Research effects of surface tile inlets on manure applied land on stream and river quality.
- Develop systems for fly control.
- Develop alternative manure management systems.

Alternative Uses for Manure

While recycling manure nutrients via crop production makes a great deal of sense; an even more efficient strategy can be to process the manure directly into animal feed. The nutrient content of manure has been shown to be 3 to 10 times more valuable as animal feed than as plant nutrients. While the ability of ruminants to utilize non-protein nitrogen gives them an advantage over other livestock (Smith and Wheeler, 1979) (Zinn, et al., 1996), refeeding has also been successful with poultry and swine (Day, et al.,
1980; McCaskey, 1995). The principal concern with refeeding has historically been animal health concerns, but the use of drying, ensiling, heat treatment, and chemical treatment have all been effective at eliminating disease transmission (McCaskey and Anthony, 1979). However, the costs of processing combined with lower nutrient values from some processing approaches (such as drying and heat treatment) have limited the application of this strategy primarily to the refeeding of poultry manure and litter to poultry and ruminants (Hauck, 1995). Further discussion of manure use as a livestock feed can be found in Section on the Use of Processed Manure as Feed of the Animal Health Report.

A somewhat less direct means of converting manure into high protein human foods is through the use of aquaculture and fish ponds. Waste treatment in ponds has been an established practice for centuries in parts of Asia and are also currently found in Europe and North America (Edwards, 1980; Polprasert, 1989). Fish have a high feed efficiency ratio and with proper design the biological treatment processes in ponds can effectively address most odor and water quality issues, although pathogen survival and transmission can still be a concern with untreated manure (Polprasert, 1989).

The other important product that can be derived from livestock manure using currently available technology is energy. Anaerobic digestion converts much of the energy in manure to methane gas, which can be burned for space and process heating and/or converted into electricity with an engine generator (Badger, et al., 1995; Hashimoto and Chen, 1981; 1989). In addition to the recoverable energy produced, anaerobic digestion also reduces the odor content of the manure. While anaerobic digestion has been demonstrated as effective with a wide variety of manures throughout the world, the relatively high capital costs and management skills required have limited its application. Because anaerobic digestion converts manure solids to gas, the moisture content of the manure increases during digestion. On farms where land application of digester effluent is constrained by limits on land availability, liquid-solid separation followed by further treatment of both the liquid and solid streams would probably be required.

While the previously described approaches to livestock manure management are available today, there is a number of other promising strategies that should be considered for the future. Of particular interest are those that use applied biotechnology to generate value-added products from manure. Composting and anaerobic digestion are two current examples of this approach, and in both cases advances in processing efficiency and product value are likely benefits from additional research. While composting biologically utilizes the energy in manure for drying, minimizing or eliminating the need for liquid treatment and disposal, anaerobic digestion biologically converts that energy into a combustible gas. In the future we may see manure converted into even more valuable products, including proteins for animal feed through algal or other microbial conversion processes (Calvert, 1979; Hauck, 1995; 1989), and enzymatic conversions to alcohol or other chemical feedstock Spellman (1994). While such systems may seem difficult to imagine today, with future research the concentrated energy and nutrients found in livestock manure are certain to be seen as a valuable resource rather than a waste.
Sharing Cost and Technical Support

Reduction of environmental risk from manure could be achieved by increasing incentives for farmers to better utilize their manure. This would include cost sharing for improving storage and handling facilities as well as developing and implementing good nutrient utilization plans. These plans should include identifying the necessary cropped area for environmentally sound utilization based on the amount of manure and crop sequence anticipated. Manure management has the potential to impact Minnesota crop production in many different ways. Probably the greatest manure management decision for livestock producers is which field or crop will receive the manure. Manure rates are generally determined by regulations, although a producer’s ability to implement rate recommendations will be constrained by both equipment and technology. Manure application methods and timing are primarily logistical decisions based on what equipment is available and the length of storage capacity on a farm. Thus, deciding which crop will receive manure and then choosing the appropriate application rate is paramount. Agronomic, environmental, economic, and logistical issues all enter into the decision process.

Cropping Systems

Typical crops in Minnesota, such as corn, soybean, alfalfa, and perennial grasses, provide different benefits and liabilities in determining the best manure management plan for a farm. Manure has traditionally been considered to be best utilized with corn. Corn has the greatest nitrogen recommendation of crops commonly grown in Minnesota and therefore seemingly presents the greatest economical advantage for replacing commercial fertilizer with manure. Survey research indicated that over 80% of all swine manure was applied to corn (Schmitt, et al., 1996). However, as the environmental issues increase, along with the evidence of manure being strongly under-credited, the justification of exclusively targeting corn is weakening. On a crop removal basis, legume crops in Minnesota, like alfalfa, remove significantly more nitrogen and similar amounts of other nutrients than corn. Applying manure for legumes can be considered an environmental safeguard when the manure is properly managed.

Amount of N, P and K removed by various crops are given in Table 15. When only grain is removed, many nutrients are left in the residues but are temporarily tied up in them and are not readily available. Estimate nutrient requirements for one crop year by assuming complete crop removal. Manure nutrients especially nitrogen are utilized more efficiently by grasses and cereals than by legumes. Legumes get most of their nitrogen from the air, so additional nitrogen is not usually needed.

Research provided agronomic and environmental evidence to the feasibility of applying manure for alfalfa (Schmitt, et al., 1994). Although some farmers report excellent results with applying manure slurry to established alfalfa, most dairy farmers avoid this for a variety of reasons, including the potential for stand damage (Schmitt, et al., 1999). The optimum manure application time is prior to seeding of alfalfa (Schmitt, et al., 1994). This application time minimized the foliage "burn" potential associated with topdress applications and places the immobile nutrients into the topsoil for more efficient use by
the plant. Significant amounts of nitrogen can be removed with alfalfa and, more importantly, the plant compensates its nitrogen fixation amounts by removing more of its nitrogen from the soil when soil nitrogen is present. Interestingly, the forage yields of manured alfalfa resulted in yields greater than established fertilizer response curves would have predicted, thus, the benefits of applying manure extend beyond the nutrient additions. Similar results were also independently measured in Wisconsin research (Kelling and Schmitt, 1996).

While applying manure for alfalfa resulted in encouraging agronomic and acceptable environmental findings, many livestock producers in a corn-soybean rotation were curious if similar results would occur by adding manure before soybean. The principles of manure for soybean parallels that of manure for alfalfa, and the research results were very similar. Schmidt and colleagues investigated manure effects for soybean and measured increased soil nitrogen removal compared to corn, increased seed yields compared to unlimited fertilizer treatments, and better residue management in applying manure into corn residue for the following soybean crop. Downside risks included increased lodging and a more favorable environment for disease incidence if the causal organisms are already present in a field.

Another major crop grown in Minnesota is grass hay. Again, as we search for alternative cropland to apply manure, grass hay was determined to be a viable alternative, especially for producers forced into summer applications of manure due to storage restrictions. We selected reed canarygrass as the most ideal grass for manure applications due to its yield potential, ability to grow under wet or dry soil conditions, its tolerance to salt burn with topdressed fertilizer, and its persistence in the field. These results confirmed that manure applications to a grass crop could be an excellent environmental and agronomic choice. Crop yields are enhanced with manure compared to unlimited fertilizer applications. This grass persists well, even under very high application rates of manure, and the nitrogen removal rates are more than twice as great as corn, thus providing a good crop for recycling of nutrients. Other grass species may provide similar results, but earlier work in Minnesota indicated that reed canarygrass was the best choice for nutrient removal and persistence.

Thus, there are a number of opportunities to use manure nutrients efficiently on a variety of crops. Farmers and their advisors need to be aware of the options they have in selecting fields for manure application.
Table 15. Amount of nutrient removal for various crops. Values are for the total above-ground portion of the plants (MWPS, 1985).

<table>
<thead>
<tr>
<th>Crop</th>
<th>Yield</th>
<th>N</th>
<th>P₂O₅</th>
<th>K₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>lb/acre</td>
<td>----</td>
<td>------</td>
<td>-----</td>
</tr>
<tr>
<td>Corn</td>
<td>80 bu</td>
<td>121</td>
<td>42</td>
<td>77</td>
</tr>
<tr>
<td></td>
<td>100 bu</td>
<td>160</td>
<td>60</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>150 bu</td>
<td>185</td>
<td>80</td>
<td>215</td>
</tr>
<tr>
<td></td>
<td>180 bu</td>
<td>240</td>
<td>100</td>
<td>240</td>
</tr>
<tr>
<td>Corn Silage</td>
<td>16 tons</td>
<td>130</td>
<td>45</td>
<td>102</td>
</tr>
<tr>
<td></td>
<td>32 tons</td>
<td>200</td>
<td>80</td>
<td>245</td>
</tr>
<tr>
<td>Soybeans</td>
<td>30 bu</td>
<td>123</td>
<td>32</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>40 bu</td>
<td>180</td>
<td>45</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>50 bu</td>
<td>257</td>
<td>48</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>60 bu</td>
<td>336</td>
<td>65</td>
<td>145</td>
</tr>
<tr>
<td>Soybeans</td>
<td>30 bu</td>
<td>123</td>
<td>32</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>40 bu</td>
<td>180</td>
<td>45</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>50 bu</td>
<td>257</td>
<td>48</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>60 bu</td>
<td>336</td>
<td>65</td>
<td>145</td>
</tr>
<tr>
<td>Soybeans</td>
<td>30 bu</td>
<td>123</td>
<td>32</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>40 bu</td>
<td>180</td>
<td>45</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>50 bu</td>
<td>257</td>
<td>48</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>60 bu</td>
<td>336</td>
<td>65</td>
<td>145</td>
</tr>
<tr>
<td>Grain sorghum</td>
<td>4 tons</td>
<td>250</td>
<td>90</td>
<td>200</td>
</tr>
<tr>
<td>Wheat</td>
<td>40 bu</td>
<td>70</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>60 bu</td>
<td>125</td>
<td>50</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td>80 bu</td>
<td>186</td>
<td>54</td>
<td>162</td>
</tr>
<tr>
<td>Oats</td>
<td>80 bu</td>
<td>75</td>
<td>35</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td>100 bu</td>
<td>150</td>
<td>55</td>
<td>150</td>
</tr>
<tr>
<td>Barley</td>
<td>65 bu</td>
<td>74</td>
<td>32</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>100 bu</td>
<td>150</td>
<td>55</td>
<td>159</td>
</tr>
<tr>
<td>Alfalfa</td>
<td>4 tons</td>
<td>180</td>
<td>40</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>8 tons</td>
<td>450</td>
<td>80</td>
<td>480</td>
</tr>
<tr>
<td>Orchardgrass</td>
<td>6 tons</td>
<td>300</td>
<td>100</td>
<td>375</td>
</tr>
<tr>
<td>Bromegrass</td>
<td>5 tons</td>
<td>166</td>
<td>66</td>
<td>254</td>
</tr>
<tr>
<td>Tall fescue</td>
<td>3.5 tons</td>
<td>135</td>
<td>65</td>
<td>185</td>
</tr>
<tr>
<td>Bluegrass</td>
<td>3 tons</td>
<td>200</td>
<td>55</td>
<td>180</td>
</tr>
<tr>
<td>Coastal Bermuda Grass</td>
<td>4 tons</td>
<td>225</td>
<td>40</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>10 tons</td>
<td>535</td>
<td>145</td>
<td>410</td>
</tr>
<tr>
<td>Clover-grass</td>
<td>4.5 tons</td>
<td>185</td>
<td>60</td>
<td>175</td>
</tr>
<tr>
<td></td>
<td>6 tons</td>
<td>300</td>
<td>90</td>
<td>360</td>
</tr>
<tr>
<td>Sugar beets</td>
<td>30 tons</td>
<td>75</td>
<td>85</td>
<td>550</td>
</tr>
<tr>
<td>Rice</td>
<td>2.25 tons</td>
<td>110</td>
<td>45</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td>3.5 tons</td>
<td>112</td>
<td>60</td>
<td>168</td>
</tr>
<tr>
<td>Timothy</td>
<td>4 tons</td>
<td>150</td>
<td>55</td>
<td>250</td>
</tr>
<tr>
<td>Pangola grass</td>
<td>12 tons</td>
<td>299</td>
<td>108</td>
<td>430</td>
</tr>
<tr>
<td>Sorghum-Sudan grass</td>
<td>8 tons</td>
<td>319</td>
<td>122</td>
<td>467</td>
</tr>
</tbody>
</table>
The nitrogen, phosphorus, zinc, and copper are all nutrient elements found in animal manures that have the potential to cause environmental degradation. Also arsenic, a non-nutrient toxic element, is found in some animal manures at concentrations that have raised concern. Soils have the capacity to retain a quantity of these elements and crops can rapidly remove very significant quantities of N and P. Thus in agricultural systems the negative environmental impacts of these elements are minimal if the quantity of these elements applied in manure does not exceed the capacity of crop uptake and the ability of soil retention. The capacity of a unit of land to safely handle the manure from a given number of animals can be calculated using the data for uptake and retention of the element of concern.

**Nitrogen**

In Minnesota the capacity of a field to safely utilize manure is defined by best management practices recommendations using an estimation of the nitrogen needs of the crop (Schmitt, et al., 1999). The “Crediting Manure Nutrients: An Asset” section of this document describes in detail how a farmer can estimate available N in any particular form an animal manure. With this information and information on the N inputs and outputs in a livestock system it is possible to calculate an N budget and estimate the carrying capacity of a cropping system for N.

**Nitrogen Leaching to Ground Water**

When excessive rates of manure N or commercial fertilizer N are applied to soils, leaching of nitrate-N into ground water may occur on sensitive soils. At soil temperatures greater than 50°F, ammonium N in manure is rapidly converted by soil microbes to nitrate. Organic N is first converted to ammonium by several types of soil organisms, and then to nitrate (O'Leary, et al., 1989). Nitrate is not retained by the soil particles and the nitrate in excess of that taken up by plants or that lost by denitrification can move with soil water into ground water. This was discussed in detail in the Economic Liability of Manure section.

Even under natural conditions, some nitrate leaches into ground water, but under conditions of long-term applications of high levels of manure or inorganic fertilizer N, nitrate can increase in ground water to values exceeding the US Public Health Service drinking water standard of 10 ppm N. When excessive nitrate leaches into ground water, then the “carrying capacity” then can be said to be exceeded.

Another threat of manure N is the ammonium N in runoff water. Runoff from freshly manured soils can contain elevated ammonium N. This common in the first runoff event following application, especially when the manure is not incorporated into the soil (Wall and Johnson, 1996)
Comparison of Manure and Commercial Fertilizer as N Sources

When manure is applied based on best management practices for determining the quantity of manure, application timing, and application method, leaching of nitrate might be expected to be less from manure than from inorganic fertilizers. This is because the organic N in manure is a slow release source that supplies N to a crop while the crop is growing. Research results, however, suggest that difference between manure and inorganic N sources may not be great.

Results of a study near Waseca showed similar nitrate leaching from liquid dairy manure and inorganic N on corn when manure N was applied using standard methods for estimating N availability. In another study with liquid dairy manure in Goodhue County, nitrate leaching was higher in corn plots with anhydrous ammonia than with liquid dairy manure (Joshi, et al., 1991). Turkey manure applied to sandy loam soils in central Minnesota resulted in similar nitrate leaching compared to inorganic fertilizer applied at similar rates of available N (Malzer, et al., 1992; Nathan, et al., 1992). Tile line water nitrate concentrations under corn in a silty-clay loam soil in Nashua, Iowa, were higher for swine manure plots than inorganic N plots (Kanwar, et al., 1995).

The variability in these results is likely due to the difficulty in estimating the availability of N in manure and in occasional lack in synchrony between N release and crop demand (Sims, 1987). However, in general, nitrate losses to ground water from manure plots are similar to those from inorganic fertilizer. This means that over application of manure N can create as severe a problem as over application of inorganic N, but also that with appropriate management manure is no worse than inorganic fertilizer in terms of nitrate leaching losses. It is very difficult to apportion the sources of nitrate in ground water. Although isotopic tracer techniques have been used (see the Water Resources report), scientific consensus on the reliability of these methods is lacking.

Calculation of Carrying Capacity for N.

When carrying capacity is considered on a broader scale than application of manure to a field or a plot, the ratio of animals to the land available for manure application must be considered. Budget calculations of animal system inputs, outputs, and losses can be useful in defining a maximum environmentally safe ratio of animals to cropland area. Figure 4 shows a N nutrient budget calculation for a dairy system in southeastern USA, with a cropping system that included rye silage, corn silage, and bermudagrass. In this system a ratio of 4.2 animals per acre did not exceed the carrying capacity for N (Van Horn, et al., 1996). This calculation considered all possible N inputs to the system, even the small amount added in rainfall, and all possible losses (although some pathways were only roughly estimated).

In this system, 30% of the N fed to the cows leaves the farm in the milk and 16% is lost to the air through ammonium volatilization from the manure. Ammonia losses are high in large part because liquid manure was applied using a spray irrigation. The system required that purchased feed comprising more than 60% of the N be fed to the cows to make up for N losses, the N sold in the milk, and N storage in soil organic matter.
With repeated application of manure, soil organic matter can increase (see discussion in the Soil Quality report). Because soil organic matter typically contains more than 3% N, this results in accumulation of soil N in forms that are much less available to plants than the organic N in manure. In an N-balanced system, application of manure P will generally exceed that removed by the crops, and soil test P will increase.

Little information is available on the nutrient budgets for the various livestock systems in Minnesota, although Dr. Chester-Jones at the Southern Research and Outreach Center in Waseca is currently collecting this information on six farms in the south central region of the state (discussed in Section on Manure Nutrient Accountability).

![Diagram of N nutrient budget for one hectare (2.5 acres) for an N-balanced dairy system in southeastern USA (Van Horn, et al., 1996)](image)

**Figure 4.** The N nutrient budget for one hectare (2.5 acres) for an N-balanced dairy system in southeastern USA (Van Horn, et al., 1996)

In calculations of carrying capacity, knowledge of the distribution of the crops grown is important. Soybeans and alfalfa are legumes and obtain much of their N from the air, so nitrogen fertilizers are not applied to these crops. The available N in the soil after an alfalfa crop is such that the following corn crop usually needs little or no additional N. The N needs for a small grain crop are much less than corn. In a typical soybean/corn rotation, common to much of southern Minnesota, the carrying capacity for N would usually be calculated using only the corn acreage. Where alfalfa is in the cropping system, the acres of corn grown in the year after alfalfa would be excluded. Recent research, however, has shown that manure can be used as a P and K source for alfalfa and soybeans, thereby extending the carrying capacity in cropping systems containing these legumes. When manure, or fertilizer, N is applied to a soil,
these legumes obtain much less N from the air, and instead take up manure or fertilizer N (Schmitt, et al., 1994;—Lamb, et al., 1995). This is discussed in more detail in the “Nutrient Sources Section” below.

Potassium:

Potassium is a nutrient element that is found in high concentration in manure. Crops need potassium and manure is a good source of this nutrient. Potassium, however, is not an element that causes environmental problems at the levels it is applied in manure. As stated earlier in this report, there are increasing concerns about animal health problems associated with high soil test K levels due to manure and fertilizer, so this element is coming under increased scrutiny.

Phosphorus

Phosphorus in strongly retained by soil particles and unlike nitrate-N it does not readily move with in soil water. However, excess P in surface soils can result in negative environmental impacts when P dissolves from P rich soils and moves by erosion into surface waters.

Also in soils that do not strongly retain P long-term heavy applications of manure can result in elevated P in shallow ground water.

Retention of P by Soils

An important parameter in determining the environmental fate of P is the ability of a soil to strongly retain P. The terms retention and sorption are often used as synonyms for the process of removal of phosphorus from soil water by soil or soil constituents (Wild, 1950). Phosphorus sorption is a function of the amount soil clay and the quantity of calcium carbonate (the mineral in limestone). The type of clay, soil pH, and the quantity of soil organic matter also influence sorption. Soil clay and other soil minerals retain P in a number of ways. Phosphate ions can be adsorbed to some extent on the edges of clay particles and on the surfaces of calcium carbonate, iron oxide and aluminum oxide minerals. Another means of P retention is the formation of compounds of iron, aluminum and calcium. In most Minnesota soils this is mostly due to calcium. In general, fine textured soils (that is clays and clay loams) have a much greater capacity to retain P than course textured soils (that is sands).

When manure is applied on the soil surface, retention by soil particles is minimal and P can run off into surface waters. The poultry industry in some area is beginning to add alum to litter to acidify the litter and reduce ammonia volatilization, which also can decreases P runoff by almost 90% (Shreve, et al., 1995). Alum also decreases the runoff losses of, arsenic and heavy metals (Moore Jr., et al., 1998).

Phosphorus adsorption capacity of the soils can be estimated by standard laboratory methods. When manure P additions are greater than crop removal, the P adsorption capacity of a soil is partially satisfied and laboratory measures of P sorption decrease.
After three years of application of swine storage basin effluent at the rate supplying 28 and 208 lb/acre of P, the sorption capacity of the surface horizon of a sandy soil was 234 ppm where 28 lb/acre of P was applied. However, the P sorption capacity of the soil in plots that received the higher rate of P was only 71 ppm (Reddy, et al., 1980). This means that the soil receiving high rates of manure application was approaching the limit of its capacity to retrain P. Field studies in Oklahoma indicate that long-term manure application reduced the P sorption in the top 2 inches of 12 soils from 354 to 174 ppm (Sims, et al., 1998). Phosphorus sorption capacity of many agricultural fields with a history of manure application in Sussex County Delaware, the site of highly concentrated poultry production, was lower than the non-manured field borders (Mozaffari and Sims, 1994). Similar trends have been reported in other areas where land application of animal manure is extensively practiced (Breeuwsma, et al., 1995;Simard, et al., 1995) (Kingery, et al., 1994). These studies indicate, not surprisingly, that long-term application of animal manure reduces the capacity of soils to retain additional P.

In estimating the capacity of a soil to retain P with sufficient strength to avoid environmental degradation laboratory determination of total P sorption capacity is not sufficient. As more P is adsorbed P becomes more available for plant uptake, more available for dissolving in surface runoff and leaching into ground water, and more available for the promotion of algae growth when soil particles are moved by erosion into surface waters. In the Netherlands a value of 25% of the total sorption capacity has been defined as a critical level that should not be exceeded (Sharpley, et al., 1996).

While some very broad based generalizations can be made about the relative P sorption capacity of agricultural soils in Minnesota, actual quantitative information on individual soils is virtually nonexistent. However, two research projects at the University of Minnesota are currently working to determine the P sorption capacity of a wide range of Minnesota soils.

**Can P Leach to Ground Water?**

Although P is considered to be quite immobile in soils, additions of very large quantities of manure or fertilizer P can sufficiently saturate the P sorption capacity to result in some leaching. This can result in elevated P concentrations in shallow ground water. The 25% critical value for sorption capacity in the Netherlands was defined by the need to minimize the potential of P to leach into shallow ground water (Sharpley, et al., 1996). Because manure has organic forms of P that are not necessarily retained as strongly as the inorganic P in commercial fertilizers the P in manure many be somewhat more mobile in some soils than inorganic fertilizer P.

Some leaching of P was seen in Nebraska in a calcareous soil (containing natural limestone) receiving 43 years of solid beef manure or commercial fertilizer. In this experiment, the addition of excess P resulted in an increase of Olsen soil test P in the surface soil to about 125 ppm, a very high value (see below for a discussion of soil test P). In soil that did not receive manure, little fertilizer P moved beneath 3.5 feet. In the soils receiving nearly equal phosphorus amounts as manure, P moved to greater depths. Possible explanations for the difference were that phosphorus from manure moved in
organic forms, or that chemical reactions occurred with compounds in the manure that may have enhanced solubility (Eghball, et al., 1996). Thus long-term application with heavy loading of manure can result in leaching of phosphorus.

A study of the results of 30 years of heavy application of hog manure to soils with a low capacity for sorption of P shows that heavy manure applications can threaten P pollution in shallow ground water. In a sandy loam soil that has a seasonal water table at one meter depth (3.3 ft) researchers found that in more that half the surface soils sorbed P was greater than 50% of the saturation capacity. At a few the 256 sites sampled the soil from 0.9 meter depth contained sorbed P at greater than 30% saturation of the sorption capacity. This presents a threat of excess soluble P in the ground water (De Smet, et al., 1996)

Research on manure-amended soils in Minnesota and other locations demonstrates that long-term application of animal manure can increase available P in subsurface horizons. Researchers at Waseca incorporated dairy manure for three years on a Webster clay loam soil. Before manure application, soil test P in the surface soils was 30 ppm, but after three years of manure application at very high rates (total of 343 ton/acre of dry manure) soil test P in the surface soil rose to 415 ppm (Randall and Iragavarapu, 1999). At the end of the study soil test P in the subsurface horizon (12-24") was three times higher than in non-manured land.

In another study in Minnesota based on disposal rates of solid dairy cattle manure, no P movement was seen passed the 2- foot depth. The manure was applied to a Webster clay loam soil with an initial soil test phosphorus level of 30 ppm (Bray). It increased soil test values by 9 and 14 times in the surface soil (Randall, et al., 1975). In a more recent study, dairy manure and commercial fertilizer were applied as N sources for 4 years, at agronomic rates, in continuous corn. After 4 years soil test phosphorus was in the surface soil was 43 ppm (Bray) in the soil receiving manure and 26 ppm where inorganic fertilizer had been applied. Losses of phosphorus in subsurface tile drainage were low (Randall and Iragavarapu, 1999).

Thus, application of manure at rates that exceed the capacity of soil to retain P from can present a threat to shallow ground water. However, research on the better agricultural soils of Minnesota that have not been subjected to long-term manure application, suggests that with manure application at agronomic rates little or no P leaching will be observed.

**Setting Environmental Critical Values for Soil Test P**

The concept of soil test phosphorus level is a universally accepted method to estimate plant available phosphorus. Each soil test method uses a different extraction solution and the correlation tables for plant response to soil test values vary with the test procedures (Table 16). Although the values from soil test procedures are in units of ppm these units do not directly compute to the quantity of plant available P. The soil test values are really just index values that have been correlated with plant response. Soil test phosphorus values for optimal crop production have been identified as a range of available soil
phosphorus at which crop response to additional phosphorus fertilizer no longer produces an economic yield benefit. For most crops, application of fertilizer or manure P is recommended for all soil test results less than the very high values in Table 16.

Table 16. Soil test phosphorus calibration for three commonly used test procedures. (Rehm et al 1998; University of Oklahoma, 1999)

<table>
<thead>
<tr>
<th>P-level</th>
<th>Bray ppm</th>
<th>Olsen ppm</th>
<th>Mehlich-3 ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>0-5</td>
<td>0-3</td>
<td>0-10</td>
</tr>
<tr>
<td>Low</td>
<td>6-10</td>
<td>4-7</td>
<td>10-20</td>
</tr>
<tr>
<td>Medium</td>
<td>11-15</td>
<td>8-11</td>
<td>20-40</td>
</tr>
<tr>
<td>High</td>
<td>16-20</td>
<td>12-15</td>
<td>40-65</td>
</tr>
<tr>
<td>Very high</td>
<td>21+</td>
<td>16+</td>
<td>65+</td>
</tr>
</tbody>
</table>

Although soil test phosphorus methods were not meant as estimates of the amount of phosphorus that may potentially be transported with surface runoff or erosion, some states have recommended critical values that if exceeded define unacceptable environmental risk (Table 17). Alabama, Arkansas, Colorado Delaware, Ohio, Mississippi Texas and Utah have established single critical values for P management recommendations that if exceeded require elimination or severe limitation of all sources of P. Indiana, Kansas, Oklahoma, Maine, Michigan and Wisconsin have set 2 or more environmentally critical levels that call for a scaled reduction in P inputs. In Oklahoma test values on the range of 30 to 130 ppm call for a 50% reduction in P rate on slopes in excess of 8%. A values in the range of 130 to 200 ppm a 50% reduction of P inputs on all soils is recommended and at greater than 200 ppm, the P addition should not exceed crop removal. In Michigan, test values in the range of 75 to 150 ppm call for additions of P not to exceed crop removal. At soil test values in excess of 150 ppm no P should be added. In Wisconsin values of 75 to 150 ppm call for planting of P-demanding crops and reduction in P application rates and at test values of greater than 150 ppm, manure should not be added (Sharpley, 1996). In Wisconsin, State regulations are tied to cost share programs.

The use of soil test values for determination of the environmental risk of soil P has been criticized for being too simplistic. Soil test values obtained for predicting potential crop nutrient needs are not necessarily good predictors of phosphorus moving into surface waters. Runoff volume and erosion are critically important components affecting soil phosphorus loss. A comprehensive integrated approach in determining potential phosphorus loss should include soil test phosphorus values and potential phosphorus losses due to runoff and erosion, generally referred to as the P risk index approach (Sharpley, 1996). Clearly, promulgation of any guidelines or regulations involves political decisions, and these issues are discussed in the report on the Role of Government.

Tempealeau County in Wisconsin has developed a phosphorus index that ranks fields for the potential for P to run off the field and reach a water body. The index incorporates soil test P but in addition includes: distance from a stream, infiltration/erodibility rates, how often manure is applied, fertilizer application rate, method of fertilizer application, and
the rate of manure P. The calculated index values resulted in 4 possible recommendations varying from application of manure to meet N needs of the crop to no application of manure (Frame, 1999, personal communication).

Table 17. Soil test phosphorus level management guidelines from seven states.

<table>
<thead>
<tr>
<th>State</th>
<th>Critical Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alabama</td>
<td>250 ppm (Mehlich 3)</td>
</tr>
<tr>
<td>Arkansas</td>
<td>150 ppm (Mehlich 3)</td>
</tr>
<tr>
<td>Colorado</td>
<td>100 ppm (Olsen)</td>
</tr>
<tr>
<td>Delaware</td>
<td>120 ppm (Mehlich 1)</td>
</tr>
<tr>
<td>Indiana</td>
<td>150/200 (Mehlich 3)</td>
</tr>
<tr>
<td>Kansas</td>
<td>100/150/200 (Bray 1)</td>
</tr>
<tr>
<td>Ohio</td>
<td>150 ppm (Bray 1)</td>
</tr>
<tr>
<td>Oklahoma</td>
<td>30/130/200 ppm (Mehlich 3)</td>
</tr>
<tr>
<td>Maine</td>
<td>40/100 ppm (modified Morgan)</td>
</tr>
<tr>
<td>Michigan</td>
<td>75/150 ppm (Bray 1)</td>
</tr>
<tr>
<td>Mississippi</td>
<td>144 (Lancaster P)</td>
</tr>
<tr>
<td>Texas</td>
<td>200 ppm (Bray 1)</td>
</tr>
<tr>
<td>Utah</td>
<td>100 ppm (Olsen)</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>75/150 ppm (Bray 1)</td>
</tr>
</tbody>
</table>

Adapted from (Sharpley, 1996, Lory and Scharf, 1999)

Calculation of Carrying Capacity for P

Manure application at disposal rates or agronomic rates designed to meet the N needs of crop result in a build up of soil phosphorus levels. If a soil already has sufficient P for maximum crop production, maintenance of crop productivity only requires addition of P sufficient to replace the P removed by the crop. Calculation of the P balance for the southeastern USA dairy system (Figure 5) showed that restricting manure P additions to crop removal rates reduced the carrying capacity to 2.2 animals per acre (Van Horn, et al., 1996). This is about one-half the value when manure is applied at rates sufficient to supply the N needs of the crops. Major differences between N and P are that the losses of P from the system are very small and essentially all the P is available for crop uptake. Also, when organic matter builds up in soil in response to repeated manure additions the accumulation of organic N is much greater than organic P. In soil organic matter, the N to P ratio is about 10, whereas in many manures the ratio is about 2 (poultry litter often has a ratio of 1). In a P-balanced livestock/cropping system, inorganic N would be needed for the production of corn and grasses.

Phosphorus budget data are not yet available for Minnesota farms. However, some understanding of the difference in the response of soils in Minnesota to P inputs at crop removal rates vs. inputs in excess of crop removal rates can be gained from the results of a long-term study of inorganic P applications at Waseca and Morris. In this study, increases in phosphorus test levels over 12 years of fertilizer application were measured in a corn/soybean cropping system. During the next 8 years, decline rates in phosphorus and potassium soil test levels were measured. Average annual additions of 22 lb/acre of P ($P_2O_5 \times 0.44 = P$), resulted in only a slight increase on soil test P (Figure 6). This is
approximately the crop removal rate. Average annual additions of 44 lb/acre of P resulted in an increase of about 35 ppm Bray soil test units after 12 years. This increase resulted from addition of about 290 lb/acre of P, in excess of crop uptake. The researchers concluded that soil test phosphorus levels maintained at 18 to 20 ppm, with an annual application of 20 to 25 lb P/acre/year (crop removal rate), would be best for optimum profitability for corn and soybeans in southwest and south central Minnesota. The results indicate that producers with very high soil test phosphorus levels (Table 16) could eliminate phosphorus application and use soil testing to monitor phosphorus drawdown (Randall, et al., 1997). Although this study did not include manure as a treatment, the concepts are similar when interpreting soil P fertilization with manure. Soils testing very high in phosphorus due to long-term or over application of livestock manure would require no additional phosphorus.

The definition of P carrying capacity of a soil/cropping system depends on the P soil test value, soil type, and crops grown. At low soil test P, phosphorus is not necessarily a factor in calculating carrying capacity. Rather carrying capacity can be defined by the crop need for N. At higher P test values the carrying capacity might logically be defined

Figure 5 The P nutrient budget for one hectare (2.5 acres) for an N balanced dairy system in southeastern USA (Van Horn, et al., 1996)
by crop P removal rates. Michigan sets a critical Bray soil test P value of 75 ppm to trigger a recommendation of P addition not to exceed crop removal. At still higher soil test P some states have chosen to recommend no manure or commercial fertilizer P application (Table 17). The increase in soil test P with addition of a given quantity of manure (or inorganic P) is a function of the P sorption capacity of a soil. Thus, the increase in soil test P with a given addition of manure or inorganic P is greater in sandy soils than in clayey soils and clayey soil can be said to have a greater capacity to retain added P.

One new way to increase P retention in manure-amended soils is to add alum, an industrial byproduct, to the manure. This approach has been championed by Patrick Moore (USDA-ARS in Arkansas) for use in poultry production. Poultry litter contains significantly greater amounts of soluble P than other manures and fertilizer. Soluble P was reduced significantly by application of alum and by composting (Chaubey, et al., 1995).

Alum added to poultry litter was effective at reducing soluble P from over 2,000 ppm P to 467 ppm P for an addition of 0.1 lb alum/lb litter and to 111 ppm P for an addition of 0.2 lb alum/lb litter (Shreve, et al., 1996). Amended poultry litter was then incubated with soil for up to 100 days. Soluble P concentrations in soil incubated at pH 7 for less than one day were 15 or 9 ppm P for the 0.1 or 0.2 lb alum rate, respectively. Much larger reductions in soluble P were attained by incubating litter in soil for as many as 100 days.

Soluble P levels in runoff from a silt loam soil receiving alum-amended poultry litter were 87% lower than levels from soil receiving amended litter without alum (Shreve, et al., 1995). Runoff loads of soluble P and total P with the alum-amended litter were reduced by over 80%.
Addition of alum to poultry litter decreases the fecal coliform levels in runoff from manured fescue plots from 63,000 to 12,000 CFU/100 mL (Moore, 1998). In comparison, plots receiving no manure had from 1,500 to 1,700 CFU/100 mL in runoff. Additions of alum also decreased runoff concentrations of arsenic, copper, iron, and zinc associated with the soluble organic carbon fraction of runoff.

Both alum and ferrous sulfate amendments to manure can significantly reduce ammonia volatilization from poultry litter (Moore, et al., 1996). This has very positive benefits to worker and poultry health. Moore (1998, personal communication) has found no
increases in soluble aluminum in soil treated with alum. Because addition of alum to poultry litter increases the availability of N to crops, reduces heavy metal runoff, improves human and poultry health, and decreases the solubility and loss of P, it promises to be an important tool in improving the environmental sustainability of poultry production.

**Zinc, Copper, and Arsenic**

Zinc, copper, and arsenic are added to animal feeds to improve animal health. Zinc and copper elements are added as anti-microbial compounds that increase weight gain. Both elements are essential nutrients that are required for plant and animals health. At higher concentrations, however, they can be toxic. Four arsenic-containing compounds has been common in the diets of broilers, turkeys, and laying hens (Fontenot, 1981).

We could not find data for As in manure in Minnesota. A mean value for poultry manure reported in 1981 was 40 ppm (Fontenot, 1981). This may not be greatly different from current concentrations in poultry manure. Recently researchers in Arkansas reported a value of 43 ppm Arsanilic acid and 3-nitro-4-hydroxyphenylarsonic acid (3-nitro) are excreted largely unchanged with as much as 88% of ingested 3-nitro occurring in the broiler excreta, according to (Fontenot, 1981). However, poultry diets have changed since then and the arsenic content of animal diets is more restricted now.

**Arsenic Retention in Soils**

Arsenate is a non nutrient toxic element that in soil behaves very much like phosphate. For example, arsenic retention in soil increases with increasing clay content and with increasing Fe and Al mineral content. The arsenic retention capacity of the soils of Minnesota has not been studied.

**Copper and Zinc Retention and Response to Manure Additions**

Copper (Cu) and zinc (Zn) are retained tightly by soil particles and do not readily move through soils with water. These elements are retained by a number of processes, including sorption by iron, manganese, and aluminum oxides, and strong bonding with soil organic matter. In a study involving sewage sludge, researchers found that copper adsorption in a soil was always greater than zinc adsorption, particularly in the surface soil. The researchers reported that copper sorption increased with increasing organic matter whereas zinc sorption was dependent on clay content (Eulalia-de-Mesquita, et al., 1993). Just as the solid organic matter in soils retains Cu, the mobility of Cu in soil water can be increased due to soluble organic matter. In a laboratory study, strong interaction of Cu with the dissolved organic matter in a swine manure slurry helped keep Cu in solution. The researchers suggested that association with dissolved organic matter is a possible factor in movement of Cu though soils after swine slurry application (Giusquiani, et al., 1998).
Soil test levels for copper increase after long applications of manure from animals fed with diets high in added Cu. Four years of application of 180 t/ha of liquid swine manure (wet weight) from animals fed with a ration containing 250 ppm added Cu substantially increased soil test Cu. However, little effect was observed in corn tissue Cu concentration (Sutton, et al., 1983). Bouldin and Klausner (1998) stated that long-term applications (10 years) of pig manure to corn at agronomic rates could increase soil Cu levels by a factor of 2 to 10 times.

Eight years of application of copper sulfate or Cu-enriched swine manure on three soils in Virginia greatly increased the soil test Cu, but did not increase corn tissue Cu concentrations or adversely affect corn production. In this study the total Cu added was as much as 300 lb/acre as copper sulfate and 250 in Cu enriched manure. The manure contained up to 1,550 ppm Cu and was produced by pigs fed diets with an average of 251 ppm Cu. The authors reported large increases in soil test Cu in the surface soils, but very little increase in subsoil Cu even in the fine sandy loam soil. Thus, little, if any, Cu was transported into the subsoil (Payne, et al., 1988). A follow up study was conducted on the same plots after eleven years of manure applications. The main finding of that study was that the capacity of the soils for sorption of Cu, in a laboratory test, was actually increased with application of high Cu manure (Zhu, et al., 1991). The increased sorption capacity was due to an increase in organic matter content after manure addition.

**EPA Sewage Sludge Limits for Copper, Arsenic, and Zinc**

Because few data are available from manure studies that are useful for estimation of limits for application of manure Cu and Zn to soils, it is necessary to look to the body of knowledge available for sewage sludge application to soil. The USEPA in 1993 established the 503 sewage sludge rules which set limits on the concentration of toxic elements in sludge (Table 18) and on quantity that can be applied over the life-time of the site (Table 19). It is unlikely that any manure would violate the ceiling concentration limits but with very long-term application, the loading limits could be exceeded.

If elemental concentrations are known and an application rate is assumed, the time for exceeding the EPA lifetime loading rates can be calculated. For average heavy metal contents of manure at manure applications of 10 to 12 tons/acre and assuming 30-40% moisture in the manure, the limits would not be exceeded for cadmium in 169 years, zinc in 388 years, copper in 660 years, and lead in 40,000 years (Sweeten, 1993). With poultry manure, arsenic (As) may be more limiting than the metals. A similar calculation for arsenic as above, assuming a 40 ppm dry weight As concentration (Fontenot, 1981), suggests the loading limit for As would be exceeded in about 110 years.

**CURRENT LEVEL OF P, Zn, and Cu**

**Soil Testing in Minnesota**

Due to the diversity in soil properties and varying solubility of different nutrients, a number of chemical extractants have been developed to measure plant available nutrients in different regions. As an example, soil testing laboratories across the USA use at least
five different chemical extractants for measuring plant available P. Each method is most suited to the region in which it is being utilized. Soil tests are also offered for K.

Because Minnesota is a large state with diverse soils, two different soil P extractants are used. The Bray-P1 method is used to measure plant available P in soils with pH lower than 7.4 and the Olsen method is used for soils with higher pH. Soils with Bray-P1 value lower than 5 ppm or an Olsen P value of less than 3 ppm are considered low in P and application of P fertilizer has a high probability of increasing crop yield (Rehm, et al., 1994). Table 16 shows current University of Minnesota interpretations for various soil P levels.

Table 18. EPA 503 Ceiling concentration for metals in sewage sludge.

<table>
<thead>
<tr>
<th>Element</th>
<th>ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>75</td>
</tr>
<tr>
<td>Cadmium</td>
<td>85</td>
</tr>
<tr>
<td>Copper</td>
<td>4,300</td>
</tr>
<tr>
<td>Lead</td>
<td>840</td>
</tr>
<tr>
<td>Mercury</td>
<td>57</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>75</td>
</tr>
<tr>
<td>Nickel</td>
<td>420</td>
</tr>
<tr>
<td>Selenium</td>
<td>100</td>
</tr>
<tr>
<td>Zinc</td>
<td>7,500</td>
</tr>
</tbody>
</table>

Table 19. EPA 503 cumulative pollutant loading rates for metals

<table>
<thead>
<tr>
<th>Element</th>
<th>Loading rate (lb/acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic</td>
<td>37</td>
</tr>
<tr>
<td>Cadmium</td>
<td>35</td>
</tr>
<tr>
<td>Copper</td>
<td>1,340</td>
</tr>
<tr>
<td>Lead</td>
<td>268</td>
</tr>
<tr>
<td>Mercury</td>
<td>15</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>-</td>
</tr>
<tr>
<td>Nickel</td>
<td>375</td>
</tr>
<tr>
<td>Selenium</td>
<td>89</td>
</tr>
<tr>
<td>Zinc</td>
<td>2,500</td>
</tr>
</tbody>
</table>

A number of private soil testing laboratories provide soil analysis services, as does the University of Minnesota Research Analytical Laboratory. Because most farmers rely on their fertilizer dealer or crop consultant to provide fertilizer recommendations, the vast majority of soil tests are performed by private laboratories associated with those companies.
In addition to K and P, the University of Minnesota Research Analytical Laboratory offers soil testing services for available Ca, Mg, and metals such as iron, copper, and zinc. Soil test for recommendations for Cu are available for soils with very high (more than 80%) organic matter (Histosols). Using DTPA it is also possible to test for manganese, chromium, cadmium, nickel, and lead. However, in Minnesota no agronomic interpretation is made for the soil test results for Mn, Cr, Cd, Ni, and Pb. Historically, the role of agronomic interpretation of soil test data has been to assess the potential nutrient deficiencies and most agricultural soils in Minnesota contain adequate levels of Cu, Mn, Fe, and zinc (Rehm, et al., 1994). A more complete discussion on fertilizer recommendations for agronomic and horticultural crops in Minnesota is provided by (Rehm, et al., 1994) and (Rosen and Eliason, 1996).

How the Data Were Collected

In 1991 to 1993, 69% of the soil samples tested by the University of Minnesota Research Analytical Laboratory had soil test P values greater than 21 ppm and 38% of the samples had exchangeable K levels greater than 120 ppm (Munter, 1994, as cited in (Randall, et al., 1997)). Other than that reference, there are no published summaries available on current levels of nutrients and metals in agricultural soils of Minnesota. Some raw data exist in the electronic archives of the University of Minnesota Research Analytical Laboratory, but data from private laboratories was not available in an electronic format or could not be converted to a format easily compatible with our statistical software for this project. We have summarized the data from the archives of the University of Minnesota Research Analytical Laboratory. To obtain a more representative sample, the data from last five years were (1994-1998) were included in the statistical analysis. The soil test values are from commercial farms only.

Presented in the APPENDIX section (Appendix Table 1) are the data for soil extractable P (Bray-P1 or Olsen method) and DTPA-extractable copper and zinc. The number of samples tested from each county, means, and standard deviations by the county are listed there. The data base contained about 24,000 observations for the Bray method, 3,670 observations for the Olsen method, 1,970 observations for copper, and 568 observations for zinc. This is a very small subsample. An additional 10,000 soil samples from farms in western Minnesota were analyzed by the North Dakota State University Laboratory during 1993-1998. Unfortunately, the format of that data was not compatible with our data base.

Because private laboratories perform the vast majority of soil test analysis, and soil samples from certain areas of Minnesota are often sent to the public laboratories in the adjacent states, the readers are cautioned that these data do not represent an unbiased sample of all Minnesota farmland. Consequently, the interpretations and conclusions in this report must be considered tentative.

Summary of Soil Test Results from University of Minnesota Archives

The distribution of soil test P by Bray or Olsen method for different counties in Minnesota is presented in Figures 7 and 8. To avoid biased results due to low sample
numbers, we present the data only for those counties where 100 or more samples had been analyzed by the University of Minnesota Research Analytical Laboratory. As a result, data for some counties are not mapped and are designated as ‘insufficient data.’ Readers interested in means for any specific county should refer to the appendix, but should not rely on that average as being definitive.

There was a wide range of variation in available phosphorus across the state. Mean soil test phosphorus values for various counties across the state ranged 6 to 65 and 5 to 38 ppm as measured by Bray and Olsen methods, respectively. The median Bray and Olsen soil test phosphorus for various counties across the state were 28 and 19 ppm, respectively. The mean value for Bray soil test P for several counties in central Minnesota ranged from 41 to 63 ppm.

These values are generally lower than seen in Wisconsin. The soil test laboratory at the University of Wisconsin has published summaries of soil test data for 1968 to 1994. These data include the University data plus the certified private laboratories in the state. The data show that the state mean for Bray P has increased from 34 for 1968-73 to 50 for 1990-94. The 1990-94 data show one county with a mean value of more than 150 ppm and 4 counties with mean values in the range of 75-150 (Combs, 1995); (Combs, et al., 1996)

Although the University of Minnesota data base had insufficient samples for many western Minnesota counties, data from North Dakota State University indicated that in general phosphorus levels in these soils were lower than in central Minnesota. This is not surprising, because many western Minnesota soils are calcareous and can tie up large amounts of phosphorus.

A few counties were selected that represented different areas of the state (Table 20). These results show that there are large numbers of fields that have excessive soil test P levels. We do not know if these high P tests are related to manure application. Stearns County generally leads other counties in milk and cattle, producing about one ninth of all milk in Minnesota and having about 70,000 adult bovines. Manure production in this county is quite high (see Water Quality report). In contrast, lower numbers of excessive soil P tests in Rock and Waseca counties probably reflects the high P-fixing capacity of their soils.

The mean, standard deviation, and the total number of samples tested for DTPA extractable (plant available) copper and zinc from all counties is presented in Table 21. There was a large variability in extractable copper and zinc in soils across the state as suggested by standard deviations that were more than twice as large as the mean. This indicates that the distribution of data likely was skewed, rather than being symmetrically bell-shaped. Therefore, the median probably better represents the central tendency of the data, that is, the median better represents what the typical soil in Minnesota contains.
With the exception of a few soils, most counties had an average soil test copper below 2.5 ppm and the median soil test copper of 0.7 ppm. In general, the critical level for DTPA extractable copper is 0.12 to 2.5 ppm (Sims and Johnson, 1991). In another words, crops grown on soils that have soils that have a DTPA extractable copper levels of less than 0.1 to 2.5 ppm may benefit from copper fertilization. However, crops in Minnesota usually do not show increased yield with copper application, except on organic soils (Rehm et al., 1994).
The median zinc soil test value for various counties across the state was 2 ppm. The critical range for DTPA extractable zinc is reported to be between 0.2 to 2 ppm (Sims and Johnson, 1991), but in Minnesota, crops typically do not respond to zinc addition at soil test levels greater than 0.75 ppm (Rehm et al., 1994).

![Olsen P Data by County](image_url)

Figure 8. Mean soil Olsen-P for Minnesota counties based on the University of Minnesota Research Analytical Laboratory database (1994-1998). Counties where less than 100 samples had been analyzed are categorized as “insufficient data”.

The data base does not suggest significant accumulation of copper and zinc in agricultural soils of Minnesota. A more definitive evaluation of the current levels of phosphorus, copper, and zinc in agricultural soils of Minnesota requires detailed
statistical analysis of considerably larger data bases from neighboring states and many private soil testing laboratories.

Table 20 Distribution of Bray P in selected counties of Minnesota.

<table>
<thead>
<tr>
<th>County</th>
<th>No. of samples</th>
<th>Percentage of samples testing greater than</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ppm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>75</td>
</tr>
<tr>
<td>Dakota</td>
<td>1,103</td>
<td>18</td>
</tr>
<tr>
<td>Rock</td>
<td>914</td>
<td>3</td>
</tr>
<tr>
<td>Stearns</td>
<td>855</td>
<td>25</td>
</tr>
<tr>
<td>Waseca</td>
<td>400</td>
<td>13</td>
</tr>
<tr>
<td>Washington</td>
<td>1,165</td>
<td>14</td>
</tr>
</tbody>
</table>

Table 21. DTPA-extractable copper and zinc in Minnesota soils, calculated from the University of Minnesota Research Analytical Laboratory data base for 1994-1998.

<table>
<thead>
<tr>
<th>Element</th>
<th>Number of samples</th>
<th>Median</th>
<th>Mean</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>-------</td>
<td>------</td>
<td>-----------</td>
</tr>
<tr>
<td>Copper</td>
<td>568</td>
<td>0.7</td>
<td>2.1</td>
<td>4.0</td>
</tr>
<tr>
<td>Zinc</td>
<td>1,974</td>
<td>2.0</td>
<td>3.5</td>
<td>9.6</td>
</tr>
</tbody>
</table>

Implications of Soil Test Results

The Minnesota database provides a reference point for evaluation of current levels of available nutrients and metals in agricultural soils of the state. However, manure-amended soils are not separated from non-manured soils. In a 1996 survey of Minnesota dairy farmers, (Russelle, 1999) found that nearly 80% of respondents reported soil test P levels greater than 20 ppm. The overall median of these reports was 40 ppm, but the median was twice as high for Alfisols than for Mollisols. This may be due to differences in manure and fertilizer management, to soil characteristics, or to a combination of factors. The finding that soil nutrient levels are high or excessive on some contemporary farms in Minnesota reflects findings in other states.

Nutrients accumulated to excessive levels in manure-amended soils can potentially be transported by runoff or leaching into surface and/or ground waters and impair water quality. Accumulation of excessive amounts of metals increases the potential for metal uptake by plants and subsequent biological magnification through the food chain. Knowledge of current levels of nutrients and potential pollutants in manure-amended
soils of Minnesota will identify problem areas that may pose a risk to environmental quality.

Such information can be used to gain insight into long-term nutrient supplying capacity of agricultural soils in Minnesota. Long-term research at Waseca and Morris, Minnesota showed that soil test P levels declined by less than 2.7 ppm/year on high-testing soils with continuous corn production and no additional P fertilizer (Randall, et al., 1997). Field research on high P soils in other states indicated that it required 16 years of continuous cropping in a high P soil (100 ppm) to decrease soil test P to 20 ppm (McCollum, 1991) (Sims and D.C. Wolf, 1994).

Quantification Of Statewide Nutrient Inputs From Various Sources

Table 22 presented in this section provides an estimate of total state-wide nutrients inputs from a number of inorganic and organic sources. However, it does not represent the amount of plant available nutrients. Missing are estimate of nutrient loss and fate during the storage, pretreatment, and handling of manure, and calculations of feed purchased from outside the state. In addition, livestock manure and soil nitrogen should be considered temporary storage pools for nitrogen that entered the state through other pathways.

It is also important to remember that not all nutrients will be retained in the soil. Understanding the pathways and factors of nutrient losses will assist all persons associated with land application to use agronomic rates and apply as close to plant uptake as possible.

A WORD OF CAUTION

Quantification of the nutrient input into any agro-ecosystem is very much dependent on the assumptions used in developing that particular nutrient budget. For example, the National Research Council developed a state by state nutrient budget for the entire USA using data from 1987 (National Research Council, 1993). For the state of Minnesota, they reported N fertilizer sale of 580,000 tons, recoverable manure N of 79,800 tons (we are reporting the estimated amount of manure excreted in 1997), and an equivalent to 242,000 tons of N from crop residue. Therefore, any nutrient budget should be evaluated with careful consideration of underlying assumptions and potential limitations involved. In the table below, many of the assumptions used in the calculations are listed as footnotes for each calculation. We do not present these as proportions of total input due to the tentative and confounded nature of these estimates. Further discussion can be found in the Water Quality section.
TABLE 22. Sources of nutrients and the assumptions used in developing the table.

NOTE: Nitrogen contribution by some of the processes quantified in this table are mutually exclusive. Consequently, summing up the amount of nitrogen produced by all various sources provides an overestimation of the total amount of nitrogen. Also nitrogen transformations in the soil such as denitrification and immobilization has not been quantified due to the complexity of the issue.

<table>
<thead>
<tr>
<th>Nutrient source</th>
<th>Nitrogen</th>
<th>Phosphorus</th>
<th>Potassium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal manure excretion</td>
<td>245,000</td>
<td>66,000</td>
<td>154,000</td>
</tr>
<tr>
<td>Commercial fertilizer</td>
<td>730,000</td>
<td>131,000</td>
<td>264,000</td>
</tr>
<tr>
<td>Soybean credit</td>
<td>123,000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Hay credit</td>
<td>36,000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Soil residual credit</td>
<td>129,000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Organic matter mineralization</td>
<td>946,000</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sewage sludge</td>
<td>1,400</td>
<td>640</td>
<td></td>
</tr>
<tr>
<td>Atmospheric deposition</td>
<td>134,000</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

--- US tons ---

\[ a \] Manure nutrient values were estimated using cattle, hog, chicken broiler, and turkey inventories and average nutrient content of manures from (Schmitt and Rehm, 1998a; Schmitt and Rehm, 1998b; Schmitt and Rehm, 1998c). The numbers do not take into account the nutrient losses during the storage. Significant amounts of nitrogen can be lost during storage, principally due to ammonia volatilization. However, research indicated that much of the volatilized ammonia will be reabsorbed by vegetation, soil, and surface water within several miles of the source.

\[ b \] 1996 fertilizer sale data. We assumed fertilizer purchase in Minnesota was applied in the state.

\[ c \] Soybean credits were computed using a recommended fertilizer credit of 40 lb/acre on soybean acreage, which is the standard value used in Fertilizer Recommendations for Agronomic Crops in Minnesota by (Rehm, et al., 1994).

\[ d \] Hay credits were computed using 100 lb/ac on 1/3 of hay acreage (assuming 1/3 of acreage in a 3-year rotation is plowed down). This is a standard fertilizer recommendation credit used in Fertilizer Recommendations for Agronomic Crops in Minnesota by (Rehm, et al., 1994) for alfalfa stands averaging 2-3 plants per square foot.

\[ e \] Residual soil N credits were computed using 50 lb/acre from wheat and corn cropland acreage in counties where a soil N test is recommended. This is the soil nitrate-N generated by soil organic matter mineralization and other processes that is carried over from the previous crop.

\[ f \] Organic matter mineralization was computed using 20 lb/acre on fertilized cropland acreage, based on two percent mineralization of organic matter nitrogen per year and using county averages of soil organic matter concentration.

\[ g \] (Stark, 1999, personal communication). These values are for the amount of total N and P that are land applied. The amount of nutrients available for potential plant uptake will depend on the rate of mineralization of these nutrients.

\[ h \] Atmospheric deposition data from (Montgomery, 1991). This data does not include dry deposition estimates, which are typically equal to wet deposition (Krupa, 1999, personal communication), nor redeposition of locally derived ammonia (Burkart and James, 1999).
CURRENT RESEARCH

Current Research Interview Sheet

Investigators: Larry J. Cihacek

Institution or Affiliation: North Dakota State University

Title of Study: Restoration of productivity in eroded fields with manure additions

Funding Agency: USDA

Duration of Study: 1990-2000

Objectives: To evaluate how effective manure is in restoring productivity of eroded soils.

Key Words: manure, erosion, soils, productivity

Location (or Locations) of Study: North Dakota

Type (or types) of Soil Used:

Climate: semiarid

Approach: Manure is being applied to eroded soils and compared to non manured soils with commercial fertilizer. Soil quality is being assessed by measuring water stable aggregates and organic carbon by depth.

Progress:

Potential Implications: A quantitative value for manure as a soil remediation treatment can be identified.
Current Research Interview Sheet

Investigators: Daniel Ginting, John F. Moncrief, and Satish C. Gupta

Institution or Affiliation: University of Minnesota

Title of Study: Losses of pollutants to surface tile inlets on a landscape scale using a paired watershed technique

Funding Agency: LCMR, MDA, and USDA

Duration of Study: 1996-2000

Objectives: To evaluate the effect of conservation tillage and manure application on profitability and pollutant losses to surface tile inlets on a landscape scale.

Key Words: tillage, conservation, manure, pollutants, drainage, surface inlet, tile

Location (or Locations) of Study: South Central Minnesota

Type (or types) of Soil Used: Spicer and Medilia clay loams

Climate: South Central MN

Approach: A paired watershed approach is being used to estimate the effect of conservation tillage and manure application on runoff losses of N, P, and oxygen demanding materials into surface tile inlets. Each watershed is about 130 acres in size and drains to a surface tile inlet. The flow is monitored with a bidirectional sensor and grab samples taken with an automated sampler.

Progress: The baseline period has been completed. The treatment period will begin in the fall of 1999.

Potential Implications: Most of the data evaluating losses are from small runoff plots. This study is unique in that it is on a large scale and quantitatively estimates the losses into surface tile inlets.
Current Research Interview Sheet

Investigators: Thomas L. Richard, Cynthia C. Cambardella, and Thomas E. Loynachan

Institution or Affiliation: Department of Agricultural and Biosystems Engineering Iowa State University, National Soil Tilth Laboratory USDA, and Department of Agronomy Iowa State University respectively

Title of Study: Surface and subsurface drainage tile pollutant losses with integration of manure into conservation tillage systems

Funding Agency: Leopold Center for Sustainable Agriculture

Duration of Study: Objectives: This study will address swine manure nitrogen dynamics as influenced by the composting process and land application of the compost product.

Key Words: swine, manure, compost, nitrogen, biofilter

Location (or Locations) of Study: Iowa

Type (or types) of Soil Used:

Climate: Iowa

Approach: Typical rates of nitrogen loss from hoop manure compost will be measured, and two management strategies to conserve nitrogen during the composting process will be evaluated: 1) the addition of topsoil to the mixture to provide extra exchange sites for nitrogen, and 2) the application of a layer of stabilized compost on top of the pile as a “biofilter” to trap ammonia in the exhaust gas stream. Incubation studies will be used to measure C and N mineralization of these composts after they are applied to soil.

Progress:

Potential Implications: The goal is to help farmers develop compost products that synchronize nitrogen release and crop-uptake and improve the overall quality of the soil.
Current Research Interview Sheet

Investigators: Thomas L. Richard, Cynthia C. Cambardella, Matt Liebman, and Derrick N. Exner

Institution or Affiliation: Department of Agricultural and Biosystems Engineering Iowa State University, National Soil Tilth Laboratory USDA, Department of Agronomy Iowa State University, and Iowa State University Extension Service respectively

Title of Study: Optimizing Swine Hoop Manure Management for Soil Quality and Crop System Performance

Funding Agency: Leopold Center for Sustainable Agriculture

Duration of Study:

Objectives: This study will evaluate the impact of alternative hoop manure management strategies on soil quality and cropping system performance.

Key Words: hoop barn, soil quality, cropping system

Location (or Locations) of Study: Iowa

Type (or types) of Soil Used:

Climate: Iowa

Approach: Alternatives to be tested include both fall and spring applications of composted or bedded manure in a corn-soybean rotation. The study will include both replicated plot studies at an ISU research farm (on-station) and field trials with members of Practical Farmers of Iowa (on-farm). The on-station experiments will allow large numbers of well controlled replicated plots and detailed measurement of soil and crop effects, while the on-farm experiments will evaluate a wider range of soil, manure, and crop management practices and help define the range of possible outcomes.

Potential Implications: The on-farm research also provides us with the opportunity to gain data on labor, equipment, and management tradeoffs, which farmers will ultimately balance against agronomic impacts in deciding which strategy to pursue.
Current Research Interview Sheet

Investigators: Thomas L. Richard and C. Clare Hinrichs

Institution or Affiliation: Department of Agricultural and Biosystems Engineering Iowa State University, Department of Sociology Iowa State University

Title of Study: Socio-economic and Environmental Dimensions of Swine Manure Management Decisions

Funding Agency: Leopold Center for Sustainable Agriculture

Duration of Study:

Objectives: This study is investigating farmer attitudes toward and decision-making about manure management systems.

Key Words:

Location (or Locations) of Study: Iowa

Type (or types) of Soil Used:

Climate: Iowa

Approach: Farmers using a wide variety of systems are being interviewed in two different watersheds to better understand their views on the advantages and disadvantages of different systems, their perspectives on how manure management fits into their overall farming operation, and assessing how concerns about environmental protection influence their decisions and actions.

Potential Implications:
Current Research Interview Sheet

Investigators: Matt Liebman and Thomas L. Richard

Institution or Affiliation: Department of Agricultural and Biosystems Engineering Iowa State University, Department of Sociology Iowa State University

Title of Study: Soil Amendment Effects on Crop–Weed Interactions

Funding Agency: Leopold Center for Sustainable Agriculture

Duration of Study:

Objectives: In this project, we will examine how substitution of composted swine hoop house manure for synthetic fertilizer affects corn and weeds common in Iowa corn fields.

Key Words:

Location (or Locations) of Study: Iowa

Type (or types) of Soil Used:

Climate: Iowa

Approach: Maintenance of soil fertility and effective regulation of weed populations are critical components of productive cropping systems. Although manure can serve as a means moving weed seeds back onto fields, composting kills many seeds. Previous work by the principal investigators also indicates that increased reliance on organic soil amendments rather than synthetic fertilizer can improve crop performance and reduce weed growth and competitive ability, due to changes in soil biochemistry and microbiology. We will test whether this is true for corn production in Iowa.

Potential Implications:
Current Research Interview Sheet

Investigators: M.P. Russelle, B. Shaw, J.F.S. Lamb

Institution or Affiliation: USDA-ARS at Univ. of Minnesota, Univ. Wisconsin

Title of Study: Preventing ground water nitrate impacts from abandoned barnyards using \( N_2 \)-fixing and non-\( N_2 \)-fixing alfalfa

Funding Agency: ARS In-house funds, WI DNR

Duration of Study: 3 years

Objectives: Determine whether non-\( N_2 \)-fixing is as effective as normal alfalfa in preventing ground water nitrate impacts after a feedlot is abandoned.

Key Words: barnyard remediation, ground water nitrate

Location (or Locations) of Study: Portage Co., WI

Type (or types) of Soil Used: Sandy loam

Climate: Moist subhumid

Approach: We planted large plots (100 X 200 feet) of alfalfa, determined spatial variability in topsoil N and soil profile inorganic N, are measuring plant response, and have installed multi-port wells to monitor up-gradient and down-gradient ground water nitrate at several depths.

Progress: Experiment was begun in 1998

Potential Implications: Use of non-\( N_2 \)-fixing alfalfa may provide a more effective means of removing nitrate from soil that has received high rates of livestock manure.

Publications: None
Current Research Interview Sheet

Investigators: M.P. Russelle, B. Shaw, D. Undersander

Institution or Affiliation: USDA-ARS at Univ. of Minnesota, Univ. Wisconsin

Title of Study: Improved pasture management on sandy soils to prevent ground water impacts

Funding Agency: ARS In-house funds, various WI sources

Duration of Study: 3 years

Objectives: Determine ground water impacts of current pasture management and improved practices for intensive rotational grazing.

Key Words: pasture, ground water nitrate

Location (or Locations) of Study: Waupaca Co., WI

Type (or types) of Soil Used: Sandy loams

Climate: Moist subhumid

Approach: We have installed multi-port wells to monitor up-gradient and down-gradient ground water nitrate at several depths in three pastures. Plant and soil samples are being taken to monitor N status. After background conditions are assessed, one-half of each paddock will receive improved practices, as jointly defined by the farmers and researchers.

Progress: Experiment was begun in 1998

Potential Implications: Although leaching losses of nitrate under pastures are very small on fine-textured soils in the North Central Region, we suspect losses may be high on sandy soils. Improved management techniques may help improve the environmental sustainability of grazing on these soils.

Publications: None
Current Research Interview Sheet

Investigators: M.P. Russelle, R. Leep

Institution or Affiliation: USDA-ARS at Univ. MN, Michigan State U.

Title of Study: Nitrate leaching losses under N-fertilized grass and grass-legume pastures on shallow, loamy soils.

Funding Agency: ARS In-house funds, U. MI In-house funds

Duration of Study: 3 years

Objectives: Determine the relative risk of nitrate leaching loss in grazed pastures that differ in source of N input (symbiotic N\textsubscript{2} fixation vs. N fertilizer).

Key Words: pastures, nitrate leaching

Location (or Locations) of Study: Kellogg Biological Research Station, MI

Type (or types) of Soil Used: Loam

Climate: Humid

Approach: In established pastures grazed by beef cattle, we have imposed treatments of split N fertilizer applications versus interseeded legumes and grass. Suction cup samplers were installed to monitor soil solution nitrate concentrations at several locations in each paddock. Plant and soil samples are being taken to monitor N status.

Progress: Experiment was begun in 1998

Potential Implications: Although leaching losses of nitrate under pastures are often very small on fine-textured soils in the North Central Region, use of fertilizer N to boost pasture production may increase leaching losses. Results will help us formulate recommendations for grazers in the region.

Publications: None
Current Research Interview Sheet

Investigators: M.P. Russelle, R. Kanneganti, R. Walgenbach

Institution or Affiliation: USDA-ARS at Univ. MN, US Dairy Forage Res. Ctr.

Title of Study: Fertilizer N rate and nitrate leaching losses under intensively grazed pasture and mowed forage on fine-texture soil.

Funding Agency: ARS In-house funds

Duration of Study: 3 years

Objectives: Determine the relative risk of nitrate leaching loss in grazed pastures that differ in amount of fertilizer N input.

Key Words: pastures, nitrate leaching

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

Type (or types) of Soil Used: Clay loam

Climate: Moist subhumid

Approach: In established pastures grazed by dairy cows, we have imposed treatments of split N fertilizer application rates (up to 600 kg N/ha). Drainage lysimeters are used to measure nitrate leaching losses, and plant and soil samples are taken to monitor N status.

Progress: Experiment was begun in 1997 and will be completed in spring 2000.

Potential Implications: Leaching losses of nitrate under pastures were small and similar to mowed forage when fertilizer N rates were low on fine-textured soils in the North Central Region. Our results indicate that fertilizer N rates should be lower on pasture than on mowed forage to keep leaching losses low.

Publications: None
Current Research Interview Sheet

Investigators: M.P. Russelle, J.F.S. Lamb

Institution or Affiliation: USDA-ARS at Univ. of Minnesota

Title of Study: Does root system architecture alter phosphorus uptake from soils with high P availability?

Funding Agency: ARS In-house funds

Duration of Study: 3 years

Objectives: Determine whether alfalfa populations selected for divergent root system architectures differ in P uptake.

Key Words: Phytoremediation, root systems

Location (or Locations) of Study: Rosemount and Becker, MN

Type (or types) of Soil Used: Silt loam and loamy sand

Climate: Moist subhumid

Approach: Four germplasms of alfalfa that had been selected for differences in root systems (number of fine roots, dominance of tap root, etc.) were planted at the two locations in plots with two P rates. Herbage dry mass and P content are being measured at each harvest.

Progress: Experiment was begun in 1997 and will be completed in fall 1999.

Potential Implications: Many fields in livestock farms have very high soil test P levels and new ways of decreasing those levels are needed to reduce the risk of P runoff to surface water. High-yielding alfalfas with root systems adapted for P uptake may provide a new tool to achieve both goals.

Publications: None
Current Research Interview Sheet

Investigators: J.F.S. Lamb, M.P. Russelle

Institution or Affiliation: USDA-ARS at Univ. of Minnesota

Title of Study: Improved salinity tolerance in alfalfa

Funding Agency: ARS In-house funds

Duration of Study: 5 years

Objectives: Develop alfalfa for improved salinity tolerance to reduce damage by topdressed manure and food processing wastewater.

Key Words: alfalfa, salinity tolerance

Location (or Locations) of Study: Rosemount and Becker, MN

Type (or types) of Soil Used: Silt loam and loamy sand

Climate: Moist subhumid

Approach: Established stands of alfalfa are exposed to drip irrigation water mixed to achieve high electrical conductivity. This water is used as a surrogate for liquid manure or food processing wastewater. Plants best able to tolerate the stress are selected and crossed to produce improved germplasm.

Progress: Experiment was begun in 1998.

Potential Implications: Farmers and food processors need options for in-season application of waste products. Alfalfa has high potential to utilize applied N, P, and K, but is not tolerant of highly saline wastes. Improved alfalfas would provide an economic and environmentally beneficial way of reusing the nutrients in these wastes to produce high-quality livestock feed.

Publications: None
Current Research Interview Sheet

Investigators: J.F.S. Lamb, M.P. Russelle

Institution or Affiliation: USDA-ARS at Univ. of Minnesota

Title of Study: Improved root extension rate in alfalfa

Funding Agency: ARS In-house funds

Duration of Study: 5 years

Objectives: Develop alfalfa for faster root growth rate.

Key Words: alfalfa, root growth

Location (or Locations) of Study: Rosemount, MN

Type (or types) of Soil Used: Silt loam

Climate: Moist subhumid

Approach: Established stands of alfalfa are selected based on how quickly they reach a given soil depth. Plants with fastest root length extension are selected and crossed to produce improved germplasm.

Progress: Experiment was begun in 1996.

Potential Implications: Alfalfa has the capacity to produce extremely deep roots and current varieties grow between 4 and 6 feet per season. To make alfalfa better able to capture mobile pollutants in the soil before they reach ground water, varieties with faster root length extension are needed.


Current Research Interview Sheet

Investigators: J.F.S. Lamb, M.P. Russelle

Institution or Affiliation: USDA-ARS at Univ. of Minnesota

Title of Study: Altering nitrate uptake by N\textsubscript{2} fixing alfalfa

Funding Agency: ARS In-house funds

Duration of Study: 5 years

Objectives: Develop alfalfa for either better or poorer nitrate uptake.

Key Words: alfalfa, nitrate uptake

Location (or Locations) of Study: Rosemount and Becker, MN

Type (or types) of Soil Used: Silt loam and sandy loam

Climate: Moist subhumid

Approach: Established stands of alfalfa are selected based on how much bromide they contain. Bromide is an excellent analog for nitrate and provides an inexpensive way to select N\textsubscript{2}-fixing plants for nitrate uptake.

Progress: Experiment was begun in 1996.

Potential Implications: Alfalfa absorbs N from the soil and fixes it from the atmosphere. New germplasm that has improved nitrate uptake could be used in phytoremediation of contaminated sites. On the other hand, germplasm that has poorer nitrate uptake may be less competitive with grass forages, reducing the need for N fertilizer.

Current Research Interview Sheet

Investigators: J.F.S. Lamb, M.P. Russelle

Institution or Affiliation: USDA-ARS at Univ. of Minnesota

Title of Study: Development of new non-N$_2$-fixing alfalfas

Funding Agency: ARS In-house funds

Duration of Study: 5 years

Objectives: Develop non-N$_2$-fixing alfalfa to clean up soils with excessive nitrate and to prevent nitrate leaching from manure and waste products.

Key Words: alfalfa, ineffectively nodulated

Location (or Locations) of Study: Greenhouse

Type (or types) of Soil Used: Sand

Climate: Controlled

Approach: Non-N$_2$-fixing alfalfas are crossed with alfalfas adapted to different regions of the USA. Progeny that are nonfixing but high yielding under high N supply are selected, recrossed with the adapted parents, and selected again.

Progress: Experiment was begun in 1996, seed increases begin in 1999.

Potential Implications: Non-N$_2$-fixing alfalfa has very high nitrate uptake capacity and effectively removes nitrate from subsoils at nitrate-impacted sites. These germplasms will be useful in preventing nitrate leaching where high rates of N-containing waste products, such as livestock manure, are applied.

Publications: None
Current Research  Interview Sheet

Investigators: Michael A. Schmitt and Gyles W. Randall

Institution or Affiliation: University of Minnesota

Title of Study: Agronomic Feasibility of Growing Low-Phytate Corn

Funding Agency: Pioneer Hi-Bred, International, MN Corn Growers, MN Pork Producers

Duration of Study: Through the 2000 growing season

Objectives: Evaluate the consistency and range in plant P uptake, phytate-P concentration, and grain yield as affected by soil P levels (from manure histories) and fertilizer P applications in corn hybrids that contain normal and high available P (low phytate) quality characteristics.

Key Words: Phytate, Manure, Phosphorus, Corn

Location (or Locations) of Study: Rochester, Waseca, Rosemount, MN

Type (or types) of Soil Used: Webster Clay loam

Climate: Southwestern MN

Approach: Field research plots are being/have been/will be established at three locations in southern Minnesota. The effect of manure history, which would create varying soil P test level differences, and fertilizer P application rates are being measured for their impact on regular and low-phytate lines of two established corn hybrids for the Upper Midwest. For each of these four corn lines (two hybrids x available P levels), grain and stover dry matter yields and grain and stover concentrations were measured, which could then provide plant uptake and crop removal information.

Progress: Based on initial field data from the study evaluating corn hybrids, corn that has the trait for low-phytate has the potential for being an important component of whole farm nutrient management planning. The low-phytate hybrids yielded slightly less than the standard lines. Yields of all corn increased as the amount of previously applied manure increased, even though sufficient N was applied with commercial fertilizer and P and K soil test indicated a low probability of yield response based on these nutrients. The inclusion of the low-phytate trait did not affect the grain or stover P concentrations, thus the plants were not compensating for a change in P form with a change in P quantities. Fertilizer P, or any P fertilizer interactions, did not significantly affect any of the measured parameters.

Potential Implications: This project shows the potential for reducing the phosphorus load of manure rather than just better management of existing manure's phosphorus load. There is great potential in today's niche corn marketing systems to success in using low-phytate corn hybrids to better manage phosphorus in agriculture.
Current Research Interview Sheet

Investigators: Michael A. Schmitt, Gyles W. Randall, Jeff S. Strock, and Neil C. Hansen

Institution or Affiliation: University of Minnesota

Title of Study: Manure Application Rate and Placement Effects on Crop Phosphorus Use Efficiency and Soil Phosphorus Build-Up

Funding Agency: USDA

Duration of Study: 1999-2009

Objectives: Project objectives include: 1) evaluating the effects of manure placement on crop P use efficiencies and stratification of soil test P; 2) quantifying the effect of manure rates on soil P build-up/drawdown rates; and 3) determining effect of tillage system on crop P use efficiencies when manure is a source of nutrients.

Key Words: Manure, Phosphorus, Tillage

Location (or Locations) of Study: Lamberton, MN

Type (or types) of Soil Used: Webster Clay loam

Climate: Southwestern MN

Approach: Within a corn-soybean rotation, manure and/or fertilizer treatments would be applied preceding the corn. Three P rates, two methods of application (broadcast and subsurface banding), two P sources (manure and fertilizer) will be applied to plot areas. Corn and soybeans will be grown under a conventional tillage system and a pseudo no-till system where the only tillage is that done by the manure/fertilizer application equipment. Phosphorus uptake and removal quantities as well as grain/stover yield will be measured annually. Soil P tests will be measured every other year.

Progress: Initial set of treatments were all applied in the fall of 1998 and corn was planted in spring of 1999. No measurements have been made yet.

Potential Implications: The implications from this experiment are critical. The uniqueness of this study is that the plot area is on the Elwell Agro-Ecology farm that has never had commercial fertilizer applied to it. The soil P test is approximately 3 ppm, thus, the dynamics of P additions from these two sources and methods should be very distinct.
Current Research Interview Sheet

Investigators: Bruce Montgomery, Mike A. Schmitt, Mike P. Russelle

Institution or Affiliation: MN Department of Agriculture, University of Minnesota, and USDA Agricultural Research Service

Title of Study: Improved Agricultural Systems Overlying Sensitive Aquifers in Southwestern Minnesota

Funding Agency: LCMR

Duration of Study: 1999-2001

Objectives: Objectives include: 1) assessment of current N best management practices (BMPs), including organic N crediting and overall N rates; 2) creation of special situation BMPs guidelines for the area; and 3) implementation of the new BMPs.

Key Words: Nitrates, Manure, Nitrogen, Crop Systems

Location (or Locations) of Study: Lincoln and Pipestone counties

Type (or types) of Soil Used:

Climate: Southwestern MN

Approach: sites will be identified that will be planted to corn in the following growing season, but may have different previous crops (i.e. soybean, alfalfa, grass hay) grown in this area of the state. With different previous crops as a backdrop, a series of fall nutrient management practices will be imposed. We are planning on applying fertilizer N at two dates in the fall; one near October 1 (this would represent an earlier-than-currently recommended date); the other near October 28 (representing the recommended date). A series of N rates (0-200 lb N/acre/yr.) would be used. At one of the fall dates, a series of manure rates would also be applied using broadcast and injected methods of application, which would provide a range of N availabilities as well as a range of crop responses. The following spring, a set of fertilizer and manure treatments would be applied as a benchmark basis for all the fall treatments.

Progress: Project will start later in 1999.

Potential Implications: Implications specifically will provide N management recommendations for crop/livestock producers that have very shallow aquifers in their fields. The effect of time on N cycle transformations is much more critical when the water table is a 5 feet rather than one hundred or more feet.
Current Research Interview Sheet

Investigators: Jeffrey S. Strock

Institution or Affiliation: University of Minnesota

Title of Study: Manure management effect on surface and subsurface nitrogen and phosphorus transport to surface water

Funding Agency: Start-up funds

Duration of Study: Three years

Objectives: The objective of the proposed research is to evaluate the relationship of manure application rate and vegetative riparian buffers to reduce N and P losses from agricultural land.

Key Words: Swine manure; runoff; erosion; leaching; nitrogen; phosphorus; riparian buffer

Location (or Locations) of Study: Lake Shetek, Murray County, Minnesota

Type (or types) of Soil Used: Barnes loam, 3 to 6 percent slopes

Climate: Warm humid summers, cold winters, 25 inch average annual precipitation.

Approach: Runoff plots 36-ft by 10-ft will be situated on a slope and liquid swine manure will be applied to the soil at three rates. Surface and subsurface transport of N and P will be measured using a combination of methods. Surface erosion and runoff water will be collected with automated water samplers and analyzed for N and P. This will be done for all naturally occurring erosion and runoff events for three years. Nitrogen and phosphorous leaching will be monitored using soil sampling and shallow piezometers installed between the lake and the experimental plots.

Progress: Plots will be established at the beginning of the 1999 cropping season. Sample analysis and data summary will occur as the project progresses. The final sampling period will be fall 2001 and results are expected to be in publication format at that time.

Potential Implications: Multiple precipitation events will allow for the characterization of N and P losses from erosion, runoff, and leaching as a function of manure application rate. These relationships will then be used to determine what combination of tillage practice and manure application rate that would minimize P loss. Understanding these relationships is critical in recommending environmentally sound management guidelines.

Publications: Results will be presented to the Lake Shetek Watershed Clean Water Partnership Resource Committee and published in a refereed professional journal.

Other Comments:
RECOMMENDATION FOR ADDITIONAL RESEARCH

MANURE RESEARCH ADDRESSING ENVIRONMENTAL CONSIDERATIONS

We need to quantify benefits of manure in addition to nutrient content, including erosion control, increased water holding capacity, and in the case of composts, weed control and disease suppression. Research has shown that manure from ruminants properly managed can reduce sediment and total P losses while still providing increased soil fertility levels and increased crop yields. This needs to be evaluated for swine and poultry manure sources. The economic value of these additional benefits needs to be part of farmers' decision making processes.

This research will identify benefits of manure that increase its value and enhance its utilization potential and provide data that support manure utilization strategies offering a win/win scenario (reduced environmental impact and increased profitability).

Evaluate the extent to which nitrate leaching and phosphorus runoff losses from Minnesota animal agriculture can be reduced.

There are several management strategies that can be used to reduce nitrate leaching and P runoff losses in Minnesota cropping systems, including choice of crop, fertilizer, and manure management, crop management, irrigation management, pasture management, etc. These will be evaluated with a computer simulation and geographic information system approach. “Ground Truth” data needs to also be collected to verify model results.

The product of this research will be maps of selected high risk areas showing predicted nitrogen and phosphorus losses under current and various improved management scenarios, and a summary of the findings. This analysis will help policymakers evaluate the likely potential impacts of proposed regulations or guidelines and changes in farmer behavior.

Characterize and evaluate whole-farm nutrient balances for different classes of livestock.

Farms will be selected to represent the range of conditions in Minnesota with respect to size, intensity, manure handling, reliance on purchased feed, soil texture and landscape characteristics, etc. of livestock operations. This effort will include consideration of nutrient distribution within individual farms to identify imbalances.

Results from this research will help define the current situation regarding nutrient balance and fate on Minnesota livestock operations. For policymakers, the research will provide thorough on-farm data on which to base their decisions regarding regulations.

Development of initial P application guidelines to protect surface water quality.
As described in the literature review, there are a number of states and counties that are adopting guidelines or regulations on P application. There is considerable disagreement about the soil test levels to invoke and the approach to incorporating them into a rational, understandable, and effective system. This work will involve determining current status of soil test P in Minnesota, evaluating soils for their P holding capacity and other characteristics, and modifying the P risk index approach using Minnesota conditions.

This research will produce a P risk index that can be evaluated by state and county agencies and other stakeholders.

What is the best management of surface tile inlets to minimize entry of pollutants from manure application? The primary strategy for reducing losses of manure derived pollutants into surface tile inlets is to keep them in place (?) on the fields with use of tillage and other conservation systems. A secondary measure is treatment at the inlet with vegetative buffer strips and/or various sand or gravel filters. There are very few references in the literature that have evaluated these options both from crop production and environmental perspectives.

Winter application of manure is still necessary for a large number of Minnesota farmers. What is the impact of winter application on runoff losses from snowmelt and rainfall runoff? Published literature on this topic is inconclusive as to the environmental hazard of winter spreading. Alternate strategies of manure application need to be evaluated: in the late fall before snow, in winter on snow, in the spring before planting, and daily or weekly spreading.

Determine the metal content by livestock species and investigate metal transport in soil systems.

Poultry and swine are sometimes fed antibiotic compounds that contain copper and arsenic. These and other micronutrient elements are a concern on landscapes that have long histories of manure application. Do manures in Minnesota conform to 'book' values in terms of metal concentration? A survey of current practices, manure analyses from across the state, and soil samples on sites with long manure histories, will determine if this is a concern in Minnesota.

MANURE RESEARCH ADDRESSING CROP PRODUCTION CONSIDERATIONS

Manure is a poor competitor with synthetic fertilizers on the basis of cost per pound of nutrient applied, and this fundamental fact goes a long way toward explaining the view in some cases that manure is a waste and not a resource. To enhance its value as a resource will require:

Better assessment of the nutrient release patterns for different types of manure (age, species, C/N ratio, etc.) applied at different times of the year in different cropping systems under varying climatic and soil conditions. Synchronicity of nutrient release
with crop demand is critical, and may best be achieved by blending synthetic fertilizers with manures. How, at what rates, and when should such combinations be applied?

Application uniformity is notoriously bad. Application variability of plus or minus 30% logically translates into over application by 30% for many manure types. We need new application equipment designed to evenly and efficiently distribute manure.

Variability is also a problem in the manure itself. Methods that homogenize the manure are one approach, while another would be real-time nutrient analysis coupled with a precision application system, which needs to be evaluated.

How much is the transportability of manure enhanced by dewatering and composting? One of the major diseconomies of manure management is the high water content. For several decades much of the published research has been with liquid systems, for which the costs of application typically exceed the benefits within a radius of less than 2 miles. Solid and especially composted manures can be transported considerably farther (12-20 miles) economically, and perhaps farther as additional manure benefits become quantified.

**Are chemical treatment approaches viable for liquid manures in Minnesota?**

Little is known about ways to reduce the environmental and human health hazard from liquid manures, whereas solid manures can be composted or treated with chemicals to achieve these goals. For example, alum appears to be a highly effective additive to poultry litter, and has multiple environmental, human health, and animal health benefits. This research will investigate whether any of several likely additives or composting can reduce phosphate solubility, ammonia volatilization, and pathogen survival in liquid manures.


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Appendix. Table 1. Current levels of phosphorus, zinc, and copper in Minnesota agricultural soils based on the information from University of Minnesota Research Analytical Laboratory. Note that due to limited number of samples this may not be a true a representation of the typical soil test levels.

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Freq. is the number of samples tested in each county.