Generic Environmental Impact Statement for Animal Agriculture in Minnesota

Topics I & J Soils and Manure Issues

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Executive Summary

Animal production is growing in Minnesota and animal densities are increasing. There are two main driving forces at work when manure utilization is considered. One is "on farm" profitability and the other is the negative "down stream" impacts. At times economic and environmental quality goals are competing. This Manure and Soils report addresses the value of manure as well the possible negative environmental effects of the use of manure on cropland.

Manure value, costs, economic forces, and water quality

Manure can be a valuable resource in a crop production system. Manure contains the macronutrients nitrogen (N), phosphorus (P), and potassium (K) and also contains numerous micronutrients. The nutrient value of manure for crop production depends on the site-specific reserve of plant available soil nutrients, the nutrient concentrations in manure, and the nutrient demands of the crop. In many areas of Minnesota soil levels of P and most micronutrients are already at adequate levels. In some soils K is also adequate for crop production. Under conditions of adequate soil P, K, or micronutrients there is little or no economic value associated with these elements in applied manure. Nitrogen is always needed for production of nonleguminous crops (e.g. corn, small grains, and grass pasture) and when correctly managed the N in manure is valuable. For legumes (e.g. alfalfa and soybeans) the N in manure is of little economic value because these crops are able to convert N in the air to plant available N. However, when, manure is applied to legumes these plants can utilize the plant available N instead of producing their own N and application to legumes can be an environmentally benign method for utilization of manure N.

The value of the nutrients in manure also depends on the value of alternative sources, mostly commercial fertilizers. Most N fertilizers are produced by conversion of N from the air using natural gas. Due to the recent rise in energy prices, the cost of N fertilizer has doubled from about $.20 to $.40 per pound. It took the previous decade for the cost to double from $.10 to $.20. The increased cost of N fertilizer has a direct impact on the value of N in manure. The cost of both fertilizer P and K has also doubled in the last decade. Thus, the value of these nutrients in manure has increased considerably and the interest in manure utilization is increasing.
In addition to supplying nutrients, manure can also improve biological and physical properties of the soil, making it more productive and less erosive. Manure, used as a part of good soil management, improves soil quality. It is difficult to put a dollar figure on this benefit.

The direct economic cost of manure is mainly for storage and application. Environmental costs are incurred if manure is over-applied, applied at the wrong time in the growth cycle, applied unevenly, or managed in such a way as to allow nutrient losses in storage, handling, and application. Water and air quality are often degraded in these situations. The risks of water and air quality degradation can be reduced with investments in high quality storage facilities. Good storage facilities reduce the environmental risk of poor containment during storage and provide for more flexibility in timing of a land application; allowing for land application to better match the time of plant uptake of nutrients. This reduces the likelihood of runoff and leaching losses of

N and P. The cost for application can be a major cost that offsets much of the value of manure if the site of application is not near the site of animal production. The cost of manure hauling increases with distance from the source. The cost of hauling is greater for manure with high water content compared to dryer manure.

The N challenge

For farmers, N is the most difficult manure element to efficiently utilize for crop production. Availability of N to the crop largely depends on the weather (temperature and precipitation) between application and plant uptake. Corn takes most of its N up between "knee high" (early June in Minnesota) and tassel emergence (early July to mid August). When manure is applied before planting there is a risk that some N can be lost by leaching before the plants are ready to take up the N. If temperatures are warm after application manure N can be converted to nitrate N, which can be lost by leaching during wet weather. This nitrate can eventually be leached into groundwater, degrading water quality. If temperatures are cool during the crop nutrient uptake period, crop uptake will be reduced; both because of low crop N demand and e the slow conversion of organic N to plant available forms. The uncertainty associated with potential N losses and plant availability, and the recognized difficulty in applying manure evenly at the desired rate are reasons why farmers take low N credit from manure. This results in over application of manure or fertilizer N.

The P challenge

Phosphorus from manure is relatively stable in soil and can reliably be measured with soil tests. This is why farmer surveys often reveal that they take P credits from manure application rather than N credits when assessing crop nutrient needs. Because of the stability of P in soil, repeated manure applications can result in an accumulation of soil plant available P. Although this usually does not have a detrimental effect on crop production, it does present possible environmental concerns. Excess P when delivered to surface waters in runoff water can greatly increase the risk of algal blooms resulting in the degradation of water quality. The risk of phosphorus loss to surface waters is associated with runoff volume and soil erosion.

Recommended manure management practices should consider the risk of off-site movement of phosphorus to surface waters. Any manure application near surface water bodies, as well as manure applied on the soil surface without incorporation, applied at excessive rates, or applied on frozen or snow covered ground pose a high level of risk. However, the risk is also site dependent, with the erosion potential and the soil P level being important considerations. The P index being developed as a part of the project that produced this report will be an important tool for identifying sites where the risk of P loss is high.

N vs. P based manure applications

The quantity of manure application is one of the most important considerations when developing a manure plan. Should the rate be based on the manure P content and soil test P levels? Or should it be based on the manure N content and crop N requirements? Manure varies in relative content of N and P, and both are present as soluble inorganic forms and relatively insoluble organic forms. The composition of manure influences both crop uptake and risk of N and P losses to ground and surface waters. Most animal species have N and K contents in their manure that is greater than the P content. Poultry manure is an exception, with more P than N and K.

Some methods of manure management can increase the P to N ratio in manures, increasing the possibility of P risk to surface waters. Ammonium N can be lost as ammonia gas during storage, handling, and after application, which increases the P to N ratio. Crops require less P than N and the result of N losses is that fertilization to maximize the production of nonlegumues will require either commercial fertilizer N or an increase in manure application rate. Increasing the manure application rate increases the risk P contamination of surface waters.

Soils are both a source and sink for P. Continued manure application to meet N needs of crops for maximal crop production can increase soil test P to values where no additional P is required.. At high soil test P the risk that runoff water will carry excessive P to surface waters increases. The risks posed by high soil test P vary depending on many landscape and management factors.

Currently, best management practices recommendations for manure application are based on N. This approach reduces the potential for nitrate pollution of waters but in the long term this approach results in a buildup of soil P levels. The increase in soil test P to high values depends on the crop sequence, frequency of manure application, and soil type. The best environmental strategy would be to use P-based rates with supplemental fertilizer N where there is high risk of environmental impact from P (high P index), and use N based rates where the P risk is low.

One approach to limit the risk posed by high soil test P is to define a critical soil test P value that sets an upper limit for soil test P. However, some soils with high soil test P pose little risk to surface waters. These are soils that are distant from surface water bodies or surface tile inlets, low in erosion potential, in depressions without drainage outlets, or are separated from a water body by a wide buffer strip of native vegetation. A better approach than setting a critical limit is to use a P index. The P index approach takes into account the likelihood of P actually reaching receiving waters. It also provides more management options for farmers to reduce the environmental risk compared to a yes or no approach based on a critical soil test P value.

Application costs

Due to the cost of hauling and applying manure, the use of commercial fertilizers is more economical than manure as the hauling distance increases. In other words, the economic pressure encourages farmers to apply manure closer to the barn and at higher rates. Water quality concerns result in a pressure to apply manure further from the barn and at lower rates to better recover nutrients and reduce losses. As the animal concentrations increases the distances for application become greater. With liquid or semiliquid sources (especially if nutrient concentrations are low) the transportation costs become prohibitive at distances greater than about one mile. With dry sources (the best example is poultry manure due to its high nutrient concentration and low water content) the distances with favorable economics are greater (~25 miles).

Environmental vulnerability due to landscape and climate

The most sensitive environmental regions in Minnesota for nitrate groundwater contamination are the deep glacial outwash sands in the central part of the state with shallow aquifers and the karst area in southeastern Minnesota where fractured limestone bedrock provides for entry of mobile contaminants directly into the aquifer. The relatively impermeable glacial till and glacial lakebed sediments in other major agricultural areas also pose a risk of nitrate loss to surface waters through the tile drainage systems that have been installed to remove excess water from the soil.

The most sensitive areas of Minnesota to P contamination of surface waters are where slopes are steep and erosion potential is high. This includes glacial moraines such as the one just south of the Twin Cities and near Alexandria as well as highly dissected landscapes such as in the southeastern part of Minnesota. Soil and water conservation techniques are important components to environmentally sound farming systems in these areas.

Risk of disease

Animal pathogens that can infect humans (zoonotic organisms) are a possible risk from application of manure to fresh market fruits and vegetables. Although transmission of pathogens to produce at concentrations that can infect consumers has occurred, the existing evidence suggests that this occurs rarely. Storage of manure decreases the concentration of disease organisms, especially under aerobic conditions, and generally reduces risk. The heat generated during composting essentially eliminates the risk. Risks can also be reduced by restricting fresh market produce production on recently manured land.

Recommendations

Nitrogen

- We must do a better job of characterizing the N in manure by utilizing chemical test to partition N into ammonium and organic forms. This allows more precision in prediction of plant available N.

- We must do a better job of placing manure N in the crop sequence to capture N. Manure N provides the most economic return if application precedes an N dependent crop. Application preceding legumes is environmentally acceptable if N does not exceed the ability of the plants to take up the available N but it does not provide any economic benefit. Deeply-rooted, long-season crops have the best chance of recovering manure N.

- Manure applications are better if they are made closer to the time of crop N need.

- We need to develop combinations of soil and plant tests and climate monitoring that will allow synchronizing N availability with crop needs to minimize risk of crop yield reduction and environmental losses.

Phosphorus

- The use of a P risk index that considers P source characteristics and transport probabilities will provide a science-based risk assessment and help assess management options that can greatly reduce the entry of this pollutant into surface waters.

- The use of conservation tillage reduces erosion and total P losses in runoff. 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.

Nitrogen and Phosphorus

- The best environmental strategy is to use P-based rates with supplemental N where there is high risk of environmental impact from P (high P index) and use N based rates where the P risk is low.

Government Assistance

A combination of "carrot and stick" measures must be adopted to reduce the potential degradation of Minnesota's water resources by manure N and P.

<u>Incentives</u>

- The financial burden of upgrading manure systems should be shared with farmers. This includes storage, handling, and application costs. Governmental agencies should have programs to promote manure trading, adoption of soil and water conservation practices, and efficient nutrient management techniques to reduce risks.

- In high risk zones easements should be purchased for establishment of buffer strips in in close proximity to environmentally sensitive surface waters. Well designed buffers can provide multiple benefits, including wildlife corridors, habitat, and feed, aesthetic surroundings for water recreation, improved water quality, etc.

Education

- Educational programs must be implemented to increase the awareness and understanding of the complexity of the issue and options available to farmers to maximize profits and minimize environmental risk. This would lead to development of specific farm and field manure management plans (utilizing tools like the "P risk index" for assessment and development of plans).

- Research support is necessary to develop improved management techniques. This includes incorporating "real time" weather considerations; soil, plant, and manure testing; and improved soil, water, crop, animal ration, and manure management techniques. This research should include traditional "plot" scale research and large-scale evaluations of the economic costs and environmental benefits.

Regulation

- Eventually, manure management plans should be required on most farms that handle livestock and poultry manure.
- There must be penalties for egregious disregard of the environmental consequences of improper manure handling**.**

Update of Literature Review for Soils and Manure

Introduction

The value of manure for maintaining and improving the productivity of the soil has been recognized from antiquity, and fertilizing crops with livestock manure nutrients began millennia ago. With careful management, manure can be a good source of N (nitrogen), P (phosphorus) and K (potassium) in a crop production system. Manure can also improve soil quality. On the other hand, improper management of land application of manure can result in negative environmental effects, including soil build-up of toxic trace elements, and pollution of ground and surface waters with nitrate-N and phosphorus. In addition human and animal pathogens can be transmitted by contamination of water and the food chain. The risk of contamination in the human food chain is discussed in a separate section.

This section of the technical working paper (TWP) is an update of the soils and manure literature reviews (sections I and J) completed in 1999 by the University of Minnesota. This update focuses mainly on literature that has been published since the original literature review, and also includes interviews with researchers who have active studies related to the published literature we reviewed. It includes sections on soil quality, air quality, toxic trace elements, nutrient management, and risk of nitrates and phosphorus transport to ground and surface water. This literature review does not update any of the material on manure storage or the phosphorus index. Updates on storage and the phosphorus index are included in separate sections in this TWP.

Soil Quality

Management practices that minimize tillage operations, provide surface residues, use cover crops, or utilize organic residues like manure maintain soil organic matter and improve soil quality. Indicators of good soil quality include improved structure, water infiltration, pH, and soil respiration, decreased bulk density, and increased available-water holding capacity.

Soil quality on organic versus conventional farms

Increasing interest in food produced using organic sources of nutrients rather than agrochemicals has led to a growth in the sales of organic foods of 20% on average for the last 8 years in the U.S. (Looker, 1997). Manure management is a key component of most organically managed farms, and generally, organic management improves soil quality.

This was verified by the results of a comparative study of five organic and five conventional farms in Nebraska and North Dakota matched by soil type (Liebig and Doran, 1999). Four of the five organic farms used manure. The organic farms had 22% more organic matter and 20% more total N in the surface 30.5 cm of the soil. Microbial biomass C and N and soil respiration were found to be higher in the soil of the organic farms as compared with that of the conventional farms, at four of five locations. The organic farms had soil pH closer to neutral, lower bulk density and higher available-water holding capacity as compared with conventional farms. The organic farms generally had more potentially mineralizable organic N (anaerobic incubation). The effects of organic management on soil nitrate, however, were inconsistent. Soil NO_3-N was greater on conventional farms, at four locations. However, soil NO_3-N on one organic farm was 10 times higher than on the comparative conventional farm. This high level of N suggests that organic production practices may not consistently be better at minimizing potential negative off-site impacts due to N loss to the environment.

Salts in manure

Very high manure applications can lead to salt accumulation in soils. Increases in soil salt content may have adverse effects on crops, particularly in dry climates. Eghball and Gilley (1999) determined the effects of simulated rainfall on runoff losses of salt following application of manure and compost to a silty clay loam soil in Nebraska. Manure, compost, and fertilizer were applied to the soil surface of no-till fields following sorghum and winter wheat, at rates required to meet the N or P requirements for corn production, and were either left on the soil surface or disked to 8 cm. No significant differences in runoff salt concentrations were found between the treatments.

Weed seeds in manure

Animal feed is often a source of weed seeds, which can consequently appear in manure. Composted and noncomposted beef cattle feedlot manures were applied to no-till fields on a silty clay loam soil in Nebraska (Eghball and Power, 1999). The effects of composted and noncomposted manure application on corn yield and weed biomass were determined. The authors concluded that weed biomass was more influenced by nutrient availability than by any weed seeds introduced by the composted or noncomposted manure application.

Air quality effects of manure in pastures and field soils

Methane (CH_4) is a greenhouse gas that can be produced by manure under anaerobic conditions. It is also produced in manure patches in pastures. This was shown in a simulated field study by Yamulki et al. (1999) in the UK. Dung and urine samples were deposited on six separate experimental plots at different times of the year to study the effects of environmental factors on CH_4 emission. The total cumulative flux of CH_4 for the dung and urine patches had mean values of 42.8 and 0.2 mg CH_4-C/patch, respectively. However, the CH_4 emissions from dung were insignificant compared to the methane produced in the cattle rumen.

Applying cattle slurry to soil may induce emissions of both CH_4 and nitrous oxide (N_2O). Nitrous oxide is also a greenhouse gas. The effects of slurry application ($43.6 m^3$/ha) were studied for 9 weeks under controlled laboratory conditions using a soil microcosm system with automated monitoring of the CO_2, N_2O, and CH_4 fluxes (Flessa and Beese, 2000). A silty loam soil with a constant water-filled pore space of 67% was used. Emissions of N_2O and CH_4 from the injected slurry were significantly higher than from the surface-applied slurry, probably due to restricted aeration. Total N_2O-N emissions were 0.2% (surface application) and 3.3% (slit injection) of the slurry N added. Methane emission occurred only during the first few days following application. Losses of N_2O from cattle slurry were of minor importance compared with the nitrate leaching and other losses from the slurry treated soil but they may significantly contribute to the N_2O emissions from agricultural ecosystems. Slurry injection, which is recommended to reduce NH_3 volatilization, appears to increase emissions of the greenhouse gases N_2O and CH_4 from the fertilized fields.

Potentially Toxic Trace Elements

Under intensive livestock management, manure can contain significant concentrations of trace elements such as arsenic (As), cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), selenium (Se) and zinc (Zn), due to feed additives. These trace elements are mostly retained in the solid phase after solid-liquid separation from slurry (Giusquiani et al., 1998). Excessive applications of poultry or pig manure may led to the accumulation of harmful levels of some of these elements in soils, and has the potential to result in toxicity to plants (phytotoxicity).

The most recent studies have concentrated on extractability, plant uptake, and leachability of trace elements, ways to reduce trace element concentrations in manure, and their potential for environmental contamination.

Extractability and plant uptake

Poultry litter can contain elements such as arsenic, cobalt, copper, iron, manganese, selenium, and zinc, all of which are added to poultry feed (Tufft and Nockels, 1991). Poultry litter from northern Georgia containing 1196, 944, and 631 mg/kg Cu, Mn, and Zn respectively, was used to study bioavailability for sorghum (Vanderwatt et al., 1994). Plant uptake of these metals from poultry litter applications equivalent to 0, 15, 30, and 60 Mg/ha (Mg = metric ton) were compared on pure quartz sand and two Georgia soils. These levels of manure application are much higher than required to meet the needs of the crop. The quantity of Cu, Mn, and Zn added in the litter treatments were in the ranges 5 to 15, 62 to 1933, and 19 to 55 mg/kg, respectively. During a 21-day growth period, the plant concentrations of Cu and Zn were in the normal range, while concentrations of Mn were found to be toxic (>400 mg/kg), but only in the clay soil. Soil pH was important in determining extractable soil Cu, Mn, and Zn. More Cu, Mn, and Zn were found in sorghum on the soils with lower soil pH. Analyses of field soils revealed a build-up of possible phytotoxic levels of Cu, Mn, and Zn in one soil that had received 6 Mg/ha/yr of poultry litter for 16 years.

Amendments with organic matter may change soil pH and make metals more available to plants. One study found that eight years of sewage sludge or pig manure applied at rates of 5 tons/ha/year of dry organic waste on a sandy loam soil decreased soil pH by half a unit and increased soil Zn and Cd concentrations, as well as Cd concentrations in field pea (Krebs et al., 1998). Ten years of liming raised the soil pH by approximately one unit and resulted in Cu, Zn and Cd concentration decreases in seeds and crop residues of field pea. The study also found that plant uptake and solubility of Zn, Cu, and Cd continued to be higher in pig manure-treated soils than in control plots after the applications ceased.

Solubility and leachability

Solubility and leachability of trace metals after application of manure is of concern for water quality. The chemical forms rather than the total concentrations are important for potential leachability and environmental pollution (He et al., 1992; Hsu and Lo, 2000). Metal leachability may be modified due to changes in the quantity of dissolved organic matter and pH.

A study was conducted to assess the leachability and environmental hazard of Cu, Mn, and Zn in swine manure composts (Hsu and Lo, 2000). The composts were enriched with Cu (154-1380 mg/kg), Mn (239-976 mg/kg), and Zn (372-2840 mg/kg). A series of extraction schemes were used to determine salt extractable metals and their distribution at various pH levels. The results showed that the Cu, Mn, and Zn contents of composted manure collected from different pig farms varied substantially. The chemical form and extractability of Cu, Mn, and Zn were independent of total content in the composted manure. The distribution of Cu, Mn, and Zn in the various soil extractions revealed that the potential leachability of these elements is generally in the order Zn > Mn > Cu. Dissolution of organic C resulting from pH changes substantially modified Cu leachability, but had little effect on the Mn and Zn leachability. Dissolution of organic matter generally increases with increase in pH. The authors concluded that most of the Cu in these composts is bonded to the soil organic matter. Furthermore, the potential leachability of Cu, Mn, and Zn are likely low although the composts may contain high amounts of these elements.

In another study the effect of swine manure were reported on the solubility of Cd and Zn in soils Almås et al. (2000) suggested that treatment increased the solubility of both Cd and Zn by metal-organic complex formation. Soluble organic acids from manure can increase the solubility of Cd and Zn and lead to increases in leaching or increased runoff losses.

Fluidized bed combustion (FBC) materials, an ash byproduct of clean coal burning, can be used to stabilize dairy feedlot surfaces, thus decreasing the mobility of trace elements. Elrashidi et al. (1999) investigated the use of FBC residue to stabilize dairy feedlot surfaces, and reduce leaching of trace elements in a laboratory column experiment with dairy manure. The columns were subjected to 10 weekly leaching with distilled water. They FBC decreased leachate concentrations by 5.6 to 100%, for most elements (e.g., P, N, K, calcium, aluminum, silicon, iron, manganese, copper, zinc, lead, cadmium, cobalt, chromium, nickel, arsenic, and selenium. Several mechanisms for this observation were proposed: (i) formation of insoluble metal-organic complexes; (ii) sorption of insoluble organic and inorganic species on mineral surfaces; and (iii) precipitation of insoluble inorganic species. However, the FBC increased concentrations of B (235%), S (47.3%), and Mg (36.5%) due to the high concentration of these elements in mobile forms in the FBC.

Reduction of trace elements in manure

Mohanna and Nys (1999) conducted a study on chicken nutrition to determine the effect of decreasing dietary Zn content on growth, plasma, tibia and whole body Zn concentrations, immune function, enzyme activity, Zn body retention and Zn concentration in excreta. Results indicated that lowering dietary Zn supplementation did not affect enzyme activity or immune response of the chicks. Furthermore, a reduction in dietary Zn content from 190 to 60 mg/kg decreased Zn concentration in chicken manure by 75%. The authors concluded that lower dietary Zn supplementation could reduce excessive Zn concentration in manure and the risks of phytotoxicity in the soil.

Surface Water Impacts of Manure P

The initial impact of manure on the concentration of P in runoff is greatly influenced by the solubility of the P in the manure. Sharpley, and Moyer (2000) investigated P solubility in samples of dairy manure, swine manure, poultry litter, and composted manure. Release of P was measured during simulated rainfall (70 mm/h for 30 min) in the laboratory (10 Mg/ha manure application rate). During a 30-min rainfall, the dissolved inorganic P concentration in leachate from manure and compost ranged from 34 mg/L (poultry compost) to 75 mg/L (poultry manure). During five simulated rainfall events, the total quantity of P leached from dairy manure, poultry manure, and poultry compost and litter, and dairy compost and swine slurry were 58%, 21%, 20%, and 15%, of the P in the manure. The amount of dissolved inorganic or organic P leached from of each material was significantly correlated to the respective water extractable inorganic ($r^2 = 0.98$) or organic P ($r^2 = 0.99$). The authors suggested that water extractable P may be used to estimate the potential for land-applied manures or composts to enrich leachate and surface runoff P.

Soil test P and other forms of extractable soil P are being used to evaluate the potential of soil P to deliver runoff P to surface waters. However, it is not clear which soil tests better correlate with the potential P pollution. Hooda et al. (2000) determined whether soil release of soil P to runoff could be predicted either by soil test values, sorption-desorption indices, or the degree of soil saturation with phosphorus. Degree of soil saturation with phosphorus is the ratio extractable P to the total quantity of P a soils can adsorb. Five methods were compared for predicting potential P release to runoff. The results of this study clearly showed that the amount of P that can potentially be released to runoff water had little relationship with either total soil P content or P sorption capacity. The most important property relating to water soluble P was the degree of soil saturation with phosphorus.

A series of experiments were conducted over 10 years to evaluate soil test methods using 163 Vermont and New York soils (Magdoff, et al., 1999). Phosphorus availability to plants, the equilibrium soluble P concentration, and $CaCl_2$-extractable P were all more closely related to ammonium acetate extractable soil test P (NH_4OAc-extractable) than soil test P extracted by solutions containing fluoride (such as Mehlich 3, Bray 1). The authors concluded NH_4OAc-extractable P could be a good parameter to be included as part of an index that ranks soils according to their potential for contribution of P to runoff.

A UK study compared the effects of high rates of liquid cattle manure with inorganic fertilizer and showed that both can increase runoff P concentrations when surface applied (Withers et al., 2001). Liquid cattle manure (186 kg P/ha) or triplesuperphoshate (330 kg P/ha) were applied to a cereal crop on a silty clay loam soil, over a 2 years period. In the first runoff events after surface application in the spring dissolved inorganic P concentrations in the control plots were only 0.1 mg/L compared to 6.5 mg/L for the fertilizer and 3.8 mg/L for the manure. Runoff dissolved P concentrations were typically <0.5 mg/L across all plots, and particulate P was the dominant P form in the runoff, for fertilizer and manure incorporated in the fall. These results show that for P in runoff the method of P application is more important than the source of P.

In soils subjected to flooding or with a fluctuating shallow water table the reducing conditions induced by moisture saturation can increase the availability of P in runoff. In a laboratory study topsoil and 2 subsoils were amended with 4g/kg poultry litter and flooded for 28 days then drained for 14 days (Vadas and Sims, 1999). The P adsorption capacity decreased in all soil horizons under these conditions. For the poultry litter amended topsoils soluble P concentrations were consistently higher than in unamended topsoils.

Poultry litter applications to pasture land result in high P concentrations in runoff. This was shown in a simulated rainfall study (Sauer et al., 2000). In a runoff event one month after application of 4.5 Mg/ha of poultry litter the dissolved inorganic P concentrations in the runoff averaged 2.20 mg/L.

The risk of transport of both P and N from pastured land into streams can be reduced by exclusion of animals from the land near streams. This was demonstrated in a study that involved excluding dairy cows from the riparian corridor along a small North Carolina stream (Line et al., 2000). The data following exclusion fencing indicated 33, 78, 76, and 82% reductions in weekly nitrate plus nitrite N, total nitrogen (TKN), total phosphorus (TP), and sediment loads, respectively. The reductions in mean weekly loads were significant ($P<0.05$) for all pollutants except nitrate plus nitrite.

Chemical additives can reduce the bioavailablity and leaching of manure P. A study was conducted to determine the effects of alum, caliche (ground arid region soil material), and class C fly ash on extractable P concentrations in stockpiled and composted cattle manure at rates of 0, 0.10, 0.25, and 0.50 kg/kg manure (Dao, 1999). The caliche, alum, and fly ash reduced water-extractable P in stockpiled manure by 21, 60, and 85% and by 50, 83, and 93% in composted manure at the 0.1 kg/kg rate. Alum and fly ash also significantly reduced soil test P (Bray-P) concentrations by 75 and 90% in stockpiled and composted manure, respectively, and >90% at higher rates. Alum contains aluminum that can become a problem in acid soils and fly ash contains a large number of trace elements. The possible negative effects of these materials must be considered before they are recommended for treatment of manure. Caliche is mostly limestone and should not pose any environmental risk.

Ground Water Impacts of Manure P

Although the risk of P to subsurface water quality is generally considered to be low, some investigators have measured manure P movement to ground water. Two to three annual applications of cattle slurry to grass and grass-clover pastures at about 25 kg P/ha/y resulted in some soluble in P in lysimeter drainage water (Hooda et al. 1999). After 9 years, an average increase of 1.0 mg Olsen-P/kg/y (soil test P) was observed in the topsoil (0-10 cm). The total soluble phosphorus concentrations in the drainage water ranged from 0.45 to 0.79 mg P/L. These P concentrations in drainage water were much higher than previous estimates. Subsoils have a much higher P-adsorption capacity than topsoil, which should keep soluble P concentrations low. The high measured soluble P indicates that significant P transport in soils can occur through preferential hydrological flow pathways in the soil (cracks and crevasses).

Manure impacts on soluble P in shallow ground water were observed after 10 years of intensive swine manure application to a Coastal Plain spray field at disposal rates (Novak et al., 2000). After 10 years the topsoil had very high soil test P (377-435 mg P/kg Mehlich 3) while in the control soil the soil test P was <10 mg P/kg. Groundwater dissolved P concentrations were initially very low (<0.040 mg P/L) in the wells installed around the spray field. After 10 years the measured values increased substantially to 0.04-0.48 mg P/L.

A laboratory study from Denmark suggests that the localized high concentrations of manure under a manure patches in a pasture can result in localized leaching of P (Magid, et al, 1999). Manure was placed on top of, or incorporated in, the soil of 40 cm intact columns. Incorporation or surface application of manure resulted in a 10- to 20-fold and 100- to 200-fo1d increases in soluble inorganic P, respectively. The authors suggested that special attention should be given to drained pastures, where the important P affecting drainage water may not be the soil P, but the P in manure patches on the surface. This P could be transported directly through preferential hydrological pathways in the soil.

Ground Water Impacts of Manure N

Nitrate leaching to ground water is a problem when excess plant available N is added regardless of whether the source is organic or inorganic fertilizer. One of the areas where there is a concern for nitrate levels in shallow ground water is on a sandy out-wash soils in West-Central Minnesota. To better understand NO_3^- contamination of ground water Puckett et al. (1999) did a mass-balance budget of N cycling study for this intensive agricultural area. The budget was developed using ground water data collected throughout the 212 km^2 study area. They looked at all forms of soil applied N including manure. On a regional scale the N sources were fertilizer, biological fixation, atmospheric deposition, and animal feed. The N sinks in the model were crop harvests, animal product exports, volatilization from fertilizer and manure, and denitrification. Denitrification, estimated by adjusting its value so the predicted and measured concentrations of NO_3^- in ground water agreed, appeared to remove 50% of the nitrate leached below the soil profile. The authors did not find a general threat to ground water. Animal agriculture seems to be of no threat to ground water, because of the small size and dispersed nature of animal production in the area. The regional approach, however, does not account for local problems that can occur from over application of N.

Denitrification process that can convert nitrate-N into gaseous products, and removing nitrate from soil and water. Denitrification can be a major pathway of N loss from soil. Marshall et al. (1999) quantified N loss via denitrification from tall fescue pastures following chicken litter application (70 kg of available N/ha) at Alabama, Georgia, and Tennessee. Total losses of N gases were all <6 kg/ha during 150 days after application, representing a loss of <5% of total N applied. The authors concluded that gaseous N losses from soil in the southeastern US are not significantly increased by the addition of chicken litter.

Nutrient Management

Recently, manure nutrient management has become a major focus in efforts to sustain or improve environmental quality while sustaining agriculture production. Today, the agronomic and economic factors of nutrient planning remain central, but nutrient planning also requires environmental impact consideration (Beegle et al., 2000). Traditionally, farmers were concerned with nutrient management to optimize economic return from crop production by applying inorganic fertilizer without giving credit for nutrients applied in manure (Schmitt et al., 1999). This practice has resulted in nutrient accumulation in the soil that exceeds agronomic requirements for crop production. Consequently, nutrients leach to groundwater or runoff to surface water leading to contamination, eutrophication and hypoxia of the water bodies (Burkart and James, 1999; Hession and Storm, 2000).

Animal agriculture in the United States is continuing to increase as illustrated in Figure 1 by Aschmann et al. (1999). Also, the size of animal operations has increased. For example, over 97% of the poultry produced in the US comes from operations of 100,000 animals or more (Aschmann et al., 1999). Deterioration of soil, water, and air quality in many localized areas has been linked to the intensification of animal production (USDA-EPA, 1999). Specialization and intensification of agricultural systems has led to P accumulation in excess of crop needs in some areas (Haygarth and Sharpley, 2000; Sims et al., 2000).

Nutrient losses from agricultural nonpoint sources are a key component of surface water impairment in the United States. Nitrogen is the primary pollutant problem in many agricultural areas; however, development of management practices that reduce phosphorus loading is becoming more important in many watersheds because phosphorus is often the limiting nutrient for fresh water eutrophication. The very recent literature has concentrated on nutrient management planning and implementation, phosphorus-based versus nitrogen-based manure management, and nutrient dynamics modeling.

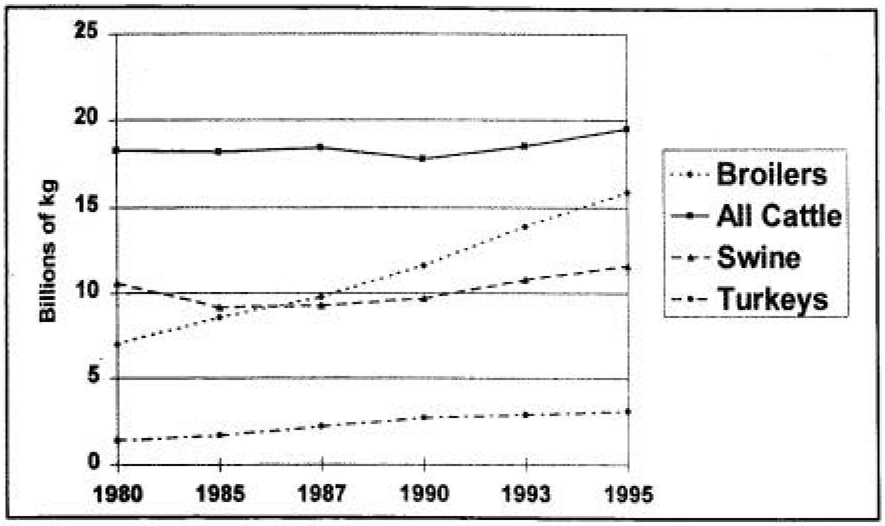

Figure 1. U.S. meat production 1980-1995. Source: USDA-NASS 1997.

Timing nitrogen availability

The goal of attaining high yields while protecting soil and water quality requires matching soil inorganic N supplies with crop N requirement over the cropping season. This was investigated using ENVIRON-GRO, a computer model, which accounts for N and irrigation management effects on crop yield and N leaching (Pang and Letey, 2000). Published data were used with the model to evaluate the multi year dynamics of N mineralization and N-uptake for corn and wheat when manure is added using N based recommendations. The results show that the N-uptake of the corn can exceed the cumulative mineralized N during part of the season. This deficit is caused by the very rapid uptake of N from knee high to tasseling. The deficit can reduce yield if no fertilizer topdress N is added. However, wheat has a low and flat N-uptake peak and manure N could better meet the N demand for wheat. The authors concluded that a crop with a very high maximum N-uptake rate, such as corn, would require inorganic N to meet peak demands if excessive N application is to be avoided.

Nutrient management planning

Nutrient management planning can reduce the N and P loss from farmland. This is illustrated in a case study conducted by VanDyke et al. (1999). Nutrient management planning was evaluated on four Virginia livestock farms using the Erosion Productivity Index Calculator (EPIC) model to calculate the effects of management changes. Changes in management practices with implementation of nutrient management are illustrated in Table 1.

Table 1. Changes in management practices with implementation of nutrient management plans (adapted from VanDyke et al., 1999)

Farm	Changes in management practices with plan
Southwest Dairy	Credit manure nutrients Reduce nitrogen fertilizer Split nitrogen applications Nitrate quick test
Shenandoah Valley Dairy	Install manure pit Apply manure to more land Credit manure nutrients Reduce commercial fertilizer applications
Southeast Swine	Construct manure storage Apply manure to all cropland Inject manure applied to corn Credit manure nutrients Reduce commercial fertilizer applications
Piedmont Poultry	Construct 2 litter sheds and mortality composter Reduce litter applications Compost poultry mortalities Sell excess litter

The results indicate that after the farms implementation of a nutrient management plan, average annual nitrogen and phosphorus losses were reduced by 23 to 45%, and 0 to 66%, respectively (Table 2). Study results suggest that the magnitude of nutrient loss reductions on livestock farms is contingent on unique farm characteristics, fertilizer management practices, and weather. Generally, fields with poor quality soils or steep slopes have much greater nutrient losses, particularly when manure provides some of the crop nutrient requirements. Nutrient management results in greater reductions of nutrient losses on these soils compared to soils with less risk of runoff and leaching.

Calculated annual farm income for these farms increased by \$395 to \$4,593, primarily due to reduced fertilizer expenses associated with crediting of manure nutrient content and increased sales of poultry litter to nearby farms (Table 3). However, it cannot be concluded that nutrient management planning increases income on all farms, due to the small number of farms analyzed for this study.

Table 2. Average annual per hectare nitrogen and phosphorus losses before and after nutrient management plan (adapted from VanDyke et al., 1999)

	Southwest Dairy	Shenandoah Valley Dairy	Southeast Swine	Piedmont Poultry
		kg/ha		
Total N loss before plan[1]	53	69	46	24
Total N loss after plan[1]	39	46	25	19
Total N loss reduction[2]	14 (27%)	23 (33%)	21 (45%)	6 (23%)
Range of N loss reduction by field	10 to 15	3 to 105	-3 to 58	1 to 12
Total P loss before plan[3]	8	18	3	9
Total P loss after plan[3]	8	14	1	6
Total P loss reduction[3]	0 (0%)	4 (23%)	2 (66%)	2 (32%)
Range in P loss reduction by field	0	-2 to 27	-1 to 10	0 to 7

[1/] Average per hectare losses are weighted averages based on the acreage of each soil and crop rotation on farm.

[2/] Totals may be affected by rounding.

[3/] P losses are nearly all attached to eroded sediment.

Table 3. Annual economic impact of nutrient management[1] (adapted from VanDyke et al., 1999)

Farm	Additional costs ($)	Reduced income ($)	Additional income ($)	Reduced costs ($)	Net income change[2] ($)
Southwest Dairy	2,270	0	0	2,665	395
Shenandoah Valley Dairy	7,643	0	0	12,236	4,593
Southeast Swine	15,041	2,195	0	20,251	3,015
Piedmont Poultry	3,020	562	2,240	3,639	2,297

[1/] Costs including annualized cost of investments and operator labor.

[2/] Net income change equals additional income plus reduced costs minus additional costs minus reduced income.

Fertilizer management practices, farm characteristics, and weather influenced nutrient losses within and across farms. Manure storage, manure nutrient crediting, and proper timing of manure applications are critical in reducing nutrient losses and increasing cost savings. The construction of storage allows flexibility to apply manure when and where it will be most beneficial to crops, thus reducing fertilizer applications, costs and nutrient losses.

Phosphorus-based manure management

Generally, manure is applied to agricultural land based on nitrogen (N) recommendations, to meet N requirements of the crop. This can result in over-application of phosphorus (P) and its accumulation in soil and consequent runoff to surface waters or possible leaching to shallow ground water.

Eghball and Power (1999) conducted a four-year study to evaluate effects of P- and N-based manure and compost application on corn yield, N and P uptake, soil P level, and weed biomass on a silty clay loam soil under rainfed conditions in Nebraska. Composted and noncomposted beef cattle feedlot manures were applied to supply the N or P needs of corn for either a one- or two-year period. Phosphorus-based manure or compost treatments also received additional N fertilizer as required.

In all four years, manure or compost application increased corn grain yield as compared with the unfertilized control. Manure or compost application resulted in similar grain yields to those of the fertilizer treatment, and yields for biennial and annual applications were similar when applied for an expected grain yield of 9.4 Mg/ha. Annual phosphorus-based manure or compost application resulted in similar grain yields to those for N-based treatments, and significantly lower soil P levels after four years of application. Biennial phosphorus-based manure or compost application also resulted in similar grain yields, but had greater soil P buildup than annual treatments because of greater amounts of P applications.

Estimated N availability was 40% for manure and 15% for compost in the first year and was 18% for manure and 8% for compost in the second year after application. Nitrogen use efficiency (plant N uptake divided by added N) was greater for manure than compost application. Phosphorus use efficiency was 2.5 to four times greater for annual P-based manure or compost application than N-based application.

Eghball and Gilley (1999) also determined the effects of simulated rainfall on runoff losses of P and N, and pH following the application of manure and compost. Manure, compost, and fertilizer were applied to the soil surface of no-till fields or disked to 8 cm following sorghum and winter wheat, at rates required to meet the N or P requirements for corn production. Generally, total and particulate P concentrations in runoff were less after wheat than sorghum, and were less for the no-till than the disked treatment. Application of manure to meet the N requirement of the crop resulted in more P in the runoff than application to meet the P need of the crop. Fertilization resulted in similar P concentration in the runoff as compost or manure application. Dissolved P constituted 91% of the bioavailable P in runoff. These results from Nebraska suggest that the method of application of manure is important in determining P in runoff.

In another study, Whalen and Chang (2001) investigated the P balance of cultivated soils under barley production with long-term annual manure amendments. Nonirrigated soils at the study site in Alberta, Canada, received 0, 30, 60, or 90 Mg/ha manure (wet weight basis) while irrigated plots received 0, 60, 120, and 180 Mg/ha annually for 16 years. All of these are disposal rates, much in excess of crop needs. The amount of P removed in barley grain and straw during the 16-year period was between 5 and 18% of the cumulative manure P applied. Over 16 years, as much as 1.4 Mg/ha of added P (180 Mg/ha/yr treatment) was not recovered in the top 150 cm of soil in the irrigated plots and was probably lost lower depths. In nonirrigated plots, there was a balance between P applied in manure and P recovered in crops and soils (to the 150-cm depth).

The total P concentrations were 1.9 to 5.2 Mg/ha greater in the amended than in the control plot, in irrigated soil to the 150 cm depth. The manure application rates of 30 Mg/ha and 60 Mg/ha provided five to six times more P than was recommended for barley production on nonirrigated and irrigated soils. These results show there is a risk of P movement to ground water with greatly excessive manure applications in irrigated plots.

Watershed ecosystem nutrient dynamics models

Nutrient dynamic models have been used to describe how nutrients are cycled and stored, and to assess the effects of management practices on nutrients transported into and out of a watershed. Osei et al. (2000) performed computer simulations to assess the impact of various management practices on phosphorus losses from dairy farms in a watershed in north central Texas. The results indicated that manure management based on crop P needs, in livestock intensive watersheds, offers sound management for reducing nonpoint source P loading. In some watersheds, where excessive P losses or soil P buildup from previous land uses, greater P reduction to less than crop removal is required. Composting all solid manure can reduce P loads by removal from the watershed. The cost to dairy producers was estimated to be about 27-30% of their baseline net returns, which could be debilitating for smaller dairies. Various options for financing composting alternatives for the dairies could be implemented to help alleviate the financial burden on farmers. The choice for each watershed depends on such key factors as available land area and the load reduction sought.

The USDA Natural Resources Conservation Service (NRCS) Water Science Institute (WSSI), in cooperation with a number of partners, has initiated a project to promote nutrient cycling within watersheds. The project has developed a watershed-scale model to examine dynamic phosphorus (P) flows into, out of, and within watersheds using a mass balance approach. The model is called Watershed Ecosystem Nutrient Dynamics (WEND). The WEND model tracks watershed P balances over time within each of the several land-use sectors. Figure 2 is a diagram of the P compartment-flux for storing and cycling P in agriculture watersheds. The model was used by Aschmann et al. (1999) to study long-term impacts of various strategic policy decisions (status quo, increased rate of development, and increased conservation polices) on P cycling in the Winooski River Watershed in Vermont. The agriculture in the watershed is primarily dairy. The model showed P losses into the surface water were significantly reduced under the conservation scenario, while water quality was impaired under the status quo, and development scenarios projected over 80 years. It was concluded that the WEND model could help in providing the framework needed to create sustainable nutrient strategies for watersheds.

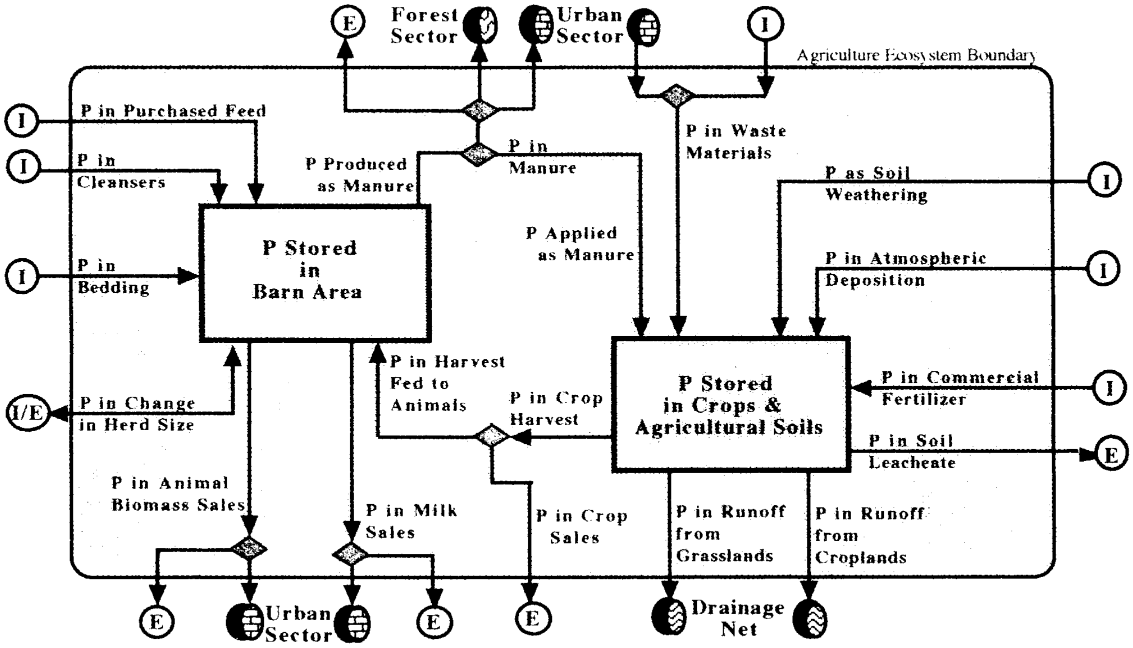

Figure 2. Phosphorus nutrient compartment of the Watershed Ecosystem Nutrient Dynamics model.

Manure nutrient guidelines, regulations and implementation

Recently concerned citizens, environmentalists and regulatory agencies have focused on manure nutrient management and deposition from concentrated feedlots. Development and use of nutrient management planning has the potential to improve the utilization of nutrients and minimize contamination of the environment. The establishment and enforcement of manure nutrient regulations will alter the future of livestock production (Meyer and Mullinax, 1999). Proposed legislation may impose monitoring and record keeping on the livestock operators. Livestock operations need to comply with regulations to minimize environmental liability and to operate.

Proposed legislation and strategies (a simplistic approach to nutrient management) may provide a false sense of security regarding environmental preservation or restoration. The challenge is to create a policy that will allow flexibility for regions and states and still provide a reasonable guideline to minimize contamination. Also proposed strategies should provide a component that accommodates specific conditions of particular farming operations or nature (Beegle et al., 2000).

Successful implementation of nutrient management policy must involve full participation of a broad range of stakeholders (Beegle et al., 2000). Major stakeholders are the farmers, allied agri-industry, public agencies, regulators, policymakers, environmental groups, and the consumer. Stakeholders are critical for developing sound objectives for the nutrient management effort. Also research, education and financial and technical assistance are critical for the success of nutrient management programs (Jackson et al., 2000). Cost-share funds or tax incentives may be critical for adoption of nutrient management plans (VanDyke et al., 1999).

Summary

- Organic farms, which generally utilize manure rather than commercial fertilizer, have higher soil quality compared to conventional farms as indicated by greater organic C, total N, microbial biomass C and N, and soil respiration, and by pH values closer to neutral, lower bulk density, and higher available-water holding capacity.

- Manure from animals receiving feed additives to improve animal health can contain high concentrations of trace elements. The quantity of these elements in manure depends on the type of manure or source (poultry vs. swine). The potential exists for some of the trace elements to eventually accumulate to phytotoxic levels in soils.

- In some cases reduction of trace metal dietary supplements, with a consequent reduction of concentrations in the manure, is possible without reducing animal health.

- The method of P application is more important that the source of P in predicting the loss of P in runoff. Manure and inorganic fertilizer P are both problematic when surface applied.

- Adding fly ash, alum or ground limestone can reduce the leachability and bioavailability of manure P. Fly ash must be used with care because of potential adverse environmental effects from trace elements. Alum is a possible problem on acid soils.

- Transport of manure P to ground water may be more of a problem than previously thought. Some transport can occur though macropores in soils without interaction with subsoil particles that can adsorb P.

- The fraction of P saturation and soil test P are good parameter for prediction of soil P solubility.

- The adoption of management practices outlined in nutrient management plans could result in significant reductions in N and P losses. Management planning can increase net farm income but the income increases may be insufficient to cause voluntary adoption of nutrient management planning.

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- Involving local experts and watershed residents in the development process of nutrient management policy allows stakeholders to understand the complexity and interactions among land-use sectors within their own watersheds.

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Current Research

Many researchers around the US are involved in studies of the economic benefits and environmental problems associated with animal manure. This section details the results of interviews of researchers who we believe are doing some of the most important research that is relevant to understanding the problems associated with manure utilization in Minnesota.

Subject of the Investigation	**Investigators**
Runoff loss of N and P following manure and compost application.	Eghball, B.
Enhancing food safety through control of food born disease agents.	Diez-Gonzalez, F.
The impact of phosphorus based manure application rates on water quality and soil properties.	Hansen, N.C. and others
Shiga-toxin producing *Escherichia* coli ocurrence and dairy cattle and risk factors for human infections.	Hedberg, C. and others
Development of poultry manure management practices for reducing phosphorus in runoff.	Moore, P. A. and others
A systems approach for improved phosphorus and management on dairy farms.	Powell, M and other
Effect of manure management on corn yield and nutrient recycling.	Powell, M and Kelling, K.
Effect of manure management on nitrate leaching and phosphorus runoff.	Radcliffe, D. E.
Watershed-scale phosphorus and bacteria loading from manures	Radcliffe, D. E, and others
Optimizing nutrient management to sustain agricultural ecosystems.	Sharpley, A. N. and other

Investigators: Bahman Eghball

Institution or Affiliation: USDA-ARS

Subject of the Investigation: To measure runoff loss of N and P following manure and compost application. Quantifying nitrogen mineralization and emission of greenhouse gases following manure and fertilizer application.

Funding Agency: USDA-ARS and USDA Funds for Rural America

Duration of Study: 3 years:

Objectives: To develop effective and environmentally sound methods for utilization of nutrients and carbon in manure.

Key Words: Manure, compost, fertilizer, site-specific management, greenhouse gasses, N mineralization, water quality, P and N transport

Location (or Locations) of Study: Mead, Phillips, and Concord in Nebraska and Akron, Colorado

Type (or types) of Soil Used: Sharpsburg, Hord, Ortello, Thurman

Climate: Temperate

Approach: Corn yield, nitrogen uptake, soil properties, emission of greenhouse gasses, and nitrogen mineralization were determined following site-specific and uniform manure and fertilizer applications.

Progress: Residual effects of manure and compost application were evaluated following manure and compost application. Runoff effects of manure and fertilizer application were determined. Research is in progress.

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Eghball, B., and J. E. Gilley. 2001. Phosphorus risk assessment index evaluation using runoff measurements. J. Soil Water Conserv. 56: (In press).

Potential Implications:

The study will provide valuable information regarding effective utilization of nutrients and carbon in manure. Information on environmental effects of manure application on soil, water, and atmospheric quality will also be obtained.

Investigators: F. Diez-Gonzalez

Institution or Affiliation: UNIV OF MINNESOTA

Title of Study: Enhancing food safety through control of food born disease agents.

Funding Agency: USDA-CSREES MIN, HATCH

Duration of Study: 5 years

Objectives: 1) Pre-harvest reduction of food-borne pathogens in animals and the environment.
2) Chemical and Physical Decontamination in Food Processing Plant Environments.

Key Words: Pathogens

Location (or Locations) of Study: Alabama, Iowa, Kentucky, Michigan, Minnesota, Mississippi, Nebraska, New York, North Carolina, South Carolina, Tennessee and Virginia

Type (or types) of Soil Used: NA

Climate: NA

Approach: Annual plans of work (POWs) will consist of experiments to be carried out by the participants to collect essential data for each factor. Subsequently, data will be interpreted by the participants so that recommendations can be made.

Progress: On-going

Potential Implications: Develop pre-harvest strategies to reduce the fecal shedding of food borne pathogens by livestock. Will reduce the potential risk of contamination of food supply.

Publications: None

Investigators: N.C. Hansen, P.D. Gessel, and J.F. Moncrief

Institution or Affiliation: University of Minnesota, Dept. Soil, Water, and Climate

Title of Study: The impact of phosphorus based manure application rates on water quality and soil properties

Funding Agency: Water Resources Research Institute, USGS

Duration of Study: 3 yrs

Objectives: The objective of this study is to evaluate how manure application at varying rates impacts soil physical properties, runoff, and the transport of phosphorus and sediment in runoff.

Key Words: Manure, water quality, nutrient transport, phosphorus

Location (or Locations) of Study: Morris, MN

Type (or types) of Soil Used: Forman Buse

Climate: Temperate

Approach: Liquid hog manure is applied annually to runoff plots in a corn-soybean rotation. Manure application rates are based on 0.5, 1.0, and 2.0 times the recommended phosphorus application to a soil low in plant available phosphorus. Runoff quantity and quality is evaluated from rainfall and snowmelt runoff.

Progress: After two years, runoff and associated phosphorus losses have been lower when manure is applied than for the non-manured control. The reduction in runoff has been greatest for the higher manure rate. Crop yields have also increased with increasing manure application rates.

Potential Implications: The results of this study illustrate the value of manure for improving soil and water quality when applied at appropriate rates on soils responsive to P application.

Publications:

P.D. Gessel, N.C. Hansen, and J.F. Moncrief. 2000. The impact of phosphorus based manure application rates on water quality and soil properties. Agronomy Abstracts

Investigators: Craig Hedberg (PI), Jeff Bender, Francisco Diez-Gonzalez

Institution or Affiliation: University of Minnesota

Subject of Investigation: Shiga-toxin producing Escherichia coli occurrence in dairy cattle and risk factors for human infections in agricultural and urban areas

Funding Agency: Academic Health Center, University of Minnesota

Duration of Study: 2 years (2001-2002)

Objectives: To compare the occurrence and serotype distribution of shiga-toxin producing Escherichia coli (STEC) among dairy cattle in Central and Southeastern Minnesota. To compare the occurrence and serotype distribution of human STEC infections among residents of agricultural and urban areas.

Key Words: E. coli, cattle survey, enterohemorrhagic

Location (or Locations) of Study: 257 ABLMS, 1242 Mayo, 395 Vet Science

Type (or types) of Soil Used: NA

Climate: NA

Approach: This project will incorporate surveillance for STEC among dairy cattle and humans in the same geographic area, with a case-control study to identify risk factors for human STEC infections.

Progress: About to start.

Potential Implications: This preliminary data provides a unique opportunity to compare the type and frequency of STEC isolated from individual herds. Additionally, this pilot project is the first to characterize STEC isolated from cattle in Minnesota. This baseline information will characterize the type of STEC agents found in cattle in limited geographic areas with the hope to evaluate herd risk factors for infection among Minnesota herds in the future.

Publications: None

Investigators: Moore, P. A. T.C. Daniel, A.N. Sharpley, D.R. Edward P.A. Moore and C.P. West

Institution or Affiliation: USDA-ARS Poultry Research Unit Arkansas

Subject of the Investigation: Development of poultry manure management practices for reducing phosphorus in runoff

Funding Agency: USDA-CRIS

Duration of Study: Long-term

Objectives: Determine the factors that affect phosphorus chemistry and transport in soil, water, and manure. Determine the long-term impacts of manure management strategies on soil, water, and air resources. Develop best management practices to reduce non-point source phosphorus runoff. Determine the factors that influence surface water runoff within watersheds. Develop predictive tools to identify critical hydrologic areas for nutrient loss within watersheds.

Key Words: Manure, runoff, nutrient transport, phosphorus, phosphorus index, hydrologic modeling, pasture management, poultry litter

Location (or Locations) of Study: Fayetteville, Arkansas and other

Type (or types) of Soil Used: Varies with the experiment

Approach: A combination of field, laboratory, and hydrologic modeling.

Progress: on-going

Potential Implications: The potential benefits of this research are enormous. Without the development of management practices to reduce pollution associated with animal agriculture, many of these commodity groups may be forced to move to other countries; a move that would negatively affect the economy of this country.

Publications: Research has recently started. Some relevant publications are:

Edwards, D.R., P.A. Moore, JR., S.R. Workman, and E.L. Bushee. 1999. Runoff of metals from alum-treated horse manure and municipal sludge. J. Amer. Water Res. Ass. 35:155-165.

Jaynes, W.F., P.A. Moore, JR., and D.M. Miller. 1999. Solubility and ion activity products of calcium phosphate minerals. J. Environ. Qual. 28:530-536.

Moore, P.A., JR. 1999. Development of a phosphorus index for pastures. pp. 30-35 in (M. Rasnake, ed.) Proc. of the 1999 Southern Soil Fertility Conference.

Moore, P.A., JR., T.C. Daniel, and D.R. Edwards. 1999. Reducing phosphorus runoff and improving poultry production with alum. Poultry Sci. 78:692-698.

Moore, P.A., JR. 1999. Reducing non-point source phosphorus runoff from poultry manure with aluminum sulfate. In (J.P. Toutant, E. Balazs, E. Galante, J.M. Lynch, J.S. Schepers, D. Werner, P.A. Werry, editors) Biological Resources Management: Connecting Science and Policy.

Pote, D.H., T.C. Daniel, D.J. Nichols, A.N. Sharpley, P.A. Moore, JR., D.M. Miller, and D.R. EdwardsDWARDS. 1999. Relationship between phosphorus levels in three ultisols and phosphorus concentrations in runoff. J. Envir. Qual. 28:170-175.

Other Comments:

Other related project are: 1) Effect of forage species and canopy cover on hydrology and runoff water quality from poultry litter amended soils.

2) Reducing P and NH_3 volitalization from poultry litter and swine manure with $ALCL_3$ and alum. 3) Construction of wetland on swine farms for waste remediation.

Investigators: Powell, M., Satter, L., Jackson-Smith, D., Bundy, L. and Converse, J.,

Institution or Affiliation: USDA-ARS Dairy Forage Research Center

Subject of Investigation: A systems approach to improved phosphorus management on dairy farms.

Funding Agency: USDA-CSREES NRI Agricultural Systems Program

Duration of Study: 3 years

Objectives: To study the dietary P management, and the effect of high P diet on soluble P in the runoff from dairy farms.

Key Words: Manure, dietary P, dairy cows, runoff

Location (or Locations) of Study: Various on-farm locations in Wisconsin

Type (or types) of Soil Used: Plano silt loam (fine-silty, mixed, mesic: Typic Agriudoll
Climate: Moist sub-humid

Approach: We looked at dietary P and P accumulation in runoff from dairy farms.

Progress: This project has shown that substantial reductions in P accumulation and runoff from dairy farms can be derived from concomitant improvements in P feeding, resulting in less P imported, fed, and excreted, and from appropriate tillage regimes, which reduce P runoff.

Potential Implications: Development of management practices that will be suitable for reducing environmental impacts under most conditions where some feed is imported.

Publications:

Bundy, L.D., T.W. Andraski, J.M. Powell, J.S. Studnicka, and A.M. Ebeling. 2000. Management practice effects on phosphorus losses in runoff. pp 23-34. In: Proc. of the 2000 Wisconsin Fertilizer, Aglime & Pest Management Conference, Madison WI, January 18-20, 2000.

Jackson-Smith, D. and J.M Powell. 2000. How Wisconsin Dairy Farmers Feed their Cows: Results of the 1999 Wisconsin Dairy Herd Feeding Study. Wisconsin Farm Research Summary No. 5. Program on Agricultural Technology Studies (PATS). University of Wisconsin-Madison. 16pp.

Wu, Z. and L.D. Satter. 2000. Milk production and reproductive performance of dairy cows fed two concentrations of phosphorus for two years. J. Dairy Sci. 83:1052-1063.

Wu, Z., L.D. Satter and R. Sojo. 2000. Milk production, reproductive performance, and fecal excretion of phosphorus by dairy cows fed three amounts of phosphorus. J. Dairy Sci.

83:1028-1041.

Powell, J.M., L.D. Bundy, and D. Jackson-Smith. 2000. Whole-farm phosphorus management on dairy farms. Special Symposium. Phosphorus Management in Dairy Systems. p. 279. Agronomy Abstracts. American Society of Agronomy. Madison, Wisconsin.

Other Comments:

The survival of many dairy farms in the U.S. will depend on farmers' ability to comply with increasingly strict environmental regulations associated with phosphorus management. This research will help with reducing the amount of P intake by animals which in turn will reduce the amount of P in the animal manure.

Investigators: Powell, M. and K. Kelling

Institution or Affiliation: USDA-ARS Dairy Forage Research Center

Subject of Investigation: The effect of manure management on corn yield and nutrient recycling.

Funding Agency: USDA-Hatch

Duration of Study: 3 years

Objectives: To evaluate the effect of manure application rate and frequency on corn silage yield and N uptake and to compare manure N uptake with that of chemical N fertilizer.

Key Words: Manure application rate, corn silage yield, N uptake

Location (or Locations) of Study: Madison, WI

Type (or types) of Soil Used: Plano silt loam.

Climate: Moist sub-humid

Approach: Field experiments are being conducted using three manure rates and three manure application intervals and six fertilizer N levels.

Progress: Using the ^{15}N method, it appears that from 10 to 18% of applied manure N is taken up by corn silage. Research is in progress.

Potential Implications: The results of this project should have several implications for improving environmental impacts of dairy manure management. The field trial is designed to evaluate the effects on N cycling of various manure management strategies.

Publications:

Powell, J.M., K.A. Kelling and GR. Munoz. 2000. Turnover of dairy manure nitrogen fractions in soil. p. 271. Agronomy Abstracts. American Society of Agronomy. Madison, Wisconsin.

Other Comments: More accurate estimates of manure nutrient availability to crops are needed if we are to expect farmers to improve manure management.

Investigators: Radcliffe, D. E.

Institution or Affiliation: University of Georgia

Subject of the Investigation: Effect of manure management on nitrate leaching and phosphorus runoff

Funding Agency: USDA-CSREES GEO-HATCH

Duration of Study: 4 years

Objective: Develop manure management practices for dairy loafing areas and poultry manure utilization

Key Words: Manure, runoff, leaching, P, NO_3

Location (or Locations) of Study: Piedmont region, north Georgia

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

Approach: Dairy corral is fenced and lined with geotextile fabric. Surface runoff and tile drain effluent are routed to the lagoon and monitored for nitrate and phosphorus. A mixture of Coastal bermuda grass and Georgia 5 tall fescue will be planted and poultry litter at several rates will be applied. Nitrogen and phosphorus in the tile drainage and surface flumes will be measured.

Progress: on-going

Potential Implications: The results of this study will be beneficial for improved housing of dairy cow and beneficial utilization of poultry manure as a fertilizer.

Publications:

Johnson, A.D., Cabrera, M.L., McCracken, D.V., and Radcliffe, D.E. 1999. LEACHM simulations of nitrogen dynamics and water drainage for a Piedmont ultisol. Agonomy J. 91:597-606.

McVay, K.A., and Radcliffe, D.E. Water quality of runoff and leachate from an improved loafing lot. 1999. K.J. Hatcher (Ed.) Proceedings of the 1999 Georgia Water Resources Conference, March 29 - 31, 1999, University of Georgia, Athens 230-233.

Myers, L.M., Bush, P.B., Segars, W.I., and Radcliffe, D.E. 1999. Impact of poultry mortality pits on groundwater quality in Georgia. K.J. Hatcher (Ed.) Proceedings of the 1999 Georgia Water Resources Conference, March 29 - 31, 1999, University of Georgia, Athens 234-239.

Investigators: Radcliffe, D. E. Miguel Cabrera, Peter Hartel, Mark McCann, Todd Rasmussen, and Mark Bakker

Institution or Affiliation: University of Georgia

Title of Study: Watershed-Scale Phosphorus and Bacteria Loading from Manures

Funding Agency: USDA-CSREES GEO-HATCH

Duration of Study: 5 years

Objectives: 1) To determine the relationship between concentrations of P in freshly applied poultry litter and P in runoff. 2) To determine the effect of riparian buffers in reducing P and bacteria leaving grass fields. 3) To develop landuse-specific parameter sets for use in watershed-scale models of P and bacteria in the Piedmont.

Key Words: Phosphorus runoff, manure, riparian buffers

Location (or Locations) of Study: Piedmont region, north Georgia

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

Approach: Rainfall simulations we will perform on small plots that have received different rates of poultry litter. Concentrations of DRP and total P will be measured in the runoff. Various measures of P in the fresh litter will be made such as water-soluble P, total P, organic P, and inorganic P. A model will be developed that includes the various pools of P in manure, the rates at which pools turn over, and DRP in runoff. The data from the rainfall simulations will be used to calibrate this model. The model will then be used to determine the relationship between the applied litter P and the mean annual runoff DRP concentration. This will be incorporated into the source part of the P-index we are developing for Georgia.
Automated samplers will be used to collect samples from the streams for P concentrations. The samplers will be placed immediately downstream of each buffer treatment. Grab samples will be used to collect samples biweekly for biological water quality. Concentrations of dissolved reactive P and total P will be measured in stream samples. Concentrations of fecal coliform and *E. coli* will be determined in grab samples with IDEXX Quantitray/2000.

Progress: About to start.

Potential Implications*:* It will help determine the contribution from fresh broiler litter to edge-of-field concentrations of P, the effect of riparian buffers in reducing P and bacterial concentrations that reach streams, and accurate parameters for watershed-scale models that will be used to assess agriculture’s contribution to basin pollutant loads.

Investigators: Sharpley, A.N., Gburek, W.A., Stout W.L., Kleinman, P. McDowell, R.

Institution of Affiliation: USDA-ARS, Pasture Systems and Watershed Management.

Subject of Investigation: Optimizing nutrient management to sustain agricultural ecosystems and protect water quality

Funding Agency: USDA-ARS appropriated funds

Duration of Study: January 2001 to December 2006

Objectives: Quantify the impacts of manure, crop and grazing management on P, N, and C cycling in soils. Define critical source areas and transport pathways of P and N by relating soil nutrient levels to losses in surface runoff and leachate. Develop and apply models and indices to assess and rank site vulnerability to nutrient loss. Define best management practices aimed at minimizing nutrient transfers from agricultural lands to water.

Key Words: Carbon, critical source area hydrology, dairy manure, dairy compost, eutrophication, groundwater recharge, leaching, nitrogen, nonpoint source pollution, nutrient management, phosphorus, poultry compost, poultry manure, poultry litter, soil management, swine manure, surface runoff, tillage, water quality.

Locations of Studies: The Northeast U.S. - Pennsylvania, New York, Delaware, Maryland, West Virginia.

Type of Soils Used: Benchmark noncalcareous and calcareous soils of the Northeast that are agriculturally important.

Climate: Temperate and humid

Approach: Laboratory, field, and landscape studies will be used to quantify manure, crop, and grazing management effects on amounts and forms of P, N, and C in soils. Simulated and natural rainfall, will be used to assess nutrient transport potential of surface runoff and ground water recharge. Management effects on nutrient losses at farm and watershed scales will be predicted by process-based models (e.g., AnnAGNPS) and user-oriented indices (e.g., P Index).

Potential Implications: This research will provide the basic knowledge and appropriate technology needed to reduce the impact of land-applied nutrients on soil and water resources from animal production systems.

Publications:

Gburek, W. J., Sharpley, A. N., and Folmar, G. J. Critical areas of phosphorus export from agricultural watersheds. p. 83-106. In Sharpley, A. N. (ed.) Agriculture and Phosphorus Management: The Chesapeake Bay. CRC Press, Boca Raton, FL. 2000.

Gburek, W. J., Sharpley, A.N., Heathwaite, L., and Folmar, G.J.. Phosphorus management at the watershed scale: A modification of the phosphorus index. J. Environ. Qual. 29:130-144. 2000.

Haygarth, P. M. and Sharpley, A. N. Terminology for phosphorus transfer. J. Environ. Qual. 29:10-15. 2000.

Heathwaite, A. L., Sharpley, A. N., and Gburek, W. J. Integrating phosphorus and nitrogen management at catchment scales. J. Environ. Qual. 29:158-166. 2000.

Heathwaite, A. L. and Sharpley, A. N. Evaluating measures to control the impact of agricultural phosphorus on water quality. Water Science and Technology 39:149-155. 1999.

Heathwaite, L., Sharpley, A.N., and Gburek, W.J.. A conceptual approach for integrating phosphorus and nitrogen management at watershed scales. J. Environ. Qual. 29:158-166. 2000.

Howarth, R. W., Anderson, D. A., Church, T. M., Greening, H., Hopkinson, C. S., Huber, W., Marcus, N., Naiman, R. J., Segerson, K., Sharpley, A. N., and Wiseman, W. J. Clean coastal waters: Understanding and reducing the effects of nutrient pollution. National Research Council. National Academy Press, Washington, D. C. 405 pages. 2000.

Kleinman, P.J.A. Source risk indicators of nutrient loss from agricultural lands. p. 237-252. Sailus, M. (ed), Managing Nutrients and Pathogens in Animal Agriculture, Northeast Regional Agricultural Engineering Service, Ithaca, NY. 2000

Pionke, Harry B., William J. Gburek, and Andrew N. Sharpley. Critical source area controls on water quality in an agricultural watershed located in the Chesapeake Basin. Ecol. Engrg. 14(2000):325-335. 2000.

Pionke, H. B., Gburek, W. J., Schnabel, R. R., Sharpley, A. N., and Elwinger, G. Seasonal flow and nutrient patterns for an agricultural hill-land watershed. J. Hydrology 220:62-73. 1999.

Pionke, H. B., Rotz, C. A., Sanderson, M. A., Stout, W. L., and Sharpley, A. N. Nitrogen and phosphorus sources and their importance to pasture-based livestock systems. p. 2-12. In Proceedings of the British Grassland Society Conference, Accounting for Nutrients. British Grassland Society, November 1999, Great Malvern, England. British Grassland Association Occasional Symposium 33. 1999.

Sharpley, A. N. The phosphorus index: Assessing site vulnerability to phosphorus loss. p. 255-281. In Sailus, M. (ed.) Managing Nutrients and Pathogens from Animal Agriculture. Natural Resource, Agriculture and Engineering Service Bulletin NRAES-130. Ithaca, NY. 2000.

Sharpley, A. N. Future trends for phosphorus management in the Chesapeake Bay watershed: Perspectives of Bay users. p. 181-186. In Sharpley, A. N. (ed.) Agriculture and Phosphorus Management: The Chesapeake Bay. CRC Press, Boca Raton, FL. 2000.

Sharpley, A. N. and Tunney, H. Phosphorus research strategies to meet agricultural and environmental challenges of the 21st century. J. Environ. Qual. 29:176-181. 2000.

Sharpley, A. N., Foy, B., and Withers, P. J. A. Practical and innovative measures for the control of agricultural phosphorus losses to water: An overview. J. Environ. Qual. 29:1-9. 2000.

Pathogen Transfer to Humans on Edible Crops

Issues of concern

What are the health risks from using manure in the production of edible crops? What pathogenic species are involved? Which crops are prone to transmitting pathogens? What are the pathways for exposure to pathogens? What factors contribute to pathogen transfer from manure to crops? Does manure refeeding pose a health risk? How can pathogen transfer be minimized? What are the measures for pathogen control in edible crops?

In this document edible crops are defined as those that are consumed for food by humans. This excludes fiber crops and all crops grown for animal feed. We began this literature review by looking for all forms for transmission of manure pathogens vial edible crops. In the end we found that the only reports of problems or potential problems are for fresh market fruits and vegetables.

What are the health risks from using manure in the production of edible crops?

Using animal manure in the production of edible crops can have a direct effect on human health if the manure contains pathogens that are transmittable from animals to humans, and if the manure or pathogens remain on the edible crops at the time of human consumption. In order to have a health effect, manure need only be ingested in small amounts from contaminated fresh fruits and vegetables. For example, ingestion of as little as 100 μg of cattle feces contaminated with Escherichia coli O157:H7 can cause infection and full symptoms development in humans (Jones, 1999) including sickness or even death. The question is whether and how often this happens.

It has been well established that some animal pathogens are transmittable to humans. These pathogens are called zoonotic. These pathogens can exist in soil, manure, or water and hence can end up on fresh fruits and vegetables, causing illness in the humans who consume them. It should be noted that manure is not the only source of zoonotic pathogens. Zoonotic pathogens exist in secretions from the nose, throat, blood, vagina, mammary gland, skin, and placenta which may be present in animal bedding (Pell, 1997).

Food borne pathogens

In several recent food-borne disease outbreaks, contamination with animal pathogens was implicated. Although livestock were not proven as the cause of the disease outbreaks, they were suspected because they are a known reservoir for the pathogens. However, non-farm animals such as deer and many other animals and birds can serve as reservoirs for pathogens (Dingman, 2000; Folsom and Frank, 2000; Keene et al., 1997; Kudva et al., 1996; Zhao et al., 1995).

Substantial scientific literature exists on the presence and isolation of zoonotic pathogens in manure, and on the surface of fresh fruits and vegetables (Beuchat, 1996; Brackett, 1999; Burnett, et al., 2000; Dingman, 2000; Fisher and Golden, 1998; Jones, 1999; Pell, 1997). However, no studies were found that directly demonstrate a causal link from manure application to zoonotic pathogens on fresh marketed crops. This makes it difficult to assess the level of risk involved.

Risk to producers

Although the risk of pathogen transfer to edible crops and surface waters is significant, the risk to producers, animal handlers, veterinarians, and others working with animals is much greater than that to the general population (Stehman et al., 1996).

What are the major pathogenic species are involved?

There are more than 150 pathogens that transmit infections from animals to humans (Strauch and Ballarini, 1994). Table 1 lists some of the diseases and parasites transmittable to humans from animal manure. These bacteria, viruses, fungi, rickettsia, protozoa, and helminths can cause zoonotic infections if steps are not taken to ensure careful handling and processing of produce treated with manure.

CAST (1996) states that because of the enhanced disease control and current animal management practices, very few of the diseases and parasites listed in Table 1 are of any concern to human health. Miner et al. (2000) states that although the frequency of human diseases due to livestock and poultry wastes is small, the potential exists. Pathogenic bacteria of potential concern in fresh produce are examined in more detail below.

Bacteria

Important pathogenic bacteria found in fresh produce are *Escherichia coli* O157:H7, *Salmonella* spp., and *Listeria monocytogenes*. These are particularly important because they have caused reported food-borne illness outbreaks.

Escherichia coli **O157:H7**

Symptoms of Infection

Symptoms of *E. coli* infection include hemorrhagic colitis (profuse and bloody diarrhea), hemolytic uremic syndrome (bloody diarrhea followed by kidney failure) in children, and thrombocytopenic purpura (involves central nervous system) in the elderly, and often death can occur (Pell, 1997). Ingestion of only 10 to 50 cells of *E. coli* can cause full symptoms of infection to develop (Jones, 1999).

Sources

Although many *E. coli* O157:H7 outbreaks have been associated with the farm environment, this pathogen can have many sources. *E. coli* O157:H7 has been isolated in cattle, sheep, deer, horses, dogs and birds (Kudva et al., 1998). A study in the UK by Wallace et al. (1997) found that this pathogen is also present in wild birds (mainly gulls). It is suspected that birds become contaminated after feeding on pastures fertilized with farm slurries and sewage sludge.

Table 1. List of pathogens transmitted from livestock (cattle, horse, poultry, sheep, swine) to humans[1/].

Organism	Human Consequences of Infection
Bacteria	
Bacillus anthracis	Anthrax; fever, headache, nausea, vomiting, shock, respiratory failure (pulmonary form 100% fatal), bloody discharges (intestinal form 50% fatal), sudden death
Brucella melitensis; B. abortus; B. suis	Mediterranean fever; abortion, sterility, genital infection, headache, chills, nausea, weight loss
Campylobacter fetus fetus; C. jejuni	Vibrio; diarrhea, intestinal cramps, fever, pseudoappendicitis, septicemia, arthritis
Chlamydia sp.	Fever, chills, anorexia, headache, nonproductive cough, late abortion/neonatal death
Clostridium perfringens	Food poisoning, gas gangrene; fever, edema, neck stiffness
Clostridium septicum	Edema
Clostridium tetani	Tetanus, lockjaw; painful contractions of muscles; 30-90% fatal
Erysipelothrix insidiosa; E. rhusiopathiae	Erysipelas; localized, swollen, hot, and painful lesions
Escherichia coli	Diarrhea (profuse), vomiting, dehydration, septicemia, toxemia, meningitis
Leptospira sp.	Weil's disease; weakness, headache, chills, fever, jaundice, kidney infection, meningitis
Listeria monocytogenes	Circling disease; flu, headache, nausea, vomiting, meningitis, abortion
Lyme arthritis	Lyme disease; only livestock reported is horse; flu like symptoms, manifestation to heart failure, neurologic disorders, meningitis
Mycobacterium sp.	Tuberculosis; anorexia, eight loss, fatigue, fever, chills, cachexia
Mycobacterium paratuberculosis	(possible) Crohn's disease
Pfiesteria piscicida	
Pseudomonas pseudomallei	Simulates typhoid fever or TB; not common in man; 80% fatal
Pseudomonas mallei	Cough, nasal discharge, skin eruptions
Salmonella spp.	Food poisoning; abdominal pain, diarrhea, nausea, fever, septicemia
Salmonella typha	Typhoid fever; rare in U.S.
Staphylococcal aureua	Food poisoning; nausea, vomiting, abdominal pain, diarrhea; toxic shock syndrome in women
Streptococcus suis	Fever, meningitis; 8% fatal
Streptococcus zooepidemicus	Respiratory symptoms, pneumonia
Yersinia pseudotuberculosis; Y. enterocolitica	Diarrhea, vomiting, anorexia, pseudo appendicitis
Virus[2/]	

Arboviruses; phlebovirus; bunyaviridae	Equine encephalitide; fever, severe headache, muscles/joint pain, photophobia
Enteroviruses	
Orthomyxoviridae	Influenza (swine/equine, fowl plague); fever, chills, headache, cough
Paramyxoviridae	Newcastle (pseudo fowl pest); conjunctivitis, fever, influenza-like; may infect humans
Rhabdovirus	Rabies, animal bite; sensitive skin, painful drinking, restless, convulsions; universally fatal
Rotavirus	Gastroenteritis; disease in humans unknown
Parvoviruses	
Fungus	
Deep systemic mycoses	Aspergillosis, etc. Histoplasmosis
Superficial mycoses	Ringworm, athlete’s foot, jock itch, dermatophytosis, tinea, trichophytosis, microsporosis; scaling, redness, vesicles, fissures, lesions, nail thickening/discoloring,
Rickettsia	
Coxiella burnetii	Q-fever (Query); frontal headache, profuse seating, muscle pain, nausea; 60% fatal
Protozoa	
Babesia divergens; B. microti	Piroplasmosis, babesiosis; irregular fever, chills, headache, muscle pain, fatigue; rare in humans
Balantidium coli	Balantidial dysentery; chronic recurrent diarrhea, alternating constipation, bloody stools
Crytosporidium parvum	Cryptosporidosis; vomiting, abdominal cramps, diarrhea, fever, weight loss, painful lymph modes
Giardia lamblia	Giardiasis; diarrhea; most common human protozoan
Toxoplasma gondii	Toxoplasmosis; fever, skin eruption, muscle pain, pneumonia; common in humans
Trypanosoma brucei; T. gambiense; T. rhodesiense	African sleeping sickness; painful lymph nodes, irregular fevers, headaches, joint pains, edema, insomnia, motor and sensory disorders, coma
Helminths	
Ascaris suum; A. lumbricoides	Roundworm infection, ascarid; fever, cough, abdominal pain, rarely fatal; *A. Suum* not common in humans, but possible

Echinococcus sp.	Tapeworm; cysts surgically removed
Schistosoma sp.	Fluke; Itchy rash, dermatitis, pneumonia, fever, abdominal pain, cough, diarrhea, dysentery
Trichinella spiralis	Trichinosis; muscle soreness, thirst, profuse sweating, chills, weakness, GI symptoms; death by myocardial failure
Trichostrongylus sp.	Diarrhea, bloody stool, abdominal cramps
Taenia solium	Pork tapeworm
Arthropod	
Fleas, ticks, mites	Scabies

[1] Diesch, 1970; Entringer and Strepelis, 1996; Hammer and Hammer, 2001; Galloway, 1974.; Gaudy and Gaudy, 1980; Metcalf and Eddy, 1979; Pell, 1997; Smith, 1994; Stehman et al., 1996.

[2] Viral transfer between animal and human is relatively unknown. The most common is from non-human primary to human.

Manure or slurry can disseminate, transmit, or propagate *E. coli* O157:H7. Healthy sheep and cattle harbor *E. coli* O157:H7 in their gastrointestinal tracts and shed it in their feces (Kudva et al., 1996; Kudva et al., 1997). Dairy farms have been identified as reservoirs for *E. coli.*

Salmonella

Symptoms

Symptoms of *salmonella* infection include cramps, nausea, vomiting, diarrhea and in some cases arthritis, especially in immunocompromised patients (Pell, 1997).

Sources

Salmonella can be found in a variety of animal species including swine, cattle, and poultry.

Outbreaks

Several outbreaks of *Salmonella* gastroenteritis have been reported in connection to consumption of fresh produce. An international outbreak of *Salmonella* in 1995 was linked to alfalfa sprouts. Subsequent to outbreaks in Oregon and British Columbia in 1996, Inami and Moler (1999) isolated and detected several serotypes of *Salmonella* from contaminated alfalfa seeds. However, it was never conclusively proven that the source was alfalfa sprouts. An outbreak of *Salmonella* in 1974 was attributed to apple cider that was contaminated with *Salmonella typhimurium* from apples that had been collected from the ground, which had been fertilized with cow manure (Fisher and Golden, 1998).

Listeria monocytogenes

Symptoms

This bacterium can cause severe neurological symptoms particularly in susceptible populations.

Sources

This pathogen lives in the plant and soil environment, and in poorly fermented silage. It can be associated with decaying plant material as well as feces and freshwater.

Outbreaks

Raw vegetables that had been fertilized with sheep manure have been implicated in a *Listeria* outbreak (Pell, 1997).

Campylobacter jejuni

Symptoms

Symptoms of infection by this pathogen are abdominal pain, fever and diarrhea (Varnam and Evans, 1991).

Sources

Campylobacter can be found in the gastrointestinal tract of a wide variety of domestic and wild animals. Water has been cited as an important vehicle for transmitting the pathogen. Mushrooms are the only edible produce that is associated with the pathogen (Brackett, 1999).

Protozoa

Protozoa of concern include *Cryptosporidium parvum* and *Giardia* spp. Protozoa are an important water-borne pathogen, but their significance as a food-borne pathogen remains questionable. *Cryptosporidium parvum* is the more difficult of these two pathogens to control, because it is not affected by water chlorination levels that are considered safe for human consumption and because it can infect a wide variety of animals (O'Donoghue, 1995).

Cryptosporidium parvum

Symptoms

Cryptosporidium parvum can cause severe diarrhea in both animals and humans (Olson et al., 1999). An infection caused by this pathogen is usually self-limiting and does not usually pose a serious long-term health risk except for people with depressed immunity (e.g. those who are receiving chemotherapy or with AIDS) (Pell, 1997).

Sources

Cryptosporidium parvum is prevalent in many species including cattle, swine, sheep, horses, cats and dogs. *Cryptosporidium* oocysts are normally excreted in large numbers (10^{10} oocysts per gram of feces) by one-month-old calves (O'Handley et al., 1999).

***Giardia* spp.**

Symptoms

Giardia spp. can cause severe diarrhea in both animals and humans (Olson et al., 1999). An infection caused by this pathogen is usually self-limiting and does not usually pose a serious long-term health risk except for people with depressed immunity (e.g. those who are receiving chemotherapy or with AIDS) (Pell, 1997).

Sources

Giardia spp is prevalent in many species including cattle, swine, sheep, horses, cats and dogs. *Giardia* is prevalent in both young and old calves (O'Handley et al., 1999). Therefore *Giardia* cysts have great potential to contaminate pastures and associated streams. Calves between four weeks and six months of age can pass up to 100,000 cysts per gram of feces (Olson et al, 1999; O'Handley et al., 1999).

Which crops are prone to transmitting pathogens?

Almost every type of fruit or vegetable is prone to contamination by bacterial pathogens and there are many products from which pathogens have been isolated (Tables 2 and 3). However, only a few (alfalfa sprouts, cabbage, carrots, cantaloupe, watermelon, tomatoes, lettuce, green onions, and apple and orange juices) have been confirmed as vehicles for food-borne illness (Beuchat, 1996; Brackett, 1999). Pathogenic bacteria associated with fresh produce and identified to be responsible for disease outbreaks are listed in Table 3.

Table 2. Products from which bacterial pathogens have been isolated or associated[a]

Product	**Pathogen**	**Product**	**Pathogen**
Asparagus	*Aeromonas*	Artichoke	*Salmonella*
Broccoli	*Aeromonas*	Beet leaves	*Salmonella*
Apple juice	*E. coli* O157:H7	Cantaloupe	*Salmonella*
Cilantro	*E. coli* O157:H7	Chili	*Salmonella*
Coriander	*E. coli* O157:H7	Egg plant	*Salmonella*
Cress sprouts	*E. coli* O157:H7	Endive	*Salmonella*
Mushrooms	*Campylobacter jejuni*	Fennel	*Salmonella*
Mustard sprouts	*B. cereus*	Mungbean sprouts	*Salmonella*
Soybean sprouts	*B. cereus*	Mustard cress	*Salmonella*
Cucumber	*L. monocytogenes*	Orange juice	*Salmonella*
Potatoes	*L. monocytogenes*	Watermelon	*Salmonella*
Green onion	*Shigella*	Carrots	*Staphylococcus*
Coconut milk	*V. cholerae*		

[a] Adapted from Brackett (1999).

Table 3. Products from which multiple bacterial pathogens have been isolated or associated[a]

Product	**Pathogens**
Alfalfa sprouts	*Aeromonas, E. coli* O157:H7
Celery	*Aeromonas, E. coli* O157:H7
Cabbage	*E. coli* O157:H7, *L. monocytogenes, V. cholerae, Salmonella*
Cauliflower	*Aeromonas, Salmonella*
Pepper	*Aeromonas, Salmonella*
Spinach	*Aeromonas, Salmonella*
Bean sprouts	*L. monocytogenes, Salmonella*
Tomato	*L. monocytogenes, Salmonella*
Lettuce	*Salmonella, Staphylococcus, Aeromonas, Shigella, E. coli* O157:H7
Parsley	*Shigella, Staphylococcus, Salmonella*
Radish	*Staphylococcus, L. monocytogenes*
Salad greens	*Salmonella, S. aureus*
Salad vegetables	*Shigella, S. aureus, L. monocytogenes, Yersinia enterocolitica*

[a] Adapted from Brackett (1999).

Table 4. Disease outbreaks associated with pathogenic bacteria from fresh produce[a]

Produce	**Pathogen**
Sliced tomatoes, sprouts, sliced water-melon, sliced cantaloupe, unpasteurized orange juice	*Salmonella* spp.
Lettuce, green onions	*Shigella* spp.
Unpasteurized apple cider/juice, lettuce varieties, alfalfa sprouts	*E. coli* O157:H7
Carrots	Enterotoxigenic *E. coli*
Coconut milk	*V. cholerae*
Cabbage	*L. monocytogenes*
Sprouts	*B. cereus*

[a] Adapted from Brackett (1999).

What are the pathways for exposure to pathogens?

The use of untreated manure and manure-contaminated water on edible crops has been identified as a potential source of pathogen contamination. However, it is often difficult to separate contamination due to manure from improper personal hygiene, unsanitized packinghouses, contamination by handlers, poorly or unsanitized transportation vehicles, and inadequate refrigeration during transport (Brackett, 1999). All of these are pathways for exposure to pathogens.

Contaminated soil or manure on the surface of fruits and vegetables

There is evidence of pathogen transmission to humans through ingestion of soil-contaminated fruits and vegetables and drinking water (Burnett et al., 2000; Dingman, 2000; Jones, 1999; Kudva et al., 1998).

Contaminated water (irrigation, hydroponic, rain, dew) on fruits and vegetables

Contamination of radish sprouts after exposure to *E. coli* O157:H7 inoculated water was carried out by Hara-Kudo et al. (1997) in the laboratory. They found that the edible parts became heavily contaminated when they were grown from seeds soaked in *E. coli* O157:H7 inoculated water. It was concluded that contamination of the edible parts of radish sprouts could pose a serious illness if the seeds or hydroponic water are contaminated with the bacterium (Hara-Kudo et al., 1997).

Burnett et al. (2000) suggested that the tissues of fruits and vegetables could be infiltrated by pathogens when produce surfaces come in contact with cells suspended in the contaminated water. In the field this can occur when rain, irrigation or dew collects on the surface of produce, or the fruit falls on contaminated ground (Burnett et al., 2000). Dingman (2000) reported that apples obtained from the ground (wind fallen apples) are highly susceptible to *E. coli* O157:H7 although no direct evidence linking dropped apples to fecal contamination of cider has been presented.

What factors contribute to pathogen transfer from manure to crops?

There are several factors that contribute to the transfer of pathogens from manure to edible crops. These include the presence of pathogens in animals (and consequently in manure), contamination of water by manure, the survivability of pathogens in manure and manure-contaminated water, and the survivability of pathogens on edible crops.

Presence of pathogens in animals

Pathogen proliferation on the farm depends on the livestock health and how the cattle are managed.

Age of the animal

Young calves are more likely to become infected with pathogens than are cows. Very few mature cows shed *E. coli* and in one study calves older than 6 months rarely tested positive (Pell, 1997).

Herd size

The same study found that calves were more likely to have *Cryptosporidium parvum* in herds with more than 100 cows than calves in smaller herds (Pell, 1997).

Animal housing

The study also found that calves born in individual pens were less likely to become infected than those in groups at calving. Those calves housed in pens in which only the bedding was removed were twice as likely to be become infected as those in pens that were washed (Pell, 1997).

Type of animal feed

Use of more natural animal feeds (such as pasture) and well-fermented silage can reduce pathogen infections (Pell, 1997). Well-fed cattle are less conducive to growth of *E. coli* O157:H7 in their gastrointestinal tracts than are cattle deprived of feed. Weaned calves (less than 24 months old) are more likely to shed *E. coli* O157:H7 than milk-fed calves (Pell, 1997). Dairy cattle fed with poultry litter without drying are more likely than cattle fed on composted litter to be infected with pathogens (Jeffrey et al., 1998).

Season

Fecal pathogen excretion in cattle appears to be seasonal, with the highest rate occurring in spring and late summer (Chapman et al., 1997). The seasonal patterns may be related to milk flushes and changes in cattle reproductive hormones, and stresses or changes in diet and water source (Jones, 1999). Increases in fecal coliform concentrations, an indicator of fecal pathogens, in waters of an upland area of northern England coincided with lambing and increased stocking density during summer (Hunter et al., 2000).

Contamination of water by manure

Surface or ground water contamination is possible from poor manure storage and application. Runoff from manure piles can carry pathogens to surface or underground water, especially in areas with karst geology. Peterson et al. (2000) reported that during a winter recharge event in mantled karst aquifers in northwest Arkansas, fecal coliform, *Escherichia coli* were present in five springs. Furthermore, they suggested that the fecal coliform, and *Escherichia coli* were moving through the mantled karst aquifer in a similar manner and provided evidence that applied manure is associated with the indicator bacteria.

Significant numbers of *Cryptosporidium. parvum* oocysts have been identified in Northern American surface waters (LeChevallier et al., 1991; Rose et al., 1991). Rose et al. (1991) also reported *C. parvum* oocysts in well water. The feces of infected farm animals is a suspected source of ground water contamination, either by subsurface or overland transport through highly permeable soils (Mawdsley et al., 1995; 1996a, b) or through drainage tiles (Kemp et al., 1995). Brush et al. (1999) studied transport of *C. parvum* from calf feces through saturated columns packed either with glass beads, coarse sand or shale aggregates. They suggested that oocysts could travel significant distances in both subsurface and overland flow.

In Southeast Minnesota, manure piles near wells or on karst topography could result in water contamination; in the Red River Valley, manure piles or manure-applied fields that are on a floodplain could result in water contamination.

Survivability of pathogens

Survival during storage, handling and treatment

Pathogen survival is affected by the storage temperature, exposure to oxygen, pH, dry matter content, age, source, and chemical composition of the manure, as well as by microbial characteristics. In general, pathogens cannot survive high temperatures and low moisture levels. It is possible that residual viable populations of pathogens are supported by the slow release of nutrients from the breakdown of organic matter and the utilization of substrates released from dying cells within the storage unit. Spore-forming bacteria (such as *Cl. perfringens* and *B. anthratics*) can survive for a long time in a harsh environment by producing endospores (Pell, 1997).

Stehman et al. (1996) outlined the following factors that limit microbial survival (increase death rate) in storage or when spread on the land:

- sunlight (UV radiation),
- freeze/thaw cycles,
- freezing,
- high temperatures,
- high or low pH,
- antibacterial and antiviral compounds,
- oxygen levels, and
- dryness.

Unfortunately, current manure storage systems contain all of the favorable environmental characteristics for pathogen survival and pathogen decrease is primarily slow for some organisms.

Manuals used for storage design ignore pathogens

Design manuals generally do not discuss pathogen survival in detail. For example, in MidWest Plan Service's (MWPS, 2001) new 91-page booklet on *Manure Storages*, there is no mention of pathogens. The Natural Resource, Agriculture, and Engineering Service (NRAES, 1999) publication *Earthen Manure Storage Design Considerations* contains a single paragraph on pathogens out of 90 pages. This single paragraph indicates that manure can be a health concern and that stored manure may still contain some pathogens and should be handled with due caution.

Natural Resource and Conservation Service *Agricultural waste management field handbook* (NRCS, 1992) indicates the presence of manure pathogens as shown by the existence of the indicator organism fecal coliform The only concern here is the water quality criteria by EPA under the 1986 Safe Drinking Water Act.

Survival of bacteria

Effect of Temperature: Decline in viable numbers of bacteria is temperature dependent as indicated by Kearney et al. (1993). They determined the T_{90} values (time taken for viable counts to decrease by one logarithmic unit, equivalent to 90% reduction) for the species reported in Table 5.

Table 5. The effect of temperature on the time (days) for decline of 90% of four bacteria species.

	4°C	17°C
Escherichia coli	>29.0	>29.0
Salmonella typhimurium	21.3	17.5
Yersinia. Enterocolitica	20.8	12.8
Listeria monocytogenes	>84.0	29.2
Campylobacter jejuni	>112.0	>112.0

Jeffrey et al. (1998) found no *Salmonella* in poultry litter samples where the internal temperature in the piles exceeded 40.2° C. This is because heat and ammonia produced from the degradation of uric acid in boiler litter are bacteriocidal for *Salmonella*. The mesophilic temperature range (20-45°C) is a more effective method of reducing pathogen numbers than the psychrophilic temperature range (<20°C). Few bacteria can withstand the heat generated during composting. Pell (1997) recommends that all parts of the compost pile reach and maintain a temperature of 60°C.

Effect of Aeration: Munch et al. (1987) compared bacteria at two temperature ranges (18-20°C and 6-9°C) for aerated and non-aerated slurry for both cattle and swine. For each species, T_{90} was always shorter in aerated than in non-aerated slurry (Table 6).

Table 6. The effect of aeration on the time (days) for decline of 90% of 4 species of bacteria.

	Aerated Slurry		Non-aerated Slurry	
	18-20°C	6-9°C	18-20°C	6-9°C
Salmonella typhimurium	2 – 7	7 – 18	7 – 21	21– 54
Yersinia. Enterocolitica	2	4 – 7	4 – 7	7 – 18
Staphylococcus. Aureus	4 – 10	4 – 10	5 – 21	10 – 119
Escherichia coli	3 – 21	10 – 25	10 – 32	12 – 126
Faecal streptococci	18 – 74	48 – 94	28 – 49	94 – 280

E. coli O157:H7 and many other pathogenic bacteria are facultative anaerobes that can survive and grow in environments with oxygen (aerobic) or without (anaerobic). However, as shown in Table 6, *E. coli* O157:H7 and many other bacteria generally survive longer under anaerobic conditions. Kudva et al. (1998) studied the survival and growth of *E. coli* O157:H7 in inoculated sheep and cattle manure, under various experimental and environmental conditions. They found that a sheep (ovine) manure pile which was periodically aerated by mixing remained culture positive for 4 months, while a cattle (bovine) manure pile remained culture positive for 47 days. The pathogen survived for more than 12 months in a non-aerated cattle manure pile and for 2 months in an aerated manure pile. *E. coli* O157:H7 viability was reduced to less than 10 days in slurry. In the laboratory, *E. coli* O157:H7 survived best under anaerobic conditions at temperatures below 23º C, but it survived for shorter times than in manure piles in the field. The average times that feces from cattle and sheep remained culture positive were 30 and 50 days, respectively (Kudva et al, 1998).

Effect of management of anaerobic biogas digestion: Anaerobic digestion for production of biogas (methane) is one possible treatment method for reducing pathogens. Kearney et al. (1993) reported the T_{90} (day) means along with lower and upper limits for batch and semi-continuous systems (Table 7). A batch treatment system is more effective at reducing pathogens than a semi-continuous system because new pathogens are not being introduced into the system.

Table 7. Comparison of batch and semi-continuous biogas digestion on the time (days) for decline of 90% of five bacteria species.

	Batch		Semi-continuous	
	Mean	Limits	Mean	Limits
Escherichia coli	0.8	0.6 – 1.4	1.5	1.0 – 4.0
Salmonella typhimurium	0.9	0.8 – 0.9	1.1	0.7 – 2.6
Yersinia. Enterocolitica	0.7	0.6 – 0.8	2.5	2.3 – 3.0
Listeria monocytogenes	12.3	8.3 – 25.6	35.7	14.2 – 71.4
Campylobacter jejuni	>71.0		>71.0	

Urine alkali treatment to reduce bacterial counts: Diez-Gonzalez et al. (2000) researched the concept that urine has antibacterial activity at a pH of 8.5. If the pH was adjusted down, then urine lost its ability to control bacteria. Under normal conditions, the feces-to-urine ratio is 2.2:1 and *E. coli* counts remain high at >10,000 cells/g. However, if this ratio was adjusted to 1:1 by adding additional urine, then after 10 days, the viable count reduces to < 10 cells/g. If this ratio was further adjusted to 0.4:1 or less, *E. coli* was not killed. Unfortunately, this process of adjusting feces-to-urine ratio is not practical at the producer level.

Animal urine contains large quantities of urea, which break down to ammonia and carbon dioxide by the enzyme urease. Diez-Gonzalez et al. (2000) concluded that the ammonia was not the antibacterial agent against *E. coli*, but the carbon dioxide formed combines with water to form bicarbonate, which has antibacterial activity at pH around 8.5. This leads to the possible supplementation of manure with carbonate for *E. coli* elimination, which Diez-Gonzalez et al. (2000) recommends at 4 g of sodium carbonate or 2 g of sodium hydroxide /kg of manure. The treatment costs would be less than $10 per cow per year.

Survival of viruses

Studies have shown that a variety of conditions can influence the survival of viruses and livestock infection (Ajariyakhajorn et al., 1997; Deng and Cliver, 1995; Pesaro et al., 1995). Factors affecting viral survival are temperature, pH, and the presence of bacteria that can inactivate viruses (Deng and Cliver, 1995). Deng and Cliver (1992 and 1995) found evidence that some bacteria isolated from manure could inactivate viruses. They showed that both hepatitis A and polio type 1 viruses were inactivated more rapidly in dairy and swine slurries than in contaminated septic tank effluent. Kelley et al. (1994) reported that viruses initially found in poultry litter were not found after five months of storage.

Survival of protozoa

When an oocyst (*Cryptosporidium parvum*) or cyst (*Giardia* spp.) is ingested by an animal, these structures can remain viable for long time periods. *Cryptosporidium* persists in calves for about two weeks and calves may shed *Giardia* for several months (O'Handley et al., 1999; Olson et al., 1999). *Cryptosporidium* oocysts are much more resistant to degradation than *Giardia* cysts. With freezing at – 4º C or storage at 4º C *Cryptosporidium* was infective at greater than 12 weeks. One week of freezing rendered *Giardia* infective. At 4º C the Giardia was only infective for one week. At higher temperatures *Cryptosporidium* in manure does degrade (Olson et al., 1999). At 25º C it was not infective after five weeks. The author suggested that manure application should be carried out after 12 weeks of storage and during warm weather to reduce the potential water contamination by *Cryptosporidium* from runoff.

Advanced animal wastewater treatment

Utilization of advanced waste water treatment techniques (techniques similar to municipal sewage treatment) for animal waste will not solve the pathogen problem. All data available indicate that pathogenic microorganisms, particularly viruses, pass through the sewage treatment process in large numbers (Gaudy and Gaudy, 1980).

Survivability in soil and water

Survivability of *E. coli*

Water content and temperature are important factors for *E. coli* survival in soils. A study of *E. coli* in two Kentucky soils showed longer survival with more available water (Mubiru et al., 2000). Studies indicate that heat stress reduces growth and survival of the pathogen under aerobic conditions. One study showed that non-O157 strains survived in soil for more than 60 days at 25º C and 100 days at 4º C (Bogosian et al., 1996).

E. coli can survive for long time periods in water, Survival of O157:H7 strains in river water has been shown for up to 90 days (Wang and Doyle, 1998).

Survivability of *Cryptosporidium* and *Giardia*

Cryptosporidium oocysts can survive in water or soil for more than 6 weeks at 25º C and more than 12 weeks at 25º C (Olson et al., 1999). Freezing for one week destroys *Giardia* but not *Cryptosporidium.* *Giardia* remained infective for more that 6 weeks at 4º C and for 2 to 4 at 35º C.

Survivability of pathogens on edible crops

E. coli

There is significant evidence of *E. coli* O157:H7 survival on fruits and vegetables for periods of more than 3 weeks. *E. coli* O157:H7 is extremely acid tolerant and can survive in fruit drinks even under highly acid conditions. It can survive at pH 3.7 in apple cider stored at 8º C for 31 days and at pH 2.0 in a laboratory medium for 24 hours (Miller and Kaspar, 1994; Zhao et al., 1993). Several studies have shown that *E. coli* O157:H7 can develop resistance to low pH levels (Lin et al., 1995; Lin et al., 1996). Folsom and Frank (2000) found that *E. coli* exposed to chlorine has more resistance to heat than unexposed cells. Preadaptation to a stress encountered by *E. coli* O157:H7 such as acid can lead to enhanced resistance to a different stress such as heat (Riordan et al., 2000). The chlorinated cells required twice as much heating time.

Listeria monocytogenesy
This bacterium grows at a wide range of pH (5.5-9.0), temperature (3 - 42º C), and in high salt concentrations (up to 12%). It is well adapted to the wet environment of food processing facilities, and is difficult to control due to the range of environmental conditions in which it can survive.

Does manure refeeding pose a health risk?

Refeeding is a of method of manure utilization that reduces the quantity of manure applied to land. CAST (1978) states that before refeeding manure needs to be processed by ensiling, dehydration, composting, chemical treatment, and/or aeration to effectively destroy certain pathogens before mixing in an animal diet.

Georgia beef producers recentely raised the safety question about feeding large quantities of poultry litter. Martin et al. (1998) tested 86 litter samples throughout Georgia for *E. coli* O157:H7 and *Salmonella*. There were 64 samples from composting piles, 18 samples were not composted, and four with unknown treatments. The composting ranged from less than one month to greater than four months. While bacteria were isolated from all litter samples, no *E. coli* O157:H7 or *Salmonella* were detected in any sample. The researchers did find extremely low mold contamination in most samples. These results suggest that poultry litter is not a source of harmful pathogenic bacteria when fed to cattle.

Jeffrey et al. (1998) tested 52 dried poultry litter samples from 13 dairies in California. No *Salmonella*, *E. coli* O157, or *Campylobacter* were identified even though other strains of *E. coli* were found. Based on their study, they determined that dried poultry litter can be used as a feed and that dried poultry litter is probably not a significant source of bacteria associated with food borne disease in humans or clinical illness in cattle.

Pugh et al. (1994) surveyed 77 veterinarians in Georgia who serves cattle growers that use broiler litters. Four of the veterinarians had diagnosed Salmonellasis in cattle, usually calves and young cattle. Eight veterinarians also observed enterotoxemia. The authors stated that salmonellosis is associated with improper processing of litters for pathogen control.

How can pathogen transfer to edible crops be minimized?

Although complete eradication of pathogens on edible crops is highly unlikely, there are management practices that can help reduce pathogen transfer. Management of food-borne pathogens must start with management of animals and their wastes on the farm. However, careful management must also extend to the harvesting, transport, storage, and processing of produce if contamination is to be avoided. A systems approach that includes all aspects of food production is required for food safety.

Reduce pathogen levels in animals

Pathogen excretion can be reduced on the farm with adequate housing and sanitation that reduces animal stress levels. Possible methods for reducing pathogen levels in animals include:

- smaller herd sizes,
- using individual birthing pens,
- delayed weaning,
- washing birthing pens between uses,
- good animal nutrition,
- feeding natural (pasture) animal feeds and fermented silage, and
- feeding poultry litter only if it is composted.

Reduce pathogen levels in manure

Pathogens in manure can be reduced if the manure is managed well on the farm. There are processes that can reduce pathogens in the manure. Drying, aerobic digestion, chemical treatment, and composting of the animal waste can substantially reduce pathogens. Mixing manure slurry with dry matter or bedding can reduce pathogens, since aerobic fermentation is more likely to occur in manure mixed with bedding than in slurry.

Storing manure can help reduce pathogen levels. In order to reduce or eliminate pathogens present, Jones (1976) recommended that manure should be stored for a month, then after manure spreading on a pasture there should be a month wait during which the pasture should not be grazed. The Commission of the European Communities stated that manure should be stored for a minimum of 60 days before spraying on land (Kelly, 1978). It is not clear what concentrations of pathogens might be acceptable before manure can be applied on pasture.

Kelley et al. (1994) found that indoor stored piles of poultry litter after four months showed significant reductions in pathogenic and indicator bacteria concentrations, and in most cases concentrations were below detection limits of approximately 30 CFU (colony forming units) / g dry weight.

Avoid water contamination

Farm and manure storage facilities should be in a location that is not susceptible to flooding or in a floodwater path, near wells, or in karst topography. Restrictions on the timing and location of manure application can reduce the risk of water contamination by pathogens. (See the Manure Storage and Handling section of this report, and the Water Quality report for more information).

What are the measures for pathogen control in edible crops?

There are no regulatory requirements that address manure handling for pathogen reduction or that provide some measures as guidelines. Feedlot rules in Minnesota (MPCA, August 3, 2000), which established environmental regulations for feedlots, cover pathogen control only in composted manure. However, the Commission of the European Communities stated that manure should be stored for a minimum of 60 days, to reduce pathogen concentrations, before spraying on land (Kelly, 1978). Also there are regulations (Part 503 of 1993 U.S. Environmental Protection Agency (EPA) regulations) that govern pathogen reduction in sewage sludge. Sewage sludge is regulated because of its very high human pathogen content. The same processes required for pathogen reduction in sewage sludge could work for manure, so it is useful to look at these restrictions. It should be noted, however, that in general the risk for transmission of human disease organisms to food is less for manure than for sewage sludge. The EPA restrictions on sewage sludge are described below.

Measures for pathogen reduction in manure

The EPA regulations separate sewage sludge into A and B categories with respect pathogen content. Class A sludge must be treated to decrease to pathogens to essentially non-detectable. Class A sludge does not have any pathogen restrictions for land application. Class B sludge is only required to have a fecal coliform density of less that 2 million (MPN) per gram. This may require some form of treatment

Measures for pathogen reduction in manure application

Restrictions for the harvest of crops and turf on sites where class B sewage sludge is land applied are contained in Table 3-11, subpart D, part 503 of the EPA regulations. These are summarized below in Table 4.

Table 4. Restrictions for the Harvesting of Crops, Grazing of Animals, and Public Access on Sites Where Class B Sewage Sludge is Land Applied

Restrictions for the harvesting of crops:

- Food crops with harvested parts that touch the sewage sludge/soil mixture and are totally above ground shall not be harvested for 14 months after application of sewage sludge.
- Food crops with harvested parts below the land surface where sewage sludge remains on the land surface for 4 months or longer prior to incorporation into the soil shall not be harvested for 20 months after sewage sludge application.
- Food crops with harvested parts below the land surface where sewage sludge remains on the land surface for less than 4 months prior to incorporation shall not be harvested for 38 months after sewage sludge application.
- Food crops, feed crops, and fiber crops, whose edible parts do not touch the surface of the soil, shall not be harvested for 30 days after sewage sludge application.
- Turf grown on land where sewage sludge is applied shall not be harvested for 1 year after application of the sewage sludge when the harvested turf is placed on either land with a high potential for public exposure or a lawn, unless other wise specified by the permitting authority.

Restrictions for the grazing of animals:

- Animals shall not be grazed on land for 30 days after application of sewage sludge to the land.

Restrictions for public contact:

- Access to land with a high potential for public exposure, such as a park or ballfield, is restricted for 1 year after sewage sludge application. Examples of restricted access include posting with no trespassing signs, or fencing.
- Access to land with a low potential for public exposure (e.g., private farmland) is restricted for 30 days after sewage sludge application. An example of restricted access is remoteness.

[a] Adapted from part 503 U.S. EPA (1993) rules.

Summary

Pathogens that exist in manure can end up on fresh fruits and vegetables, causing illness or even death in the humans that consume them. Animal manure may contain bacteria, protozoa, and viruses that are transmissible to humans. Farm animals, birds, deer and many other animals can serve as reservoirs for pathogens, and often the exact source of food-borne disease outbreaks cannot be established.

Substantial scientific literature exists on the presence of pathogens in manure and in fresh fruits and vegetables. Almost every type of fruit and vegetable is prone to contamination by bacterial pathogens. However, only a few fruits and vegetables have been confirmed as vehicles for food-borne illness. Edible crops can carry pathogens if they have manure or manure-contaminated soil on their surfaces, or if they have been exposed to manure-contaminated water (through hydroponics or irrigation). We found no evidence of transmission of zoonotic pathogens to consumers via field crops that are processed before consumption.

Factors that contribute to pathogen transfer include the presence of pathogens in animals (influenced by age, herd size, housing, and feed), manure contamination of water, pathogen survivability during manure storage and handling and in water, and survivability on edible crops. Pathogen transfer can be reduced by promoting animal health, reducing pathogen levels in manure with storage and treatment, avoiding water contamination, using proper manure application procedures, and using proper harvest procedures. While there are no manure regulations that provide measures for pathogen control in application of manure to land used for edible crops, U.S. Environmental Protection Agency regulations for the use of sewage sludge on edible crops could be used for guidance in developing guidelines or regulations

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A Phosphorus Index For Minnesota

Background

Environmental policies of the past three decades have significantly reduced the amount of phosphorus entering surface waters from point sources. However, eutrophication of fresh waters due to transport of excessive amounts of phosphorus from non-point sources such as municipal and agricultural activities is still a major environmental concern.

Application of phosphorus in fertilizer and manure in excess of the quantities removed by crops has elevated phosphorus levels in many agricultural soils above the agronomically optimum levels. Runoff and erosion from these soils can transport phosphorus into surface waters if there is a hydrological connection.

Recognizing the fact that high phosphorus soils can contribute to eutrophication of surface waters, many states have established threshold soil test phosphorus levels that limit application of additional phosphorus in soils exceeding the threshold (Sharpley et al., 1996). However, soil phosphorus measurements used to estimate crop responses have not been evaluated in relationship to water quality issues. Further, the movement of phosphorus from agricultural soils to water bodies is influenced by many factors and a more holistic approach is needed for protection of vulnerable water bodies. In response to that need a group of researchers from universities and government agencies in the early 1990's developed the concept of phosphorus index.

The original phosphorus index was introduced as a screening tool to rank various fields with respect to their vulnerability to off-farm phosphorus loss (Lemunyon and Gilbert, 1993). The original phosphorus index has been shown to relate to off-site transport of phosphorus from small agricultural watersheds in Texas, Oklahoma, and other regions (Sharpley, 1995; Stevens et al., 1993). Modified versions of the original phosphorus index have been used by many states and governmental agencies. Recently, the US Department of Agriculture, Natural Resource Conservation Service (USDA-NRCS) has directed states to adopt a phosphorus guidance, with the option of using a soil threshold approach or a state-specific phosphorus index. A phosphorus index developed for Minnesota will be an important means of accomplishing water quality goals by focusing resources and efforts on areas with the highest potential for transport of phosphorus to surface waters.

Development Process

It is important that the Minnesota phosphorus index relate to the risk of phosphorus transport to surface waters. The Minnesota phosphorus index will be developed and evaluated at two scales, the field scale and at a regional scale. This will allow use of the index for field scale nutrient management plans as well as for achieving water quality goals at the watershed and sub-watershed scales. If an index is going to be used as a field assessment tool, the data needed for assessment must be easily obtainable (i.e. NRCS databases, producer records), and the methodology must allow easy computation of site vulnerability rating (Stevens et al, 1993). In developing the Minnesota phosphorus index, we have involvement with USDA-NRCS personnel to assure that we accomplish these goals.

The development process for the Minnesota phosphorus index will follow these steps:

- Phosphorus index literature review
- Establishment of soil critical levels
- Testing and evaluation of field scale index
- Testing and evaluation of regional scale index
- Pilot Test

Phosphorus Index Literature Review

The purpose of this review is to provide background on the development of the various phosphorus indices used or being developed in the US. From the review, we consider all of the factors used in the various indices for determining risk of phosphorus loss to surface water. Each factor will be considered for relevance under Minnesota conditions. Additional factors unique to Minnesota will also be considered, such as phosphorus movement by snowmelt runoff.

The original phosphorus index

The original phosphorus index was based on the concept that phosphorus loss from agricultural land is governed by the combination of "source factors" and "transport factors." The index was an eight-by-five weighted matrix that related the source and transport factors to the potential for phosphorus loss from a site (Table 1). Each factor is assigned a weighting factor based on its potential impact on the overall export of phosphorus from a field. The factors and their respective weight are:

Source Factors: agronomic soil test phosphorus (1.0), inorganic phosphorus application rate (0.75) and method (0.50), organic phosphorus application rate (1.0) and method (0.5).

Transport Factors: soil erosion (1.5), irrigation erosion, runoff class (0.5).

The values of the weighting factors were at the time based on the professional judgement of the group that developed the index. Each site characteristic had a range of numerical value ratings of low (1), Medium (2), High (4), or very high (8) (a base 2 system) (Sims et al., 2000). To calculate the phosphorus loss rating for each characteristic, the value of that characteristic was multiplied by its respective weighting factor. For example the weighted soil erosion value for a site with medium erosion was 2 * 1.5 = 3 (Table 1). The overall risk was then calculated by summing the weighted values. When the source and transport matrices are combined by adding their respective values, it is referred to as an *additive* index. The quantitative phosphorus loss score was then converted into a qualitative rating of site vulnerability to phosphorus loss as follows: Site phosphorus vulnerability rating: Low (<8), Medium (8-14), High (15-32), Very High > 32.

In the original phosphorus index, water erosion was calculated from the Revised Universal Soil Loss Equation (RUSLE) and wind erosion was calculated from the Wind Erosion Equation (WEQ). Runoff class was calculated from soil saturated hydraulic conductivity and the percentage slope of the site.

The authors of the original phosphorus index acknowledged the need for individual states to modify the index and its algorithm for specific uses or locations. The additive nature of the original index makes the value of such a rating questionable. It is possible to have a field with a high source value and low transport potential rated as a medium to high risk for phosphorus loss. Also, the original phosphorus index does not consider proximity of the field to receiving waters. For this reason, it evaluates risk of phosphorus delivery to the field edge and not necessarily the risk of actual delivery to a water body.

Table 1. (Adapted from Birr and Mulla, 2001). The original version of the phosphorus index to prioritize phosphorus loss vulnerability (adapted from Lemunyon and Gilbert, 1993).

	Phosphorus Loss Potential (value)				
Site characteristic (weight)	Very low (0)	Low (1)	Medium (2)	High (4)	Very high (8)
Transport factors					
Soil erosion (1.5)[1]	Not applicable	<11	11-22	22-34	> 34
Runoff (0.5)[2]	0-8	9-13	14-16	17-21	> 21
Source factors					
Soil test P (1.0)[3]	0-5	6-10	11-15	16-20	> 20
Fertilizer P application rate (0.75)[4]	0	1-15	16-45	46-74	> 74
Fertilizer P application method (0.5)	None applied	Placed with planter deeper than 5 cm	Incorporated immediately before	Incorporated >3 mo before crop or surface applied <3 mo before crop	Surface applied >3 mo before crop
Organic P source application rate (1.0)[4]	0	1-15	16-29	30-45	> 45
Organic P source application method (1.0)	None applied	Placed with planter	Incorporated immediately before	Incorporated >3 mo before crop or surface applied <3 mo before crop	Surface applied >3 mo before crop

1 Units for soil erosion are Mg/ha.
2 Units for runoff are cm.
3 Soil test P is Bray-1 extractable P and units are mg P/kg.
4 Units for P application are kg P/ha.

A multiplicative phosphorus index

Gburek Fang et al. (2000) evaluated hydrologic and chemical factors controlling phosphorus export from a 39.5 acre mixed watershed in Pennsylvania (using GIS modeling) and modified the original phosphorus index. The index assembled by Gburek Fang et al. makes several adjustments to the original phosphorus index. The two most significant modifications made are:

1. The phosphorus source and transport matrices are combined in a *multiplicative* manner rather than using the additive approach.

2. Risk of phosphorus delivery from field edge to a water body is included by means of the hydrologic return period.

The inclusion of these two factors improved the utility of the index and provided a better fit with the water quality monitoring data from the watershed. The multiplicative approach provides a better way to identify sites at risk for off site movement of phosphorus due to the combination of source and transport properties. Further, when considering the impact of phosphorus on water quality, including a means to evaluate the connectivity of the field to surface water is important.

Multiplicative phosphorus index for northeastern US

Sharpley (2000) introduced a modified multiplicative phosphorus index for the Northeastern US. This index maintained the separation of source and transport factors with a multiplicative approach. Two additional tables were added to simplify the interpretation of the index score. The rating interpretation table relates the index score to the risk level (low, medium, high, very high) and the management options table assigns specific management choices depending upon the risk level. For example, if the risk is low, then nutrients can be managed on a nitrogen basis, while if the risk is high, phosphorus application is recommended at or below crop removal rates. Other important features of this index are the inclusion of factors for leaching potential, subsurface drainage, and distance from the edge of the field to surface waters.

Maryland phosphorus index

Scientists at the University of Maryland have modified the above multiplicative phosphorus index for the state of Maryland (Maryland Cooperative Extension, 2000). The Maryland phosphorus index is currently one of the most developed phosphorus indices in the US and its use is required for sites meeting certain criteria. The basic structure of that index is similar to the one presented by Sharpley. However, the addition of vulnerability ranking for the water body that receives the drainage water from the site makes it a more comprehensive index. The transport factor matrix has provisions for ranking the site with respect to distance from surface water and presence of vegetative buffers. The index has eight supplemental tables for calculating phosphorus loss ratings for various factors.

Vermont phosphorus index

The Vermont phosphorus index is a modification of the original phosphorus index (Lemunyon and Gilbert, 1993). Several unique features important in Vermont have been incorporated (Jokela, Jokela,1999). In the Vermont index, rather than using a categorical approach to calculating the index, a formula is used for both source and transport factors. The results of the two formulas are then combined in a multiplicative approach and the numerical outcome is translated into a qualitative phosphorus loss rating.

Another unique feature of the Vermont index is the inclusion of a soil analysis result other than soil test phosphorus. Specifically, Vermont researchers included a factor related to the amount of extractable aluminum in their phosphorus index. This is because the amount of extractable aluminum in the soil plays a significant role in phosphorus availability. In general, soils with higher aluminum have a higher capacity for phosphorus than those with lower aluminum (Jokela, Jokela, 1999).

Florida phosphorus index

The Florida phosphorus index is another good example of adapting and modifying the original phosphorus index to address the needs of a specific region. A number of additional site and transport factors are included in the Florida phosphorus index. Similar to other indexes, the Florida index divides the index into a source and a transport matrix and combines them with a multiplicative process. The quantitative score is then converted to a qualitative ranking from low to very high. Unique features of the Florida index are the inclusion of wastewater application as a separate factor and also the inclusion of a sensitivity factor for surface water bodies.

Wisconsin phosphorus index

Similar to other states, the Wisconsin index is composed of two matrices, one for *transport factors* and one for *site management factors* or phosphorus *source* (Bundy and Kaap, 1999). Weighting factors are used within each of the two matrices and the matrices are combined in a multiplicative manner. The Wisconsin index uses somewhat different weights for individual transport factors than those for other indices. The soil erosion factor is more heavily weighted. Also, a separate factor is included for the slope of the site and for distance to water. In the source factor matrix, more attention is focused on the nutrient management options than is apparent in other indices. This is based on the assumption that phosphorus loss potential is lower when manure is incorporated within one week after application compared to when it is left on the field over the winter. The value of the Wisconsin method-timing factor varies from 0.4 to 1.0, where 0.4 is used when phosphorus is incorporated 2" deep or more and 1.0 is used when phosphorus is incorporated greater than one week after application or is not incorporated for winter-applied manure. Also in the source matrix, the measured soil phosphorus level at the site is divided by 30 to obtain a comparison of the soil test value with an agronomically optimum value of 30 mg/kg for Bray phosphorus (Bundy and Kaap, 1999).

Iowa phosphorus index

The Iowa phosphorus index is fundamentally different in philosophy then the original phosphorus index. This index does away with the categorical approach found in the other indices with the intent of developing a phosphorus index that generates a rough quantitative estimate of the phosphorus loss from a site. The developers argue that "lack of consideration of estimates of phosphorus loads that leave the field complicates the comparison (or normalization) of the different indices developed in various states" (Mallarino, 2000).

The Iowa index is field based. While it acknowledges the importance of the interaction of the source and transport factors, it attempts to deal with these interactions internally within three components of the index: the *erosion* component, the *runoff* component, and the *subsurface drainage* component. Each of these components estimates the phosphorus lost from the field by that transport mechanism. When the three components are added together, the index is an estimate of the phosphorus lost from the field in lbs P/acre. The Iowa phosphorus index is unique in other ways as well. It puts more emphasis on bioavailable phosphorus than the other indices by including an availability factor for sediment P. It attempts to account for distance to receiving waters by using a sediment delivery ratio based on the distance from the edge of the field to the water. These additional considerations of the Iowa index lead to a complex, heavily developed phosphorus index that operates on several assumptions. The technical documentation for the index includes all the details necessary to calculate the index value in eight tables and four figures.

Table 2. Comparison of factors used in several phosphorus indices.

MATRIX ELEMENT	-- INDEX DEVELOPER OR STATE ---------------------------------							
	Lemunyon & Gilbert	Gburek et al.	Sharpley	MD	VT	FL	WI	IA*
Source factors								
soil test P (STP)	X	X	X	X	X	X	X	X
Fertilizer P application rate	X	X	X	X	X	X	X	X
Fertilizer P application method	X	X	X	X	X	X	X	X
Organic P application rate	X	X	X	X	X	X	X	X
Organic P application method	X	X	X	X	X	X	X	X
Others	-	-	-	-	-	Waste Water Application	Appliaton Timing	-

Transport factors								
soil erosion	X	X	X	X	X	X	X	X
Irrigation erosion	X	-	-	-	-	-	-	-
Runoff	X	X	X	X	X	X	X	X
Leaching potential	-	-	X	X	-	X	-	-
dist. to water body	-	X	X	X	-	-	X	X
buffer strip	-	-	-	-	X	-	X	X
Subsurface drainage	-	-	X	X	-	-	-	X
Hydrological return period	-	X	-	-	X	-	-	-
sensitivity of receiving water	-	-	-	X	-	X	-	-
Others					Flooding		Slope	Precipitation, total P, soluble P
Index Mathematical Processing	additive	multiplic	multiplic	multiplic	multiplic	multiplic	multiplic	additive

Summary of phosphorus index literature

The original phosphorus index has served as the basis for the development and use of many modified indices. Nearly all of the states have modified the original index by combining source and transport factors in a multiplicative approach rather than the original additive approach. No uniform scale has been developed for phosphorus indices, which complicates direct comparison of the various approaches. In most indices, the outcome is a relative level of the risk of off-site phosphorus transport. Only in the Iowa index is the computed index value an estimate of phosphorus delivery (lb/ac) rather than a relative risk level. The core factors from the original phosphorus index are included in essentially all of the modified indices, while several additional factors have been added to meet region-specific needs. The factors used in different versions of the phosphorus index are summarized in Table 2. Most indices have included a term to account for proximity of the field to surface water. Another difference among phosphorus index versions is the weighting of individual factors. For example, some indices weight organic phosphorus application as higher in risk than inorganic phosphorus sources, while others do not. The indices also vary in the weighting of erosion, runoff, and management practices. Finally, some indices, such as the Wisconsin index, focus more on management options available to the field manager than others do.

Establishment of Soil Critical Levels

The main goal of this subtask is to identify soil and site characteristics that should be used in development and validation of the Minnesota phosphorus index. This goal is accomplished through a combination of a laboratory extraction study and a simulated rainfall study on a wide range of Minnesota soil. The results of both studies will provide information for the development and validation of the phosphorus index.

Laboratory extraction study

During the early fall of 2000 soil samples were collected from the surface horizon of more than 160 agricultural soils across the state. Sites were selected where a paired sample could be obtained with pairs different in soil phosphorus levels due to management history. Sampling sites represented major agricultural soils and cropping systems in the state (Figure 1). At each site information was collected on type of crop, fertilizer and manure history, tillage practices and other crop management practices and a database has been developed from that information.

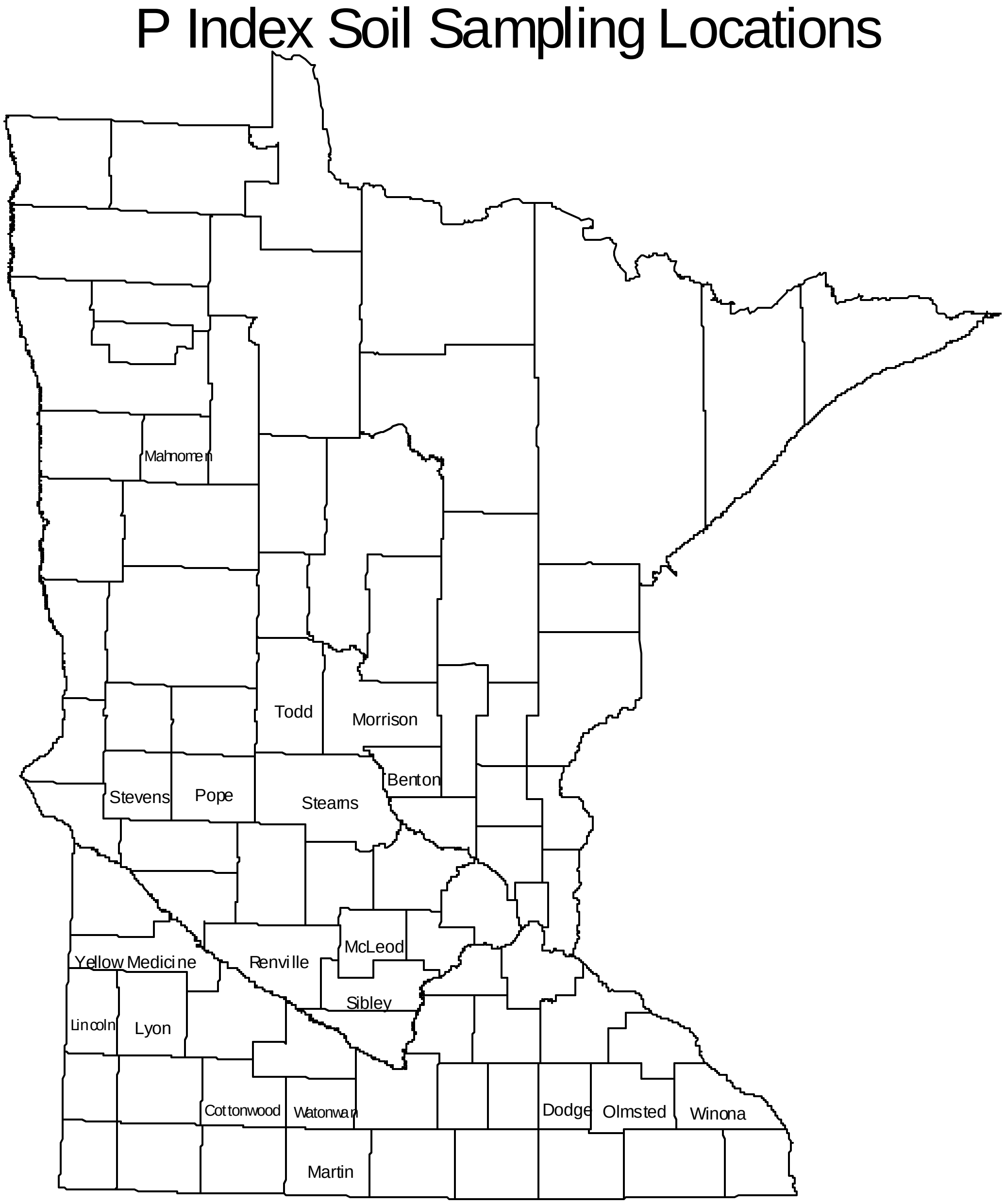
Soil samples were transported to the lab and are being analyzed for soil properties that have a significant influence on the potential transport of phosphorus from agricultural fields into the surface and ground water. These properties include soil pH, the amount of plant available phosphorus (as estimated by Bray, Mehlich, and Olsen method), total P, soil texture, soluble P, phosphorus sorption capacity, organic matter and calcium carbonate equivalent.

Data will initially be used to gain a better understanding of phosphorus behavior under the Minnesota climate and farming practices. For example, correlation between the available phosphorus (or total P) and soluble phosphorus can be investigated. The relation between phosphorus sorption capacity and soil test P, soil texture, and other soil chemical properties can be investigated. Such information will help in identifying soil properties that should be included in the Minnesota phosphorus index. The data will also guide us in selecting soils for the runoff simulation studies described below.

Simulated runoff study

We have selected soil samples from 38 of the agricultural soils used in the laboratory extraction study for the simulated rainfall study. Similar to the extraction study these soils have a diverse range in cropping conditions and their properties reflect major geological and hydrological conditions in the state. The protocol for the runoff study is fashioned after the USDA-NRCS approach for conducting simulation studies for phosphorus index development with necessary modifications.

Figure 1. Counties represented in soil sampling. A total of 160 soils were sampled and the samples are distributed throughout the indicated counties.


P Index Soil Sampling Locations

Briefly this will involve packing the soil in 60 x 15 x 10-cm PVC boxes, using a standardized packing procedure. A space of 2.5 cm will be created between the soil and the bottom of the boxes with a perforated PVC sheet to facilitate rainwater drainage (Fang, Birr , and Mulla, 2001). A mesh screen, followed by a double-layer cheesecloth, will be laid on top of the percolated PVC sheet to prevent loss of soil particles. Prior to applying rainfall, soil will be moistened from the bottom by a Marriot bottle until water appears on the surface. The boxes will be set at a slope of 4%, a typical value for the landscape in Minnesota. Rainfall will be applied for 30 min at a rate of 6 cm h^{-1}, the mean of the 30-min rain storm intensity with a 5-year return frequency in Minnesota. Deionized water will be used as the feed water for the rainfall simulator.

Runoff from each soil sample for an entire rain event will be composited in an acid-washed 3-L plastic container. A 50-mL aliquot will be immediately filtered through a 0.45 um syringe filter unit and stored at 4 ^{o}C until it can be analyzed for soluble P. The unfiltered runoff will be stored at 4 ^{o}C. This sample will be analyzed for biologically available phosphorus as measured by the Fe-strip method, total P, and total suspended sediment. Every effort will be made to complete the analysis within 5 days of sample collection. Unfiltered runoff samples will be used to measure algal growth in response to phosphorus in the runoff.

The data will allow us to relate the concentration of soluble and particulate phosphorus in the runoff to the amount of available P. It will be used to quantitatively evaluate the effect of other soil properties that were determined in soil extraction study (i.e., soil texture, soil phosphorus sorption capacity, soil pH, organic matter and calcium carbonate equivalent) on the concentration of total and soluble phosphorus in the runoff or algal growth.

This information will help us identify soil properties that should be included in the Minnesota phosphorus index and their relative importance of these soil properties. For example if our data suggest that there is a strong relation between the phosphorus concentration in the runoff and phosphorus sorption capacity or soil clay content, then inclusion of these factors in the Minnesota phosphorus index will enhance the quality of the index. The information gathered will also be used for calibration and validation of the Minnesota phosphorus index.

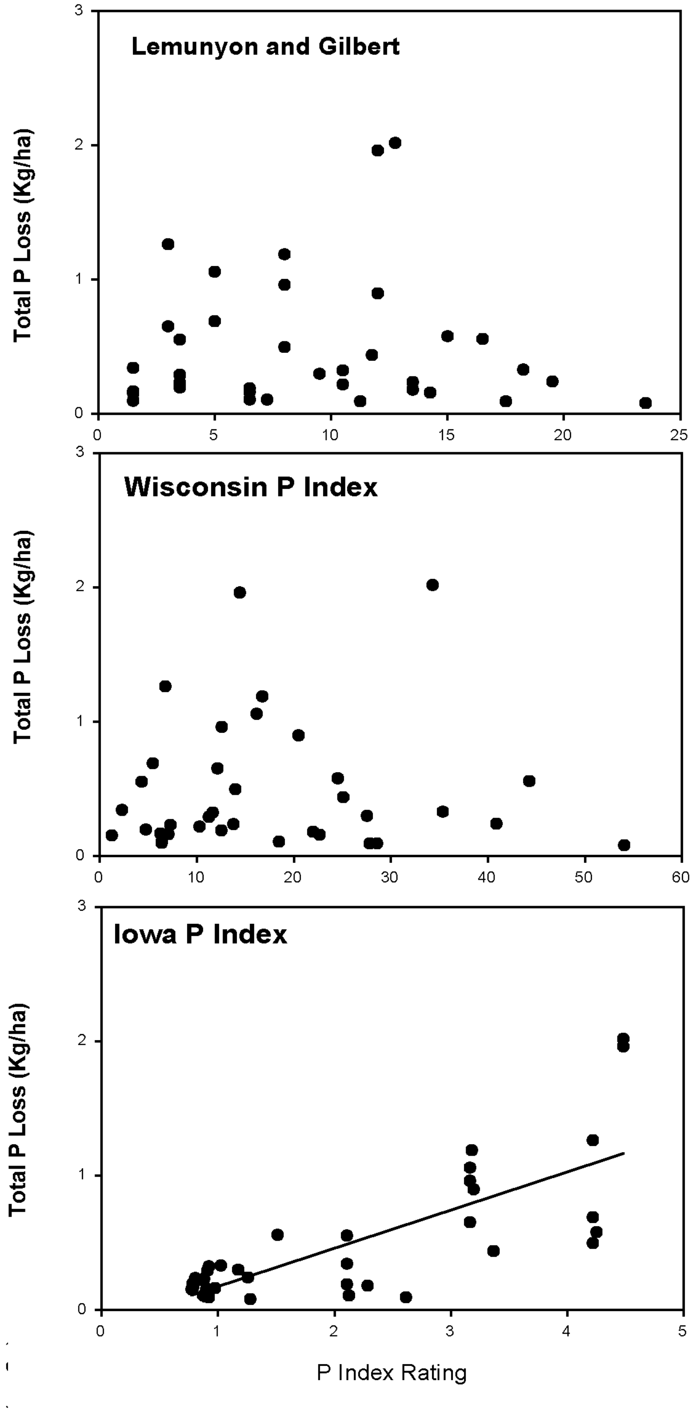
Testing and Evaluation of a Field Scale Index

The testing and evaluation of the Minnesota phosphorus index will be an iterative process to evaluate the importance of individual source and transport factors in the phosphorus index and their respective weighting factors. This evaluation will be done using results of runoff studies conducted in Minnesota. For each plot, the phosphorus index will be calculated and the results will be correlated against measured annual total phosphorus losses. Numerous runoff studies have been conducted throughout Minnesota that will be useful in evaluating factors and weights. A database of these studies is being assembled.

A preliminary evaluation was performed to contrast the phosphorus indices being used or developed in neighboring states. In this example, three versions of the phosphorus index were compared to total phosphorus loss from a simulated rainfall study conducted in Morris, Minnesota during 2000. The Morris study was an evaluation of different phosphate fertilizer management practices over a six-year study period. Treatments included in the study were tillage practice, fertilizer rate, fertilizer placement, and fertilizer application frequency. At the time of the rain simulations, soil test phosphorus ranged from 5 to 50 ppm. The tillage practices were no-till and fall chisel plowing. Fertilizer was either broadcast applied or deep banded in the fall for both tillage systems and at four different rates. Simulated rain events were conducted in the spring of 2000 after corn emergence. Rainfall was applied at a rate of 2.0 in/hr for 1.5 hr. The indices compared were the original index, the Wisconsin index, and the Iowa index. Risk values for each index were calculated without modifying the published index.

The original phosphorus index did not relate well to total phosphorus loss (Figure 2). The Iowa phosphorus index had a linear relationship to total phosphorus loss, while the Wisconsin index did not. The example lends some credence to the philosophical approach being used in the Iowa index. It is interesting to note that the erosion component is responsible for 88% of the phosphorus delivery estimated by the Iowa index. In the measured runoff, eroded particles were responsible for about 95% of total phosphorus loss. This example is included here to illustrate the utility of testing the index against measured runoff data. Numerous other data sets will be used in like manner. It must be noted that this example alone does not evaluate all the components of the phosphorus indices evaluated. Because it is a plot scale study, we are not able to evaluate the elements of the indices that relate to transport of phosphorus to surface waters. Further, this study did not include a manure treatment.

Figure 2. The relationship of three different phosphorus indices to the measured loss of total phosphorus in a rainfall simulation study conducted in Morris, MN in 2000.



Testing and Evaluation of a Regional Scale Index

The purpose of this sub-task is to assess the usefulness of a phosphorus index to identify areas susceptible to phosphorus loss at the regional scale. Using a Geographic Information System (GIS) to organize the input data, a phosphorus index was applied to 60 watersheds within Minnesota ranging in size from 9,840 to 1,340,000 acres with a mean area of 680,000 acres. Phosphorus index values were compared with phosphorus monitoring data collected from both watershed outlets and lakes. Two different versions of the phosphorus index were applied to the study area, the original version of the phosphorus index (Lemunyon and Gilbert, 1993) and a new modified version of the original phosphorus index. In either case, the irrigation erosion site characteristic included in the original phosphorus index was not used because irrigation is not prevalent in Minnesota.

In the original phosphorus index, both soil test phosphorus and runoff class were classified based on nominal ratings of low, medium, high, and very high (Lemunyon and Gilbert, 1993). Our intent is to determine the cutoffs for soil phosphorus levels from the soil characterization. For this portion of the study, soil test phosphorus was categorized based on cutoff levels for fertilizer recommendations (Rehm et al., 1994). The runoff categories are the result of using a matrix of both soil permeability class and slope or runoff curve number and slope (NRCS,). Phosphorus application method and timing could not be differentiated among the watersheds in the study given the generalized nature of the data available. Despite the importance of this factor in the phosphorus index framework, the highest organic and fertilizer phosphorus application method rating value was used to represent a worst-case scenario.

The modified phosphorus index (Table 3) was developed in an attempt to more accurately represent regional conditions influencing phosphorus movement within Minnesota based on monitoring data (Table 2.3). Weighting factors for organic phosphorus application rate and soil test phosphorus were decreased from 1.0 to 0.5 and 0.75, respectively. The weighting factor for fertilizer application rate was increased from 0.75 to 1.0 based on observed relationships between site characteristics and the monitoring data. Sharpley (1995) used a similar weighting factor for the organic phosphorus application rate in an assessment of the phosphorus index at the field scale. The proportion of a watershed comprised of cropland and pastureland within a buffer of drainage ditches and perennial streams was also included as a site characteristic. Recent versions of the phosphorus index have included a proximity to water component of the phosphorus index (Sharpley et al., 1999).

Table 3. The modified version of phosphorus index as proposed by Birr and Mulla (2001).

	Phosphorus Loss Potential (value)				
Site characteristic (weight)	Very low (0)	Low (1)	Medium (2)	High (4)	Very high (8)
Transport factors					
Soil erosion (1.5)[1]	0	1-5	6-14	15-21	> 21
Runoff (0.5)[2]	0-8	9-13	14-16	17-21	> 21
Percentage of cropland and pastureland within buffer of water course (1.5)	0-1.2	1.3-3	3.1-4.2	4.3-6.2	> 6.2
Source factors					
Soil test P (0.75)[3]	0-19	20-26	27-31	32-39	> 39
Fertilizer P application	0-7	8-13	14-19	20-24	> 24
Fertilizer P application method (0.5)	None applied	Placed with planter deeper than 5 cm	Incorporated immediately before	Incorporated >3 mo before crop or surface applied <3 mo before crop	Surface applied >3
Organic P source	0-2	3-6	7-8	9-11	> 11
Organic P source application	None applied	Placed with planter deeper than 5 cm	Incorporated immediately before	Incorporated >3 mo before crop or surface applied <3 mo before crop	Surface applied >3

1 Units for soil erosion are Mg/ha.

2 Units for runoff are cm.

3 Soil test P is Bray-1 extractable P and units are mg P/kg.

4 Units for P application are kg P/ha

Validation of the phosphorus index rating was conducted using long-term water quality monitoring data consisting of total phosphorus concentrations collected from watersheds and lakes. A narrow range of phosphorus index rating (19.3-37.8) resulted using the original version of the phosphorus index. A poor correlation between phosphorus index rating and total phosphorus losses in watersheds was observed using the original version of the phosphorus index ($r^2 = 0.15$). The modified version of the phosphorus index produced an improved correlation between phosphorus index rating and observed phosphorus losses in watersheds ($r^2 = 0.60$). A close relationship was also observed between phosphorus index rating and lake water quality ($r^2 = 0.68$) using the modified phosphorus index. The phosphorus index ratings for the Red River Basin had a strong correlation with observed total phosphorus losses in watersheds ($r^2 = 0.58$); however, the distribution of phosphorus index ratings was lower compared to the other basins. Results of this study suggest that, with certain limitations, the modified phosphorus index can be used at a regional scale to prioritize phosphorus loss vulnerability using state and national databases.

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Manure Storage and Handling

Introduction

This section builds on the original literature review and is primarily focused on the relationship between manure storage and handling impacts on soils and crops and is limited to published information from June 1999 to the present. Some limited information is provided on seepage from manure storages in karst topography and pathogens in manure storage.

Manure storage is a critical component of animal agriculture in Minnesota. Manure storage allows manure nutrients to be better utilized for crop production and to be used in a more environmentally sound manner through timely and seasonal application. Manure storage reduces the need to apply manure onto frozen, snow-covered, or saturated soils or at times when crops cannot utilize the manure nutrients, and reduces the concentration of pathogens. Grazing systems reduce the need for manure storage during the summer months; however, some storage is still required during those times animals are in confinement (during the winter months or in holding areas for milking). The benefits, drawbacks, and costs of different manure handling systems were outlined in the original literature review. Table 1 contains a summary of the current manure storage systems along with the advantages and disadvantages of each system.

Although manure handling systems are typically comprised of manure collection, storage, and land application, there are some alternative manure handling systems that may offer benefits for soil, water, and air quality. These alternative manure handling systems include manure treatment such as aeration, anaerobic digestion, and solid-liquid separation. These systems continue to require manure storage and land application but serve to concentrate nutrients, stabilize organic matter and nutrients, reduce pathogens, and/or reduce odors. These systems are typically more expensive than traditional manure systems, but in some situations the additional benefits may offset the additional cost. Solid manure handling systems and grazing systems also offer an alternative to traditional manure handling systems.

Table 1. Advantages and disadvantages associated with common types of manure storage facilities. (MWPS 18-2, 2001; Natural Resources Conservation Service, 1998)

Manure storage type	Advantages	Disadvantages
Solid manure, roofed or covered (earthen, concrete pad)	• High nutrient density. • Do not have to haul water. • Little or no seepage. • Low nutrient loss. • No runoff from stacked manure.	• More expensive than open stacks. • Not applicable as sole storage for systems with lot runoff or high water use. • Bedding may be required.
Solid manure, not covered (earthen, concrete)	• Less expensive than roofed storage. • High nutrient density. • Do not have to haul water. • Low nutrient loss, but higher than a covered storage. • Most applicable in arid regions.	• Rainfall/runoff contamination potential. • Runoff controls may be required. • Not applicable as sole storage for systems with lot runoff or high water use. • Bedding may be required. • Less applicable in humid regions.
Slurry pit, reception pit, or roofed tank (earthen, concrete)	• Relatively high nutrient density. • Low/moderate nutrient loss. • Manure may be injected or incorporated. • No rainfall effects.	• More expensive than earthen storage. • May have more odor. • May require pit ventilation. • May not be compatible with systems having significant lot runoff or high water use. • Relatively expensive application equipment.

Manure storage type	Advantages	Disadvantages
Below building pit (concrete)	- Relatively high nutrient density. - Low/moderate nutrient loss. - Manure may be injected or incorporated. - No rainfall effects.	- More expensive than earthen storage. - May have more odor. - Animal/worker health problems may result with prolonged exposure to manure gases. - May require pit ventilation. - Not appropriate for regions with shallow water table on high-risk geology. - Relatively expensive application equipment. - Manure solids are more difficult to remove.
Slurry pit or tank, not roofed (concrete, steel)	- Relatively high nutrient density. - Low/moderate nutrient loss. - Manure may be injected or incorporated.	- More expensive than earthen storage. - May have more odor than covered storage. - Rainfall adds extra water. - May not be compatible with systems having significant lot runoff or high water use. - Relatively expensive application equipment.
Earthen slurry basin or pit (earthen)	- Relatively high nutrient density. - Low/moderate nutrient loss. - Manure may be injected or incorporated. - Less expensive than concrete or steel tanks. - Can be sized for lot runoff and minimal fresh water inputs.	- May have highest odors because of greater surface area. - Rainfall adds extra water. - May be difficult to properly agitate. - Requires soils evaluation, proper soil material, and seal construction. - Relatively expensive application equipment. - Not appropriate for regions with shallow water table on high-risk geology.

Manure storage type	Advantages	Disadvantages
Lagoon (earthen)	• Used for frequent crop irrigation in western states. • Most feasible for long-term storage. • Can be sized for lot runoff and fresh water inputs. • Provides biological treatment of manure. • Can be managed with irrigation equipment.	• May have offensive odors, especially seasonally. • High loss of nitrogen due to volatilization. • High phosphorus levels in sludge if not agitated and removed regularly. • Agitation may be difficult due to size. • Requires soils evaluation, proper soil material, and seal construction. • Irrigation not suitable on steeper slopes. • Not appropriate for regions with shallow water table on high-risk geology.
Runoff holding ponds (earthen, concrete)	• Most applicable for storm events in arid regions. • Primarily used for storage of lot runoff from storms. • Can be managed with irrigation equipment.	• Should be preceded by solids separation. • Requires soils evaluation, proper soil material, and seal construction. • Not appropriate for regions with shallow water table on high-risk geology.

The costs and benefits of all manure handling systems are site specific, relying on geographic conditions, acreage available for land application, cropping sequence, soil types, labor availability, topography, etc. Rising energy costs and nitrogen fertilizer prices will likely play a role in future decisions regarding manure handling systems. A recent report by "Environmental Defense" reviewed the environmental problems in North Carolina resulting from swine lagoons and irrigation of the effluent on sprayfields (Cochran et al., 2000). The study estimated the cost of building and operating a new lagoon/sprayfield at $3.72 per finished hog. Costs to add advanced manure handling systems to existing lagoon/sprayfield systems ranged from $-0.35 to $5.21 per finished hog. Unfortunately, these cost estimates were based specifically on hog production systems in North Carolina where manure nutrient utilization is limited. This, along with the fact that these lagoon/sprayfields are not used in Minnesota, makes these cost estimates of limited transferability to Minnesota conditions. However, the information reported indicates the potential for alternative manure handling systems to be cost effective.

Manure Treatment

Anaerobic digestion

A considerable amount of interest has been focused on the anaerobic digestion of manure. Fig. 1 illustrates how a digester can be placed into an existing manure collection, storage, and land application system. Anaerobic digestion refers to a manure treatment process that converts some of the organic matter in the manure to biogas, a mixture of carbon dioxide and methane and trace amounts of other gases. This biogas can be used as fuel to produce electricity or hot water. Concentrations of nitrogen, phosphorus and potassium do not change as manure is digested nor is there any reduction in manure volume. The only substantial changes occurring during anaerobic digestion are a decrease in odor concentration, a shift from organic nitrogen to ammonia/ammonium nitrogen, and more uniform distribution of nutrients in the digested manure. The conversion of organic nitrogen to ammonia nitrogen results in a source of nitrogen that is more immediately available for crop utilization. This change in nitrogen availability and the more uniform distribution of nutrients make it easier to plan and utilize the manure nutrients in crop production. Anaerobic digestion systems can be designed for all types of livestock and poultry liquid manure systems.

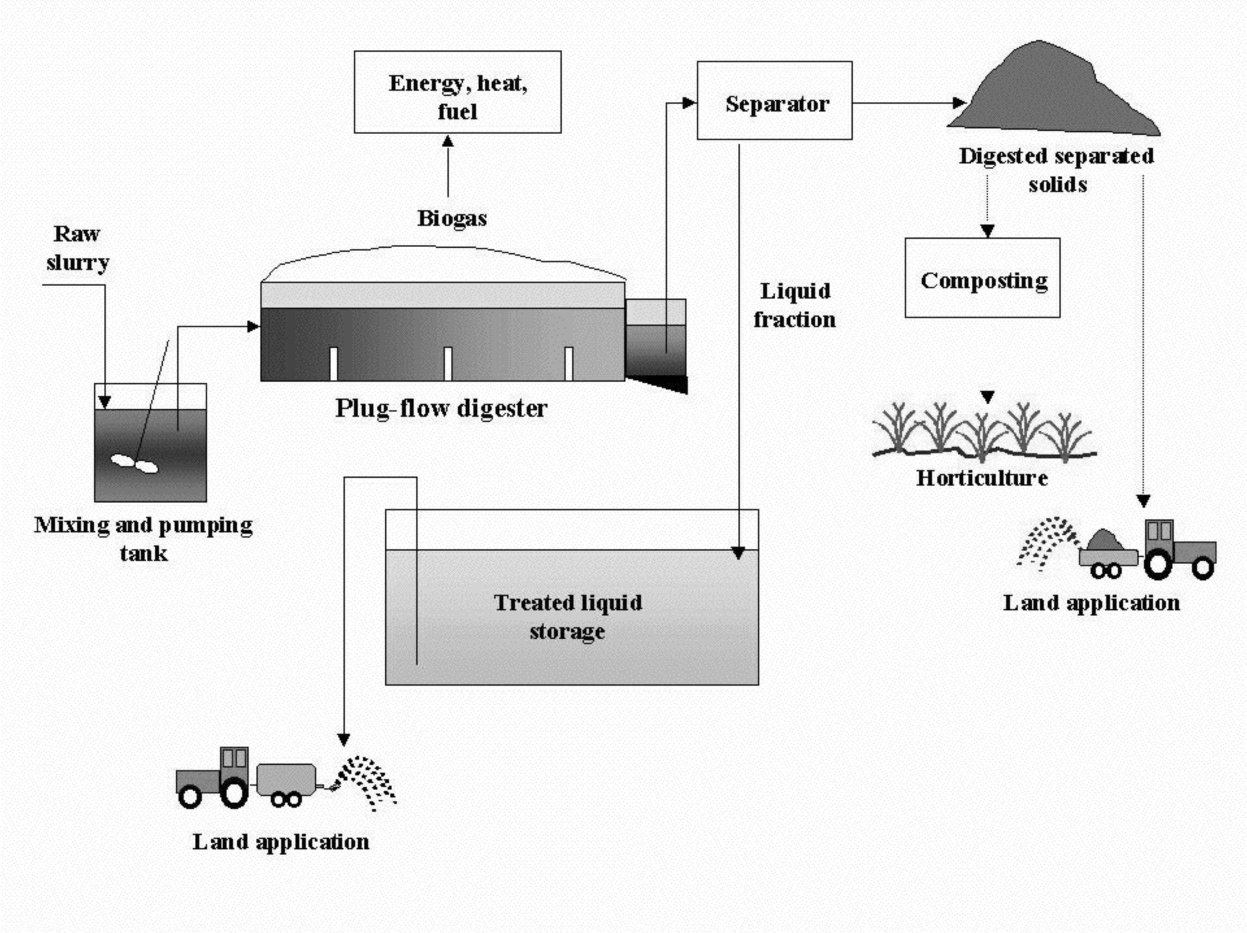

Figure 2. Anaerobic digestion for manure treatment prior to land application.

There were only 28 on-farm anaerobic digestion systems operating in the U.S. in 2000 (USEPA, 2000). This number is likely to increase with the renewed interest in anaerobic digestion and increased energy costs. A case study of the operating on-farm anaerobic digesters in the U.S. was conducted by Lusk (1998). The report provides a brief description of 23 farms currently operating an anaerobic digester and includes design criteria and a summary of the system economics. A more detailed case study was conducted for an anaerobic digester on a 900 cow-dairy farm near Princeton, MN (Nelson, 2000). This system was installed as part of a dairy expansion in 1999 as a means of controlling odor and improving nutrient utilization. The report documents a capital cost of $355,000 with a payback period of seven years with a selling price of electricity of 7.25 cents per kWh.

Jewell (1997) evaluated the feasibility of an anaerobic digestion system for a group of small dairy farms in New York. This study viewed a centralized anaerobic digestion plant primarily as a solution to pollution problems associated with manure storage and land application at several small dairies, each less than 200 cows. The report concludes that a centralized manure treatment plant (anaerobic digester) could be economically feasible and may actually cost less than constructing individual manure storage systems at several small farms. The report assumes that the manure would not be returned to the individual farms but applied on cropland near the centralized facility.

Anaerobic digestion is both technically and environmentally sound. Although the return on economic investment currently limits the use of anaerobic digestion systems, higher electrical energy costs will make on-farm anaerobic digestion more economically feasible through electrical use savings and the possibility of selling electricity back to the supplier. Increasing farm sizes and concern over odor may also result in the installation and operation of more anaerobic digesters.

Aeration

Alternative manure systems might include aeration of the manure. The addition of oxygen changes the microbial breakdown of the organic matter in the manure, which results in the stabilization of nutrients, elimination of odor, and nitrogen loss through denitrification. Recent research by Yang (1999) evaluated the use of intermittent aeration in combination with solid-liquid separation and anaerobic digestion of swine manure to reduce the nutrients available for land application. The addition of intermittent aeration resulted in reductions of total nitrogen of 92.7% and total phosphorus of 71% in the liquid effluent. Nitrogen was lost either by ammonia stripping or nitrification/denitrification and phosphorus went with the solids. Cost of the total system was $8.00 per sow per year.

One of the significant drawbacks of aeration systems is cost. Methods to reduce the cost of aeration include providing methods to monitor oxygen levels in the manure and more efficient transfer of oxygen to the manure. Oxygen added above that necessary for maintaining aerobic populations of microbes only increases the cost of the aeration system. For system efficiencies and to better control the fate of nutrients and organic material, aerobic systems are often combined with anaerobic systems and solid-liquid separation. These systems are referred to as sequencing batch reactors. Ra et al. (1999) evaluated a system to monitor and control a sequencing batch reactor process by measuring the oxidation-reduction potential of the manure. This system provided removal rates of nitrogen and phosphorus in the liquid effluent of 96%.

Solid-liquid separation

Several studies have evaluated the efficiency of solid-liquid separation for nutrient removal from the liquid fraction of the manure and the subsequent concentration of nutrients in the solids fraction. Separation includes gravity settling or mechanical separation systems. Often these systems can be enhanced with chemical additions. Concentration of nutrients in the solid fraction provides a cost-effective means of utilizing manure nutrients at distances farther from the animal production site. Unfortunately, assessing the performance of separation systems on nutrient separation is difficult because of the variability in manure sources and operation of the equipment. A summary of solid-liquid separation systems by Zhang (1997) shows total nitrogen separation efficiencies ranging from 3-35% and 1-68% of total phosphorus ending up in the solid fraction.

An extensive series of solid separation systems for removing organic matter and nutrients is reported by Pieters (1999). In this study, swine manure with total solids between 1.5 and 2% was separated using one of four methods: a filter press, a vibrating screen, a hydrocyclone, and a screw press. Nitrogen removal was 31, 5, 0, and 11%, respectively, while phosphorus removal was 42, 3, 0, and 7%, respectively. With the addition of microfiltration and reverse osmosis to one of the above processes, nutrients and organic matter in the filtrate showed 0 mg/l dry matter, 0 mg/l suspended solids, a total nitrogen content of 100 mg/L and a total phosphorus content of 2 mg/L. Cost for this combination treatment system was estimated at $30.00 per 1000 gallons of manure treated, thus cost prohibitive at the producer level.

Vanotti (1999) studied nutrient removal from swine finishing manure using polyacrylamides (PAM) and gravity separation. Removal efficiency for organic nitrogen was 11% using settling only and 83% with the addition of 200 mg PAM / L of manure. Organic phosphorus removal was 17% with settling only and 89% with the addition of 200 mg/L PAM. Chemical costs for this treatment were $2.79 per finished pig. In a similar study using alum as an aid in solids settling, removal efficiencies for phosphorus were 38% without, and 75% with alum additions (Worley, 2000). Alum addition did not improve nitrogen and potassium removal.

Seepage Concerns

Minnesota Feedlot Rules Chapter 7020 was recently updated to address a variety of environmental concerns regarding animal agriculture. The rules specifically address site restrictions and requirements for design, construction, maintenance, and operation of liquid manure storage structures (7020.2100), poultry barn floors (7020.2120), and solid manure storage (7020.2125) in order to protect ground and surface water quality. These rules state that design and construction of any earthen storage must “achieve a maximum theoretical seepage rate of not more than 1/56 inch per day over the life of the manure storage” (7020.2100 subpart 3.B). These regulations also prohibit runoff from manure storage structures except in the case of a 25-year, 24-hour or greater storm event. These regulations are based on currently available scientific data. (MPCA, 2000).

Earthen basins

Concern continues to be expressed regarding the quantity and quality of seepage from earthen manure storage. Seepage water qualities of most concern are nitrates and pathogens. Studies to evaluate and document seepage from manure storages are numerous. However, only two studies have been conducted or reported from June 1999 to the present. Ruhl (1999) reported on the quantity and quality of seepage from two earthen storage basins in Minnesota. These basins were built with a standard soil liner, designed to meet the 1/56 (0.018) inch/day seepage rate. One area of each of these storages was lined with a secondary flexible membrane liner to collect the seepage through the soil liner. Results indicate that the total seepage varied widely and ranged from 0.03 to 0.43 inches/day. Seepage rate through the sidewalls of the earthen basin generally increased with the depth of manure, while there was no correlation between manure depth and seepage through the bottom of the basin. One of the sites showed nitrate concentrations in the seepage that exceeded the USEPA maximum contaminant level (MCL) of 10 mg/L. In 17 of the 22 samples, however, no nitrate contamination conclusions could be drawn because the background groundwater samples taken at the site also exceeded the USEPA MCL standard. The other site showed nitrate concentrations of 5.24 mg/L or less. This nitrate must be from ammonium that was nitrified in the soil after leaving the basin or from an outside non-manure source. Neither site showed increases in fecal *Coliform*.

The Minnesota Pollution Control Agency is also reviewing groundwater data taken near earthen manure storage sites in Minnesota from 1994 to 2000 from four separate studies (MPCA 2000b, draft). In the first study, groundwater samples were taken adjacent to manure storages ranging in age from 6 to 40 years. Sites included dry feedlots with no liquid storage, clay lined and concrete lined manure storages. Sampling at each site consisted of 8 to 24 temporary wells where a variety of water quality parameters were measured. Preliminary data from this study suggests some degradation in groundwater quality within 300 feet of manure storages or open lots with course textured soils. The second study reviewed water quality data taken from monitoring wells both up and down gradient from 19 different manure storage structures. Data from this study was inconclusive. The third study reported by the MPCA (MPCA 2000, draft) was done in conjunction with the USGS study and reported by Ruhl (2000) earlier in the previous paragraph of this document. The fourth study monitored groundwater beneath a manure storage with a geosynthetic liner (HDPE and bentonite clay). Unfortunately, this site has only been monitored since 1998 and no conclusive evidence can be drawn on the impact of the manure storage and liner on groundwater quality.

Seepage from 28 earthen manure storage systems in Iowa was evaluated using a mass-balance approach (Glanville, 2000). Forty-three percent of the structures tested had seepage rates lower than 1/16 (0.0625) inch per day. Those structures built in glacial till soils (0.0036 inch per day) showed significantly lower seepage rates than those constructed in loess, colluvium, or sand and gravel (0.061 inch per day). No significant difference was found in age of storage or between lagoons and earthen storage basins.

Concrete

Concern over seepage from earthen manure storages and a moratorium on earthen manure storages for swine manure, imposed by the 1998 Minnesota State Legislature, has led to an increase in the number of concrete manure storage structures being constructed (MPCA, personal communication). MPCA rules, Chapter 7020.2100, address specific design and construction standards for concrete manure storages. However, the concern over seepage through cracks in concrete is often expressed. University of Minnesota researchers, funded by the Minnesota Department of Agriculture, are currently investigating manure seepage through concrete manure storage structures (Clanton, 2000). This study is evaluating the potential for cracks in concrete to be “sealed” by manure. Preliminary results indicate that concrete cracks seal within a couple of hours and that swine manure with 3% total solids reduced steady-state flow (7 to 34 days after manure addition) by a factor of 100,000 as compared with water.

Karst topography

One controversial aspect of the 7020 Feedlot rules is related to construction of manure storages in karst topography. Although the rules specifically discuss design and construction requirements in karst topography, the 2000 Minnesota State Legislature specifically asked the MPCA to form a workgroup to study the issue and propose design standards for these areas. The workgroup developed interim standards until further study on evaluation of sinkhole formation can be completed (MPCA, 2000c). The standards can be summarized as follows:

Location restrictions

- Maintain a 300-foot setback from existing sinkholes
- Relocate if subsoil inspections indicate soil subsidence or sinkhole development
- Avoid construction over mapped caves registered with the State

Design specifications

- Use dual-liners, concrete liners, or above ground glass-fused metal
- Limit maximum capacity of a single cell to three million gallons
- Maintain a five-foot minimum separation between manure and bedrock
- Convey roof and runoff away from the storage area
-

Identifying and responding to failures

- Monitor manure levels regularly and conduct annual inspection of the liner
- Develop an emergency response plan

The workgroup emphasized that further work is needed to:

- Determine geostatistical probabilities of soil collapse in different types of geologic settings
- Study pathogen transport through soils below liquid manure storage systems
- Develop a generic emergency response plan that can then be tailored for specific feedlot operations
- Conduct research and demonstration projects on alternative manure management approaches that do not rely on liquid storage
- Conduct regular monitoring and inspections of existing liquid manure storage systems
- Collect, manage, analyze, interpret, and map geologic and hydrogeologic information needed for engineers designing liquid storage basins in karst areas
- Assign a state agency to record and keep records of known caves.

Summary

Currently there is no quick method of assessing the impact of liquid manure storage on groundwater quality. Evidence to suggest that liquid manure storage structures in Minnesota are impacting water quality in Minnesota is inconclusive. Proper design and construction will likely limit any environmental impacts.

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Policy Implications or Potential Long-Range Consequences of Current Observed Trends

Introduction

Animal agriculture in Minnesota continues to go through significant technological and structural changes. Some of these changes may have important impacts on the management of manure and consequently on soil properties. Local, state, and federal governmental policies can have important influences on animal agriculture and may need to be adapted in response to trends in the industry. There are three important questions to consider in examining long-range consequences and the role of policies in the continued development of Minnesota's livestock industry:

- What are the current trends in Minnesota's animal agriculture that are relevant to manure management and soil properties?
- What are the important impacts these trends will have on manure management and consequently on soil properties?
- What are the policy implications of these trends in Minnesota's animal agriculture and expected impacts on manure management and soil properties?

Each of these questions is considered separately below:

What are the current trends in Minnesota's animal agriculture that are relevant to manure management and soil protection?

Swine

The number of hogs in Minnesota continues to increase. There were about 5.80 million hogs in the state in 2000 compared to 4.95 million in 1995. Although the growth rate has not been steady, there has been an average annual increase of about 3% (National Agricultural Statistics Service, NASS).

More hogs are being raised on large hog farms. In 2000, approximately 80% of the hogs were raised on 20% of the state's hog farms. These farms had at least 1000 head. Over 40% of the hogs raised in the state were on farms with more than 5000 head (NASS).

The number of small hog farms continues to decrease. There is an annual loss of about 7% in the number of hog farms in Minnesota. About one-half of hog farms with less than 1000 head have been lost since 1992 (NASS). A small percentage of these farms may have transitioned into larger operations.

New facilities for raising swine usually include under-building pits for swine manure storage. In response to regulations, earthen storage basins are no longer being constructed for manure storage. In addition, there is a continued loss of small hog farms that may have been using open lots, solid manure handling systems, and open storage. Under-building pits have become the

most economical means of manure storage for most hog farms.
Some hoop structures that use deep bedding and a solid manure handling system are being built for raising swine. The low cost of construction and the environment for the hogs and workers are the primary reasons for using hoop structures. The manure is handled by having bedding materials such as corn stalks that adsorb swine excrement. The bedding material is removed and land applied a few times per year.

Phytase, an enzyme feed supplement that increases the availability of phosphorus (P) in corn for swine, is being added to feed by some producers. Presently, the cost of using phytase is similar to the cost of adding P supplement to the feed. The use of phytase can reduce the P content of the manure by approximately 35%. In addition, low phytate corn is becoming available and may increase in usage if acceptable crop yields can be achieved. Low-phytate corn has more of the P in available forms for swine. Feeding this corn will reduce the amount of P in the manure, which could help to reduce the amount of P that could end up in runoff to surface waters.

The amounts of nitrogen (N) and P in the swine manure produced in Minnesota that are available for crops are increasing due to increased numbers of hogs, increased use of beneath building pits, and increased amounts of manure being applied to soils with an injection or incorporation system. Making some assumptions about how manure is handled, an estimate can be made of the N and P that is potentially available in the manure produced by the approximately 5.8 million swine in Minnesota. The following assumptions will be used:

- Most manure is stored in beneath-building pits with 20% storage and handling losses of N.
- The average availabilities are 70% and 100% for N and P, respectively, when land applied with injection or incorporation
- Approximately 0.07 pounds of N and 0.05 pounds of phosphate (P_2O_5) are produced by each animal per day.

Using these assumptions will give an estimate of the amounts of N and P that are potentially available and will overestimate the actual amounts available under current management practices. With these assumptions, there will be about 42,000 tons of N and 53,000 tons of P_2O_5 available annually in Minnesota from swine manure.

Dairy

The total number of dairy cows in Minnesota is approximately 540,000 and is decreasing by about 2 to 3% annually (NASS). Milk production per cow has continued to increase so that Minnesota's production of milk is remaining quite constant at about 9.4 billion pounds per year.

The dairy industry in Minnesota has continued the trend to fewer and larger dairy farms. The number of dairy farms is decreasing by about 6% annually with most of the losses reflected in the number of dairy farms with less than 50 head (NASS). Milk production by farms with more than 200 head has replaced the production of milk by dairy farms with less than 50 head that have been lost. The amount of milk produced by dairy farms with 50 to 200 head has been relatively constant. The dairy industry remains concentrated in the central and southeast regions of the state.

The P nutrition of dairy cows is being reexamined. The amount of P in the dairy rations may be higher than necessary for good animal health. New strategies may reduce the amount of P in the diet and consequently the amount in dairy manure.

Dairy manure is increasingly stored and land applied as a liquid. Manure handling systems generally consist of scraping the manure and transferring it to a storage facility such as an earthen storage basin, storage pad, or other holding area. Most liquid manure is applied to the land by injection or incorporation after top spreading. It is estimated that from 20 to 40% of dairy farms are daily scrape and haul or have less than 2 weeks of storage.

The amounts of N and P in the dairy manure produced in Minnesota that are available for crops are remaining quite constant. Making some assumptions about how manure is handled, an estimate could be made of the N and P that is potentially available in the manure produced by the approximately 540,000 dairy cows in Minnesota. The following assumptions will be used:

- Dairy manure is stored in earthen storage pits and one-half is stored as a manure pack until land applied with an average of 30% storage and handling losses of N.
- The average availabilities of N and P are 70% and 100% for nitrogen and phosphate, respectively, when land applied with injection or incorporation.
- About 0.5 pounds of N and 0.2 pounds of P_2O_5 are produced by each animal per day.

Using these assumptions will give an estimate of the amounts of N and P that are potentially available and will overestimate the actual amounts available under current management practices. With these assumptions, there will be about 24,000 tons of N and 20,000 tons of P_2O_5 available annually in Minnesota from dairy manure.

Cattle

The number of cattle other than dairy cows is presently about 2 million and has shown little change during the last 5 years (NASS). The number of cattle farms has also remained fairly constant but with some loss of cattle farms with less than 100 head. Cattle production occurs over much of the state with several counties with large concentrations.

Most cattle continue to be raised in open feedlots. Most large feedlots have earthen storage basins to contain manure that is scraped from the feedlots. Most small feedlots do not have any storage facility. These lots will be cleaned as needed with the solids applied to the land. With the small amount of change in the number of cattle farms, the methods of raising cattle and handling cattle manure are not changing significantly.

The amounts of N and P in the cattle manure produced in Minnesota that are available for crops are remaining fairly constant due to few changes in the number of cattle being raised and in the way in which manure is handled. Making some assumptions about how manure is handled, an estimate could be made of the N and P that is potentially available in the manure produced by the approximately 2 million cattle (excluding dairy cows) in Minnesota. The following assumptions will be used:

- Cattle manure is stored in earthen storage pits or as a manure pack until land applied with an average of 30% storage and handling losses of N.
- The average availabilities of N and P are 70% and 100% for nitrogen and phosphate,

respectively, when land applied with injection or incorporation.
- About 0.3 pounds of N and 0.2 pounds of P_2O_5 are produced by each animal per day.

Using these assumptions will give an estimate of the amounts of N and P that are potentially available and will overestimate the actual amounts available under current management practices. With these assumptions, there will be about 54,000 tons of N and 73,000 tons of P_2O_5 available annually in Minnesota from cattle manure.

Poultry

The poultry industry made a transition to large operations several years ago. The industry continues to change with some additional vertical integration and some increases in size of individual operations. Turkey, chicken, and egg production has remained relatively constant during the last few years (Agricultural Statistics Board, 1999).

Most of the manure continues to be handled in a solid form. In large operations the manure is delivered to farms that have agreed to receive the manure. Terms may include payment based on analysis, cost of hauling, cost of spreading, and time of delivery. Feedlot regulations and increased demand for crop nutrients will continue to encourage improved use of the nutrients in poultry manure.

The amounts of N and P in the poultry manure produced in Minnesota that are available for crops are remaining quite constant due to relatively stable numbers of poultry and in the way manure is handled. Making some assumptions about how manure is handled, an estimate could be made of the N and P that is potentially available in the manure produced by the poultry in Minnesota. The following assumptions will be used:

- Most manure is stored in manure packs with 30% storage and handling losses of N.
- The average availabilities are 70% and 100% for N and P, respectively, when land applied with incorporation.
- About 0.009 pounds of N and 0.008 pounds of P_2O_5 are produced by each turkey per day; and about 0.003 pounds of N and 0.002 pounds of P_2O_5 are produced by each broiler or layer per day.

Using these assumptions will give an estimate of the amounts of N and P that are potentially available and will overestimate the actual amounts available under current management practices. With these assumptions, there will be about 16,000 tons of N and 25,000 tons of P_2O_5 available annually in Minnesota from poultry manure.

General trends in manure management

The use of applicators with tote hoses is increasing in order to lower application costs and to avoid soil compaction. Many custom operators have the necessary pumps, hoses, and applicators for applying manure to fields within approximately 1 mile from the storage facility. Manure can also be hauled with tanker trucks to the field and applied there by an applicator with a tote hose.

With the increase in size of livestock farms, large amounts of manure are being generated at individual feedlots. This often requires feedlot operators to develop agreements with neighboring farmers to accept the manure. The financial arrangements vary depending on who applies the manure, the frequency of application, the nutrient content of the manure, and hauling distance. Due to economic factors and the potential for yield increases, there is an increasing demand for manure. Many feedlot facilities have been built with prior financial agreements on the use of the manure produced.

Manure produced at large livestock operations will be applied to land within a distance that is dependent on the costs of hauling, land ownership, other feedlots, and other factors. This generally results in land near livestock facilities receiving manure on a regular basis while land farther away potentially never receives manure. While such an effect was always present even with many more small feedlots, a change in scale is occurring so that the area of land application focuses on several hundred acres around each large facility. If P is being applied at rates greater than crop removal rates, soil test P levels could be increasing in those regions, potentially leading to increased P in runoff to surface waters.

There are concerns about the manure application rates that are being used in all sizes of operations. There are opposing factors that may affect the decision on the rate of manure application. From the perspective of the feedlot operation, reducing the cost of getting rid of the manure means increased profit. From the perspective of the crop producer, applying manure at rates that maximize the efficient use of the nutrients in the manure reduces fertilizer costs and increases profits. With large livestock operations there are often agreements that link the cost of removing the manure from the feedlot with the value received by the cropland. Recent increases in the prices of fertilizers will increase these agreements. Increases in the cost of N fertilizer and concerns about shortages are increasing the demand for manure and the efficient use of N in manure. Livestock producers are getting calls from neighbors about manure availability.

There has been limited adoption of practices that incorporate the manure in the soil while protecting crop residue. When manure is applied to fields that have been in soybeans and will be going into corn, typical injectors can bury much of the soybean residue. This may make the soil more susceptible to wind and water erosion. Several injectors are available that incorporate the manure while protecting the existing crop residue.

Site-specific technology for manure application is being used by some commercial applicators. This technology can be used to track the application rate across fields and to apply the manure at variable rates across the field, depending on the site-specific characteristics. As this technology is more widely adopted, manure application can become more precise and fine tuned to meet crop nutrient needs.

The requirement of comprehensive nutrient management planning by local, state, and federal agencies has caused a significant increase in the number of manure management plans. Depending on the size and location of a feedlot, a plan for the application of manure produced and record of application will be required.

There has been some adoption of manure treatment systems that reduce the manure volume. Separating the solids from the liquids can reduce hauling costs, allow for composting of manure, and allow for recycling of water.

There is a continued uncertainty about environmental regulations and potential changes in feedlot rules. This uncertainty has definite effects on how decisions are made on building, expanding, or abandoning a feedlot site.

Activist groups that oppose feedlot expansion are having a strong influence on the agency decisions concerning feedlot permits. Expansions or new facilities are often held up when a group of citizens brings forward concerns about the potential impacts of the feedlot on air and water quality.

What are the important impacts that these trends will have on manure management and consequently on soil properties?

There are several trends in the livestock industry that will be affecting how manure is stored and applied, which will in turn affect the impact on soils. Application of manure can have beneficial impacts on soil in that it can increase the organic matter content, improve physical properties, and increase the availability of crop nutrients. There can be risks associated with manure application, such as compaction, excessive levels of crop nutrients, salts, and pathogens.

Changes in amounts of available crop nutrients from animal manures

While livestock numbers are gradually growing in Minnesota, the amounts of N and P available in animal manure are less than that needed by the corn and soybeans grown in the state. The following table summarizes the amounts of N and P_2O_5 available in animal manures and needed by corn and soybeans in Minnesota. The assumptions used were that corn needs about 110 lb/acre of N and removes about 80 lb/acre of P_2O_5. It was assumed that soybeans remove about 45 lb/acre of P_2O_5.

Animal	Available N	Available P_2O_5
	----------- thousand tons	----------------
Swine	42	53
Dairy	24	20
Beef	54	73
Poultry	16	25
Total available nutrients	136	171
Nutrients needed by crops	390	424

From these estimates it is apparent that manure cannot adequately supply the N and P needs of the State's corn and soybean crops and that there is room at least statewide for more animal agriculture based on the need for crop nutrients. However, these statewide calculations should not minimize the concerns about potential local surpluses in manure. There are certain regions of the state that may have excess crop nutrients because of high concentrations of livestock operations. In addition to the nutrients needed by corn and soybean, there are several other crops that could make use of nutrients in manure, including alfalfa, wheat, and oats.

The use of phytase, low phytate corn, and reduction in levels of P in feed may reduce levels of P in animal manure. Reducing the level of P in manure would make it more achievable to apply manure on a regular basis to land to supply N requirements without causing a build up of soil test P.

Changes in manure management and land application

The shift to larger feedlots causes manure to be applied to land within an economically reasonable distance from the storage facility. As described above this will result in fields within one or two miles of feedlots receiving most of the manure, while fields beyond this zone may possibly never receive manure. Over time the soils in these zones around feedlots may have higher levels of soil test P and organic matter, improved tilth, increased availability of nutrients, and higher yield potentials than soils not receiving regular manure applications.

Soil management

The use of drag hoses will help control soil compaction. Eliminating the pulling of a manure tank through the field during application can help reduce the risk of soil compaction, especially under wet conditions.

As the drainage of agricultural land continues to be improved, manure will be applied on more land that has improved subsurface drainage. Applying manure to land with subsurface drainage has both some advantages and potential risks. Improved drainage can make the soil more able to bear the weight of the manure applicator and help reduce the risks of compaction. Improved drainage can increase crop yields and the efficient uptake of nutrients from manure applied to the soil. However, there are concerns about leaching of nitrate to drainage lines. Excessive amounts of available N from over-application of manure could increase this loss of nitrate through the drainage system. There is also the concern of pathogens from manure reaching the drainage system and being transported to surface waters.

Surface inlets and blind rock inlets are another management concern in drained land. Surface applied manure without incorporation must not be applied within 300 feet of an open inlet. It is not clear how manure should be managed near rock inlets. There is also concern that manure may be injected through rock inlets because they may not be visible in the presence of crop residue after harvest.

Maintaining crop residue levels to control soil erosion is more difficult with manure application. If manure is injected with a knife or sweep injector or if manure is incorporated after a broadcast application with a tillage implement, major portions of residue such as soybean can be buried as well. Injectors that leave much of the residue undisturbed are available but have been adopted by only a few farmers due to some potential initial increased costs, the lack of promotion by manufacturers, and a low level of concern about the increased risk of erosion.

Fertilizer management

Nitrogen-fertilizer prices have increased in late 2000, causing an increased demand for manure. Perceiving that manure has significant economic value will likely increase the efficiency of use through manure testing and more careful rate determination.

While the price increases may be changing awareness for the 2001 season, there have been challenges in taking adequate credit for nutrients in applied manure. Some fertilizer dealers have been reluctant to cut back on N rates on land that has received manure. This probably stems from a concern about a decrease in yield if there is not enough N available. If the amount of available N in the manure is not known, it is a perceived safer decision to put on the regular rate of N. Also, the application of manure may not be adequately uniform so that parts of a field receiving manure may not get enough available N while other parts will have excess available N.

What are the policy implications of these trends in animal agriculture and expected impacts on manure management and soil properties?

Policies by local, state, and federal governments have and will continue to impact Minnesota's animal agriculture. Ideally, policies should help provide guidance to animal agriculture in protecting natural resources and in keeping the industry viable and sustainable. Policies could be effective guiding the development and management strategies of Minnesota's animal agriculture in some of the following ways relevant to manure and soils:

- Prevent the build up of animal densities to levels so high that adequate land for manure application is not available within reasonable hauling distances
- Encourage sound management of manure so that the nutrients in manure are efficiently used by crops
- Encourage manure-management practices that minimize risks to water quality and soil properties

In addition, planning of rural development is needed in order to avoid conflicts between owner/managers of livestock operations and other residents that may be impacted by livestock operations. Policies should guide the placement of livestock operations, residential dwellings, commercial building, and various public facilities. In determining what are the policy implications of the trends in animal agriculture, at least two questions should be answered:

- Are current policies adequately encouraging good management of manure and the protection of soils?
- If changes in policy are needed, what educational efforts, incentive programs, and/or regulations are needed to address the concerns with manure management and soil protection as related to Minnesota's animal agriculture?

Guiding the development of animal agriculture

An important role of policy is to guide the development of the animal industry to prevent the excessive concentration of feedlot operations that will lead to over application of manure, poor economic use of crop nutrients, excessive hauling costs, and other problems that could be associated with crowding of feedlots. This would be especially true if regulations change restricting the amount of nutrients like P that can be applied per acre. Some policies are already in place at the local, state, and federal levels that are limiting the concentration of feedlot operations.

On a statewide basis there is probably not much reason to limit the growth of animal agriculture. The state still has ample land for the application of the nutrients contained in animal manure. However, there may be a problem with the uneven distribution of feedlots across the state.

On a county level, the process for registration and permitting of feedlots that is administered through both the counties and the state can ensure that adequate land is available for the application of the manure produced in the feedlot. This will probably remain the primary way of preventing excessive amounts of livestock in a region.

Encouraging sound manure management

On the field scale, there is still the challenge of encouraging more efficient use of the nutrients. Present regulations require adequate amounts of land for manure application based on N. Record keeping requirements will be a strong incentive to apply manure at rates that do not exceed the N needs of the crop. However, P management may still be improved. Encouraging farmers to avoid the build up of soil test P levels may still be needed. However, they may be faced with increased hauling costs to apply manure to more remote fields. Incentives and educational programs may be needed to achieve better management for P.

Requirements for storage can have a significant impact on manure management. Livestock operations that need to apply manure on a frequent basis will often have to apply manure during less than favorable conditions. These manure applications can result in soil compaction, loss of nutrients in manure, and exposure of the manure to risks of runoff losses. Requiring long-term storage facilities is a complex economic issue due to the cost associated with their construction. Cost sharing has been an effective way for helping farmers improve their manure storage facilities.

Further reducing environmental risks in manure management

Whole-farm nutrient management plans

The proper application of manure on a field-by-field basis will help reduce environmental risks and improve the efficient use of nutrients in manure. Further reductions in environmental risks may require the development of whole-farm nutrient management plans that will call for avoiding environmentally sensitive areas (VanDyke, et al., 1999). A whole-farm management strategy may involve seeking a nutrient balance in a livestock operation (Beegle, et al., 2000).

Improved P management

While there has been some discussion of P-based manure management plans, the requirement of such plans may cause considerable economic stress on many livestock producers. The use of tools like the P Index could be used to identify areas that pose the greatest environmental risks due to P. A P management strategy could be different on the areas identified.

Improved N management

In a similar way, achieving further reductions in environmental risks associated with N in manures may require the avoidance of sensitive areas of a farm. Development of an N index tool could be used to address concerns of N leaching through subsurface drainage systems (Heathwaite, et al., 2000).

Encouraging adoption of methods to reduce N and P contents of manures

Presently the use of phytase in swine feed is effective in reducing the P content of manure by about one-third. However, there is little financial incentive to use phytase at this time. There are new strategies in decreasing the P content of dairy manure as well. Non-regulatory methods may be helpful in increasing the use of phytase and the adoption of other strategies to reduce P in manure.

Reducing the risks associated with pathogens in manures

Considerable information is available on the risks of pathogens from manure getting into our food chain. While the risks are generally quite low, fresh fruits and vegetables that come in contact with soils that have received manure application may become carriers of pathogens. Methods for reducing these risks should be promoted where necessary.

Adjusting for new technologies

Policies need to be able to account for the development of new technologies in manure management. Changes in methods of feeding, processing manure, handling and applying manure, and soil and crop management may lead to new methods of reducing environmental risks and protecting soil properties. Policies should be flexible enough to adjust for these developments.

Reducing uncertainty in regulations

Livestock operation owners and managers express concern about the uncertainty and complexity of feedlot regulations. The number of levels of government and different agencies involved in obtaining permission to build or expand leads to confusion and frustration. In addition there are several ways that concerned citizens can make the process complex and time consuming. Improvements have been made in the feedlot rules, but more policy changes are needed to allow for the building or expanding of livestock operations while still ensuring that steps are taken to protect the environment and the interests of other rural residents.

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