1993 Project Abstract
FOR THE PERIOD ENDING JUNE 30, 1995
This project was supported by the MN Future Resources Fund

TITLE: Effective Manure Management in Conservation Tillage Systems for Karst Areas
ORGANIZATION: Dept. Of Soil, Water, and Climate, University of MN and the Agronomy and Planning Divisions of the MN Dept. Of Agriculture
LEGAL CITATION: M.L. 1993 Chapter 172, Sect.14, Subd.3(j) Agriculture:
APPROPRIATION AMOUNT: $500,000

Statement of Objectives:
A. Survey soil hydraulic properties, farmer practices, and computer simulated outcomes.
B. Determine the influence of landscape, soil type, and climate on nitrogen release from organic sources such as soil organic matter, alfalfa, and manure.
C. Determine the near surface stratigraphy (layering of glacial till and loess materials) in southeastern Minnesota.
D. Evaluation of manure management practices, which include manure applications and alfalfa in the rotation, in the context of soil conservation techniques for southeastern Minnesota.
E. Evaluate alternative methods for utilizing poultry mortality and analyze the environmental and economic benefits compared to other disposal methods.
F. Educational program.

Overall Project Results

The farm survey showed that farmers in southeastern MN have reduced "off farm" N inputs based on University of MN recommendations substantially. Ninety percent are following recommended best management practices. Nitrogen credits from organic sources offers the greatest uncertainy (due to the influence of climate during the growing season) and consequentially the greatest potential for improved management. It is evident from this survey that targeted educational programs need to continue to accelerate adoption of new technology and recommendations.

Manure applications were shown to improve water infiltration and reduce runoff in southeastern MN. The influence of crop residue was greater than manure application. This project also showed that the current "soil quality" indices need improvement to assess the changes due to manure applications.

Aspect and slope were shown to influence corn development, growth and amount of N released from organic sources. Several models were developed to account for the influence of aspect (regression and neural network).

Use of magnetic inductance resistivity (MIR) was evaluated for detection of the presence of residuum, glacial till strata, and loess thickness. This technique was successful at one site out of two. It is hoped that there may be potential for noninvasive sampling of near surface strata (<20 feet) with MIR to determine which N management guidelines are appropriate on a field scale. Success was limited.

Runoff plots were used to evaluate the Groundwater Loading Effects of Agricultural Management (GLEAMS) computer model. This model over predicted runoff early in the season and under predicted in the late season. Erosive losses of N and P from unmanured plots was close to predicted values. GLEAMS under predicted P from manured plots. This model will need more validation for southeastern MN conditions.

Waste wood and newspapers were found to be more economic carbon sources than straw for composting turkey mortality. Comparisons of compost, turkey manure, and urea N sources resulted in no differences in corn grain yield, quality, or weed density at two sites. Compost and manure was applied to seeding year alfalfa and evaluated for incidence of root rots at one site. There were no measurable differences.

Extrusion of turkey/chicken mortality was found to be viable as an alternative to composting. Extrusion with waste vegetable oil from restaurants, foxtail seeds from oat screenings, soybeans, and corn at varying ratios with dead birds showed that mixtures with high amounts of soybean and dead birds produced the product with the highest protein and fat content. The most economical mixture was with the second highest concentration of dead birds and soybeans combined with the lowest percentage of corn.

A team of county professionals lead by the MN Extension Service Educator had responsibility for the educational program (included the six counties in the karst area). The team included the Natural Resource Conservation Service, the Soil and Water Conservation Districts, and non profit organizations. The team implemented an intensive educational program by additional "on farm" demonstrations, field days, winter meetings, and dissemination of written materials through newsletters, papers, and publications.

Effective Manure Management in Conservation Tillage Systems for Karst Areas

LCMR Final Report - Summary - Research
M.L. 1993, Chapter 172, Section 14, Subdiv. 3(j) Agriculture

Department of Soil, Water and Climate
University of Minnesota

and

Minnesota Department of Agriculture

July 1, 1995

Date of Report: July 1, 1995

LCMR FINAL REPORT - Summary - Research

I. Project Title: Effective Manure Management in Conservation Tillage Systems for Karst Areas

Program Manager: Dr. John F. Moncrief
Soil Science Department
University of Minnesota
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A. Legal Citation: M.L. 1993 Chapter 172, Sect. 14, Subd.3(j) Agriculture This appropriation is from the future resources fund to the commissioner of agriculture for a contract with the University of Minnesota to investigate factors that influence losses of contaminants to surface and ground water.
Total Biennial LCMR Budget: $500,000 Balance: $0

B. LMIC Compatible Data Language: yes

C. Status of Match Requirement: not applicable

II. Project Summary: This project will be focused in the six county area in the southeastern part of Minnesota where ground and surface water quality is of concern. The soils are overlaying karst and sink holes in the area are numerous. This project will investigate controllable (such as tillage system and erosion control measures; manure and fertilizer source, application timing, and rates) and uncontrollable factors (such as soil type and climate) that influence losses of contaminants from agricultural activities to surface and ground water. There is also a large poultry industry in this part of Minnesota. Composting and land application of dead birds has shown promise as a cost effective method of disposal. This technique does need to be refined and evaluated in soil conserving farming systems in this area of the state however. The emphasis of this project will be on water, manure, and poultry mortality compost utilization in the context of the soils, landscapes, and cropping systems in southeastern Minnesota.

III. Statement of Objectives:
A. Survey soil hydraulic properties, farmer practices, and computer simulated outcomes.
B. Determine the influence of landscape, soil type, and climate on nitrogen release from organic sources such as soil organic matter, alfalfa, and manure.
C. Determine the near surface stratigraphy (layering of glacial till and loess materials) in southeastern Minnesota.
D. Evaluation of manure management practices, which include manure applications and alfalfa in the rotation, in the context of soil conservation techniques for southeastern Minnesota.
E. Evaluate alternative methods for utilizing poultry mortality and analyze the environmental and economic benefits compared to other disposal methods. F. Educational program.

IV. Research Objectives

A. Title of objective: Survey soil hydraulic properties, develop benchmarks of farm nutrient management practices, and generate computer simulated outcomes to be used in research and teaching.

A.1. Activity: Conduct an inventory of existing farmer practices that will supply real time-data inputs for models that can estimate leaching and surface runoff losses of nitrogen and phosphorus as well as aid in identifying or further refining best management practices.

A.1.a. Context within the project: Currently there is a shortage of information statewide on how farmers manage nitrogen and phosphorus fertilizers, organic N and P sources (manures, legumes) and other management criteria (such as timing of application, tillage, etc) which have an direct effect on water quality. This inventory will supply data inputs for computer simulation models and aid in identifying or further refining best management practices.

A.1.b. Methods. Detailed field by field nutrient management assessments for each selected farm will provide the specific information required for computer simulation efforts. Farmers will be asked to describe nitrogen inputs/management on a field by field basis for the past two cropping seasons. Site-specific soil type information will be collected from existing soil surveys or collected with the cooperation of the Soil Conservation Service. Manure analysis from each farm will assist in calculating a nitrogen balance.

Information will be grouped by geographic regions, soils and crops grown, as well as management factors. Data will be used to drive computer simulation modeling efforts elsewhere in the overall project. Establishment of "benchmarks" in current management practices will help in identifying future education directions.

A.1.c. Materials: Questionnaires and Extension Bulletins
A.1.d. Budget $43,000 Balance: $0

A.1.e Timeline

	7/93	1/94	6/94	1/95	6/95
Design inventory questions/forms	xx				
Data base programming.		xx			
Establish sampling populations.	xx				
One-on-one interviews		xx			
Summary, publication of results.				xx	

A.1.f. Status:

Current Nutrient Management Practices in Southeast Minnesota

Sixty-three farms, covering over 25,000 acres, participated in the **FA**rm **N**utrient **M**anagement **A**ssessment **P**rogram (**FANMAP**) with staff from the Minnesota Department of Agriculture. Producers volunteered 2-4 hours of their time to share information about their farming operation. Producers were carefully selected to represent a wide diversity of management skills and farm characteristics. The overall purpose of the program was to develop a clear understanding of current farm practices regarding agricultural nutrients and utilize this knowledge for future water quality educational programs.

Nitrogen management in this region of the state is challenging due to its karst topography, significant alfalfa acres, and high dairy density. Manure management is also confounded by the popularity of daily scrape and haul collection systems. Approximately 20% of the manure-N available for land application results from this type of system. This area has a high diversity of storage/collection systems, most of which provide some opportunity for storage. The process of manure crediting is greatly simplified with manure storage systems that allow for a minimal number of land application events. Approximately 75% of the N retained after storage originated from a variety of systems that allowed for some storage benefits.

Proper timing of N applications is one of the key management strategies that producers in this region can implement to minimize N leaching losses. In the last 5 years, producers have been encouraged to avoid fall application. FANMAP determined that fall application of N was extremely rare; spring preplant and starter N accounted for 90% of applied N fertilizer. Source selection of N fertilizers were also in excellent agreement with current BMPs developed by MES in conjunction with MDA. Over 90% of the N fertilizers were ammonium based products.

The overall N rate attributed from all three sources (fertilizers, legumes and manure) is a critical issue. Manure accounts for approximately 25% of the 'first year available' N; legumes account for another 25%. Obviously proper crediting of both of these sources is needed to successfully manage N in southeast Minnesota. On corn acres where no previous manure or legume credits existed to confound the rate selection process, producers appear to be in excellent agreement with recommendations that were made by UM/MES **four to five years ago**. Consequently due to the development of more conservative recommendations, producers were over-applying fertilizer inputs by 17 lb/N/A. Roughly 70% of the acreage in this particular scenario received N rates in excess of UM recommendations. Interestingly, the remaining 30% were significantly under-fertilized (-53 lb/A).

Overall, producers reduced N fertilizer inputs following "first year" alfalfa. However, additional reductions (50 lb/A) could be made with a low probability of yield loss. Producers also reduced N fertilizer inputs by approximately 20 lb/A for second year alfalfa; additional credits of 47 lb/A could be obtained by following research based BMPs. It appears that producers need the assessment tools for determining alfalfa stand densities and record keeping systems to aid in more effectively capturing alfalfa credits. Soybean crediting was almost non-existent, however, this crop occupied only 5% of the total cropland of the farms participating in the study.

Producers were basically reducing commercial N inputs by 45 lb/A in scenarios where previous manure applications were made to non-legume crops such as corn. Producers were under-estimating the value of the manure by approximately 40 lb/A. In southeast MN, it is a very common practice to apply manure to old alfalfa stands which are followed by corn in the rotation. In this scenario, producers were found to reduce their commercial inputs by approximately 70 lb/A. However the combination of alfalfa and manure credits, coupled with the fertilizer (average of 50 lb/A), resulted in over-applications of 80 lb/A. In these situations, only a starter N application should be applied and would trim 30 to 35 lb/N/A from the N budget. Producers could capture a much higher percentage of the "fertilizer replacement value" by applying the manure intoother corn rotations. Although 85% of the "first year" available N was applied to corn in this study, only 50% of the corn acres received annual applications of manure. From a water quality perspective, the most significant impacts could be made by improving the N crediting process in this particular cropping scenario.

In previously studies by the MN Extension Service, the nutrient value from manure has been found to be highly variable. Results from the 46 samples analyzed as part of this program were no exception. Manure testing needs continual promotion as a fundamental part of a nutrient management plan. Only 15% of the producers had tested their manure previously to this project.

There were some very positive findings from this study. There is strong evidence that producers are voluntarily adopting the educational materials and strategies developed by the University of Minnesota/MN Extension Service. It is also evident that promotional activities need to continue and be specifically targeted to deliver the most recent technology and recommendations.

A.2. Activity: To prepare an inventory of soil hydraulic properties in the context of surface runoff.

A.2.a. Context within the project: Rate of water entry plays an important role in the partitioning of rainwater into surface runoff and soil matrix flow. Because of the steep landscapes in the karst area, a significant quantity of rain water can runoff. The best management practice of the area should be the one that encourages less runoff and greater infiltration (interaction of water and surface applied chemical with soil matrix) to reduce contamination of both surface and subsurface waters. This objective will inventory the effects of tillage, earthworm macropores and surface seal on rate of water entry into several soils of the area.

A.2.b. Methods: Soil survey records and completed student theses will be searched for information on hydraulic properties of the soils in the area. For some of the major soils of the area where this information is lacking, tests will be undertaken in the field to characterize the rate of water entry using simulated rainfall. The data obtained under this objective will provide input to the models that simulate contaminant transport both in soils and in surface runoff.

A.2.c. Materials: Disc infiltrometers, rainfall simulator
A.2.d. Budget: $55,000 Balance: $0
A.2.e. Timeline:

	6/93	1/94	6/94	1/95	6/95
Inventory of soil properties	xxxxxxxxxx				
Field characterization of rate of water entry		xxxxxxxxxxxxxxxx			
Summary, publication of results				xxxxxxxxx	

A.2.f. Status: Earthworm macropores have been proposed as pathways for agricultural chemicals to move into the ground water through the shallow soils in the karst region of Southeastern Minnesota. In this area, manure application to the land is a common practice. It has also been suggested that soil health, or quality, will improve because of the organic carbon addition, and the increased earthworm activity. This study quantifies the effects of long term tillage and liquid dairy manure addition on infiltration and several soil quality parameters.

Soil physical properties were characterized on plots that have been under long term (12 years) continuous corn with two different tillage systems (no tillage and chisel plow) and two different nitrogen sources (liquid dairy manure and inorganic fertilizer). The experimental site is located near Red Wing in Goodhue Co., Minnesota, and the soil at this site is a Seaton silt loam (Typic Hapludalf, fine-silty, mixed, mesic).

Measurements included bulk density, organic matter content, infiltration rates, sediment yields, aggregate stability, and earthworm population. The infiltration rates for various tillage and N-source treatments were evaluated using a ponded infiltrometer, tension infiltrometer, and a rainfall simulator. Ponded and tension infiltration measurements were used to separate the macroporous flow from the matrix flow.

Ponded infiltration rates were significantly higher under chisel plow than no-till, but the effect was opposite with the rainfall simulator (higher infiltration rates under no tillage than chisel plow). Higher ponded infiltration rates in chisel plow were probably a result of increased soil porosity due to soil loosening; whereas higher infiltration rates in no tillage (no-till) under rainfall simulation were due to the presence of surface residues that minimized surface sealing. As a result of soil loosening, macroporous flow was also greater for the chisel plow treatment than the no-tilltreatment. Infiltration rates for plots that received manure were significantly higher than fertilizer plots for both ponded infiltrometer and simulated rainfall. Manure application resulted in significantly more macroporous flow than fertilizer, which was due either to the soil loosening associated with manure injection or to an increase in the number of earthworm macropores in the manure plots.

Earthworm populations were significantly greater in the no-till plots than in the chisel plow plots, but there was no statistical difference due to N-source. Spatial measurements of *Lumbricus terrestris* (nightcrawler) around the experimental site pointed to the lawn as the source of the nightcrawlers, which were found only in the third replication.

Statistically, neither tillage nor N-source were found to affect organic carbon content at 0-7.6 cm, a parameter often measured to quantify soil quality. Tillage affected bulk density at three depths (3-9, 15-21, and 27-33 cm), but there was no N-source effect on bulk

density at 15-21 or 27-33 cm depth.
Sediment production under simulated rainfall was greater in chisel plow than no-till, but there were no significant differences in sediment yield due to N-source. Similarly, aggregate stability was significantly lower in chisel plow than no-till plots, and there were no significant differences in aggregate stability due to N-source. It is concluded that tillage effects on soil quality are much more dominating than the effects of manure addition at the rates manure was applied in this study. Lack of statistical differences in earthworm populations and statistically higher macroporosity in manure compared to chisel plow treatment shows that earthworm population is not directly related to soil macroporosity as assumed in soil quality investigations. Furthermore, it is shown that the parameters for evaluating soil quality proposed in the literature are not effective in quantifying the differences in soil quality between management practices because of the dominating effects of climate, soil variability, and the soil-atmosphere boundary conditions such as the presence of residue or plant canopy cover on various soil quality goals.

A.3. Activity: To calibrate/validate the simulation model NCSWAP on experimental data documenting the effect of manure and tillage on continuous corn in the Karst areas of MN. To use the model to situations outside the bounds of the experimental plots.

A.3.a. Context: The extent of N mineralization from soil organic matter and manure depends on soil, landscape and climatic conditions. A simulation model will be used to give credence to the scientific approach in the eye of the field practitioners, and allow explanation of the localized observations in reference to quantitative and general relations.

A.3.b. Methods: The model NCSWAP will be calibrated to account for the data collected in Goodhue county from 1982 to 1990, to study the long-term effect of tillage and liquid dairy manure application on nitrogen availability to corn. Working with project members familiar with management conditions in the karst areas, simulations will be developed to illustrate the relationships between changes in management practices and their likely environmental outcomes.

A.3.c. Materials: Data from the long-term manure study are readily available. The simulation model NCSWAP is available and has been extensively tested. Computers are available.
A.3.d. Budget: $15,000 Balance: $0

A.3.e. Timeline:	7/93	1/94	6/94	1/95	6/95
Calibration	xxxx				
Collection and simulation of anecdotal situations	xxxx				
Preliminary evaluation	xxxx				
Evaluation				xxxxxxxxx	

A.3.f. Status: The model NCSWAP was modified to simulate multi-year cropping. The multi-year version of NCSWAP requires one input file to specify the soil initial conditions; and yearly, 5 input files which contain the driving variables: climatic (rainfall; soil and air temperature; pan-evaporation); crop (crop kinetics under no water and N stress; degree days to maturity); and management (date, amount, and type of inorganic and organic additions; date and depth of tillage; date of crop emergence and harvest). Experimental data documenting 8 year (1982-1990) of continuous corn for 5 contrasted treatments - (1) zero-N; (2) fertilizer (117 kg N-NH4 plus 117 kg N-NO3 .ha-1 annually); and liquid dairy cattle manure (153 kg N-inorganic plus 135 kg N-organic .ha-1, C/N=20) injected in soil (3) annually; (4) biennially; and (5) triennially - were used to validate the model.

Simulated data accounted for the differences in yield observed between treatments. Yield differences from year to year were reproduced by simulation for the biennial and triennial treatments. The overall decline in yield observed from 1982 to 1990 for the triennial manure treatment was also simulated by the model.

The half-life of the organic fraction of the liquid dairy manure was set to 115 days (.006 day-1, decay rate). It corresponded to the value obtained in another study for the organic fraction of solid beef manure.

Simulation was used to estimate the rate of fertilizer addition which would compensate for yield decline in between years of manure triennial applications. Yields responded marginally to changes in air (2°C) and soil (5°C) temperatures

B. Title of Objective: Determine the influence of landscape, soil type, and climate on nitrogen release from organic sources such as manure and soil organic matter.

B.1. Activity: Field experiments to assess slope aspect, soil, and weather impacts on nitrogen release from organic sources.

B.1.a. Context: Variable soil slopes and climatic conditions in the Karst topography of South East Minnesota can affect nitrogen release from organic sources and uptake by plants by causing differences in soil temperature and moisture. Soil and climatic measurements on different aspects will be used to validate a predictive model of soil temperature and moisture, and statistically relate aspect effects to plant available N and yield goals. Results will be used to develop probability distributions for N availability and yield goals based on aspect and weather.

B.1.b. Methods: Field plots will be laid out on contour strips of north and south facing slopes on either side of a ridge. Treatments will consist of two aspects (north versus south) x three N sources (dairy manure applied in the fall, anhydrous ammonia applied in the spring, versus control) x tillage treatments outlined in Objective D. Soil temperatures and moisture will be measured at the 1, 15, 30, and 60 cm depths using heat dissipation sensors. Microclimate (air temperature, relative humidity, radiation, rainfall, and wind speed) will be recorded by data logger monitoring stations on each aspect. Time series analysis (cf. Krupa and Nosal, 1989) and process-oriented simulation models (Campbell, 1985) will be used to relate plant available N and microclimate to optimum sidedress N applications. The process-oriented model will first be calibrated on data from eight years of manure treatment on plots of different aspects (Joshi, 1992). Results from these analyses will be used to generate qualitative and/or quantitative schemes for utilizing weather to determine optimum sidedress N applications on plots of differing aspects.

B.1.c. Materials: Field sensors, sensor monitoring equipment, and computer support will be needed to carry out this objective. Investigators will provide computer equipment for the project.

B.1.d. Budget: $60,000 Balance: $0

B.1.e. Timeline:	7/93 1/94 6/94 1/95 6/95
Establish treatments	xxxx
Collect data	xxx xxxxxxxx xxxxxxxx
Prepare annual summary	xxxx
Soil modelling	xxxxxxxxxxxxxx
Time series analysis	xxxxxx xxxxxx
Prepare final report	xxxx

B.1.f. Status: B.1.1 Field measurements
The 1994 growing season were generally favorable for crop growth. Soil temperatures on the North-facing slope were colder than the South-facing slope. This was associated with much wetter soil conditions on the North-facing slope. These wet, cool conditions on the North aspect contributed to poorer growth. This was exhibited early on in the growing season. Corn development on the North aspect lagged behind development on the South aspect throughout the season.

Plant available nitrogen (PAN) was significantly greater on the North aspect. Season average plant available nitrogen was 12 ppm on the North slope and 10 ppm on the South slope. Ammonium contributed very little to plant available nitrogen indicating that soil testing for nitrate alone is sufficient to characterize PAN.

Overall grain yield on the South aspect was 12 bu/ac higher than that on the North aspect. The higher yields on the South aspect were associated with greater growth and development and higher plant N uptake. This was reflected in the lower residual plant available N in the soil prior to tasseling on the South aspect.

The N treatment effect on grain yield exhibited the same pattern as its effect on PAN. As with PAN, yield on the control plots were significantly lower than manure or fertilizer treatments. Yields within a treatment were consistently higher on the South aspect. Yields among N treatments on both aspects and the manure treatment on the South aspect were not significantly different. The yield depression on the North aspect was much less for the Fertilizer treatment than for Control or Manure treatments. Since all nitrogen in the Fertilizer treatment was available when applied, this indicates that nitrogen mineralization from soil organic matter and manure was less on the North aspect.

B.1.2 Soil modeling and time series analysis
Based on the microclimate, topographic and experimental data, two models were developed. One is a multiple regression model. Another is a neural network model. Nitrogen availability can be predicted by

these models. We found that the sum of growing degree days, temperature at the depth of 60 cm, moisture in 60 cm depth, aspect, and fertilizer treatment were good predictors of plant available nitrogen.

Using multiple linear regression analysis, we found that soil temperature and moisture at the 60 cm depth were more important in predicting PAN than corresponding measurements at 15 or 30 cm. However, we do not think that this is evidence that most of the N mineralization is occurring at the 60 cm depth. Rather, we suspect that the transport of PAN to 60 cm is correlated with the transport of heat and moisture from the surface. Therefore, N mineralization near the surface is probably highly correlated with temperature and moisture near the surface, but the appearance of PAN at depth is correlated with the time lag associated with heat and moisture transport from the surface.

In addition to the multiple linear regression model, we also analyzed the availability of nitrogen using a neural network model. Neural networks represent a relatively new modeling technique, therefore a brief review follows.

A three-layer neural network structure was used in this study. Nine variables: soil temperature (15cm, 30 cm, 60 cm depths), soil matric suction (15cm, 30cm, 60cm depths), cumulative growing degree days (base 10°C), aspect, and N treatment (Control, Manure, Fertilizer) were used as predictors. Both PAN and nitrate alone were well predicted using the neural network approach, and are much better than the regression model.

Slope aspect affects plant available nitrogen and grain yield through its effect on microclimatic factors such as air temperature, soil temperature, moisture, cumulative growing degree days, and solar radiation. We found that GDD, T60 and M60 are the best predictors of PAN based upon results from both the neural network and multiple regression analysis.

Nitrogen treatment also affects PAN and has a significant effect on grain yield. However, grain yield is not significantly different between Manure and Fertilizer treatments on slopes with a southern aspect. The same trend was also observed for PAN.

Comparing the neural network model and multiple regression model, the neural network yields better predictions of PAN. The strength of the variables used in both models are about the same. Thus, the best indicators in neural network model were also the best predictors in the regression model. A drawback of the neural network model is that the rules governing the model response cannot be extracted from the computer code. The neural network remains a 'black box' which limits its portability. In contrast, the regression model can easily be described by an equation although it does not predict the data as well as the neural network.

Both models indicated that temperature and moisture at the 60 cm depth are good predictors. The exact reasons for this are not clear since we expect most mineralization to occur nearer the surface. We propose that N mineralization near the surface is probably highly correlated with temperature and moisture near the surface, but the appearance of PAN at depth is correlated with the time lag associated with heat and moisture transport from the surface.

C. Title of Objective: Near surface stratigraphy:

C.1. Activity: This portion of the project will determine the near surface stratigraphy at sites selected for this project at a scale suitable for on-farm management of manures. Layers of glacial till, clayey residuum, and/or other materials are sometimes present between the surficial loess and the underlying karst in many areas of southeastern Minnesota. These layers are often nearly impermeable to waters leaching through the soil. The presence of these layers drastically alters the flow paths and subsurface hydrology of sites, which strongly influences the fate of manure-applied nitrogen. Current methods of determining the presence and extent of these materials are too time-consuming and expensive to be used to map the subsurface stratigraphy at a scale suitable for on-farm management.

C.1.a. Context within the project: This portion of the project will provide information regarding the presence of subsurface layers of glacial till, residuum, and other materials which may lie between the loess and the underlying karstic bedrock. These layers strongly influence the flow paths for soil moisture and the subsurface hydrology between the loess and the karst.

C.1.b. Methods: Subsurface stratigraphy of study sites will be assessed using magnetic inductance resistivity (MIR). This technique is a non-destructive geosensing technique that measures the electrical resistance of soils and sediment.

Study areas will be gridded and MIR measurements will be taken at each grid point. The location of grid points will be determined using a geographical positioning system (GPS), which is based on satellite technology. Soil and sediment cores will be taken at a smaller number of grid points using a truck-mounted soil probe in order to determine the exact nature of the materials underlying the karst. The stratigraphy observed in the cores will be used to verify the MIR measurements. A map of the underlying subsurface materials will be produced for use in other parts of this project.

C.1.c. Materials: The main equipment needed for this project is a magnetic induction resistivity meter. The other equipment (a truck-mounted soil probe, a geographical positioning system ground station, and a GIS system) are all owned by the U of M Soil Science Department.
C.1.d. Budget: $45,000 Balance: $0
C.1.e. Timeline: 7/93 1/94 6/94 1/95 6/95

Selection of Field Sites	xxxxxxxx
MIR measurements	xxxxxxxxxxxxxxxxxxxxxxx
Probe truck coring	xxxxxxxxxxxxxxx
Development of GIS database	xxxxxxxxxxxxxxxxxxx
Final reporting	xxxxxxxxx

C.1.f. Status:
The purpose of this portion of this project was to determine the near surface stratigraphy at two research sites within the karst region of southeastern Minnesota (Sikkink) and southwestern Wisconsin (Lancaster). For each site, a three dimensional spatial database of soil strata was constructed at a detailed (~ 1:10,000) scale for interpretation of hillslope water movement within the unsaturated zone. The near-surface stratigraphy of each site is Wisconsinan aged loess over clayey residuum over karstic limestone or dolomite. The thickness and presence of each strata varied considerably, depending on landscape position and study site. The residuum has a very low permeability and is the most important strata for implications on hydrology. At the Lancaster site, it is found on 90% of the hillslope. It is thickest on summits and interfluves. At the Sikkink site, the residuum is thin to absent over the majority of the hillslope. It occurs on stable summits and flat portions of the underlying bedrock topography. The spatial variability and thickness of the residuum can control the residence time and flow paths of water within the vadose zone. In thin or absent residuum, water containing high nitrate concentrations can be transmitted directly into aquifers. The efficacy of magnetic inductance resistivity (MIR) as a means of rapidly determining the thickness and depth of each near-surface stratigraphic unit was investigated. Correlations between measured and MIR-predicted strata thickness were highly variable between the two sites. At the Sikkink site, correlations for loess thickness along 6 transects were significant ($0.64 < R^2 < 0 .94$, $a = 0.01$), but only one was significant for the residuum ($R^2 = 0.54$, $a = 0.01$). The Lancaster site produced no significant correlations.

D. Title of objective: Evaluation of manure management practices in the context of soil conservation techniques for southeastern Minnesota.

D.1.a. Activity: The focus of this study is to quantify the interactions of manure and tillage on nutrient (nitrogen and phosphorus) loading of runoff water for the karst areas of Minnesota.

D.1.b. Context within the project: Dairy and beef cattle are an important part of the economy in the karst area. Manure application to land is also an important management practice and generally manure is surface applied daily. Most of the soils have developed in loess and are underlain by fractured dolomitic bedrock. This silty loess material varies in thickness from .3 to over 6 meters. The terrain is rolling to steep and farming is done on contour strips. Chisel plowing and ridge tillage are common tillage systems. If manure is not incorporated there is danger of excessive runoff losses from manure supplied nutrients. This study will identify the best combinations of tillage type to minimize soil erosion and nutrient loss.

D.1.b. Methods: The experiment will quantify sediment loss and the nutrient loading (N and P) of surface runoff from 21m x 3m plots. Treatments will include two tillage (chisel and ridge tillage) systems; and two manure sources (poultry and dairy). The crop will be continuous corn and will be replicated twice. Plots will be isolated with corrugated steel borders. Sediment and runoff water will be collected on an individual storm basis.

The runoff, sediment and nutrient loading data will be used to test a field scale model that will provide a tool to identify the management practices for other soils and slope conditions that will minimize sediment and nutrient loading of surface runoff.

D.1.c. Materials: Corrugated steel edging, 225 l barrels, PVC pipe, pumps, automated sampler, reagents, and glassware for chemical analysis.

D.1.d. Budget: 100,000 Balance: $0

D.1.e. Timeline: 7/93 1/94 6/94 1/95 1/95 6/95

Selection of field sites	xxxx
Establishment of treatments	xxxx
Collection of data	xxxxxxxxxxxxxxxxxxxxxxxxxxxx
Validation of computer model	xxxx
Extrapolation to other situations	xxxx

D.1.f. Status:
A study was undertaken in 1994 to measure the runoff and associated sediment and nutrient's losses in Goodhue county of Southeastern Minnesota. The soil is Seaton Silt Loam and has 12 percent slope. Four (10' X 70') runoff plots were set up in a no till field which has standing corn residues from a previous year. Liquid Hog manure was applied in plot one and three and urea was applied in plots two and four. A corn crop was grown in the plots.
The GLEAMS (Groundwater Loading Effects of Agricultural Management System) model was used to simulate runoff and associated nutrients' losses for four experimental plots set up in Goodhue County. Since it was a year study only, storm by storm runoff and nutrients simulation option was chosen. The model run needs six input files which include a daily precipitation data file, average daily temperature file, hydrology parameter file, erosion parameter file, nutrient's parameter file, and pesticide nutrients file.
Daily rainfall records measured by an electronic raingauge at the experimental site were used to create the precipitation data input file. The average daily temperature and other climatic data were acquired from continuing long-term weather records at near by weather station. The detailed information on soil type and properties were collected from soil survey reports. The crop information, nutrients and pesticide input were derived from the detailed log book of the field work.
Except for plot four, the model under predicted the runoff for the first half of the season but over predicted for second half of the season. This could be due to the fact that the model did not consider the surface sealing because of the residue presence and allowed more infiltration in the beginning of the season. Cultivation was performed in the middle of the season which resulted in increased infiltration and less measured runoff. The model did not consider the effect of cultivation and over predicted the runoff in later half of the season. Plot four had unusually high runoff during the season so the model predictions are lower than the measured runoff.
Since the total nitrogen predicted by the model depends on the runoff, the model predictions for total nitrogen are less for the first half of the season and more for the second half of the season. For the fertilizer treatment plots, model predictions for total nitrogen are more close to the measured values. For manure treatment plots, the model under predicted the total nitrogen in the first half of the season and over predicted the total nitrogen in second half of the season.
The model under predicted the total phosphorus in manure treatment plots. The total phosphorus predictions are close to measured values for fertilizer treatment plots except in the second of season of the plot four which had unusually high runoff.

E. Title of Objective: Evaluate alternative methods for utilizing poultry mortality and analyze the environmental and economic benefits of the compost as a nutrient source compared to other disposal methods and compared to raw manure and purchased fertilizers.

E.1.a. Activity: Evaluate the economic and environmental potential for various carbon sources in the composting of poultry mortality. This will also be compared to other disposal methods.

E.1.a. Context: As manure is examined for effective usage back into various agricultural production systems, so should the application of other livestock production by-products such as mortality and various rural and urban carbon sources.

E.1.b. Methods: Various carbon sources/bulking agents will be used to evaluate their effect and the economics of composting of dead birds. Temperatures monitoring and testing of the final product and visual appraisal will provide information on odors, pest problems, killing of pathogens and nutrient content and stability of the final product. Grinding of the carcasses will be evaluated for enhancement of cold weather composting.

E.1.c. Materials: Materials used will be the producers bin composting site, various carbon sources (newspaper, sawdust, poultry litter, leaves), and thermometers to monitor biological activity, data collection sheets and sample containers.

E.1.d. Budget: $29,000 Balance: $0

E.1.e. Timeline:	7/93	1/94	6/94	1/95	6/95
Design substrate test	xxxx				
Set-up bin compost sites	xxxx	xxxx	xxxx	xxxx	
Monitor/test sites	xxxx	xxxx	xxxx	xxxx	
Evaluate/redesign test		xxxx		xxxx	xxxx
Data summary				xxxx	

E.1.f. Status: Standard bin composting of turkey mortality has used turkeys, turkey litter and straw layered to achieve a 20:1 carbon:nitrogen ration and approximately 60% moisture. Chopped newspaper, wood mulch and leaves were compared to the standard procedure to replace the straw as a carbon source to lower the cost of composting. Based on data and observation, newspaper and wood mulch appear to be acceptable substitutes for straw for quality of compost and are better than straw economically - waste newspaper and wood are generally free - transportation to the composting site is the only expense. Data is being collected from the third comparison using leaves. All alternative carbon sources were In the newspaper/straw comparison, composting temperature in the primary bins were 140 degrees in the newspaper treatment and 150 degrees in the straw treatment; however, after turning the compost into the secondary bin, the newspaper compost rose to 160 degrees while the straw compost rose to 155 degrees. These measured temperatures are adequate to kill pathogens. There were no pest or odor differences between the treatments were observed. There was no seepage from either treatment. The newspaper compost was noticeably easier to turn. Nutrient tests showed no significant difference between straw and newspaper compost for total N or organic N, phosphorus or potassium. The straw compost had 67% of the total nitrogen content in an organic form and the newspaper compost had 74% of the total nitrogen in an organic form. The higher the percent in an organic form, the smaller the amount readily available for leaching or volatilization. Newspaper used for composting turkey mortality could be done at about 65% of the cost of using straw.

In the second comparison, waste wood mulch from a recycling center was substituted for straw in the compost. Nutrient tests comparing the straw and wood compost and the raw manure (unadjusted for moisture) showed a significant reduction in moisture content through composting as expected, higher total N and organic N in the composts, slightly more nitrogen in the organic form in the straw compost, and comparable levels of phosphorus and potassium in all three samples.

No salmonella or staphylococcus bacteria were detected in any treatments.

Results of these comparisons have been used by the cooperators at Jerome Foods to make recommendations to their turkey facility managers.

Extrusion of turkey/chicken mortality was investigated as an alternative to composting. Extrusion cooks, sterilizes, dehydrates and texturizes by creating heat through friction. Extrusion adds value to this waste product in combination with other low value materials and grain which can then be used as a small portion of the ration for ruminant animals. The extrusion process creates enough heat to dry out the product several percentage points so that is has a longer storage life and to kill most pathogens that could be a problem in the dead birds.

Several combinations varying the ratios of dead birds (ground to 1/2 inch pieces), soybeans, corn, foxtail from oat screenings and used vegetable oil from restaurants were used to determine the best mixtures for the extrusion process and for the , moisture and nutrient content and pathogen kill in the final product. The finished product in each combination was tested for microbiological organisms especially those pathogenic organisms of particular interest to the poultry producers (Salmonella and Pasteurella) as well as for feed value - moisture, crude protein, fat, crude fiber, total ash, calcium and phosphorus. The results from the microbiological testing are pending and will be submitted when received from the University of Minnesota - Department of Veterinary Pathobiology.

Four mixtures were tested in the first experiment and nutrient testing indicated highest protein and fat levels in mixtures with the highest percentage of dead birds and soybeans in the mixture and comparable TDN, fiber, ash, calcium and phosphorus in all mixtures.

The nutrient value in dollars of the end product on a protein and energy basis was calculated for 2000 pounds of each mixture based on the nutrient tests and using standard protein and TDN content and current prices for soybeans and corn, respectively. The two mixtures with the highest percentage of dead birds and soybeans had the highest total value based on nutrient content. When the cost of producing the extrusion product including cost of ingredients and labor, and equipment costs was calculated and subtracted from the value of the nutrients to determine the net value of the end product, the mixture with the second highest percentage of dead birds, soybeans, and lowest percentage of corn showed the highest net value.

Initial observations of the extrusion process and final product were used to fine tune. Moisture levels of 29% or above for the raw ingredients entering the extruder were too high and did not allow theextruder to reach optimal temperatures for pathogen elimination and for a drier end product. Also, at that moisture level, the extruder did not auger well. Also, grinding the corn for the mixture increases the surface area which changes the consistence of the mixture and improves the mixture for use in the extruder. The extrusion products produced in these experiments were fed to hogs without feed refusal.

E.2. Activity: Evaluate the agronomic and environmental impact of compost application to agricultural land.

E.2.a. Context: Composting will tighten up the cycle of livestock waste production, management, and reutilization with the potential to reduce feedlot waste pollution and agricultural non-point ground and surface water contamination. The project will reinforce the value of composting for stabilizing nitrates and other leachable elements from farm wastes and making use of community generated wastes as carbon sources.

E.2.b. Methods: On-farm plots (same cooperators identified in Objective F.1) will be established comparing compost and raw manure, in cooperators' existing crop rotations. Raw manure will be applied at recommended rates and compost at 75, 100 and 120% of recommended rates.

E.2.c. Materials: i) farm equipment, seed, manure supplied by farm; ii) sample bags, nutrients tests; iii) scales to determine application rates and yields, suction tubes, data collection sheets.

E.2.d. Budget: $40,000 Balance: $0

E.2.e. Timeline:	7/93	1/94	6/94	1/95	6/95
Identify Cooperators	xxxx				
Design Demonstrators	xxxx				
Design Data Collection Sheets		xxxx		xxxx	
Implement Demo and Collect Data			xxxx		xxxx
Field Tours	xxxx		xxxx		
Prepare Data Summary		xxxx			
Farmer Workshops		xxxx		xxxx	

E.2.f. Status: Three demonstrations were designed and planted. Siemon Farm: A demonstration was set up on a silt loam soil on the Siemon turkey farm at Altura. Treatments applied prior to fall tillage for corn production included: manure in the form of turkey litter applied at the U of M recommended rate using a two foot nitrate test; compost including dead birds using same N criteria as manure; and a commercial fertilizer, urea, as control was applied in the spring. Treatments were replicated three times. A fall soil test was taken 10/18/93.

Compost, turkey manure and urea were applied at 4 tons, 6 tons and 350lb per acre, respectively, and yield, moisture and test weight were taken when the corn was harvested (10/17/94). There were no significant differences among the treatments for yield, grain moisture or test weight, weed pressure, insects, lodging or color of the crop during the growing season. Nutrient tests of the compost and manure showed higher total N in the compost with more of the nitrogen in the organic form.

Lingenfelfter Farm: A similar design was used for the demonstration at the Lingenfelter farm at Dover to represent a sandy loam soil. Three replications of three treatments compared urea, compost and manure applied to chisel plowed corn stalks in the spring. A fall soil test was taken 10/18/93.

Compost, turkey manure and urea were applied at the 4.9 tons, 6.4 tons, and 390 lb. per acre, respectively, and yield, moisture and test weight were taken when the corn was harvested (11/7/94). There were no significant differences among the treatments for yield, grain moisture or test weight, weed pressure, insects or color of the crop throughout the growing season. At harvest, the compost and manure treatments had approximately 1.5 lodged stalks per 1000 ft. of row while the urea treatment had approximately 6.0 lodged stalks per 1000 ft. of row. However, this difference did not affect yields because the combine was able to pick up lodged stalks. In this comparison of compost and manure from the Lingenfelter farm, the total nitrogen was comparable with slightly more nitrogen in the organic form in the manure - this may indicate inadequate composting.

Meyer Farm: A demonstration site was planted to study the effect of manure and compost on incidence of root rot pathogens in new seeded alfalfa.

Treatments replicated three times included control plots (chemical fertilizer applied at U of M recommended rate for alfalfa production), plots receiving 154 lb. available nitrogen per acre in the form of 2.7 tons of turkey manure/acre and plots receiving 265 lb. available nitrogen per acre in the form of composted turkey manure and carcasses. Compost and manure for these plots were taken from the

Siemon farm. Compost quality for this site was not good. There was adequate biological activity to kill turkey disease pathogens but notenough to stabilize nitrogen or reduce odor. Only 70% of total nitrogen was in the organic form and the bad odor indicated fermentation instead of aerobic digestion. The alfalfa stand was inspected and evaluated for root rot diseases in July and August. Disease incidence in the field was negligible across all treatments. Alfalfa yields were not significantly different among the treatments.

F. Title of objective: Educational program

F.1. Activity: Disseminate information gathered in objectives A through D with "on farm" demonstration, field days, winter meetings, and publications.

F.1.a. Context within the project: An information dissemination program will be focused in the six counties of southeastern Minnesota where soils overlay karstic topography. This will allow rapid technology transfer from this project to agency field staff and farmers.

F.1.b. Methods: The core of this educational program will be demonstrations on cooperating farmer fields. Demonstrations will have replicated manure management/conservation systems. Crop response will be characterized and data will be organized in tables to illustrate significant treatment responses.

F.1.c. Materials: A vehicle will be purchased to allow for transportation to cooperating farms in the six counties in this project. It will be necessary to visit demonstration sites A freezer and oven will be purchased to store manure, soil, plant, and water samples or dry soil and plant tissue samples at a site located central to the study area until they can be transported to the St. Paul campus of the University of Minnesota for chemical analysis.

F.1.d. Budget: $63,000 Balance: $0

F.1.e. Timeline:

	7/93	1/94	6/94	1/95	6/95
Identify Cooperators	xx				
Design Demonstration	xx				
Establish Treatments	xx				
Monitor Crop Response	xx		xx		
Field Tours	xx				
Organize Data		xx		xx	
Winter Meetings					xx
Publication					xx

F.1.f. Status: In 1993 seven studies on five farms in southeastern Minnesota were used to evaluate integration of manure into residue management systems. Aspect and timing of alfalfa kill dramatically affected no till corn growth and yield. There were relatively small differences in early growth and development of both corn and soybeans under high residue systems. The growth delay persisted through flowering and physiological maturity. Yield differences due to N source and tillage were variable.

Field days were held at three sites. Three winter meetings were also held. The information gathered from these demonstrations was also disseminated in written summary form and in news letters.

In 1994 tillage and N source were evaluated for corn and soybean production on four farms in southeastern MN. Generally "in row" cover with corn or soybean residue reduced corn development. Soybean growth was slowed in some instances but no yields. Tillage had variable effects on grain yields. Manure generally resulted in increased early growth and development compared to commercial fertilizer.

Field days and winter meetings were held at two sites. Again, the information gathered from the demonstrations in 1994 was also disseminated in written summary form and in news letters.

F.2. Activity: Develop and implement a soil fertility management component to educate farmers about the value of on-farm nutrient sources.

F.2.a. Context within the project: On-farm nutrient sources have often been under utilized. Individualized development of plans with farmer peer follow-up and support has proven very effective in accelerating changes in agricultural practices. This technique will be utilized in this effort.

F.2.b. Methods: Manure management field days in the six targeted counties will provide basic information on sampling, testing, calibration, and distribution of manures and composts. These will be held in conjunction with the on-farm demonstrations in Activity F.1 above, where possible. Workshops involving extension, SCS, SWCDs, farming associations, and agricultural specialists, will assist participating farmers in developing soil fertility management plans using the data that they have collected.

F.2.c. Materials: Sample containers for manure and soil, use of existing assorted laboratory equipment for analyzing soil and manure samples, scales for determining manure application rates, data forms, paper sheets for manure calibration, field markers, tape measure, other plot related miscellany, fact sheets, field maps and advertising flyers.

F.2.d. Budget: $50,000 Balance: $0

F.2.e. Timeline:

	7/93	1/94	6/94	1/95	6/95
Design soil fertility packets		xxxx			
Manure management field days/ distribute packets				xxxx	
Workshops/Develop individual plans		xxxx		xxxx	
Implementation support		xxxxxxxxxxxxxxxxxx			
Evaluation/redesign/case study		xxxxxxxxx		xxxxxxx	

F.2.f. Status: Soil fertility packets were designed and assembled and distributed to and through local NRCS and SWCD staff trained in nutrient management in cooperation with a Section 319 USEPA grant. Farm nutrientmanagement packets include information on how to take nutrient credits for manure, legumes, crop rotations, and organic matter, soil and manure sampling and spreader calibration instructions and data sheets to record specific information for their operation such as cropping history, soil type, soil test history, legume plant population, manure analysis, yield potential, etc. Approximately 30 people attended the first 2-day training seminar in Rochester last winter (1994). Initial participant evaluations indicated the need for additional training to increase confidence to begin training and working with farmers to development nutrient management plans.

Additional surveys were sent out this fall (1994) to facilitate more specific planning of winter events to meet local ag-professionals' training needs. (Survey included in Appendix). Based on the survey, sessions this winter (Feb. 1995) provided additional skill training (how to do manure workshops, calibration, communication skills, manure planning software, etc.) to field staff and local government staff from eleven counties. (Meeting agenda, presenters, training evaluation, etc. included in the Appendix). These local trainers received audio-visual materials (slide sets on nitrogen BMPs and fertilizer basics and videotapes on manure calibration and application) to supplement farm nutrient management packets for use at farmer workshops and field days planned for this spring and summer. Nutrient management packets including easy-to-use laminated reference guides have also been distributed at conferences, workshops, farm shows, field days, etc. throughout the state. Almost 1,000 packets and 3,000 laminated swine manure guides were distributed. Nutrient management informational display materials were distributed to trainers to use at farm shows, meetings, at field days and other events. Packets and slide sets have also been distributed for use by farm services companies for use in the client training workshops. Additional training on-site in county offices in the use of Manure Application Planner (MAP) software is scheduled for this summer.

V. Evaluation: Each individual objective will be evaluated on how well each achieved specific research and educational goals. Evaluation of the overall project will be obtained by feed back from field staff as to the amount of changes in farmer practices which have impact on contamination of ground water with agricultural chemicals.

VI. Context within Field: The soils and landscapes of the karst topography in southeastern MN pose unique problems for environmentally sound crop production. The soils are steep and prone to crusting which makes water runoff likely. Management of water in the context of manure applications is important for farmers. The potential for environmental degradation with the N and P associated with water movement over the surface or through these thin soils is high.

Improvement of recycling methods of waste (dead birds and manures) are important to make farming systems more environmentally and economically sound.

The effects of management options on soil water and nitrate movement in conjunction with regional conditions will be used to improve the BMPs in southeastern Minnesota.

VII. Benefits: This project will provide data that will allow a risk assessment based on soils and climate. This in conjunction with BMP recommendations for managing water and manure will reduce inputs and environmental contamination. The most valuable resource benefit to Minnesota is the potential impact on reduction of agricultural chemical losses to groundwater.

VIII. Dissemination: This project has an objective devoted entirely to technology transfer and information dissemination. In place field based staff of the Minnesota Extension Service, the Soil Conservation Service, Soil and Water Conservation Districts, and the Minnesota Department of Agriculture will be responsible for information dissemination with participation from state based staff.

IX. Time: This information generated from this project will be limited by its one biennium time frame but never the less yield much useful data.

X. Cooperation: Active participants cooperating include nine faculty at the University of Minnesota, five specialists at the Minnesota Department of Agriculture, and seven county Extension agents. There will also be input from the Minnesota Association of Conservation Districts and the Minnesota Pollution Control Agency.

A. **Dr. Jay C. Bell**, Remote Sensing/Soil Classification Specialist, will be responsible for the Geographic Information System/Geographic Positioning System dimension of the stratigraphy effort (3% time commitment on objective C).
B. **Dr. H.H. Cheng**, Soil Biochemist, Soil Science Department, UM, will participate in the evaluation of management practices and use of alternative methods and sources of N on water quality (objectives B and D, 5% time commitment).
C. **Dr. Satish C. Gupta**, Soil Physicist, Soil Science Department, UM, will provide leadership in the water flow modeling and field validation effort (objectives A.2. and D, 5% time commitment).
D. **Dr. Jean A.E. Molina**, Soil Microbiologist, Soil Science Department, UM, will provide advice on the N transformation dimension of several objectives and have primary responsibility for the computer modeling effort in objective A.3 (5% time commitment).
E. **Dr. John F. Moncrief**, Extension Soil Scientist, Soil Science Department, UM, will advise on the field demonstrations and provide input on all objectives (time commitment 10%).
F. **Dr. Ed A. Nater**, Soil Chemist/Mineralogist, Soil Science Department, UM, will provide expertise in the application of magnetic inductive resistivity techniques for stratigraphic sequencing (objective C, 3% time commitment).
G. **Dr. Sally Noll**, Animal Scientist, Animal Science Department, UM, will provide leadership in the turkey mortality composting and the manure utilization dimensions of objectives D, E, and F (5% time commitment).
H. **Dr. Clive F. Reece**, Atmospheric Soil Physicist, Soil Science Department, UM, will provide leadership in the water flow modeling and field validation effort addressing climate and soil effects on N crop available N (objective B.1., 10% time commitment).
I. **Dr. Mark W. Seeley**, Extension Climatologist, Soil Science Department, UM, will provide leadership on the climatic influences on conditional probabilities for field working days and leaching losses of contaminants (objective B.1., 5% time commitment).
J. **Dr. Ward C. Stienstra**, Extension Plant Pathologist, Plant Pathology Department, UM, will provide expertise in the evaluation of compost effects on nemetode activity (objective E, consulting basis).
K. **Mr. Bruce R. Montgomery**, Special Projects Coordinator, Minnesota Department of Agriculture, will have primary responsibility for the farming practices survey (objective A1. 4% time commitment).
L. **Mr. Doug J. Gunnink**, On-farm project coordinator, Minnesota Department of Agriculture, will have primary responsibility for coordination of the poultry mortality-composting effort (objectives E and F, 30% time commitment).
M. **Dr. Mary J. Hanks**, Supervisor, Energy and Sustainable Agriculture Program, Minnesota Department of Agriculture, will have primary responsibility for supervision of the composting and fertility planning components (objectives E and F, 5% time commitment).
N. **Mr. Niel R. Broadwater, Mr. Bruce A. Christensen, Mr. Dave J. Kjome, Mr. Chuck R. Schwartau, Mr. Bruce W. Schwartau, Mr. Peter R. Scheffert, Mr. Jerry A. Tesmer**, of the Minnesota Extension Service will coordinate the educational activities in their respective counties. The time commitment for the county Extension agents will be small and variable.
O. **Mr. Fritz Breitenbach and Mr. Tim L. Wagar**, Area Integrated Pest Management and Crops and Soils Specialists respectively, will coordinate the educational effort among the counties in the study area (objective F, 5% time commitment for Wagar only).

XI. Reporting Requirements: Semiannual status reports will be submitted not later than Jan. 1, 1994, July 1, 1994, Jan. 1, 1995 and a final status report by June 30, 1995.

1993 Project Abstract
FOR THE PERIOD ENDING JUNE 30, 1995
This project was supported by the MN Future Resources Fund

TITLE: Effective Manure Management in Conservation Tillage Systems for Karst Areas
ORGANIZATION: Dept. Of Soil, Water, and Climate, University of MN and the Agronomy and Planning Divisions of the MN Dept. Of Agriculture
LEGAL CITATION: M.L. 1993 Chapter 172, Sect.14, Subd.3(j) Agriculture:
APPROPRIATION AMOUNT: $500,000

Statement of Objectives:
A. Survey soil hydraulic properties, farmer practices, and computer simulated outcomes.
B. Determine the influence of landscape, soil type, and climate on nitrogen release from organic sources such as soil organic matter, alfalfa, and manure.
C. Determine the near surface stratigraphy (layering of glacial till and loess materials) in southeastern Minnesota.
D. Evaluation of manure management practices, which include manure applications and alfalfa in the rotation, in the context of soil conservation techniques for southeastern Minnesota.
E. Evaluate alternative methods for utilizing poultry mortality and analyze the environmental and economic benefits compared to other disposal methods.
F. Educational program.

Overall Project Results

The farm survey showed that farmers in southeastern MN have reduced "off farm" N inputs based on University of MN recommendations substantially. Ninety percent are following recommended best management practices. Nitrogen credits from organic sources offers the greatest uncertainy (due to the influence of climate during the growing season) and consequentially the greatest potential for improved management. It is evident from this survey that targeted educational programs need to continue to accelerate adoption of new technology and recommendations.

Manure applications were shown to improve water infiltration and reduce runoff in southeastern MN. The influence of crop residue was greater than manure application. This project also showed that the current "soil quality" indices need improvement to assess the changes due to manure applications.

Aspect and slope were shown to influence corn development, growth and amount of N released from organic sources. Several models were developed to account for the influence of aspect (regression and neural network).

Use of magnetic inductance resistivity (MIR) was evaluated for detection of the presence of residuum, glacial till strata, and loess thickness. This technique was successful at one site out of two. It is hoped that there may be potential for noninvasive sampling of near surface strata (<20 feet) with MIR to determine which N management guidelines are appropriate on a field scale. Success was limited.

Runoff plots were used to evaluate the Groundwater Loading Effects of Agricultural Management (GLEAMS) computer model. This model over predicted runoff early in the season and under predicted in the late season. Erosive losses of N and P from unmanured plots was close to predicted values. GLEAMS under predicted P from manured plots. This model will need more validation for southeastern MN conditions.

Waste wood and newspapers were found to be more economic carbon sources than straw for composting turkey mortality. Comparisons of compost, turkey manure, and urea N sources resulted in no differences in corn grain yield, quality, or weed density at two sites. Compost and manure was applied to seeding year alfalfa and evaluated for incidence of root rots at one site. There were no measurable differences.

Extrusion of turkey/chicken mortality was found to be viable as an alternative to composting. Extrusion with waste vegetable oil from restaurants, foxtail seeds from oat screenings, soybeans, and corn at varying ratios with dead birds showed that mixtures with high amounts of soybean and dead birds produced the product with the highest protein and fat content. The most economical mixture was with the second highest concentration of dead birds and soybeans combined with the lowest percentage of corn.

A team of county professionals lead by the MN Extension Service Educator had responsibility for the educational program (included the six counties in the karst area). The team included the Natural Resource Conservation Service, the Soil and Water Conservation Districts, and non profit organizations. The team implemented an intensive educational program by additional "on farm" demonstrations, field days, winter meetings, and dissemination of written materials through newsletters, papers, and publications.

Effective Manure Management in Conservation Tillage Systems for Karst Areas

LCMR Final Report - Detailed - Research
M.L. 1993, Chapter 172, Section 14, Subdiv. 3(j) Agriculture

Department of Soil, Water and Climate
University of Minnesota

and

Minnesota Department of Agriculture

July 1, 1995

Date of Report: July 1, 1995

LCMR FINAL REPORT - Detailed for Peer Review - Research

I. Project Title: Effective Manure Management in Conservation Tillage Systems for Karst Areas

Program Manager: Dr. John F. Moncrief
Soil Science Department
University of Minnesota
St. Paul, MN 55108
Phone: (612) 625-2771 FAX (612) 625-2208

A. Legal Citation: M.L.93, Chpt.172, Sec.14, Subd.3(j) Agriculture

Total Biennial LCMR Budget: $500,000
Balance: $0

Appropriation Language as drafted 7/27/92: This appropriation is from the future resources fund to the commissioner of agriculture for a contract with the University of Minnesota to investigate factors that influence losses of contaminants to surface and ground water. The emphasis will be on soil, crop residue, and manure management to maximize crop recovery of nitrogen and minimize losses to surface and groundwater.

B. LMIC Compatible Data Language: not applicable

C. Status of Match Requirement: not applicable

II. Project Summary: This project will be focused in the six county area in the southeastern part of Minnesota where ground and surface water quality is of concern. The soils are overlaying karst and sink holes in the area are numerous. This project will investigate controllable (such as tillage system and erosion control measures; manure and fertilizer source, application timing, and rates) and uncontrollable factors (such as soil type and climate) that influence losses of contaminants from agricultural activities to surface and ground water. There is also a large poultry industry in this part of Minnesota. Composting and land application of dead birds has shown promise as a cost effective method of disposal. This technique does need to be refined and evaluated in soil conserving farming systems in this area of the state however. The emphasis of this project will be on water, manure, and poultry mortality compost utilization in the context of the soils, landscapes, and cropping systems in southeastern Minnesota.

III. Statement of Objectives:

A. Survey soil hydraulic properties, farmer practices, and computer simulated outcomes.
B. Determine the influence of landscape, soil type, and climate on nitrogen release from organic sources such as soil organic matter, alfalfa, and manure.
C. Determine the near surface stratigraphy (layering of glacial till and loess materials) in southeastern Minnesota.
D. Evaluation of manure management practices, which include manure applications and alfalfa in the rotation, in the context of soil conservation techniques for southeastern Minnesota.
E. Evaluate alternative methods for utilizing poultry mortality and analyze the environmental and economic benefits compared to other disposal methods. F. Educational program.

IV. Research Objectives

A. Title of objective: Survey soil hydraulic properties, develop benchmarks of farmer nutrient management practices, and generate computer simulated outcomes to be used in research and teaching.

B. Title of Objective: Determine the influence of landscape, soil type, and climate on nitrogen release from organic sources such as manure and soil organic matter.

C. Title of Objective: Near surface stratigraphy:

D. Title of objective: Evaluation of manure management practices in the context of soil conservation techniques for southeastern Minnesota.

E. Title of Objective: Evaluate alternative methods for utilizing poultry mortality and analyze the environmental and economic benefits of the compost as a nutrient source compared to other disposal methods and compared to raw manure and purchased fertilizers.

F. Title of objective: Educational program

V. Evaluation: Each individual objective will be evaluated on how well each achieved specific research and educational goals. Evaluation of the overall project will be obtained by feed back from field staff as to the amount of changes in farmer practices which have impact on contamination of ground water with agricultural chemicals.

VI. Context within Field: The soils and landscapes of the karst topography in southeastern MN pose unique problems for environmentally sound crop production. The soils are steep and prone to crusting which makes water runoff likely.

Management of water in the context of manure applications is important for farmers. The potential for environmental degradation with the N and P associated with water movement over the surface or through these thin soils is high.

Improvement of recycling methods of waste (dead birds and manures) are important to make farming systems more environmentally and economically sound.

The effects of management options on soil water and nitrate movement in conjunction with regional conditions will be used to improve the BMPs in southeastern Minnesota.

VII. Benefits: This project will provide data that will allow a risk assessment based on soils and climate. This in conjunction with BMP recommendations for managing water and manure will reduce inputs and environmental contamination. The most valuable resource benefit to Minnesota is the potential impact on reduction of agricultural chemical losses to groundwater.

VIII. Dissemination: This project has an objective devoted entirely to technology transfer and information dissemination. In place field based staff of the Minnesota Extension Service, the Soil Conservation Service, Soil and Water Conservation Districts, and the Minnesota Department of Agriculture will be responsible for information dissemination with participation from state based staff.

IX. Time: This information generated from this project will be limited by its one biennium time frame but never the less yield much useful data.

X. Cooperation: Active participants cooperating include nine faculty at the University of Minnesota, five specialists at the Minnesota Department of Agriculture, and seven county Extension agents. There will also be input from the Minnesota Association of Conservation Districts and the Minnesota Pollution Control Agency.

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B. **Dr. H.H. Cheng**, Soil Biochemist, Soil Science Department, UM, will participate in the evaluation of management practices and use of alternative methods and sources of N on water quality (objectives B and D, 5% time commitment).

C. **Dr. Satish C. Gupta**, Soil Physicist, Soil Science Department, UM, will provide leadership in the water flow modeling and field validation effort (objectives A.2. and D, 5% time commitment).

D. **Dr. Jean A.E. Molina**, Soil Microbiologist, Soil Science Department, UM, will provide advice on the N transformation dimension of several objectives and have primary responsibility for the computer modeling effort in objective A.3 (5% time commitment).

E. **Dr. John F. Moncrief**, Extension Soil Scientist, Soil Science Department, UM, will advise on the field demonstrations and provide input on all objectives (time commitment 10%).

F. **Dr. Ed A. Nater**, Soil Chemist/Mineralogist, Soil Science Department, UM, will provide expertise in the application of magnetic inductive resistivity techniques for stratigraphic sequencing (objective C, 3% time commitment).

G. **Dr. Sally Noll**, Animal Scientist, Animal Science Department, UM, will provide leadership in the turkey mortality composting and the manure utilization dimensions of objectives D, E, and F (5% time commitment).

H. **Dr. Clive F. Reece**, Atmospheric Soil Physicist, Soil Science Department, UM, will provide leadership in the water flow modeling and field validation effort addressing climate and soil effects on N crop available N (objective B.1., 10% time commitment).

I. **Dr. Mark W. Seeley**, Extension Climatologist, Soil Science Department, UM, will provide leadership on the climatic influences on conditional probabilities for field working days and leaching losses of contaminants (objective B.1., 5% time commitment).

J. **Dr. Ward C. Stienstra**, Extension Plant Pathologist, Plant Pathology Department, UM, will provide expertise in the evaluation of compost effects on nemetode activity (objective E, consulting basis).

K. **Mr. Bruce R. Montgomery**, Special Projects Coordinator, Minnesota Department of Agriculture, will have primary responsibility for the farming practices survey (objective A1. 4% time commitment).

L. **Mr. Doug J. Gunnink**, On-farm project coordinator, Minnesota Department of Agriculture, will have primary responsibility for coordination of the poultry mortality-composting effort (objectives E and F, 30% time commitment).

M. **Dr. Mary J. Hanks**, Supervisor, Energy and Sustainable Agriculture Program, Minnesota Department of Agriculture, will have primary responsibility for supervision of the composting and fertility planning components (objectives E and F, 5% time commitment).

N. **Mr. N. Broadwater, Mr. B.A. Christensen, Mr. D. Kjome, Mr. C.R. Schwartau, Mr. J. Tesmer**, of the Minnesota Extension Service will coordinate the educational activities in their respective counties. The time commitment for the county Extension agents will be small and variable.

O. **Mr. F. Breitenbach and Mr. Tim L. Wagar**, Area Integrated Pest Management and Crops and Soils Specialists respectively, will coordinate the educational effort among the counties in the study area (objective F, 5% time commitment for Wagar only).

XI. Reporting Requirements: Semiannual status reports will be submitted not later than Jan. 1, 1994, July 1, 1994, Jan. 1, 1995 and a final status report by June 30, 1995.

XII. Literature Review

Nation wide, there is an increase in the number of studies documenting the presence of pesticides and nitrate in groundwater (Hallberg et al., 1984; CAST, 1985; Nielsen and Lee, 1987; Klaseus et al., 1988). A Minnesota survey by Klaseus et al. (1988) found pesticides and nitrate in 33% and 43%, respectively, of the 500 wells tested in 51 counties. In this survey, most of the contaminated wells were in the Southeast (Karst region) and Central (Sand Plain region) Minnesota.

The Karst terrain of southeast Minnesota is along the Mississippi river. These Karst features also extend to southwestern Wisconsin, northeastern Iowa and northwestern Illinois. In this area of the Midwest, dairy and beef cattle are an important part of the economy. The major crops of the area are corn (C) and alfalfa (A) usually grown in a five year rotation (CCAAA). Predominant tillage practices are chisel plowing or no-till. Manure application to land is also an important management practice and generally, manure is surface applied daily.

Most of the soils are loess derived and are underlain with a fractured dolomitic bedrock. This silty loess material probably blew from the Mississippi River bottoms soon after the most recent glacial period (Witzel et al., 1969) and varies in thickness from 3 to over 6 meters. Generally, the soils are shallow along the Mississippi river, and they become thicker as the distance from the river increases. The terrain is rolling to steep and farming is done on contour strips. The soils are moderately permeable when protected from the direct impact of raindrops (Freebairn et al., 1989). In some places, a discontinuous compacted till layer exists between the soil and the bedrock which causes horizontal movement of infiltrated water. Horizontal flow is often noticeable as seepage between the till and the loess layer or between the loess and the bed rock along the road side cuts during spring and after heavy rainfalls.

Due to the application of manure on these landscapes, there is an enhanced activity of earthworms (Fuchs and Linden, 1988). In non-manured soils, the earthworm population is mainly Aporrectodea tuberculata, a subsurface dweller and feeder that burrows horizontally and meanders to depths of 0.3 m (Zachman et al., 1987; Ela et al., 1992). However, in manured soils, the earthworm population consists of Aporrectodea tuberculata, Lumbricus rubellus and Lumbricus terrestris (Zachman et al., 1987; Munyankusi, 1992). Both Lumbricus rubellus and Lumbricus terrestris are deep vertically burrowing earthworms and could burrow in the soils to depths over 0.3 m. Edwards et al. (1988) has shown that Lumbricus terrestris can burrow to over 1 m depth.

Large cores (0.3 m diameter by 1 m deep) taken from the field where manure has been applied during the previous nine years showed the presence of earthworm macropores at a depth of 1m (Munyankusi, 1992). The size of the macropores varied from 1 to over 5 mm. Earthworm species included A. tuberculata and L. rubellus. Breakthrough curves obtained from these cores showed enhanced flow of both water and non-adsorbed ions (Cl^- and Br^-). Paint injected in the visible macropores at the soil surface indicated continuity of surface macropores to a 1 m deep.

Nitrate leaching through soils greatly depends upon the infiltration characteristics of the soil, tillage and cropping history, steepness of the landscape, type of rainstorms (intensity and duration of rain), timing of rainstorms relative to the time of manure and fertilizer application and amount of fertilizer and manure applied at the surface. Extensive literature exists dealing with the effect of tillage and too some extent on the effects of manure (either singly or jointly) on the quantity and quality of surface runoff (Witzel et a l., 1969; Römkens et al., 1973; Wendt and Corey, 1980; Mueller et al., 1984 a,b; Andraski et al., 1985a,b; and Johnson et al., 1979; Long et al., 1975; Hensler et al., 1970). The majority of these studies have used simulated rains to generate runoff. The intensities of the rainfall in these studies generally correspond to the mid to upper ranges of intensities found in the area. Most of the findings dealing with the water quality issue in these studies only address the nutrient concentrations in the surface water. In some cases, inferences have been drawn on the quality of subsurface water by using the mass balance approach of rain input and runoff output. However, this extrapolation of data under mid-to high-intensity simulated rainfall minimizes the subsurface water quality concerns and greatly exaggerates the water and nutrient losses in runoff water. In general, there is limited information in the literature on the effects of tillage and manure interactions on water quality (phosphorus and nitrogen losses).

Minshall et al., (1969) indirectly measured the subsurface water quality by studying the base flow of streams in Southwestern Wisconsin. This base flow from 36 drainage areas over a two year period corresponded to 12.5 cm/yr about 18% of the annual precipitation. Annual nutrient losses in base flow were: nitrogen, 1.1 lbs/acre; phosphorus, 0.1 lbs/acre; and potassium, 1.8 lbs/acre. These losses were only one fourth of those reported by these authors for small watersheds on similar landscapes (Witzel et al., 1969). In all these studies, there was no specific mention of tillage or manure treatments.

Hallberg et al. (1983, 1984) found that in the Big Spring Basin (Clayton

County, Iowa), total N lost to the ground water was an equivalent to 33% and 47% of the applied agricultural nitrogen in 1982 and 1983, respectively. This amounted to 27 and 43 lbs of N per acre for the entire basin during 1982 and 1983, respectively. In each of these years, about 6% and 13% of this nitrogen was due to direct runoff into sink holes and 94% and 87% was from basin or broad-scale (103 square miles) infiltration. Basin infiltration of Hallberg et al. (1983,1984) includes field runoff that infiltrates through the depressional areas in the landscape (focussed recharge).

Since the early 70's, considerable work has been reported on the non-point source pollution from manure and sludge application to landscapes. Among these studies, there has also been a some evaluation of the practices of spreading manure onto frozen fields (Young and Mutchler, 1976; Everts, 1980). Young and Mutchler (1976) showed that nutrient concentrations in spring runoff were high from all manured plots, compared to non-manured plots. However, total nutrient losses varied greatly depending on the type of soil surface receiving manure and the time of application. Up to 20% of the N and 16% of the ortho-P in the manure was carried away in spring runoff from alfalfa plots while no more than 3% of the N and 4% of the ortho-P was lost from manured fall-plowed plots. Applying manure to frozen plowed land reduced soil losses 100% and runoff up to 80%. This was due to manure acting as mulch and retarding the flow of water until the soil was able to absorb it. Results from manure spread on the top of snow rather than before snow fall were also better for reducing soil, water, and nutrient losses in runoff although this effect differed with melting conditions.

Questions also remain unanswered as to the development and characteristics of earthworm macropores over time following the application of manure. Freebairn et al.(1989) showed that infiltration to a bare Port Byron silt loam soil was a function of cumulative rainfall since tillage. However in between the rainfall events, the infiltration rates increased because of the disruption of surface seal by biological (including earthworms) activities and soil cracking by drying.

Infiltration and runoff during the snow melt period depends upon the amount of snow, thermal properties of soil and snow, surface microrelief, and degree of soil saturation during freezing. How do the earthworm macropores contribute to subsurface flow during the snow melt period is an open question? Furthermore, what is the quality of water that flows through these macropores, if the manure is applied before or after snow fall?

Currently, the model of heat and water flow in frozen and partially frozen soils lack a description of macropore flow. It has been shown by Thunholm et al. (1989) that models based on the continuity equations of heat and water flow underpredict infiltration rates in frozen and partially frozen soils. These authors attributed this lack of prediction to not accounting for flow through cracks and macropores in fine textured soils of Sweden.

Literature Cited

Andraski, B. J., D. H. Mueller, and T. C. Daniel. 1985. Effects of tillage and rainfall simulation date on water and soil losses. Soil Sci. Soc. Am. J. 49: 1512-1517.

Andraski, B. J., D. H. Mueller, and T. C. Daniel. 1985. Phosphorus losses in runoff as affected by tillage. Soil Sci. Soc. Am. J. 49: 1523-1527.

Bengtsson, L. 1980. Evaporation from a snow cover: Review and discussion of measurements. Nordic Hydrol. 11: 221-234.

Campbell, G.S. 1985. Soil physics with BASIC: Transport models for soil-plant systems. Elsevier Sci. Publ. Co., New York, 150 pp.

Cooley, K. R. 1990. Frozen soil impacts on agricultural, range and forest lands. CRREL Special report no. 90-1. U. S. Army Corps of Engineers, Hanover, NH. 318p.

Council for Agriculture Sciences and Technology. 1985. Agriculture and water quality. Rep. No. 103. Council for Agricultural Sciences and Technology, Ames, IA.

Edwards, W. M., R. R. van der Ploeg, and W. Ehlers. 1979. A numerical study of the effects of noncapillary-sized pores upon infiltration. Soil Sci. Soc. Am. J. 43: 851-856.

Edwards, W. M., M. J. Shipitalo, and L. D. Norton. 1988. Contribution of macroporosity to infiltration into continuous corn no-tilled watershed: Implications for contaminant movement. J. Conta. Hydrol. 3: 193-205.

Ela, S. D., S. C. Gupta, W. J. Rawls. 1992. Macropore and surface seal interactions affecting water and infiltration into soil. Soil Sci. Soc. Am. J. (March-April). In press.

Ela, S. D., S. C. Gupta, W. J. Rawls, and J. F. Moncrief. 1991. Role of earthworm macropores formed by Aporrectodea tuberculata on preferential flow of water through a Typic Hapludoll. ASAE Proceedings of the National Symposium on Preferential Flow, Chicago, IL, December 16-17, 1991, 68-76.

Everts, C. J. 1980. Effects of tillage and manure on nitrogen and phosphorus with sediment and surface runoff. M. S. Thesis. University of Minnesota, St. Paul, p118.

Flerchinger, G. N. and K. E. Sexton. 1989 a. Simultaneous heat and water model of a freezing snow-soil-residue system. I. Theory and development. Trans. ASAE, 32: 565-571.

Flerchinger, G. N. and K. E. Sexton. 1989 a. Simultaneous heat and water model of a freezing snow-soil-residue system. II. Field verification. Trans. ASAE 32: 573-578.

Freebairn, D. M., S. C. Gupta, C. A. Onstad, and W. J. Rawls. 1989. Antecedent rainfall and tillage effects upon infiltration. Soil Sci. Soc. Am. J. 53:1183-1189.

Fuchs, D. J. and D. R. Linden. 1988. An earthworm population and activity survey of selected agronomic areas in Minnesota. Unpublished manuscript.

Grant, R. F. 1992. Dynamic simulation of phase changes in snowpacks and soils. Soil Sci. Soc. Am. J. (in press).

Hallberg, G. R., R. D. Libra, E. A. Bettis, and B. E. Hoyer. 1984. Hydrogeologic and water quality investigations in Big Spring Basin, Clayton County, Iowa: 1983 water year. Open-file Rep. No. 84-4. Iowa Geological Survey.

Hallberg, G. R., B. E. Hoyer, E. A. Bettis, and R. D. Libra. 1983. Hydrogeology, water quality, and land management in the Big Spring Basin, Clayton County, Iowa. Open-file Rep. No. 83-3. Iowa Geological Survey.

Hensler, R. F., R. J. Olsen, S. A. Witzel, O. J. Attoe, W. H. Paulson and R. F. Johannes. 1970. Effect of method of manure handling on crop yields, nutrient recovery and runoff losses. Trans. ASAE 13: 726-731.

Holder, M., K. W. Brown, J. C. Thomas, D. Zabcik, and H. E. Murray. 1991. Capillary-wick unsaturated zone soil pore sampler. Soil Sci. Soc. Am. J. , 55: 1195-1202.

Jarvis, N.J., P.-E. Jansson, P. E. Dik, and I. Messing. 1990. Modeling water and solute transport in macroporous soil. I. Model description and sensitivity analysis. (Unpublished manuscript).

Johnson, H. P., J. L. Baker, W. D. Shrader, and J. M. Laflen. 1979. Tillage system effects on sediment and nutrients in runoff from small watersheds. Trans. ASAE 22:1110-1114

Joshi, J.R. 1992. Tillage effects on the fate of nitrogen applied to corn as animal manure and fertilizer. Ph.D. thesis. University of Minnesota, St. Paul,

Klaseus, T. G., G. C. Buzicky, and E. C. Schneider. 1988. Pesticides and groundwater: Survey of selected Minnesota wells. Report for the Legislative Commission on Minnesota Resources, Minnesota Dept. of Health and Minnesota Dept. of Agriculture.

Knisel, W. G., D. C. Moffitt and T. A. Dumper. 1985. Representing seasonally frozen soil with the CREAMS model. Trans. Amer. Soc. Agric. Eng. 28: 1487-1497.

Krupa, S.V. and M. Nosal. 1989. Application of spectral coherence analysis to describe the relationships between ambient ozone exposure and crop growth. Environ. Pollution 60:319-330.

Laflen, J. M., M. Amemiya and E. A. Hintz. 1981. Measuring residue cover. J. Soil and Water Conservation. 32: 341-343.

Long, F. L., Z. F. Lund, and R. E. Hermanson. 1975. Effect of soil incorporated dairy cattle manure on runoff water quality and soil properties. J. Environ. Qual. 4: 163-166.

Minshall, Neal, M. Starr Nichols and S. A. Witzel. 1969. Plant nutrient in base flow of streams in southwestern Wisconsin. Wat. Resou. Res. 5: 706-713.

Mueller, D. H., R. C. Wendt, and T. C. Daniel. 1984. Soil and water losses as affected by tillage and manure application. Soil Sci. Soc. Am. J. 48: 896-900.

Mueller, D. H., R. C. Wendt, and T. C. Daniel. 1984. Phosphorous losses as affected by tillage and manure application. Soil Sci. Soc. Am. J. 48: 901-905.

Munyankusi, E. 1992. Effect of tillage and manure on earthworm macropore distribution and continuity. M. S. Thesis. (in progress).

Nielsen, E. G. and L. K. Lee. 1987. The magnitude and costs of groundwater contamination from agricultural chemicals: A national perspective. Agricultural Economic Rep. No. 576, U. S. Dept. of Agriculture.

Pikul, Jr., J. L. and J. F. Zuzel. 1990. Heat and water flux in a diurnally freezing and thawing soil. In. Cooley (ed.), Proceedings of International Symposium on "Frozen soil impacts on agricultural, range and forest lands", Spokane, WA, March 21-22, 1990, 113-119.

Price, A. G. an d T. Dunne. 1976. Energy balance computations of snowmelt in a subarctic area. Water Resour. Res. 12: 686-694.

Reynolds, J. W. The earthworms (Lumbricidae and Sparganophilidae) of Ontario. Miscellaneous Publications, Royal Ontario Museum, Life Sciences.

Römkens, M. J. M., D. W. Nelson, and J. V. Mannering. 1973. Nitrogen and phosphorus composition of surface runoff as affected by tillage method. J. Environ. Qual. 2: 292-295.

Shaffer, M. J. and W. E. Larson. (ed.). 1987. NTRM, a Soil-Crop simulation model for nitrogen, tillage and crop-residue management. U. S. Dept. of agriculture, Conservation Research Report, 34-1, 103p.

Thunholm, B., L. C. Lundin, and S. Lindell. 1989. Infiltration into frozen heavy clay soil. Nordic Hydrology, 20: 153-166.

Wall, D. B. 1987. The influence of snow depth on soil frost penetration depth. M. S. Thesis. University of Minnesota, St. Paul, MN. 210p.

Witzel, S. A., Neal Minshall, M. Starr Nichols and John Wilke. 1969. Surface runoff and nutrient losses of Fennimore watersheds. Trans. ASAE12:338-341.

Wendt, R. C. and R. B. Corey. 1980. Phosphorus variations in surface runoff from agricultural lands as a function of land use. J. Environ. Qual. 9:130-136.

Young, R. A. and C. K. Mutchler. 1976. Pollution potential of manure spread on frozen ground. J. Environ. Qual. 5: 174-179.

Young, R. A. and R. F. Holt. 1977. Winter-applied manure: effects on annual runoff, erosion, and nutrient movement. J. Soil and Water Cons. 32: 219-222.

Zachman, J. E. D. R. Linen and C. E. Clapp. 1987. Macroporous infiltration and redistribution by earthworms, tillage and residue. Soil Sci. Soc. Am. J. 51: 1580-1586.

Zachman, J. E. 1986. Earthworms and infiltration as affected by residue in tillage systems. M. S. Thesis. University of Minnesota, St. Paul, MN, pp103.

APPENDIX

Qualifications:

JAMES C. BELL

Soil Science Department, UM
Rank: Assistant Professor

Educational History:

Ph.D., Agronomy, The Pennsylvania State University. August, 1990. Dissertation: A GIS-based soil-landscape modeling approach to predict soil drainage class.

M.S., Agronomy, Virginia Polytechnic Institute and State University. August, 1982. Thesis: Evaluation of site suitability of mine soils for residential housing developments.

B.S., Agronomy, Virginia Polytechnic Institute and State University. June, 1980.

Professional Appointments:

1990 - present Assistant Professor, Soil Science Department, University of Minnesota.
1989 - 1990 Post Doctoral Associate, Agronomy Department, The Pennsylvania State University.
1986 - 1989 Graduate Assistant, Agronomy Department, The Pennsylvania State University.
1982 - 1986 Research Associate, Agronomy Depart., Virginia Polytechnic Institute and State Univ.
1980 - 1982 Research Assistant, Agronomy Depart., Virginia Polytechnic Institute and State Univ.

Professional and Honorary Societies

Soil Science Society of America
Soil and Water Conservation Society
American Society for Surface Mine Reclamation Research
Minnesota Association of Professional Soil Scientists
American Society for Photogrammetry and Remote Sensing
Gamma Sigma Delta
Phi Sigma

Selected Publications

Bell, J. C., R. L. Cunningham, and M. W. Havens. 1992 Calibration and validation of a soil-landscape model for predicting soil drainage class. *Soil Science Society of America Journal.* (In Press)

Bell, J. C., R. L. Cunningham, and M. W. Havens. The application of a soil-landscape model and a digital geographic database to map soil drainage characteristics. *Submitted to Soil Science Society of America Journal.*

Gardner, T. W., J. B. Ritter, C. A. Shuman, J. C. Bell, K. C. Sasowsky and

N. Pinter. 1991. A periglacial stratified slope deposit in the valley and ridge province of Central Pennsylvania, USA: sedimentology, stratigraphy, and geomorphic evolution. *Permafrost and Periglacial Processes*. 2:141-162.

Bell, James C., W. L. Daniels, and C. E. Zipper. 1989. The practice of "approximate original contour" in the central Appalachians: I. Slope stability and erosion potential. *Landscape and Urban Planning* 18:127-138.

H. H. CHENG

Soil Science, UM
Professor and Head

Education

Berea College, Berea, KY B.A. 1956. Agricultural Science
University of Illinois, Urbana, IL M.S. 1958. Agronomy
University of Illinois, Urbana, IL Ph.D. 1961. Soil Science

Employment History

At University of Minnesota: Professor and Head, Department of Soil Science, 1989-present

At Washington State University: Professor, Department of Agronomy and Soils, 1977-89, Interim Chair 1986-87, Associate Professor 1971-77, Assistant Professor 1965-71; Chair, Program in Environmental Science and Regional Planning, 1988-89,1977-79; Associate Dean, Graduate School, 1982-86.

At Iowa State University: Assistant Professor, Department of Agronomy, 1964-65; Research Associate 1962-64.

Recent Publications (last 5 years)

Roberts, S., and H. H. Cheng. 1988. Estimation of critical nutrient range of petiole nitrate for sprinkler-irrigated potatoes. Am. Potato J. 65:119-124.

Lehmann, R. G., and H. H. Cheng. 1988. Reactivity of phenolic acids in soil and formation of oxidation products. Soil Sci. Soc. Am. J. 52:1304-1309.

Cheng, H. H. 1989. Assessment of the fate and transport of allelochemicals in the soil. p. 209-216. In C. H. Chou and G. R. Waller, eds. Phytochemical Ecology: Allelochemicals, Mycotoxins, and Insect Pheromones and allomones. Institute of Botany, Academia Sinica Monogr. Ser. No. 9, Taipei.

Roberts, S., H. H. Cheng, and F. O. Farrow. 1989. Nitrate concentration in potato petioles from periodic applications of ^{15}N-labeled ammonium nitrate fertilizer. Agron. J. 81:271-274.

Mulla, D. J., H. H. Cheng, G. Tuxhorn, and R. Sounhein. 1989. Management of ground water contamination in Washington's Columbia Basin. State of Washington Water Research Center Reprt No. 72. 29 p.

Cheng, H. H. 1990. Organic residues in soils: Mechanisms of retention and extractability. Intern. J. Environ. Anal. Chem. 39:165-171.

Cheng, H. H. 1990. Pesticides in the soil environment: An overview. p. 1-5. In: H. H. Cheng, ed. Pesticides in the soil environment: Processes, impacts, and modeling. SSSA Book Ser. No. 2. Soil Science Society of America, Madison, WI.

Cheng, H. H., ed. 1990. Pesticides in the soil environment: Processes, impacts, and modeling. SSSA Book Ser. No. 2. Soil Science Society of America, Madison, WI. 530 p.

Cheng, H. H., and D. J. Mulla. 1990. Sample analyses for groundwater studies. p. 90-96. In: D. W. Nelson and R. H. Dowdy, ed. Methods for Ground Water Quality Studies. Proceedings of a National Workshop, Arlington, Virginia, November 1988. University of Nebraska, Lincoln.

Nor, Y. M., and H. H. Cheng. 1990. Characterisation of H^+ and Cu^{2+} binding to humic and fulvic acids. Chem. Speciat. Bioavail. 2:93-101.

Roberts, S., H. H. Cheng, and F. O. Farrow. 1991. Potato uptake and recovery of nitrogen-15-enriched ammonium nitrate from periodic applications. Agron. J. 83:378-381.

Cheng, H. H., S. E. Swanson, and T. E. McKone. 1991. Fate and transport of dioxins and furans in soil. p. 21-28. In J. W. Gillett et al. Peer Review of "Land Application of Sludge from Pulp and Paper Mills Using Chlorine and Chlorine-Derivative Bleaching Processes: Proposed Rule" for Human Dietary and Ecotoxicological Risks. U.S. Environmental Protection Agency, Office of Toxic Substances, Washington, D.C.

Cheng, H. H. 1992. A conceptual framework for assessing allelochemicals in the soil environment. p. 21-29. In: S. J. H. Rizvi and V. Rizvi, eds. Allelopathy: Basic and Applied Aspects. Chapman & Hall, London.

Roberts, S., H. H. Cheng, and I. W. Buttler. 1992. Recovery of starter nitrogen-15 fertilizer with supplementarily applied ammonium nitrate on irrigated potato. Am. Potato J. 69:309-314.

Larson, W. E., and H. H. Cheng. 1992. Information systems for soil management. p. 131-141. In: V. W. Ruttan, ed. Sustainable Agriculture and the Environment. Westview Press, Boulder CO.

Burgard, D. J., R. H. Dowdy, W. C. Koskinen, and H. H. Cheng. 1992. Movement of metribuzin in a sandy soil under irrigated potato production. Soil Tillage Res. (in press)

DOUGLAS GUNNINK

Department: Minnesota Department of Agriculture
Ag Planning & Development Division
Rank: Sustainable Agriculture On-Farm Research Coordinator

Education

B.S., Agricultural Education, University of Minnesota, 1975.

Employment History

1989 - present On-Farm Research Coordinator for the Energy and Sustainable Agriculture Program, Minnesota Department of Agriculture.
1987 - 1989 County Extension Agent for the Sibley County Extension Office
1984 - 1986 Adult Farm Management Instructor for Pine Technical Institute
1985 - 1986 Contractor for Farmers Home Administration
1981 - 1984 Project Manager for Rural Ventures, Inc.
1975 - 1981 Vocational Agriculture Instructor for Albany Area Schools

Professional and Honorary Societies

Director, Minnesota Dorset Association
Treasurer, Minnesota Lamb & Wool Producers
Committee for livestock certification rules, Organic Growers and Buyers

SATISH C. GUPTA

Professor of Soil Science
Soil Science Department, U of MN

Education:

Ph. D., Utah State University, Logan, UT
M. Sc. and B. Sc., Punjab Agricultural University, India.

Positions Held:

Professor, University of Minnesota, 1988-present
Associate Professor, University of Minnesota, 1985-1988
Soil Scientist, USDA-ARS, St. Paul, MN, 1977-85
Research Fellow, University of Minnesota, St. Paul, MN, 1972-77 Research Assistant, Utah State University, Logan, UT, 1969-72.

Memberships:

Soil Science Society of America
American Society of Agronomy Society
International Soil Science Society
Soil and Tillage Research Organization
American Society of Agricultural Engineers
American Geophysical Union
American Association for Advancement of Science.

Selected Publications

Ela, S. D., S. C. Gupta, and W. J. Rawls. 1992. Macropore and surface interactions affecting water infiltration into soil. Soil Sci. Soc. Am. J., 56: March-April, (in press).

Gupta, S. C., Birl Lowery, J. F. Moncrief, and W. E. Larson. 1992. Modeling tillage effects on soil physical properties. Soil Tillage Res. 20: 293-318.

Sharma, P. P., S. C. Gupta, W. J. Rawls. 1991. Effect of soil strength on soil detachment by single raindrops o varying kinetic energy. Soil Sci. Soc. Am. J. 55: 301-307.

Gupta, S. C., J. F. Moncrief and R. P. Ewing. 1991. Soil crusting in mid-western United States. Adv. Soil Sci. (In Press).

Ela, S. D., S. C. Gupta, W. J. Rawls and J. F. Moncrief. 1991. Role of earthworm macropores formed by Aporrectodea tuberculata on preferential flow through a Typic Hapludoll. Proceedings of the ASAE National Symposium on Preferential Flow, December 16-17, 1991, 68-76p.

Freebairn, D. M., S. C. Gupta, and W. J. Rawls. 1991. Influence of Aggregates, microrelief and rainfall intensity on development of surface crusts. Soil Sci. Soc. Am. J. 55: 188-195.

Gupta, S. C. and R. P. Ewing. 1991. Modeling water retention characteristics and surface roughness of tilled soils. Proceeding of the Workshop "Indirect methods of estimating the hydraulic properties of unsaturated soils, Riverside, CA. (Van Genuchten, M. Th. Ed), (in press).

Gupta, S. C., J. K. Radke, J. B. Swan, and J. F. Moncrief. 1990. Predicting soil temperatures under a ridge-furrow system in the U.S. Corn Belt. Soil & Till. Res. 18: 145-165.

Freebairn, D. M. and S. C. Gupta. 1990. Microrelief, rainfall and cover effects on infiltration. Soil & Tillage Res. 16: 307-327.

Freebairn, D. M., S. C. Gupta, C. A. Onstad and W. J. Rawls. 1989. Antecedent rainfall and tillage effects upon infiltration. Soil Sci. Soc. Am. J. 53: 1183-1189.

Schuh, W.M., J.W. Bauder, and S.C. Gupta. 1984. Evaluation of simplified methods for determining unsaturated hydraulic conductivity of layered soils. Soil Sci. Soc. Am. J. 48:730-736.

Gupta, S. C., W. E. Larson, and R. R. Allmaras. 1984. Predicting soil temperatures and soil heat flux under different tillage-surface residue conditions from daily maximum and minimum air temperatures. Soil Sci. Soc. Am. J. 48: 223-232.

Gupta, S. C., W. E. Larson, and D. R. Linden. 1983. Tillage and surface residue effects on upper boundary temperatures. Soil Sci. Soc. Am. J. 47: 1212-1218.

Gupta, S. C., J. K. Radke, W. E. Larson and M. J. Shaffer. 1982. Predicting temperatures of bare and residue-covered soils from daily maximum and minimum air temperatures. Soil Sci. Soc.. Am. J. 46: 372-376.

Gupta, S. C., J. K. Radke, and W. E. Larson. 1981. Predicting temperatures of bare and residue covered soils with and without a corn crop. Soil Sci. Soc. Am. J. 45: 405-412.

Shaffer, M.J., and S.C. Gupta. 1981. Hydrosalinity models and field validation. pp. 136-181 (Chapter 7). In I.K. Iskander (ed.). Simulating nutrient transformation and transport during land treatment of wastewater. John Wiley and Sons, New York.

Gupta, S.C., and W.E. Larson. 1979. Estimating soil water retention characteristics from particle size distribution, organic matter percent, and bulk density. Water Resour. Res. 15:1633-1635.

Gupta, S. C., M. J. Shaffer and W. E. Larson. 1978. Review of physical/ chemical/ biological models for prediction of percolate water quality. p121-132. In Proc. Internat'l. Symp. Land Treatment of Wastewater, Vol. I. Hanover, NH. 20-25 Aug. 1978.

MARY J. HANKS

Department: Minnesota Department of Agriculture
Ag Planning & Development Division
Rank: Planning Program Supervisor

Education

Ph.D., Plant Pathology, Iowa State University, Ames, May, 1980. Dissertation: Alternaria Leaf Spot of Maize. Advisor: Dr. Charlie Martinson.

M.S., Plant Pathology, Iowa State University, Ames, February, 1977. Thesis: Inoculum Potential of Helminthosporium maydis Regulated by Inoculum Source. Advisor: Dr. Charlie Martinson.

B.S., Biology, University of Missouri, Kansas City, May, 1974.

Employment History

1991 - present Supervisor for the Energy and Sustainable Agriculture Program, Minnesota Department of Agriculture.
1990 - 1991 Integrated Pest Management Coordinator, Minnesota Department of Agriculture.
1980 - 1990 Plant Pathology Department Head, Northrup King Co.

Professional and Honorary Societies

American Society of Agronomy
American Phytopathological Society

Publications

Fox, C.C., M.M. Rekoske, J. Magsam, M.J. Trainor and Bill Knipe. 1989. A rapid seedling test for evaluation of Phytophthora root rot resistance in alfalfa. Proceedings of the 21st Central Alfalfa Improvement Conference, July, 1989.

Trainor, M.J. and C.A. Martinson. 1981. Epidemiology of Alternaria leaf blight of maize. Phytopathology 71: 262. (Abstract).

Trainor, M.J. and C.A. Martinson. 1978. Nutrition during spore production and the inoculum potential of Helminthosporium mydis Race T. Phytopathology 68:1049-1053.

Tipton, C.L., R.E. Betts, R.V. Paulsen, C.A. Martinson, W.M. Park and M.J. Trainor. 1976. Ophiobolin A production by Helminthosporium maydis in culture and effects on maize seedling tissues. Proceedings of the American Phytopathol. Soc. 3:68. (Abstract).

Weck, E., D. Beckman, D. Mead, C. Bredenkamp and M.J. Trainor. 1991. The use of near-isogenic lines for mapping MDMV resistance in Zea mays L. (In preparation).

Weck, E., D. Beckman, D. Mead, C. Bredenkamp, C. Wangen, C. Perry and M. J. Trainor. 1988. Mapping MDMV resistance in maize. Eucarpia Conference, Poster, Denmark, 1988.

J.A.E. MOLINA

Professor of Soil Science
University of Minnesota

Education
Cornell University, NY: M.S., 1963, Major in Agronomy-Soil Microbiology; Ph.D., 1967, Major in Agronomy-Soil Microbiology, Minor in Biochemistry and Microbiology.

Professional Appointments:
Department of Agronomy, University of Illinois, Urbana-Champaign, 1967-1970.
Department of Soil Science, University of Minnesota, St. Paul, 1970-present.

Publications 1990-92

Molina, J.A.E., A. Hadas, and C.E. Clapp. 1990. Computer Simulation of Nitrogen Turnover in Soil and Priming Effect. Soil Biology and Biochemistry, 22:349-353.

Clay, D.E., C.E. Clapp, J.A.E. Molina, and R.H. Dowdy. 1990. Influence of N fertilization, tillage, and residue management on a soil nitrogen mineralization index. Commun. Soil Sci. Plant Anal. 21:323-335.

Clay, D.E, C.E. Clapp, J.A.E. Molina, and D. Linden. 1990. Soil Tillage Impact on the Diurnal Redox-Potential Cycle. Soil Sci. Soc. Am. J. 54:516-521.

Barak, P., J.A.E. Molina, Aviva Hadas, and C.E. Clapp. 1990. Optimization of an Ecological Model with the Marquardt Algorythm. Ecological Modeling 51:251-263.

Barak, P., J.A.E. Molina, Aviva hadas, and C.E. Clapp. 1990. Mineralization of Amino Acids and Evidence of Direct Assimilation of Organic Nitrogen. Soil Sci. Soc. Am. J. 54:769-774.

Clapp, C.E., J.A.E. Molina, and R.H. Dowdy. 1990. Soil Organic Matter, Tillage, and the Rhizosphere. In Rhizosphere Dynamics. (J. Boc, L. Hammond Ed.). AAAS Selected Symposium 113. pp 55-82.

Clay, D.E., C.E. Clapp, D.R. Linden, and J.A.E. Molina. 1991. Tillage influence on redox potential following rainfall. Soil Tillage Research 22:211-219.

Molina, J.A.E. Nitrogen exchange between organic and inorganic pools in soil-organic residues systems. 1991. BARD report. 110 pp.

Clay, D.E., C.E. Clapp, R.H. Dowdy, and J.A.E. Molina. 1991. Mineralization of fertilizer and soil nitrogen in lime-treated acid soils. Biol. Fert. Soils 12: (accepted for publication 1/91).

Hadas, Aviva, M. Sofer, J.A.E. Molina, P. Barak, and C.E. Clapp. 1992. Assimilation of nitrogen by soil microbial population: NH4 vs. organic N. Soil Biol. Biochem. 24:137-143.

JOHN F. MONCRIEF

Associate Professor of Soil Science
Soil Science Department, University of Minnesota

Education:

Ph.D. 1981, University of Wisconsin-Madison, Soil Science major, Botany minor. Dissertation: The effect of Tillage on Soil Physical Properties and the Availability of Nitrogen, Phosphorus, and Potassium to Corn (Zea mays L.). L.M. Walsh and E.E Schulte, co-advisors.

M.S., 1977, Montana State University, Soil Science major, Geology minor. Thesis: The Effect of Irrigation on Soil and Ground Water Quality in the Huntley Irrigation District, Huntley, Montana. Hayden Ferguson, major professor.

B.S., 1975, University of Wisconsin-Stevens Point, Double Major:

Soil Science and Natural Resource Management

Employment Record:

7/85-present University of Minnesota-Extension Soil Scientist and Associate Professor of Soil Science Appointment is split 80 % Extension and 20% Research

11/81-7/85 University of Minnesota-Extension Soil Scientist and Assistant Professor of Soil Science-Appointment is split 80 % Extension and 20% Research

8/77-11/81: Research Assistant/Associate, University of Wisconsin-Madison.

6/75-8/77: Research Assistant, Montana State University.

Membership in Professional and Honorary Societies (1989)

1. American Society of Agronomy
2. Soil Science Society of America
3. Soil Conservation Society of America
4. Xi Sigma Pi
5. Sigma Xi

Selected Publications

Moncrief, J.F. and E.E. Schulte. 1991. Fertilizer management with conservation tillage systems. 14 pg. In: Implementation of Conservation Tillage Systems in the Midwest (in Press) Midwest Plan Service, Iowa State Univ., Ames Iowa

J.S. Hickman, Moncrief, J.F., and N.C. Wollenhaupt. 1991. The effect of conservation tillage on water quality: fertilizers and pesticides. 15 pg. In: Implementation of Conservation Tillage Systems in the Midwest (in press). Midwest Plan Service, Iowa State Univ., Ames Iowa

Griffith, D., J.F. Moncrief, D. Eckert, J.B. Swan, and D.D. Breitbach. Influence of soil, climate, and residue on crop response to conservation tillage systems. 19 pg. 1991. In: Implementation of Conservation Tillage Systems in the Midwest. (in press) Midwest Plan Service, Iowa State Univ., Ames Iowa

Gupta, S.C., J.F. Moncrief, and R.P. Ewing. 1991. Soil Crusting in mid-western United States. Adv. Soil Sci (in press).

Gupta, S.C., B. Lowery, J.F. Moncrief, and W.E. Larson. 1991. Modeling tillage effects on soil physical properties. Soil Tillage Research, 20: 293-318.

BRUCE MONTGOMERY

Soil Scientist, Agronomy Services Div.
MN Dept. of Ag.

Education

M.S. Soil Science, North Dakota State University, 1984
B.S. Soil Science, Univ. of Wisconsin-Stevens Point, 1975

...ment History

... present: Minnesota Department of Agriculture
1977-1990: Department of Soil Science, North Dakota State University

Recent Publications

Costa, J.L., Lyle Prunty, B.R. Montgomery, J.L. Richardson, and R.S. Alessi. 1991. Water quality effects on soils and alfalfa: II. Soil physical and chemical properties. Soil Sci. Soc. Am. J. 55:203-209.

Montgomery, B.R. 1991. Nitrogen in Minnesota Ground Water (MDA's component). Legislative Water Commission Report prepared in a cooperative effort between the Minnesota Pollution Control Agency and the Minnesota Department of Agriculture. St. Paul, MN.

Montgomery, B.R., L. Prunty and E.C. Stegman. 1990. Influence of irrigation and nitrogen management on nitrate leaching losses. In 1990 North Dakota Water Quality Symposium Proceedings. P. 95-114. March 20-21, 1990, Fargo, N.D.

Montgomery, B.R., L. Prunty, A.E. Mathison, E.C. Stegman, and W. Albus. 1988. Nitrate and pesticide concentrations in shallow ground water aquifers underlying coarse textured soils of S.E. North Dakota. In Proceedings of the Agricultural Impacts on Ground Water-A Conference. p. 361-387, March 21-23. Des Moines, Ia.

Prunty, Lyle and B.R. Montgomery. 1991. Lysimeter study of nitrogen fertilizer and irrigation rates on quality of recharge water and corn yield. J. Environ. Qual. 20:373-380.

Prunty, Lyle, B.R. Montgomery, and M.D. Sweeney. 1991. Water quality effects on soils and alfalfa. I. Water use, yield, and nutrient concentration. Soil Sci. Soc. Am. J. 55:196-202.

EDWARD A. NATER

Department: Soil Science
Rank: Assistant Professor

Education

Ph.D., Soil Science, University of California, Davis, July, 1987. Dissertation: Experimental pedology: The formation of kaolinite on feldspar surfaces. Advisor: Dr. Michael J. Singer.

M.S., Natural Resources, University of Wisconsin - Stevens Point, December, 1982. Thesis: A chemical and physical characterization of iron mining wastes of the Mesabi Iron Range, Minnesota. Advisors: Dr. R. David Hillier and Mr. John P. Borovsky.

B.S., Botany, Western Illinois University, Macomb, December, 1973.

Employment History

1987 - present Assistant Professor, Soil Science Department, University of Minnesota.
1986 - 1987 Post Doctoral Fellow, Department of Soil Science, University of Saskatchewan.
1982 - 1986 Research Assistant, Department of Land, Air and Water Resources, University of California, Davis.
1980 - 1982 Research Assistant, Department of Natural Resources, University of Wisconsin - Stevens Point

Professional and Honorary Societies
Soil Science Society of America
The Geochemical Society
Minnesota Association of Professional Soil Scientists
Sigma Xi

Publications
Nater, E.A., and D.F. Grigal. 199_. Regional Trends in Mercury Distribution Across the Great Lakes States, North Central U.S.A. *Nature* 358:139-141.

Bouabid, R., E.A. Nater, and P. Barak. 1992. Measurement of particle and pore size distribution in a lamellar B horizon by fluorescence microscopy and image analysis. *Geoderma* 53 (3/4):309-328.

Laird, D.A., P. Barak, E.A. Nater, and R.H. Dowdy. 1991. Chemistry of smectitic and illitic phases in interstratified soil smectite. *Soil Science Society of America*, 55:1499-1504.

Inskeep, W.P., E.A. Nater, P.R. Bloom, D. Vandervoort, and M.S. Erich. 1991. Characterization of laboratory weathered labradorite surfaces using x-ray photoelectron spectroscopy and transmission electron microscopy. *Geochimica et Cosmochimica Acta* 55:787-800.

Mason, J.A., E.A. Nater, and H.C. Hobbs. 1992. Transport direction of Wisconsinan loess in southeastern Minnesota, and implications for Wisconsinan vegetation history. Submitted to *Quaternary Research*.

Mason, J.A., and E.A. Nater. 1992. Relationships of soil morphology to parent material grain size in soils formed in Peoria Loess, southeastern Minnesota. Submitted to *Soil Science Society of America Journal*.

SALLY L. NOLL

Department of Animal Science, UM
Associat Professor

Education
1974 University of Minnesota, Animal Science, B.S.
1978 University of Minnesota, Animal Science, M.S.
1985 University of Minnesota, Animal Science, Ph.D.

Employment Record
1974-80 University of Minnesota, Research Assistant
1980-85 University of Minnesota, Assistant Scientist
1985-90 University of Minnesota, AssistantProfessor and Extension Animal Scientist - Turkeys
1990-present University of Minnesota, Associate Professor and Extension Scientist

Memberships

Poultry Science Association
World's Poultry Science Association
Member, Minnesota Turkey Grower Association-research subcommittees on Breeders, Processing, Nutrition, Disease, and Management
Education Program Coordinator - Midwest Poultry Federation Convention

Publications Selected

Noll, S.L., 1989. Management of breeding stock. In: Recent Advances in Turkey Science. Ed. C. Nixey and T.C. Grey. Butterworths, London, p. 119-131.

Noll, S.L. and P.E. Waibel, 1989. Lysine requirements of growing turkeys in varying temperature environments. Poultry Sci. 68:781-794.

Halvorson, D.A., S.L. Noll, M.E. Bergeland, H.A. Cloud and R. Pursley, 1989. The effects of stray voltage on turkey poults. Avian Diseases 33:582-585.

Noll, S.L., M.E. El Halawani, P.E. Waibel, P. Redig, and K. Janni, 1991. Effect of diet and population density on male turkeys under various environmental conditions. 1. Turkey growth and health performance. Poultry Sci. 70: 923-934.

Halvorson, J.C., P.E. Waibel, E.M. Oju, S.L. Noll, and M.E. El Halawani, 1991. Effect of diet and population density on male turkeys under various environmental conditions 2. Body composition and meat yield. Poultry Sci 70: 935-940.

Noll, S.L. and D.A. Halvorson, 1988. Turkey Production: Study Guide for Brooding and Growing Management Techniques". Minnesota Extension Service AG-VC-3410.

Halvorson, D.A., and S.L. Noll, 1988. Turkey Production: Study Guide for Disease Control and Prevention". Minnesota Extension Service AG-VC-3412.

Noll, S. L., 1991. Turkey manure handling. AG-FO-5653-B. Minnesota Ext. Service, University of Minnesota, St. Paul, MN.

Noll, S. L., 1991. Dead turkey handling. AG-FS-5652-A. Minnesota Ext. Service, University of Minnesota, St. Paul, MN.

Noll, S. L., 1991. Turkey farm siting and maintenance. AG-FS-561-A. Minnesota Extension Service, University of Minnesota, St. Paul, MN.

CLIVE F. REECE

Department: Soil Science, UM
Rank: Assistant Professor

Education

Ph.D., Soil Science, Washington State University, Pullman, May, 1991. Dissertation: Sparse Plant Community Effects on Soil Water Balance of an Arid Site. Advisor: Dr. Gaylon S. Campbell.

M.S., Soil Science, Cornell University, Ithaca, NY, January, 1988. Thesis: Effects of Flooding on Transpiration and Root Hydraulic Conductance of Conifer Transplants. Advisor: Dr. Susan J. Riha.

B.S., Plant and Soil Biology, Universit[illegible]ifornia - Berkeley, December, 1983.

Employment History

1991 - present Associate member of Graduate Faculty in Soil Science, University of Minnesota.
1991 - present Assistant Professor, Soil Science Department, University of Minnesota.
1987 - 1990 Laboratory Graduate Fellowship, U.S. Department of Energy.
1985 - 1987 Research Associate, Agronomy Department, Cornell University.

Professional and Honorary Societies

Soil Science Society of America
American Society of Agronomy
American Geophysical Union

Publications

Reece, C.F. and S.J. Riha. 1991. Role of root systems in response to flooding Eastern larch and white spruce. Plant, Cell and Environment 14:229-234.

Cortes, P., C.F. Reece and G.S. Campbell. 1991. A simple and accurate apparatus for the generation of a calibrated vapor pressure. Agric. For. Meteorol. 57:27-33.

MARK W. SEELEY

Extension Climatologist
Soil Science Department, UM

Assistant Professor, 1978 - 1982 (100% Extension)
Associate Professor, 1982 - 1989 (80% Ext. 20% Res.)
Professor, 1989 - present (80% Ext. 20% Res.)
Sabbatical leave to United Kingdom, Ministry of Agriculture (Feb. 89 to Feb. 90)

Position: responsible for coordinationa and operations of the Minnesota Cooperative Agricultural Weather Advisory Program and the Minnesota Agricultural Weather Networks (including the automated weather station network). Provide education programs in weather/climate and their application to management of agricultural enterprises and natural resources. Conduct applied research in appropriate areas.

Research Activities

Currently involved in an EPA regional research project: "Bioeconomic Models of Risk" (1990-1993) with Agricultural Economics and Agronomy and Plant Genetics.

"Centennial Data Digitization for Statistical Climate Studies and Hydrologic Models" with the Minnesota DNR-State Climatology Office (1991-1993). Funded WRRC through the USGS.

Recent Articles, Presentations and Publications:

Some Applications of Minnesota's Centennial Climate Data Base. 1992. with Jim Zandlo at Minnesota Water '92. Mpls Convention Center.

Weather, Climate and Cereal Growth. 1992. Minnesota Small Grains Institute, Red River Valley Winter Shows, Crookston,

Climatic Cycles: Uncertainties for 1991 and Beyond. 1990 Soils Fertilizer and Agricultural Pesticides Short Course. Mpls Convention Center.

Seeley, M.W., J.M. Graham and C.A. Schrader. 1990. The Importance and Utilization of Agricultural Weather Information In Minnesota: A Survey. J. Agron. Ed., vol. 19, No. 1:86-91.

Seeley, M.W. 1990. Climatic Considerations Relevant to the Use of Growth Regulators in Winter Cereals. British Ministry of Agriculture MAFF/ADAS Tech. Note 26 (38 pp)

WARD C. STIENSTRA

Professor
Plant Pathology, UM

Education

Institution	Major Area	Degree-Dates
Calvin College	Biology	B.A. - 1964
Michigan State University	Botany	M.S. - 1966
Michigan State University	Plant Pathology	Ph.D. - 1970

Employment

University of Minnesota, Professor, Jan 1981 -
Department of Plant Pathology Extension Specialist present
University of Minnesota, Associate Professor, July 1975 -
Department of Plant Pathology, Extension Specialist, 1980
University of Minnesota, Assistant Professor, May 1970 -
Department of Plant Pathology Extension Specialist, June 1975

Professional Societies

Sigma Xi
Epsilon Sigma Phi
Minnesota Golf Course Superintendents Association
The Scientific Research Society of North America
American Phytopathological Society
American Association for the Advancement of Science
Gamma Sigma Delta
International Turfgrass Society

Publications

Stromberg, E.L., W.C. Stienstra, T. Kommedahl, C.A. Matyac, C.E. Windels, and J.L. Geadelmann. 1984. Smut expression and resistance of corn to Sphacelotheca reiliana in Minnesota. Plant Disease 68:880-884.

Stienstra, W.C., T. Kommedahl, E.L. Stromberg, C.A. Matyac, C.E. Windels and F. Morgan. 1984. Corn head smut suppression with seed and soil treatments. Plant Disease 68:880-884.

Stienstra, W.C., T. Kommedahl, E.L. Stromberg, C.A. Matyac, C.E. Windels, and F. Morgan. 1985. Suppression of Corn Head Smut with Seed and Soil Treatments. Plant Disease 69:301-302.

Kennedy, B.W., J. Orf, and W.C. Stienstra. 1986. Outbreak of Powdery Mildew of Soybeans in Minnesota in 1985. Plant Disease 70:694. Disease Notes.

Windels, C.E., T. Kommedahl, W. C. Stienstra, and P. Burnes. 1988. Occurrence of Fusarium Species in Symptom-free and Overwintered Corn Stalks in Northwestern Minnesota. PD 72:990-993

A. Title of objective: Survey soil hydraulic properties, develop benchmarks of farmer nutrient management practices, and generate computer simulated outcomes to be used in research and teaching.

A.1. Activity: Conduct an inventory of existing farmer practices that will supply real time-data inputs for models that can estimate leaching and surface runoff losses of nitrogen and phosphorus as well as aid in identifying or further refining best management practices.

A.1.a. Context within the project: Currently there is a shortage of information statewide on how farmers manage nitrogen and phosphorus fertilizers, organic N and P sources (manures, legumes) and other management criteria (such as timing of application, tillage, etc) which have an direct effect on water quality. Obtaining this type of information is critical due to the complex water flow patterns associated with these karst regions. High N and P inputs associated with manure applications in this region adds to the complexity of understanding water quality. This inventory will supply real time data inputs for computer simulation models, such as CREAMS, that can estimate leaching losses and surface runoff as well as aid in identifying or further refining best management practices.

A.1.b. Methods. Detailed field by field nutrient management assessments for each selected farm will provide the specific information required for computer simulation efforts. Due to the intense nature of this approach, the number of farms will be limited to 60-80. Sampling population selection will be based upon a "focal group" concept rather than a random or stratified random design. This is a reasonable method of insuring that the sampling population is representative of the diversity of this region of the state. County agents will first be interviewed to get a broad perspective of a wide array of agricultural practices currently being used in Goodhue, Wabasha, Olmsted, Winona, Fillmore and Houston counties. Practices will be categorized; the agents will then be asked to suggest individual potential cooperators representing various levels of management skills. Particular attention will be placed on the method that each producer uses to store/handle manure since this can have a profound effect on manure management strategies. A total "on-farm" nitrogen inventory will first be collected by summing annual fertilizer tonnage, legume credits, and available nitrogen generated based on animal inventories. Farmers will be asked to describe nitrogen inputs/management on a field by field basis for the past two cropping seasons. Site-specific soil type information will be collected from existing soil surveys or collected with the cooperation of the Soil Conservation Service. Manure analysis from each farm will assist in calculating a nitrogen balance. Information will be grouped by geographic regions, soils and crops grown, as well as management factors. Data will be used to drive computer simulation modeling efforts elsewhere in the overall project. Establishment of "benchmarks" in current management practices will help in identifying future education directions.

A.1.c. Materials: Questionnaires and Extension Bulletins
A.1.d. Budget $43,000   Balance $0
A.1.e Timeline

	7/93	1/94	6/94	1/95	6/95
Design inventory questions/forms	xx				
Data base programming.		xx			
Establish sampling populations.	xx				
One-on-one interviews				xx	
Summary, publication of results.					xx

A.1.f. Final Detailed report

General Information

County Educators (MN Extension Service) from Fillmore, Goodhue, Houston, Olmsted, Wabasha, and Winona Counties were contacted and individually interviewed in July, 1993. Purpose of the interviews was: to inform them of the specifics of the project and overall goals; obtain pertinent county information (i.e. dairy density distributions in relation to Karst regions); and potential candidates (farmers) and their agronomic management skills as perceived by the County Educator. County Educators also served as an important link between the farmers and the researchers; Educators commonly made personnel telephone calls to the potential participants after the introduction letter (Appendix A-1) was mailed. Fifteen to twenty contacts, classified as either "Low", "Average" , or "High" management skills, were collected in each of the six counties. Introduction letters, signed by the Commissioner of Agriculture, were mailed out to the farmers in late July and early August, 1993. The letter's intent was to identify : the overall LCMR project; the purpose of the nutrient assessment; why they were selected; and what types of information and amount of their time would be necessary to successfully complete the project.

Nutrient Management Data Collection

Inventory forms and data base design were patterned after a previous successful project[1] . A copy of the inventory form is included in Appendix A-1. Timing,

[1]Effective Nitrogen and Water Management for Water Quality Sensitive Regions of Minnesota, LCMR 1991-93

rates, method of applications were collected for all nitrogen (N) and phosphate (P_2O_5) inputs (fertilizers, manures, and legumes) on **a field-by-field basis for all acres owned or rented**. There were 921 management areas in the entire study. A management area is defined as a field or group of fields (managed by the same producer) that had the same nutrient inputs. If an individual field was not managed uniformly, it would be broken down into separate management areas. Soil and manure testing results were also collected if available. Nutrient inputs and yields were specific for the 1993 cropping season. Crop types and manure applications (starting in the fall of 1992) were also collected from the 1992 season for purposes of 1993 nitrogen crediting. Long term yield data generally reflected the past 3 to 5 years. Livestock census and other specifics for the entire farm (i.e. types of manure storage systems, total farm sizes) were also recorded.

Farm Size and Crop Characteristics of the Selected Farms

Sixty-three (63) farmers were interviewed during August and September, 1993. Total inventoried acres by county (and number of farms per county) are as follows: Fillmore 6,200 (11), Goodhue 5,100 (11), Houston 4,400 (11), Olmsted 3,900 (10), Wabasha 3,000 (10), and Winona 3,200 acres (10). Total area covered by the interviews was 25,700 acres; 17,350 acres were identified as tillable (Table A.1.1). The average farm size was 405 acres with 274 acres in cropland and an average herd size of 68 cows.

Corn (46%), alfalfa (32%), small grains (12%), and soybeans (6%) accounted for over 96% of the cropland acres (Figure A.1.1). In contrast, the cropland distribution across all farms in the six county area[2] was comprised of corn (49%), alfalfa (22%), soybeans (16%), small grains (10%), and miscellaneous crops (3%) (Figure A.1.2). The selected farms were skewed towards alfalfa acres and less soybeans than the overall six county distribution. County specific data is given in Table A.1.2

Table A.1.1. General description of all farms participating in the 1993 Southeast MN nutrient management assessment.

		Total Acreage Inventoried			Average Acreage by Farm			
Average County Size	Farm	Total[1]	Crop[2]	Noncrop	Total[1]	Crop[2]	Noncrop	Herd
		.... Acres						Number of (Cows)
Fillmore	11	6212	4120	2092	565	374	191	67
Goodhue	11	5089	3594	1495	463	327	136	72
Houston	11	4374	2398	1976	398	218	180	55
Olmsted	10	3853	3034	819	385	303	82	84
Wabasha	10	3011	1999	1012	301	200	101	59
Winona	10	3160	2233	927	316	223	93	68
Mean		**4,283**	**2,519**	**1,387**	**405**	**274**	**130**	**68**
Total	**63**	**25,699**	**17,378**	**8,321**				
Percent Total		**100**	**67.6**	**32.4**				

(1) Includes owned, rented and rented out acres.
(2) Includes fertilized or manured pasture and set-aside acres.

[2]MN Agricultural Statistics 1994. National Agricultural Statistics Service, St. Paul, MN.

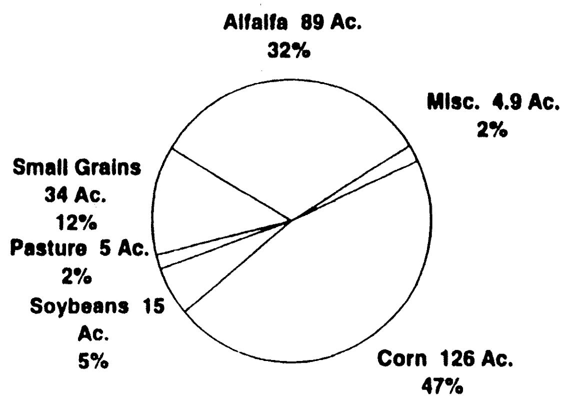


Figure A.1.1. Crop type distribution across all cropland acres of the selected farms. Acres listed are the averages per farm.

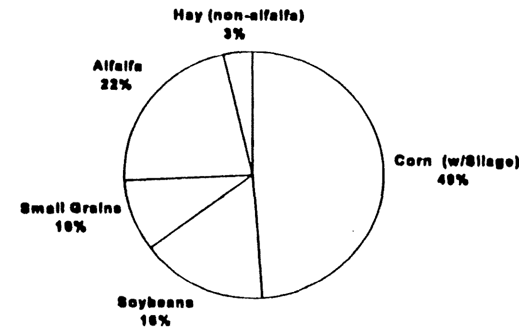


Figure A.1.2. Crop type distribution across **all** 1993 cropland acres in Fillmore, Goodhue, Houston, Olmsted, Wabasha, and Winona Counties (MN Agricultural Statistics, 1994).

Table A.1.2. Average distribution of cropland acres per farm by county - 1993								
County	Corn	Soybean	Alfalfa	Small Grains	Sweet Corn	Other	Fertilized Pasture	TOTAL
	In Acres							
Fillmore	186	42	96	40	0	3.9	7.3	374
Goodhue	142	17	103	40	14.4	9.4	0	327
Houston	97	8	76	32	0	1.5	4.4	218
Olmsted	148	11	102	29	0	1.6	12	303
Wabasha	80	6	80	31	0	0	3.0	200
Winona	104	8	76	31		1.2	3.0	223
Mean	**126**	**15**	**89**	**34**	**2.4**	**2.4**	**5.0**	**274**
Total	**7,992**	**987**	**5,595**	**2,146**	**158**	**191**	**309**	**17,378**
% by Crop Type	**46.0**	**5.7**	**32.2**	**12.3**	**0.9**	**1.0**	**1.8**	

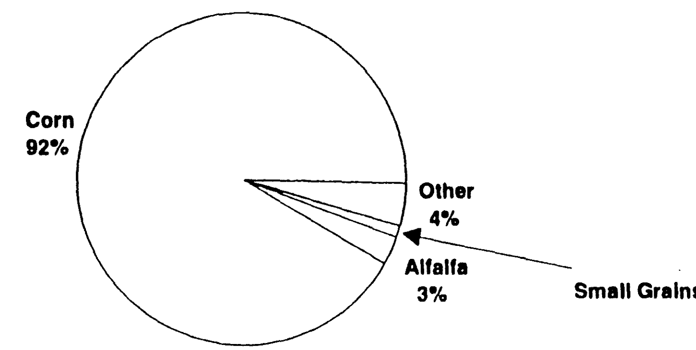


Figure A.1.3. Distribution of commercial nitrogen fertilizer by crop type. Total nitrogen supplied by fertilizer was 730,000 pounds across all farms.

Commercial Fertilizer Use Characteristics on Selected Farms

Corn accounted for 92% of the total N commercial fertilizer use (Figure A.1.3) and 94% of the total corn acreage received commercial N fertilizer. Average fertilizer N rate on corn acres was 90 lb/A; this rate is calculated as the means across all commercially fertilized corn acres regardless of past manure or legume N credits. Total N inputs will be discussed later in the "Nitrogen Balances and Economic Considerations" section. Alfalfa, small grains, and soybeans received 19, 20, and 42 lb/N/A, respectively, however the total acreage of any of these crops receiving commercial N is very limited (Table A.1.3 and Figure A.1.5). Phosphate rates on corn and alfalfa were 30 and 34 lb/A, respectively (Table A.1.3). Over 93% of the P_2O_5 fertilizer purchased on the farms was applied to these two crops (Figure A.1.4).

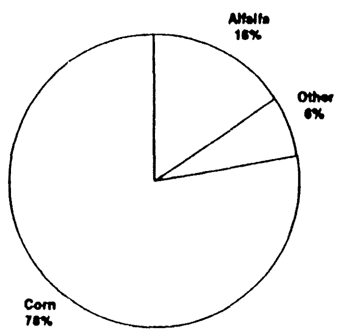


Figure A.1.4. Distribution of P_2O_5 fertilizer by crop type. Total P_2O_5 supplied by fertilizer was 285,000 pounds across all farms.

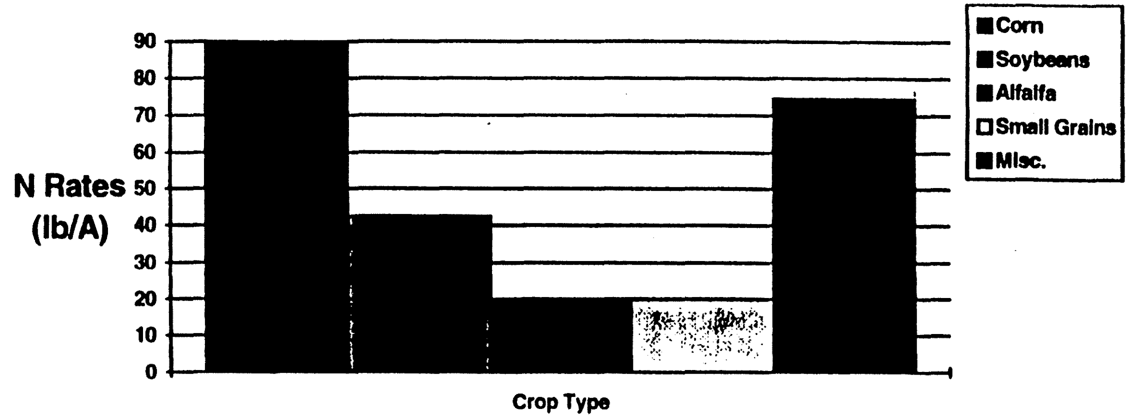


Figure A.1.5. Average N fertilizer rates across fertilized acres by crop type.

Table A.1.3. Distribution of commercial nitrogen and phosphate applications on cropland - 1993

Crop	Acres Receiving N Fertilizer	Total N Applied (LBS X 1000)	Acres Receiving P_2O_5 Fertilizer	Total Applied P_2O_5 (LBS X 1000)
Corn	7,495	671.7	7,508	222.3
Soybeans	165	7.0	165	4.2
Alfalfa	1,027	19.7	1,283	44.2
Small Grains	364	7.3	459	9.9
Other	321	23.9	163	4.3
TOTALS	**9,372**	**730**	**9,578**	**284.9**

Timing of N fertilizer applications is an important consideration in maximizing fertilizer use efficiency and minimizing environmental effects. There has been a great deal of concern about fall N applications in the Karst areas of Minnesota. Fall applied N is not recommended[3] under any circumstances. In this study, there was **no fall fertilization on corn** (Figure A.1.6) and less than 3% of all remaining N fertilizers used on non-corn crops was fall applied. Even common phosphate fertilizers, such as 18-46-0, 9-23-30 and 7-21-7, were almost exclusively spring applied.

Based on MDA tonnage sales reports[4] (Figure A.1.7), it was previously believed that fall-application was still a relatively common practice. Sales data indicate that approximately 23% of the N is purchased in the fall. It appears that farmers are buying fertilizers in the fall for price advantages and tax purposes however the products are being spring applied.

Another important BMP for this region is to apply N as a spring preplant N on corn using anhydrous ammonia or urea. These two forms of N account for approximately 74% of the total commercial use (Figure A.1.8). Granulars[5] accounted for another 15% of the applied commercial N. UAN[6] is not an ideal source for preplant application. This product accounts for less than 10% of the overall sales and, although details regarding the timing of the application of this product are not yet known, the rate per application is approximately 50 lb/N/A. It is speculated that most of the usage is a either as a herbicide carrier and for sidedress applications. Negative environmental impacts from this type of use is probably minimal.

[3] G.W. Randall and M.A. Schmitt, 1993. Best Management Practices for Nitrogen Use in Southeastern MN. . AG-FO-6126-B.

[4] MN Department of Agriculture is responsible for tracking county level fertilizer sales based on dealer information.

[5] Granular fertilizers represent a large array of various formulations, excluding urea, which are dominantly ammonium based.

[6] Urea Ammonium Nitrate (28% N by weight).

Producers are recommended to apply sidedress applications prior to the corn reaching a height of 12". Over 91% of the fertilizer N is applied prior to the corn reaching a height of 8". Producers are highly motivated to apply N as a sidedress prior to the 12" height due to difficulties in physically clearing the crop canopy with the required fertilizer/tillage equipment.

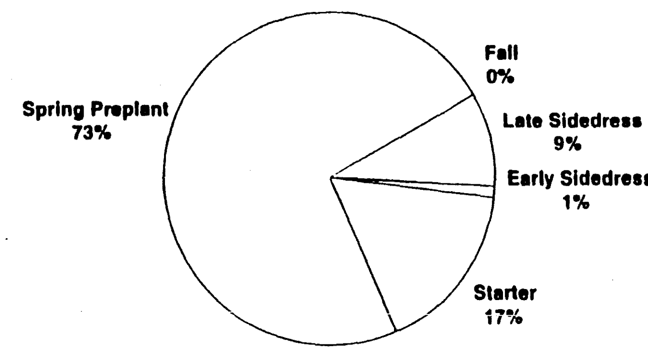


Figure A.1.6. Timing of N fertilizer applications across all crop types.

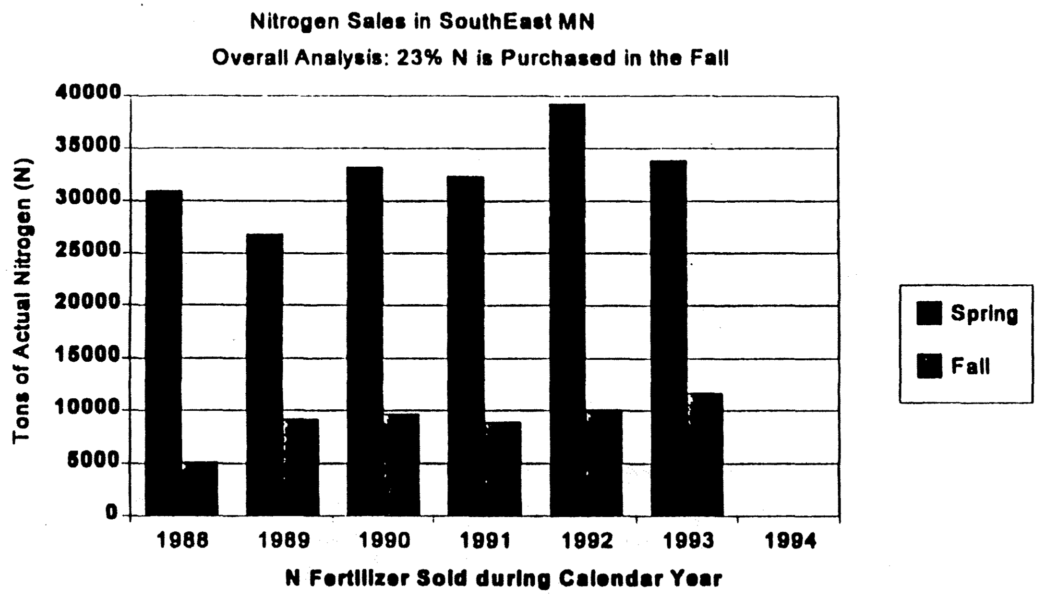


Figure A.1.7. County based N fertilizer sales during 1988-93 for Fillmore, Goodhue, Houston, Olmsted, Wabasha, and Winona counties. Data provided by the MN Department of Agriculture.

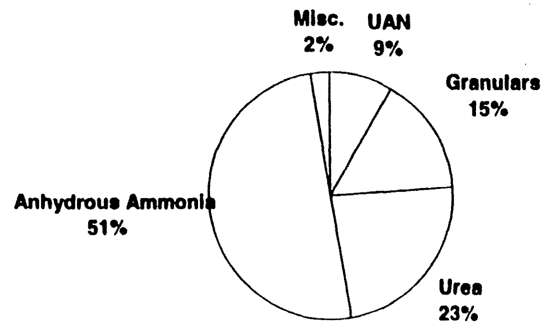


Figure A.1.8. Contributions of N from all fertilizer sources from the 63 selected farms.

The use of nitrification inhibitors can be helpful in controlling either leaching losses (coarse-textured soils) or denitrification during periods of near-saturated conditions on the fine-textured soils such as those that dominate much of southeast MN. Generally inhibitor use would not be recommended in this region of the state. No inhibitors were used with any N source, however, one producer had used the product with applications of liquid manure.

Livestock and Manure Characteristics of the Selected Farms

Factors directly affecting nutrient availability from land applied manure (including manure storage, types, manure amounts being generated, application methods, incorporation factors and rates) were also quantified to complete the "whole farm" nutrient balance. These farms were dominantly dairy with an average herd size of 68 cows. Over 10,000 dairy animals (cows, calves, heifers, and steers) were inventoried. A complete animal inventory, including nitrogen and P_2O_5 produced and collected, are summarized in Table A.1.4.

Table A.1.4. 1993 livestock numbers, and manure N and P_2O_5 produced and collected by livestock types in sample population.

Livestock Type	Livestock Number	Manure Nitrogen Produced	Manure Nitrogen Collected	Manure P_2O_5 Produced	P_2O_5 Collected
		Pounds X 1000		Pounds X 1000	
Dairy Cows	4,594	895.8	692.7	362.9	280.6
Calves & Heifers	4,936	474.6	318.4	190.4	127.3
Dairy Steers	868	130.2	104.2	52.9	42.3
Boars	3	0.1	0.1	0.1	0.1
Sows & Litters	45	1.4	1.4	1.1	1.1
Feeders (20 - 50 pounds)	6,473	0.9	0.9	0.7	0.7
Finishers (50 -240 pounds)	6,643	30.2	30.2	22.9	22.9
Bulls	7	1.1	0.6	0.8	0.4
Beef Cows & Calves	224	27.5	15.5	21	1.8
Beef Feeders	169	12.2	6.5	9	4.8
TOTAL	**23,962**	**1,574**	**1,170**	**662**	**492**

Estimated amounts of N and P_2O_5 **per farm** produced from all livestock were 25,000 and 10,500 pounds, respectively (Figure A.1.9). Dairy cows, calves and heifers generated approximately 86% of the associated N and P_2O_5 produced through manure (Figure A.1.10).

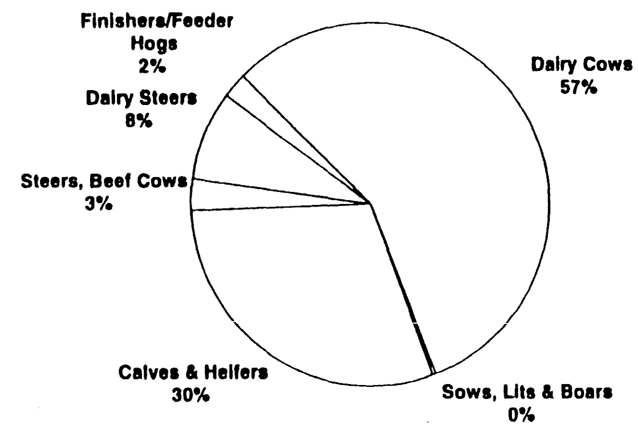


Figure A.1.9. Amounts of nitrogen (total) generated by animal types across all selected farms. Total N produced per farm was 25,000 pounds.

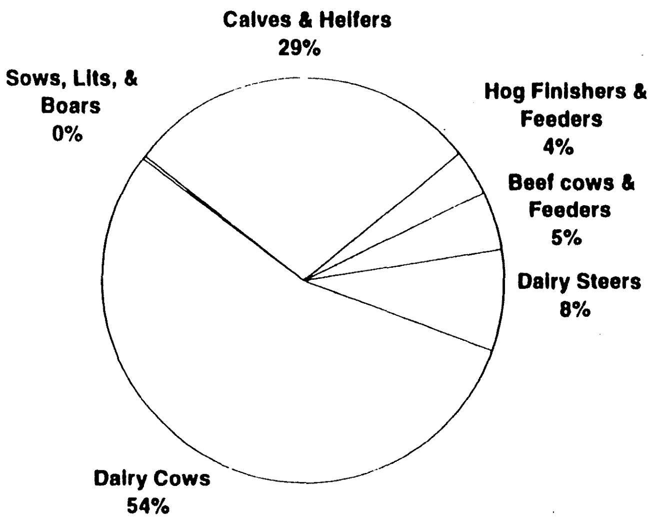


Figure A.1.10. Amounts of P_2O_5 generated by animal types across all selected farms. Total P produced per farm was 10,500 pounds.

Types of storage systems available for producers is an important consideration in efficiently retaining nutrients and allowing enough storage to field apply the manure in an environmentally safe manner. Twenty six (26) farms had liquid systems; the remaining 37 farms were dominantly daily scrape and haul operations. For purposes of this report, the following definitions were used: *Daily Scrape and Haul*-No storage available, manure is hauled generally on a daily basis. Common in dairy operations with stanchion or tie-stall barn designs; *Paved and Unpaved Pads*-Areas where solid manure is stacked on either the ground or cement pads to allow storage through the winter months until fields are accessible for spreading; *Paved and Unpaved Lots*-Cement or gravel covered areas that confine cattle. Manure (solid) is often hauled once or twice a year although some are cleaned monthly: *Animal Barns*- Buildings used to house livestock. The floors can either be cement, such as in a normal frame barn, or commonly a dirt floor often found in pole barns. Manure (solid) is often hauled in spring and fall, although the barns housing young calves are usually hauled more frequently; *Earthen Pits*- A majority of these pits are designed to meet Minnesota Pollution Control Agency and Natural Resource Conservation Service standards. Bottoms are frequently lined with compacted clay or other near-impervious material. Pits are usually emptied once or twice a year and are not covered; and *Slurry Store*-Above ground steel tanks which are generally emptied once or twice per year. Tanks are generally not covered.

Amounts of N and P collected, lost in storage, and amounts retained for land application are summarized by collection systems in Table A.1.5. Based on the N retained after collection (Figure A.1.11), the dominant collection systems of southeast MN are; animal barns(24%), daily scrape and haul systems (19%), earthen pits (19%) and slurrystore systems (16%). It appears that producers have the equipment facilities to store roughly three-fourths of the manure (based on retained N) and shouldn't be subjected to applying manure during poor weather conditions. Daily scrape and haul systems pose difficult en-vironmental challenges and field-applied losses after are high if not properly incorporated.

Table A.1.5. Manure N and P_2O_5 collected and storage losses by all livestock on all farms in 1994

	Nitrogen Pounds X 1000			**Phosphate Pounds X 1000**		
Livestock Type	**Collected**	**Lost**	**Retained**	**Collected**	**Lost**	**Retained**
Daily Scrape/Haul	216	54	162	87.5	0	87.5
Unpaved Lot	80.8	40.4	40.4	32.9	09.8	23.1
Paved Lot	71.1	35.6	35.5	31.9	09.6	22.3
Animal Barn	274.9	82.8	192.1	116.6	0	116.6
Pit Under Barn	73.4	16.1	57.3	30.7	0	30.7
Concrete Tank	36.3	11.1	25.2	14.6	0	14.6
Slurrystore	189.8	41.8	148	76.9	0	76.9
Unpaved Pad	9.4	2.8	6.6	3.8	0	3.8
Earthen Pit (open)	143.6	43.1	100.5	63.7	0	63.7
Earthen Pit (covered)	75.2	22.5	52.7	33.3	0	33.3
SUBTOTAL	**1,170.5**	**350.2**	**820.3**	**491.9**	**19.4**	**472.5**

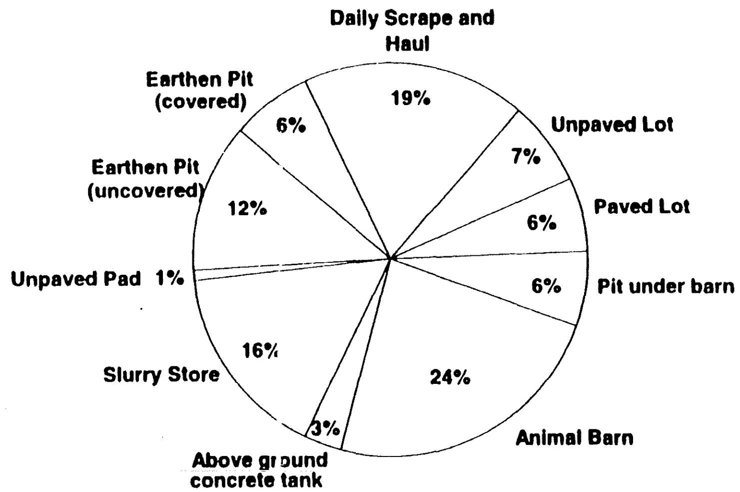


Figure A.1.11. Contributions of total nitrogen retained after storage by manure collection systems.

Nutrient losses from collection and storage were estimated from accepted guidelines[7] for each individual storage system. Losses as a function of application methods and timing factors were calculated on a field-by-field basis (Table A.1.6). Manure generated a total of 407,000 lb of "first year available" N. This represents 6,500 lb/N/farm.

The fate of manure-N has been summarized in a simple flow diagram (Figure A.1.12). This diagram simplifies the complexities associated with N from excretion to "plant available". Almost 85% (on a weight basis) of the "first year available" N is applied to corn. Alfalfa (5%), small grain (5%) and soybeans (4%) received the bulk of the difference (Figure A.1.13).

Manure testing is a critical component in nutrient management planning. Approximately 15% of the producers had done some manure testing prior to this project. Usually these producers had tested the manure only once. Participants were offered manure and well water testing as part of the program. Due to the high variability found in manure analysis, individual tests greatly enhanced the value of the on-farm nutrient balance. Forty-six manure analysis were performed and the results from all types of systems is summarized in Table A.1.7.

[7] Livestock Waste Facilites Handbook, Midwest Plan Services, Iowa State University, Ames, Iowa. 1985.

Table A.1.6. Distribution of applied manure to cropland, application and timing losses, and manure plant available nitrogen in 1993

		Manure Nitrogen Applied Pounds X 1,000			Nitrogen Losses Pounds X 1,000		
Crop	Total	$NH4^+$ (Inorganic)	Organic N	Mineralized Organic N 1st Yr. Avail	Application Losses	Timing Losses	Manure-N 1st Yr. Available
		Pounds Manure Nitrogen X 1000					
Corn	667.7	334.0	333.6	100.5	78.7	16.1	339.8
Soybean	32.3	16.4	16	4.8	5.5	0.2	15.4
Alfalfa	38.9	19.8	19	5.7	3.9	0.6	21
Sm. Grains	44.7	22.4	22.4	6.7	7.7	0.4	21
Other	21.8	10.8	11	3.6	4.2	0.1	10
TOTAL	**805**	**403**	**402**	**121**	**100**	**17**	**407**

Fate and Amounts of Manure N Across the 63 Farms

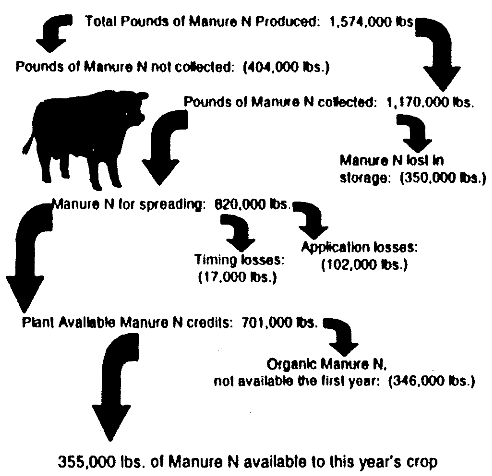


Figure A.1.12. Fate of manure-N across all storage and management factors.

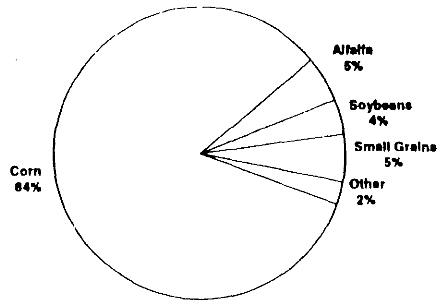


Figure A.1.13. Distribution of "first year available" nitrogen by crop type calculated on a weight basis.

Table A.1.7. Manure testing results summarized by collection systems.

System Description	Number of	Nitrogen			Phosphate			Potash		
Lbs per Ton	**Samples**	**Min.**	**Ave**	**Max.**	**Min.**	**Ave**	**Max.**	**Min.**	**Ave**	**Max.**
Daily Scrape & Haul	19	8	18	63	5	10	33	3	12	62
Unpaved Lot	3	8	10	13	5	6	6	2	7	13
Paved Lot	1	7	7	7	4	4	4	5	5	5
Animal Barn	4	10	11	14	7	8	9	3	7	11
Lbs per 1000 Gallon										
Pit Under Barn	3	39	42	45	20	21	24	26	28	30
Cement Tank	3	10	14	19	3	4	7	12	20	34
Slurry store	4	27	34	41	12	17	22	20	24	28
Earthen Pit (Covered)	1	48	48	48	36	36	36	19	19	19
Earthen Pit (Open)	6	3	26	48	2	12	23	3	20	38
Lagoon	2	16	21	26	7	11	12	14	17	20

manure test results from daily scrape and haul (19 samples) and liquid systems (19 samples) are illustrated in Figure A.1.14A and A.1.14B, respectively. Samples were highly variable particularly in the daily haul systems. Nutrient values with the sample group were generally higher than University of MN values. Liquid nutrient values were somewhat more consistent. This data is additional evidence of the high variability from farm to farm and manure testing is highly recommended.

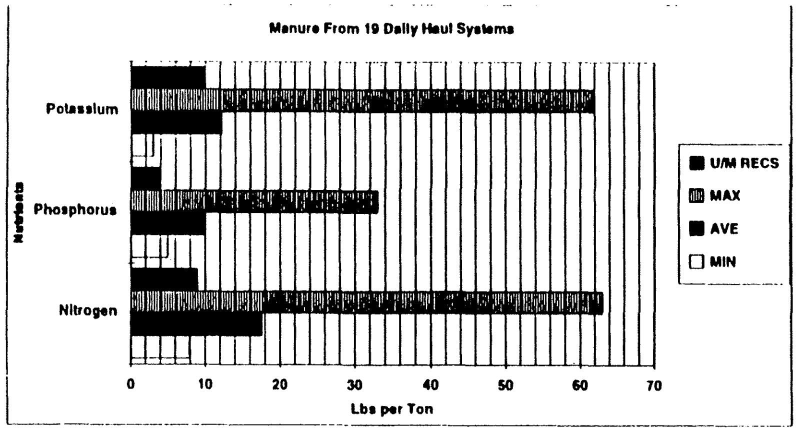


Figure A.1.14A. Nutrient values from 19 daily scrape and haul systems. University of MN average values are also included for comparison.

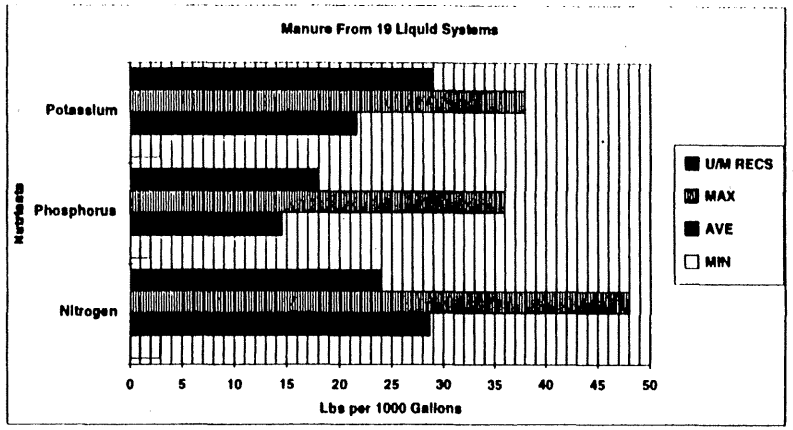


Figure A.1.14B. Nutrient values from 19 liquid systems (mixed systems). University of MN average values are also included for comparison.

Relative Importance of N and P Sources on the Selected Farms

Commercial fertilizer (49%), manure (27%), and legume[8] (24%) contributed a total of 1,489,000 pounds of "first year available" N across all farms. Commercial fertilizer (38%) and manure (62%) contributed a total of 757,400 pounds of P_2O_5.

Commercial fertilizer (49%), manure (25%), and legume (26%) contributed a total of 1,364,000 pounds of "first year available N" to **corn acres** (Figure A.1.15).

[8] Approximated value; total legume credits has been calculate however the value across all crops has not yet been determined.

This is an average N rate of 167 lb/A across all corn acres. Contributions from organic sources (accounting for a total of 50% of the inputs) is considerably higher in southeast MN than in other locations of the state. Proper crediting for these sources is critical in maintaining economic and environmental balances.

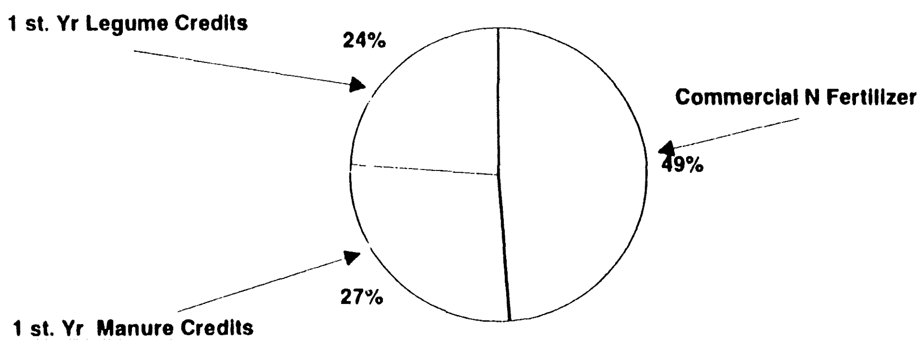


Figure A.1.15. Relative contributions from fertilizers, manures and legumes on first year available N across all corn acres. Average N input across all corn acres 167 lb/A.

Nitrogen Balances and Economic Considerations

The corn yield goal across all six counties was 147 bushels/A. Current University of Minnesota N recommendations to fulfill this goal is 135 lb/N/A (Figure A.1.16). It is important to note that these recommendations[9] are based on information that was not available to producers during the 1993 cropping season. Fertilizer rates have been decreased from previous recommendations. In 1990[10], N recommendations for 150 bushel corn following a Group 2 previous crop (crops with no residual N credit such as corn) would have been between 180 and 150 lb/A for soil organic matter groups of low-to-medium and high, respectively. In 1994, 120 lb/N/A and 150 lb/N/A would have been recommended for 131-150 and 151-170 bushel corn (now classified as medium to high soil organic matter).

Factoring in all appropriate credits from fertilizer, legumes and manures, there was an over-application rate of 53 lb/N/A. Within this report, averages across fields (on a county basis) have been reported. More detailed analysis will follow which will "weight" the data to account for the wide range in field sizes.

These numbers are somewhat conservative in nature due to the fact that only "first year credits" from manure are included in the analysis. A vast majority of the producers did not have adequate records from the previous year (1992[11]) to accurately credits these sources. Also the producers generally did not have sufficient information regarding alfalfa stand densities prior to terminating the crop therefore an average credit of 100 lb/A was assumed. A previous soybean crop is now given a 40 lb/A credit. We inadvertently used a 30 pound

[9] G.Rehm, M. Schmitt and R. Munter. 1994. Fertilizer recommendations for agronomic crops in Minnesota. BU-6240-E.

[10] G.Rehm and M. Schmitt 1990. Fertilizer recommendations for agronomic crops in Minnesota. AG-MI-3901.

[11] Referring to any manure applications prior to those made in the fall of 1992.

credit which would have been correct several years ago. Since the amount of acres in beans is minimal in this sample population, the error is minimal. Based only on the N fertilizer replacement value, proper crediting could save these producers approximately $10 to $11/A assuming no additional transportation and labor costs.

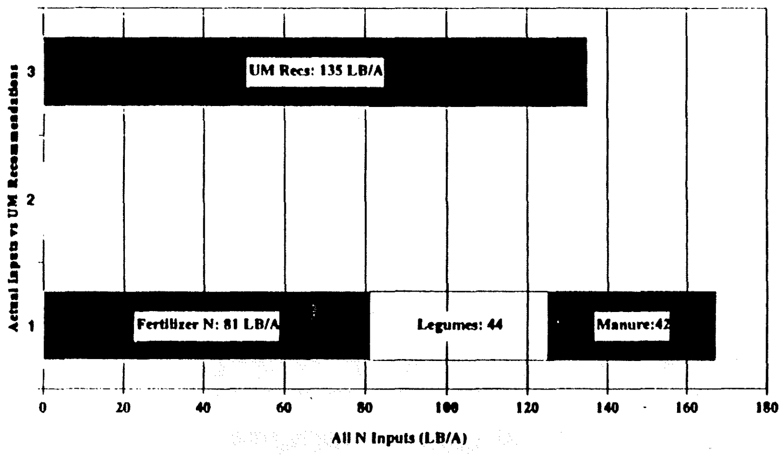


Figure A.1.16. Crop N requirements based on University of MN recommendations in comparison to actual N inputs (fertilizer, legumes, and manure) across all corn acres. Total corn area in this analysis was 7,992 acres.

Balances were examined in more detail by lumping the **corn acreage** into six different scenarios:

Scenario 1: N from fertilizer only; no manure or legume credits;
Scenario 2: Previously alfalfa (1992); no manure applied;
Scenario 3: Previously soybeans (1992); no manure applied;
Scenario 4: Previously a non-legume crop, manure applied;
Scenario 5: Previously a legume crop (1992), manure applied;
Scenario 6: Previously alfalfa (1991).

Nitrogen balances for all corn acres are broken down into these scenarios in Table A.1.8. Fertilizer N rates specific to each scenario is illustrated in Figure A.1.17. Rates in scenario 1 (no legumes, no manure) averaged 122 lb/A. One method to determine the credits attributed to the various organic contributions is to compare the subsequent commercial rates. **The following comments are based completely on the net differences in fertilizer N inputs comparing corn fields receiving only fertilizer N to the other scenarios:**

* Producers reduced N fertilizer by 49 lb/A for the "first year" alfalfa credits (N rate averaged 73 lb/A);

* Crediting for soybeans was extremely limited;

* Producers also significantly reduced fertilizer inputs on manured fields. Fertilizer N rates in scenario 4 (non-legume, manure applied) and scenario 5 (legume, manure applied) were reduced by 45 lb/A and 72 lb/A, respectively. These translate into reduction of 37 and 59%, respectively, in comparison to acres receiving only commercial N;

* Second year crediting for alfalfa is an important consideration in this region of the state. This scenario accounted for approximately 15% of the total corn acreage. Producers were reducing fertilizer N rates by 18 lb/A.

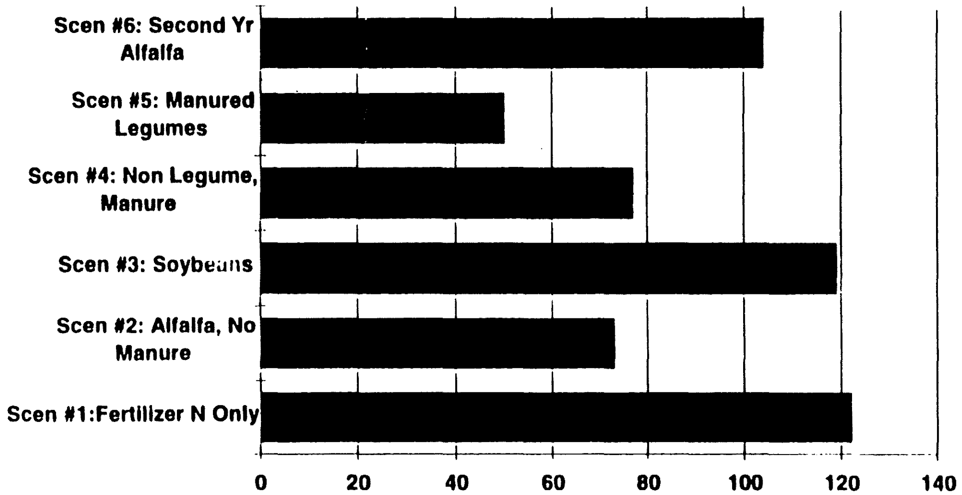


Figure A.1.17. Commercial fertilizer N rates on corn by management scenario.

Factoring in legume and manure credits into the process on a field-by-field basis, the amounts in excess[12] of 1994 University of MN recommendations are illustrated in Figure A.1.18. One of the huge advantages of the technique developed through the nutrient assessment process is the ability to examine in great detail the nutrient balances and make some inferences on where the biggest gains in water quality can be obtained through focused educational programs. Nitrogen balances are given in Table A.1.8.

[12] In all scenarios, the balance was excess rather that a shortage.

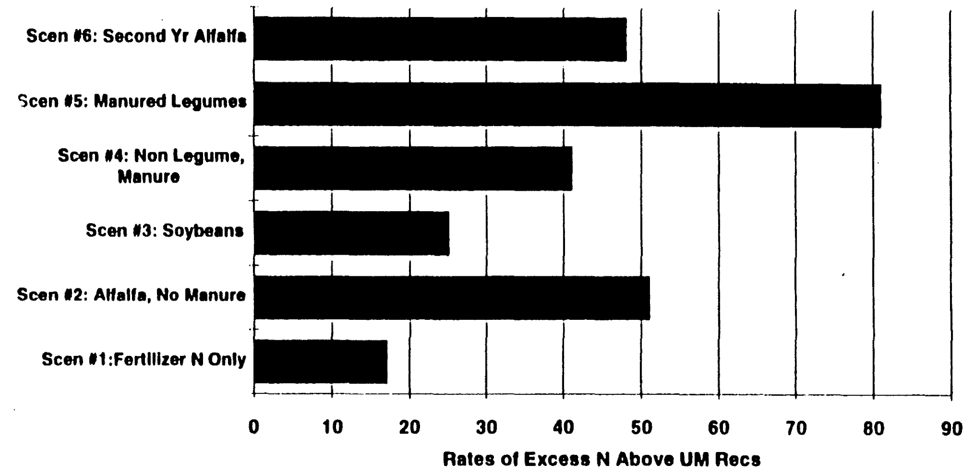


Figure A.1.18. Amounts of N in excess of 1994 University of Minnesota recommendations across the different management scenarios. Analysis includes all 7,992 acres.

As previously mentioned, the UM recommendations have been in the stage of transition over the past 5 years. In scenario #1, producers would have been very close to recommendations made in 1990. Using the new recommendations, producers were over-applying by 17 lb/A. Over-application rates in scenarios 2 through 4 ranged from 25-50 lb/A. Clearly the scenario where producers most severely over-applied N was on previous legume crops which received manure applications prior to corn production. Under-estimation of alfalfa credits was similar for both first and second year crediting.

Acreage distributions and N balances were then divided into two additional categories; ABOVE and BELOW UM recommendations. Data are given in Tables A.1.8B and A.1.8C respectively. Seventy-six (76%) of the total corn acres were classified into the ABOVE category. Excess amounts of N averaged 70 lb/Acre. The remaining acres (24%) were classified as BELOW UM recommendations. Shortage amounts of N average 39 lb/A and it is interesting to note that most of this shortage fell into scenario 1.

Viewing the distribution of excess N from a water quality perspective, a helpful indicator is the cumulative excess N values found in Table A.1.8A. These figures factor in both the total acres of any given scenario as well as the rate of excess (shortage) of N. Clearly where producers could gain the most N credits and make the biggest impact on water quality is to take the credits associated with scenario #5. Figure A.1.19 captures this concept by illustrating the relative excess N by the various management scenarios.

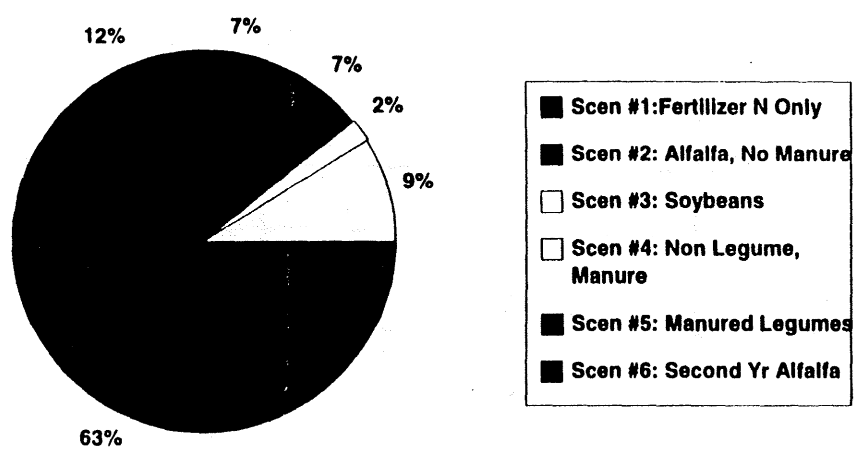


Figure A.1.19. Relative contributions of total excess N by the different management scenarios across all corn acres.

Table A.1.8A.
Nitrogen Inputs and Balances Across All Southeast Areas

Scenario Number	Total Acres	PCN[13] (LBS/A) PNC Total	Manure N (LBS/A)	Manure Total	Fert N (LBS/A)	Fert N Total	N Rec.[1] (LBS/A)	N Rec. Total	Excess (LBS/A)	Excess Total	
1	1,779	0	0	0	0	122	21,089	127	226,302	17	30,06
2	592	100	59,200	0	0	73	43,277	26	15,120	51	30,43
3	332	30	9,960	0	0	119	39,615	98	32,644	25	8,14
4	919	0	0	72	65,977	77	70,723	132	121,724	41	37,74
5	3,310	70	230,260	80	266,417	50	166,457	55	181,743	81	266,83
6	1,060	50	53,000	0	0	104	109,870	67	71,476	48	51,18
TOTALS FOR ALL SCENARIOS	**7,992**	**44**	**352,420**	**42**	**332,393**	**81**	**647,031**	**81**	**649,000**	**53**	**424,38**

[13] PNC = Previous Crop Nitrogen credit.

[1] Recommendations based on yield goal, previous crop and the organic matter according to the University of Minnesota recommendations where soil nutrient test results were not available.

Table A.1.8B.
Nitrogen Inputs and Balances Across Excess Nitrogen - Southeast Areas

Scenario Number	Total Acres	PCN[1] (LBS/A)	PNC Total	Manure N (LBS/A)	Manure Total	Fert N (LBS/A)	Fert Total	N Rec.[2] (LBS/A)	N Rec. Total	Excess (LBS/A)	Excess Total
1	1,195	0	0	0	0	145	172,839	113	134,499	33	39,536
2	496	100	49,600	0	0	88	43,624	27	13,339	61	30,172
3	270	30	8,100	0	0	125	33,856	98	26,333	28	7,534
4	602	0	0	84	50,641	111	67,098	132	79,233	66	39,804
5	2,631	74	193,786	84	220,966	60	157,171	49	129,210	95	250,019
6	869	50	43,450	0	0	134	116,711	66	57,366	68	59,335
TOTALS FOR ALL SCENARIOS	**6,063**	**49**	**294,936**	**45**	**271,607**	**98**	**591,299**	**73**	**439,980**	**70**	**426,419**

Table A.1.8C.
Nitrogen Inputs and Balances Across Shortage Nitrogen Acres - Southeast Areas

Scenario Number	Total Acres	PCN[1] (LBS/A)	PCN Total	Manure N (LBS/A)	Manure Total	Fert N (LBS/A)	Fert Total	N Rec.[2] (LBS/A)	N Rec. Total	Shortage (LBS/A)	Shortage Total
1	581	0	0	0	0	85	49,504	138	80,253	53	30,543
2	96	100	9,600	0	0	11	1,052	25	2,426	14	1,374
3	62	30	1,860	0	0	124	7,661	135	8,370	11	693
4	317	0	0	62	19,502	19	5,973	137	43,443	57	17,928
5	679	53	35,796	56	38,171	12	8,106	90	60,977	21	14,476
6	191	50	9,550	0	0	20	3,785	71	13,478	50	9,626
TOTALS FOR ALL SCENARIOS	**1,926**	**29**	**56,806**	**30**	**57,673**	**40**	**76,081**	**108**	**208,947**	**39**	**74,640**

Scenario Definitions:

Scenario 1 = Acres receiving only fertilizer N; no PCN or manure applied.
Scenario 2 = Acres previously in alfalfa; no manure applied.
Scenario 3 = Acres previously in soybeans; no manure applied.
Scenario 4 = Acres receiving manure with no previous PCN.
Scenario 5 = Acres receiving manure with PCN.
Scenario 6 = Acres previously in alfalfa in 1991.

Conclusions and Summary of the Current Nutrient Management Practices in Southeast Minnesota

Sixty-three farms, covering over 25,000 acres, participated in the **FA**rm **N**utrient **M**anagement **A**ssessment **P**rogram (**FANMAP**) with staff from the Minnesota Department of Agriculture. Producers volunteered 2-4 hours of their time to share information about their farming operation. Producers were carefully selected to represent a wide diversity of management skills and farm characteristics. The overall purpose of the program was to develop a clear understanding of current farm practices regarding agricultural nutrients and utilize this knowledge for future water quality educational programs.

Nitrogen management in this region of the state is challenging due to its karst topography, significant alfalfa acres, and high dairy density. Manure management is also confounded by the popularity of daily scrape and haul collection systems. Approximately 20% of the manure-N available for land application results from this type of system. This area has a high diversity of storage/collection systems, most of which provide some opportunity for storage. The process of manure crediting is greatly simplified with manure storage systems that allow for a minimal number of land application events. Approximately 75% of the N retained after storage originated from a variety of systems that allowed for some storage benefits.

Proper timing of N applications is one of the key management strategies that producers in this region can implement to minimize N leaching losses. In the last 5 years, producers have been encouraged to avoid fall application. FANMAP determined that fall application of N was extremely rare; spring preplant and starter N accounted for 90% of applied N fertilizer. Source selection of N fertilizers were also in excellent agreement with current BMPs developed by MES in conjunction with MDA. Over 90% of the N fertilizers were ammonium based products.

The overall N rate attributed from all three sources (fertilizers, legumes and manure) is a critical issue. Manure accounts for approximately 25% of the 'first year available' N; legumes account for another 25%. Obviously proper crediting of both of these sources is needed to successfully manage N in southeast Minnesota. On corn acres where no previous manure or legume credits existed to confound the rate selection process, producers appear to be in excellent agreement with recommendations that were made by UM/MES **four to five years ago**. Consequently due to the development of more conservative recommendations, producers were over-applying fertilizer inputs by 17 lb/N/A. Roughly 70% of the acreage in this particular scenario received N rates in excess of UM recommendations. Interestingly, the remaining 30% were significantly under-fertilized (-53 lb/A).

Overall, producers reduced N fertilizer inputs following "first year" alfalfa. However, additional reductions (50 lb/A) could be made with a low probability of yield loss. Producers also reduced N fertilizer inputs by approximately 20 lb/A for second year alfalfa; additional credits of 47 lb/A could be obtained by following research based BMPs. It appears that producers need the assessment tools for determining alfalfa stand densities and record keeping systems to aid in more effectively capturing alfalfa credits. Soybean crediting was almost non-existent, however, this crop occupied only 5% of the total cropland of the farms participating in the study.

Producers were basically reducing commercial N inputs by 45 lb/A in scenarios where previous manure applications were made to non-legume crops such as corn. Producers were under-estimating the value of the manure by approximately 40 lb/A. In southeast MN, it is a very common practice to apply manure to old alfalfa stands which are followed by corn in the rotation. In this scenario, producers were found to reduce their commercial inputs by approximately 70 lb/A. However the combination of alfalfa and manure credits, coupled with the fertilizer (average of 50 lb/A), resulted in over-applications of 80 lb/A. In these situations, only a starter N application should be applied and would trim 30 to 35 lb/N/A from the N budget. Producers could capture a much higher percentage of the "fertilizer replacement value" by applying the manure into other corn rotations. Although 85% of the "first year" available N was applied to corn in this study, only 50% of the corn acres received annual applications of manure. From a water quality perspective, the most significant impacts could be made by improving the N crediting process in this particular cropping scenario.

In previously studies by the MN Extension Service, the nutrient value from manure has been found to be highly variable. Results from the 46 samples analyzed as part of this program were no exception. Manure testing needs continual promotion as a fundamental part of a nutrient management plan. Only 15% of the producers had tested their manure previously to this project.

There were some very positive findings from this study. There is strong evidence that producers are voluntarily adopting the educational materials and strategies developed by the University of Minnesota/MN Extension Service. It is also evident that promotional activities need to continue and be specifically targeted to deliver the most recent technology and recommendations.

Appendix

August 5, 1993 (612)297-3219

I do not have to travel very far anywhere in the state of Minnesota to hear conversation about agriculture and what effects our farming profession could potentially have on our groundwater resources. These conversations are universal -- from the local coffee shop to Extension events; the concerns have been carried over to the Capitol as well. Environmental responsibilities have been on the increase over the past few years and trends strongly indicate a growing public concern. You as a livestock producer may already feel the added responsibilities.

Our dairy industry is a highly visible one and a specialized segment of Minnesota agriculture that will have to be ready to respond to the new environmental challenges ahead of us. Regulations can be avoided down the road if we can provide adequate educational support and research based technology to our farming community.

In early July, the University of Minnesota, the Minnesota Extension Service (MES) along with the Minnesota Department of Agriculture (MDA) received a research/educational grant from the Legislative Commission on Minnesota Resources (LCMR). You may already be aware of some of the activities as a result of this grant. Dr. John Moncrief and other University of Minnesota soil scientists are currently doing a number of studies related to nitrogen and manure management in the "karst" regions of southeast Minnesota.

Another critical component of this project involves you! We simply do not have adequate information on how our dairy farmers handle their nitrogen sources .... whether it is from fertilizers, manures, or legumes. It is critical that there is a logical "link" between what the research community is doing and what is currently being practiced in the real world of production agriculture.

I am asking you, along with 80 other dairy farmers, to participate in a survey of nitrogen management practices. I have summarized a series of questions that you may already be asking yourself:

August 5, 1993
Page Two

Why was I selected?

This project focuses on dairy farmers from the "karst" regions of Goodhue, Fillmore, Houston, Olmsted, Wabasha and Winona counties. Your name was suggested as a possible participant by your local County Extension Educator.

Who else was selected?

Due to the high cost associated with this type of data collection, we will be limited to 80 participants. It is critical that the farmers selected are representative of farming practices typical for this region.

What kinds of questions would I be asked?
You will be asked questions about each individual field that you farm. Questions include such things as crop type, nitrogen fertilizer rates, timing of applications, manure applications, cost information and factors motivating nitrogen decisions. Questions will be limited to the 1992 and 1993 cropping seasons.

How long will the meeting last?
It will be dependent on the number of individual fields you farm and how complex your own inventory will be. Most interviews would last between 1 to 2 hours.

How will this information be treated? Will it be publicized?
No. Individual results will be reported in this study. The MDA will seek approval to make your information legally confidential.

When will the meeting take place and where?
We would like to meet with you, at your convenience, at your farm. We would like to collect the information between late July and conclude the data collection early September, if possible.

Who will come to my farm?
Dr. Tom Legg from St. Cloud State University has been contracted to handle the data collection. Denton Bruening, a student from St. Cloud State, will be conducting the interviews. Denton is from a dairy farm in Lincoln County and is well acquainted with Minnesota dairy farm operations. During the past few summers, Denton has been doing custom milking for dairy farmers fortunate enough to have a spare week to get away during the busy summer.

What can I gain by participating in this process?
You will be making a significant contribution to our agriculture community. This information will provide a "benchmark" on where we are at in terms of nitrogen and manure management strategies. "Benchmark" information can then be used to document changes in producer adoption for future educational programs

August 5, 1993
Page Three

Manure analysis, as well as domestic well analysis for nitrates, will be offered free to each cooperator. At the completion of the study, we will also provide each participant with a summary of the results and conclusions.

I am interested .... what will happen next?

You will receive a telephone call from Jerry Tesmer, your "County Extension Educator" within the next few days. This will be your opportunity to ask any additional questions you may have. You will then be asked if you would like to participate in the interview. Interview times will be set up at a later date.

I hope you will join the University of Minnesota, Minnesota Extension, as well as the Minnesota Department of Agriculture in this project.

Sincerely,

Elton R. Redalen
Commissioner

ERR:BRM:clj

CC: Greg Buzicky
Bruce Montgomery
Denton Bruening
Thomas Legg
Jerry Tesmer

NITROGEN MANAGEMENT INTERVIEW CONTROL FORM-S-E Dairy

June 14, 1995

Farm Number__________________

NAME__________________________________ PHONE___________

ADDRESS____

____

DIRECTIONS____

____

DATE_________________________ TIME_____________________

U:\data\interview.doc

MAP CONTACT:

WATER TESTS:

LIQUID MANURE TESTS:

SOLID MANURE TESTS:

BROCHURES

General Notes:

NITROGEN MANAGEMENT INTERVIEW FORM

Farm Number____________________

DATE___________________________ TIME________________________

I. BASIC FARM CHARACTERISTICS.

Years operated_______________

Acres______ Owned______ Rented in______ Rented out___

Farm type:

Cash crop_____________ Mixed________

Type of Livestock_______________

Main Crops______________ ______________

Herd average (lbs of milk):______________________________

Recent Acreage Changes(Last three years): Y or N____

Acreage______________________Year_________

Planned Acreage Changes(Next five years): Y or N____

Acreage______________________Year_________

Do you use a crop consultant?_____

Services:____

____

Name and Co.____

____

How many full time equivalents are provided by:

Family:___________ Hired Labor:__________

What is your soil type?____________________________________

Note:____

III.LIVESTOCK AND DAIRY ANIMALS.(1 Of 3)

General description of operation:____________________________

____

____

Recent changes Animal(last three years):______________________

____

Planned changes Animal(next five years):______________________

____

Now, as a basis for determining total manure production, we need to calculate the average number of animals and their average weights during 1993 and 1994.

Dairy:

Breeds:	Ave._%_of_herd
____________	________
____________	________

Ave # animals during yr.	_1993_	_1994_	"AVG "
11 - cows, milking and not	_____	_____	_____
12 - calves less than 1 yr.	_____	_____	_____
13 - rep. heifers 1-2 yrs. old	_____	_____	_____
15 - feeder steers	_____	_____	_____
avg. weight(steers)	_____	_____	_____
avg. weight at sale	_____	_____	_____

Farm Number______________

IV.Livestock and dairy operations (2 of 3)

Swine:

Type of operation: (check each applicable catagory)

_____ farrow _____ farrow to finish _____ finishing

For 1994 estimate number of hogs to be sold

Ave # animals during year	_1993_	_1994_	"AVG "
21 - Boars	_____	_____	_____
22 - Sows	_____	_____	_____
Farrow to feeder:			
23 - Pigs sold (total)	_____	_____	_____
Pigs on hand(ave)	_____	_____	_____
Weight of pigs sold	_____	_____	_____
Farrow to finish:(slaughters raised from birth)			
25 - Slaughters sold(total)	_____	_____	_____
Slaughters on hand	_____	_____	_____
Weight of slaughters sold	_____	_____	_____
Finishing only:			
24 - Slaughters sold(total)	_____	_____	_____
Slaughters on hand(ave)	_____	_____	_____
Weight of feeders purchased	_____	_____	_____
Weight of slaughters sold	_____	_____	_____

Notes____

____

____

Farm Number________

Livestock and dairy operations (3 of 3)

Beef:Type of operation: ______ combined cow-calf/feedlot oper.

_______Cow-calf operation ______ feedlot (finishing) operation

Breeds: Ave._%_of_herd

___________________ ____________

___________________ ____________

We are trying to determine the number of beef that are raised on your farm. In the ON HAND category please list the average number of beef you had on hand for the year.

Ave # animals during yr.	_1993_	_1994_	"AVG "
31 - Bulls	______	______	______
32 - Cows	______	______	______
Cow-calf operation:			
33 - Calves sold (total)	______	______	______
Calves on hand	______	______	______
Avg. age at sale	______	______	______
Feedlot operation:			
34 - Feeders sold (total)	______	______	______
Feeders on hand	______	______	______
Avg. weight at purch	______	______	______
Avg. weight at sale	______	______	______
Calf to finish:(birth to slaughter)			
35 - Feeders sold (total)	______	______	______
Feeders on hand	______	______	______
Avg. weight at sale	______	______	______

IV.MANURE HANDLING; EXCLUDING APPLICATION

MANURE STORAGE:

1---No storage, daily scrape and haul ________

2---Unpaved lot__________

3---Paved lot____________

4---Animal barn____________

20---HALF BARN HALF LOT

If you have a solid, Semi-solid ,or liquid storage what type?

5---Paved pad, covered________________

6---Paved pad, uncovered_______________

7---Drained storage, covered____________

8---Drained storage, uncovered____________

9---Storage building_____________

10--Pit under barn _______________

11--Above ground tank, concrete______________

12--Above ground tank, steel (Slurrystore)_____________

13--Unpaved pad, covered_____________

14--Unpaved pad, uncovered_____________

15--Outside earthen storage pit, covered_______________

16--Earthen storage pit, uncovered_______________

17--lagoon_____________

18--Poultry pit___________________

19--Compost system___________

IV.MANURE HANDLING; EXCLUDING APPLICATION *HOG MANURE*

GENERAL DESCRIPTION: ________________________________

List the manure collections in terms of livestock type to each system. Account for each system identified on page 6.

System 1: Codes________

Conveyed_____

1-NONE 2-GRAVITY 3-FLUSHED
4-PUMPED 5-HAULED 6-CONVEYER

Tis 20--Nursery (APPROX 10-20 LB)
21--GROWER(APPROX 20-50LB)
22--Feederpig days (APPROX 0-50LB)
23--Feeder to Slaughter(50LB TO 240)
24--Birth to Slaughter(0-240LB)
25--Mature Hogs(SOWS BOARS)
26--Mature Hogs(with young 0-20LB)

	Animal Type	Number	Time in System or Months
Months_______ SYSTEM CAPACITY:			
MANURE TYPE:_____ (-LI1QUID 2-SOLID)			
Months_______ SPREADING FREQUENCY:			
SPEADER CAP:________			
UNITS:________ (GAL, BUSH, TON)			

System 2: Codes________

Conveyed_____

1-NONE 2-GRAVITY 3-FLUSHED
4-PUMPED 5-HAULED 6-CONVEYER

Tis 20--Nursery (APPROX 10-20 LB)
21--GROWER(APPROX 0-50LB)
22--Feederpig days (APPROX 0-50LB)
23--Feeder to Slaughter(50LB TO 240)
24--Birth to Slaughter(0-240LB)
25--Mature Hogs(SOWS, BOARS)
26--Mature Hogs(with young 0-20LB)

	Animal Type	Number	Time in System or Months
Months_______ SYSTEM CAPACITY:			
MANURE TYPE:_____ (-LI1QUID 2-SOLID)			
Months_______ SPREADING FREQUENCY:			
SPEADER CAP:________			
UNITS:________ (GAL, BUSH, TON)			

System 3: Codes________

Conveyed_____
50LB)

1-NONE 2-GRAVITY 3-FLUSHED
4-PUMPED 5-HAULED 6-CONVEYER

Tis 20--Nursery (APPROX 10-20 LB)
21--GROWER(APPROX 20-50LB)
22--Feederpig days (UP TO APPROX

23--Feeder to Slaughter(50LB TO 240)
24--Birth to Slaughter(0-240LB)
25--Mature Hogs(SOWS,BOARS.REPLACE)
26--Mature Hogs(with young 0-20LB)

	Animal Type	Number	Time in System or Months
Months_______ SYSTEM CAPACITY:			
MANURE TYPE:_____ (-LI1QUID 2-SOLID)			
Months_______ SPREADING FREQUENCY:			
SPEADER CAP:________			
UNITS:________ (GAL, BUSH, TON)			

System 4: Codes________

Conveyed_____
50LB)

1-NONE 2-GRAVITY 3-FLUSHED
4-PUMPED 5-HAULED 6-CONVEYER

Tis 20--Nursery (APPROX 10-20 LB)
21--GROWER(APPROX 20-50LB)
22--Feederpig days (UP TO APPROX

23--Feeder to Slaughter(50LB TO 240)
24--Birth to Slaughter(0-240LB)
25--Mature Hogs(SOWS,BOARS)
26--Mature Hogs(with young 0-20LB)

	Animal Type	Number	Time in System or Months
Months_______ SYSTEM CAPACITY:			
MANURE TYPE:_____ (-LI1QUID 2-SOLID)			
Months_______ SPREADING FREQUENCY:			
SPEADER CAP:________			
UNITS:________ (GAL, BUSH, TON)			

System 5: Codes__________

Conveyed_____ 50LB)

1-NONE 2-GRAVITY 3-FLUSHED
4-PUMPED 5-HAULED 6-CONVEYER

Tis 20--Nursery (APPROX 10-20 LB)
21--GROWER(APPROX 20-50LB)
22--Feederpig days (UP TO APPROX

23--Feeder to Slaughter(50LB TO 240)
24--Birth to Slaughter(0-240LB)
25--Mature Hogs(SOWS,BOARS.REPLACE)
26--Mature Hogs(with young 0-20LB)

Months________
SYSTEM CAPACITY:

MANURE TYPE:_____
(-LI1QUID 2-SOLID)

Months________
SPREADING FREQUENCY:

SPEADER CAP:_________

UNITS:_________
(GAL, BUSH, TON)

Animal Type	Number	Time in System or Months
______	______	________
______	______	________
______	______	________
______	______	________
______	______	________
______	______	________
______	______	________

System 6: Codes__________

Conveyed_____ 50LB)

1-NONE 2-GRAVITY 3-FLUSHED
4-PUMPED 5-HAULED 6-CONVEYER

Tis 20--Nursery (APPROX 10-20 LB)
21--GROWER(APPROX 20-50LB)
22--Feederpig days (UP TO APPROX

23--Feeder to Slaughter(50LB TO 240)
24--Birth to Slaughter(0-240LB)
25--Mature Hogs(SOWS,BOARS)
26--Mature Hogs(with young 0-20LB)

Months________
SYSTEM CAPACITY:

MANURE TYPE:_____
(-LI1QUID 2-SOLID)

Months________
SPREADING FREQUENCY:

SPEADER CAP:_________

UNITS:_________
(GAL, BUSH, TON)

Animal Type	Number	Time in System or Months
______	______	________
______	______	________
______	______	________
______	______	________
______	______	________
______	______	________
______	______	________

System 7: Codes__________

Conveyed_____ 50LB)

1-NONE 2-GRAVITY 3-FLUSHED
4-PUMPED 5-HAULED 6-CONVEYER

Tis 20--Nursery (APPROX 10-20 LB)
21--GROWER(APPROX 20-50LB)
22--Feederpig days (UP TO APPROX

23--Feeder to Slaughter(50LB TO 240)
24--Birth to Slaughter(0-240LB)
25--Mature Hogs(SOWS,BOARS.REPLACE)
26--Mature Hogs(with young 0-20LB)

Months________
SYSTEM CAPACITY:

MANURE TYPE:_____
(-LI1QUID 2-SOLID)

Months________
SPREADING FREQUENCY:

SPEADER CAP:_________

UNITS:_________
(GAL, BUSH, TON)

Animal Type	Number	Time in System or Months
______	______	________
______	______	________
______	______	________
______	______	________
______	______	________
______	______	________
______	______	________

System 8: Codes__________

Conveyed_____ 50LB)

1-NONE 2-GRAVITY 3-FLUSHED
4-PUMPED 5-HAULED 6-CONVEYER

Tis 20--Nursery (APPROX 10-20 LB)
21--GROWER(APPROX 20-50LB)
22--Feederpig days (UP TO APPROX

23--Feeder to Slaughter(50LB TO 240)
24--Birth to Slaughter(0-240LB)
25--Mature Hogs(SOWS,BOARS)
26--Mature Hogs(with young 0-20LB)

Months________
SYSTEM CAPACITY:

MANURE TYPE:_____
(-LI1QUID 2-SOLID)

Months________
SPREADING FREQUENCY:

SPEADER CAP:_________

UNITS:_________
(GAL, BUSH, TON)

Animal Type	Number	Time in System or Months
______	______	________
______	______	________
______	______	________
______	______	________
______	______	________
______	______	________
______	______	________

Farm Number____________________

IV.MANURE HANDLING; EXCLUDING APPLICATION

MANURE HANDLING SYSTEM GENERAL QUESTIONS

GIVEN DAILY SCRAPE AND HAUL

If you were to build a manure handling system, liquid or solid, what type would it be?____________________

What do you think the total cost would be?____________________

Is cost sharing available in your area?____________________

If so, do you know how much you could get on the system you identified above?____________________

Compared to your daily scrape and haul system, how do you think the system identified above would affect the amount of the following nutrients provided by your manure? Think now about the amounts made available to crops. (Example answers: no change, 50%, more, etc.)

N __________

P __________

K __________

Why haven't you installed it?____________________

____

Will you, or under what conditions would you reconsider?

____

____

Notes____________________

____

Farm Number____________________

IV.MANURE HANDLING

MANURE HANDLING SYSTEM GENERAL QUESTIONS

GIVEN LONG TERM STORAGE

When did you install last system____________________

Previous system____________________

Approximate installation cost (whole system) ____________________

Labor savings or loss compared to previous system ____________________

____

Other savings or extra costs from previous system ____________________

____

Motivating Factor____________________

____

Second thoughts____________________

Notes____________________

____

V. OFF FARM MANURE PURCHASE; GENERAL QUESTIONS

System number_______ (101 or more)

If you purchase, or receive free, manure:

Animal Type	Number	Time in System or Months
_______	_______	_______
_______	_______	_______
_______	_______	_______

OR

AMOUNT RECEIVED_________ BUSHELS, GALLONS TONS___________

IS THIS TOTAL AMOUNT OR PER ACRE?__________

What form is it? (1-liquid 2-solid)______________

On what basis do you purchase it? (Volume, analysis, etc)

____

ANALYSIS INCLUDE ON ANALYSIS PAGE

On what basis do you pay for it?______________________________

Total cost_______________ Cost per unit_______________________

Does the cost above include: Unit description?__________

-transport to your farm?__________ application?__________

How do you determine and monitor app.__________________________

Total tons of manure purchased:________ (may be calculated by multiplying ton/acre by acres on page 19.)

Do you sell or give away any manure?

How much?

Tons________ Gallons__________ Bushels__________

OR

Animal TYPE_______ NUMBER______ TIS Code_______

Farm Number____________________

VII. CROPS AND ROTATIONS

Please describe your general rotation pattern:

____

Do you part. in ASCS Comm. Prog.?________ Does it affect your rotations?____

How many acres were planted to the following crops

Year	1993	1994	"AVG"
Acres in:			
CRP/ RIM	________	________	________
CORN	________	________	________
Soybeans	________	________	________
Small grains	________	________	________
Alfalfa	________	________	________
Pasture	________	________	________
Edible beans: type____	________	________	________
Sunflowers	________	________	________
Sugar beets	________	________	________
Peas	________	________	________
Sweet corn	________	________	________
POTATOES	________	________	________
Buildings\roads	________	________	________
Other______________	________	________	________
Other______________	________	________	________
______________	________	________	________
Total (AS IN SEC.I)	________	________	________

Farm Number____________________

VIII. IDENTIFICATION OF MANAGEMENT AREAS.

We are attempting to analyze crop management differences across your farm. Before considering N applications and irrigation more specifically, we need to identify the areas you manage differently. We are primarily interested in areas which are irrigated AND/OR to which you apply commercial N, follow legumes in rotation (soybeans or alfalfa [2 years]), or apply manure. All combinations of these four practices, plus differences in crops define separate management areas. For example, irrigated cont. corn w/ scrape and haul manure differs from an identical area except that it receives liquid manure.(Differences in physical characteristics may also determine management areas. The map of the farm would be good here.)(Identify the most productive field with √ in NOTES column.)

1-Conventional 2-Conservation 3-Notill 4-Ridgetill

AREA #	CROPS			ACRES	TILL?	MAN?	*N*?	NOTES
	94 -	93 -	92					√

Farm Number___________ CONTINUED

AREA #	CROPS			ACRES	TILL?	MAN?	*N*	NOTES
	94 -	93 -	92					√

Identify most productive field with a checkmark.

Farm Number________

Did you have analysis done on your manure? _____

System Number___ Date of last test?________

Percentage?___ Per gallon?___ Per ton?___

Avail N____ Total N____ P205____ K20____

System Number___ Date of last test?________

Percentage?___ Per gallon?___ Per ton?___

Avail N____ Total N____ P205____ K20____

System Number___ Date of last test?________

Percentage?___ Per gallon?___ Per ton?___

Avail N____ Total N____ P205____ K20____

System Number___ Date of last test?________

Percentage?___ Per gallon?___ Per ton?___

Avail N____ Total N____ P205____ K20____System Number___

Test lab where analysis is done______________________________

Cost of analysis______________________________

If you have not had a recent test, Why?__________

1--Too Expensive 2--Not Accurate 3--No Time 4--other

Notes____

____

Farm Number____________
MANURE APPLICATIONS:(2 of 2)
List the destination of the manure from:(Systems, barns, and lots)
Include EACH application as a separate entry.
(Don't forget to include application of off farm manure produced off the farm, regardless of who applies it). Amount Per Acre column is for manure applied where amount applied per acre is known. Measure column
1--bushel per acre 2--gallon per acre 3--tons per acre

<--------------THIS------------------>OR<------THIS---------->

SYSTEM ______

AREA	AMOUNT	DATE	APP METH	APA	MEASURE
____	______	____	________	______	________
____	______	____	________	______	________
____	______	____	________	______	________
____	______	____	________	______	________
____	______	____	________	______	________
____	______	____	________	______	________
____	______	____	________	______	________
____	______	____	________	______	________
____	______	____	________	______	________
____	______	____	________	______	________

NOTE: Be sure that you have accounted for 100% of the collected manure from each manure handling system. You also need to make sure that all manured areas are accounted for here!!! Don't forget
off farm manure!!!!

List below any manure system collected but not available and

why:____

____

SYSTEM ______

AREA	AMOUNT	DATE	APP METH	APA	MEASURE

SYSTEM ______

AREA	AMOUNT	DATE	APP METH	APA	MEASURE

SYSTEM ______

AREA	AMOUNT	DATE	APP METH	APA	MEASURE

SYSTEM ______

AREA	AMOUNT	DATE	APP METH	APA	MEASURE

SYSTEM ______

AREA	AMOUNT	DATE	APP METH	APA	MEASURE

SYSTEM ______

AREA	AMOUNT	DATE	APP METH	APA	MEASURE

FARM NUMBER____________

DEFINITION PAGE FOR COMMERCIAL NITROGEN

Growth stages can be:

1-Fall

2-Spring preplant

3-Starter (with the planter)

4-Emergence (0-2 inches)

5-Early sidedress (2-8 inches)

6-Late sidedress (8 inches to harvest) 7-Other

Type of nitrogen applied *DEFINE STARTERS*

11-Anhydrous ammonia

12-urea

13-U.A.N. (solutions or liquid nitrogen)

14-Ammonium nitrate

15-Liquid starter 16-Dry mix(urea or unknown) 17-Other

Form of nitrogen:

21-gas (NH3)

22-liquid

23-dry

24-other

Application method: Define method of planter app. from bellow!!

(SAME FOR MANURE) 31-injected 32-broadcast

33-incorporated (include broadcast fields worked in 2 days)

34-banded (side dress) 35-irr 36-other

37-Knived in (man only) 38-Swept in (man only)

XI. COMMERCIAL FERTILIZER APPLICATIONS (N, P, and K).**careful**

MGMT AREA #__________ Crop Year__________

Application #	1	2	3	4
App. date				
Growth stage				
Nit type (anhydrous,urea,etc)				
Fert. form (dry, liquid, gas)				
Analysis(% N,P,K)*ASK IF %*				
Lbs fert. (FOR %)				
OR Lbs. nut. **(ACTUAL)**				
App. method(broad,inj,etc)				
Nitrif. inhib.? (N-SERV)				
Fert. Cost (mat. or nut./lb.)				
Custom App Cost				
Appl. time (if self app, hrs)				

Last soil test in this area?__________

By who?Crop consultant:__________

Lab:__________

Nitrogen results:

Organic matter %:____ or low/med/high____ or derived number:____

Nitrate soil test: ppm:_____ pounds per acre:_______

pH:____ Olson test: ppm:_____ pounds per acre:_______

Bray 1 (low bray): ppm:_____ pounds per acre:_______

Potasium (K2o):____

Affect on applications?__________

How often do you test each field?____

Farm Number__________

XI.COMMERCIAL FERTILIZER APPLICATIONS (N, P, and K)

Changes over the last three years__________

____

Why__________

XII.IRRIGATION

Do you irrigate any farm land?______

Mgmtarea	In./year	Type of irrigator	N-P-K Applied with Irr	Date

Note__________

FARM NUMBER______ ______________ XII. Yield info

CORN, POTATOES AND EDIBLE BEANS (by management area)

PEAS SOYBEANS

AREA	ROT.	MAN.?	1993	AVG	YIELD GOAL	1994

NOTES____

Did this survey fairly represent your farm and manure managment practices and the amounts applied?______ If not why not?______

____ __________

Would you like the manure management plan?______

FARM NUMBER____________________

THANK YOU FOR YOUR TIME AND EFFORT. AS I SUMMARIZE THE RESULTS, AN ADDITIONAL QUESTION, OR THE NEED FOR SOME CLARIFICATION MAY ARISE.IF SO, I HOPE I CAN GIVE YOU A CALL TO GET THE ADDITIONAL INFORMATION.

AS INDICATED BEFORE, WE WILL BE CONTACTING YOU LATER THIS YEAR FOR INFO REGARDING YOUR 1992 YIELDS AND IRRIGATION APPLICATIONS.

[WHAT ABOUT MANURE TESTING]!!!!!!!!

THANKS AGAIN!!!!!!!!!!!!!!!!!!!!!!!!!

CHECKLIST FOR COMPLETENESS AND CONSISTENCY. Take a minute to check these out before the farmer is freed.

1. Total acreage on the crop summary (p. 14) must agree with total land on p. 1 ._____

2. Acreages of mgmt areas (p. 15-16) must be reconciled with crop summary (p. 14)._____

3. All management areas (p.15-16) must be supported by appropriate supporting info re irrigation, manure apps and commercial N apps (p 20-22)._____

4. Manure applications (p. 19) must account for all collected manure (p. 6-10)._____

7. All cash crops acres must be accounted for on the yield sheet (p. 23)._____

A.2. Activity: To prepare an inventory of soil hydraulic properties in the context of surface runoff.

A.2.a. Context within the project: Rate of water entry plays an important role in the partitioning of rainwater into surface runoff and soil matrix flow. Several studies have identified a number of factors that affect the hydrologic characteristics of a landscape. These factors include soil type, tillage management practices, slope and type of rainstorm. The interaction of these factors at a particular site determines how and where water moves. Possible pathways for water movement are uniform infiltration into soil, preferential flow through large soil macropores, and surface run off of water from upslope to downslope areas where water subsequently infiltrates. Relative contributions of various pathways determine the degree of loss of applied chemicals and the type of environmental problems (surface or subsurface water contamination). Because of the steep landscapes in the karst area, a significant quantity of rain water can runoff. Also, the soils of the area being high in silt content (thus prone to crusting) could further increase runoff. Since manure application is one of the major management practice of the area, there is some possibility that rain water may enter into soil through earthworm macropores and may contribute to significant ground water contamination. The best management practice of the area should be the one that encourages less runoff and greater infiltration (interaction of water and surface applied chemical with soil matrix) to reduce contamination of both surface and subsurface waters. This objective will inventory the effects of tillage, earthworm macropores and surface seal on rate of water entry into several soils of the area.

A.2.b. Methods: Soil survey records and completed student theses will be searched for information on hydraulic properties of the soils in the area. These properties will include hydraulic conductivity-water content relationships, water retention characteristics and saturated and unsaturated infiltration rates. For some of the major soils of the area where this information is lacking, tests will be undertaken in the field to characterize the rate of water entry using simulated rainfall. The soil surface before and after the rainfall will also be characterized for saturated and unsaturated infiltration rates using the disk infiltrometer under both covered (no surface seal) and uncovered (surface seal) conditions. Unsaturated infiltration rates will correspond to a suction of -3.5 bars suction. At the suction all the water entry is through the soil matrix and thus excludes the contribution of macropores to water entry. The difference between the saturated and unsaturated infiltration will quantify the contributions of earthworm macropores and also if surface sealing blocks off some of the visible macropores at the soil surface. The data obtained under this objective will provide input to the models that simulate contaminant transport both in soils and in surface runoff. Earthworms will also be collected to identify the species present at the experimental sites. The procedure for collection of earthworm species will involve pouring 8-12 liters of dilute formaldehyde solution on a 30x30 cm area and collecting the earthworms that emerge. Collected earthworms will be taken to the laboratory for specie identification.

A.2.c. Materials: Disc infiltrometers, rainfall simulator
A.2.d. Budget: $55,000 Balance $0
A.2.e. Timeline:

	6/93	1/94	6/94	1/95	6/95
Inventory of soil properties	xxxxxxxxxx				
Field characterization of rate of water entry		xxxxxxxxxxxxxxxx			
Summary, publication of results					xxxxxxxxx

A.2.f. Status: Final Detailed Report

TILLAGE AND NITROGEN SOURCE INTERACTIONS ON MACROPOROUS FLOW AND SOIL QUALITY

BY TODD WADE SCHUMACHER

ABSTRACT

Earthworm macropores have been proposed as pathways for agricultural chemicals to move into the ground water through the shallow soils in the karst region of Southeastern Minnesota. In this area, manure application to the land is a common practice. It has also been suggested that soil health, or quality, will improve because of the organic carbon addition, and the increased earthworm activity. This study quantifies the effects of long term tillage and liquid dairy manure addition on infiltration and several soil quality parameters.

Soil physical properties were characterized on plots that have been under long term (12 years) continuous corn with two different tillage systems (no tillage and chisel plow) and two different nitrogen sources (liquid dairy manure and inorganic fertilizer). The experimental site is located near Red Wing in Goodhue Co., Minnesota, and the soil at this site is a Seaton silt loam (Typic Hapludalf, fine-silty, mixed, mesic).

Measurements included bulk density, organic matter content, infiltration rates, sediment yields, aggregate stability, and earthworm population. The infiltration rates for various tillage and N-source treatments were evaluated using a ponded infiltrometer, tension infiltrometer, and a rainfall simulator. Ponded and tension infiltration measurements were used to separate the macroporous flow from the matrix flow.

Ponded infiltration rates were significantly higher under chisel plow than no-till, but the effect was opposite with the rainfall simulator (higher infiltration rates under no tillage than chisel plow). Higher ponded infiltration rates in chisel plow were probably a result of increased soil porosity due to soil loosening; whereas higher infiltration rates in no tillage (no-till) under rainfall simulation were due to the presence of surface residues that minimized surface sealing. As a result of soil loosening, macroporous flow was also greater for the chisel plow treatment than the no-till treatment. Infiltration rates for plots that received manure were significantly higher than fertilizer plots for both ponded infiltrometer and simulated rainfall. Manure application resulted in significantly more macroporous flow than fertilizer, which was due either to the soil loosening associated with manure injection or to an increase in the number of earthworm macropores in the manure plots.

Earthworm populations were significantly greater in the no-till plots than in the chisel plow plots, but there was no statistical difference due to N-source. Spatial measurements of *Lumbricus terrestris* (nightcrawler) around the experimental site pointed to the lawn as the source of the nightcrawlers, which were found only in the third replication.

Statistically, neither tillage nor N-source were found to affect organic carbon content at 0-7.6 cm, a parameter often measured to quantify soil quality. Tillage affected bulk density at three depths (3-9, 15-21, and 27-33 cm), but there was no N-source effect on bulk density at 15-21 or 27-33 cm depth.

Sediment production under simulated rainfall was greater in chisel plow than no-till, but there were no significant differences in sediment yield due to N-source. Similarly, aggregate stability was significantly lower in chisel plow than no-till plots, and there were no significant differences in aggregate stability due to N-source. It is concluded that tillage effects on soil quality are much more dominating than the effects of manure addition at the rates manure was applied in this study. Lack of statistical differences in earthworm populations and statistically higher macroporosity in manure compared to chisel plow treatment shows that earthworm population is not directly related to soil macroporosity as assumed in soil quality investigations. Furthermore, it is shown that the parameters for evaluating soil quality proposed in the literature are not effective in quantifying the differences in soil quality between management practices because of the dominating effects of climate, soil variability, and the soil-atmosphere boundary conditions such as the presence of residue or plant canopy cover on various soil quality goals.

INTRODUCTION

An increasing number of studies are documenting the presence of nitrate and pesticides in groundwater (Hallberg *et al.*, 1984; CAST, 1985; Nielsen and Lee, 1987). In a survey of drinking wells in fifty-one counties in the state of Minnesota, Klauseus *et al.* (1988) reported the presence of nitrate in 33% and pesticides in 43% of the 500 wells tested. Many of the contaminated wells are located in the karst region of southeastern Minnesota.

The karst region of Southeastern Minnesota, Southwestern Wisconsin, Northeastern Iowa, and Northwestern Illinois is characterized by a thin loess soil overlying fractured dolomite and limestone bedrock. The presence of many sink holes in the area is also an indication of the fractured nature of the bedrock. Sink holes develop due to the caving-in of bedrock that has under gone considerable dissolution from flowing water. The fractured nature of the bedrock can also be seen along road cuts. Besides the direct entry of land applied chemicals into ground water through sink holes, there is concern that these chemicals may also be arriving rapidly at the interface of the soil and fractured bedrock. Two possibilities for this rapid flow are: (1) the presence of shallow soil overlying the fractured bedrock, and (2) the presence of macropores.

The karst region along the upper Mississippi river valley is a dairy farming area. Manure application to the land is a common practice. Converse *et al.* (1976), Fuchs and Linden (1988) and Munyankusi *et al.* (1994), all have reported enhanced activities of earthworms in soils that received manure additions. In soil columns taken from long term manure and commercial fertilizer applied plots, Munyankusi *et al.* (1994) showed that although saturated flow rates were nearly similar, there was an earlier appearance of tracer at the bottom of the soil column from the manure plot during breakthrough curves. These authors concluded that the early appearance of tracer during breakthrough in manure applied soils was due to the presence of deeper burrowing earthworm species.

The objective of this study was to quantify the interactions of tillage and nitrogen sources on the rate of water entry into the soil. It is hypothesized that (a) the long-term manure application will increase the number of earthworm macropores, and the presence of nightcrawlers which form long, deep macropores, and (2) chisel plowing, as compared to no tillage, will reduce the number of macropores and the continuity of earthworm burrows that are open at the soil surface.

Recently, there is also an increased awareness (Larson and Pierce, 1991; Parr *et al.*, 1992; Stork and Eggleton, 1992; Karlen *et al.*, 1994) regarding the improvement of soil characteristics due to organic farming. It has often been implied that addition of organic manure can lead to better soil quality, and thus toward more sustainable methods of agriculture. However, there are no clear-cut guidelines on the type of measurements needed to gauge soil quality. Other than the soil organic matter, the most often cited measurements of improved soil quality are the soil physical characteristics related to water infiltration and aggregate stability. Since the measurements of infiltration due to macropores will be taken at a site where manure and commercial fertilizer have been applied over a long term (12 years), an additional objective of this study was to evaluate if soil quality parameters suggested in the literature effectively represent the quality of the soil under various tillage and N-source management conditions.

LITERATURE REVIEW

Earthworms have been studied for their ecological impacts as well as their impacts on soil amelioration (Lee, 1985). With recent concerns over groundwater contamination, earthworm studies have begun to look at the role of earthworm burrows on the preferential transport of water and chemicals through soils. The effect of soil management practices on earthworm populations and speciation are being closely examined to determine what, if any, impact they may have on groundwater contamination.

Earthworm Ecology

Earthworms are found in all but the driest, coldest parts of the earth. They have adapted to inhabit most of the world's terrestrial ecosystems (Edwards and Lofty, 1982a). Earthworms require moisture adequate for respiration to facilitate O_2/CO_2 diffusion through their body wall. Most species require a soil temperature in the range of 0°C-35°C for long term survival, but adaptation mechanisms exist in worms to facilitate survival in seasonal or periodic temperature fluctuations outside of the optimal range (Lee, 1985; Satchell, 1967). The adaptation mechanisms that allow worms to survive are hibernation (low temperature response- worm inactive and coiled into a ball below the frost line), quinesence (low temperature/water response- worm dehydrates), and diapause (low water response- coil into a ball in a mucus lined chamber).

Earthworms require oxygen in the atmosphere or oxygenated water. Earthworms have adapted to living underground by being able to survive in concentrations of CO_2 higher than those usually found in the soil atmosphere. Ultra-violet radiation is fatal to earthworms; therefore, they spend the daylight hours safely underground. Earthworms prefer a medium textured soil. Coarse soils are abrasive to their soft bodies, and are also susceptible to drought. Fine soils are susceptible to oxygen deficit during periods of high rainfall, and this is why earthworms are often seen on the soil surface after a heavy rain. Earthworms also require a pH greater than 4 because large amounts of calcium ions are necessary for proper functioning of the earthworms glandular system (Lee, 1985; Satchell, 1967).

The above basic environmental requirements are common in most of Minnesota's agricultural areas. This makes the earthworm and agriculture partners. Earthworm eating habits can be divided into two basic types, detritivores and geophages. Detritivores consume dead materials such as plant residues, roots, and manures near the soil surface. Geophages ("earth eaters") ingest soil, preferring soil high in organic matter for the extraction of food (Lee, 1985; Satchell, 1967).

Earthworms reproduce by depositing eggs in a cocoon. This cocoon contains the eggs of one individual earthworm. Once deposited in the soil, the cocoons are left on their own. Most of the activity in cocoon production occurs during periods of high rainfall (spring and autumn), but reproduction may occur in any season (Satchell, 1985).

Man is known to have transported the nightcrawler to the United States, New Zealand, Canada, and Australia from Europe; and it is also believed that the nightcrawler followed man and agriculture from Asia into Europe (Lee, 1985). Once introduced, earthworms have several modes of dispersion. Earthworms move along the soil surface at night and often reenter the soil at different locations than the one from which they exited. Earthworms and their cocoons also move downslope by the action of flowing water (Barley, 1961). *L. terrestris* has been shown to spread at the rate of about 4 m y^{-1} (Hoogerkamp *et al.*, 1983).

Tillage impacts on earthworms and their burrows: It is well known that agricultural practices affect both the population and the species of earthworms in the soil. This, in turn, has an impact on the preferential transport of water and chemicals in the soil as it is influenced by earthworm burrows. Natural grasslands (and long-term alfalfa/pasture) contain the largest numbers of earthworms. A continuous corn monoculture, however, appears to have relatively low earthworm populations. Mackay and Kladivko (1985) reported 1298 earthworm macropores m^{-2} in pastures, 100 times more than under continuous corn. Fuchs and Linden (1988) counted 21-397 earthworms m^{-2} in grasslands/pastures; but only 9-78 earthworms m^{-2} in continuous corn. Hopp (1947) observed that earthworms were numerous throughout the year in sod, but that they were only numerous in tilled soils in the autumn.

Fuchs and Linden (1988) found that *Aporrectodea tuberculata* was the dominant species in agricultural soils in Minnesota, and *L. terrestris* was found in two of the three areas sampled in the karst region. *A. tuberculata* is a relatively horizontal burrower that rarely burrows deeper than 30 cm in the soil. The major vertical burrowing species (*L. terrestris*, or nightcrawler) is rare in tilled soils, but has been found in no-till systems (Edwards *et al.*, 1988; Edwards and Lofty, 1975; Nuutinen, 1991).

Many studies (Gerard and Hay, 1979; Edwards and Lofty, 1982b; and Kemper *et al.*, 1987) have shown an increase in earthworm populations (especially nightcrawler populations) under no-till systems. Gerard and Hay (1979) reported 50 to 100% more earthworms in no-till than tilled soils. No-till soils were also found to contain 4 times more nightcrawlers than the tilled soils. Edwards and Lofty (1982b) showed that there were 17.5 times more nightcrawlers in direct drill systems than under conventional (moldboard plow) tillage systems, and 3 to 4 times more shallow dwellers in direct drill than plowed systems. Kemper *et al.* (1987) found 367 nightcrawlers in a no-till plot; whereas a tilled plot contained only 29 nightcrawlers. House and Parmelee (1985) reported 149 m^{-2} earthworms in chisel plow plots, and 967 m^{-2} in no-till small grains in Georgia. Fuchs and Linden (1988) found 242 and 292 earthworms m^{-2} in two no-till fields under corn-soybean rotation in Southeastern

Minnesota. In the four corresponding tilled fields 219, 238, 178, and 192 worms m^{-2} were found. Barnes and Ellis (1979) reported 196.8 earthworms m^{-2} after four years of direct drill, but only 50 earthworms m^{-2} in the moldboard plowed plots. These authors also reported finding 802 channels >1.5 mm m^{-2} in direct drill plots, and only 294 channels >1.5 mm m^{-2} in moldboard plowed plots.

Several factors account for the reduced numbers of earthworms in tilled plots. Tillage implements may physically damage earthworms, and turning over the soil during cultivation also exposes earthworms to predation (Lee, 1985; Kemper *et al.*, 1987). An additional factor for the reduced number of earthworms in tilled soils is the incorporation of the plant materials. These surficial plant materials are consumed by surface feeding species such as the nightcrawler, and plowing puts these species at a disadvantage, while providing food for subsurface feeding species such as *A. tuberculata* (Lee, 1985). The resultant effect of tillage is a decrease in the number of earthworms, as well as a disruption in the continuity of earthworm burrows and reduced preferential flow.

Surface residues, such as those left under minimum tillage systems, have been shown to increase the population of surface feeding earthworms. Jensen (1985) found that returning 4 T ha^{-1} of straw to a field increased the population of earthworms by 150% after eight years, and by 300% after fifteen years. Almost fifty years ago, Hopp (1947) found 80,000 earthworms A^{-1} where corn stover was removed, and 213,000 earthworms A^{-1} in areas where corn stover was allowed to remain and manure was added. Barnes and Ellis (1979) reported 13.2 nightcrawlers m^{-2} in plots where residues had been burned, and 61.4 nightcrawlers m^{-2} in plots where residues were returned to the soil surface. Zachmann *et al.* (1987) showed that the more surface residues and the less tillage a system received, the more earthworm burrows that were open to the surface.

Edwards *et al.* (1988) found that *L. terrestris* burrows may be 10 mm in diameter and extend to over a meter into the soil. These channels are more or less vertical, and they may extend directly into a shallow water table. Other species, such as *A. tuberculata, A. trapezoides,* and *L. rubellus,* tend to form shallow, horizontal, 1-5 mm diameter burrows (Zachmann *et al.*, 1987). It is the large, vertical burrows formed by the nightcrawler that are most likely to transport contaminants to greater depths in the soil, especially if they are open at the soil surface.

The continuity of these nightcrawler burrows is the key in preferential transport of contaminants to deeper depth in the soil. A burrow that is open at the surface, but plugged shortly below the surface, will not be useful for conducting water. Earthworm macropores open at the surface, however, are rarely continuous to deeper depths (Ela *et al.*, 1992; Munyankusi, 1992). Casts and residues may plug earthworm burrows and thus limit their effectiveness as conductors (Germann *et al.*, 1984). Tillage may also sever the pores below the surface, causing them to be open at the surface, but not continuous much below the soil surface (Ehlers, 1975; Carter, 1988; Chan and Mead, 1989). Ehlers (1975) found 4 times more pores in no-till than tilled soils at 2 cm depth. He also reported that many of the pores were continuous to 180 cm in no-till treatments, and the volume of pores was double in no-till treatments as compared to tilled agricultural systems. It was concluded that tillage severed macropores, causing them to be non-effective for water transport.

<u>Nitrogen source impacts on earthworms:</u> Organic nitrogen sources have been shown to increase earthworm populations and species diversity. Cotton and Curry (1980) showed that earthworm numbers increase with the addition of traditional semisolid farmyard manure when spread onto the soil surface and liquid slurry injected under the soil surface. Many sources of organic waste, such as pig manure (Cotton and Curry, 1980), cattle manure (Curry, 1976; Cotton and Curry, 1980), human sewage (Edwards, 1980), and poultry manure (Curry, 1976) have been shown to increase earthworm populations. It is believed that nightcrawlers use the carbon in the organic fertilizer as a food source (Lee, 1985).

Fuchs and Linden (1988) found *L. terrestris* in cultivated fields that had manure added to them as a nitrogen source. Similarly, Edwards and Lofty (1975) reported increased populations of all earthworm species, especially *L. terrestris*, in plots treated with organic nitrogen. These authors measured 90 worms m^{-2} with the addition of farmyard manure, compared to 7 worms m^{-2} in the control plot. The increase in *L. terrestris* in plots treated with the farmyard manure was 12 times greater than the control plots. Edwards and Lofty (1982c) reported on the effects of organic manure in the short and the long term. In their long term experiment, they found that *L. terrestris* increased from 12.6 m^{-2} to 28.7 m^{-2} in plots that had received farmyard manure from 1843-1982. In the short term experiment, these authors reported that the *L. terrestris* population increased from 0.9 m^{-2} in the spring to 4.2 m^{-2} in the autumn after farm yard manure was applied.

In 200 m^2 plots, Cotton and Curry (1980) found 2997 earthworms in plots with an inorganic N-source, and 4348 in plots with an organic N-source (including 98 *L. terrestris* in inorganic vs. 112 in organic, and 31 A. tuberculata in inorganic vs. 42 in organic plots). Curry (1976) reported 9 nightcrawlers m^{-2} in control plots and 13.5 m^{-2} in plots where cattle manure was applied as a slurry in an autumn population survey. In addition, the percentage of the population that consisted of *L. terrestris* increased from 9.2 to 12.9% of the population with the addition of pig slurry. Poultry manure applied as a slurry was also found to increase the earthworm population similar to that of cattle slurry, but the nightcrawler population was about half of what it was in the cattle slurry. Converse *et al.* (1976) found 494 earthworms m^{-3} (top 0.15 m) in their control plots, compared to 1766-2189 earthworms m^{-3} (top 0.15 m) in plots that received manure.

Inorganic N-sources also increase earthworm populations, but not by as much as organic N-sources. Gerard and Hay (1979) found that there were 33%

more earthworms in plots treated with 50-100 kg N ha^{-1} than in control plots (those that had not received any nitrogen fertilizer). Edwards and Lofty (1982c) reported that there were 6 times more worms, and almost 4 times more nightcrawlers in plots that received 192 kg N ha^{-1} as calcium nitrate than in control plots.

Ammonium nitrogen sources, however, have been shown to be detrimental to earthworm populations. Potter *et al.* (1985) reported 66% and 33% fewer earthworms in May and October, respectively, on plots that received 25 g N m^{-2} as NH_4NO_3. It is believed that the decrease in soil pH caused by ammonium fertilizers results in the subsequent decline in earthworm numbers (Potter *et al.*, 1985; Kemper *et al.*, 1987). At the Flueger farm, Munyankusi *et al.* (1994) found that the macroporosity in chisel plow plots with manure and ammonium fertilizers was about the same, but macropores were continuous to deeper depths in the manure applied plot as compared to the inorganic fertilizer plot. Sampling of the earthworm species in the study showed the presence of *L. terrestris, L. rubellus, A.trapezoides,* and *A. tuberculata* in the manure plot, whereas all the earthworms in the inorganic fertilizer plot were *A. tuberculata*. These authors concluded that increased continuity in manure applied plots was due to the presence of *L. terrestris*.

Water Infiltration

Water infiltration refers to the process by which water enters the soil surface. Figure 1 shows the hypothetical curve on the rate of water entry into the soil as a function of time. At the initial time of water application, the rate of water entry is constant and equal to the application rate. As the time from the initial application increases, the rate of water entry decreases until it reaches a steady state value.

During the constant rate stage, the hydraulic conductivity of the soil surface is increasing (if the soil was initially dry); whereas the hydraulic gradient is decreasing. In the declining rate stage, the hydraulic conductivity of the soil surface is constant and equal to the saturated hydraulic conductivity (under ponded conditions) or some unsaturated hydraulic conductivity (under sprinkler applied water). The gradient is still declining because of an increase in distance to the wetting front. Steady state infiltration rate refers to the conditions where the surface hydraulic conductivity and hydraulic gradient are relatively constant, with the hydraulic gradient nearly equal to the gravitational gradient.

The cross hatched area of Figure 1 shows the amount of runoff when the rate of application is greater than the rate of water entry. Besides the steady state infiltration rate, time to ponding (tp) is another important parameter that characterizes the management effects as well as the initial conditions of the soil.

The knowledge of water entry into the soil is important in determining the runoff and sediment leaving the landscape (Freebairn *et al.*, 1989). The factors affecting infiltration, runoff, and sediment transport have been extensively investigated. In this thesis, we will mainly be dealing with tillage and N-source effects on ponded, simulated rainfall, and tension infiltration rates. The next section briefly summarizes the effects of tillage on macropore development, and its impact on water entry, runoff, and sediment production.

Infiltration as influenced by earthworm macropores: Environmental conditions favorable to *L. terrestris* will help create deeper continuous macropores, and this can help increase infiltration and decrease runoff and soil erosion. Measuring this difference, however, can be difficult. The variation in infiltration rates in soils containing macropores is high, making it necessary to sample large areas for infiltration rate measurements (Sauer *et al.*, 1990; Wu *et al.*, 1992; Smettem and Collis-George, 1985).

Many authors have reported on the effects of earthworm macropores on water flow (Edwards *et al.*, 1990; Kladivko *et al.*, 1986; Ehlers, 1975). Ehlers (1975) reported that tillage reduced the effectiveness of earthworm macropores to conduct water. The author also stated that soils that had effective macropores could infiltrate 6 times more water than soils without effective macropores. In no-till corn, Edwards *et al.* (1990) found that 100 mm yr^{-1} more water infiltrated because of the presence of earthworm burrows. Kladivko *et al.* (1986) reported 15 times more infiltration due to earthworm burrows in a greenhouse experiment. These authors concluded that increased infiltration was due to a weakening of the surface crust formed during rainfall simulation by earthworm activity. Occasionally, large infiltration values were found in a field infiltration experiment reported by Smettem and Collins-George (1987). These large values were attributed to the presence of a few continuous macropores of >2 mm in diameter.

Tillage impact on infiltration, runoff, and sediment production: Literature review on the macropore impact on infiltration has been covered in several theses by Ela (1990), Munyankusi (1992), Zachmann (1986), and Dicky (1990). There are two possible types of tillage impacts on infiltration, runoff, and sediment production. The first type is in terms of earthworm populations (as discussed earlier), and the second type is in terms of the surface residue cover. As discussed earlier, soil tillage leads to destruction of earthworm burrows and a reduction in earthworm numbers. No-till, on the other hand, has more earthworms and more continuous burrows than tilled soils, which increases infiltration and reduces runoff and sediment production.

It has been well documented in the literature that a change in the surface residue cover due to tillage has a major impact on infiltration, and the subsequent runoff and soil losses. Plant residues left on the soil surface from the reduced tillage systems protect the soil surface from rain drop impact; thereby preventing surface seal development that increases infiltration and reduces soil loss.

Surface seals are known to significantly reduce infiltration rates

(Freebairn *et al.*, 1991; Freebairn *et al.*, 1989; Kladivko *et al.*, 1986). Freebairn (1989) showed that removing cover decreased steady state infiltration rates for no-till from approximately 85 mm h^{-1} with cover to approximately 27 mm h^{-1} without cover. The infiltration rate was reduced from approximately 90 mm hr^{-1} for a chisel plowing system with cover to 45 mm hr^{-1} for a chisel plowing system without cover.

Surface residues have also been shown to effectively reduce runoff and soil erosion from tilled soil surfaces. A paper by Jones *et al.* (1969) reported 10.4% runoff from a tilled surface without residue cover, and only 1.5% runoff from a tilled surface that had 6.7 kg ha^{-1} of straw added as a mulch. These authors also showed that a no-till surface that had residues hoed into the soil had 8.2% runoff of natural rainfall compared to only 1.6% runoff for a no-till surface that had residue cover. Based on a simulated rainfall experiment, Meyer *et al.* (1970) reported that a tilled surface with no surface residue lost 36.4 T ha^{-1} of soil and had 64.6% runoff. The addition of 2.24 T ha^{-1} of surface residue reduced the soil loss to 3.8 T ha^{-1} and the runoff loss to 59.8%. Similarly, the addition of 8.96 T ha^{-1} of surface residue further reduced sediment loss to 0.9 T ha^{-1}. Other researchers (Mostaghimi *et al.*, 1988) reported that tilled soils lost 35.5% of the water applied during rainfall simulation as runoff with no residue compared to 18.0% with residue present. In this experiment, time to ponding was increased from 2 to 7 minutes, and sediment yields were decreased from 2813 to 513 kg ha^{-1} with the addition of 1500 kg ha^{-1} of straw at the soil surface. Similarly in no-till plots, runoff decreased from 4.5% to 0.2% of the water applied, time to ponding increased from 2 to 7 minutes, and sediment yield was decreased from 72 to 7 kg ha^{-1} with the addition of 1500 kg ha^{-1} of residue in the same experiment.

The combined effects of surface microrelief, residue cover, and increased earthworm activity on infiltration, runoff, and sediment production has also been documented in various field studies. Kemper *et al.* (1987) found 12.4 cm of runoff from tilled areas compared to only 0.2 cm of runoff from no-till areas. Mannering *et al.* (1966) reported 24% more infiltration and 34% less soil loss from no-till plots as compared to conventional tillage plots. These authors attributed the increased infiltration and reduced soil loss to the increased residue cover and surface storage in no-till plots. No-till plots with 1500 kg ha^{-1} of straw reduced runoff 90 times as compared to conventional tillage (moldboard plow) during rainfall simulation (Mostaghimi *et al.*, 1988). These authors also reported that soil loss was reduced 91 times, and time to ponding was increased by 4 times in no-till plots compared to tilled plots due to the beneficial effects of residue cover. Jones *et al.* (1969) found that conventional tillage (moldboard plowing) lost 10.4% of its water as runoff as compared to 1.6% in no-till plots under a continuous soybean rotation. McGregor *et al.* (1975) measured 29% of the rain as runoff from a conventionally tilled system with 17.5 T ha^{-1} of sediment loss, compared to 23% of the rain left as runoff and soil loss dropped to 2.5 T ha^{-1} in the no-till system due to the presence of residue. From the interrow areas of a Typic Hapludalf, Hill (1993) reported 1228 ml m^{-2} min^{-1} of runoff and 8.8 g m^{-2} min^{-1} of sediment from moldboard plowed fields compared to 748 ml m^{-2} min^{-1} of runoff and 0.3 g m^{-2} min^{-1} of sediment loss from a ridge tillage system. Hill (1993) attributed this reduction in runoff and sediment loss to the presence of plant residues. Thomas *et al.* (1992) reported that sediment loss was cut from 21.1 T ha^{-1} for moldboard plowing to only 4.6 T ha^{-1} for ridge tillage due to the presence of residue.

<u>N-source influence on infiltration, runoff, and sediment yield:</u> Nitrogen source effects on infiltration, runoff, and soil loss have not been as well studied as the effects of tillage. As with tillage, N-sources that increase nightcrawler populations (organic sources) should create more continuous macropores, increase infiltration, and reduce soil loss. The study by Converse *et al.* (1976) found that plots that received manure produced less runoff than plots that received no manure. These authors also found that adding manure to the soil in fall reduced runoff from 136 mm in the check plots to only 73 mm in manure plots. Manure applied during the winter and spring reduced runoff to a lesser amount (104 mm and 106 mm of runoff for winter and spring applied manure, respectively). With a 14.5 cm hr^{-1} application of simulated rainfall on a 1.35 m^2 plot, Mueller *et al.* (1984) reported 108 liters of runoff in no-till with manure compared to 248 liters without manure. In chisel plow treatments, 129 liters of runoff were measured with manure compared to 259 liters without manure. These authors credited much of the reduction in runoff to the surface application of manure; which they believe made the manure act as a surface cover (similar to plant residues).

In spite of extensive literature on tillage and manure impacts on water infiltration, there is limited literature on the impact of these management practices on macroporous flow, especially under long term conditions. This study is designed to quantify the impact of long term tillage and application of manure and inorganic fertilizer on macroporous flow.

Soil Quality

Recently, there has been an increased interest in quantifying the health, or quality of the soil. There are, however, numerous problems with the methods being used for quantifying soil quality. This section deals with the constraints in quantifying soil quality.

<u>Definition of soil quality:</u> There are many definitions of soil quality in the literature. Larson and Pierce (1991) define soil quality as "The capacity of a soil to function within the ecosystem boundaries and interact positively with the environment external to that ecosystem." They identify the following three functions that they believe a healthy soil should perform: 1. Provide medium for plant growth, 2. Regulate water flow, 3. Serve as an environmental filter. Another definition proposed by Arshad and Coen (1992) states that "Soil quality can be expressed in terms of the sustaining capability of a soil to accept,

store and recycle water, minerals and energy for the production of crops at optimum levels while preserving a healthy environment."

The next two definitions are less desired because they do not provide a clear understanding of the goals, or measurements needed to quantify soil quality. Parr *et al.* (1992) define soil quality as "An inherent attribute of a soil that is inferred from its specific observations (*e.g.* compactability, erodibility, and fertility)." Stork and Eggleton (1992) define soil quality as "The fitness of a soil for the sustainable production of healthy, agriculturally important plants."

Soil quality parameter sets: Several sets of soil parameters have been used by various authors to quantify soil quality. A few of these parameter sets and the corresponding authors are listed in Table 1. As can be seen from the above examples, there is no universal soil quality parameter set. Different authors define soil quality differently, have different goals, and thus use different soil quality parameters sets.

Table 1. Examples of soil quality parameter sets reported in the literature.

Larson and Pierce (1991):	Nutrient availability Organic carbon Plant available water Soil structure form Aggregate stability Soil strength Maximum rooting depth pH
Arshad and Coen (1992):	Soil Depth Water holding capacity and water retention characteristics Structural type/ aggregate stability Hydraulic conductivity and infiltration rates Bulk density/ penetration resistance Organic matter Cation exchange capacity pH and base saturation Electrical conductivity Exchangeable sodium percentage
Karlen *et al.* (1994):	Aggregation Porosity (upper 75 and 500 mm) Bulk density (upper 75 and 500 mm) Microbial biomass Respiration Ergosterol Earthworm population Soil pH Total Carbon (75 and 600 mm) Total Nitrogen (75 and 600 mm) Cation exchange capacity Plant available water Water filled pore space

Soil quality indices: Efforts have been made to combine soil quality parameters into a single soil quality value also called a soil quality index. This index is developed by multiplying the sufficiency values for soil quality parameters by their appropriate weighting factors, and summing together all of the values. Soil quality indices can be found in Karlen *et al.* (1994), Doran and Parkin (1994), and Granatstein and Bezdicek (1992).

An example of the soil quality index developed by Karlen *et al.* (1994) is mentioned below. This index was selected since it is one of the newer and more detailed indices in the literature.

$$\text{Index Value} = q_{we} * wt_1 + q_{wt} * wt_2 + q_{rd} * wt_3 + q_{spg} * wt_4 \quad [1]$$

where:

q_{we} = Accommodating water entry.
q_{wt} = Water transport and absorption.
q_{rd} = Resisting degradation.
q_{spg} = Supporting plant growth.
wt = Weighting factor for each function.

The four different "q" values are sufficiency factors indirectly estimated from soil quality parameters. In the scheme by Karlen *et al.* (1994) for calculating the soil quality index, up to four different levels of calculations are involved for determining the desired "q" value. The details of the supporting structure are given in Figs. 2 and 3. Several of the soil quality parameters are used more than once and have different weighting factors for different "q" values. For example, organic carbon in the upper 75 mm is used under q_{rd} at level 3 with a weighting factor of 0.10, and under q_{spg} at level 4 with a weighting factor of 0.25. The details of the supporting structure for the soil quality index as proposed by Karlen *et al.* (1994) can be viewed in Table 2.

The process for calculating "q" values involves converting soil measurements to a value between 0 and 1 using one of the three sufficiency curves shown in Fig. 4. Figure 4a depicts a situation where less of a parameter is better for soil quality, Figure 4b depicts a situation where more is better for soil quality, and Figure 4c represents a situation where some middle value is optimum. Once the sufficiency factors are obtained, it is multiplied by its weighting factor and summed together with the rest of the parameters at that level. This process is repeated at each level on up until a single soil quality index value is obtained.

Karlen *et al.* (1994) computed the soil quality value for three different long term (10 years) residue management treatments under a no-till tillage system. The different treatments were removing the residue from one treatment (Removing residue), adding the residue to another treatment (Double residue), and a Normal residue treatment. These authors calculated soil quality index values of 0.45 for removing residue treatment, 0.68 for normal residue treatment, and 0.86 for double residue treatment.

One limitation of the above soil quality indices is that although the shapes of the three curves in Fig. 4 are based on scientific literature, the actual values assigned

Table 2. Details of the supporting structure for the soil quality index value as proposed by Karlen *et al.*, 1994, weighting factors are in parenthesis.

Resist degradation (0.20)- Level 1
- Aggregate stability (0.60)- Level 2
- Microbial processes (0.40)
  - Microbial biomass (0.30)- Level 3
  - Respiration (0.30)
  - Ergosterol (0.20)
  - Surface 75 mm total carbon (0.10)
  - Surface 75 mm total nitrogen (0.10)

Accommodate water entry (0.20)- Level 1
- Aggregate stability (0.60)- Level 2
- Surface 75 mm total porosity (0.20)
- Earthworms (0.20)

Facilitate water transfer and adsorption (0.20)- Level 1
- Upper 500 mm porosity (0.60)- Level 2
- Upper 600 mm total carbon (0.20)
- Earthworms (0.20)

Sustain plant growth (0.40)- Level 1
- Nutrient relations (0.30)- Level 2
  - pH (0.30)- Level 3
  - CEC (0.20)
  - Upper 600 mm total nitrogen (0.10)
  - Upper 600 mm total carbon (0.10)
  - Nutrient cycling (0.30)
    - Microbial biomass (0.10)- Level 4
    - Respiration (0.10)
    - WFPS (0.25)
    - Ergosterol (0.05)
    - Surface 75 mm total N (0.25)
    - Surface 75 mm total C (0.25)
- Rooting depth (0.30)
  - Surface 75 mm bulk density (0.20)
  - Earthworms (0.10)
  - Upper 500 mm bulk density (0.50)
  - Plant available water (0.20)
- Water relations (0.30)
  - Plant available water (0.25)
  - Surface 75 mm porosity (0.25)
  - Upper 500 mm porosity (0.40)
  - Upper 600 mm total carbon (0.10)
- Chemical barriers (0.10)

to the points on the curve are subjective and based on the authors experience and knowledge. Also, the weighting factor corresponding to each soil quality parameter is based on the experience and intuition of the authors, and no consideration is given to change the weighting factor for different soil types, crops, or climates. In addition, the bottom line is what does the soil quality index value mean? For example, does a soil quality index value of 0.86 for double residue mean it will have half as much degradation compared to removing residue where soil quality index is 0.45? One can almost assuredly come to the conclusion that there will not be twice as much plant growth and half as much degradation. In other words, the values of the soil quality index are just values and do not relate to the differences in the goals of soil quality. The next question is, what is the minimum index value that will signify good soil quality? With a subjective model, how accurate is the determination of good or bad soil quality?

Other soil quality indices: There are several soil quality indices that already exist in the literature. Most of these indices deal with one soil function (*i.e.* soil erosion, crop growth, etc.). Among the most well known soil quality indices is the soil erodibility factor (K) in the Universal Soil Loss Equation (Wischmeier and Smith, 1978).

$$A = KRLSCP \quad [2]$$

where:

A = Computed soil loss, T A^{-1}.
K = Soil erodibility factor.
R = Rainfall and Runoff factor.
L = Slope length.
S = Slope steepness.
C = Cover and management.
P = Supporting practices factor.

The soil erodibility is estimated by dividing the measured soil loss by all the factors (except soil erodibility) in the Universal soil loss equation. It is well accepted that the soil erodibility factor is relatively a fixed value for a given soil. The Soil Conservation Service has provided soil erodibility values for soils across the United States. In accepting that the soil erodibility factor is relatively constant, we assume that changes in the soil due to management practices are relatively small and have a minimal affect on soil erosion compared to other factors in the Universal Soil Loss Equation. Furthermore, most of the effect of management is represented by C and P values in the USLE.

On a subprocess level, soil quality indices will be the interrill (K_i) and rill (K_r) erodibility factors used to estimate rill and interrill erosion

$$r = K_r\ (I - I_t)^a \quad [3]$$
$$i = K_i\ I^b \quad [4]$$

where:
r = rill soil erosion, T ha^{-1}.
I_t = threshold intensity needed to initiate the rill erosion.
I = rainfall intensity.
a, b = empirical factors.
i = interrill soil erosion, T ha^{-1}.

Sharma *et al.* (1994) suggested the following equation for interrill soil erosion which is comparable to interrill erosion (Eq. 4).

$$i = K_t\ I(E - E_t)S_f \quad [5]$$

where:
K_t = interrill sediment transportability coefficient.
S_f = interrill slope factor =[1.05-0.85 exp(-4sinϕ); ϕ =slope angle].
E = cumulative energy.
E_t = threshold energy needed to initiate soil detachment.

In all these equations, the equivalent soil quality indices are K_r, K_i, I_t, E_t, a, and b. It has been shown that soil quality indices in the above equations are a function of soil strength and clay content. Management effects, like surface residue cover, have very little influence on the soil quality factors in the above equations. The effects of other management factors, like tillage, will be reflected in soil strength, and in turn on the threshold values needed to initiate the interrill and rill soil erosion processes.

Another soil quality index is the productivity index (Larson *et al.*, 1983). In this index, the major factors affecting soil quality is the soil depth or its water holding capacity. Larson *et al.* (1983) and Pierce *et al.* (1983) have shown that when normalized with respect to maximum yield in the area, the productivity index is a good measure of crop yield. This index relates crop yield to soil properties in the rooting zone. The goal of this study is to assess the impact of long term tillage and manure interactions on soil quality goals.

METHODS AND MATERIALS

Soil physical and chemical measurements were made on an experimental site at the Dale and Steve Flueger farm near the city of Red Wing in Goodhue Co., Minnesota. The site has been under a long term experiment (the study began in 1982) on the effects of tillage and N-source on corn (*Zea Mays* L.) yields and soil nitrogen. The soil at the site is a Seaton silt loam (Typic Hapludalf, fine-silty, mixed, mesic), and the particle size analysis for the top 13 cm are 14.9% clay, 9.7% sand, and 75.4% silt. Results of these experiments have been reported by Burford (1986), Joshi *et al.* (1994a,b), Munyankusi *et al.* (1994), and Wu *et al.* (1992).

The long term study had been set up as a randomized complete block with replications as the main block followed by tillage (chisel plow system and no tillage system), nitrogen (N) source (commercial fertilizer and manure) and N frequency (annual, biennial, and triennially applied manure) as subplots (Fig. 5), details of the treatments are listed in Table 3.

Liquid dairy manure was applied to manure treatments by injecting it into the soil. The average manure application rate is 8.7 T ha^{-1}; and with an average organic carbon content of 5.9% for the manure, the average organic carbon addition to the plots each year in the manure is 0.5 T ha^{-1}. Manure was applied every spring to annual manure plots, the biennial manure plots received manure every other year, and the triennially manure plots received manure every third year. Commercial fertilizer was usually applied after the manure injection. The study also included zero N (check) treatment which served as a control treatment. Soil physical and chemical measurements characterized in this thesis refers only to the annual manure, annual fertilizer, and check plots. The site has been under continuous corn since 1982 when the experiment began. Other cultural practices and information on the study are described in the annual summaries in Appendices A and B.

From 1982 to 1986 the manure plots were further split into two subplots where K_2O was applied at the rate of 0 and 224 kg ha^{-1}. The commercial fertilizer plots were split into three subplots and K_2O applied at the rate of 0, 224, and 448 kg ha^{-1}. The K_2O treatments ended in 1987. Plots where infiltration and other soil physical measurements were made are: 1-2, 18-2, and 25-2 (no-till, commercial fertilizer); 5-5, 20-5, and 35-5 (chisel plow, commercial fertilizer); 111-9, 130-9, and 151-9 (no-till, annual manure); 120-15, 127-15, and 153-15 (Chisel plow, annual manure); 112-7, 129-7, and 152-7 (no-till, check); 114-14, 133-14, and 148-14 (Chisel plow, check).

Table 3. Details of the tillage and N-source treatments at the Flueger farm.

No tillage system (no-till)	Manure	Fertilizer	Check
Injection	X		
Fluted coulter	X	X	X
Anhydrous applicator		X	
Chisel plowing system (chisel plow)			
Injection	X		
Fluted coulter	X	X	X
Anhydrous applicator		X	
Chisel plowing	X	X	X
Discing	X	X	X

Infiltration Measurements

Tillage and N-source interactions on water entry into the soil was characterized by measuring the infiltration rates under both saturated and unsaturated conditions. Saturated infiltration rates were measured with a ponded infiltrometer (Bower, 1986) and unsaturated infiltration rates were measured with a tension infiltrometer (Ankeny *et al.*, 1990). Ponded and tension infiltration measurements were taken from September 23 to October 9, 1993.

Ponded infiltration: The ponded infiltrometer consisted of two circular galvanized steel rings, both approximately 35 cm high. The inner and outer rings were approximately 33 and 50 cm in diameter, respectively. Since each set of rings varied in diameter, separate measurements of diameter were taken for each ring.

In each treatment, an area representative of the plot was selected. Both the inner and outer rings were then driven approximately 20 cm into the soil with a flat hammer. Residues and plant material were cleared from the inner ring and coarse sand (grade 1.3) was poured to level the soil surface. A piece of air conditioner filter was then set on the top of the sand to minimize soil disturbance during the addition of water into the rings. Metal wire with a sharpened point was set at 3 to 4 cm above the sand. This height represented, approximately, the head during ponded infiltration. Water height was maintained at about the same level in both the inner and the outer rings. Infiltration rates were measured by recording the time it took to infiltrate a given amount of water into the soil. The infiltration rates were measured until a steady rate was achieved, or 20 minutes, which ever came later. Steady state infiltration rates were calculated from the slope of the regression line (Borland International, Inc., 1992) calculated from the cumulative infiltration (mm) vs. time (hr) measurements taken at the tail end of the infiltration run. Statistical analysis was done using ANOVA procedures with a P = 0.10 (SAS Institute, Inc., 1988). Mean separation was done using Duncan's Multiple Range Test with alpha = 0.10.

Tension infiltration: After the Ponded infiltration was completed, a tension infiltrometer was placed over the sand in the inner ring. The tension infiltrometer used in this study (Fig. 6) was a modified version of the one described in Perroux and White (1988).

The tension infiltrometer consisted of a 10 cm diameter by 100 cm long water reservoir, and a 5 cm diameter tube simulating a Mariotte bottle system. The reservoir and Mariotte cylinders were connected and permanently glued to the base (25 cm diameter).

Calibrated Scalafix[1] tape (Curtin Matheson Scientific, 7677 Equitable Dr., Eden Prairie, MN 55344) was affixed to the side of the reservoir for monitoring the water level. Final assembly of the tension infiltrometer was done in the field. The process involved placing the air conditioner filter over the stainless steel screen on the base plate, covering the filter with a 35 µm nylon screen[1] (Small Parts inc., P.O. box 4650, Miami Lakes, FL, 33014-0650) and stretching it over the base plate. The screen cloth is held in place with an o-ring and a pipe clamp around the base plate. The pipe clamp over the o-ring ensured that there was no air leakage into the water reservoir. The Mariotte bottle was then filled with water, and the entire infiltrometer was lowered into a large container of water where the reservoir cylinder was filled by vacuuming the air out of the reservoir. After filling, the tension infiltrometer was placed on a metal tray and observed for air leaks. If no leaks were observed, the tension infiltrometer was transferred to the inner ring of the ponded infiltrometer and placed onto the sand.

The desired tension was set by manipulating the depth of one air entry tube in the Mariotte cylinder. Once the desired depth was set, the initial water level in the reservoir was recorded. The selected air entry tube in the Mariotte cylinder was then opened to the atmosphere and the water level in the reservoir was recorded as a function of time. Water levels and time were recorded until a steady state condition was reached, or for approximately one half hour, which ever came first.

At the end of the infiltration measurement for a given tension setting, the air entry tube in the Mariotte bottle open to the atmosphere was closed and a new tension level was set. The tensions selected were -3.5 and -7.0 cm, and they were run in the descending order (from lower to higher tension). The steady state tension infiltration was estimated from the slope of the regression line between cumulative infiltration (mm) and time (hr) measurements taken at the tail end of the run.

Hysteresis effect: After discussions with Dr. Dan Reynolds of Agriculture Canada, a concern was raised that tension infiltration measurements made after ponded infiltration may be slightly higher. The reason is that the bottom of the soil profile is draining under saturated conditions while the top part was wetting under higher tension. To evaluate this hysteresis effect, additional tension infiltrometer and ponded infiltration measurements were taken on June 17, 1994. These measurements were made on plots 151-9 and 28-2. These plots represented extreme values in infiltration rates from the previous infiltration measurements; and these plots contained, or were near where nightcrawlers were found.

The procedures were nearly the same as the previous tension infiltration measurements with a few exceptions. First, a 30 cm diameter by 30 cm long PVC (polyvinyl chloroethane) pipes were pounded into the soil approximately 15 cm deep. On plot 151-9, 62-83 µm glass beads were poured onto the soil surface, whereas a fine sand (grade 8) was added to the surface on plot 28-2. The infiltration measurements were then taken in the sequence -7.0 cm, -3.5 cm, ponded, -3.5 cm, -7.0 cm tensions. After the infiltration measurements, the PVC pipes were then covered with plastic, and the soil was allowed to drain for several days.

These PVC pipes with soil were then dug out of the field and transported back to a cooler where they were kept for several weeks before running CT scans on August 13, 1994 to evaluate the macroporosity and continuity of the earthworm macropores in the top soil. In each plot, infiltration measurements were made at three locations. One of cores (Core F) in plot 151-9 contained a gopher hole that resulted in the collapse of the core, and it could not be used to obtain CT scan images. The CT scan images were taken at the University of Minnesota medical school on a CT scan unit manufactured by Simmons[1]. All scans were taken vertically along the length of the soil core. A slice width of 8 mm was selected for cores A, B, C, and D to provide for a continuous picture through the core. Soil core E was scanned at 5 mm slices resulting in overlap between the adjacent x-ray images.

Rainfall infiltration: Infiltration rates were also measured under simulated rainfall. This was done to create conditions as close as possible to natural rainfall scenarios. The rainfall simulator used in this study was a drop former type rainfall simulator (Onstad et al., 1981), and was borrowed from the USDA-ARS, North Central Soil Conservation Research Laboratory at Morris, Minnesota. The unit consisted of a large water reservoir, a pump, flow regulators, hoses, and panels from which the simulated rain drops emerged (Fig. 7). The panels were 2.44 m above the soil surface, and the median drop size corresponded to 2.5mm (Freebairn *et al.*, 1989). The combination of the panel height and drop size provided raindrop energy equivalent to 72% of the terminal energy of naturally occurring raindrops. The water was pumped from the reservoir to the raindrop forming panels through the flow regulators. These regulators controlled the rate at which the rainfall was occurring. In this experiment, the flow regulators were set at a rainfall intensity of 100 mm hr^{-1}.

Infiltration rates under simulated rainfall were run between July 6 and August 3, 1993. A representative area of the 18 plots was selected for rainfall simulation. Rainfall infiltration was calculated by subtracting the amount of runoff from the amount of water added in simulated rainfall.

Runoff plot areas were delineated by hammering large galvanized steel borders into the soil. The approximate size of the runoff plot was 150 cm x 90 cm. The plot was laid in such a manner so that the long part of the plot ran parallel to the rows. This orientation was selected to quantify runoff along the row. A border plate and a funnel shaped collector was installed at the end of the plot. The top of the border plate was at the same level as the soil surface.

Before rainfall, all corn plants and weeds were cut off at the soil surface using a scissors. A pit was dug at the downslope edge of the plot to install a tipping bucket. The funnel shaped collector routed the runoff from the plot to the tipping bucket. This tipping bucket had a magnet that sent switch closure signals to a Campbell 21x datalogger[1] (Campbell Scientific, Inc., 815 W. 1800

N., Logan, Utah 84321-1784) which recorded the runoff as a function of time. A vacuum cleaner attached to the base of the tipping bucket removed the runoff and sediment after each tip and transported them to a large PVC holding tank.

Large canvas curtains were hung around the scaffolding to prevent the raindrops from being carried away by wind. While waiting for the panels to fill and rainfall intensity to stabilize to the set intensity, one of these curtains was pulled across the plot. Once the panels had been filled and simulated rainfall reached a constant intensity, the curtain was removed from across the plot and rain was allowed to strike the plot. A stage recorder monitored the volume of runoff in the holding tank as a function of time. Infiltration runs were made for approximately 60 minutes.

After the rainfall ceased and all of the runoff was collected, the contents of the PVC cylinder were emptied into a large plastic garbage container and mixed thoroughly with a stick. Two one liter samples of the mixture of runoff and sediment were then collected for sediment content. The water from the two samples was boiled off, and the remaining sediments were weighed after oven drying at 105° C for 48 hours. The weight of oven dried sediments was converted to soil loss per hectare using the amount of runoff in one hour and the plot area. For plots where rainfall simulations were less than one hour, data was extrapolated to one hour so that each plot would have been subjected to the same amount of rainfall.

Organic Carbon and Bulk Density

Soil samples for both organic carbon and bulk density were taken from the same plots on which infiltration measurements were taken. Soil samples for organic carbon were taken with a 2.5 cm diameter soil probe to a depth of 15 cm on June 24, 1993. Samples were taken from 15 random sites within each plot and then composited in the field. The samples were brought into the laboratory, poured into a paper bag, and oven dried at 37° Celsius. The oven dried samples were ground to pass through a 2 mm sieve and then analyzed for organic carbon using the Walkley-Black method (Nelson and Sommers, 1982).

Bulk density samples were taken on August 6, 1993 using a core sampler with an outside diameter of 5.7 cm and a length of 6 cm. The bulk density sample was bracketed on the top and bottom by a 3 cm long cylinder. Soil samples were taken by driving down the sampler with a drop hammer. Once driven completely into the soil, the sample cylinder was removed. The top and bottom 3 cm cylinders were removed, and the remaining soil was shaved off from the top and bottom of the 6 cm cylinder using a spatula in the field. The contents of the 6 cm cylinder were then emptied into a moisture can and brought back into the laboratory. Bulk density samples were taken at 3-9, 15-21, and 27-33 cm in the same hole. Bulk density was calculated by dividing the oven dry (at 105° Celsius for 48 hours) weight by the sample volume.

Earthworm Survey

A survey of the earthworm population was also conducted in the same eighteen plots as used for infiltration studies on May 27, 1994. The procedure for collecting earthworms involved setting up of the outer ring of the ponded infiltrometer and adding approximately 20 liters of a 0.5% formaldehyde solution at the soil surface. Before adding the solution, residues were removed from soil surface to ensure that all of the earthworms were found. In order to avoid disturbing the earthworms with vibrations caused by pounding, the ring was slightly pressed into the soil by standing over the edge of the ring.

Formaldehyde solution was poured into the ring from a watering can. As the formaldehyde solution penetrates the soil and makes contact with the earthworms, it causes a skin irritation which causes the earthworms to rise to the soil surface. As the earthworms appeared at the soil surface, they were collected by hand and put into a container of water to wash off the formaldehyde solution. After approximately 15 minutes, all of the washed earthworms were removed from the water container and put into a styrofoam container with moist soil. The earthworms were then taken into the laboratory for identification.

While gathering data at the experimental site, it was noticed that middens were only present in the third replication. Replication 3 also produced generally higher infiltration rates. To determine from where the earthworms may have come into replication 3, we conducted another population survey along the perimeter of the plot area on August 19, 1994. The procedure used for this survey was identical to the previous survey.

Aggregate Stability

These measurements were conducted to compare the results of this experiment to the sediment yield data from the rainfall simulation experiment. Samples from the same eighteen plots as used for the infiltration measurements were collected with a blunt end shovel on September 9, 1994, and a composite of the top 15.2 cm of five samples was returned to the laboratory. The samples were dried for three days at 30° C in an oven, and then sieved between a 1 and 2 mm sieve.

Approximately 4 g of the 1 to 2 mm aggregates were weighed into a 60 mesh, 3.9 cm diameter sieve. This sieve was placed in a chamber attached to a humidifier for 30 minutes. The sieve containing the moistened aggregates was placed into a wet sieving apparatus where they were dunked into a pail of water at 35 strokes min^{-1} for three minutes. The sieve was removed, and the contents of the sieve were transferred into a beaker and dried at 105° C for 48 hours. Aggregate stability is the percent of the oven dry weight of the remaining soil on the sieve after sieving compared to the oven dry weight of the initial sample.

RESULTS AND DISCUSSION

Bulk Density

Average bulk density of the surface soil (3-9 and 15-21 cm depths) by tillage and N-source treatments is plotted in Figs. 8 and 9. The standard deviation is shown above the bar, and bars with different letters are significantly different. Bulk density values by individual plot are given Appendix C, along with the statistical analysis output. In general, the bulk density of the top 21 cm was higher for the no-till compared to the chisel plow plots. On average, soil bulk density for 3-9 and 15-21 cm depths were 1.46 and 1.47 Mg m^{-3}; and 1.37, and 1.35 Mg m^{-3} for the no-till and chisel plow plots, respectively. Statistical analysis showed that the differences in bulk density due to tillage were significant both at 3-9 ($P = 0.039$) and 15-21 cm ($P = 0.007$) depths. This is expected because in chisel plow, the soil is loosened due to the lifting of the soil; whereas in no-till, soil consolidates over time with minimal disturbance (samples taken 9 w weeks after tillage). Bulk density of the top 21 cm was highest for the fertilizer treatment, followed by the check and manure treatments. On average, bulk density for the 3-9 and 15-21 cm depths were 1.44 and 1.40 Mg m^{-3}; 1.44 and 1.45 Mg m^{-3}; and 1.36 and 1.38 Mg m^{-3} for the check, fertilizer, and manure treatments, respectively. Lower bulk density in the manure plots is expected considering that the manure was injected, and thus there is some loosening of the soil. Bulk densities were significantly different ($P = 0.053$) by N-source only at 3-9 cm depth. At 3-9 cm, manure produced significantly lower bulk density values than the fertilizer and check treatments, which may have been due to the tillage associated with the manure injection.

The interaction between tillage and N-source was significant ($P = 0.001$) at 3-9 cm depth (Fig. 10). Bulk density was highest in no-till fertilizer (1.59 Mg m^{-3}), followed by no-till check (1.47 Mg m^{-3}), chisel check (1.41 Mg m^{-3}), and chisel manure (1.41 Mg m^{-3}), no-till manure (1.32 Mg m^{-3}), and chisel fertilizer (1.28 Mg m^{-3}). A combination of traffic and natural consolidation of the soil in no-till fertilizer plots is hypothesized to result in higher surface bulk density. Lower bulk density of the surface soil for the chisel fertilizer and no-till manure plots are unexpected. For the manure plots, the lower bulk density may have been caused by better soil aggregation due to manure, and loosening due to manure injection. The lower bulk density of the chisel fertilizer treatment may have been due to soil loosening by the chisel plow, and the placement of these plots where there was less traffic. Being located on the ends of the replications, the fertilizer plots received less traffic from the heavy manure applicator than the manure plots. Soil bulk density at 27-33 cm was significantly ($P = 0.046$) higher for no-till (1.55 Mg m^{-3}) compared to chisel plow (1.49 Mg m^{-3}) (Fig. 11). This difference in bulk density due to tillage was unexpected, since there was no tillage to this depth. There was no differences in bulk density due to the N-source treatments. Average bulk density for the check, fertilizer, and manure treatments at 27-33 cm were 1.52, 1.53, and 1.50 Mg m^{-3}, respectively. There was no interaction between tillage and N-source on soil bulk density at this depth. This is expected since neither the manure nor the fertilizer are incorporated to this depth.

Organic Carbon

Soil organic carbon content by tillage and N-source at depths of 0-7.6 and 7.6-15.2 cm are shown in Figs. 12 and 13, respectively. Detailed measurements by plot are given in Appendix D. Statistically, there is no difference in soil organic carbon at 0-7.6 cm depth due to tillage, N-source, or their interaction. At 0-7.6 cm depth, the no-till plots had an organic carbon content of 1.47% as compared to 1.50% for the chisel plow plots. The soil organic carbon for the annual manure plot were 1.57%, compared to 1.57% and 1.32% for the fertilizer and check plots respectively. At 7.6-15.2 cm depth, the tillage effect and the tillage x N-source interaction on soil organic carbon were absent, but the soil organic carbon due to N-sourcewere statistically different ($P = 0.078$). Average soil organic carbon at the 7.6-15.2 cm depth were 1.27% and 1.21% for the chisel plow and no-till plots, respectively. The corresponding values by N-source were: 1.08%, 1.37%, and 1.27% for the check, fertilizer and manure treatments, respectively. Individual treatment comparisons showed that there was no statistical difference in the soil organic carbon content at 7.6-15.2 cm depth between fertilizer and manure plots and between the manure and check plots. Fertilizer plots contained significantly more organic carbon at 7.6-15.2 cm than the check plots.

Lack of differences in soil organic carbon due to tillage is unexpected. In no-till, residue is left at the soil surface, there is minimal soil disturbance, and soil temperatures are lower, which contribute to reduced residue decomposition and a build up of soil organic matter. The small number of soil samples (9 from each tillage system) may have been insufficient to show the differences between tillage systems.

Organic carbon values were multiplied by the bulk density to determine the weight of organic carbon present in the soil (Table 4). Statistical analysis was similar to the percent organic carbon results as already presented. Neither tillage nor N-source was significantly different at either depth. There was, however, a significant tillage x N-source interaction at 7.6-15.2 cm ($P = 0.036$).

Table 4. Average organic carbon (Mg ha) for the two tillage and three N-source treatments by depth.

		NO-TILL	CHISEL
DEPTH	N-SOURCE	Organic C (Mg ha)	
0-7.6 cm	MANURE	28.8	35.3
	FERT.	37.3	30.1
	CHECK	30.2	26.8
7.6-15.2 cm	MANURE	24.1	28.3
	FERT.	34.2	23.7
	CHECK	22.0	24.8

Residue Cover

Residue cover as a percentage of the soil surface was also measured as a subset of all the plots (Appendix B). Residue measurements were taken on June 24, 1993 by the transect method. A summary of the residue cover by tillage and N-source is presented in Fig. 14. As expected, residue cover in the no-till (61.9%) plots was statistically higher (P = 0.006) than the chisel plow (16.1%) plots. Residue cover due to N-source was not statistically different. Residue cover by N-source treatments was: 46.5, 48.2, and 39.3% for the check, fertilizer and manure treatments, respectively. Also, there was no significant interaction between tillage and N-source.

Differences in residue cover due to tillage are expected because in chisel plowing, soil is turned over and surface residues are buried; whereas in no-till, the residue is left at the soil surface. Since manure injection involves some soil disturbance, and residue cover was measured after manure injection, this treatment had the lowest residue cover as compared to the check and fertilizer treatments.

Infiltration

Ponded infiltration: Ponded infiltration represents water flow through all types of soil pores including the earthworm macropores. Steady state ponded infiltration was calculated from the cumulative infiltration versus time curves by taking the slope of the regression line when the rate of entry over time is constant. Figure 15 shows an example of such a graph for plot 35-5. Steady state ponded infiltration for this plot correspond to the slope of the line in Fig. 15 between the times of 0.20 and 0.32 hrs. The ponded infiltration data for the various plots is given in Appendix E, along with the statistical analysis output.

The steady state ponded infiltration rates were significantly influenced by both tillage (P = 0.057) and N-source treatments (P = 0.042) (Fig. 16). There was no significant interaction between tillage and N-source on steady state ponded infiltration. Average steady state ponded infiltration was higher for the chisel plow (424 mm hr^{-1}) than the no-till (204 mm hr^{-1}) treatment. Average steady state infiltration was significantly higher for the manure treatment (440 mm hr^{-1}) than the fertilizer (286 mm hr^{-1}) and check (216 mm hr^{-1}) treatments.

Previous studies in the literature (Edwards *et al*, 1990; Zachmann *et al.*, 1987) have suggested higher infiltration rates under no-till compared to chisel plow plots. This increase in infiltration in no-till has been attributed to the presence of earthworm macropores. Lower ponded infiltration rates in no-till in our experiment suggest that the macropores in the no-till, if present, are not open to deeper depths in the soil. Higher ponded infiltration rates in chisel plow compared to no-till may be due to an increase in porosity caused by soil disturbance during chisel plowing. The greater infiltration in the manure treatment may by due to an increase in the continuity of the earthworm burrows present, or due to the tillage associated with manure injection.

Tension infiltration: Tension infiltration rates refer to the rate of water entry when the water is under a given tension. In our study, we set the tension at -3.5 and -7.0 cm head in the tension infiltrometer. The capillarity equation (Eq. 6) can be used to calculate the largest pore conducting water at a given tension.

$$r = [2\ \sigma \cos\theta]/(d\ g\ h) \qquad [6]$$

where:

σ = Surface tension of water, 72.8 g s^{-2}.
θ = Contact angle between the capillary tube and water, 0°.
d = Density of water, 1.0 g cm^{-3}.
g = Gravitational acceleration, 981 cm s^{-2}.
h = Head, cm.

Equation [6] shows that the infiltration rates measured at -3.5 and -7.0 cm head refer to the rate of water entry through all pores smaller than a radius of 0.42 mm and 0.21 mm, respectively. Figure 17 shows an example of the graph of cumulative infiltration vs. time at -3.5 cm head for plot 35-5. Data for the other plots are included in Appendix E, along with the statistical analysis output. Regression procedures described in the previous section were also used to calculate the steady state infiltration rate at a given tension.

Average steady state infiltration at -3.5 and -7.0 cm head by tillage and N-source are shown in Figs. 18 and 19, respectively. There was no significant difference in steady state infiltration rates at any tension between the tillage and N-source treatments. Also, the tillage x N-source interactions were absent. Since infiltration rates at -3.5 and -7.0 cm represents water entry through soil matrix pores, there should be a minimal influence of soil management practices on infiltration rate. As expected, steady state infiltration rates followed the order: ponded infiltration rate > infiltration rate at -3.5 cm head > infiltration rate at -7.0 cm head.

At -3.5 cm head, the average steady state infiltration rates were 83 and 45 mm hr^{-1} for the chisel plow and no-till treatments, respectively. The corresponding infiltration rates for N-source treatments were 38, 55, and 99 mm hr^{-1} for check, fertilizer, and manure treatments, respectively. At -7.0 cm head, no-till plots averaged a steady state infiltration rate of 15 mm hr^{-1} vs. 16 mm hr^{-1} for the chisel plow plots. The corresponding infiltration rates for the manure plots averaged 22 mm hr^{-1} as compared to 13 mm hr^{-1} for fertilizer and the check plots.

Infiltration under simulated rainfall: Since the soils in this area of the state are sloping, it is unlikely that ponded water conditions exist over the landscape for a long period of time. Therefore, infiltration measurements under simulated rainfall provides a more realistic assessment of the treatment effect on water infiltration under natural rainfall scenarios.

In Figure 20 is shown an example of the infiltration data collected during the simulated rainfall infiltration experiments. Similar graphs for the other plots is given in Appendix F (along with the statistical analysis output), and the program used in the Campbell's 21X datalogger for counting tips of the tipping bucket can be seen in Appendix G. The cumulative infiltration vs. time regression used to determine the steady state infiltration rate for plot 1-2 in Figure 20 was run between 0.5 and 0.97 hours.

The infiltration rate versus time graph is shown in Figure 21. As expected, initially the infiltration rate is nearly constant, and then declines with an increase in time. The constant portion of the curve corresponds to 100 mm hr^{-1}, the rate of water application. The decline in infiltration rate over time is due to a decrease in the hydraulic gradient between the soil surface and the wetting front, and possibly due to the presence of a surface seal. Any water addition greater than the infiltration rate during the declining part of the curve represents surface runoff. The peaks and valleys in Fig. 21 indicate the dynamics of surface seal development, as well as the destruction of microrelief which allows water to move from low spots in the plot area to the collector.

Steady state infiltration rates under simulated rainfall by tillage and N-source treatments are summarized in Fig. 22, and the individual values for each plot are listed in Appendix H, along with the statistical analysis output. Both tillage ($P = 0.034$) and N-scurce ($P = 0.061$) significantly influenced the infiltration rates under simulated rainfall. For the tillage treatments, average infiltration rates were 37 mm hr^{-1} for the no-till compared to 17 mm hr^{-1} for the chisel plow treatment. For the N-source treatments, the infiltration rate was significantly greater for the manure treatment (39 mm hr^{-1}) than the fertilizer (23 mm hr^{-1}) and the check (20 mm hr^{-1}) treatments.

There was also a significant interaction between the tillage and N-source treatments on steady state infiltration rates under simulated rainfall (Fig. 23). Steady state infiltration rates were highest for the no-till manure (58 mm hr^{-1}); followed by no-till fertilizer (34 mm hr^{-1}); no-till check, chisel plow manure, and chisel plow check (all at 20 mm hr^{-1}); and chisel plow fertilizer (11 mm hr^{-1}). It is believed that the no-till manure treatment had the best combination of tillage (from the manure injection) and residue cover. This combination both protected the soil surface from surface sealing and allowed water to infiltrate quickly due to greater porosity.

Surface residue played a much bigger role in determining treatment effects on simulated rainfall infiltration rates than earthworm macropores. Infiltration rates for no-till were higher than chisel plow mainly due a greater amount of surface residue, which in turn reduced the raindrop impact energy and thus lowered the potential for surface seal development. The effect of earthworm macropores will be minor in relation to the effects of surface residues under natural rainfall conditions on this soil. The reasons are that this soil is susceptible to sealing, and the slope makes ponded conditions (necessary for macropore flow) unlikely.

Time to ponding: The time when the infiltration rate starts to decline refers to the time to ponding. Besides the steady state infiltration rate, time to ponding is another important parameter in assessing the effects of tillage and N-source treatments on infiltration and runoff. The longer is the time to ponding, the less likely it is that a brief storm will cause any runoff.

There was no statistical difference between the tillage and N-source treatments on time to ponding (Fig. 24). Also, there was no tillage and N-source interaction on time to ponding. Numerically, the no-till treatment had the longest time to ponding of the tillage treatments and manure for the N-source treatments. Average time to ponding was 7.7 and 12.6 minutes for chisel plow and no-till, respectively; and 7.6, 9.2, and 13.7 minutes for check, fertilizer, and manure plots , respectively. The values for time to ponding by individual plot are listed in Appendix H, along with the statistical analysis output. Since no-till and manure treatments are expected to have an increased activity of earthworms, it is also expected to have a longer time to ponding. However, the time to ponding is a highly sensitive parameter depending upon the microrelief of the runoff plots; it is suspected that microrelief in combination with spatial variability in macropore numbers may have masked the tillage and N-source effects on time to ponding.

Ponded vs. rainfall simulation infiltration rates: Comparison between the steady state ponded and simulated rainfall infiltration rates provides an interesting observation on tillage and N-source treatment effects on infiltration rates. As is apparent in Figure 25, different methods of measuring infiltration rate result in completely different treatment effects.

For ponded infiltration, chisel plow had the highest infiltration rates and no-till the lowest, but the treatment effects were reversed for infiltration rates with the rainfall simulator. Ponded infiltration rates were an order of magnitude higher than the infiltration rates from the rainfall simulator.

The rainfall simulator infiltration rates are influenced by more than the soil itself. Surface residues play a large role in these infiltration rates. Surface residues protect the soil surface from raindrop impact, and thus result in a higher infiltration rate than the bare soil. Since chisel plow plots have less residue, more of the surface area in chisel plowed plots is subjected to surface seal development and reduced infiltration rates. Ponded infiltration is not influenced by the presence of residue, and there is no effect of the surface seal. The order of magnitude difference between the two methods is due to the nature of the two experimental setups. The ponded infiltrometer has a constant supply of water (several centimeters of water) above the soil surface. Water is always present to infiltrate into the soil. Under rainfall simulation, excess water is allowed to runoff of the plots. The only place water ponds is in depressions within the plot. Water is added at small increments to the surface, and is not always ponded over the soil surface. These results suggest that if infiltration rates for natural rainfall are desired, ponded infiltration will not give an accurate picture unless the soil is not susceptible to surface seal development and develops ponded conditions.

Sediment Production

Erosion is a major problem in the upper Midwest, especially in soils similar to those of Southeastern Minnesota. This is because of the susceptibility of these loess soils to develop a surface seal in combination with the steep slopes in the area. It has been suggested in the literature (Tisdall and Oades, 1982; Lersch *et al.*, 1991) that organic matter addition, such as manure application, will help increase soil aggregate stability, and thus decrease soil erosion. The goal of this measurement was to evaluate the long term effects of tillage and manure application on sediment production under simulated rainfall conditions. Although the author is aware that soil erosion is highly dependent upon the rainfall intensity, the sediment yield was measured under a constant rainfall intensity of 100 mm hr^{-1} because of the difficulty in simulating various rainfall intensity rates. It is also noted that 100 mm hr^{-1} would be a high rainfall intensity for Minnesota.

As expected, tillage significantly influenced sediment production (P = 0.035). Average sediment yield (Fig. 26) was 11.1 T ha^{-1} for chisel plow treatments compared to 3.1 T ha^{-1} from no-till treatments. The sediment yield by individual plot is given in Appendix H (along with the statistical analysis output), and were calculated from the sediment concentration in two 1 liter water samples taken from each plot multiplied by the 1 hour runoff volume (or the extrapolated 1 hour runoff volume for some plots). Lower sediment yield in no-till plots compared to chisel plowed plots was mainly due to the presence of higher residue cover (61.9% vs. 16.1%) which protected the soil surface from raindrop energy, and thus reduced splash erosion. Higher sediment yield in chisel plow compared to no-till is also due to the increased soil disturbance in this treatment. Figure 27 shows that irrespective of treatments, the average sediment loss was exponentially related to residue cover. The R^2 value of 0.73 further indicates that residue cover is the main factor in determining sediment production among all the tillage and N-source treatments.

The differences in sediment production due to N-source was not significant. The tillage x N-source interaction on sediment production was also absent. Average sediment production was 9.0, 6.4, and 6.0 T ha^{-1} for the manure, fertilizer, and check plots, respectively. As stated earlier, it was expected that manure addition over the past 12 years would have increased aggregate stability, and thus lowered sediment production from the manure applied plots compared to fertilizer applied and check plots. Since manure application has been shown to increase earthworm population (Curry, 1976; Cotton and Curry, 1980), it was also expected that increased earthworm activity will help increase infiltration, reduce surface runoff, and thus reduce sediment yield. Higher sediment loss in the manure treatment is believed to be due to lower surface residue cover (39.3%) compared to fertilizer (48.2%). During manure injection, there is soil disturbance and some of the surface residue is buried. A combination of all these factors probably resulted in higher sediment yield in the manure than the fertilizer or check plots. In comparing the differences in sediment production, it is concluded that presence of surface residues is a more dominant factor in controlling sediment production than the improvement in aggregate stability.

Macroporous Infiltration

We defined the macroporous infiltration as the steady state infiltration rate due to pores greater than 0.42 mm. Since in the literature (Munyankusi, 1992) there is no agreement on the cut off value above which a pore is considered a macropore; in this study, we used a radius of 0.42 mm (corresponding to a tension of -3.5 cm) as the cut off value for macroporous infiltration. This is similar to the assumption of Ela (1990). Therefore, steady state macroporous infiltration is defined as the difference between the ponded infiltration rates and the infiltration rates at -3.5 cm head.

Figure 28 shows the plot of macroporous flow by tillage and N-source treatments. Values for the individual plots are given in Appendix E, along with the statistical analysis output. Statistically, there was no effect of tillage on macroporous flow. Steady state macroporous infiltration was 341 mm hr^{-1} for the chisel plow as compared to 159 mm hr^{-1} for the no-till. Since the ponded infiltration rates were much higher for the chisel plow compared to no-till, it is expected that the macroporous flow will also be higher for the chisel plow treatment. As discussed in the Ponded Infiltration section, higher rates of macropore infiltration in chisel plow may be due to increased porosity caused by soil disturbance.

Steady state macroporous infiltration was 248, 161, and 341 mm hr^{-1} for the check, fertilizer, and manure treatments, respectively. Differences in steady state macroporous infiltration rates for N-source were found to be significantly different at $P = 0.090$. Statistically, steady state macroporous infiltration rates for the manure and check plots were equal, but higher than the fertilizer plots. There was no statistical difference in steady state macroporous infiltration between the check and the fertilizer plots.

Lack of a significant difference between the chisel plow and no-till treatments was due to large variability in field infiltration measurements. This variability may be the inherent variability of the field, or due to the presence of a few continuous earthworm macropores. Higher macroporous infiltration rates in the manure treatment than the fertilizer treatment indicate an increased number of macropores and an increase in the continuity of these macropores in the manure treatment. This is expected considering that several authors have indicated increased activity of earthworms in manure applied plots (Munyankusi, 1992; Converse *et al.*, 1976). Numerically, fertilizer plots had lower macroporous infiltration than the check plot.

Characterization of Hydrologically Active Porosity

Information on macropore size distribution, number, and macroporosity is needed to model macroporous flow through soils. Currently, most of the models assume that surface measurements are representative of the conditions below the soil surface. Ela *et al.* (1990) and Munyankusi *et al.* (1994) have shown that the number of macropores and the macroporosity are maximum at 1 to 2 cm below the soil surface, and the number of macropores and macroporosity both decrease with depth. Munyankusi *et al.* (1994) also showed that it is the continuity of the macropores that is important in controlling the preferential flow of water and chemicals through the soil. Since the current methods (destructive sampling, CT scan images) of quantifying number of macropores, macroporosity, and continuity are destructive, time consuming, and expensive, it is highly desirable to evaluate alternative techniques for quantifying these parameters.

Several attempts have been made in the literature to quantify macropores with tension infiltrometers. White *et al*, (1992), Wilson *et al.* (1988), and Reynolds and Elrick (1991) are a few notables who have attempted to characterize macropores with tension infiltrometers. In most of these studies, infiltration rates at a given tension are converted into a number of macropores corresponding to the maximum radius of a capillary tube that can conduct water under a given tension based on the capillarity equation (Eq. 6). In practice, most of the conducting pores are smaller than the maximum radius calculated using the capillarity equation because of the inherent soil structure or because of constrictions within the pores.

Recently, Reynolds *et al.* (1994) suggested a procedure to estimate the number and radius of hydrollogically active macropores from tension infiltrometer measurements. The procedure is based on Wooding's (1968) solution of Richard's equation for infiltration from a shallow, circular pond.

$$Q_o = [\pi a^2 K_o] + [G a M_o] \qquad [7]$$

where:
Q_o = the steady state flow rate.
K_o = near saturated hydraulic conductivity of the soil.
G = 4.219 (a dimensionless shape factor constant).
a = radius of the infiltration surface receiving water from the tension infiltrometer.
M_o = the matrix flux potential of the soil.

The M_o value was defined as the area under the curve of K vs. Ψ by Gardner (1958) as being

$$M_o = \quad K(\Psi)\ d(\Psi);\ \Psi 1 \le \Psi \le \Psi o \le 0 \qquad [8]$$

where:
K(Ψ) = hydraulic conductivity pressure head relationship.
Ψ1 = Initial Pressure head.
Ψ = Selected pressure head.
Ψo = Pressure head at which no macropore flow is assumed.

The flow weighted mean pore radius (R_o) for the conducting pores between the given pressure heads is defined as (Philips, 1987)

$$R_o = [\sigma K_o] / [d g M_o] \qquad [9]$$

where:
σ = the surface tension of water.
d = density of water.
g = gravitational acceleration.

Reynolds *et al.* (1994) suggested calculating the number of conducting pores m^{-2} (N_o) of the radius (R_o) using Poiseuille's Law for flow in capillary tubes.

$$N_o = [8 \mu K_o] / [d g \pi R_o^4] \qquad [10]$$

where:
μ = the dynamic viscosity of water.

Reynolds *et al.* (1994) showed that N_o increased sharply with an increase in R_o, reached a maximum, and then exponentially declined to a very low value at large R_o. The peak in the N_o vs. R_o relationship at small pore radii was attributed to the presence of constrictions (e.g. pore necks and entrapped air bubbles) and discontinuous pores. The authors concluded that the above analysis of the tension infiltration data was an effective method of characterizing macropore characteristics (R_o and N_o) and in distinguishing the differences in macroporous flow between no-till and moldboard plow tillage under corn.

We used the analysis of Reynolds *et al.* (1994) on our tension infiltrometer data to assess the effects of tillage and N-source on the transmission properties of hydrologically active macropores. Although the authors have not suggested it, we used the N_o and R_o values to calculate the hydrollogically active macroporosity, assuming the macropores are circular. In Table 5, the values for Q_o, R_o, N_o, and the macroporosity using the geometric mean of the Q_o values (as suggested by the authors) for our data are listed. In general, R_o decreased with an increase in tension; however, there were four treatments (no-till fertilizer, chisel fertilizer, no-till manure, and chisel manure) where the radius of the pores was greater at -7.0 cm head than -3.5 cm head, and/or was greater at -3.5 cm head than under saturated conditions. This is not consistent with the observations of Reynolds *et al.* (1994) where R_o continually increased with decreasing tension.

Except for the chisel check plots and no-till manure plots, all of the other treatments have N_o values decreasing with increasing tension. This is also inconsistent with the findings of Reynolds *et al.* (1994). These authors found that there is a smaller number of pores at low tension and a greater number at higher tensions.

Table 5. Geometric mean Q_o, geometric mean K_o, R_o, N_o, and percent hydrollogically active porosity for the two tillage and three N-source treatments.

Treatment	Head	Q_o (cm^3 s^{-1})	K_o (cm s^{-1})	R_o (cm)	N_o (m^{-2})	Porosity (%)
No-till, Fert.	0	1.97	0.0014	0.0085	68974	0.155
	-3.5	0.35	0.0003	0.0138	2081	0.012
	-7.0	0.11	9.8E-05	0.0165	343	0.003
Chisel, Fert.	0	6.51	0.0060	0.0210	8036	0.111
	-3.5	1.74	0.0017	0.0239	1307	0.024
	-7.0	0.23	0.0002	0.0257	132	0.003
No-till, Manure	0	5.91	0.0060	0.0357	965	0.039
	-3.5	0.99	0.0007	0.0105	15944	0.055
	-7.0	0.54	0.0004	0.0111	7153	0.028
Chisel, Manure	0	12.35	0.0122	0.0230	3990	0.112
	-3.5	2.39	0.0024	0.0345	443	0.017
	-7.0	0.07	7.1E-05	0.0388	8	0.0004
No-till, Check	0	2.65	0.0027	0.0318	669	0.021
	-3.5	0.54	0.0005	0.0306	158	0.005
	-7.0	0.11	0.0001	0.0284	41	0.001
Chisel, Check	0	8.08	0.0087	0.0594	182	0.020
	-3.5	0.48	0.0005	0.0230	160	0.004
	-7.0	0.18	0.0002	0.0178	421	0.004

The problem encountered is that there are two variables, N_o and R_o. Since the flow is based on the total area, or porosity, and porosity can be any combination of these two parameters. Appendix I lists Q_o, R_o, N_o, and the hydrollogically active porosity for each individual plot, and also shows the inconsistencies in the calculations of R_o and N_o when using individual measurements.

Since R_o and N_o are linked to each other through the steady state infiltration rate, we decided that calculating the hydrollogically active area (porosity) may eliminate these inconsistencies. Except for the no-till manure treatment, the hydrollogically active porosity decreased with an increase in tension. However, the hydrollogically active porosity is much lower than the values of <2% measured by Munyankusi (1992) for chisel plow fertilizer plots using the paint injection technique. The reasons for the inconsistencies in the no-till manure plots is not apparent. It is concluded that the approach used by Reynolds *et al.* (1994) needs additional testing under a variety of soil management conditions before evaluating its usefulness.

Earthworm Population

Earthworm population as influenced by tillage and N-source is shown in Fig. 29. No-till plots have a significantly higher (P = 0.067) number of earthworms (77 earthworms m^{-2}) compared to the chisel plow (9 earthworms m^{-2}) plots. For N-source treatments, the check and manure plots had the highest number of earthworms (45 earthworms m^{-2}), followed by the fertilizer (39 earthworms m^{-2}) treatment; however, N-source effects and the tillage x N-source interaction on earthworm population were not significant.

The differences between the two tillage systems considered in this study on earthworm population is expected. As discussed in the Literature Review section, many researchers have shown a higher number of earthworms in no-till compared to tilled systems. This is mainly due to an increased intensity of the soil disturbance in chisel plow compared to the no-till treatment. Increased soil disturbance leads to physical damage to the earthworms, an increased susceptibility of earthworms to be consumed, and decreased availability of food (especially for earthworms such as *Lumbricus terrestris* that are detritivores).

Since manure is a food source for many earthworm species, manure treatment was expected to show an increased number of earthworms. The lack of a significant N-source effect may be due to the small differences in organic carbon between the three N-source treatments (1.32 % to 1.57% organic carbon). Another factor may be the overwhelming presence of residue as a food source compared to the amount of manure applied.

In general, the number of worms was lower in the manure plots in the third replication compared to the other two replications. However, it was only in the third replication where nightcrawlers were present. It is suspected that the lower number of worms in the manure plots in replication 3 was caused by the presence of the nightcrawlers, and the food supply may have limited the number of worms since larger nightcrawlers require more food. To prove the above hypothesis, it may have been more meaningful to record the weights of the worms along with their numbers; however, this was not realized at the time of the measurement.

In Table 6 is shown the distribution of earthworms by species present in each plot, but only twelve plots are shown due to earthworm mortality before they could be identified. Nightcrawlers were identified in the field due to their significance in water infiltration. *A.tuberculata* (a native to Minnesota) was the most numerous specie in all the plots followed by *L. rubellus* and then *L.* terrestris.

An intersting observation was the location of *L. terrestris* (nightcrawlers) among the various plots. Nightcrawlers were found in only two plots in the third replication, and both these plots had received manure. While working in the field, middens (residue pulled into nightcrawler burrows) were observed in only the third replication. The concentration of middens in the third replication was greatest towards the farmer's (Steve Flueger's) home. The number of middens in the field also seemed to decrease with an increase in distance from the house and from the grassed terrace. There were very few middens observed in the fertilizer treatment of the third replication, and no middens were observed past the half way point between the grassed terrace and the upper edge of the field.

Since the deep vertical burrows of the nightcrawler are most effective in transporting water to deeper depths, the location of these burrows is important in explaining the differences in infiltration between treatments. Nightcrawlers are not native to Minnesota. We believe the lawn outside the farmer's house was the source of nightcrawlers in the third replication. We hypothesize that nightcrawlers were transported to the farmer's (Steve Flueger's) home during earthmoving for the establishment of the lawn. The nightcrawlers present in the new soil were then able to spread down the grassed terrace which has conditions similar to that of a lawn. From the grassed terrace, nightcrawlers moved into plots such as the no-till or manured plots that they found most favorable.

Table 6. Survey of earthworms in the various tillage and N-source plots by earthworm species (number m^{-2}), numbers (number m^{-2}), and maturity (number m^{-2}).

Plot	Treatment	*L.t.*†	*A.t.*	*L.r.*	*Imm A.t.*	*Imm L.r.*
1-2	NT, FERT	0	5	5	33	9
18-2	NT, FERT	0	5	19	5	10
25-2	NT, FERT	0	19	0	14	0
112-7	NT, CHECK	0	9	9	19	5
129-7	NT, CHECK	0	9	19	19	5
152-7	NT, CHECK	0	9	0	0	0
130-9	NT, MAN	0	0	0	19	0
151-9	NT, MAN	33	0	0	0	0
120-15	CHISEL, MAN	0	5	0	0	0
153-15	CHISEL, MAN	9	0	0	0	0
114-14	CHISEL, CHECK	0	5	0	0	0
5-5	CHISEL, FERT	0	5	0	0	0

† L. t.- *Lumbricus terrestris*, A. t.- *Aporrectodea tuberculata*, L. r.- *Lumbricus rubellus*, Imm- Immature.

The above hypothesis was tested by sampling the earthworm population around the perimeter of the plots on August 19, 1994. As is apparent from Figure 30, the number of nightcrawlers was much greater in the grassed terrace near the Flueger's home than anywhere else. Only one small population was found near replication 1, and very few were found near replication 2. The presence of the population near replication 1 may be explained by nightcrawlers moving along the fence line, but its true source remains unclear. From our earlier population survey, it is apparent that the nightcrawlers have not inhabited the plots in replication 1. The nightcrawlers in the corn above the plot area are likely left overs from the previous alfalfa stand. This area was in alfalfa until fall 1993, when the alfalfa was chisel plowed under in preparation for corn in spring 1994. The nightcrawlers probably dispersed here during the favorable years under alfalfa.

The total earthworm population by location along the perimeter of the field is given in Figure 31. Table 7 shows the species present at all of the sampling points; however, some of the plots have no earthworms identified, and the sum of the earthworm species do not equal the totals because of earthworm mortality before identification could begin.

Table 7. Survey of earthworms by species (number m^{-2}), number (number m^{-2}), maturity (number m^{-2}), and vegetation along the perimeter of the experimental site on August 19, 1994.

SAMP.	*L. ter.†*	*L. rub.*	*A. tuber.*	*A. trap.*	IMM	TOT	VEG
1	14	0	0	0	0	113	GRASS
2	9	0	0	0	0	165	GRASS
3	0	0	0	0	0	132	GRASS
SAMP.	*L. ter.†*	*L. rub.*	*A. tuber.*	*A. trap.*	IMM	TOT	VEG
4	0	0	0	0	0	28	GRASS
5	0	0	5	0	5	89	GRASS
6	9	0	0	0	9	113	GRASS
7	0	0	5	0	0	56	GRASS
8	52	9	5	0	0	174	GRASS
9	9	0	5	0	0	52	GRASS
10	33	9	14	0	9	160	GRASS
11	24	0	9	0	0	47	GRASS
12	33	0	19	0	5	75	LAWN
13	33	0	14	0	0	89	LAWN
14	19	0	9	0	5	38	CORN
15	0	5	9	0	14	28	CORN
16	47	0	9	0	5	80	ALF.
17	19	14	9	0	19	99	ALF.
18	5	0	0	0	0	75	ALF.
19	0	0	5	0	5	89	ALF.
20	5	0	5	0	19	47	ALF.
21	0	19	9	5	42	94	ALF.
22	5	5	5	0	0	85	ALF.
24	0	0	5	0	9	24	CORN
25	0	9	9	0	28	71	CORN
SAMP.	*L. ter.†*	*L. rub.*	*A. tuber.*	*A. trap.*	IMM	TOT	VEG
26	0	0	0	0	0	47	CORN
27	0	0	0	0	0	28	CORN

28	0	0	0	0	5	42	CORN
29	0	5	0	5	28	47	CORN
30	0	0	14	0	28	71	CORN
31	0	0	0	0	5	9	CORN
32	0	0	0	0	0	24	CORN
33	0	0	24	0	0	71	CORN
34	0	0	0	0	0	52	CORN
35	0	9	0	0	5	33	CORN
36	9	5	0	0	0	56	CORN
37	5	5	0	0	5	14	CORN
38	19	0	0	0	0	38	CORN
39	9	0	9	0	9	56	CORN
40	28	0	0	0	0	71	CORN
41	28	0	0	0	0	28	CORN

† L. ter.- *Lumbricus terrestris*, A. tuber.- *Aporrectodea tuberculata*, L. rub.- *Lumbricus rubellus*, A. trap.- *Aporrectodea trapezoides*.

As expected, the greatest population of earthworms was found in the grassed waterway, followed by the alfalfa, and finally the corn. The grassed waterway and the alfalfa both provide food for the earthworms and are free from tillage. Since the corn is tilled, there is little food available for the worms, especially at the soil surface. The species present were similar to the earlier population survey with the exception of two *A. trapezoides* found at two sampling points along the perimeter of the plots.

An interesting observation is that plowing up an alfalfa field and planting corn cuts the nightcrawler population by 33% (Fig. 30; average of 24 nightcrawlers m^{-2} for the three alfalfa samples around replication 3 with nightcrawlers, compared to an average of 16 nightcrawlers m^{-2} for the six samples around replication 3 in the corn that contained nightcrawlers). The total earthworm population is also more than reduced by half (average earthworm population in alfalfa is 94 earthworms m^{-2}, whereas the average earthworm population in corn following alfalfa was 43 earthworms m^{-2}) from plowing down an alfalfa stand and planting corn.

Influence of Nightcrawlers on the Rate of Water Entry

Since nightcrawlers form large, vertical burrows and are known to influence infiltration rates, it was hypothesized that their presence around replication 3 may have influenced the rate of water entry in this replication. To assess whether the presence of nightcrawlers might have influenced the rate of water entry, the infiltration rate under ponded infiltration (Figure 32) and rainfall simulation (Figure 33) were plotted for each replication by treatment. Except for no-till fertilizer treatment, Figure 32 shows that all the treatments have the highest ponded infiltration rates in the third replication. Since the soil seals and the water flow under the seal is unsaturated, it was not expected that infiltration rates under rainfall simulation would be influenced by nightcrawler burrows. Figure 33 shows the infiltration rates under simulated rainfall are approximately equal for all the treatments in all three replications. The exception to this trend is chisel plow manure plot in replication 3 that had a much higher infiltration rate than the other two replications. There was also a slightly higher infiltration rate in the third replication for the no-till manure plot. The combination of the data in Figs. 32 and 33 supports the hypothesis that the higher infiltration rates for manure treatments in replication 3 are due to the presence of nightcrawlers in these plots.

Hysteresis Effect on Tension Infiltration Rates

In our discussions with Dr. Reynolds of Agriculture Canada (one of the original developers of the tension infiltrometer), a concern was raised that infiltration measurements with tension infiltrometer should only be conducted during the wetting cycle. In other words, the soil should be relatively dry compared to the tension set on the infiltrometer. The reason for such a concern is that if the soil is relatively wet when the bottom of the profile may be draining while the top of the profile is wetting, this combination could lead to higher infiltration rates. This hysteresis effect *i.e.* the effect of the wetting (from higher tension to lower tensions) and drying (from lower tension to higher tension) history on infiltration rates measured with a tension infiltrometer.

Most often, the rates reported in the literature have been taken on the drying sequence (from lower tension to higher tension). The reason for this sequence is the difficulty of measuring tension infiltration rates on soils which are initially dry. Because of the dryness, there is some impedance between the soil surface or the covered sand layer and the membrane of the tension infiltrometer. This impedance slows the initiation of the infiltration at higher tensions. In the drying sequence, since the soil surface or contact material layer is wet, the contact material is able to transmit the water to the soil surface from the infiltrometer more rapidly. This leads to rapid arrival of steady state infiltration conditions.

In our preliminary experiments, we started conducting our tension infiltration measurements in the sequence from high to low tensions. Because of the impedance problem, we switched to the sequence of low to high tensions. Since the question of hystersis was raised; and, since all our tension infiltration measurements were taken after the ponded infiltration measurements (on the drying sequence), we wanted to quantify the effects of previous wetting and drying on the tension infiltration rates. For this study, we selected two plots which showed a great difference in infiltration rates. These plots were 151-9 and 25-2 representing no-till manure and no-till fertilizer treatments, respectively. In each plot, three locations were chosen; and at each location, infiltration measurements were taken from -7.0, -3.5, saturated, -3.5, and -7.0 cm tension. Each of these measurements are represented by a labeled soil core, A through F. After the tension infiltration experiment, the soil was covered and allowed to dry. After three days of drying, the soil cores were excavated for CT scanning.

The infiltration rates for the five tension settings for each core are listed in Table 8. In general, the infiltration rate at a given tension was higher when going from a sequence of lower to higher tension (wet to dry) than higher to lower tension (dry to wet), but this trend was not consistent at all locations. Infiltration rates for soil core C were not completed due to an unexplained stoppage of flow after the ponded infiltration run, this phenomenon was not previously observed.

Table 9 shows the method and spatial standard deviations for the two plots for each tension setting, and for the high to low and low to high tension runs. The methods standard deviation was computed as the standard deviation of infiltration rates of the two tension runs at a given head, for each core in each plot (i.e. the average standard deviation of the two -7.0 cm tension runs in cores A to C). The spatial deviation was calculated as the average standard deviation of the infiltration rates of the three cores for each tension setting and for each run (i.e. the average standard deviation of the three high-low tension -7.0 cm runs in cores A to C). Table 9 shows that the spatial standard deviations are generally greater than the methods standard deviations. This suggests that the variability in tension infiltration rates due to variation in soil characteristics are greater than the variability in tension infiltration rates due to the wetting and drying sequence. Thus it is concluded that for our study, the measurement of tension infiltration rate on the drying sequence will have a minimal influence on the interpretation of treatment effects on macroporous flow and soil quality.

Table 8. Infiltration rates for the individual cores for the June 1994 Hysteresis experiment.

PLOT 25-2; NO-TILL, FERTILIZER				
	A	B	C	AVERAGE
-7.0	17.4	3.4	3.9	8.2
-3.5	43.4	6.8	7.3	19.2
SAT	177.3	45.1	43.4	88.6
-3.5	17.7	7.8		12.8
-7.0	3.4	3.4		3.4
PLOT 151-9; NO-TILL, MANURE				
	D	E	F	AVERAGE
-7.0	4.2	4.7	7.2	5.4
-3.5	27.6	10.5	27.9	22.0
SAT	84.7	101.5	372.01	186.1
-3.5	20.6	10.7	35.9	22.4
-7.0	9.4	9.2	13.6	13.6

CT Scanning Results

CT scans were done to determine the macropore continuity of five cores (core F collapsed in the field due to a gopher burrow) used in the "hysteresis" experiment. The x-ray photographs of the cores showed the presence of several continuous and non-continuous macropores. Macropore continuity as estimated from the three CT scanned cores is summarized in Table 10.

Plot 151-9, Core D (no-till, manure) contained two continuous macropores and one large, vertical root channel. This core also had five surface pores that were not continuous throughout the core. Core E contained one continuous macropore and five subsurface macropores that were not continuous.

Table 9. Method and Spatial standard deviations for the Hysteresis experiment in June, 1994.

PLOT 25-2				
		A	B	C
METHOD STD -7.0		7.0	0.0	2.0
METHOD STD -3.5		12.9	0.5	3.7
		DRY-WET	WET-DRY	
SPATIAL STD -7.0		6.5	1.6	
SPATIAL STD -3.5		17.1	7.2	
PLOT 151-9				
		D	E	F
METHOD STD -7.0		2.6	2.3	7.5
METHOD STD -3.5		3.5	0.1	4.0
		DRY-WET	WET-DRY	
SPATIAL STD -7.0		1.3	6.0	
SPATIAL STD -3.5		8.1	10.4	

Table 10. Infiltration rate, macroporosity, number of continuous pores, and number of non-continuous pores from the C-t scan images for the five cores scanned.

Core	Infiltration rate (mm hr^{-1})	Macroporosity (%)	Continuous Pores	Non-continuous Pores
A	177.3	6.3	0	9
B	45.1	6.8	1	5
C	43.4	5.3	0	6
D	84.7	8.1	2 (plus 1 root)	5
E	101.5	8.2	1	5

The x-ray images were also used to assess the macroporosity of the soil in the two plots. The macroporosity of the cores was estimated using a dot grid with 16 dots cm^{-2} overlain on each of the individual x-ray images. The macroporosity of the individual images was then summed up, and the average was taken for each individual core. The macroporosity of the fertilizer and manure treatments is plotted in Figure 34. The difference in macroporosity between manure (8.2%) and fertilizer (6.1%) was significant (P = 0.068).

Qualitatively, the infiltration rates of the cores can be explained by comparing the x-ray images and the macroporosity values. Table 10 also shows the infiltration rates, macroporosity, number of continuous pores, and number of non-continuous pores for each individual core. All of the cores, except Core A, follow the trend of increased infiltration rate with increased porosity. Considering that Core A had lower macroporosity and no continuous macropores, the reasons for the higher infiltration rate in Core A is a not apparent.

The number of continuous macropores did not seem to influence the ponded infiltration rates. Since Core D contained two continuous pores, but the infiltration rate was lower than that of two other cores. Apparently, the continuous macropores observed in the x-ray images were not continuous at depths much below the excavated layer.

Aggregate Stability

Stability of 1-2 mm aggregates taken from the no-till treatment was significantly (P = 0.082) higher than the chisel plow treatment (Fig. 35). On average, 70.5% of the 1-2 mm aggregates remained on the 60 mesh (250 µm) sieve after 3 minutes of wet sieving for the no-till treatment compared to 61.6% for the chisel plow treatment. Values for aggregate stability by individual plot and the statistical analysis output is listed in Appendix J. No-till was expected to have greater aggregate stability than chisel plow because of the higher organic carbon content that is known to bind the aggregates together. Furthermore, there is more mechanical disturbance (in chisel plow) that may weaken the soil aggregates.

There was no significant affect of N-source on aggregate stability. The wet aggregate stability is 68.2%, 65.9%, and 64.0% for check, fertilizer, and manure treatments, respectively. Manure was expected to increase aggregate stability due to the increase in organic carbon additions. The lack of significant differences in aggregate stability by N-source may be because there was no statistical differences in the organic carbon contents due to N-source at 0-7.6 cm.

It is often argued in the literature that aggregate stability may be a good indicator of the erosion potential of the soil, and thus represents a change in the soil quality. We tested this hypothesis by comparing the trends in aggregate stability with sediment production from rainfall simulation as influenced by two tillage systems (Fig. 36). As expected, no-till resulted in less sediment production and greater aggregate stability. There was a large difference, however, in sediment production between the two tillage treatments, but the differences in the aggregate stability were not nearly as large. This supports our earlier point that in evaluating tillage effects, aggregate stability may be less important in influencing sediment production than residue cover.

The following section discusses the constraints in quantifying soil quality using the static parameters proposed in the literature. A major constraints are that the parameters are measured at one time and are assumed to represent the whole climatic cycle.

Another limitation is that some of the soil parameters are assumed to quantify soil processes. In several cases, this assumption may be unrealistic. An example of the above limitation is earthworm population at a point in time as a parameter of soil quality (Karlen *et al.* 1994). Since earthworm populations depend on environmental conditions, it will change with time. A count on one day may have little relationship to the population at another time of the year. Furthermore, earthworm population is taken as a surrogate for macroporosity (*i.e.* more earthworms means more macropores, and thus a higher infiltration rate and less runoff). As discussed earlier, not all earthworm species are equally effective in increasing infiltration, and the number of earthworms is not necessarily a realistic measure of macropore infiltration. For example, *L. terrestris*, the common nightcrawler, makes vertical burrows down to 1.5 m and can reach a shallow water table (Dunger, 1964). These deep, vertical burrows may facilitate greater water entry into soil or groundwater if they are open at the surface. Other common species, such as *L. rubellus* and *A. tuberculata*, make horizontal burrows that are not continuous to deeper depths in the soil surface. Therefore, such burrows will be less useful in increasing water infiltration into the soil. A large number of subsurface burrowers or a small number of vertical burrows is no indication of higher or lower infiltration rates. Thus, earthworm population as a surrogate for macroporosity is an unrealistic assumption.

Another parameter that may be unrealistic in quantifying soil quality is the wet aggregate stability. Wet aggregate stability involves wet sieving 1-2 mm aggregates taken from the field (Kemper and Rosenau, 1986). In accepting aggregate stability as an indicator of soil quality, it is assumed that it is representative of the aggregates in the field, and all of the sediment is coming from these 1-2 mm aggregates. Knowing that larger aggregates are weaker and highly susceptible to erosion, this assumption will be highly erroneous. Furthermore, the wet sieving method ignores the effects of residues and plant canopies on soil erosion in the field. The last two components have been shown to be much more important in resisting soil erosion than aggregate stability. The differences in surface residue cover will make the extrapolation of aggregate stability data to field erosion highly questionable. Figure 36 shows that the differences between aggregate stability due to tillage treatments are relatively small (less than 9%) compared to the large differences (over 350%) in sediment production. Figure 37 shows that their is only a week logarithmic relationship (R^2 = 0.21) between sediment production and aggregate stability for the treatments used in this study. This further supports the hypothesis that more than just aggregate stability is important in sediment loss under natural rainfall conditions.

The limitations of the proposed soil quality parameters are further highlighted by comparing some of the measurements taken during 1993 and 1994 on plots under long-term (12 years) no-till and chisel plow treatments at the Flueger farm in Goodhue Co., MN. This is the same data that was presented earlier in this thesis. For example, Figure 38 shows the comparison of organic carbon and bulk density between the no-till and chisel plow plots. Average organic carbon in no-till (1.34%) was not significantly different than chisel plow (1.38%). On the other hand, bulk density in no-till (1.49 Mg m^{-3}) was significantly higher than chisel plow (1.40 Mg m^{-3}). These measurements show that even after long-term management, the differences in some of the soil quality parameters such as organic carbon and bulk density are rather small, and with the kind of variability (coefficient of variation = 6-12% for these measurements) observed in the field (Warrick and Nielsen, 1980), these differences might be hard to quantify.

Another constraint in quantifying soil quality is the type of methods used for characterizing these parameters. Figure 39, for example, shows the comparison of infiltration rate measured with the ponded infiltrometer and the rainfall simulator. The infiltration rates using the ponded infiltrometer are an order of magnitude higher than infiltration rates measured using a rainfall simulator. Also, the trends were reversed between no-till and chisel plow plots with the two different methods.

Simulated rainfall resulted in infiltration rates of 37 mm hr^{-1} for no-till, and 17 mm hr^{-1} for chisel plow. On the other hand, the ponded infiltrometer resulted in infiltration rates of 204 mm hr^{-1} for no-till, and 424 mm hr^{-1} for chisel plow. The difference in infiltration rates between the two methods is the type of water flow. During simulated rainfall, the infiltration rate represents unsaturated flow conditions below the seal; whereas in the case of ponded infiltrometer, the soil is flooded and represents saturated flow. Furthermore, lower infiltration rates for chisel plow under simulated rainfall are due to a lack of residue cover and due to the formation a surface seal. Then the question becomes, what is the appropriate method of measuring infiltration for characterizing soil quality?

The next question to be asked is what is the relevance of this soil quality assessment? If the answer to that is that in the steep landscapes of Southeastern Minnesota, it is rare to find flooded conditions, then the appropriate method of measuring infiltration is under simulated rainfall. Although simulated rainfall represents the higher end of natural rainfall intensities, it more accurately reflects the infiltration process that occurs in the field under natural rainfall conditions.

An additional problem in characterizing soil quality is the value used in a soil quality index equation. Even though the differences between two treatments may be large, it may not be significantly different. The differences in organic carbon at 0-7.6 cm as affected by N-source are a good example. Here, organic carbon averaged 1.57% for the manure and the fertilizer plots, and the check plots averaged 1.32% organic carbon. These differences, however, are not significantly different. When only values are plugged into the soil quality index equation, the fact that these values are not significantly different is ignored; but a better value for soil quality would be obtained for fertilizer and manure treatments than for the check treatment. Statistically, we know that these two values can not be said to be different, but the soil quality index may still show better soil quality. Since there are so many limitations in the soil quality index value proposals, no such index value was calculated for our treatments.

Proposed Methodology for Evaluating Soil Quality.

The above discussion points out the pit falls in the current methods of estimating soil quality. One of the major constraints in quantifying soil quality is in separating the direct and indirect effects of management on the soil quality goal. Sometimes, the indirect effects may overwhelm the small changes that may have occurred in soil quality due to management. For example, it has been shown by Freebairn *et al.*, (1989) that tillage, per se, has little influence on the rate of water entry into the soil. However, it is the presence of the surface residues (indirect effect) that helps increase infiltration in no-till compared to moldboard and chisel plowing (Fig. 40). Surface residues reduce the energy of the raindrop impact and thus prevent the formation of surface seals. As shown in Figure 40, the moldboard tillage practice results in about the same infiltration rates as no-till and chisel plow if surface residues were present, and conversely, no-till performs as poorly as moldboard if the residues were removed. This suggests that increased infiltration in no-till compared to moldboard plow are due to the indirect effects of surface residue, and have less to do with the direct effects that represent soil quality.

The above argument suggests that in comparing various measurement schemes on soil quality, one must be careful in not confusing indirect effects with improvement or degradation of soil quality. Other factors, like surface residues, crop canopies, etc., may be more important than the improved soil quality in several management schemes, and improved soil quality in some management systems may only be realized when considered in totality. In evaluating soil quality differences between different management treatments, care should be taken in having field conditions with similar residue and canopy conditions. For example, water infiltration in soil must be evaluated in the presence of surface residues. Even though surface residue is not a part of the soil and is not counted as a soil quality parameter, it is assumed that increased infiltration due to increased earthworm activity in no-till will not be realized unless the infiltration rates were measured in the presence of surface residues. This logic implies that management systems must be evaluated in totality in order to assess the soil quality. As an example, in the case of soil erosion, one must combine the soil erodibilty factor (K) with the cropping management factor (C) to evaluate soil quality. A further extrapolation could be that in evaluating management effects on soil quality, one should evaluate the soil quality goal rather than a soil quality parameter or a soil quality index.

At the present time, the effects of the climate have not been integrated into any soil quality index. Climate is an important consideration when comparing soil quality values over time and across climatic zones. To include the effect of climate on soil quality, we believe that it may be better to evaluate a soil quality goal, rather than an index. We believe that in order to assess soil quality goals, process based models simulating a soil quality goal may be an effective way to incorporate climatic variation.

Process based models such as EPIC (Erosion Prediction Impact Calculator; Williams and Renard, 1985) and CREAMS (Chemicals, Runoff and Erosion from Agricultural Management Systems; Knisel, 1980) could be used to assess the impact of management on one or more of the soil quality goals. Each goal should be assessed over a long time period to take into account the variations in weather from year to year. Two examples of the hypothetical results of a soil quality goal are given in Figs. 41 and 42. These hypothetical results show that management may help achieve one soil quality goal and not another.

In Figs. 41 and 42, cumulative probability of 0.50 corresponds to the climatic conditions of a median year. The values 0.25 and 0.75 represent the upper and lower quarter around the median value. In Figure 41, the two cumulative probability lines are close to each other. This would suggest that soil management had little effect on the soil quality goal 1. Instead, another factor is overwhelming the slight improvement that may have occurred in soil quality due to management. On the other hand, Fig. 42 shows a situation where the two cumulative probability lines are far apart. This suggests that improvements in soil quality due to management were important in modifying this goal over various weather conditions. The advantage of using this approach is that one can test if soil quality parameters are important for a given goal, and calculate the change in the goal that can be expected to occur under differing circumstances and management practices. In conclusion, there is no universal soil quality definition or parameter set. Furthermore, we should not be confusing soil quality with soil management evaluations. Also, soil quality indices produce results, but the relationship between the numbers and the stated goals is unclear. Process based models may provide a better way of quantifying soil quality goals.

SUMMARY AND CONCLUSIONS

This study quantified the effects of long term (12 years) tillage and N-source treatments on macroporous flow and soil quality parameters. The macroporous flow was characterized by measuring the differences in infiltration rates between ponded and tension infiltrometers. Soil quality differences were determined by measuring bulk density, organic carbon, earthworm population by species, infiltration rate, runoff and sediment yield, and aggregate stability. Other supporting measurements included macroporosity and macropore continuity from CT scan images, and the hysteresis effect on tension infiltrometer measurements.

Ponded infiltration results were much higher in chisel plow plots (424 mm hr^{-1}) compared to no-till plots (204 mm hr^{-1}). The difference is believed to be caused by the higher porosity (lower bulk density) of the chisel plow treatment. Under simulated rainfall, the steady state infiltration rates were an order of magnitude lower, and the treatment effects were reversed (no-till infiltration rate, 37 mm hr^{-1}; chisel plow infiltration rate 17 mm hr^{-1}). The difference between rainfall simulator and ponded infiltrometer is believed to be due to the type of water flow in the soil: unsaturated flow for the rainfall simulator and saturated flow for the ponded infiltrometer. Differences between the no-till and chisel plow infiltration rates during simulated rainfall are attributed to an increase in surface residue cover in the no-till treatment, which inhibited the development of a surface seal and resulted in greater infiltration rates. This comparison shows the importance of methodology on the results of infiltration experiments. Long term manure compared to long term fertilizer treatments resulted in greater infiltration rates under both the ponded and the rainfall simulation. This was expected because of increased earthworm activity and some soil disturbance during manure injection in the manure plots.

Steady state -3.5 and -7.0 cm tension measurements were not significantly different for either the tillage or the N-source treatments. Since tension infiltration reflects the unsaturated flow of water in the soil matrix, it is not expected to be influenced by different management schemes. Furthermore, the spatial variability of this measurement might have overshadowed any treatment effect.

Macroporous infiltration was less for no-till plots (159 mm hr^{-1}) than chisel plowed plots (341 mm hr^{-1}). This indicates that the earthworm macropores, if present, were not continuous to great depth in the soil. As with the ponded infiltrometer experiment, macroporous infiltration rates were greater in manure than the fertilizer treatments. CT scan images from one fertilizer and one manure plot showed there were few continuous macropores. The fertilizer plot only had one continuous pore through 15 cm of soil in three columns, and the manure plot had three continuous macropores in two cores. Macroporosity was also found to be greater in the manure plot (8.2%) than the fertilizer plot (6.1%).

Earthworm population for the no-till treatment (77 worms m^{-2}) was much greater than the chisel plow treatment (9 worms m^{-2}). Surprisingly, manure plots had only 45 earthworms m^{-2} compared to the fertilizer plots with 39 earthworms m^2. This is contrary to the observations in the literature where manure application significantly increased earthworm populations. Nightcrawlers were only found in replication 3, and it is believed that they originated from the farmer's lawn. It is also believed that the presence of the nightcrawlers in replication 3 influenced the ponded infiltration rates as well as the macroporous flow in replication 3.

The organic carbon contents of the plots was low (a maximum of 1.57% for both the manure and fertilizer plots), and was not found to be influenced by tillage or N-source. Bulk density at 3-9, 15-21, and 27-33 cm depth was affected by the type of tillage, but there was no N-source effect on bulk density below 9 cm.

Sediment production was found to be 3.1 T ha^{-1} for no-till compared to 11.1 T ha^{-1} for chisel plow. This difference was attributed to the difference in residue cover between the two tillage systems. Residue cover reduced the raindrop impact energy, and thus reduced soil detachment and reduced the formation of a surface seal. N-source did not influence the sediment production. Wet aggregate stability data shows that no-till aggregate stability (70.5%) was significantly greater than chisel plow (61.6) aggregate stability, but N-source did not significantly affect aggregate stability. Manure application was expected to increase soil quality due to the addition of organic carbon to the soil, but no such differences were observed in this study. It may be that the rate of organic matter addition from the manure application was not high enough to cause any difference in the organic carbon content of the soil or on soil quality parameters.

The organic carbon content, bulk density results, earthworm populations, aggregate stability, infiltration rate, and the runoff and sediment production data show that the differences in soil quality, as influenced by various tillage and N-source treatments, may be difficult to assess by the proposed parameters. The soil-atmosphere interface and the inherent variability in soils and climate may overwhelm the differences due to management. We also point out the limitations in methodology for assessing soil quality. Infiltration rates under rainfall simulation and ponded conditions, for example, show that different methodologies can result in different interpretations of the soil quality value. An alternative method using models that can integrate the long term climate variation in its simulation is proposed for assessing soil quality.

FUTURE RESEARCH

1. The role of climate on burrowing characteristics of earthworms is not clearly understood. It will be highly desirable to quantify a relationship between earthworm burrow characteristics, earthworm population, and species as a function of temperature and precipitation. To undertake this research, one could choose a North-South temperature transect, and a West-East transect for moisture gradient in Minnesota. This research should be done at sites with similar long

term management treatments, such as tillage and manure application.

2. It would be useful to quantify soil quality on long term plots that have received various rates of manure application. This research could provide the amount of manure (or organic carbon additions) necessary to improve soil quality under specified tillage system and climatic conditions.

3. At the Flueger site, a unique situation exists where the spread of *L. terrestris* can be monitored. A more detailed survey of the area should be undertaken to determine the exact location of the nightcrawlers, their rate of spread, and their preferred pathways.

4. Although there have been several attempts, there is still no quick method for determining macropore continuity in the field. A method for determining the depth of macropore continuity is highly desirable to model the preferential flow of water and contaminants through the soil.

FIGURES

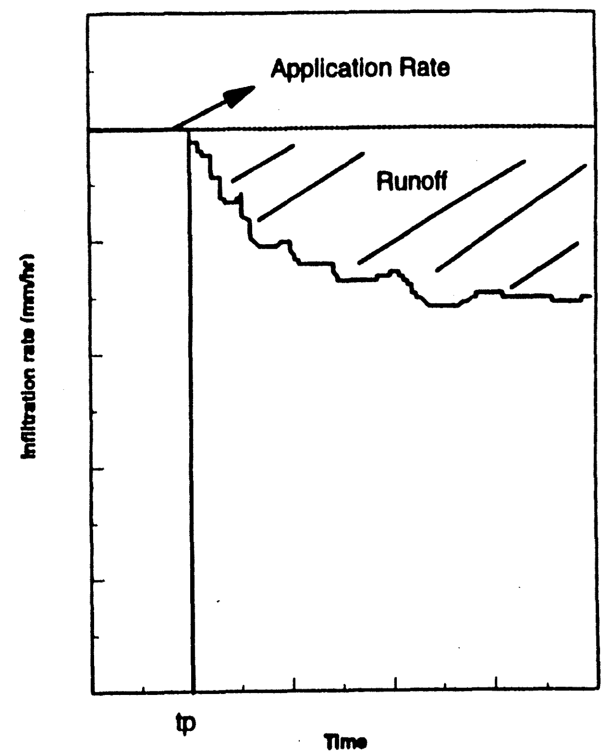


Figure 1. Theoretical infiltration rate vs. time curves for soil.

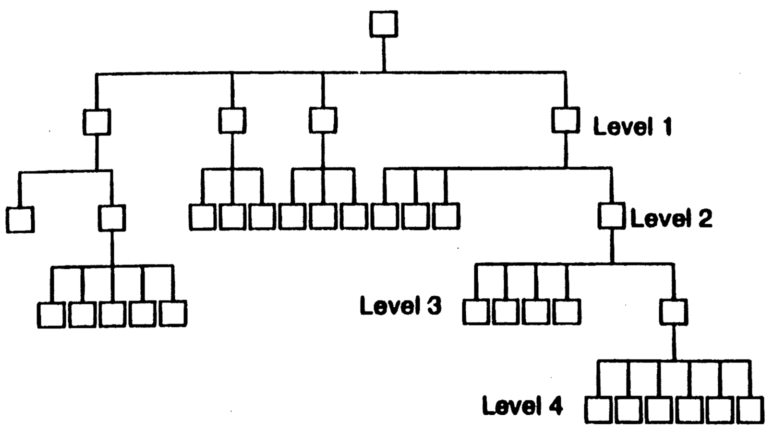


Figure 2. Supporting structure for the soil quality index value (from Karlen *et al.*, 1994).

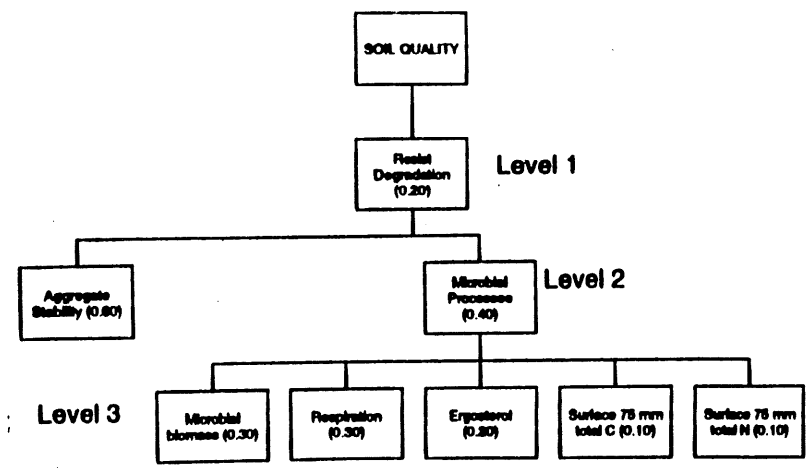


Figure 3. Supporting structure for level 1 resisting degradation (from Karlen *et al.*, 1994).

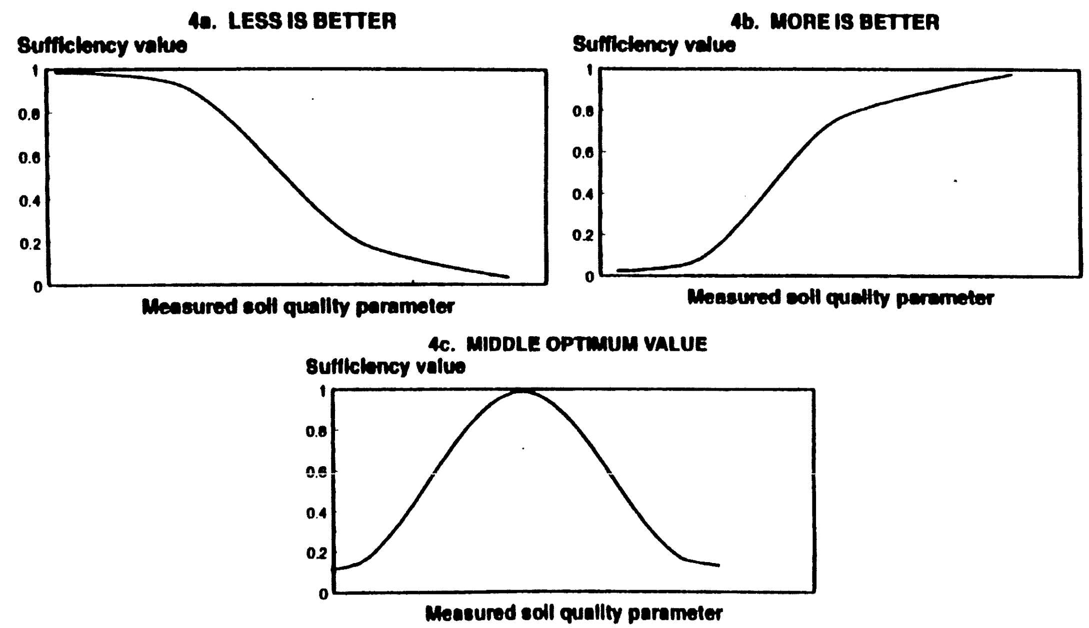
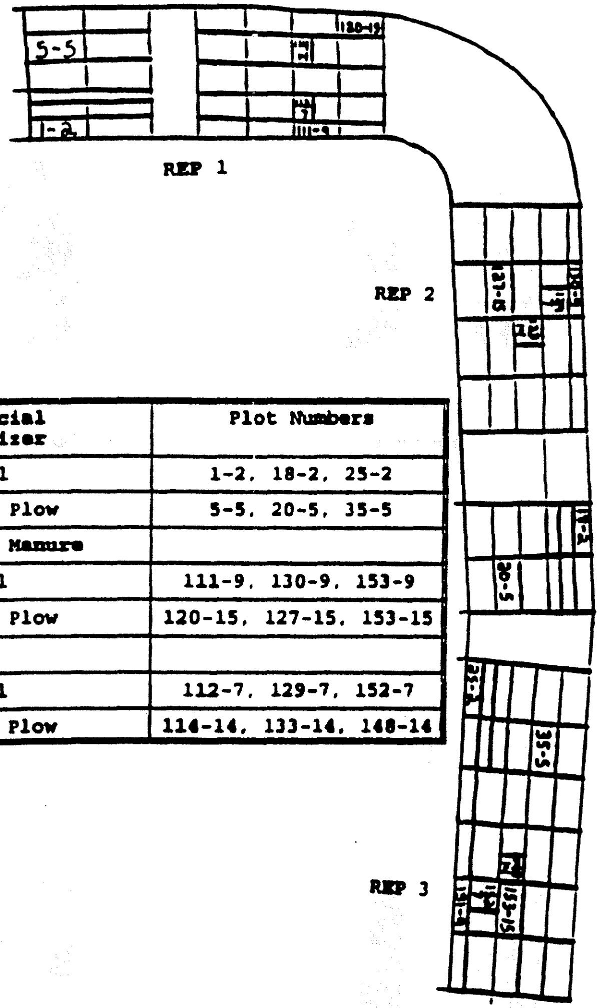


Figure 4. Three types of sufficiency curves for normalizing soil quality measurements.



Commercial Fertilizer	Plot Numbers
No-till	1-2, 18-2, 25-2
Chisel Plow	5-5, 20-5, 35-5
Annual Manure	
No-till	111-9, 130-9, 153-9
Chisel Plow	120-15, 127-15, 153-15
Check	
No-till	112-7, 129-7, 152-7
Chisel Plow	114-14, 133-14, 148-14

Figure 5. Plot diagram for the tillage and N-Source study at the Flueger farm in Goodhue Co., Minnesota.

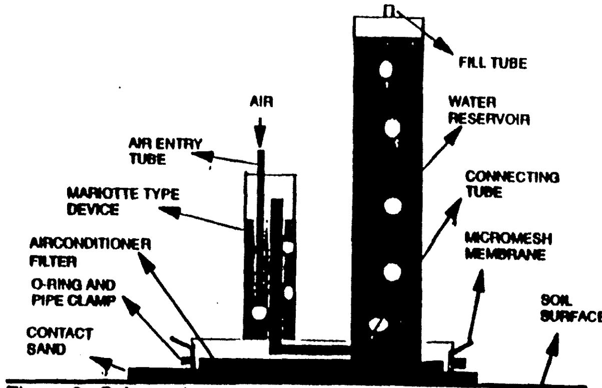


Figure 6. Schematic representation of a tension infiltrometer. Adapted from Ela (1990).

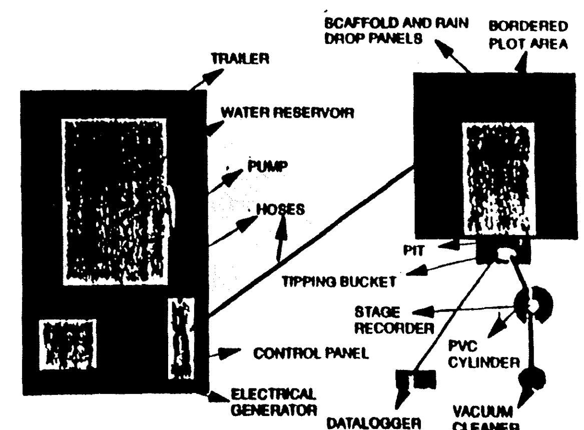
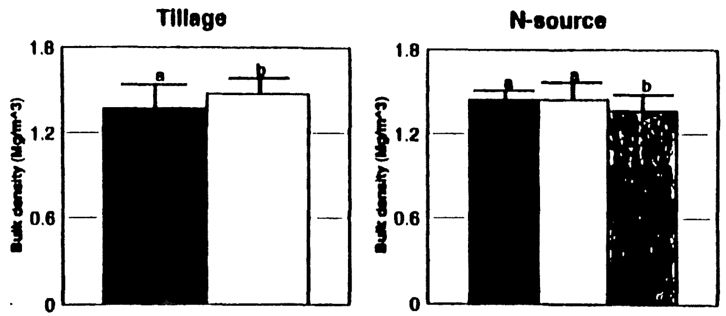


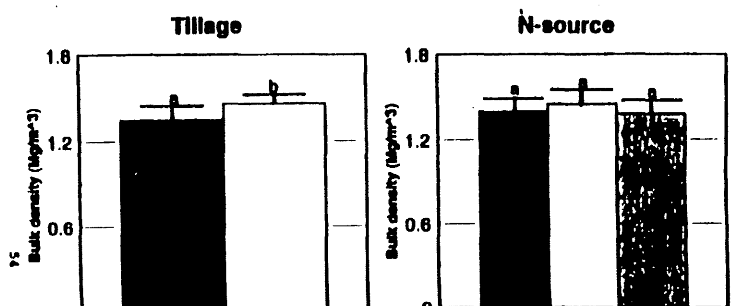
Figure 7. Schematic representation of the rainfall simulator.



CHISEL PLOW	■	1.37
NO-TILL	□	1.47

CHECK	■	1.44
FERTILIZER	□	1.44
MANURE	■	1.36

Figure 8. Average soil bulk density (Mg/m^3) at 3-9 cm depth as affected by two tillage and three N-source treatments.



CHISEL PLOW	■	1.35
NO-TILL	□	1.46

CHECK	■	1.40
FERTILIZER	□	1.45
MANURE	■	1.38

Figure 9. Average soil bulk density (Mg/m^3) at 15-21 cm depth as affected by the two tillage and three N-source treatments.

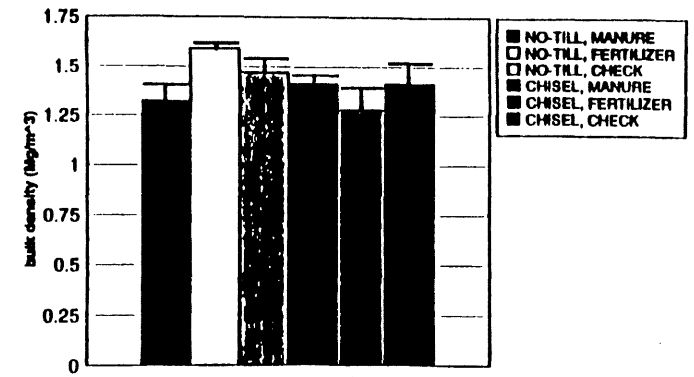
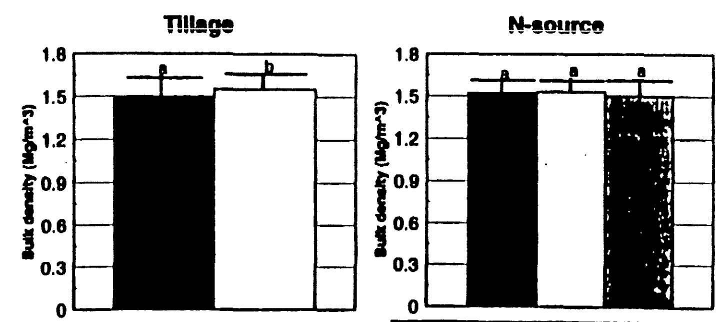


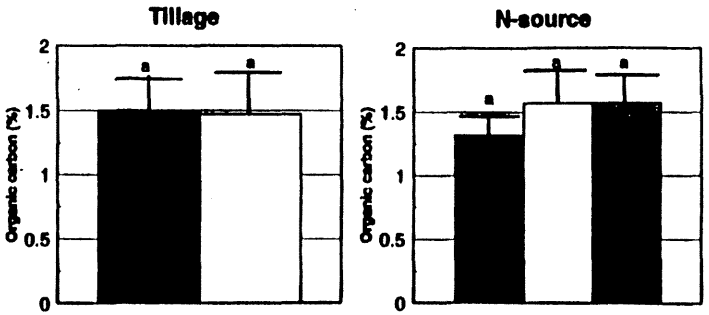
Figure 10. Tillage x N-source interaction on soil bulk density (Mg/m^3) at 3-9 cm depth.



CHISEL PLOW	■	1.49
NO-TILL	□	1.55

CHECK	■	1.52
FERTILIZER	□	1.53
MANURE	■	1.50

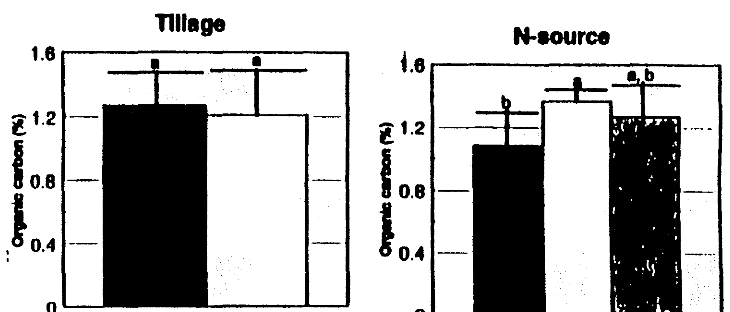
Figure 11. Average soil bulk density (Mg/m^3) at 27-33 cm depth for the two tillage and three N-source treatments.



CHISEL PLOW	■	1.50
NO-TILL	□	1.47

CHECK	■	1.32
FERTILIZER	□	1:57
MANURE	■	1:57

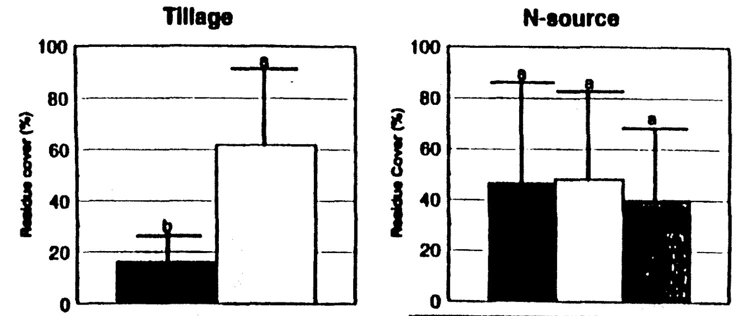
Figure 12. Organic carbon (%) at 0-7.6 cm depth as influenced by the two tillage and three N-source treatments.



CHISEL PLOW	■	1.27
NO-TILL	□	1.21

CHECK	■	1.08
FERTILIZER	□	1.37
MANURE	■	1.27

Figure 13. Organic carbon (%) at 7.6-15.2 cm depth as influenced by the two tillage and three N-source treatments.



CHISEL PLOW	■	16.1
NO-TILL	□	61.9

CHECK	■	46.5
FERTILIZER	□	48.2
MANURE	■	39.3

Figure 14. Residue cover (%) as influenced by the two tillage and three N-source treatments.

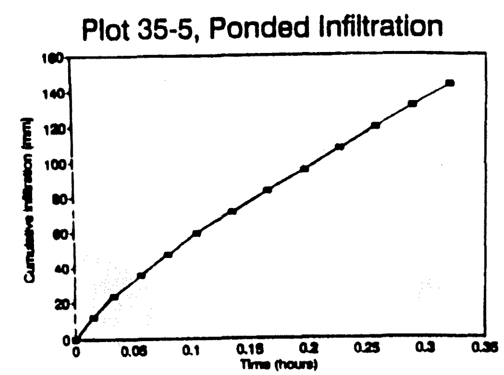


Figure 15. Graph of cumulative infiltration vs. time for the ponded infiltration run in plot 35-5.

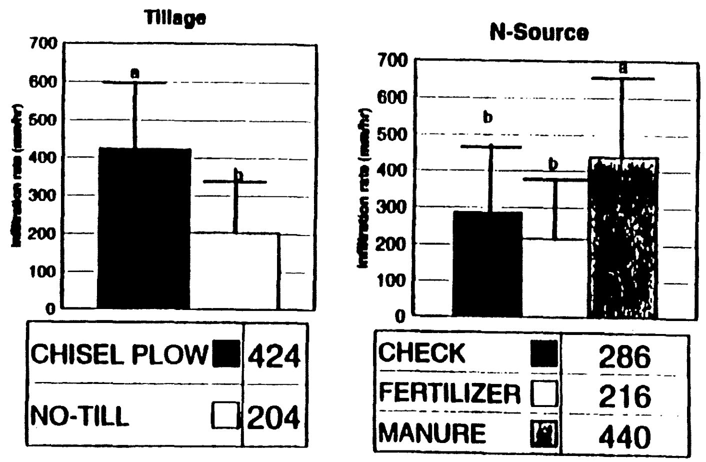


Figure 16. Steady state ponded infiltration rates (mm/hr) for ponded infiltration as influenced by two tillage and three N-sourc treatments.

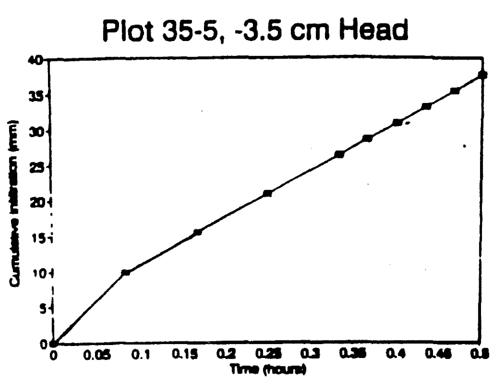


Figure 17. Graph of cumulative infiltration vs. time for the -3.5 cm tension infiltrometer run in plot 35-5.

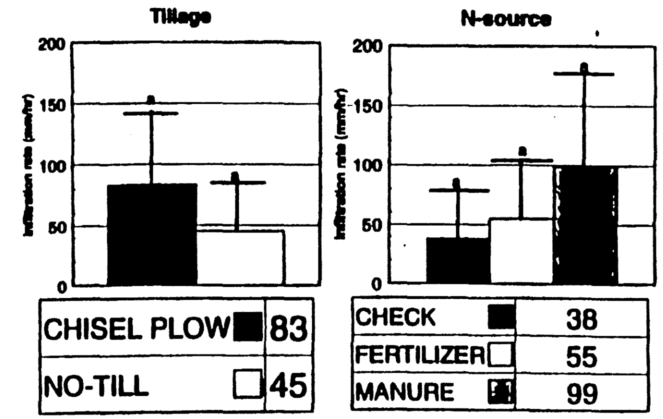


Figure 18. Average infiltration rate (mm/hr) at -3.5 cm head for two tillage and N-source treatments.

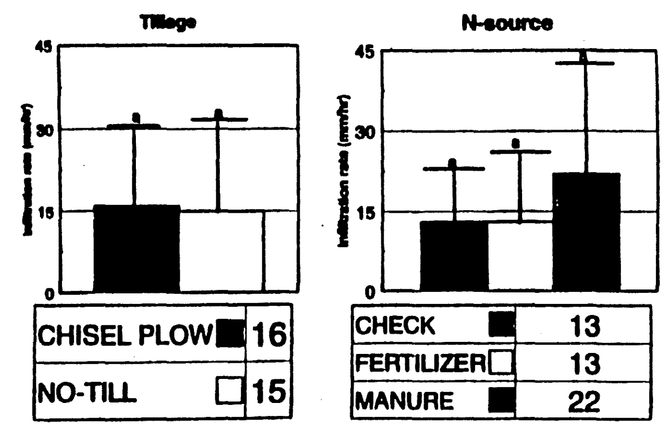


Figure 19. Average infiltration rate (mm/hr) at -7.0 cm head for two tillage and three N-source treatments.

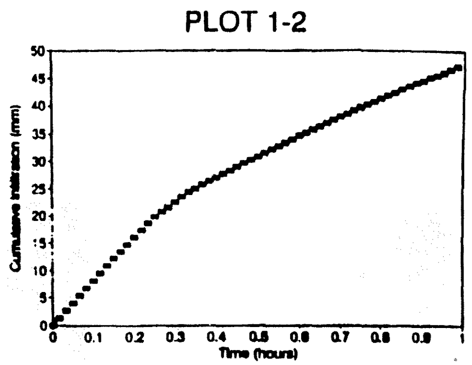


Figure 20. Cumulative infiltration rate vs. time during simulated rainfall in plot 1-2.

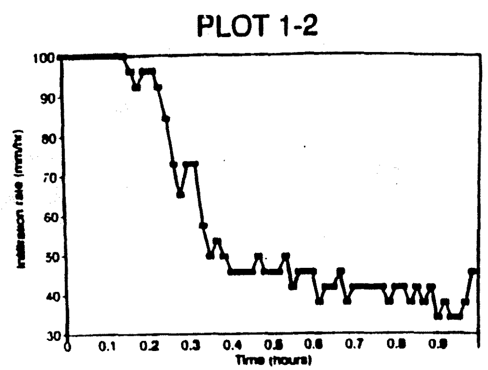


Figure 21. Infiltration rate vs. time during simulated rainfall in plot 1-2.

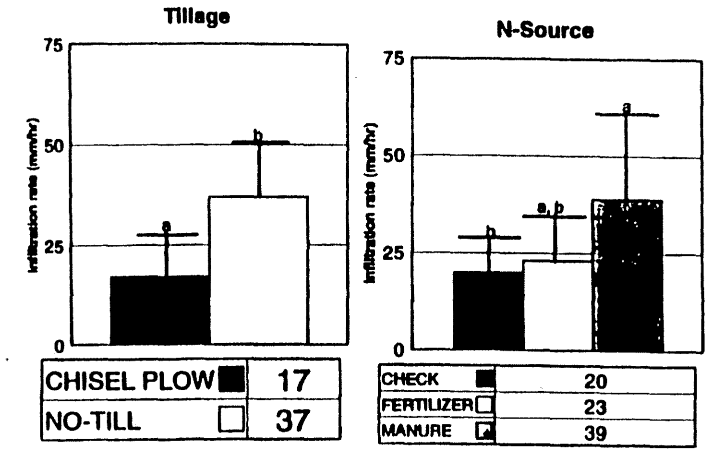


Figure 22. Steady state infiltration rate (mm/hr) under simulated rainfall as influenced by the two tillage and three N-Source treatments.

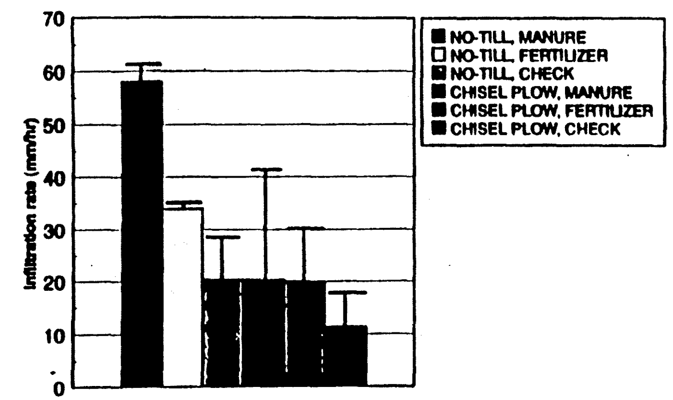


Figure 23. Steady state infiltration rate (mm/hr) under simulated rainfall as influenced by the tillage x N-source interaction.

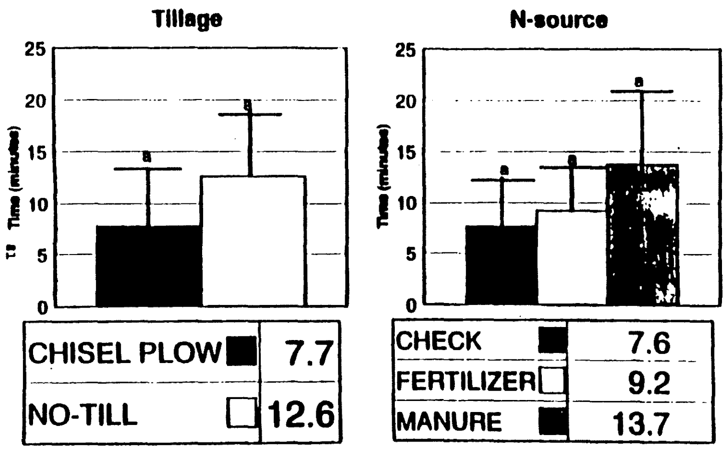


Figure 24. Influence of the tillage and N-source treatments on time to ponding (minutes).

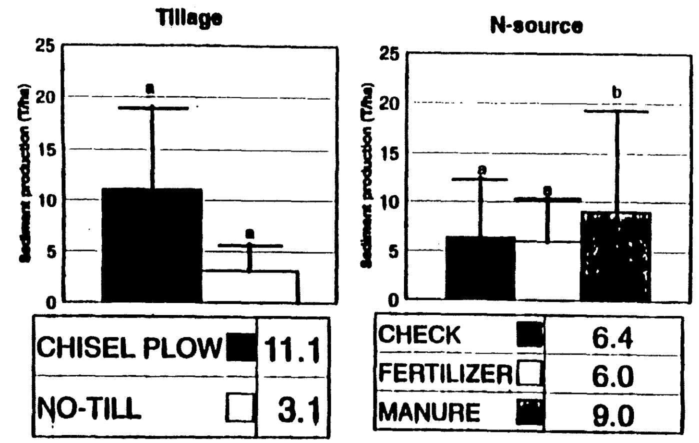


Figure 26. Sediment production (T/ha) in one hour under 100 mm/hr of simulated rainfall as influenced by two tillage and three N-source treatments.

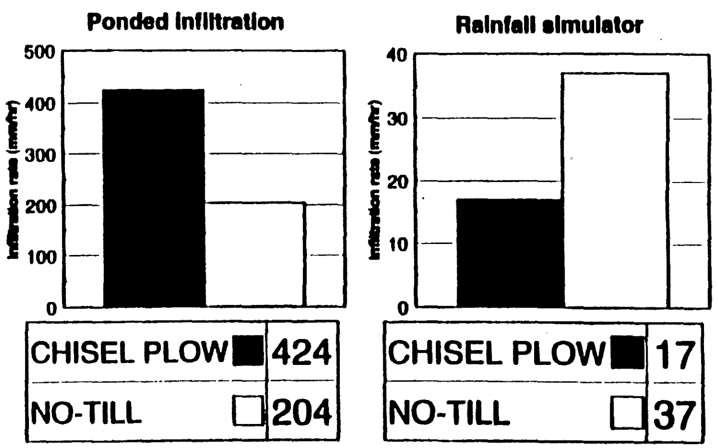


Figure 25. Comparison of rainfall simulation infiltration rate and ponded infiltration rate (mm/hr) as influenced by tillage.

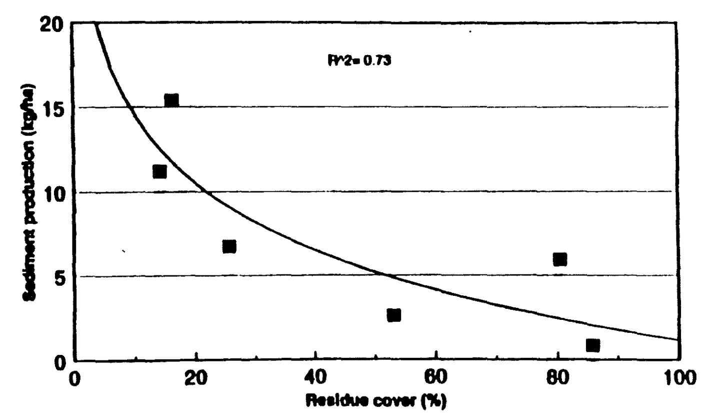


Figure 27. Relationship of sediment production as a function ofsurface residue cover.

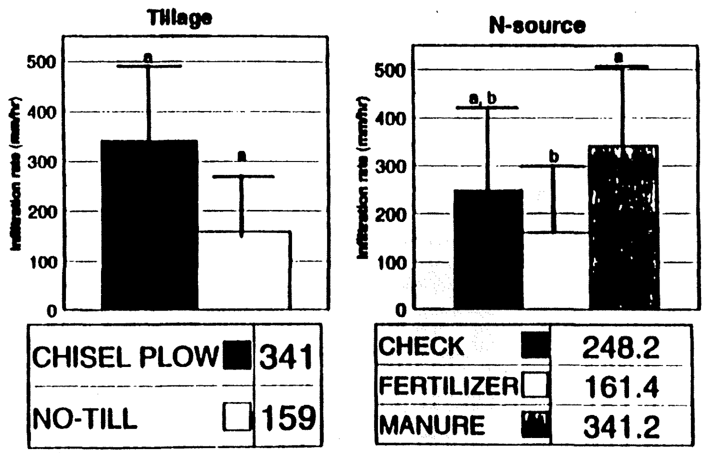


Figure 28. Average steady state macroporous infiltration rate (mm/hr) for two tillage and three N-source treatments.

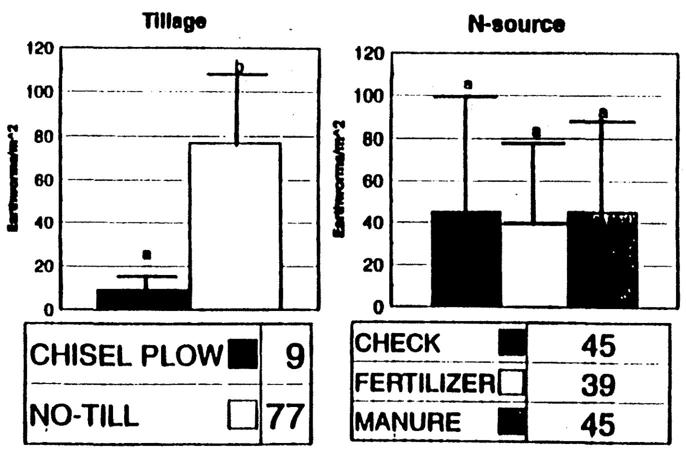


Figure 29. Average earthworm population for the two tillage and three N-source treatments.

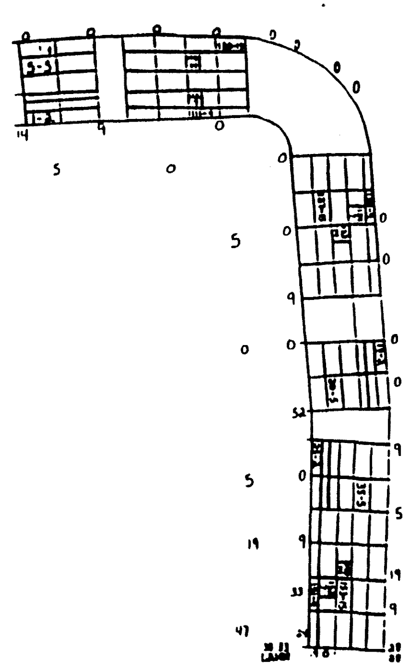


Figure 30. Location and number of *L. terrestris* (number m^{-2}) along the perimeter of the plots on August 19, 1994.

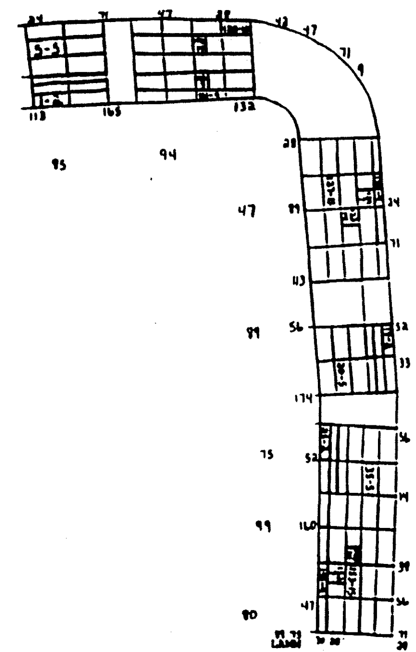


Figure 31. Location and number of all earthworm species (number m^{-2}) along the perimeter of the plots on August 19, 1994.

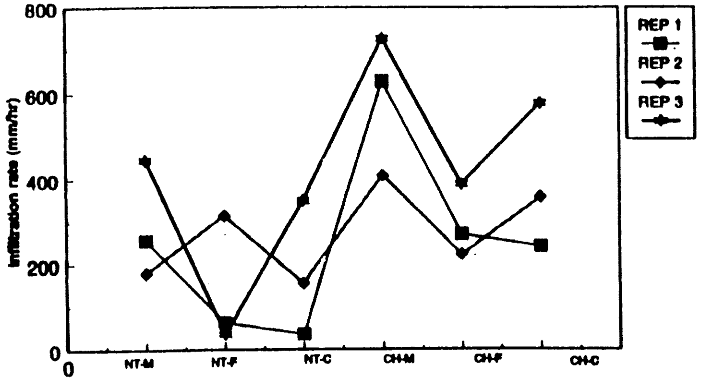


Figure 32. Variation in ponded infiltration rate by replication for the various tillage and N-source treatments. The treatment abbreviations are: NT= No-till, CH= Chisel plow, M= Manure, F= Fertilizer, C= Check.

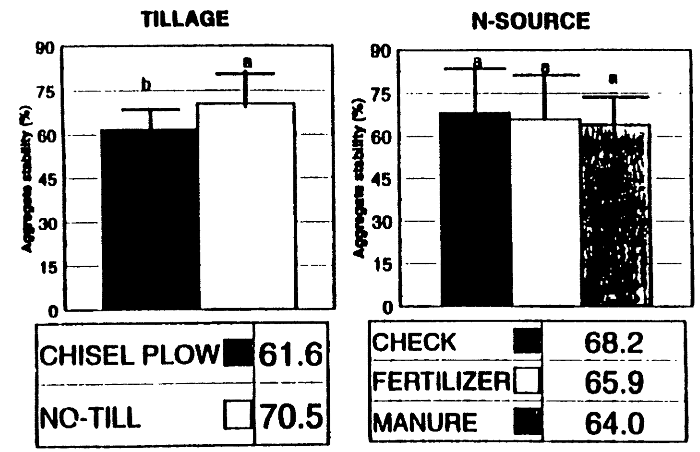


Figure 35. Aggregate stability (%) as influenced by two tillage and three N-source treatments.

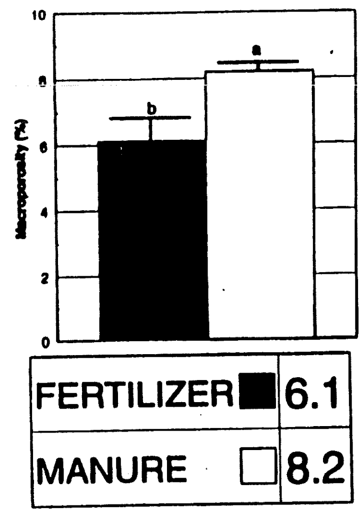


Figure 34. Estimated percent macroporosity from CT scan images of soil cores from the "Hysteresis" experiment.

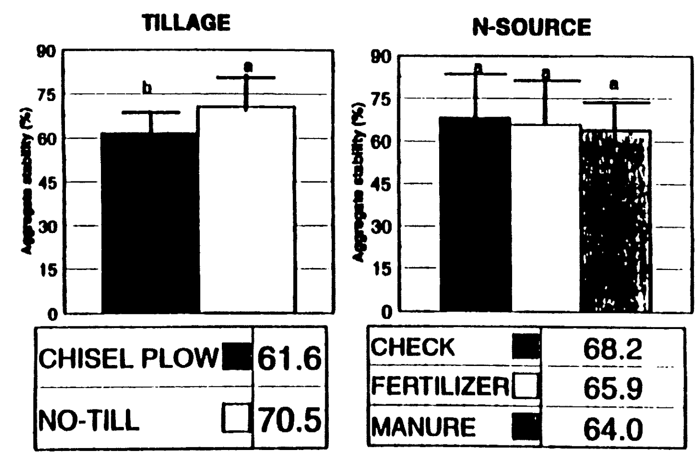


Figure 35. Aggregate stability (%) as influenced by two tillage and three N-source treatments.

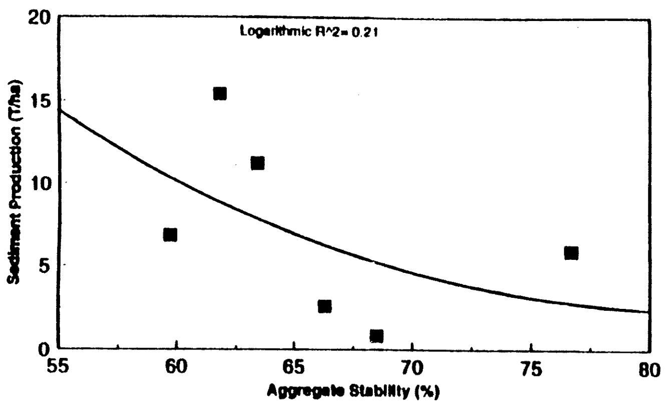


Figure 37. Sediment production as a function of aggregate stability.

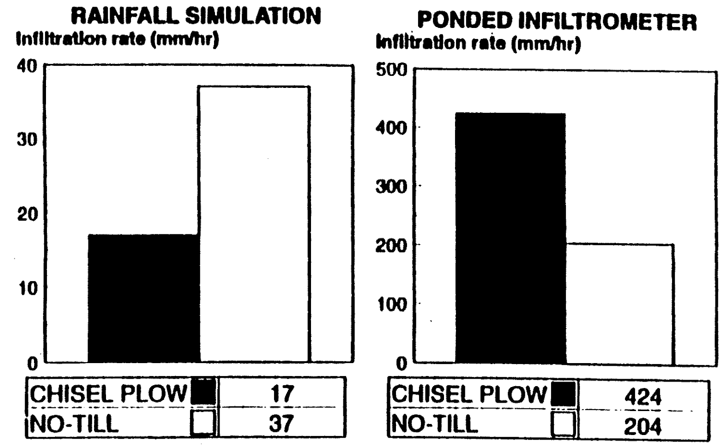


Figure 39. Infiltration rates of chisel plow and no-till treatments as measured with the rainfall simulator and ponded infiltrometer.

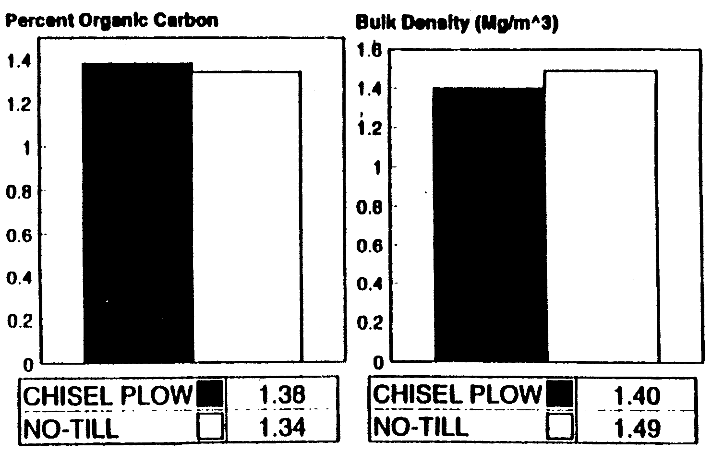


Figure 38. Organic carbon and bulk density of long term no-till and chisel plow plots.

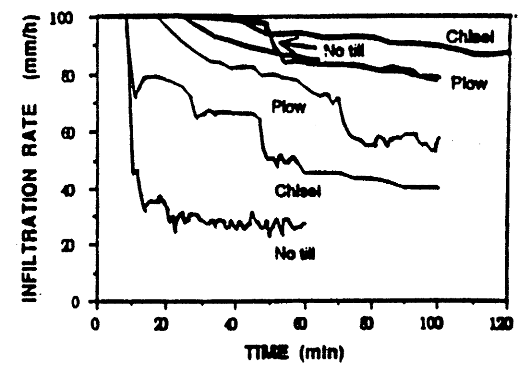


Figure 40. Rate of infiltration in Port Byron silt loam (July) 2 weeks after tillage for chisel plow (chisel) and moldboard plow (plow), and 11 weeks after planting for no-till treatments with (heavy lines) and without cover (Freebairn et al., 1989).

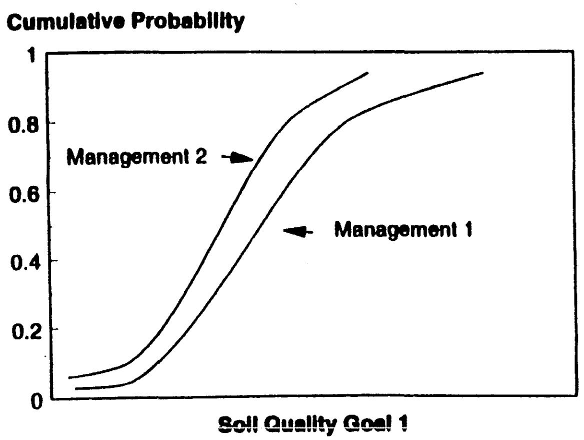


Figure 41. Hypothetical output from model for treatments where soil quality is not the controlling factor.

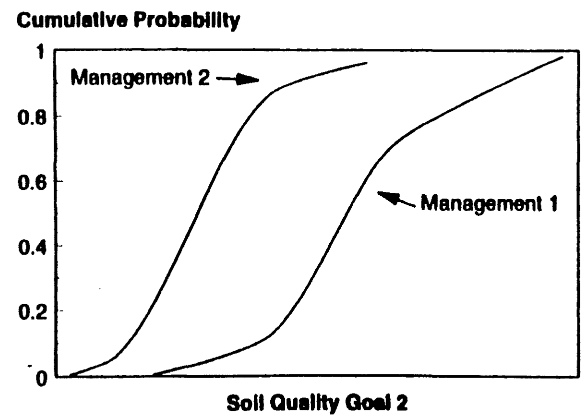


Figure 42. Hypothetical output from the model for treatments where soil quality is the limiting factor.

REFERENCES

Ankeny, M.D., R. Horton, and T.C. Kaspar. 1990. Field estimates of hydraulic conductivity from unconfined infiltration measurements. p. 95-100. *In* K. Roth et al. (ed.) Field-scale solute and water transport through soil. Birkhauser Verlag, Basel.

Arshad, M.A., and G.M. Coen. 1992. Characterization of soil quality: physical and chemical criteria. Am. J. Alter. Agric. 7:25-31.

Barley, K.P. 1961. The abundance of earthworms in agricultural land and their possible significance in agriculture. Adv. Agron. 13:249-268.

Barnes, B.T., and F.B. Ellis. 1979. effects of different methods of cultivation and direct drilling, and disposal of straw residues on populations of earthworms. J. Soil Sci. 30:669-679.

Borland International, Inc. 1992. Quatro-pro user's guide, version 4.0. Borland International, Scotts Valley, CA.

Bouwer, H. 1986. Intake rate: Cylinder infiltrometer. pp. 825-844 *In* A. Klute (ed.) Methods of soil analysis Part 1. 2nd. ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Burford, P.M. 1986. The effects of tillage, source and placement of potassium on its availability to corn. M.S. thesis. Univ. of Minnesota.

Carter, M.R. 1988. Temporal variability of soil macroporosity in a fine sandy loam under mouldboard ploughimg and direct drilling. Soil Tillage Res. 12:37-51.

Chan, K.Y., and J.A. Mead. 1989. Water movement and macroporosity of an Austrailian Alfisol under different tillage and pasture conditions. Soil Tillage Res. 14:301-310.

Converse, J.C., G.D. Bubenzer, and W.H. Paulson. 1976. Nutrient losses in surface runoff from winter spread manure. Trans. ASAE 19:517-519.

Cotton, D.C.F., and J.P. Curry. 1980. The effects of cattle and pig slurry fertilizers on earthworms (Oligochaeta Lumbricidae) to high applications of pig slurry. Pedobiologia 20:189-196.

Council for Agriculture Sciences and Tchnology. 1985. Agriculture and water quality. Rep. No. 103. Council for Agricultural Sciences and Technology, Ames, Iowa.

Curry, J.P. 1976. Some effects of animal manures on earthworms in grassland. Pedobiologia 16:425-438.

Dickey, J.B. 1990. Earthworm numbers, distribution, and sampling under conservation tillage. Ph. D. Thesis, Purdue Unviersity, West Lafayette, IN.

Doran, J.W., and T.B. Parkin. 1994. Defining and assessing soil quality. p.3-22 *In* J.W. Doran, D.C. Coleman, D.F. Bezdicek, and B.A. Stewart (eds.) Defining soil quality for a sustainable environment. SSSA Special publication Number 35. Madison, WI.

Dunger, W. 1964. Tiere im Boden. Ziemsen, Wittenberg, 265p. *In* Tippkotter R. 1983. Morphology, spatial arrangement and origin of macropores in some hapludalfs, West Germany. Geoderma 29:355-371.

Edwards, C.A., and J.R. Lofty. 1975. The influence of cultivation on soil animal populations. pp. 399-408 *In* J. Vanek (ed.) Progress in soil zoology. Academia Publishing House, Prague.

Edwards, C.A. 1980. Interactions between agricultural practice and earthworms. pp. 3-12 *In* Soil Biology as related to land use practices. Proceedings of the VII International Colloquium of Soil Zoology. United States EPA, Washington D.C.

Edwards, C.A., and J.R. Lofty. 1982a. Biology of earthworms. Second edition. Chapman and Hall, London.

Edwards, C.A., and J.R. Lofty. 1982b. The effects of direct drilling and minimal cultivation on earthworm populations. J. Applied Ecology. 19:723-734.

Edwards, C.A., and J.R. Lofty. 1982c. Nitrogenous fertilizers and earthworm population in agricultural soils. Soil Biol. Biochem. 114:515-521.

Edwards, W.M., L.D. Norton, and C.E. Redmond 1988. Characterizing macropores that affect infiltration into nontilled soil. Soil Sci. Soc. Am. J. 43:851-856.

Edwards, W.M., M.J. Shipitalo, L.B. Owens, and L.D. Norton. 1990. Effect of *Lumbricus terrestris* L. burrows on hydrology of continuous no-till corn fields. Geoderma 46:73-84.

Ehlers, W. 1975. Observations on earthworm channels and infiltration on tilled and untilled loess soil. Soil Sci. 119:242-249.

Ela, S.D. 1990. Macropore and surface sealing interactions on water infiltration into soil. M.S. Thesis. University of Minnesota, St. Paul, MN.

Ela, S.D., S.C. Gupta, and W.J. Rawls. 1992. Macropore and surface seal interactions affecting water and infiltration into soil. Soil Sci. Soc. Am. J. 56:714-721.

Freebairn, D.M., S.C. Gupta, C.A. Onstad, and W.J. Rawls. 1989. Antecedent rainfall and tillage effects upon infiltration. Soil Soc. Am. J. 53:1183-1189.

Freebairn, D.M., S.C. Gupta, and W.J. Rawls. 1991. Influence of aggregate size and microrelief on development of surface soil crusts. Soil Sci. Soc. Am. J. 55:188-195.

Fuchs, D.J., and D.R. Linden. 1988. An earthworm population and activity survey of selected agronomic areas in Minnesota. Unpublished manuscript.

Gardener, W.R. 1958. Some steady-state solutions of the unsaturated moisture flow equation with application to evaporation from a water table. Soil Sci. 85:228-232.

Gerard, B.M., and R.K.M. Hay. 1979. The effect on earthworms of ploughing, tined cultivation, direct drilling and nitrogen in a barley monoculture system. J. Agric. Sci. 93:147-155.

Germann, P.F., W.M. Edwards, and L.B. Owens. 1984. Profiles of bromide and increased soil moisture after infiltration into soils with macropores. Soil Sci. Soc. Am. J. 48:237-244.

Granatstein, D., and D.F. Bezdicek. 1992. The need for a soil quality index: local and regional perspectives. Am. J. Alter. Agric. 7:12-16.

Hallberg, G.R., D.R. Libra, E.A. Bettis, and B.E. Hoyer. 1984. Hydrological and water quality investigations in Big Spring Basin, Clayton County, Iowa: 1983 water year. Open-file Rep. No. 84-4. Iowa Geological Survey.

Hill, R.L. 1993. Tillage and wheel traffic effects on runoff and sediment losses from crop interrows. Soil Sci. Soc. Am. J. 57:476-480.

Hoogerkamp, M., H. Rogaar, and H.J.P. Eijsackers. 1983. Effect of earthworms on grassland on recently reclaimed polder soils in the Netherlands. pp. 85-105 *In* J.E. Satchell (ed.) Earthworm Ecology. Chapman and Hall, London.

Hopp H. 1947. The ecology of earthworms in cropland. Soil Sci. Soc. Am. Proc. 12:503-507.

House, G.J., and R.W. Parmelee. 1985. Comparison of soil arthropods and earthworms from conventional and no-tillage agroecosystems. Soil Tillage Res. 5:351-360.

Jensen, M.B. 1985. Interactions between soil invertebrates and straw in aerable soil. Pedobiologia 28:59-69.

Jones, J.N., Jr., J.E. Moody, and J.H. Lillard. 1969. Effects of tillage, no-tillage, and mulch on soil water and plant growth. Agron. J. 61:719-721.

Joshi, J.R., J.F. Moncrief, J.D. Swan, and P.M. Burford. 1994a. Long-term tillage and manure effects on corn I. Nitrogen availability. Soil Tillage Res. 31:211-224.

Joshi, J.R., J.F. Moncrief, J.D. Swan, and G.L. Malzer. 1994b. Long term tillage and manure effects on corn II. Nitrogen concentration in soil water. Soil Tillage Res.31:225-233.

Karlen, D.L., N.C. Wollenhaupt, D.C. Erbach, E.C. Berry, J.B. Swan, N.S. Nash, and J.L. Jordahl. 1994. Crop residue effects on soil quality following 10- years of no-till corn. Soil Tillage Research. 31:149-168.

Kemper, W.D. and R.C. Rosenau. 1986. Aggregate stability and size distribution. p. 425-442. *In* A. Klute (ed.) Methods of soil analysis Part 1. 2nd. ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Kemper, W.D., T.J. Trout, A. Segeren, and M. Bullock. 1987. Worms and water. J Soil and Water Conserv. 42:401-404.

Kladivko, E.J., A.D. Mackay, and J.M. Bradford. 1986. Earthworms as a factor in the reduction of soil crusting. Soil Sci. Soc. Am. J 50:191-196.

Klauseus, T.G., G.C. Buzicky, and E.C. Schneider. 1988. Pesticides and groundwater: Survey of selected Minnesota wells. Report for the Legislative Commission on Minnesota Resources, Minn. Dept. of Health and Minn. Dept. of Agriculture.

Knisel, W.G. (ed.). 1980. CREAMS: a field-scale model for chemicals, runoff and erosion from agricultural management systems. USDA Conservation Research Report, 26, USDA, Washington D.C.

Larson, W.E., F.J. Pierce, and R.H. Dowdy. 1983. The threat of soil erosion to long-term crop production. Science 219:458-465.

Larson, W.E., and F.J. Pierce. 1991. Conservation and enhancement of soil quality. *In* Proceedings of the international workshop on evaluation for sustainable land management in the developing world. Vol. 2: Technical Papers. Bangkok, Thailand: International Board for Soil Research and Management, 1991. IBSRAM Proceedings No. 12(2).

Lee, K.E. 1985. Earthworms: Their ecology and relationships with soils and land use. Academic press, Inc., Orlando, FL, 411p.

Lehrsch, G.A., R.E. Sojka, D.L. Carter, and P.M. Jolley. 1991. Freezing effects on aggregate stability affected by texture, mineralogy, and organic matter. Soil Soc. Am. J. 55:1401-1406.

Mackay, A.D., and E.J. Kladivko. 1985. Earthworms and the rate of breakdown of soybean and maize residues in soil. Soil Biol. Biochem. 17:851-857.

Mannering, J.V., L.D. Meyer, and C.B. Johnson. 1966. Infiltration and erosion as affected by minimum tillage for corn (*Zea Mays* L.). Soil Sci. Soc. Am Proc. 30:101-105.

McGregor, K.C., J.D. Greer, G.E. Gurley. 1975. Erosion control with no-till cropping practices. Trans. ASAE 18:918-920.

Meyer, L.D., W.H. Wischmeier, and G.R. Foster. 1970. Mulch rates required for erosion control on steep slopes. Soil Sci. Soc. Am. Proc. 34:928-931.

Mostaghimi, S., T.A. Dillaha, and V.O. Shanoltz. 1988. Influence of tillage systems and residue levels on runoff, sediment, and phosphorus losses. Trans. ASAE 31:128-132.

Mueller, D.H., R.C. Wendt, and T.C. Daniel. 1984. Soil and water loss as affected by tillage and manure application. Soil Sci. Soc. Am. J. 48:896-900.

Munyankusi, E. 1992. Effect of long-term manure and fertilizer application on earthworm macropores and water and tracer transport through a Typic Hapludalf. M.S. Thesis. University of Minnesota, St. Paul, MN.

Munyankusi, E., S.C. Gupta, J.F. Moncrief, and E.C. Berry. 1994. Earthworm macropores and preferential transport in a long-term manure applied Typic Hapludalf. Journal Environ. Q. 23:773-784.

Nelson, D.W., and L.E. Sommers. 1982. Total carbon, Organic carbon, and Organic matter. pp. 539-580 *In* A.L. Page, R.H. Miller, and D.R. Keeney (eds.) Methods of analysis Part 2. 2nd. ed. Agron. Monogr. 9. ASA and SSSA, Madison, WI.

Nielsen, E.G., and L.K. Lee. 1987. The magnitude and costs of groundwater contamination from agricultural chemicals: A national perspective. Agricultural Economic Rep. No 576, U. S. Dept. of Agriculture.

Nuutinen, V. 1992. earthworm community response to tillage and residue management on different soil types in southern Finland. Soil Tillage Res. 23:221-239.

Onstad, C.A., J.K. Radke, and R.A. Young. 1981. An outdoor portable rainfall erosion laboratory. pp. 415-422 *In* Erosion and Sediment measurement (Proc. Florence Symp., June) IAHS Publ. 133. Intl. Assoc. Hydrologic Sciences, Florence, Italy.

Parr, J.F., R.I. Papendick, S.B. Hornick, and R.E. Meyer. 1992. Soil quality: attributes and relationship to alternative and sustainable agriculture. Am. J. Alter. Agric. 7:5-11.

Perroux, K.M., and I. White. 1988. Designs for disk permeameters. Soil Sci. Soc. Am. J. 52:1205-1215.

Philips, J.R. 1987. The quasilinear analysis, scattering analog, and other aspects of infiltration and seepage. pp. 1-27 *In* Y.S. Fok (ed.) Infiltration development and Application. Water Resources Research Center, Honolulu, Hawaii.

Pierce, F.J., W.E. Larson, R.H. Dowdy, and W.A.P. Graham. 1983. Productivity of soils: Assessing long-term changes due to erosion. Journal of Soil and Water Conservation. 38:39-44.

Potter, P.A., B.L. Bridges, and F.L. Gordon. 1985. Effect of nitrogen fertilizer on earthworms and microarthropod populations in Kentucky bluegrass turf. Agron. J. 77:367-372.

Reynolds, W.D., and D.E. Elrick. 1991 Determination of hydraulic conductivity using a tension infiltrometer. Soil Sci. Soc. Am. J. 55:633-644.

Reynolds, W.D., E.G. Gregorich, and W.E. Curnoe. 1994. Characterization of water transmission properties in tilled and untilled soils using tension infiltrometers. Soil Tillage Res. IN PRESS.

SAS Institute Inc. 1988. SAS/STAT™ user's guide. Release 6.03. SAS Institute, Cary, NC.

Satchell, J.E. 1967. Lumbricidae. *In* A. Burges and F. Raw (ed.) Soil biology. Academic Press, London and New York.

Sauer, T.J., B.E. Clothier, and T.C. Daniel. 1990. Surface measurements of the hydraulic properties of a tilled and untilled soil. Soil Tillage Res. 15:359-369.

Sharma, P.P., S.C. Gupta, and G.R. Foster. 1994. Raindrop induced soil detachment and sediment transport from interrill areas. Soil Soc. Am. J. 55:301-307.

Smettem, K.R.J., and N. Collins-George. 1985. Prediction of steady-state ponded infiltration distributions in a soil with vertical macropores. J. Hydrol. 79:115-122.

Stork, N.E., and P. Eggleton. Invertebrates as determinants and indicators of soil quality. Am. J. Alter. Agric. 7:38-47.

Thomas, M.L., R. Lal, and T.J. Logan. 1992. Land use and management effects on nonpoint loading fom Miamian soil. Soil Sci. Soc. Am. J. 56:1871-1875.

Tisdall, J.M., and J.M. Oades. 1982. Organic matter and water stable aggregates in soils. J. Soil Sci. 33:141-163.

Warrick, A.W., and D.R. Nielsen. 1980. Spatial variability of soil physical properties in the field. pp. 317-344 *In* D. Hillel (ed.) Applications of soil physics. Academic Press. New York.

White, I., M.J. Sully, and K.M. Perroux. 1992. Measurement of surface-soil hydraulic properties: Disk permeameters, tension infiltrometers, and other techniques. pp. 105-122 *In* G.C. Clarke, W.D. Reynolds, and R.E. Green (eds.) Advances in measurement of soil physical properties: Bringing theory into practice. Soil Science Society of America, Inc. Madison, WI.

Williams, J.R., and K.G. Renard. 1985. Assessments of soil erosion and crop productivity with process models (EPIC). pp. 68-105 *In* R.F. Follett and B.A. Stewart (eds.) Soil erosion and crop productivity. Soil Science Society of America, Inc. Madison, WI.

Wilson, G.V., and R.J. Luxmoore. 1988. Infiltration, macroporosity, and mesoporosity distributions on two forested watersheds. Soil Sci. Soc. Am. J. 52:329-335.

Wischmeier, W.H., and D.D. Smith. 1978. Predicting rainfall erosion losses- A guide to conservation planning. USDA Hdbk. 537.

Wooding, R.A. 1968. Steady state infiltration from a shallow circular pond. Water Resour. Res. 4:1259-1273.

Wu, L., J.B. Swan, W.H. Paulson, and G.W. Randall. 1992. Tillage effects on measured soil hydraulic properties. Soil Tillage Res. 25:17-33.

Zachmann, J.E. 1986. Earthworms and infiltration as affected by residues in tillage systems. M.S. Thesis. University of Minnesota, St. Paul, MN.

Zachmann, J.E., D.R. Linden, and C.E. Clapp. 1987. Macroporous infiltration and redistribution as affected by earthworms, tillage, and residue. Soil Sci. Soc. Am. J. 51:1580-1586.

LIST OF APPENDICES

Appendix A. Field data from the 1992 season at the Flueger farm.

Table 1. 1992 cultural practices at the Flueger farm in Goodhue County, MN.

Soil: Seaton silt loam (mixed, mesic, fine silty Typic hapludalf), well drained, 2 to 12% slope.

Cropping History:

1981-1988	Corn	Pioneer 3906
1989	Corn	Pioneer 3737
1990	Corn	Pioneer 3751
1991	Corn	NK 3624
1992	Corn	Pioneer 3751

Manure Application and Analysis: Liquid dairy manure injected on May 12, 1992.

	1992 rate	
	Mean	Std. Dev.
Manure (gal/A)	9700	-----
Total N (lbs/A)	387	35
NH_4 N (lbs/A)	192	8
P_2O_5 (lbs/A)	65	3
K_2O (lbs/A)	225	24
Solids (%)	9.1	.2

Fertilizer:

Material	Tillage	N (lbs/A)	Date Applied	Application
82-0-0	Both	180	June 5,1992	Injected
5-14-42	Both	6	May 18, 1992	As a starter

Planting and Harvest Information: A four row John Deere Maxi-Emerge planter with two inch fluted coulters was used to plant on May 18, 1992. Corn was harvested on October 24, 1992.

Insect control: 5.2 lbs/A Thimet 20G applied May 18, 1992.

Weed Control: .75 lbs/A Prowl and 1.2 lbs/A Bladex 90 DF applied on May24, 1992. All plots cultivated on June 10, 1992.

Table 2. Surface residue cover and population as affected by tillage, N source, and row position at the Flueger farm in Goodhue Co., .MN.

N source AND FREQUENCY	Row POSITION	RESIDUE (%) NO TILL	RESIDUE (%) CHISEL	6/5/92 Pop.[1] NO TILL	6/5/92 Pop.[1] CHISEL	10/24/92 Pop. NO TILL	10/24/92 Pop. CHISEL
Annual Manure	In	18.7	9.7	17000	18100	24200	25900
	Between	22.2	7.7				
Anhydrous Ammonia	In	29.3	8.7	17600	18300	27600	24900
	Between	33.5	11.3				
Biennial Manure (yr of application)	In	19.7	9.0	17700	19500	23700	28000
	Between	22.3	10.3				
Biennial Manure (yr after application)	In	36.7	9.7	16200	16300	22700	29400
	Between	41.7	11.0				

[1] Plant population count apparently taken prior to complete germination.

Table 3. Significance table for surface residue cover and population at the Flueger Farm in Goodhue Co., MN.

treatment	Till(T)	N	T*N	Row(R)	T*R	N*R	T*N*R
Residue	.000	.000	.000	.061	.276	.948	.880
Population	.231	.305	1.00	----	----	----	----
Harvest pop.	.021	.752	.011	----	----	----	----

Table 4. Grain yield, grain moisture, and grain N percentage as influenced by tillage, N source and frequency and potassium rates at the Flueger farm in Goodhue Co., MN.

N source & freq.	K_2O lbs/A	Grain Yield NoTil	Grain Yield Chsl	Grain Yield Mean	Grain Moisture NoTill	Grain Moisture Chsl	Grain Moisture Mean	Grain N Notill	Grain N Chsl	Grain N Mean	Grain N uptake No Till	Grain N uptake Chisel	Grain N uptake Mean
		------bu/A-----			--------%-------			-------%--------			-------lbs/A-------		
Annual	0	94	86	**90**	36.1	36.6	**36.3**	1.45	1.47	**1.46**	64.9	59.9	**62.4**
Manure	200	125	125	**125**	37.1	37.0	**37.1**	1.58	1.52	**1.55**	92.2	91.0	**91.6**
Mean		**110**	**106**	**108**	**36.6**	**36.8**	**36.7**	**1.49**	**1.50**	**1.50**	**78.6**	**75.5**	**77.0**
Biennial	0	120	99	**110**	37.5	38.5	**38.0**	1.54	1.53	**1.54**	86.0	71.7	**78.9**
Manure	200	91	114	**103**	35.6	39.0	**37.3**	1.62	1.38	**1.50**	68.0	72.0	**70.0**
(yr of) **Mean**		**106**	**107**	**107**	**36.6**	**38.8**	**37.7**	**1.58**	**1.46**	**1.52**	**77.0**	**71.9**	**74.5**

Biennial	0	44	89	**67**	46.7	36.9	**41.8**	1.30	1.22	**1.26**	27.9	53.2	40.6
Manure	200	64	67	**66**	39.8	45.7	**42.8**	1.14	1.02	**1.08**	34.3	32.5	33.2
(yr after)	**Mean**	**54**	**78**	**66**	**43.3**	**41.3**	**42.3**	**1.22**	**1.12**	**1.17**	**31.1**	**42.9**	**36.9**
Anhydrous	0	83	115	**99**	40.6	37.1	**38.9**	1.54	1.57	**1.56**	60.7	85.4	73.1
Ammonia	200	90	108	**99**	40.4	37.6	**39.0**	1.61	1.63	**1.62**	68.7	83.2	76.0
	400	83	117	**100**	40.8	37.6	**39.2**	1.64	1.60	**1.62**	64.4	87.2	75.8
	Mean	**85**	**113**	**99**	**40.6**	**37.4**	**39.0**	**1.60**	**1.60**	**1.60**	**64.6**	**85.3**	75.0
Overall Mean		**91**	**104**	**98**	**39.3**	**38.2**	**38.8**	**1.53**	**1.47**	**1.50**	**63.0**	**70.7**	66.8
Check (0 N)[1]		26.2	41.3	**33.8**	42.9	38.7	**40.8**	1.21	1.21	**1.21**	4.2	7.3	5.8

	Till(T)	N source(N)	T*N	K rate(K)	K*T	K*N	K*N*T
Grain Yield	.084	.001	.259	.475	.913	.173	.206
Grain Moisture	.052	.000	.009	.433	.028	.351	.011
Grain N %	.011	.000	.081	.715	.096	.177	.518
N uptake	.238	.000	.109	.517	.866	.037	.337

[1] Check plots not included in the statistical analysis.

Table 5. Grain yields, percent moisture, and N percentage at harvest for triennially applied manure with chisel plowing system at the Flueger farm in Goodhue Co., MN.

Year of manure Application	**K_2O** lbs/A	**Grain Yield** ---bu/A----	**Grain Moisture** -------%-----	**Grain N** ---%---
First Year	0	93	36.3	1.44
	200	98	38.1	1.35
	Mean	**96**	**37.2**	**1.40**
Second Year	0	76	37.7	1.28
	200	68	38.0	1.15
	Mean	**72**	**37.9**	**1.22**
Third Year	0	50	36.0	1.08
	200	50	37.2	1.09
	Mean	**50**	**36.6**	**1.09**

Appendix B. Field data from the 1993 season at the Flueger farm.

Table 1. 1993 cultural practices at the Flueger farm in Goodhue County, MN.

Soil: Seaton silt loam (mixed, mesic, fine silty Typic hapludalf), well drained, 2 to 12% slope.

Cropping History:

1981-1988	Corn	Pioneer	3906
1989	Corn	Pioneer	3737
1990	Corn	Pioneer	3751
1991	Corn	NK	3624
1992-1993	Corn	Pioneer	3751

Manure Application and Analysis: Liquid dairy manure injected on May 20, 1993.

	1993 rate Mean
Manure (gal/A)	7675
Total N (lbs/A)	300
NH_4 N (lbs/A)	130
Solids (%)	9.0

Fertilizer:

Material	Tillage	N (lbs/A)	Date Applied	Application
82-0-0	Both	180	July 24,1993	Injected
5-14-42	Both	6	June 4,1993	As a starter

Planting and Harvest Information: A four row John Deere Maxi-Emerge planter with two inch fluted coulters was used to plant on June 4, 1993. Corn was harvested on Nov 27, 1993.

Insect control: 5.2 lbs/A Thimet 20G applied June 4, 1993.

Weed Control: .75 lbs/A Prowl and 1.2 lbs/A Bladex 90 DF applied on June 18, 1993.

Table 2. Surface residue cover and population as affected by tillage, N source, and row position at the Flueger farm in Goodhue Co., MN, measured on 6/24/93.

N source AND FREQUENCY	Row POSITION	RESIDUE (%) NO TILL	RESIDUE (%) CHISEL	Pop. (1000 plants/A) NO TILL	Pop. (1000 plants/A) CHISEL
Annual Manure	In	38.0	11.0	27.0	28.4
	Between	62.2	24.3		
Anhydrous Ammonia	In	67.4	12.1	27.9	28.1
	Between	84.2	22.5		
Biennial Manure (yr. of application)	In	29.0	15.7	26.1	28.0
	Between	26.3	18.0		
Biennial Manure (yr after application)	In	59.0	11.7	26.6	27.2
	Between	77.0	21.3		
			Average	**26.9**	**27.9**

Table 3. Significance table for surface residue cover and population at the Flueger Farm in Goodhue Co., MN.

	Till(T)	N treatment(N)	T*N	Row(R)	T*R	N*R	T*N*R
Residue	.000	.000	1.00	.000	.023	.065	1.00
Population	.255	.753	.814	----	----	----	----

Table 4. Grain yield, grain moisture, and grain N percentage as influenced by tillage, N source and frequency and potassium rates at the Flueger farm in Goodhue Co., MN.

N source & freq.	K_2O lbs/A	Grain Yield NoTill	Grain Yield Chsl	Grain Yield Mean	Grain Moisture NoTill	Grain Moisture Chsl	Grain Moisture Mean	Grain N NoTill	Grain N Chsl	Grain N Mean	Grain N uptake No Till	Grain N uptake Chisel	Grain N uptake Mean
		------bu/A------			--------%-------			-------%--------			--------lbs/A------		
Annual	0	67	90	**79**	29.7	25.0	**27.4**	1.40	1.47	**1.44**	44.6	63.0	**53.8**
Manure	200	85	104	**95**	25.2	23.3	**24.3**	1.58	1.52	**1.55**	62.8	74.4	**68.6**
	Mean	**76**	**97**	**87**	**28.5**	**24.1**	**26.3**	**1.49**	**1.50**	**1.50**	**53.7**	**69.7**	**61.2**
Biennial	0	77	80	**79**	27.5	26.1	**26.8**	1.30	1.22	**1.26**	46.0	47.2	**46.6**
Manure	200	51	88	**70**	29.7	21.5	**25.6**	1.14	1.02	**1.08**	27.3	43.0	**35.2**
(yr of)	**Mean**	**64**	**84**	**74**	**28.6**	**23.8**	**26.2**	**1.22**	**1.12**	**1.17**	**36.7**	**45.1**	**40.9**
Biennial	0	57	78	**68**	33.2	26.1	**29.7**	1.54	1.53	**1.54**	41.6	56.7	**49.2**
Manure	200	54	72	**63**	31.7	21.5	**26.6**	1.62	1.38	**1.50**	41.6	47.0	**44.3**
(yr after)	**Mean**	**56**	**75**	**66**	**32.5**	**24.2**	**28.3**	**1.58**	**1.46**	**1.52**	**41.6**	**51.9**	**46.7**
Anhydrous	0	41	72	**57**	33.2	22.6	27.9	1.55	1.57	**1.56**	30.9	53.6	**42.3**
Ammonia	200	51	67	**59**	28.8	25.3	**27.1**	1.61	1.63	**1.62**	38.9	51.4	**45.2**
	400	51	75	**63**	29.7	21.9	**25.8**	1.63	1.60	**1.62**	38.7	56.7	**47.7**
	Mean	**48**	**71**	**60**	**30.6**	**23.3**	**27.0**	**1.60**	**1.60**	**1.60**	**36.2**	**53.9**	**45.1**
Overall Mean		**61**	**82**	**72**	**30.1**	**23.9**	**27.0**	**1.47**	**1.42**	**1.45**	**42.1**	**55.2**	**48.6**
Check (0 N)[1]		37	55	**46**	31.5	27.3	**29.4**	1.21	1.21	**1.21**	20.8	31.2	

26.0

	Till(T)	N source(N)	T*N	K rate(K)	K*T	K*N	K*N*T
Grain Yield	.076	.001	.900	.687	.851	.375	.333
Grain Moisture	.122	.385	.757	.357	.860	.880	.299
Grain N %	.492	.000	.469	.727	.250	.017	.609
N uptake	.167	.000	.339	.703	.986	.129	.670

[1] Check plots not included in the statistical analysis.

Table 5. Grain yields, percent moisture, and N percentage at harvest for triennially applied manure with chisel plowing system at the Flueger farm in Goodhue Co., MN.

Year of manure Application	K_2O	Grain Yield	Grain Moisture	Grain N	N Uptake
	lbs/A	---bu/A----	------%-----	---%---	--lbs/a--
First Year	0	88	24.8	1.09	45.4
	200	88	22.8	1.09	45.4
	Mean	**88**	**23.8**	**1.09**	**45.4**
Second Year	0	73	24.7	1.43	49.4
	200	69	23.6	1.35	44.1
	Mean	**71**	**24.2**	**1.39**	**46.7**
Third Year	0	60	27.7	1.28	36.3
	200	49	28.0	1.15	26.7
	Mean	**55**	**27.9**	**1.22**	**31.8**

Table 6. Infiltration rates, sediments, and time to beginning of runoff for rainfall simulation at the Flueger farm in Goodhue, Co., MN, measured 7/6/93 through 8/3/93.

Nsource	Inf. rate*			Sediments			Time to runoff		
	Notill	Chisel	Mean	Notill	Chisel	Mean	Notill	Chisel	Mean
	--------mm/hr-----			-------T/ha-------			--------min-------		
Annual manure	58.0	20.3	**39.2**	2.6	15.4	**9.0**	16.2	11.2	**13.7**
Fertilizer	33.9	11.3	**22.6**	.8	11.2	**6.0**	12.5	5.8	**9.2**
Check	20.3	19.9	**20.1**	5.9	6.8	**6.4**	9.0	6.2	**7.6**
Mean	**37.4**	**17.2**	**27.3**	**3.1**	**11.1**	**7.1**	**12.6**	**7.7**	**10.2**

	Till(T)	Nsource(N)	T*N
Inf. Rate	.031	.073	.337
Sediments	.035	.672	.267
Time to Runoff	.132	.176	.267

* 21 to 25% gravimetric water content during rainfall simulation experiment.

Table 7. Infiltration rates (taken 9/23 through 10/9), organic carbon (taken 6/24), and bulk density measurements (taken 8/6) at the Flueger farm in Goodhue Co., MN.

Nsource & freq.	Inf. Rate* SAT			Inf. Rate* -3.5			Inf. Rate* -7.0			Organic Carbon 0-3 in			Organic Carbon 3-6 in		
	Notil	Chsl	Mean	Notil	Chsl	Mean	Notil	Chsl	Mean	Notil	Chsl	Mean	Notil	Chsl	Mean
	------------------mm/hr									--------------%					
Annual Manure	293	587	**440**	61	137	**99**	31	12	**22**	1.47	1.67	**1.57**	1.20	1.33	**1.27**
Fert.	139	293	**216**	25	84	**55**	8	18	**13**	1.57	1.57	**1.57**	1.43	1.30	**1.37**
Check	180	392	**286**	49	28	**39**	6	19	**13**	1.37	1.27	**1.32**	1.00	1.17	**1.09**
Mean	**204**	**424**	**314**	**45**	**83**	**64**	**15**	**16**	**16**	**1.47**	**1.50**	**1.49**	**1.21**	**1.27**	**1.24**

	Bulk Density 1-3 in			5-7 in			9-11 in			1-11 in		
	Notil	Chsl	Mean	Notil	Chsl	Mean	Notil	Chsl	Mean	Notil	Chsl	Mean
	---------------------------Mg/m³											
Annual Manure	1.32	1.41	**1.37**	1.44	1.32	**1.38**	1.53	1.46	**1.50**	1.43	1.39	**1.41**

Fert.	1.59	1.28	**1.44**	1.49	1.40	**1.45**	1.57	1.50	**1.54**	1.55	1.39	**1.47**
Check	1.47	1.41	**1.44**	1.46	1.33	**1.40**	1.54	1.51	**1.53**	1.49	1.42	**1.46**
Mean	**1.46**	**1.37**	**1.42**	**1.46**	**1.35**	**1.41**	**1.55**	**1.49**	**1.52**	**1.49**	**1.40**	**1.45**

	Till(T)	Nsource(N)	T*N	Depth(D)	D*T	D*N	D*T*N
Saturated	.057	.042	.652	----	---	---	----
-3.5 cm	.305	.144	.241	----	---	---	----
-7.0 cm	.794	.500	.171	----	---	---	----
Organic C.	.661	.108	.621	.002	.864	.811	.415
Bulk Density	.039	.053	.001	.000	.449	.756	.009

* 23 to 28% gravimetric water content during infiltration experiment.

Appendix C. Bulk density values for the individual plots at the Flueger farm and the statistical analysis output.

PLOT	TREATMENT	REP	BULK DENSITY (Mg m^{-3})		
			3-9 cm	15-21 cm	27-33 cm
5-5	CHISEL, FERT.	1	1.36	1.36	1.35
20-5	CHISEL, FERT.	2	1.29	1.48	1.56
35-5	CHISEL, FERT.	3	1.20	1.35	1.59
1-2	NO-TILL, FERT.	1	1.62	1.48	1.54
18-2	NO-TILL, FERT.	2	1.54	1.46	1.54
25-2	NO-TILL, FERT.	3	1.61	1.54	1.61
111-9	NO-TILL, MANURE	1	1.42	1.50	1.46
130-9	NO-TILL, MANURE	2	1.30	1.43	1.63
151-9	NO-TILL, MANURE	3	1.24	1.38	1.51
120-15	CHISEL, MANURE	1	1.49	1.38	1.46
127-15	CHISEL, MANURE	2	1.35	1.23	1.36
153-15	CHISEL, MANURE	3	1.38	1.29	1.56
112-7	NO-TILL, CHECK	1	1.52	1.45	1.53
129-7	NO-TILL, CHECK	2	1.48	1.49	1.45
152-7	NO-TILL, CHECK	3	1.42	1.44	1.63
114-14	CHISEL, CHECK	1	1.46	1.40	1.60
133-14	CHISEL, CHECK	2	1.48	1.30	1.47
148-14	CHISEL, CHECK	3	1.30	1.29	1.46

Statistical Analysis output for bulk density results.

	3-9 cm Pr>F	15-21 cm Pr>F	27-33 cm Pr>F
Tillage	0.039	0.007	0.046
N-Source	0.053	0.251	0.816
Tillage X N-Source	0.001	0.909	0.913

Depth[1]	0.0001		
Depth x Tillage[1]	0.449		
Depth x N-Source[1]	0.756		
Depth x Tillage x N-Source[1]	0.009		

[1] Depth run as an independent variable.

Appendix D. Organic carbon values for the individual plots at the Flueger farm and the statistical analysis output.

PLOT	TREATMENT	REP	% ORGANIC C 0-7.6 cm	% ORGANIC C 7.6-15.2 cm
5-5	CHISEL, FERT.	1	1.5	1.2
20-5	CHISEL, FERT.	2	1.6	1.3
35-5	CHISEL, FERT.	3	1.6	1.2
1-2	NO-TILL, FERT.	1	1.9	1.4
18-2	NO-TILL, FERT.	2	1.8	1.4
25-2	NO-TILL, FERT.	3	1.0	1.5
111-9	NO-TILL, MANURE	1	1.2	0.9
130-9	NO-TILL, MANURE	2	1.5	1.3
151-9	NO-TILL, MANURE	3	1.7	1.5
120-15	CHISEL, MANURE	1	1.8	1.6
127-15	CHISEL, MANURE	2	1.6	1.2
153-15	CHISEL, MANURE	3	1.6	1.2
112-7	NO-TILL, CHECK	1	1.2	0.7
129-7	NO-TILL, CHECK	2	1.6	1.2
152-7	NO-TILL, CHECK	3	1.3	1.1
114-14	CHISEL, CHECK	1	1.3	1.0
133-14	CHISEL, CHECK	2	1.2	1.4
148-14	CHISEL, CHECK	3	1.3	1.1

Statistical analysis output for organic carbon results.

	0-7.6 cm Pr>F	7.6-15.0 cm Pr>F
Tillage	0.775	0.753
N-Source	0.245	0.078
Tillage X N-source	0.640	0.359
Depth[1]	0.002	
Tillage x Depth[1]	0.864	
N-Source x Depth[1]	0.811	
Tillage x N-Source x Depth[1]	0.415	

[1] Depth run as independent variable.

Appendix E. Ponded infiltration, tension infiltration, and macroporous flow values for the individual plots at the Flueger farm, and the statistical analysis output.

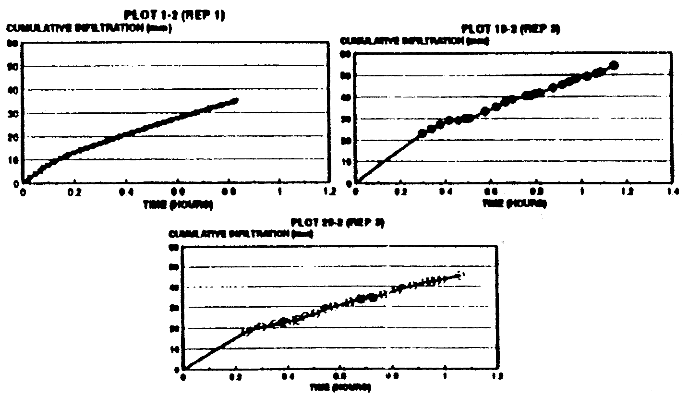
PLOT	TREATMENT	REP	PONDED ($mm\ hr^{-1}$)	-3.5cm ($mm\ hr^{-1}$)	-7.0cm ($mm\ hr^{-1}$)	MACROPORE FLOW ($mm\ hr^{-1}$)
5-5	CHISEL, FERT.	1	271.4	48.8	2.9	222.6
20-5	CHISEL, FERT.	2	221.7	135.3	8.9	86.4
35-5	CHISEL, FERT.	3	386.9	67.3	41.3	319.6
1-2	NO-TILL, FERT.	1	64.1	58.2	15.5	5.9
18-2	NO-TILL, FERT.	2	314.2	9.8	1.7	304.4
25-2	NO-TILL, FERT.	3	37.3	37.3	5.3	29.7
111-9	NO-TILL, MAN.	1	256.0	64.8	26.5	191.2
130-9	NO-TILL, MAN.	2	179.4	14.4	10.2	165.0
151-9	NO-TILL, MAN.	3	444.0	102.3	56.2	341.7
120-15	CHISEL, MANURE	1	627.9	41.9	18.0	586.0
127-15	CHISEL, MANURE	2	406.5	139.4	0.1	267.1
153-15	CHISEL, MANURE	3	727.0	230.6	18.2	496.4
112-7	NO-TILL, CHECK	1	36.2	6.8	3.2	29.4
129-7	NO-TILL, CHECK	2	155.6	20.3	3.1	135.3
152-7	NO-TILL, CHECK	3	349.2	119.1	12.4	230.1
114-14	CHISEL, CHECK	1	242.3	13.5	3.4	228.8
133-14	CHISEL, CHECK	2	356.5	32.9	33.8	323.6
148-14	CHISEL, CHECK	3	577.8	36.1	20.1	541.7

Statistical analysis output for ponded infiltration rate, tension infiltration rates, and macroporous flow rates.

	Ponded Pr>F	-3.5 cm Pr>F	-7.0 cm Pr>F	Macroporous flow Pr>F
Tillage	0.057	0.305	0.794	0.148
N-Source	0.042	0.144	0.500	0.090
Tillage X N-Source	0.652	0.241	0.171	0.586

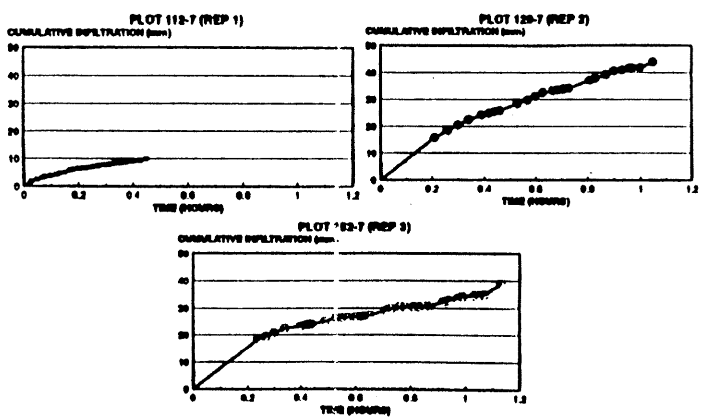
Appendix F.

Appendix F. Rainfall simulator cumulative infiltration vs. time graphs for the individual plots.



Rainfall simulation data for No-Till, Fertilizer plots

Appendix F continued.



Rainfall simulation data for No-Till, Check plots

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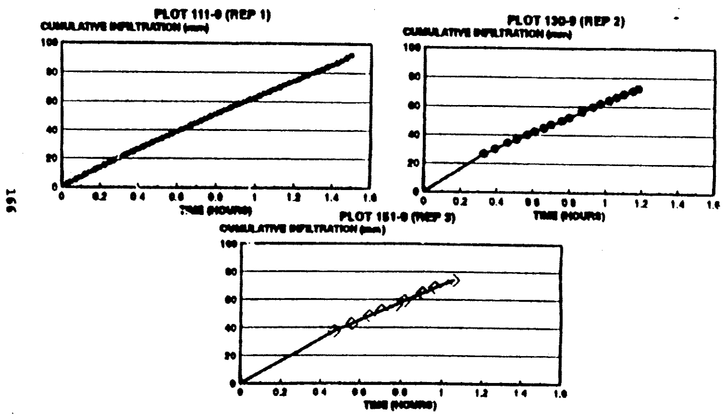
Appendix F continued.



Rainfall simulation data for No-Till, Manure plots

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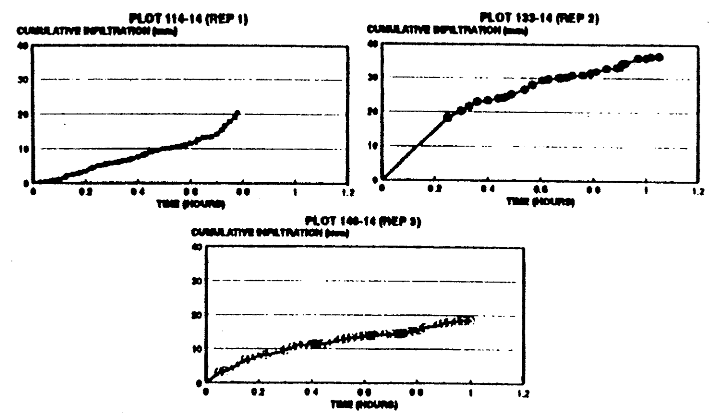
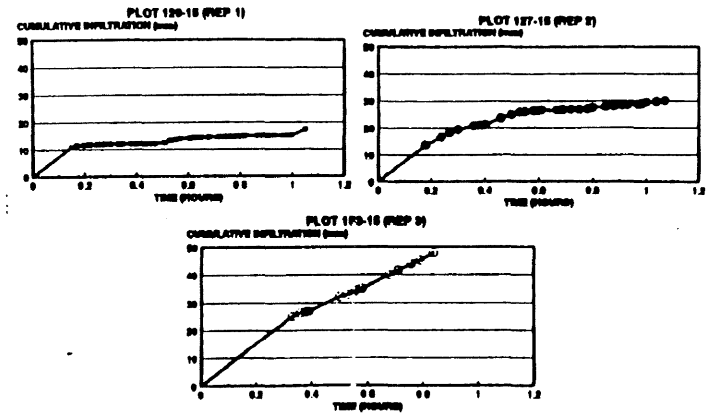
Appendix F continued.



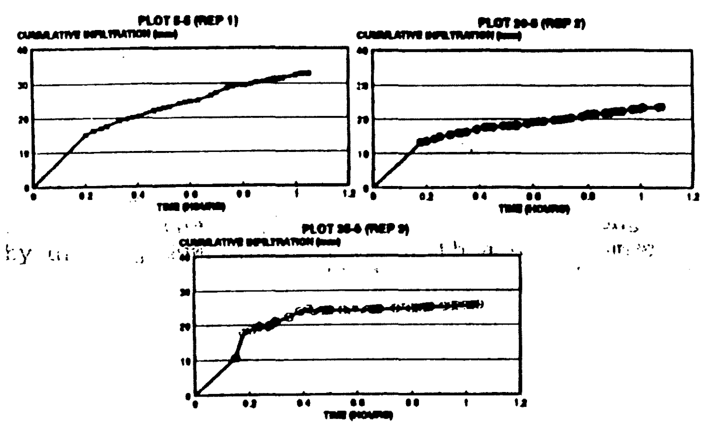
Rainfall simulation data for Chisel plow, check

Appendix F continued.



Rainfall simulation data for Chisel plow, Manure plots

Appendix F continued.



Rainfall simulation data for Chisel plow, Fertilizer plots

Appendix G. Campbell 21X datalogger program for monitoring tipping bucket used to record runoff during the rainfall simulation experiment.

```
Program:  Monitors one rain gauge for runoff
  Todd Schumacher, ver. 1.0, June 30, 1993
Flag Usage:  Flag 1 disables datalogger
Input Channel Usage:
Excitation Channel Usage:
Continuous Analog Output Usage:
Control Port Usage:
Pulse Input Channel Usage:  Port 1 = Rain gauge
Output Array Definitions:
  Array, Day, Hrmin, Liters


     1          Table 1 Programs
  01: 60        Sec. Execution Interval

01:  P91        If Flag
  01: 11        1 is set
  02: 0         Go to end of Program Table

02:  P3         Pulse
  01: 1         Rep
  02: 1         Pulse Input Chan
  03: 2         Switch closure
  04: 1         Loc [:liters   ]
  05: .088      Mult
  06: 0         Offset

03:  P89        If X<=>F
  01: 1         X Loc liters
  02: 2         <>
  03: 0         F
  04: 10        Set high Flag 0 (output)

04:  P77        Real Time
  01: 110       Day,Hour-Minute

05:  P70        Sample
  01: 1         Rep
  02: 1         Loc liters

06:  P          End Table 1
```

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```
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*      1        Table 1 Programs
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  02: 1         Pulse Input Chan
  03: 2         Switch closure
  04: 1         Loc [:liters   ]
  05: .088      Mult
  06: 0         Offset

03:  P89        If X<=>F
  01: 1         X Loc liters
  02: 2         <>
  03: 0         F
  04: 10        Set high Flag 0 (output)

04:  P77        Real Time
  01: 110       Day,Hour-Minute

05:  P70        Sample
  01: 1         Rep
  02: 1         Loc liters

06:  P          End Table 1
```

Appendix H. Simulated rainfall infiltration rates, time to ponding, and sediment production values for the individual plots at the Flueger farm, and the statistical analysis output.

TREATMENTS	REP	SIMULATED RAIN INF. RATE (mm hr^{-1})	TIME TO PONDING (minutes)	SEDIMENT PRODUCTION (T ha^{-1})
NO-TILL, FERT.	1	32.4	10.0	.56
NO-TILL, FERT.	2	35.3	14.5	.85
NO-TILL, FERT.	3	34.0	13.0	1.1
CHISEL, FERT.	1	18.0	10.0	6.3
CHISEL, FERT.	2	9.2	1.5	13.0
CHISEL, FERT.	3	6.8	6.0	14.4
NO-TILL, MANURE	1	58.1	8.0	1.1
NO-TILL, MANURE	2	54.1	17.5	4.3
NO-TILL, MANURE	3	61.7	23.0	2.5
CHISEL, MANURE	1	5.2	7.5	20.9
CHISEL, MANURE	2	9.7	9.0	22.0
CHISEL, MANURE	3	46.0	17.0	3.2
NO-TILL, CHECK	1	13.1	6.0	11.0
NO-TILL, CHECK	2	29.5	9.0	1.5
NO-TILL, CHECK	3	18.2	12.0	5.3
CHISEL, CHECK	1	31.5	3.0	4.5
CHISEL, CHECK	2	16.5	14.0	4.9
CHISEL, CHECK	3	11.8	1.5	10.8

Statistical analysis output for rainfall simulation infiltration rate, time to ponding, and sediment production.

	Rainfall Infiltration Pr>F	Time to Ponding Pr>F	Sediment Production Pr>F
Tillage	0.034	0.132	0.035
N-source	0.061	0.176	0.672
Tillage X N-Source	0.088	0.822	0.267

Appendix I. Q_o, R_o, N_o, and porosity values for the individual plots from the fall 1993 tension infiltration runs as calculated using the procedures described by Reynolds (1994).

PLOT	Head (cm)	Q_o (cm^3 s^{-1})	R_o (cm)	N_o (m^{-2})	Porosity (%)
1-2	0	1.40	0.0020	6266323	0.0121
	-3.5	1.27	0.0070	86044	0.0008
	-7.0	0.34	0.0270	161	0.0002
18-2	0	7.33	0.0735	72	0.0121
	-3.5	0.23	0.0480	12	0.0008
	-7.0	0.04	0.0371	6	0.1336
25-2	0	0.74	0.034	152	0.0054
	-3.5	0.15	0.014	780	0.0050
	-7.0	0.11	0.0076	5476	0.0099
5-5	0	6.33	0.0366	940	0.0394
	-3.5	1.14	0.0465	67	0.0045
	-7.0	0.07	0.0574	2	0.0002
20-5	0	4.83	0.0104	79597	0.2721
	-3.5	2.95	0.0203	4167	0.0537
	-7.0	0.19	0.0739	2	0.0003
35-5	0	9.03	0.0370	1284	0.0551
	-3.5	1.57	0.0177	3700	0.0363
	-7.0	0.96	0.0105	15711	0.0539
112-7	0	0.72	0.0353	123	0.0048
	-3.5	0.14	0.0230	119	0.0020
	-7.0	0.06	0.0165	194	0.0017
129-7	0	3.39	0.0435	258	0.0153
	-3.5	0.44	0.0416	40	0.0022
	-7.0	0.07	0.0377	9	0.0004
152-7	0	7.61	0.0228	6868	0.1122
	-3.5	2.59	0.0320	645	0.0207
	-7.0	0.27	0.0476	14	0.0010
111-9	0	5.97	0.0292	2108	0.0563
	-3.5	1.51	0.0237	1179	0.0208
	-7.0	0.61	0.0187	1174	0.0129
130-9	0	3.58	0.0529	117	0.0107
	-3.5	0.29	0.0044	99308	0.0607
	-7.0	0.21	0.0067	16804	0.0237

151-9	0	9.67	0.0312	2655	0.0809
	-3.5	2.23	0.0190	4016	0.0455
	-7.0	1.22	0.0128	9414	0.0487
114-14	0	4.84	0.0611	98	0.0115
	-3.5	0.27	0.0400	28	0.0014
	-7.0	0.07	0.0290	25	0.0006
148-14	0	13.48	0.0570	357	0.0364
	-3.5	0.84	0.0230	728	0.0121
	-7.0	0.47	0.0123	4269	0.0202
120-15	0	14.65	0.0586	348	0.0376
	-3.5	0.98	0.0283	390	0.0098
	-7.0	0.42	0.0179	946	0.0095
127-15	0	8.12	0.0227	7488	0.1209
	-3.5	2.78	0.0431	218	0.0127
	-7.0	0.002	0.1526	0.0011	8.02E-07
153-15	0	15.84	0.0245	10931	0.2056
	-3.5	5.02	0.0345	931	0.0348
	-7.0	0.40	0.0537	13	0.0012

Appendix J. Aggregate stability data for the individual plots at the Flueger farm, and the statistical analysis.

PLOT	TREATMENT	AGGREGATE STABILITY (%)
1-2	NO-TILL, FERT.	70.4
18-2	NO-TILL, FERT.	71.9
25-2	NO-TILL, FERT.	63.0
5-5	CHISEL, FERT.	69.5
20-5	CHISEL, FERT.	74.3
35-5	CHISEL, FERT.	46.3
112-7	NO-TILL, CHECK	82.1
129-7	NO-TILL, CHECK	74.1
152-7	NO-TILL, CHECK	73.9
111-9	NO-TILL, MANURE	78.1
130-9	NO-TILL, MANURE	61.0
151-9	NO-TILL, MANURE	59.7
114-14	CHISEL, CHECK	61.6
133-14	CHISEL, CHECK	60.8
148-14	CHISEL, CHECK	56.6
120-15	CHISEL, MANURE	61.4
127-15	CHISEL, MANURE	61.0
153-15	CHISEL, MANURE	63.1

	AGGREGATE STABILITY
TILLAGE	0.082
N-SOURCE	0.603
TILLAGE X N-SOURCE	0.265

A.3. Activity: To calibrate/validate the simulation model NCSWAP on experimental data documenting the effect of manure and tillage on continuous corn in the Karst areas of MN. To use the model to quantify the vernacular knowledge pertaining to agricultural management practices in the Karst area.

A.3.a. Context: The extent of N mineralization from soil organic matter (SOM) and manure depends on soil, landscape and climatic conditions. Vernacular knowledge of these conditions and their influence on crop yield is extensive but anecdotal. To relate this knowledge to soil transformations of C and N as described by a simulation model would give credence to the scientific approach in the eye of the field practitioners, and allow explanation of the localized observations in reference to quantitative and general relations.

A.3.b. Methods: The model NCSWAP will be calibrated to account for the data collected in Goodhue county from 1982 to 1990, to study the long-term effect of tillage and liquid dairy manure application on nitrogen availability to corn. After calibration, the model will be used to describe anecdotal situations (e.g. the influence of slope orientation on soil temperature) and to translate them into quantitative consequences (e.g. the influence of the slope on net N mineralization of manure and thus on nitrate leaching at thawing). The range of calibration will encompass the conditions of the region in which the model is intended to be used for prediction. A survey of vernacular sayings related to agricultural management will be made. Gaps between the anecdotes, in terms of edaphic and climatic continuums, will be identified and analyzed by the simulation model.

A.3.c. Materials: Data from the long-term manure study are readily available. The simulation model NCSWAP is available and has been extensively tested. Computers are available.

A.3.d. Budget:
Post doctoral assistant: $15,000 Balance $0

A.3.e. Timeline:	7/93	1/94	6/94	1/95	6/95
Calibration	xxxx				
Collection and simulation of anecdotal situations	xxxx				
Preliminary evaluation	xxxx				
Evaluation				xxxx	xxx

A.3.f Final Detailed Report:

Effective Manure Management in Conservation Tillage Systems for Karst Areas of Minnesota

Objective: To calibrate/validate the simulation model NCSWAP on experimental data documenting the effect of manure and tillage on continuous corn in the Karst areas of MN.

Summary

The model NCSWAP was modified to simulate multi-year cropping. The multi-year version of NCSWAP requires one input file to specify the soil initial conditions; and yearly, 5 input files which contain the driving variables: climatic (rainfall; soil and air temperature; pan-evaporation); crop (crop kinetics under no water and N stress; degree days to maturity); and management (date, amount, and type of inorganic and organic additions; date and depth of tillage; date of crop emergence and harvest).

Experimentla data were obtained from Dr. Joshi's thesis (Department of Soil Science, University of Minnesota, April 1982). Continuous corn was grown from 1982 to 1990. Five treatments were considered: (1) zero-N; (2) fertilizer (117 kg N-NH4 plus 117 kg N-NO3 .ha-1 annually); and liquid dairy cattle manure (153 kg N-inorganic plus 135 kg N-organic .ha-1, C/N=20) injected in soil (3) annually; (4) biennially; and (5) triennially.

Simulated data accounted for the differences in yield observed between treatments. Yield differences from year to year were reproduced by simulation for the biennial and triennial treatments. The overall decline in yield observed from 1982 to 1990 for the triennial manure treatment was also simulated by the model.

The half-life of the organic fraction of the liquid dairy manure was set to 115 days (.006 day-1, decay rate). It corresponded to the value obtained in another study for the organic fraction of solid beef manure.

Simulation was used to estimate the rate of fertilizer addition which would compensate for yield decline in between years of manure triennial applications. Yields responded marginally to changes in air (2°C) and soil (5°C) temperatures (Figure 7 and 8). Increased soil temperatures decreased yields by reducing net N mineralization. Yields were increased by reduced air temperatures which lenghtened the plant cycle, thus allowing more time for N release from soil.

Overall Project Results:
Experimental data documenting 8 year (1982-1990) of continuous corn for 5 contrasted treatments - (1) zero-N; (2) fertilizer (117 kg N-NH4 plus 117 kg N-NO3 .ha-1 annually); and liquid dairy cattle manure (153 kg N-inorganic plus 135

kg N-organic .ha-1, C/N=20) injected in soil (3) annually; (4) biennially; and (5) triennially - were used to validate the model.

Simulated data accounted for the differences in yield observed between treatments. Yield differences from year to year were reproduced by simulation for the biennial and triennial treatments. The overall decline in yield observed from 1982 to 1990 for the triennial manure treatment was also simulated by the model.

The half-life of the organic fraction of the liquid dairy manure was set to 115 days (.006 day-1, decay rate). It corresponded to the value obtained in another study for the organic fraction of solid beef manure.

Simulation was used to estimate the rate of fertilizer addition which would compensate for yield decline in between years of manure triennial applications. Yields responded marginally to changes in air (2°C) and soil (5°C) temperatures

Introduction

The increased confinement of livestock has raised the issue of manure management. Manure application to soil offers an alternative to the use of commercial fertilizer. It should be done in such a way as to maximize crop production and to limit nitrate pollution of ground water. Manure provides two types of N sources: (1) readily plant available NH4-N and NO3-N, and (2) organic N which may become plant available upon conversion to NH4-N by net mineralization. Net N mineralization is a process which is biologically mediated by biotic and abiotic factors (soil temperature and water content; C/N ratio and amount of manure and crop residues added; availability of inorganic N to drive the process of immobilization...). It is impossible to estimate the dynamics of N plant availability in a soil amended with manure without the help of a quantitative computer program devised to integrate the complexity of C and N transformations in soil. The overall objective of this study was to show that the program NCSWAP could be used as a tool to help divise management strategies for the application of manure to soil for conditions corresponding to the Karst areas of Minnesota.

The Model

The module of NCSWAP which computes C and N transformations in soil is the program NCSOIL. As a stand-alone unit, NCSOIL was initiated in 1981 (Molina, et al., 1983). It has been validated against many data sets (e.g. Nicolardot et al., 1993). NCSOIL was one of the 9 models (3 from the USA) selected among 53 world-wide to participate in a NATO Advanced Research Worshop (Rothamsted, UK; May, 1995). NCSOIL is part of the Global Network of Soil Organic Matter Models (SOMNET) of the International Geosphere-Bioshere Programme. NCSWAP (Hetier et al. 1989-1990; Lengnick et al., 1994) integrates NCSOIL with modules which compute the flux of water, C and N in the soil-plant-air system. NCSWAP requires one input file to specify the soil initial conditions, and yearly, 5 input files which contain the driving variables: climatic (rainfall; soil and air temperature; pan-evaporation); crop (crop kinetics under no water and N stress; degree days to maturity); and management (date, amount, and type of inorganic and organic additions; date and depth of tillage; date of crop emergence and harvest). NCSWAP considers different soil layers vertically, but assumes horizontal homogeneity. Stresses on crop other than water, N and temperature are not computed by NCSWAP.

The Experimental Data

The experiment was conducted in a field located in Section 15 of Haycreek Township in Goodhue County. It was performed in partial fulfillment of Dr. Jaya Raj Joshi's doctoral thesis, under the supervision of Drs. J. Moncrief, S. Gupta, and J. Swan. Results were obtained from Dr. Joshi's thesis (Department of Soil Science, University of Minnesota, April 1982). Continuous corn was grown from 1982 to 1990. Five treatments were considered: (1) zero-N; (2) fertilizer (117 kg N-NH4 plus 117 kg N-NO3 .ha-1 annually); and liquid dairy cattle manure (153 kg N-inorganic plus 135 kg N-organic .ha-1, C/N=20) injected in soil (3) annually; (4) biennially; and (5) triennially. Manure was collected from an anaerobic pit. No-till was used for the first 4 treatments, and chisel plowing for the triennial manure treatment. Three replication plots were established per treatments. Above-ground dry matter production was measured and reported as organic N . ha-1.

Results and Discussion

The experimental data were used to validate NCSWAP and to identify differences between the treatments in the kinetics of dry matter production. The model was used to find out (1) management alternatives to manure application; (2) and to estimate the impact of soil and air temperature on crop yield.

Validation and Differences between Treatments:

Experimental and simulated data are shown for the above ground dry matter production in Figures 1 (zero-N added), 2 (fertilizer), 3, 4, and 5 (manure added annually, biennially and triennially, respectively). Data are expressed in terms of above ground N. Experimental data for the fertilizer treatment were available for the years 1987, 88, 89, and 90, only. Simulated data accounted for the differences in yield observed between treatments. Yield differences from year to year were reproduced by simulation for the biennial and triennial treatments. The overall decline in yield observed from 1982 to 1990 for the triennial manure treatment was also simulated by the model.

The half-life of the organic fraction of the liquid dairy manure was set to 115 days (.006 day-1, decay rate). It corresponded to the value obtained in another study for the organic fraction of solid beef manure.

Simulated Scenarios:

Simulation was used to estimate the rate of fertilizer addition which would compensate for yield decline in between years of manure triennial applications. Figure 6 shows the effect of 250, 150, 100, and 0 kg N-NH4 . ha-1 added in 1983, 84, 86, 87, 89, and 90.

The effect of temperature on yields was computed by simulation to estimate differences due to slope orientations. Soil and air temperatures were modified indepently from each other. In the model, soil temperatures impact on C and N soil transformations; while air temperatures control the kinetics of crop growth (thus, of N and water demand) and date of maturity.
Yields responded marginally to changes in air (2°C) and soil (5°C) temperatures (Figure 7 and 8). Increased soil temperatures decreased yields by reducing net N mineralization. Yields were increased by reduced air temperatures which lenghtened the plant cycle, thus allowing more time for N release from soil.

Literature Cited

Hetier J.M., Zuvia M., Houot S., and Thiery J.M. 1989-1990. Comparaison de trois modeles choisis pour la simulation du cycle de l'azote dans les agro-systems tropicaux. Cah. ORSTOM, ser. Pedol., vol. XXV, no.4:443-451.

Houot S., J.A.E. Molina, R. Chaussod, and C.E. Clapp. 1989. Simulation by NCSOIL of net mineralization in moils from the Deherain and 36 Parcelles fields at Grignon. Soil Sci. Soc. Am. J. 53:451-455.

Lengnick L.L., Fox, R.H. 1994. Simulation by NCSWAP of seasonal nitrogen dynamics in corn: I. Soil nitrate. Agron. J. 86:167-182.

Molina J.A.E., Clapp C.E., Shaffer M.J., Chichester F.W., and Larson W.E. 1983. NCSOIL, a model of nitrogen and carbon transformations in soil: description, calibration, and behavior. Soil Sci. Soc. Am. J. 47:85-91.

Nicolardot C., and J.A.E. Molina. 1993. C and N fluxes between Pools of soil organic matter: Model calibration with long-term filed experimental data. Soil Biol. Biochem. 26:245-251.

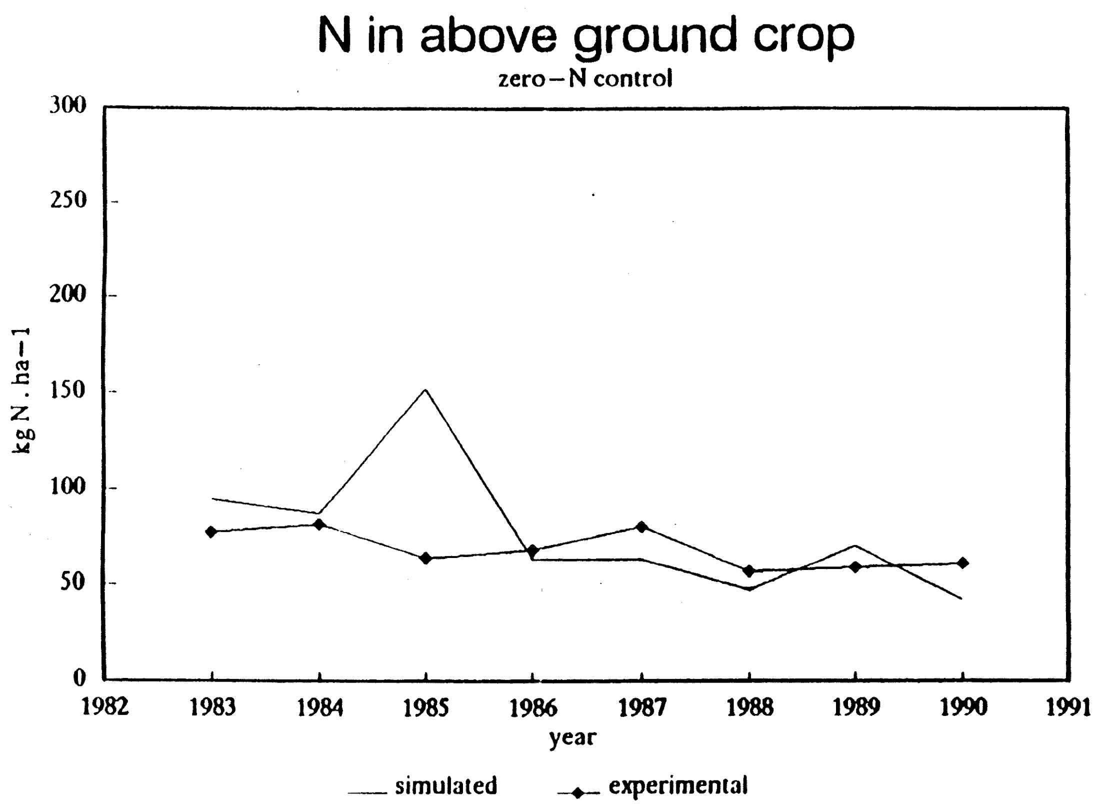
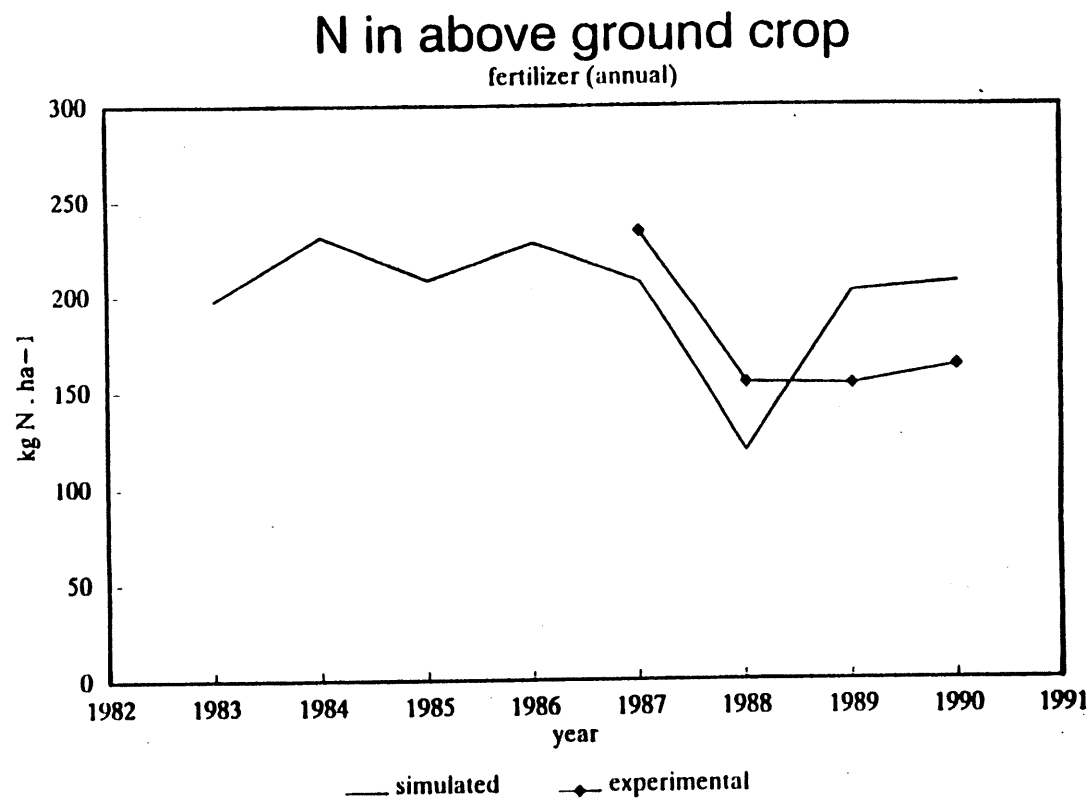


Figure 1



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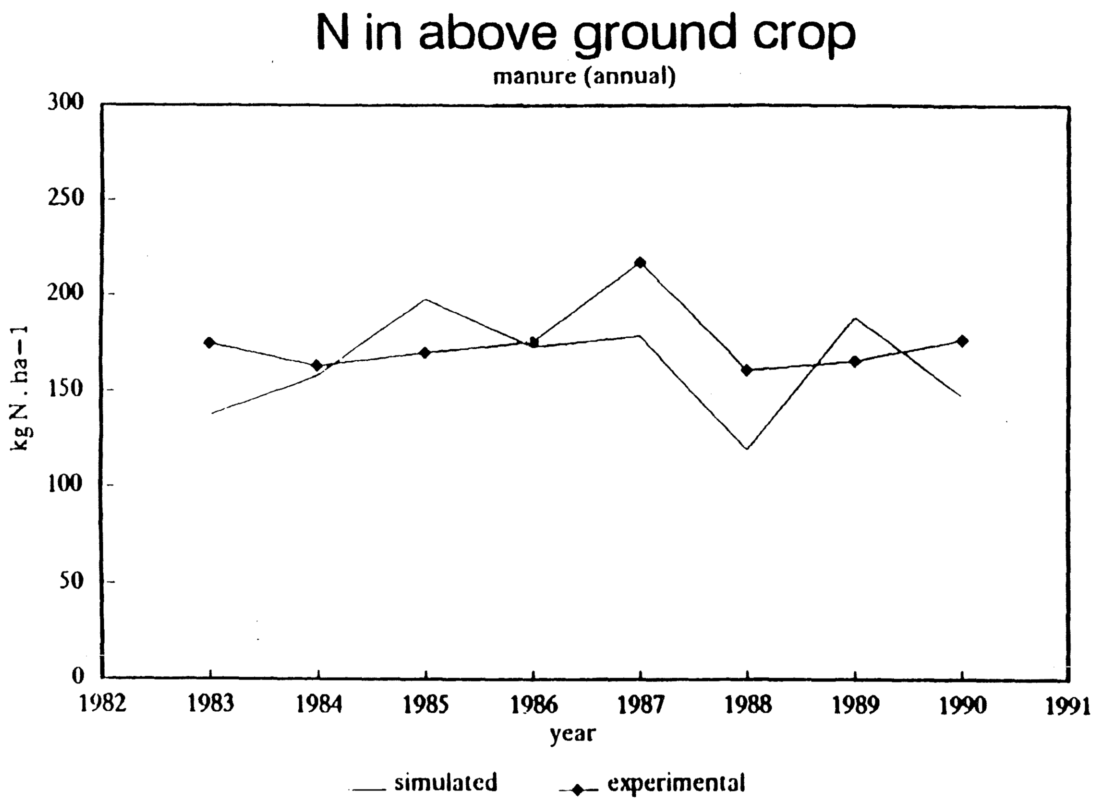

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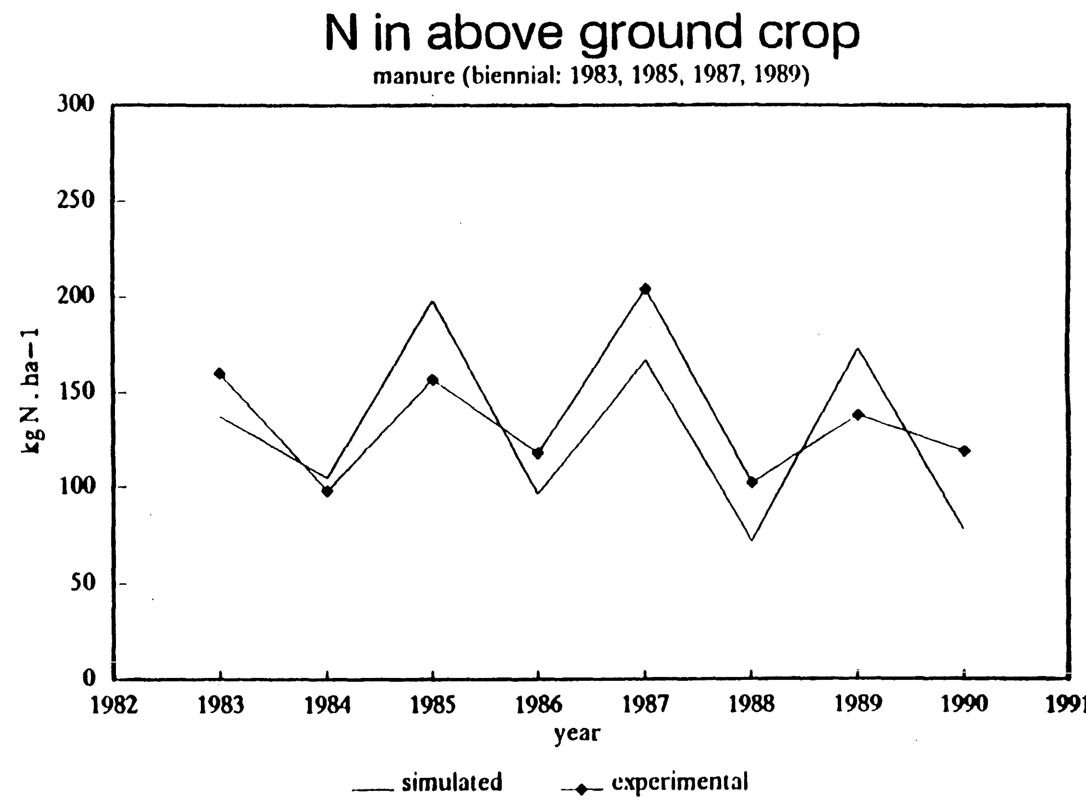

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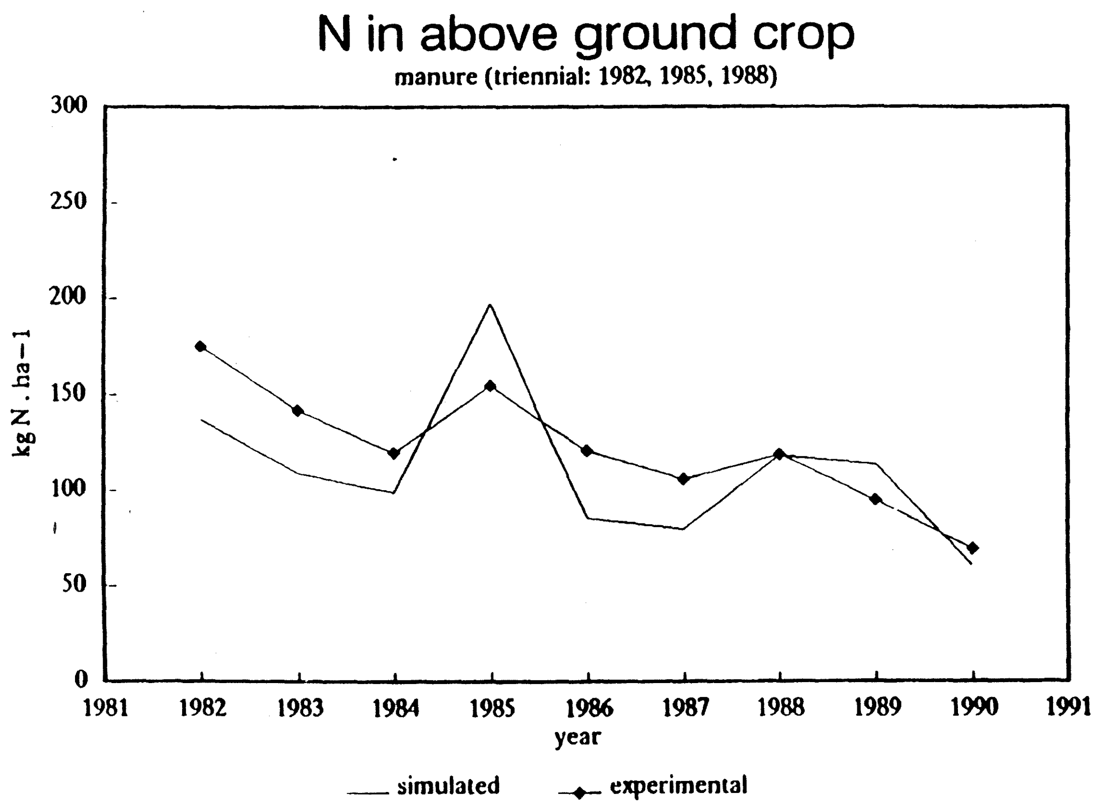

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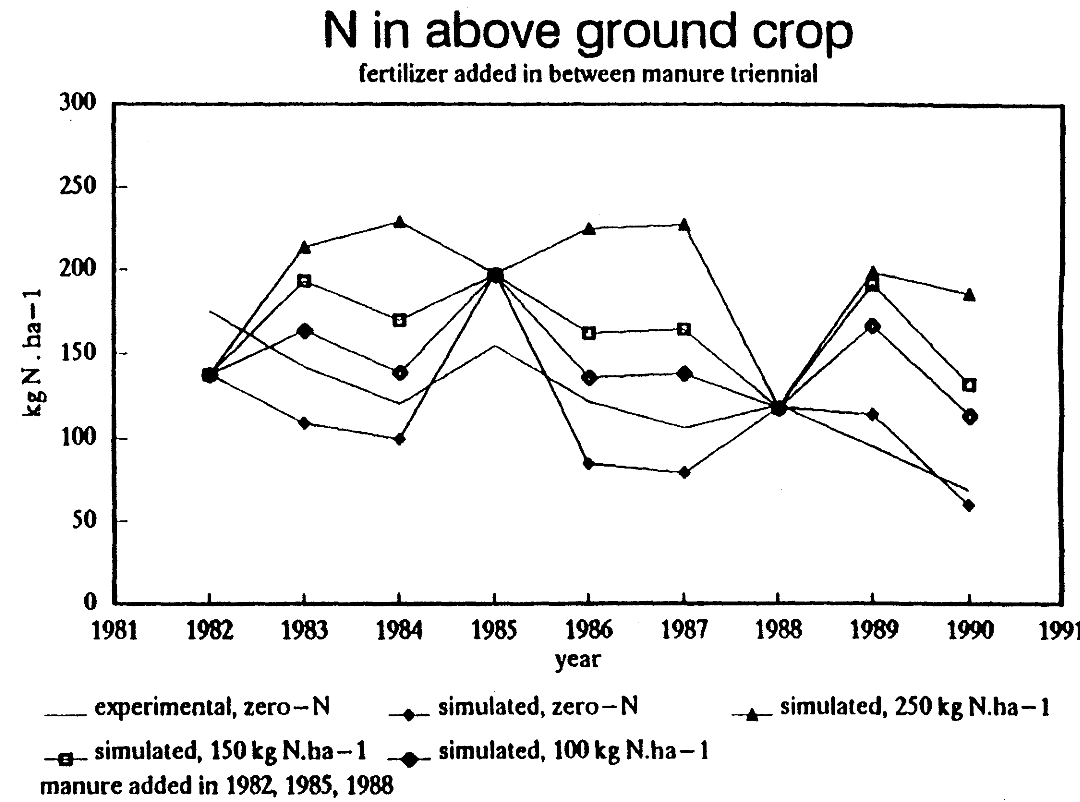

Figure 6

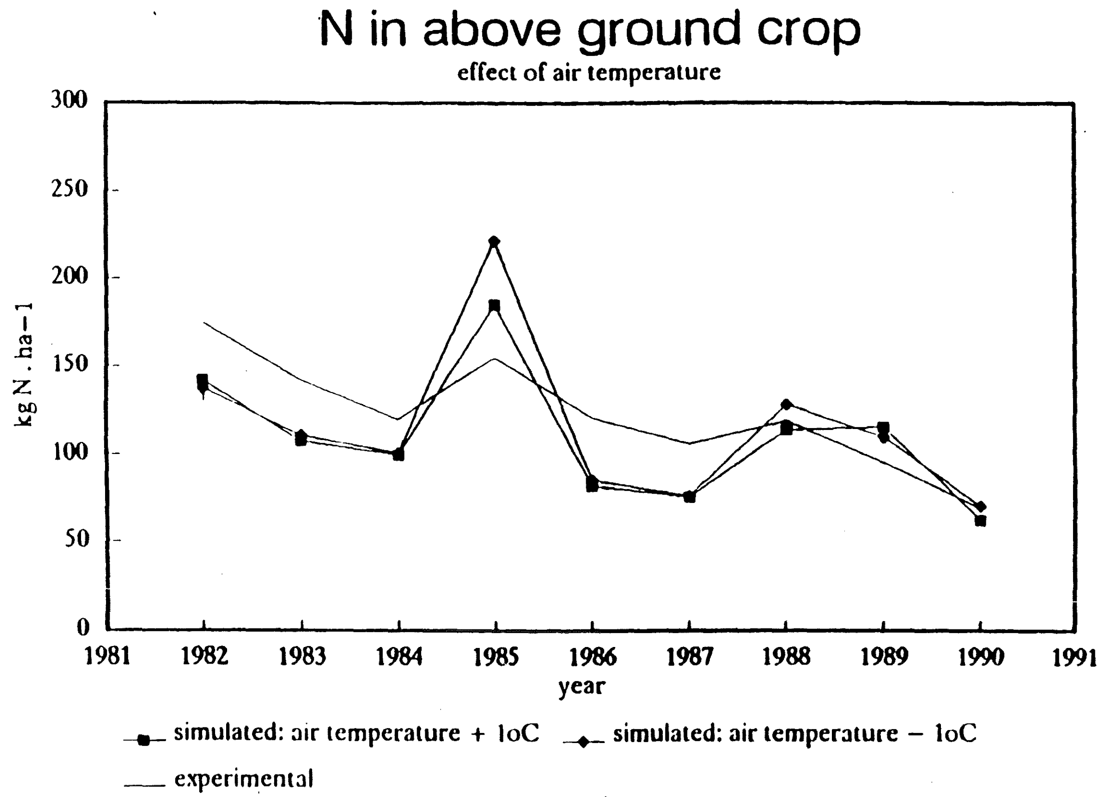

Figure 7

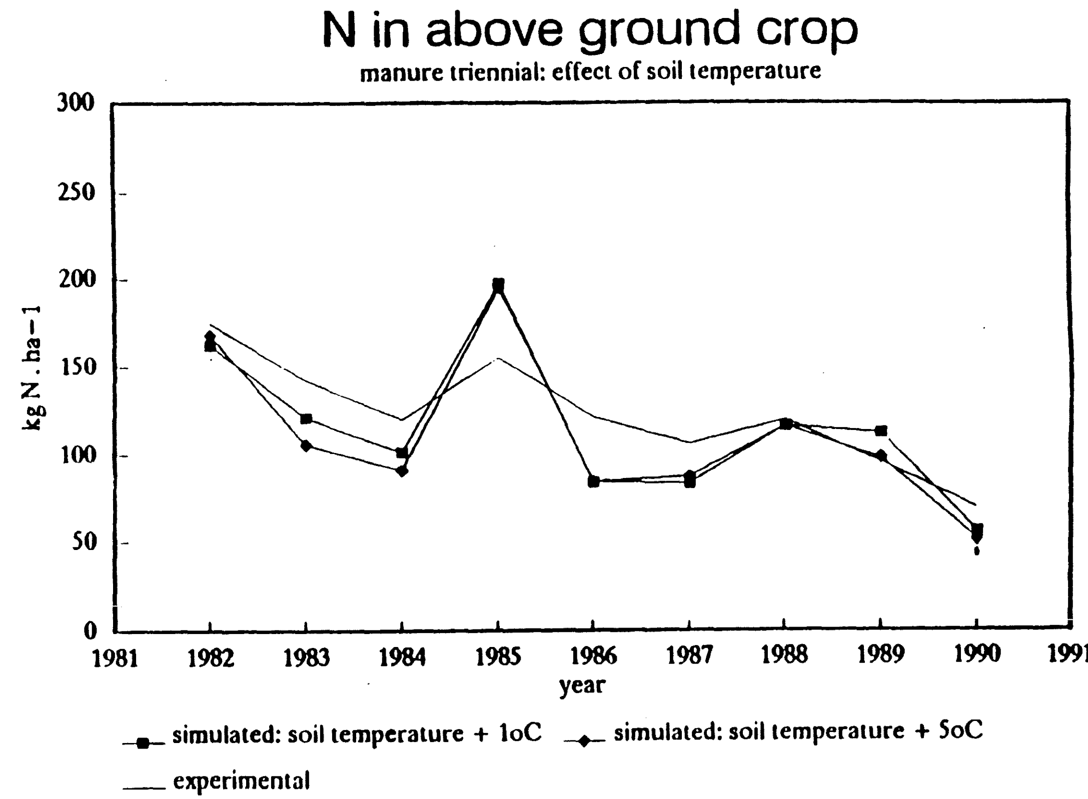

Figure 8

B. Title of Objective: Determine the influence of landscape, soil type, and climate on nitrogen release from organic sources such as manure and soil organic matter.

B.1. Activity: Field experiments to assess slope aspect, soil, and weather impacts on nitrogen release from organic sources.

B.1.a. Context: Variable soil slopes and climatic conditions in the Karst topography of South East Minnesota can affect nitrogen release from organic sources and uptake by plants by causing differences in soil temperature and moisture. Aspect effects on microclimate may also influence yield goals due to differences in growing degree days. Soil and climatic measurements on different aspects will be used to validate a predictive model of soil temperature and moisture, and statistically relate aspect effects to plant available N and yield goals. Results will be used to develop probability distributions for N availability and yield goals based on aspect and weather.

B.1.b. Methods: Field plots will be laid out on contour strips of north and south facing slopes on either side of a ridge. Treatments will consist of two aspects (north versus south) x three N sources (dairy manure applied in the fall, anhydrous ammonia applied in the spring, versus control) x tillage treatments outlined in Objective D. Soil temperatures and moisture will be measured at the 1, 15, 30, and 60 cm depths using heat dissipation sensors. Microclimate (air temperature, relative humidity, radiation, rainfall, and wind speed) will be recorded by data logger monitoring stations on each aspect. Soil NO_3-N and NH_4-N will be measured in 1 ft increments to depths of 5 ft (pre-plant and pre-sidedress) supplemented with biweekly measurements to a depth of 2 ft. Plant N uptake will measured biweekly up to sidedress N application. Measured changes in soil N and plant N uptake will be used to estimate nitrogen availability. Three rates of sidedress N (0, 20, 40 lb N/acre) will be applied to plots to determine optimum sidedress N rates for the year on each treatment.

Time series analysis (cf. Krupa and Nosal, 1989) and process-oriented simulation models (Campbell, 1985) will be used to relate N ~~mineralization~~ plant available N and microclimate to optimum sidedress N applications. The process-oriented model will first be calibrated on data from eight years of manure treatment on plots of different aspects (Joshi, 1992). Results from these analyses will be used to generate qualitative and/or quantitative schemes for utilizing weather to determine optimum sidedress N applications on plots of differing aspects.

B.1.c. Materials: Field sensors, sensor monitoring equipment, and computer support will be needed to carry out this objective. Investigators will provide computer equipment for the project.

B.1.d. Budget: $60,000 Balance $0

B.1.e. Timeline:	7/93 1/94 6/94 1/95 6/95
Establish treatments	xxxx
Collect data	xxx xxxxxxxx xxxxxxxx
Prepare annual summary	xxxx
Soil modelling	xxxxxxxxxxxxxx
Time series analysis	xxxxxx xxxxxx
Prepare final report	xxxx

B.1.f Final Detailed Reports

B.1.1. Field measurements

The 1994 growing season was favorable for crop growth. Soil temperatures quickly rose to near 22°C at 15 cm and to near 19°C at 60 cm depth during mid-June after a brief period of cool weather in early June (Fig. B.1.1). The North-facing slope was very wet, almost saturated, throughout the growing season (Fig. B.1.2). Soil matric suction was near one-tenth of a bar throughout the vegetative growth stage. By contrast, the South aspect was initially drier than the North aspect and had soil moisture conditions favorable to growth (between 0.6 and 1.0 bar suction) throughout the vegetative growth stage.

These wet, cool conditions on the North aspect contributed to poorer growth. This was exhibited early on in the growing season. Corn development on the North aspect lagged behind development on the South aspect (Fig. B.1.3). Leaf stage on the North aspect was always about half a leaf behind corn development on the South aspect.

Paired t-tests were conducted to determine the effects of slope aspect and fertilizer source on grain yield and plant available nitrogen (PAN). PAN was significantly greater on the North aspect (p-value = 0.08). Season average plant available nitrogen was 12 ppm on the North slope and 10 ppm on the South slope (Fig. B.1.4). Ammonium contributed very little to plant available nitrogen (Fig. B.1.5) indicating that soil testing for nitrate alone is sufficient to characterize PAN.

Figure B.1.6 shows the effect of nitrogen treatment (manure, ammonium nitrate fertilzer, and control) on PAN. PAN in the control treatment was significantly lower than manure and fertilizer treatments. However, there was no statistically significant difference between manure and fertilizer (p-value = 0.78) when both aspects were pooled even though the fertilizer treatment was slightly higher.

The overall grain yield on the South aspect was 12 bu/ac higher than that on the North aspect (Fig. B.1.7). The higher yields on the South aspect were associated with greater growth and development and higher plant N uptake. This was reflected in the lower residual plant available N in the soil prior to tasseling on the South aspect (Fig. B.1.8).

The N treatment effect on grain yield exhibited the same pattern as its effect on PAN. As with PAN, yield on the control plots were significantly lower than manure or fertilizer treatments. Yields within a treatment were consistently higher on the South aspect. Yields among N treatments on both aspects and the manure treatment on the South aspect were not significantly different. The yield depression on the North aspect was much less for the Fertilizer treatment than for Control or Manure treatments. Since all nitrogen in the Fertilizer treatment was available when applied, this indicates that nitrogen mineralization from soil organic matter and manure was less on the North aspect.

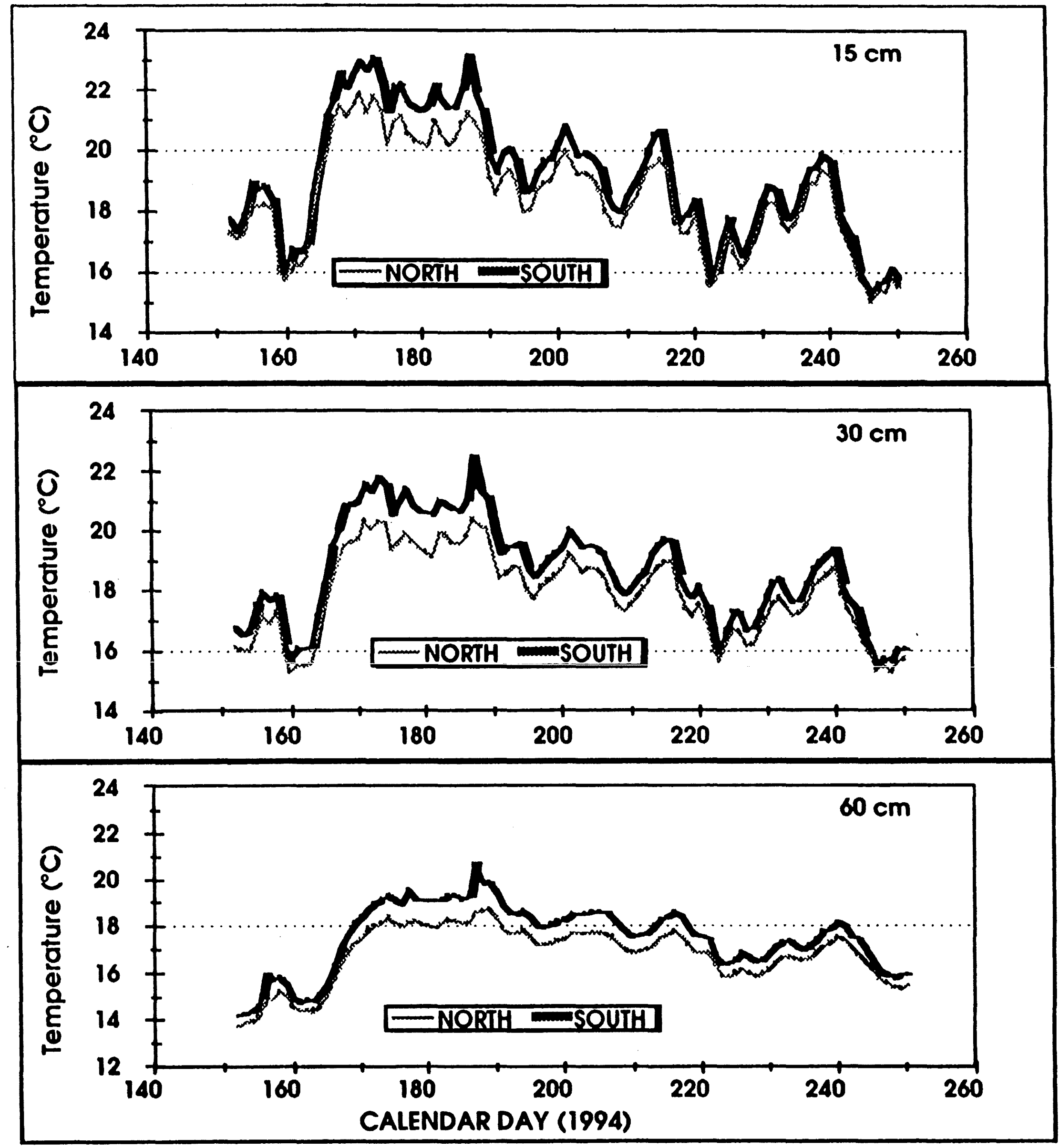

Fig. B.1.1. Soil temperatures at 15, 30, and 60 cm for the North- and South-facing aspects.

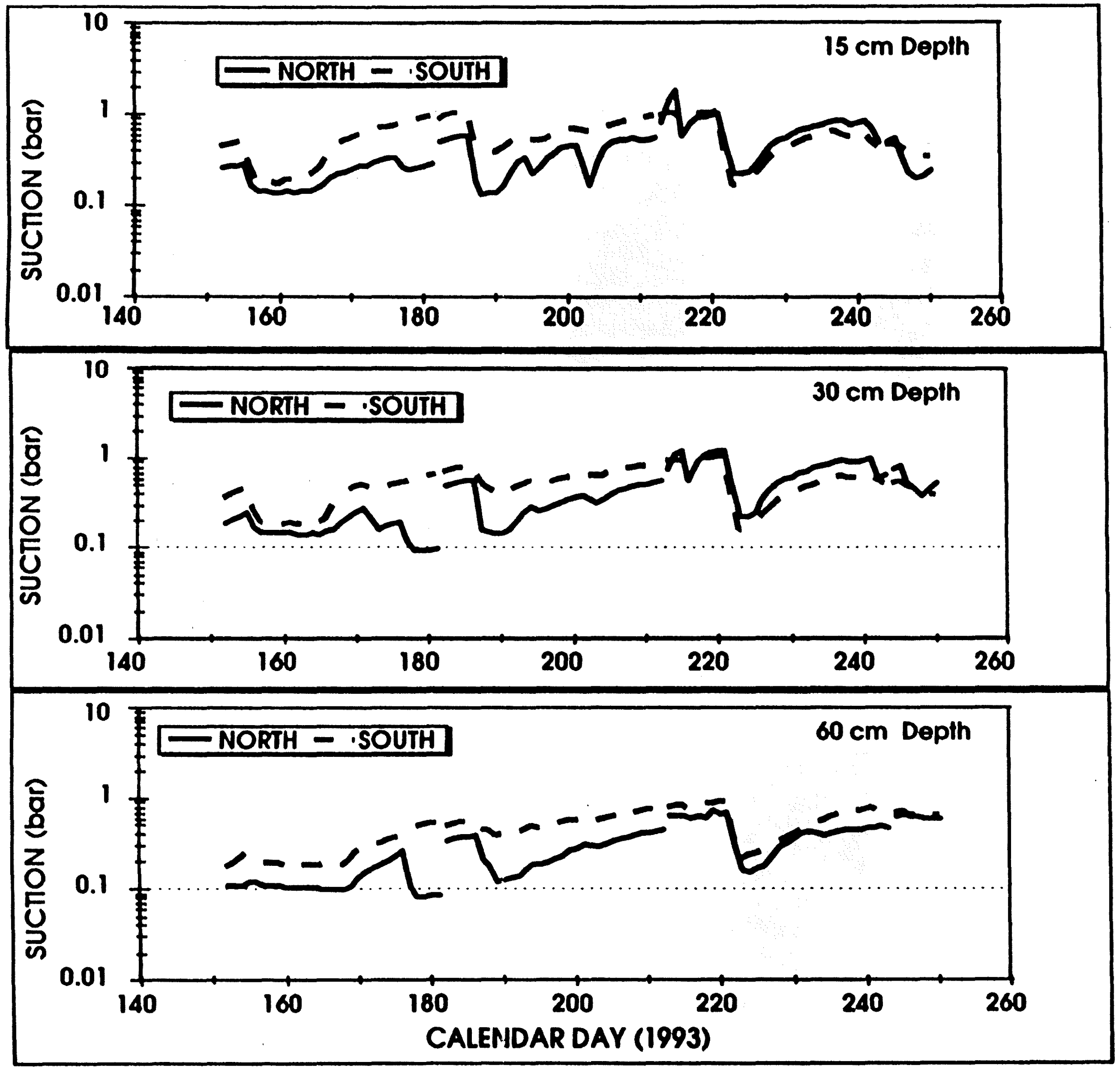

Fig. B.1.2. Soil matric suction at 15, 30, and 60 cm for the North- and South-facing aspects.

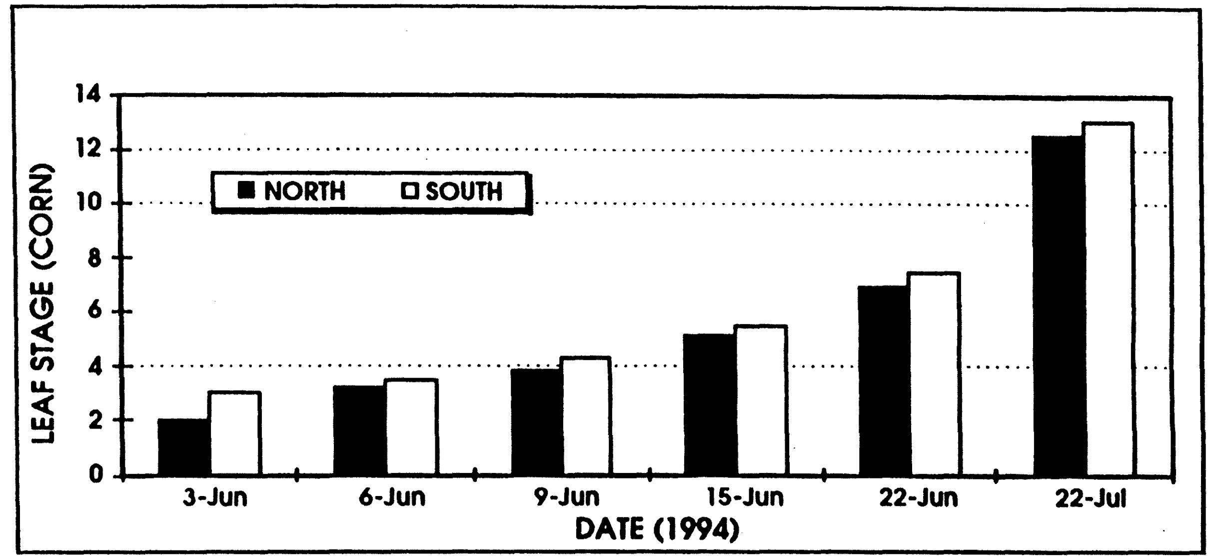

Fig. B.1.3. Corn leaf development given by leaf stage on the North- and South-facing aspects.

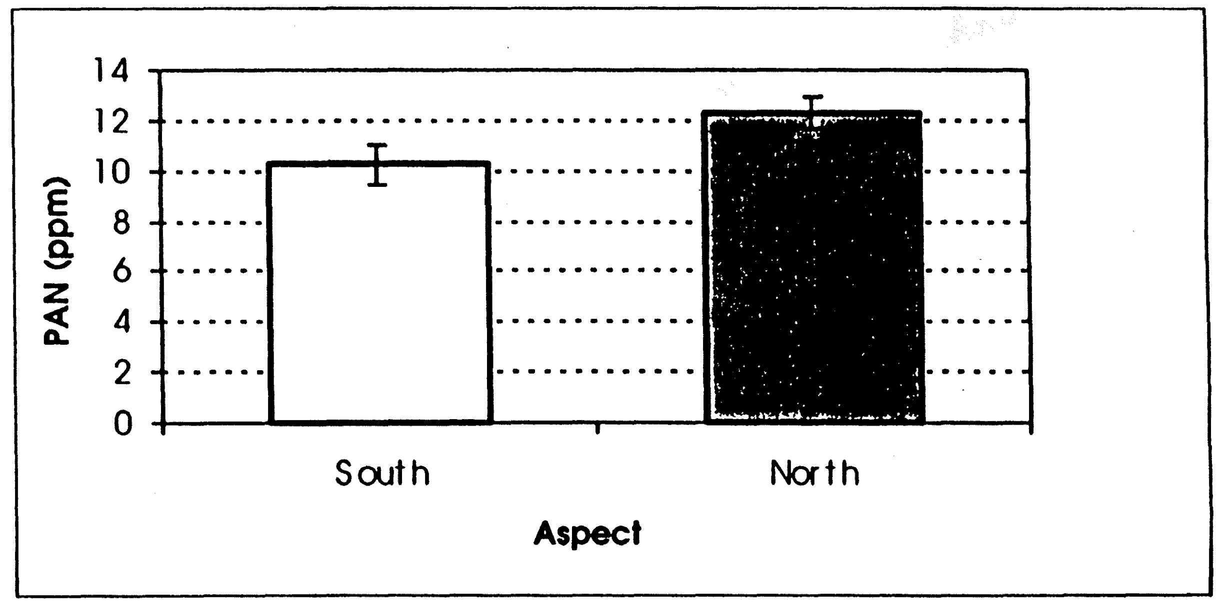

Fig. B.1.4. Effect of slope aspect on plant available nitrogen.

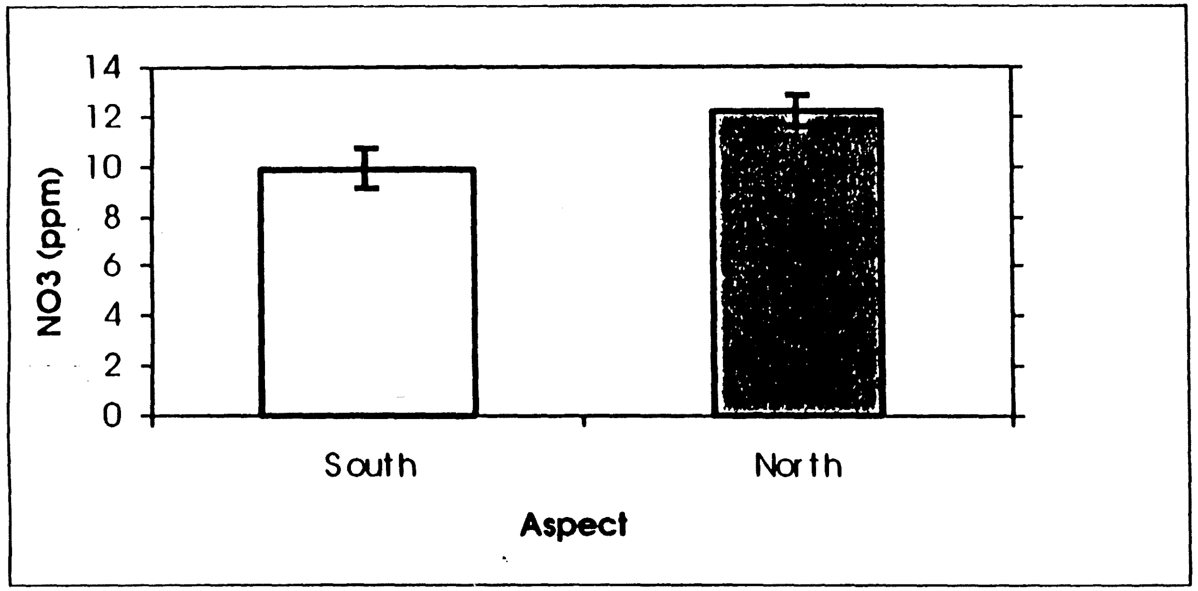

Fig. B.1.5. Effect of slope aspect on soil nitrate.

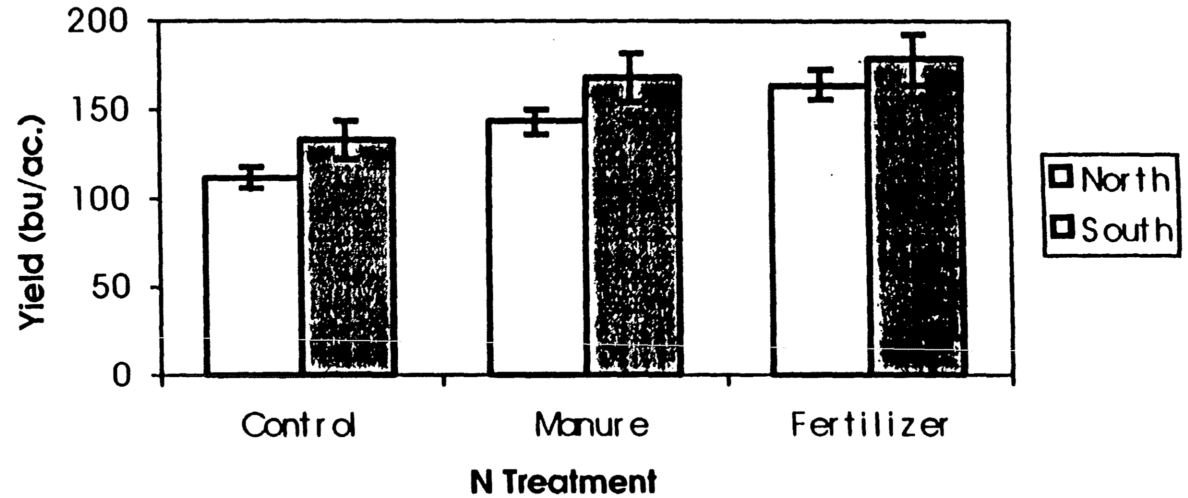

Fig. B.1.7. Aspect and N treatment effects on grain yield.

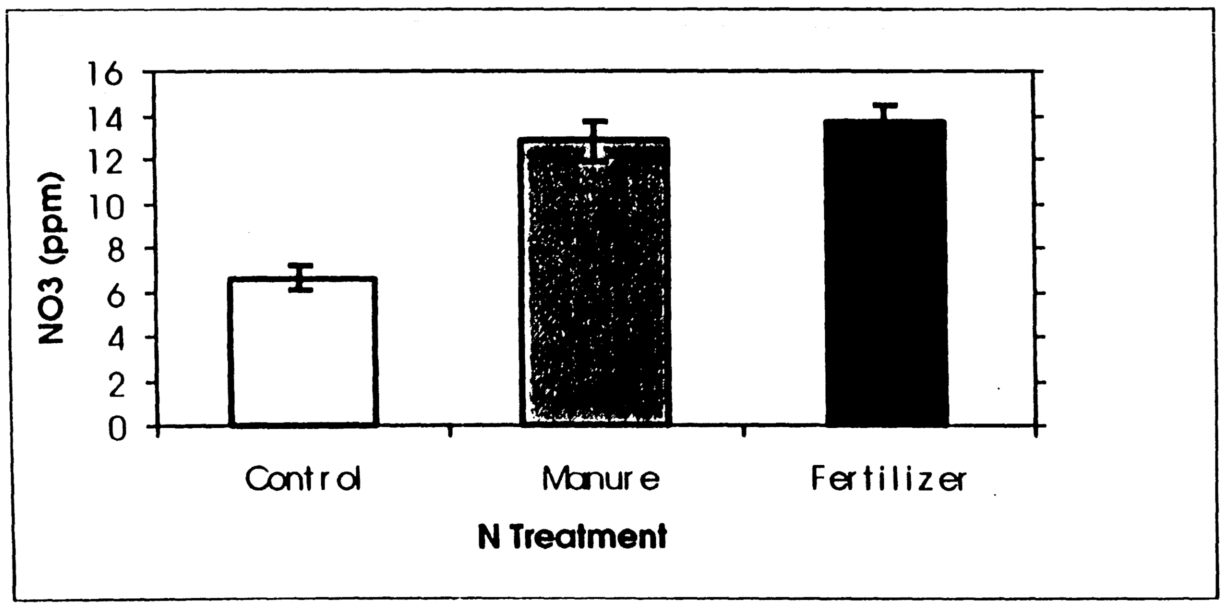

Fig. B.1.6. ct of N treatment on plant available nitra 'aspect effect is pooled).

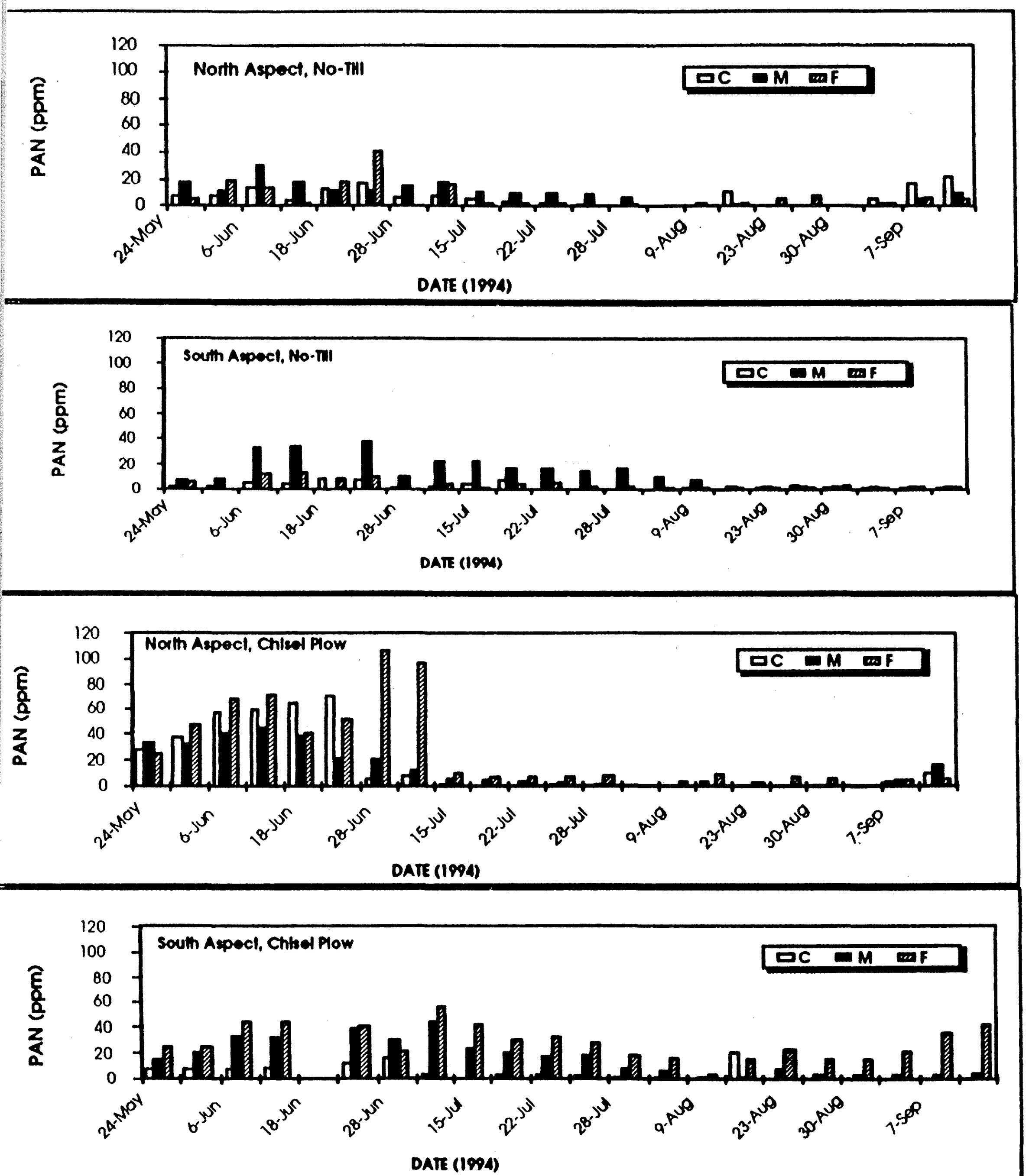

Fig. B.1.8. Time series of PAN in 1994 according to aspect, N treatment, and tillage.

B.1.2. Soil modeling and time series analysis

Based on the microclimate, topographic and experimental data, two models were developed. One is a multiple regression model. Another is a neural network model. Nitrogen availability can be predicted by these models. We found that the sum of growing degree days, temperature at the depth of 60 cm, moisture in 60 cm depth, aspect, and fertilizer treatment were good predictors of plant available nitrogen.

Multiple linear regression analysis was conducted to predict PAN. Step-wise regression analysis method was employed. We found that PAN could be predicted by the following equation:

$$PAN = 53 - 0.026 \times GDD - 17 \times T_{60} + 0.96 \times M_{60} - 14 \times T_{15}, \quad R^2 = 0.87 \qquad [B.2.1]$$

where *GDD* represents the cumulative growing degree days (base 10°C), T_{60} represents soil temperature at the 60 cm depth, M_{60} represents soil matric suction (bars) at the 60 cm depth, and T_{15} represents soil temperature at the 15 cm depth. The standard errors and p-values associated with the coefficients in Eq. [B.2.1] are shown in Table B.2.1.

Although the coefficients for variables used in the regression model were highly significant, the coefficients for cumulative growing degree days and soil temperature had the lowest standard errors. We found that soil temperature and moisture at the 60 cm depth were more important in predicting PAN than corresponding measurements at 15 or 30 cm. However, we do not think that this is evidence that most of the N mineralization is occurring at the 60 cm depth. Rather, we suspect that the transport of PAN to 60 cm is correlated with the transport of heat and moisture from the surface. Therefore, N mineralization near the surface is probably highly correlated with temperature and moisture near the surface, but the appearance of PAN at depth is correlated with the time lag associated with heat and moisture transport from the surface.

In addition to the multiple linear regression model, we also analyzed the availability of nitrogen using a neural network model. Neural networks represent a relatively new modeling technique, therefore a brief review follows.

A neural network model mimics the brain's own problem solving process. Just as humans apply knowledge gained from past experience to new problems or situations, a neural network takes previously solved examples to build a system of "neurons' which makes new decisions, classifications, and predictions. A neural network will look for patterns in training sets of data, then learn these patterns and develop the ability to correctly classify patterns or to make predictions. The basic building block of neural network technology is the simulated neuron. Independent neurons are of little use unless they are interconnected in a network of neurons. The network processes a number of INPUTS from the outside world to produce an OUTPUT, the network's prediction. The neurons are connected by WEIGHTS, which are applied to values passed from one neuron to the next. A group of neurons is called A SLAB. Neurons are also grouped into LAYERS by their connections to the INPUT layer. If a neuron contains a prediction, it is an OUTPUT layer. The neural network "learns" by adjusting the interconnection weights between layers. The answers that the network produces are repeatedly compared with the correct answers, and each time the connecting weights are adjusted slightly in the direction of the correct answers.

Figure B.2.1 shows a three layer neural network structure which was used in this study. Nine variables: soil temperature (15cm, 30 cm, 60 cm depths), soil matric suction (15cm, 30cm, 60cm depths), cumulative growing degree days (base 10°C), aspect, and N treatment (Control, Manure, Fertilizer) were used as predictors. Figure B.2.2 shows the Input Strength of those variables for predicting PAN. The order of the strength (i.e. the order of the effects of those variables) is: GDD > T60 > M60 > T15 > Aspect > Treatment > Others. Various measures of goodness of fit for neural network models for predicting PAN are shown in Table B.2.2.

The low R^2 for predicting ammonium is due to its small value relative to nitrate. Both PAN and nitrate alone were well predicted using the neural network approach, and are much better than the regression model. Comparison between predicted total nitrogen by the neural network model and measured total nitrogen illustrates how well the neural network model fits the measured data (Fig. B.2.3).

Slope aspect affects plant available nitrogen and grain yield through its effect on microclimatic factors such as air temperature, soil temperature, moisture, cumulative growing degree days, and solar radiation. We found that GDD, T60 and M60 are the best predictors of PAN based upon results from both the neural network and multiple regression analysis.

Nitrogen treatment also affects PAN and has a significant effect on grain yield. However, grain yield is not significantly different between Manure and Fertilizer treatments on slopes with a southern aspect. The same trend was also observed for PAN.

Comparing the neural network model and multiple regression model, the neural network yields better predictions of PAN. The strength of the variables used in both models are about the same. Thus, the best indicators in neural network model were also the best predictors in the regression model. A drawback of the neural network model is that the rules governing the model response cannot be extracted from the computer code. The neural network remains a 'black box' which limits its portability. In contrast, the regression model can easily be described by an equation although it does not predict the data as well as the neural network.

Both models indicated that temperature and moisture at the 60 cm depth are good predictors. The exact reasons for this are not clear since we expect most mineralization to occur nearer the surface. We propose that N mineralization near the surface is probably highly correlated with temperature and moisture near the surface, but the appearance of PAN at depth is correlated with the time lag associated with heat and moisture transport from the surface.

Table B.2.1. Coefficients and associated standard errors from multiple regression model for NO3.

	intercept	GDD	T60	M60	T15
Coefficient	51.1	-0.0251	-16.78	1.02	-13.5
Std. Err of b	18.3	0.0055	4.09	1.05	5.71
p-value	0.006	0.000017	0.00086	0.002	0.065

Table B.2.2. Various measures of goodness of fit for neural network models for predicting PAN.

	Total N	NH4	NO3
R^2	0.934	0.509	0.932
Mean Square Error (ppm)	9.181	0.041	9.310
Mean Abs. Error (ppm)	1.622	0.129	1.604
Max. Abs. Error (ppm)	13.03	0.801	13.25

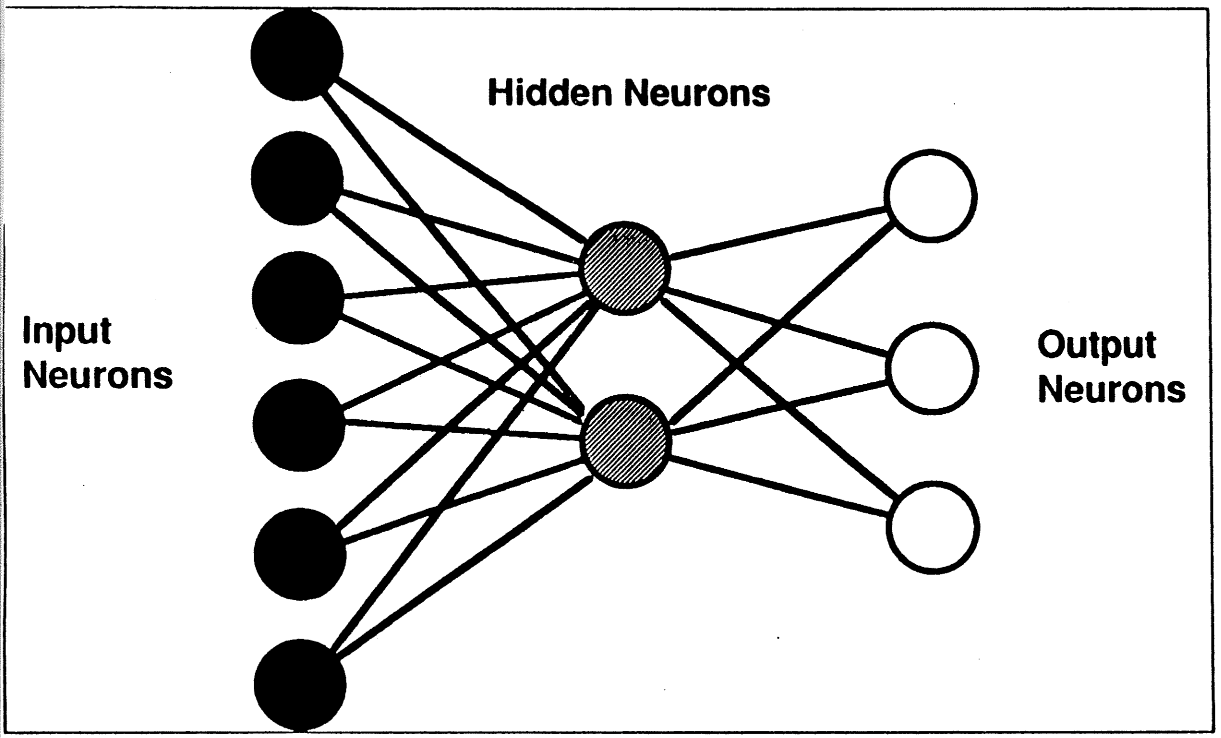

Fig. B.2.1. Schematic of a three-layer neural network model.

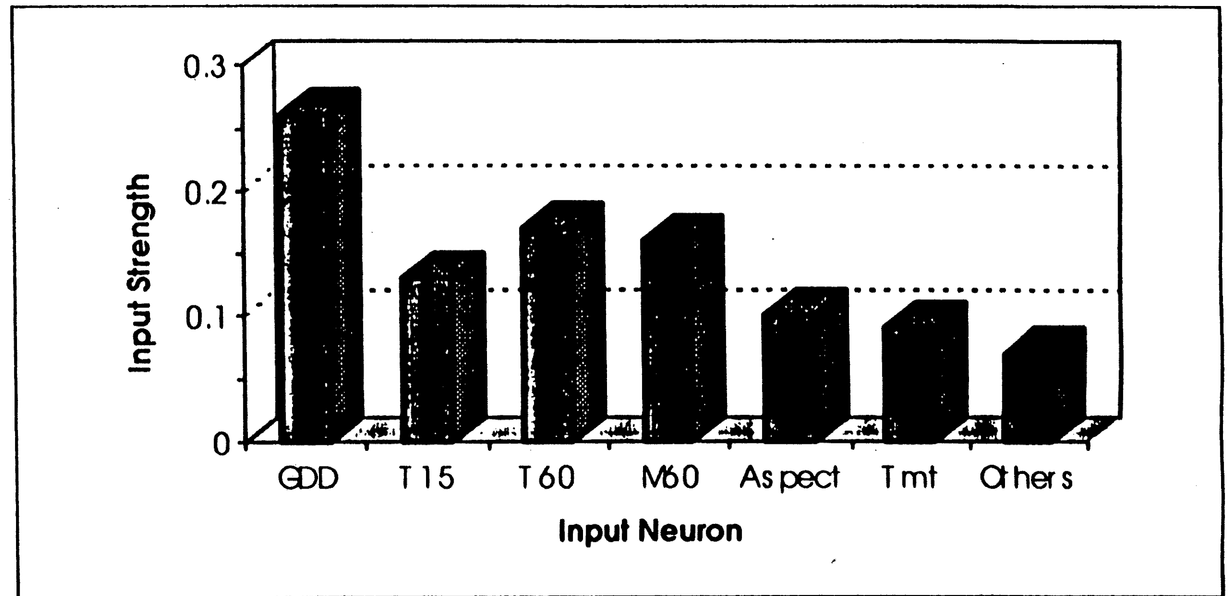

Fig. B.2.2. Comparison of strength among various input neurons for predicting PAN.

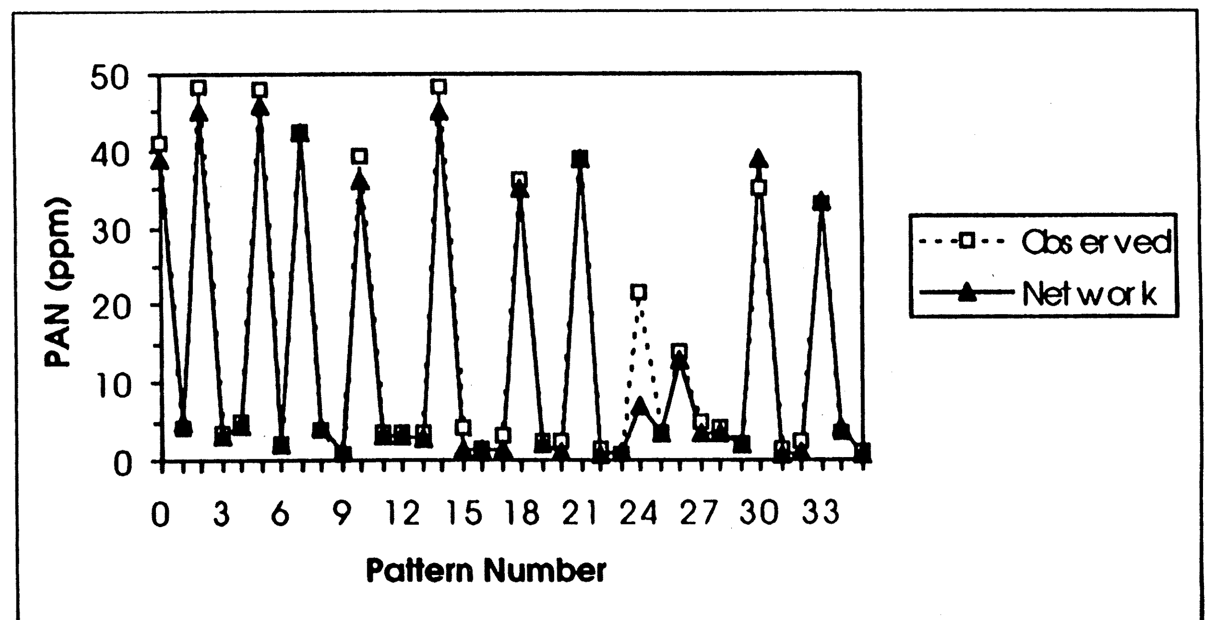

Fig. B.2.3. Comparison of measured total nitrogen and values predicted by neural network model.

Table B.2.1. Coefficients and associated standard errors from multiple regression model for NO3.

	intercept	GDD	T60	M60	T15
Coefficient	51.1	-0.0251	-16.78	1.02	-13.5
Std. Err of b	18.3	0.0055	4.09	1.05	5.71
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B.1.3 Time Series and Probability Analyses

Introduction: Since the Karst region encompasses much of southeastern Minnesota, climate stations with continuous long term records were sought for temporal and spatial analysis of parameters related to nitrogen mineralization and uptake. Locations selected included Zumbrota (nearest the Nord farm in Goodhue County), Theilman, Winona, Caledonia, and Rosemount (Agricultural Experiment Station).

Climatic parameters significantly related to observed mineralization rates at the Nord farm included soil temperature, soil moisture and growing degree days. The temporal distribution of these parameters and associated climatic measurements such as maximum and minimum air temperatures, precipitation, and length of frost-free growing season were examined using the Minnesota state climatic data base available from the DNR State Climatology Office. The only station with a significant recording period for soil temperatures was the Rosemount Agricultural Experiment Station, where the Waukegan silt loam soil series is similar to the Seaton silt loam soil series at the Nord farm. The temporal characteristics of this soil temperature record were examined.

A time series of soil moisture measurements in southeastern Minnesota was not available. A number of computer models for estimating soil moisture values from standard climatic data were considered. A soil moisture submodel taken from the CERES-Maize model of corn growth and development published by Jones and Kiniry (1986) was selected and used to estimate daily soil moisture values from the Zumbrota historical climatic records (1932-1994) in order to derive the temporal distribution characteristics for the relevant layer of soil where the majority of mineralization occurs (top one foot). The model was run using the water holding characteristics for a Seaton silt loam (the soil series at the Nord farm), and one of the soil series prevalent in the topography of southeastern counties. This soil is capable of holding 2.88 inches of available moisture in the top foot. The temporal distribution of soil moisture derived from this model for the period from April through October was also examined.

Results: Tables B.1.3.5 through B.1.3.9 summarize the climatological variables of the five southeastern Minnesota locations. The median length of the frost free growing season ranges from 136 days at Theilman, along the Zumbro River Valley in Wabasha County to 163 days at Winona, along the Mississippi River Valley in Winona County. Theilman and Zumbrota have had spring frost as late as June 11, while the other locations latest spring frost dates are either the 29th or 30th of May. Earliest fall frost dates are the first few days of September at Theilman, Zumbrota and Rosemount, while the earliest date at Winona and Caledonia is September 12th.

These spatial differences across the region illustrate the microclimatological effects of landscape position and the Mississippi River. The climate around Winona, though relatively low in the landscape is modified to a great extent by Mississippi River Basin. The combined effects of higher water vapor and the thermal radiation released by the river overnight tend to moderate temperatures in the Winona area producing a much longer frost free season than other regions of the state. On the other hand, the relatively low position of Theilman at 737 ft elevation in the Zumbro River Valley allows for cold air drainage overnight, producing a higher frequency of frosts in the spring and fall.

The temporal variability or year to year variability can be significant as well. The shortest observed frost free season at Zumbrota has been 104 days while the longest has been 173 days with a median value of 139 days.

Figure B.1.3.10

ROSEMOUNT, MN 1985 - 1993
4" SOIL TEMPERATURE DATA

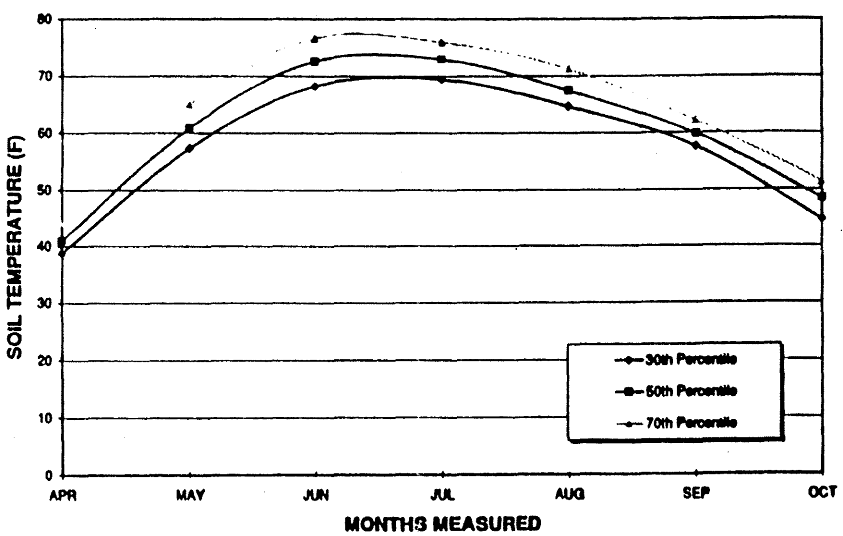


Figure B.1.3.11

ROSEMOUNT, MN 1985 - 1993
8" SOIL TEMPERATURE DATA

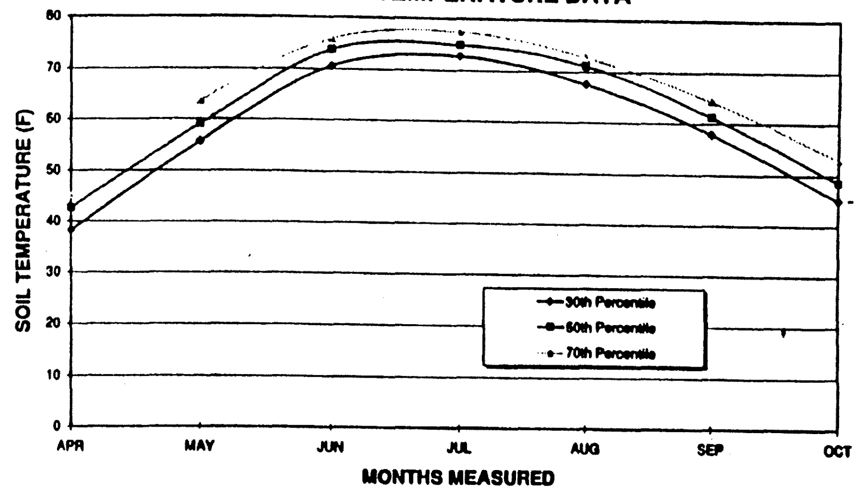


Figure B.1.3.12

Zumbrota, MN 1932 - 1994
0 - 12 Inch Depth; Seaton Soil Series
Soil Moisture Data

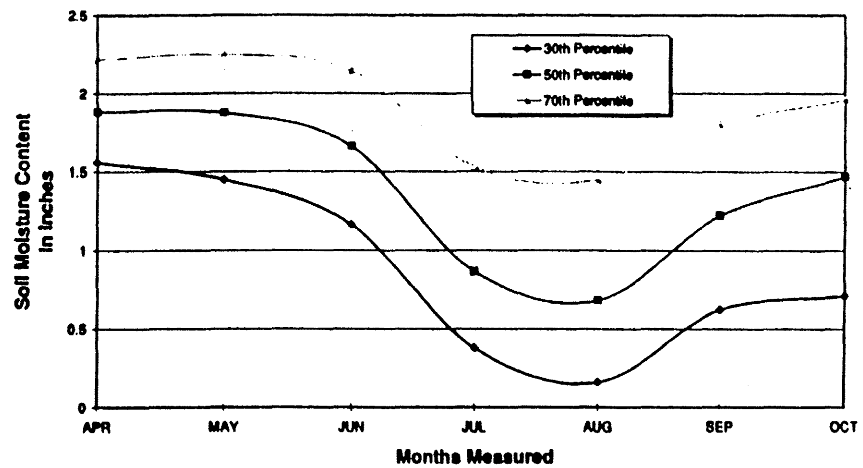


Table B.1.3.5. Growing Season Summary for Theilman, MN:
Elevation: 737 ft County: Wabasha Years: 1962 to 1994

Base	Date of Last Spring Occurrence					Date of First Fall Occurrence				
Temp	Median	Early	90%	10%	Late	Median	Early	10%	90%	Late
32	5/17	4/16	4/30	5/31	6/11	9/25	9/03	9/13	10/07	10/12
30	5/08	4/09	4/21	5/29	6/01	9/30	9/18	9/22	10/09	10/28
28	5/03	4/06	4/08	5/22	5/29	10/04	9/18	9/23	10/28	12/02
24	4/12	3/18	4/02	5/03	5/27	10/19	9/21	9/28	11/10	12/03
20	4/08	3/18	3/23	4/24	5/09	10/31	10/01	10/10	11/16	12/05
16	4/01	3/06	3/13	4/11	4/20	11/11	10/01	10/22	11/29	12/06

Base	Length of Season (Days)				
Temp	Median	Shortest	10%	90%	Longest
32	136	105	112	153	162
30	147	118	120	164	172
28	160	121	129	188	225
24	188	141	157	219	227
20	206	167	170	233	246
16	225	177	202	254	260

Table B.1.3.6. Growing Season Summary for Zumbrota,MN:
Elevation: 985 ft County: Goodhue Years: 1948 to 1994

Base	Date of Last Spring Occurrence					Date of First Fall Occurrence				
Temp	Median	Early	90%	10%	Late	Median	Early	10%	90%	Late
32	5/11	4/11	4/24	5/26	6/11	9/26	9/01	9/18	10/05	10/28
30	5/07	4/09	4/24	5/20	5/29	9/28	9/03	9/20	10/10	10/28
28	4/29	4/05	4/16	5/15	5/29	10/03	9/11	9/23	10/19	10/28
24	4/16	3/28	4/05	5/05	5/10	10/18	9/22	10/02	11/02	11/12
20	4/06	3/21	3/26	4/19	5/02	10/31	10/02	10/12	11/13	11/22
16	3/26	2/26	3/13	4/09	5/01	11/09	10/02	10/26	11/25	11/30

Base	Length of Season (Days)				
Temp	Median	Shortest	10%	90%	Longest
32	139	104	119	157	173
30	148	119	128	159	177
28	157	131	139	178	190
24	188	139	160	198	225
20	205	177	189	225	241
16	229	189	202	250	256

Table B.1.3.7. Growing Season Summary for Rosemount,MN:
Elevation: 950 ft County: Dakota Years: 1951 to 1994

Base	Date of Last Spring Occurrence					Date of First Fall Occurrence				
Temp	Median	Early	90%	10%	Late	Median	Early	10%	90%	Late
32	5/09	4/08	4/22	5/20	5/29	9/28	9/02	9/15	10/08	10/15
30	5/04	4/08	4/16	5/15	5/29	10/03	9/12	9/21	10/16	10/29
28	4/29	4/04	4/11	5/10	5/23	10/10	9/21	9/28	10/24	11/04
24	4/13	3/22	3/31	5/01	5/13	10/24	9/21	10/06	11/10	11/15
20	4/06	3/18	3/24	4/19	5/03	11/03	10/01	10/19	11/15	11/23
16	3/28	3/06	3/16	4/13	4/18	11/08	10/06	10/26	11/23	11/29

Base	Length of Season (Days)				
Temp	Median	Shortest	10%	90%	Longest
32	146	113	122	161	181
30	153	113	127	176	191
28	161	139	147	188	198
24	194	148	168	213	223
20	209	177	187	228	235
16	229	191	200	246	265

Table B.1.3.8. Growing Season Summary for Winona,MN:
Elevation: 652 ft County: Winona Years: 1948 to 1994

Base	Date of Last Spring Occurrence					Date of First Fall Occurrence				
Temp	Median	Early	90%	10%	Late	Median	Early	10%	90%	Late
32	4/28	3/30	4/09	5/13	5/30	10/06	9/12	9/22	10/25	11/04
30	4/23	3/29	4/07	5/06	5/15	10/15	9/12	9/30	10/30	11/04
28	4/17	3/27	4/01	5/04	5/11	10/19	9/22	10/03	11/02	11/04
24	4/07	3/21	3/25	4/19	5/02	10/31	10/02	10/17	11/10	11/16
20	3/29	3/07	3/17	4/13	5/01	11/09	10/02	10/26	11/24	12/04
16	3/23	2/23	3/07	4/07	4/14	11/18	10/17	11/02	12/06	12/17

Base	Length of Season (Days)				
Temp	Median	Shortest	10%	90%	Longest
32	163	124	141	183	190
30	176	138	152	191	209
28	186	139	167	204	211
24	205	161	188	222	224
20	221	183	200	245	255
16	240	194	218	266	282

Table B.1.3.9. Growing Season Summary for Caledonia,MN:
Elevation: 1175 ft County: Houston Years: 1959 to 1994

Base	Date of Last Spring Occurrence					Date of First Fall Occurrence				
Temp	Median	Early	90%	10%	Late	Median	Early	10%	90%	Late
32	5/06	4/13	4/20	5/26	5/30	9/30	9/12	9/20	10/14	10/20
30	5/04	4/10	4/11	5/22	5/29	10/06	9/13	9/21	10/19	10/31
28	4/23	4/05	4/08	5/14	5/29	10/11	9/13	9/28	11/01	11/04
24	4/14	3/31	4/04	5/01	5/09	10/27	9/21	10/10	11/12	11/15
20	4/07	3/17	3/23	4/20	5/09	11/02	10/01	10/20	11/13	11/21
16	3/25	3/07	3/11	4/07	4/12	11/10	10/10	10/26	11/29	12/06

Base	Length of Season (Days)				
Temp	Median	Shortest	10%	90%	Longest
32	153	113	125	169	173
30	158	113	131	182	186
28	174	125	136	192	207
24	194	151	167	216	223
20	208	176	189	227	229
16	229	188	209	256	264

The distribution maximum and minimum air temperatures, as well as precipitation also shows a high degree of temporal variability and also spatial variability affected by landscape position. Tables B.1.3.10 through B.1.3.24 show the probability distribution of daily maximum and minimum air temperatures and monthly precipitation for the five locations.

The probability distributions show that even in March, there is a 5 percent chance of having a maximum temperature above 60 degrees F for all locations. In years without remaining soil frost in March, these maximum temperatures would likely be enough to initiate N mineralization activity in the soil. While the extreme values of maximum temperature show little range among locations, the extreme values of minimum temperature show a wider range due to landscape position, and at least in the case of Winona, due to the proximity of the Mississippi River. With respect to these spatial differences in temperature probabilities, they would be further amplified by differences in slope aspect. This degree of spatial variability suggests that site-specific management of soil and nitrogen sources based on soil type and landscape position would be important in adjusting nitrogen application timing and rates to correspond with expected mineralization and crop uptake curves.

The monthly precipitation probabilities for the five locations show that in early spring, prior to crop canopy development, there is a five percent probability of receiving precipitation in excess of 5.5 inches, with extreme values ranging from 7-9 inches for the months of April and May. Little can be done from a management standpoint to adjust manure or fertilizer applications for this level of rainfall. Reduced tillage practices can help prevent erosion from these levels of precipitation, but leaching and runoff losses of nitrogen would be significant under such scenarios. In the fall, there is a five percent probability of receiving precipitation in excess of 4-5 inches, however at this time of year, soil storage efficiency is very high and little runoff or leaching loss occurs unless individual storm rainfall intensity is quite extreme.

The majority of very heavy monthly rainfalls of 10 inches or greater occur in the summer months (June-September) for all locations. Runoff and leaching losses of nitrogen are usually tempered by the presence of full crop canopies which reduce raindrop impact and deplete rootzone storage such that soils are more capable of storing a higher proportion of the precipitation.

The probability distributions of maximum and minimum air temperatures, along with precipitation can be used as guidelines to define what range in climates can be accounted for in soil tillage and nitrogen management strategies.

Table B.1.3.10. Probabilities for Daily Maximum Temperature (F) at Theilman,MN Elevation: 737 ft Years: 1962 To 1994

Mo	Low	5%	10%	25%	50%	75%	90%	95%	High
Ja	-14	0	6	16	27	34	40	42	56
Fe	-7	10	14	22	32	39	44	46	65
Ma	5	25	28	35	41	50	58	63	83
Ap	28	40	43	50	59	68	75	80	92
Ma	40	56	59	65	72	79	85	88	94
Jn	53	68	70	75	80	86	90	92	100
Ju	60	72	76	80	84	88	92	94	103
Au	57	70	73	78	82	87	90	92	104
Se	42	58	60	66	72	79	85	87	99
Oc	32	44	47	54	61	69	75	79	88
No	10	26	30	35	42	51	59	62	75
De	-16	9	14	23	30	36	41	45	62
Period									
An	-16	18	25	38	60	78	86	89	104
Wi	-16	5	11	20	30	37	42	45	65
Sp	5	31	36	45	59	70	80	83	94
Su	53	70	73	78	82	87	91	93	104
Fa	10	32	37	47	60	71	79	83	99

Table B.1.3.11. Probabilities for Daily Minimum Temperature (F) at Theilman,MN Elevation: 737 ft Years: 1962 To 1994

Mo	Low	5%	10%	25%	50%	75%	90%	95%	High
Ja	-44	-26	-20	-10	5	16	24	28	35
Fe	-38	-20	-15	-5	10	20	29	31	43
Ma	-28	-4	5	14	22	30	35	40	56
Ap	0	19	22	28	34	40	48	52	69
Ma	18	29	32	38	45	52	59	60	71
Jn	32	40	43	49	55	60	64	67	78
Ju	39	47	50	54	60	65	68	70	77
Au	32	44	46	51	56	61	65	68	78
Se	22	32	34	40	48	55	60	64	76
Oc	7	21	24	30	36	44	51	55	70
No	-17	7	11	19	25	32	37	42	55
De	-38	-16	-10	0	12	22	28	31	50
Period									
An	-44	-9	3	20	35	52	60	64	99
Wi	-44	-22	-16	-5	10	20	27	30	50
Sp	-28	9	15	25	34	44	52	57	99
Su	32	43	46	51	57	62	66	69	78
Fa	-17	15	20	28	36	46	55	60	76

Table B.1.3.12. Probabilities for Monthly Precipitation (in) at Theilman, MN Elevation: 737 ft Years: 1948 To 1994

Mo	1%	5%	10%	25%	50%	75%	90%	95%	99%
Ja	0.04	0.11	0.18	0.36	0.69	1.18	1.78	2.22	3.21
Fe	0.00	0.00	0.12	0.28	0.55	0.94	1.41	1.75	2.50
Ma	0.21	0.42	0.59	0.97	1.57	2.38	3.30	3.95	5.37
Ap	0.51	0.89	1.17	1.77	2.65	3.78	5.04	5.91	7.78
Ma	0.86	1.33	1.65	2.29	3.18	4.28	5.46	6.25	7.93
Jn	0.83	1.39	1.79	2.63	3.84	5.37	7.06	8.21	10.68
Ju	0.77	1.38	1.82	2.77	4.18	6.01	8.05	9.45	12.48
Au	0.49	0.98	1.36	2.21	3.54	5.31	7.34	8.75	11.84
Se	0.45	0.89	1.23	2.00	3.21	4.82	6.66	7.94	10.75
Oc	0.10	0.28	0.46	0.93	1.77	3.02	4.55	5.66	8.16
No	0.00	0.00	0.33	0.77	1.47	2.45	3.61	4.44	6.29
De	0.10	0.22	0.31	0.53	0.88	1.36	1.91	2.30	3.17
Period									
An	17.71	20.84	22.65	25.93	29.92	34.30	38.60	41.32	46.77
Wi	0.63	0.98	1.22	1.69	2.36	3.19	4.07	4.67	5.94
Sp	3.71	4.72	5.33	6.46	7.91	9.55	11.21	12.29	14.49
Su	5.00	6.70	7.75	9.76	12.38	15.44	18.57	20.64	24.89
Fa	1.74	2.77	3.47	4.90	6.92	9.43	12.14	13.98	17.89

Table B.1.3.13. Probabilities for Daily Maximum Temperature (F) at Zumbrota,MN Elevation: 985 ft Years: 1948 To 1994

Mo	Low	5%	10%	25%	50%	75%	90%	95%	High
Ja	-16	0	5	15	25	33	38	41	57
Fe	-10	7	12	21	30	37	42	46	63
Ma	0	22	26	33	39	47	56	61	82
Ap	26	39	42	49	58	67	75	79	92
Ma	40	54	58	64	72	78	84	87	93
Jn	55	67	70	75	80	85	90	92	102
Ju	63	73	76	80	85	89	92	95	103
Au	60	70	73	78	82	87	91	93	103
Se	44	58	62	67	73	79	85	88	98
Oc	31	43	48	55	62	69	76	80	87
No	6	23	28	34	42	51	59	63	75
De	-15	6	12	21	30	36	41	44	62
Period									
An	-16	16	24	36	60	78	85	89	103
Wi	-16	4	10	19	28	35	41	44	63
Sp	0	29	34	43	58	70	79	83	93
Su	55	70	73	78	83	87	91	93	103
Fa	6	31	36	48	62	72	80	84	98

Table B.1.3.14. Probabilities for Daily Minimum Temperature (F) at Zumbrota,MN Elevation: 985 ft Years: 1948 To 1994

Mo	Low	5%	10%	25%	50%	75%	90%	95%	High
Ja	-45	-23	-20	-10	3	15	22	27	35
Fe	-35	-20	-15	-5	8	20	27	30	46
Ma	-36	-5	1	12	22	29	33	37	53
Ap	-1	20	23	27	33	40	46	52	66
Ma	20	30	33	38	45	52	58	61	72
Jn	32	40	43	49	55	61	65	68	81
Ju	39	47	50	54	59	65	68	71	78
Au	34	43	46	52	58	62	67	69	79
Se	21	32	35	41	48	55	61	65	76
Oc	9	22	24	30	37	44	51	55	67
No	-17	3	10	18	25	31	37	40	55
De	-40	-15	-10	0	12	21	28	30	42
Period									
An	-45	-9	1	19	35	52	61	65	81
Wi	-45	-20	-15	-5	8	19	26	29	46
Sp	-36	6	14	25	33	43	52	57	72
Su	32	43	46	52	57	63	67	70	81
Fa	-17	12	19	27	36	47	55	59	76

Table B.1.3.15. Probabilities for Monthly Precipitation (in) at
Zumbrota, MN Elevation: 985 ft Years: 1948 To 1994

Mo	1%	5%	10%	25%	50%	75%	90%	95%	99%
Ja	0.04	0.12	0.19	0.36	0.67	1.12	1.67	2.06	2.94
Fe	0.00	0.00	0.08	0.26	0.54	0.96	1.46	1.82	2.63
Ma	0.19	0.39	0.55	0.91	1.48	2.25	3.14	3.76	5.12
Ap	0.51	0.88	1.15	1.73	2.57	3.66	4.86	5.69	7.46
Ma	0.66	1.13	1.45	2.15	3.16	4.44	5.86	6.83	8.91
Jn	0.95	1.54	1.94	2.78	3.98	5.48	7.12	8.23	10.60
Ju	0.56	1.08	1.48	2.37	3.72	5.52	7.56	8.98	12.08
Au	0.50	0.98	1.34	2.15	3.39	5.04	6.92	8.22	11.06
Se	0.27	0.64	0.94	1.68	2.89	4.59	6.59	8.01	11.15
Oc	0.00	0.28	0.51	1.03	1.90	3.14	4.62	5.67	8.02
No	0.07	0.19	0.32	0.67	1.31	2.28	3.47	4.34	6.32
De	0.12	0.24	0.33	0.55	0.89	1.34	1.86	2.23	3.03
Period									
An	16.27	19.59	21.54	25.10	29.49	34.36	39.18	42.26	48.46
Wi	0.69	1.03	1.27	1.73	2.37	3.15	3.98	4.54	5.72
Sp	3.15	4.21	4.86	6.10	7.72	9.60	11.54	12.80	15.41
Su	4.67	6.31	7.34	9.30	11.88	14.89	18.00	20.04	24.26
Fa	1.46	2.46	3.16	4.63	6.75	9.45	12.41	14.44	18.78

Table B.1.3.16. Probabilities for Daily Maximum Temperature (F) at
Rosemount,MN Elevation: 950 ft Years: 1951 To 1994

Mo	Low	5%	10%	25%	50%	75%	90%	95%	High
Ja	-16	-1	3	12	23	32	37	40	57
Fe	-10	6	11	19	29	36	42	45	58
Ma	1	21	25	32	38	45	55	60	81
Ap	24	38	41	48	57	66	74	79	93
Ma	34	53	58	64	71	78	84	87	97
Jn	53	66	70	74	80	85	89	92	100
Ju	59	73	75	79	84	88	91	94	105
Au	59	69	72	77	81	86	90	92	103
Se	44	57	60	66	72	79	84	87	97
Oc	30	42	46	53	61	68	75	80	88
No	3	21	27	34	40	49	58	61	74
De	-8	5	10	20	28	35	40	43	63
Period									
An	-16	14	22	35	58	77	85	88	105
Wi	-16	3	8	17	27	34	40	43	63
Sp	1	28	33	42	57	70	78	83	97
Su	53	69	72	77	82	86	90	92	105
Fa	3	30	35	46	60	71	79	83	97

Table B.1.3.17. Probabilities for Daily Minimum Temperature (F) at
Rosemount,MN Elevation: 950 ft Years: 1951 To 1994

Mo	Low	5%	10%	25%	50%	75%	90%	95%	High
Ja	-38	-23	-19	-10	2	13	21	25	35
Fe	-32	-18	-13	-5	9	20	27	30	41
Ma	-34	-4	2	13	22	29	33	36	52
Ap	4	20	23	28	33	40	46	50	66
Ma	20	31	34	39	45	53	58	61	70
Jn	36	42	45	50	56	61	65	67	77
Ju	41	49	51	55	60	65	68	70	77
Au	37	46	48	53	58	63	67	69	80
Se	24	34	37	42	48	55	61	65	73
Oc	11	23	26	30	37	44	51	53	69
No	-18	2	8	17	25	31	36	40	54
De	-31	-15	-10	0	12	20	27	30	52
Period									
An	-38	-9	0	18	35	52	61	65	80
Wi	-38	-20	-15	-5	7	18	26	29	52
Sp	-34	7	14	25	33	43	52	56	70
Su	36	45	48	53	58	63	67	69	80
Fa	-18	12	18	27	37	47	54	59	73

Table B.1.3.18 Probabilities for Monthly Precipitation (in) at
Rosemount, MN Elevation: 950 ft Years: 1948 To 1994

Mo	1%	5%	10%	25%	50%	75%	90%	95%	99%

Ja	0.04	0.10	0.17	0.36	0.71	1.25	1.92	2.40	3.51
Fe	0.00	0.10	0.18	0.38	0.71	1.17	1.73	2.13	3.02
Ma	0.20	0.43	0.61	1.03	1.70	2.61	3.65	4.39	6.01
Ap	0.38	0.72	0.98	1.54	2.40	3.53	4.81	5.70	7.62
Ma	0.96	1.49	1.84	2.56	3.55	4.78	6.10	6.99	8.87
Jn	0.58	1.14	1.58	2.55	4.06	6.08	8.38	9.98	13.49
Ju	1.13	1.71	2.10	2.88	3.95	5.27	6.68	7.63	9.63
Au	0.79	1.37	1.78	2.65	3.92	5.56	7.36	8.60	11.25
Se	0.29	0.66	0.97	1.71	2.93	4.63	6.63	8.05	11.19
Oc	0.00	0.22	0.44	0.97	1.89	3.24	4.88	6.07	8.73
No	0.09	0.24	0.38	0.75	1.40	2.37	3.54	4.39	6.29
De	0.09	0.21	0.30	0.53	0.91	1.45	2.07	2.51	3.49
Period									
An	17.66	21.14	23.17	26.87	31.42	36.45	41.42	44.59	50.95
Wi	0.66	1.05	1.32	1.87	2.64	3.61	4.65	5.36	6.86
Sp	3.19	4.31	5.02	6.37	8.14	10.21	12.34	13.75	16.65
Su	5.52	7.21	8.25	10.21	12.73	15.63	18.59	20.52	24.48
Fa	1.68	2.72	3.43	4.89	6.97	9.58	12.41	14.33	18.42

Table B.1.3.19 Probabilities for Daily Maximum Temperature (F) at
Winona,MN Elevation: 652 ft Years: 1948 To 1994

Mo	Low	5%	10%	25%	50%	75%	90%	95%	High
Ja	-16	0	5	16	26	34	40	43	57
Fe	-5	10	14	22	31	39	45	48	68
Ma	1	23	28	34	41	49	57	62	82
Ap	28	39	42	49	58	67	75	80	96
Ma	38	53	57	64	71	79	85	88	95
Jn	51	66	70	75	80	85	91	93	104
Ju	56	73	76	80	85	89	93	95	103
Au	59	69	73	77	82	87	91	94	103
Se	47	58	61	67	73	80	85	89	100
Oc	34	44	47	54	62	70	77	80	93
No	3	26	30	36	43	53	61	65	84
De	-13	8	13	23	31	37	43	47	64
Period									
An	-16	17	25	37	59	78	86	89	104
Wi	-16	5	11	20	30	37	43	46	68
Sp	1	30	35	43	57	69	79	84	96
Su	51	69	72	78	83	88	92	94	104
Fa	3	33	37	48	61	72	80	84	100

Table B.1.3.20 Probabilities for Daily Minimum Temperature (F) at
Winona,MN Elevation: 652 ft Years: 1948 To 1994

Mo	Low	5%	10%	25%	50%	75%	90%	95%	High
Ja	-32	-20	-16	-8	5	16	23	27	41
Fe	-29	-15	-10	-2	9	20	26	30	38
Ma	-28	0	4	13	22	29	34	38	63
Ap	4	21	24	29	35	42	49	53	72
Ma	21	34	36	41	47	53	60	63	73
Jn	37	45	47	52	57	62	67	69	79
Ju	44	52	54	58	62	67	70	73	80
Au	40	48	50	54	59	64	68	70	83
Se	27	35	39	44	49	55	61	65	76
Oc	13	25	28	33	39	45	52	55	68
No	-11	7	12	20	27	33	38	42	58
De	-28	-12	-8	2	14	22	28	31	48
Period									
An	-32	-6	3	20	37	54	63	66	83
Wi	-32	-17	-12	-2	9	20	26	30	48
Sp	-28	8	14	25	35	45	53	58	73
Su	37	47	50	55	60	65	69	71	83
Fa	-11	15	22	29	39	48	55	59	76

Table B.1.3.21 Probabilities for Monthly Precipitation (in) at
Winona, MN Elevation: 652 ft Years: 1948 To 1994

Mo	1%	5%	10%	25%	50%	75%	90%	95%	99%
Ja	0.04	0.12	0.20	0.42	0.83	1.46	2.24	2.82	4.12
Fe	0.00	0.00	0.01	0.20	0.58	1.23	2.12	2.89	2.97
Ma	0.21	0.44	0.62	1.02	1.65	2.51	3.50	4.19	5.70
Ap	0.60	1.02	1.31	1.93	2.84	3.99	5.25	6.12	7.98
Ma	1.14	1.70	2.06	2.79	3.80	5.02	6.31	7.18	9.01
Jn	0.95	1.55	1.97	2.84	4.08	5.64	7.33	8.49	10.96
Ju	0.93	1.52	1.92	2.76	3.96	5.47	7.11	8.22	10.60
Au	0.76	1.32	1.71	2.57	3.82	5.42	7.20	8.42	11.04
Se	0.19	0.52	0.81	1.56	2.86	4.77	7.06	8.71	12.41
Oc	0.12	0.32	0.50	0.94	1.71	2.81	4.14	5.09	7.21
No	0.10	0.28	0.44	0.87	1.62	2.74	4.08	5.06	7.25
De	0.00	0.30	0.44	0.71	1.10	1.59	2.14	2.52	3.34
Period									
An	18.80	22.16	24.11	27.62	31.91	36.63	41.25	44.19	50.06
Wi	0.72	1.16	1.47	2.10	3.00	4.13	5.36	6.20	7.98
Sp	4.07	5.21	5.91	7.20	8.86	10.75	12.66	13.91	16.44
Su	5.63	7.29	8.29	10.19	12.62	15.40	18.23	20.08	23.85
Fa	1.70	2.74	3.45	4.92	7.01	9.62	12.45	14.38	18.47

Table B.1.3.22 Probabilities for Daily Maximum Temperature (F) at
Caledonia,MN Elevation: 1175 ft Years: 1959 To 1994

Mo	Low	5%	10%	25%	50%	75%	90%	95%	High
Ja	-19	0	4	14	25	33	38	40	52
Fe	-9	8	13	21	30	37	42	44	57
Ma	8	23	27	33	39	47	57	61	82

Ap	29	37	40	48	57	64	72	78	93
Ma	36	52	56	62	69	76	81	84	90
Jn	50	65	68	73	78	83	87	90	97
Ju	58	70	73	78	82	86	90	92	100
Au	55	68	70	75	79	85	88	90	102
Se	41	54	59	65	70	77	82	85	92
Oc	31	42	45	51	59	66	73	76	91
No	8	22	28	34	41	50	57	60	75
De	-16	6	11	21	29	35	40	44	62
Period									
An	-19	15	23	35	57	75	83	86	102
Wi	-19	3	9	19	28	35	40	43	62
Sp	8	29	34	42	56	68	76	80	93
Su	50	68	70	75	80	85	89	91	102
Fa	8	31	35	46	59	69	77	80	92

Table B.1.3.23 Probabilities for Daily Minimum Temperature (F) at Caledonia,MN Elevation: 1175 ft Years: 1959 To 1994

Mo	Low	5%	10%	25%	50%	75%	90%	95%	High
Ja	-37	-21	-17	-9	4	15	22	27	37
Fe	-31	-15	-11	-2	10	20	26	30	37
Ma	-32	-1	4	13	22	29	34	37	54
Ap	2	19	22	28	33	40	46	51	62
Ma	19	31	34	40	45	52	58	60	69
Jn	35	43	45	50	55	60	64	66	74
Ju	42	49	51	55	59	63	67	69	75
Au	35	45	48	52	57	62	66	68	77
Se	24	33	36	42	48	54	60	63	71
Oc	13	23	26	30	36	43	49	53	67
No	-16	5	9	18	25	31	37	40	55
De	-28	-15	-9	1	13	21	27	30	43
Period									
An	-37	-7	2	19	35	52	60	63	77
Wi	-37	-18	-13	-3	9	19	26	29	43
Sp	-32	8	14	25	34	44	52	57	69
Su	35	45	47	52	57	62	66	68	77
Fa	-16	13	19	28	36	46	54	58	71

Table B.1.3.24 Probabilities for Monthly Precipitation (in) at Caledonia, MN Elevation: 1175 ft Years: 1948 To 1994

Mo	1%	5%	10%	25%	50%	75%	90%	95%	99%
Ja	0.06	0.16	0.24	0.46	0.82	1.36	2.00	2.45	3.48
Fe	0.00	0.00	0.03	0.26	0.67	1.31	2.12	2.73	4.15
Ma	0.31	0.60	0.81	1.29	2.01	2.97	4.05	4.80	6.43
Ap	0.64	1.12	1.45	2.17	3.22	4.57	6.06	7.09	9.29
Ma	0.82	1.35	1.71	2.47	3.56	4.93	6.42	7.44	9.61
Jn	0.85	1.46	1.89	2.82	4.17	5.90	7.81	9.12	11.94
Ju	0.62	1.20	1.63	2.61	4.11	6.11	8.36	9.94	13.36
Au	0.63	1.16	1.56	2.41	3.70	5.39	7.27	8.58	11.41
Se	0.34	0.76	1.10	1.92	3.24	5.09	7.23	8.76	12.11
Oc	0.23	0.49	0.70	1.18	1.95	3.00	4.21	5.07	6.95
No	0.11	0.29	0.46	0.91	1.71	2.88	4.31	5.34	7.65
De	0.11	0.25	0.37	0.66	1.14	1.80	2.59	3.14	4.37
Period									
An	20.58	24.11	26.15	29.82	34.29	39.18	43.96	47.00	53.05
Wi	0.75	1.21	1.53	2.19	3.14	4.32	5.60	6.48	8.34
Sp	4.37	5.60	6.34	7.72	9.49	11.50	13.54	14.86	17.57
Su	4.99	6.78	7.91	10.06	12.90	16.22	19.65	21.91	26.59
Fa	2.21	3.35	4.11	5.65	7.77	10.37	13.14	15.01	18.95

Since the rate of Growing Degree Day (GDD) accumulations was significantly related to plant available nitrogen (PAN) in the field experiment at the Nord Farm, the historical GDD distributions were examined for each of the five locations. GDD were calculated using the standard method for field corn, setting a base value of 50 degrees F and resetting any maximum temperature greater than 86 degrees F to 86 degrees F for purposes of calculating the daily mean. These monthly and annual totals are show in Tables B.1.3.25 to B.1.3.29.

The range in historically averaged annual GDD across southeastern Minnesota is from 2747 GDD at Caledonia to 3110 at Winona. However, the spatial variability of any given year is relatively modest when compared to the temporal (year to year) variability at an individual site. For example at Rosemount, annual GDD were 2420 in 1951 and 3485 in 1988, a range of 1065 GDD. The variability of monthly GDD is greatest in March and April, as well as October and November, all of which are months when soil testing and nitrogen (manure or fertilizer) applications would be more common. Thus it is not surprising to find that GDD relate closely to mineralization rages of nitrogen in the soil. Corn growth and development is so closely related to GDD that it can also serve as a general index of nitrogen uptake, at least in the absence of significant moisture stress.

Though both the spatial and temporal variability of GDD values in southeastern Minnesota are significant, the impact of slope aspect on this parameter is quite large, as observed in the range of crop development on north and south aspect at the Nord Farm in 1994. The combined effects of these characteristics amplify the variability of GDD and imply that consideration of site specific management for the purpose of setting yield goals and subsequent nitrogen needs might be well worth the effort.

Table B.1.3.25 Monthly and Annual Growing Degree Days at Theilman, MN
From Year 1962 To 1994 Corn Growing Degree Days (Base:50F Ceiling: 86F)

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1962	0	0	5	131	430	504	558	574	314	234	9	17	2776
1963	0	0	71	171	325	581	641	549	424	366	55	0	3183
1964	0	5	9	172	450	553	761	572	387	192	100	0	3201
1965	0	0	0	76	407	489	566	553	230	225	46	2	2594
1966	0	2	61	99	309	543	717	550	402	227	18	0	2928
1967	0	0	45	144	274	552	580	541	407	191	7	1	2742
1968	0	0	135	204	275	513	635	593	414	245	17	8	3039
1969	0	0	5	200	398	412	673	653	444	154	50	1	2990
1970	0	0	0	180	411	607	678	598	392	194	9	4	3073
1971	0	0	8	214	312	641	532	553	437	286	23	0	3006
1972	0	0	4	95	387	469	529	544	308	128	4	0	2468
1973	2	0	40	112	243	463	617	552	315	299	10	0	2653
1974	0	0	13	170	261	447	719	562	327	210	28	0	2737
1975	0	0	0	48	373	513	693	679	311	297	99	2	3015
1976	0	16	58	239	308	602	712	631	431	168	13	0	3178
1977	0	0	55	295	557	537	703	568	451	184	53	0	3403
1978	0	0	34	144	427	563	664	662	495	175	67	0	3231
1979	0	0	0	115	337	541	696	609	412	199	31	3	2943
1980	0	0	11	207	453	575	717	642	427	164	51	0	3247
1981	3	39	70	223	385	595	740	698	401	155	57	0	3366
1982	0	0	7	118	441	432	710	601	371	177	21	15	2893
1983	0	0	29	90	250	543	758	727	389	166	29	0	2981
1984	0	2	2	104	286	564	588	631	372	240	28	2	2819
1985	0	1	49	273	471	485	650	533	419	168	10	0	3059
1986	0	0	66	260	380	596	695	504	371	172	14	0	3058
1987	0	3	73	301	456	598	726	565	405	123	56	0	3306
1988	0	0	19	152	472	590	675	686	407	131	20	0	3152
1989	0	0	37	150	347	502	667	579	396	249	9	0	2936
1990	0	2	56	186	299	538	604	602	464	183	60	0	2994
1991	0	0	35	209	457	708	670	661	398	185	0	1	3324
1992	0	0	24	82	413	481	512	535	387	184	3	0	2621
1993	0	0	10	110	327	477	664	657	255	182	7	0	2689
1994	0	1	24	192	425	599	583	542	438	211	28	0	3043
Avg	0	2	32	166	372	539	652	598	387	202	32	1	2989

Table B.1.3.26 Monthly and Annual Growing Degree Days at ZUMBROTA, MN

From Year 1948 To 1994 Corn Growing Degree Days (Base:50F Ceiling: 86F)

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1948	0	0	41	234	310	469	695	632	507	204	29	2	3123
1949	0	0	5	156	415	626	754	682	347	272	51	3	3311
1950	0	0	0	58	293	541	584	514	390	295	27	0	2702
1951	0	0	1	69	412	442	646	558	322	193	13	2	2658
1952	0	0	1	216	323	584	685	593	437	177	73	0	3089
1953	0	0	32	66	365	596	656	670	430	372	99	2	3288
1954	0	10	9	217	280	634	708	603	414	155	53	0	3083
1955	0	0	18	263	449	506	802	721	454	251	3	0	3467
1956	0	0	0	108	360	640	585	637	371	330	48	0	3079
1957	0	1	8	197	328	526	743	588	355	156	13	0	2915
1958	0	12	11	152	413	419	563	622	424	271	49	0	2936
1959	0	0	15	169	418	572	673	739	437	107	3	3	3136
1960	0	0	14	162	351	481	650	681	447	223	28	2	3039
1961	0	2	21	60	323	569	634	653	402	250	20	0	2934
1962	0	0	0	152	431	504	586	608	335	260	13	21	2910
1963	0	0	78	212	339	598	687	609	463	399	53	0	3438
1964	0	5	12	170	448	566	734	568	382	221	98	0	3204
1965	0	0	0	91	410	528	652	584	244	266	58	0	2833
1966	0	2	67	104	315	566	727	538	401	181	5	0	2906
1967	0	0	36	120	260	533	603	539	395	184	12	2	2684
1968	0	0	120	187	281	528	637	609	384	238	14	6	3004
1969	0	0	0	177	372	380	677	671	410	152	33	0	2872
1970	0	0	0	160	385	578	678	605	388	199	4	2	2999
1971	0	0	8	201	286	626	538	571	438	272	31	0	2971
1972	0	0	3	101	386	496	577	583	356	147	7	0	2656
1973	0	0	51	126	270	554	654	649	381	292	21	0	2998
1974	0	0	8	167	265	462	722	548	343	219	36	0	2770
1975	0	0	0	46	396	536	691	629	317	292	105	0	3012
1976	0	15	61	228	323	555	674	605	406	158	13	0	3038
1977	0	3	57	298	534	538	716	511	386	155	44	0	3242
1978	0	0	33	113	386	526	603	625	483	177	62	0	3008
1979	0	0	0	99	317	502	626	575	432	162	32	2	2747
1980	0	0	6	200	436	549	702	613	389	127	39	0	3061
1981	10	30	67	197	321	516	647	598	352	150	81	0	2969
1982	0	0	8	132	400	408	681	594	384	194	15	10	2826
1983	0	0	25	86	259	543	737	722	435	170	34	0	3011
1984	0	0	1	139	292	583	616	684	371	240	21	0	2947
1985	0	1	49	268	466	460	637	526	400	166	12	0	2985
1986	0	0	68	211	395	583	714	540	396	196	15	0	3118
1987	0	0	68	316	489	628	758	597	420	126	52	0	3454
1988	0	0	24	171	497	647	714	711	450	147	28	0	3389
1989	0	0	37	163	356	525	695	624	408	280	7	0	3095
1990	0	4	65	206	292	584	643	640	489	204	83	0	3210
1991	0	0	45	203	431	656	650	624	399	203	1	0	3212
1992	0	0	21	93	418	491	486	502	388	199	3	0	2601
Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1993	0	0	12	100	307	458	623	613	265	194	5	0	2577
1994	0	0	30	185	403	604	585	533	460	228	40	0	3068
Avg	0	1	26	160	366	540	660	609	397	210	33	1	3010

Table B.1.3.27 Monthly and Annual Growing Degree Days at Rosemount, MN

From Year 1951 To 1994 Corn Growing Degree Days (Base:50F Ceiling: 86F)

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1951	0	0	0	61	392	402	609	504	275	168	6	3	2420
1952	0	0	0	203	307	531	651	528	395	140	41	0	2796
1953	0	0	13	46	317	545	627	625	389	338	85	0	2985
1954	0	3	0	165	220	572	647	565	331	103	33	0	2639
1955	0	0	16	233	407	478	763	689	407	217	0	0	3210
1956	0	0	0	94	331	598	520	561	321	307	40	0	2772
1957	0	0	4	181	308	480	743	580	330	138	5	0	2769
1958	0	9	16	146	400	401	571	614	421	242	43	0	2863
1959	0	0	25	149	395	582	660	715	406	77	3	1	3013
1960	0	0	10	149	326	451	639	662	404	210	25	1	2877
1961	0	1	17	52	308	556	620	644	390	231	21	2	2842
1962	0	0	0	143	416	499	557	594	314	229	12	20	2784
1963	0	0	71	163	290	578	669	591	427	347	58	0	3194
1964	0	2	4	158	414	554	715	572	378	170	72	0	3039
1965	0	0	0	67	365	476	624	549	222	214	36	0	2553
1966	0	1	50	75	284	546	743	546	393	188	6	0	2832
1967	0	0	34	101	263	510	598	543	399	186	18	0	2652
1968	0	0	126	202	266	533	640	598	381	230	8	2	2986
1969	0	0	0	163	398	390	636	646	419	146	31	0	2829
1970	0	0	0	148	366	597	680	619	373	186	0	1	2970
1971	0	0	8	186	295	621	557	564	429	244	27	0	2931
1972	0	0	1	98	404	518	577	581	337	129	6	0	2651
1973	0	0	47	104	269	560	672	675	365	280	9	0	2981
1974	0	0	4	160	279	476	750	546	338	214	30	0	2797
1975	0	0	0	38	404	539	724	613	310	258	88	0	2974
1976	0	11	49	230	351	587	714	645	416	153	12	0	3168
1977	0	0	33	273	549	558	712	520	384	148	39	0	3216
1978	0	0	30	98	400	548	627	632	483	180	61	0	3059
1979	0	0	0	89	300	516	647	572	422	151	22	0	2719
1980	0	0	2	203	435	554	709	634	388	138	31	0	3094
1981	7	19	58	188	335	517	662	617	352	134	70	0	2959
1982	0	0	4	130	402	438	719	625	386	168	12	8	2892
1983	0	0	16	86	276	537	755	753	420	166	18	0	3027
1984	0	0	1	141	310	566	644	700	335	206	14	0	2917
1985	0	1	35	254	437	454	664	505	384	143	14	0	2891
1986	0	0	55	202	376	581	703	546	359	180	11	0	3013
1987	0	3	72	302	485	653	765	601	426	133	45	0	3485
1988	0	0	25	195	510	650	728	698	470	142	8	0	3426

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1989	0	0	22	175	379	549	740	636	429	272	3	0	3205
1990	0	7	63	212	326	610	651	611	484	193	69	3	3229
1991	0	2	40	203	422	656	655	632	381	180	0	0	3171
1992	0	0	11	89	427	481	490	483	378	181	0	0	2540
1993	0	0	14	114	306	453	609	624	251	174	2	0	2547
1994	0	0	27	174	426	587	597	538	454	202	29	0	3034
Avg	0	1	22	150	360	533	658	602	379	192	26	0	2928

Table B.1.3.28 Monthly and Annual Growing Degree Days at Winona, MN
From Year 1948 To 1994 Corn Growing Degree Days (Base:50F Ceiling: 86F)

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1948	0	1	67	291	363	561	763	705	552	214	33	7	3557
1949	0	0	20	219	458	706	819	768	367	308	60	6	3731
1950	0	0	1	81	352	588	665	587	466	340	44	0	3124
1951	0	2	5	85	505	541	719	631	337	209	15	0	3049
1952	0	1	7	227	344	630	747	651	442	172	82	0	3303
1953	0	0	41	70	366	648	745	750	470	393	115	1	3599
1954	0	16	14	215	271	686	755	646	396	156	60	0	3215
1955	0	0	17	235	435	502	827	755	439	211	3	0	3424
1956	0	0	3	88	334	645	626	643	349	287	56	0	3031
1957	0	1	13	160	278	525	757	597	344	166	21	1	2863
1958	0	14	16	163	385	422	620	626	417	264	80	0	3007
1959	0	0	12	143	441	589	654	717	444	101	7	6	3114
1960	0	0	15	173	331	446	633	656	441	219	32	6	2952
1961	0	4	19	66	309	552	661	653	404	227	37	5	2937
1962	0	0	11	156	431	513	586	620	339	239	15	20	2930
1963	0	0	64	172	285	580	708	595	433	407	79	0	3323
1964	2	1	25	175	441	566	742	584	385	189	116	0	3226
1965	0	0	0	80	412	508	630	576	276	230	52	4	2768
1966	0	3	52	95	280	576	747	586	424	209	21	0	2993
1967	0	1	40	133	270	594	635	570	407	202	17	4	2873
1968	3	0	100	161	255	524	631	601	349	229	26	6	2885
1969	0	0	8	170	371	368	666	681	416	129	62	1	2872
1970	0	0	0	170	350	589	728	649	392	214	11	7	3110
1971	0	0	6	210	278	632	602	568	434	297	45	0	3072
1972	0	0	6	96	430	495	573	592	367	137	5	0	2701
1973	2	0	66	116	237	547	678	617	397	324	22	1	3007
1974	0	0	20	175	267	446	701	533	320	187	43	0	2692
1975	0	0	1	65	390	494	667	581	301	265	128	7	2899
1976	0	20	59	194	309	600	689	614	412	163	8	0	3068
1977	0	5	59	302	605	531	769	525	387	173	53	0	3409
1978	0	0	24	122	388	535	610	599	482	164	74	0	2998
1979	0	0	0	110	305	510	706	596	455	152	36	4	2874
1980	0	0	14	192	423	524	739	629	366	130	42	0	3059
1981	7	30	61	187	322	540	625	653	375	147	71	0	3018
1982	0	1	9	117	384	414	711	610	343	174	32	13	2808
1983	0	0	28	97	252	574	823	743	395	148	48	0	3108
1984	0	8	5	129	324	657	710	630	409	237	15	10	3126
1985	0	0	54	270	463	558	768	608	443	173	11	0	3348
1986	0	0	42	218	390	589	699	513	320	165	8	0	2944
1987	0	1	74	309	490	635	755	613	435	136	56	0	3504
1988	0	0	35	184	485	717	825	770	442	161	28	0	3674
1989	2	0	55	159	413	597	793	710	456	267	12	0	3464
1990	0	4	47	218	313	606	741	686	527	187	87	0	3416
1991	0	0	44	220	484	668	735	711	375	171	0	0	3408
1992	0	0	20	97	433	530	565	565	383	207	4	0	2804
1993	0	0	17	105	350	534	712	712	278	175	11	0	2894
1994	0	5	24	179	427	671	704	597	508	243	63	0	3421
Avg	0	2	28	163	365	559	703	632	400	212	43	2	3119

Table B.1.3.29 Monthly and Annual Growing Degree Days at Caledonia, MN
From Year 1959 To 1994 Corn Growing Degree Days (Base:50F Ceiling: 86F)

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1959	0	0	2	125	413	551	627	702	398	87	5	2	2912
1960	0	0	5	154	290	429	577	616	390	171	29	4	2665
1961	0	2	5	44	258	484	543	553	319	185	13	7	2413
1962	0	0	3	122	371	431	502	500	251	185	10	14	2389
1963	0	0	54	136	240	528	576	446	305	301	57	0	2643
1964	0	2	6	127	381	490	636	492	320	147	77	0	2678
1965	0	0	0	66	369	428	548	513	205	185	34	3	2351
1966	0	0	43	70	243	459	665	508	343	172	23	0	2526
1967	0	0	35	110	244	499	585	525	350	154	13	2	2517
1968	0	0	115	193	280	523	637	619	368	212	16	5	2968
1969	0	0	4	164	381	358	675	645	[illegible]	[illegible]	27	0	2812
1970	0	0	0	174	378	557	682	615	375	182	7	4	2974
1971	0	0	8	194	273	644	552	546	457	299	35	0	3008
1972	0	0	5	106	420	512	594	614	384	136	5	0	2776
1973	0	0	64	111	261	571	680	633	384	283	19	3	3009
1974	0	0	12	182	273	439	696	544	322	189	27	0	2684
1975	0	0	0	73	385	514	652	609	301	268	93	4	2899
1976	0	15	60	206	313	547	682	593	407	151	15	0	2989
1977	0	0	63	294	514	492	682	510	357	144	37	0	3093
1978	0	0	36	113	335	491	603	555	410	107	47	0	2697
1979	0	0	0	82	325	520	618	558	389	172	17	3	2684
1980	0	0	3	191	401	517	692	621	398	127	29	0	2979
1981	1	16	40	199	280	508	638	568	340	138	50	0	2778
1982	0	0	13	129	398	383	668	611	357	163	24	9	2755
1983	0	0	25	79	193	531	739	720	387	149	24	0	2847
1984	0	5	1	108	239	547	593	653	332	204	18	4	2704
1985	0	0	24	222	401	433	637	496	378	126	5	0	2722

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1986	0	0	55	185	334	521	662	489	333	142	10	0	2731
1987	0	0	49	222	406	604	720	563	365	91	43	0	3063
1988	0	0	20	126	439	619	720	675	389	108	18	0	3114
1989	0	0	33	113	301	486	702	599	344	208	8	0	2794
1990	0	3	42	158	219	528	626	575	425	136	73	0	2785
1991	0	0	30	162	407	630	632	608	331	147	0	0	2947
1992	0	0	9	63	342	449	460	441	314	154	0	0	2232
1993	0	0	7	66	280	435	593	600	203	145	4	0	2333
1994	0	0	24	144	334	569	560	477	408	173	29	0	2718
Avg	0	1	25	140	329	505	626	571	352	170	26	1	2755

Figures B.1.3.10 and B.1.3.11 show the climatology of soil temperatures at Rosemount (1985-1993). This was the only historical record of soil temperatures in southeastern Minnesota to examine. These temperatures have been recorded at the Agricultural Experiment Station site in a Waukegan silt loam soil series. The temporal pattern of the 30th, 50th and 70th percentile values for both the four inch and eight inch depths during the growing season are shown. Soil temperatures show a high degree of variability (exhibited as a range across percentiles) associated with the spring and fall. Average four inch soil temperatures (expressed as the 50th percentile values) reach 50 degrees F about the middle of April. Higher variability in soil temperatures at this time is a function of soil moisture, snow cover and soil frost penetration over the winter. Because of this large variability, nitrogen sources in the soil could be subject to significant mineralization rates several weeks ahead of normal planting dates for corn in the region. This would be verified by a spring preplant soil test, as a followup to a fall soil test.

The average four inch soil temperatures drop below 50 degrees F in the fall, about mid October. Manure and inorganic nitrogen fertilizer applied to the soil after October 15 would be subject to little mineralization in most years because of the relatively steep decline in soil temperatures at that time. In dry years, soil temperatures decline even more steeply in the late fall due to the reduced capacity of the soil to store heat. Average soil freeze-up is on or about December 10 at which point most biological and chemical activity within the soil all but ceases for the winter.

Based on the seasonal trend in both four inch and eight inch soil temperatures, peak mineralization rates within the soil rootzone would be expected to persist from mid June to late August, inhibited only by lack of soil moisture in dry years. Because of the relatively strong relationship between soil temperature and nitrogen mineralization rates, other soil temperature monitoring stations should be established in southeastern Minnesota to examine the temporal pattern in different soil series and at different positions in the landscape.

Using the CERES-Maize model of corn growth and development published by Jones and Kiniry (1986), a submodel to produce soil moisture estimates for each day in the Zumbrota historical climatic records (1932-1994) was run. Zumbrota represents the climatic station closest to the Nord farm in Goodhue County. The resulting 63 year record of daily soil mositure estimates was used to derive the temporal distribution characteristics for the relevant layer of soil where the majority of mineralization occurs (top 1 foot). The model was run using the water holding characteristics for a Seaton silt loam, which is the soil series where field experiments were conducted and is also relatively common throughout southeastern Minnesota. This soil is capable of holding 2.88 inches of available moisture in the top foot. Figure B.1.3.12 shows the temporal distribution of the 30th, 50th and 70th percentile levels for soil moisture derived from this model and covering the period from April through October. At the 50th percentile level, soil moisture is at 1.5 inches or greater for the period from April to mid June After mid June, soil moisture values fall to less than one inch and reach the lowest level in August. Thus the lack of soil moisture becomes a limiting factor to continued high mineralization rates during this time. This effect would be amplified on fields with a southerly aspect. On the average, soil moisture values remain below 1.5 inches in the top foot for much of the September and October period as well (at least 70 percent of the time), helping to limit mineralization rates from fall applied nitrogen. Fall applications of fertilizer N are not generally recommended as a best management practice in southeastern counties due to the risk of losses from leaching, runoff or denitrification, however many producers apply manure sources of N in the fall.

The combined effects of the temporal pattern for soil moisture and that of soil temperature illustrate the need to have timely planting of corn in the southeastern region. Optimal conditions for mineralization and uptake of nitrogen usually occur in late May and early June. Therefore it is necessary to have plant development at a point where available nitrogen can be efficiently and readily taken up by the root mass. It is also quite important to make split applications of N fertilizer in a timely manner in the spring and early summer to take advantage of the more optimal soil conditions. Fall applications of nitrogen (generally from manure sources) which occur after late October are typically placed in a cooler and drier soil environment which limits mineralization, preserving this source of N for use by next year's crop. In some years, heavy fall rainfall can lead to significant N losses due to leaching or runoff.

In addition to compiling probability statistics for climatic parameters related to nitrogen mineralization, distributions of heavy precipitation events were examined in the southeastern region of Minnesota to assess the temporal risks of leaching and runoff which tend to cause losses of nitrate N from the soil profile. Tables B.1.3.30 through B.1.3.34 show the frequencies of 1, 2, and 3 inch 24 hr precipitation events at the five climatic stations in southeastern Minnesota. It is not surprising that the highest frequencies are in the summer months when greater precipitable water (atmospheric water vapor) is available. Crops at full canopy can usually withstand and recover from such rains. However, heavy rainfall events in March, April, May, as well as October and November usually occur in the absence of a protective crop canopy and are potentially more

Table B.1.3.30 Frequencies of 1, 2, and 3 inch 24 hr precipitation events at Theilman, MN Years: 1948 to 1994 (47 years)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
One Inch Events													
	3	1	10	28	36	53	60	54	42	22	10	2	321
Two Inch Events													
	1	0	0	2	4	6	13	11	10	5	3	0	55
Three Inch Events													
	0	0	0	0	0	1	7	4	3	3	0	0	18

Table B.1.3.31 Frequencies of 1, 2, and 3 inch 24 hr precipitation events at Zumbrota, MN Years: 1948 to 1994 (47 years)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
One Inch Events													
	1	0	9	24	32	49	55	43	45	23	13	2	296
Two Inch Events													
	0	0	0	1	3	10	15	13	12	5	3	0	62
Three Inch Events													
	0	0	0	0	1	7	3	3	1	1	0	0	16

Table B.1.3.32 Frequencies of 1, 2, and 3 inch 24 hr precipitation events at Rosemount, MN Years: 1948 to 1994 (47 years)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
One Inch Events													
	2	2	13	20	38	55	52	61	37	25	13	3	321
Two Inch Events													
	0	0	0	1	3	9	12	10	6	1	1	0	43
Three Inch Events													
	0	0	0	1	0	3	5	3	3	0	0	0	15

Table B.1.3.33 Frequencies of 1, 2, and 3 inch 24 hr precipitation events at Winona, MN Years: 1948 to 1994 (47 years)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
One Inch Events													
	4	2	12	19	45	50	59	44	42	14	19	3	313
Two Inch Events													
	0	0	0	6	4	8	22	8	10	1	2	0	61
Three Inch Events													
	0	0	0	1	0	1	3	4	1	0	1	0	11

Table B.1.3.34 Frequencies of 1, 2, and 3 inch 24 hr precipitation events at Caledonia, MN Years: 1948 to 1994 (47 years)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
One Inch Events													
	5	4	13	26	37	60	65	54	43	19	21	6	352
Two Inch Events													
	0	0	2	6	5	16	19	10	10	2	3	1	74
Three Inch Events													
	0	0	1	0	1	5	6	3	2	0	0	0	18

damaging in terms of nitrate leaching and runoff, as well as soil erosion. Severe precipitation events in excess of 3 inches occur with a frequency of once every 2-3 years. There are really no management options to mediate the effects of such events. Fortunately most occur during the months when crop water use is high, crop canopies are full and mineralization and uptake of a relatively large fraction of nitrogen has already taken place.

Spatially, it appears that extreme southeastern Minnesota (Caledonia) may be subject to more frequent occurrences of heavy precipitation than other locations in the southeast. A more well defined spatial pattern for heavy precipitation events might be derived from incorporating other climatic stations such as those along the Wisconsin and Iowa borders.

Summary: Probability distributions and other statistics for selected climatic parameters including frosts, growing season lengh, maximum and minimum air temperatures, and precipitation (including amount and intensity) were derived for several southeastern Minnesota climate stations. Many of these climatic parameters exhibited characteristics associated with relative landscape position. Both spatial and temporal variabilities, though significant would likely be further amplified by slope and aspect differences at the field scale.

These climatic distributions and probabilities can be useful in evaluating expected rates of nitrogen mineralization from manure and inorganic fertilizers, as well as examining the risks of nitrogen losses due to leaching or runoff.

Because soil temperature and moisture were found to be significantly related to mineralization and plant available nitrogen (PAN) at the Nord farm, time series analysis was performed on single station climatic records for these parameters. The historical records of soil temperature at Rosemount were examined and found to show high variability in the early spring and fall. A soil moisture model was used to study the temporal pattern of the top foot of a Seaton soil series at Zumbrota using 63 years of climatic data.

The spring and summer distributions of soil temperature and moisture suggest that timing nitrogen applications is becoming increasingly important if crop utilization is to be maximized and leaching potential minimized. Despite a high degree of climatic variability in the spring, soil temperature and moisture distributions suggest that N sources in the soil will be subject to increasing mineralization rates starting about early April in most years. Timely planting is critical to fully utilize the mineralization rate increases typically seen in late April, May and June.

Best management practices for fertilizer N in southeastern Minnesota discourage fall application of nitrogen and encourage split applications during spring and early summer. These recommendations seem quite justified by the climatic characteristics. However, manure applications occur often throughout the year, and nitrogen mineralization and losses from these organic sources are equally regulated by climate. With new techologies and information available from soil surveys, precision farming techniques which incorporate the spatial and temporal characteristics of climate along with soil, slope and aspect considerations on a field scale could potentially improve nitrogen management in the cropping systems of southeastern Minnesota.

References:

Baker, D.G., Nelson, W.W., and E.L. Kuehnast. 1979. Climate of Minnesota: Part XII The Hydrologic Cycle and Soil Water. Univ. of MN Agric. Exp. Sta. Tech. Bul. 322, 23pp.

Kuehnast, E.L., Baker, D.G. and J.A. Zandlo. 1982. Climate of Minnesota: Part XIII Duration and Depth of Snow Cover. Univ. of MN Agric. Exp. Sta. Tech. Bul. 333, 24pp.

Malzer, G.L., Seeley, M.W., and J.L. Anderson. 1983. Nitrogen Loss Potential and Nitrogen Fertilizer Management of Minnesota Soils. Univ. of MN Agric. Exp. Sta. Rep. 186, 4pp.

Jones, C.A. and J.R. Kiniry. 1986. CERES-Maize, A Simulation Model of Maize Growth and Development. Pub. Texas A&M Univ. Press.

C. Title of Objective: Near surface stratigraphy:

C.1. Activity: This portion of the project will determine the near surface stratigraphy at sites selected for this project at a scale suitable for on-farm management of manures. Layers of glacial till, clayey residuum, and/or other materials are sometimes present between the surficial loess and the underlying karst in many areas of southeastern Minnesota. These layers are often nearly impermeable to waters leaching through the soil. The presence of these layers drastically alters the flow paths and subsurface hydrology of sites, which strongly influences the fate of manure-applied nitrogen. Current methods of determining the presence and extent of these materials are too time-consuming and expensive to be used to map the subsurface stratigraphy at a scale suitable for on-farm management.

C.1.a. Context within the project: This portion of the project will provide information regarding the presence of subsurface layers of glacial till, residuum, and other materials which may lie between the loess and the underlying karstic bedrock. These layers strongly influence the flow paths for soil moisture and the subsurface hydrology between the loess and the karst. If these layers are sufficiently thick and relatively continuous, they may effectively seal surficial openings in the karst, thereby producing lateral subsurface flow instead of the excessively rapid downward flow through the karst and into ground and surface waters, a process characteristic of karstic landscapes and one of the causes of poor water quality in karstic regions.

C.1.b. Methods: Subsurface stratigraphy of study sites will be assessed using magnetic inductance resistivity (MIR). This technique is a non-destructive geosensing technique that measures the electrical resistance of soils and sediment. It uses electromagnetic waves to induce electrical currents deep within the soil and then measures the electrical conductivity of the subsurface materials influenced by that current, all without the need to take cores (except for verification purposes) or even disturb the soil surface. Studies in England have shown that the electrical resistances of subsurface materials (such as loess, glacial till, clayey residuum, and limestone) in karstic landscapes are sufficiently different so that they can usually be distinguished by MIR. Because MIR is a non-destructive geosensing technique, subsurface stratigraphy can usually be differentiated more rapidly (500 or more measurements per day) and easily by this technique than by other means.

Study areas will be gridded and MIR measurements will be taken at each grid point. The location of grid points will be determined using a geographical positioning system (GPS), which is based on satellite technology. Soil and sediment cores will be taken at a smaller number of grid points using a truck-mounted soil probe in order to determine the exact nature of the materials underlying the karst. The stratigraphy observed in the cores will be used to verify the MIR measurements. Once the MIR and core measurements have been taken, the underlying stratigraphy will be mapped using GIS techniques, and interpolated between measured points using geostatistical techniques such as kriging. A map of the underlying subsurface materials will be produced for use in other parts of this project.

C.1.c. Materials: The main equipment needed for this project is a magnetic induction resistivity meter. The other equipment (a truck-mounted soil probe, a geographical positioning system ground station, and a GIS system) are all owned by the U of M Soil Science Department.

C.1.d. Budget: $45,000 Balance $0

C.1.e. Timeline:

	7/93 1/94 6/94 1/95 6/95
Selection of Field Sites	xxxxxxxx
MIR measurements	xxxxxxxxxxxxxxxxxxxxxxx
Probe truck coring	xxxxxxxxxxxxxxx
Development of GIS database	xxxxxxxxxxxxxxxxxxx
Final reporting	xxxxxxxxx

C.1.f. Final Detailed Report

C1: NEAR SURFACE STRATIGRAPHY

ABSTRACT

The purposes of this portion of project were to: (i) determine the near-surface stratigraphy at two research sites within the karst region of Minnesota and Wisconsin and construct a 3-dimensional database of stratigraphy and (ii) evaluate the efficacy of magnetic induction resistivity (MIR) as a remote sensing method for rapid determination of near-surface stratigraphy. Direct observations of near-surface strata indicated that the upper 1 to 5 meters is composed of Roxana and/or Peoria loess (aeolian silts). These unconsolidated sediments are typically underlain by a clayey residuum remnant of a paleosol that developed in the limestone bedrock prior to burial by loess. The clayey residuum was discontinuous across the landscape and tended to be absent in highly-erodible portions of the hillslope. The residuum, or loess where residuum is absent, is underlain by limestone or dolomite bedrock. Profound soil particle and pore size contrasts between the loess and residuum coupled with observations of soil redoximorphic features and the presence of saturated soils in some soil cores indicated that water was accumulating above the loess-residuum boundary and probably flowed laterally above the residuum in a downslope direction creating an ephemeral, shallow, surficial aquifer. Conceivably, soil water, and associated contaminants, would accumulate in drainageways and depressions. Where the clayey residuum was not present, the shallow aquifer could flow directly into bedrock fissures and the groundwater system associated with the karst bedrock. Where continuous residuum was present, the shallow aquifer would be diverted towards surficial streams. The near-surface stratigraphy may significantly impact the flow path, residence time, and potential for water-born contaminants to undergo biochemical transformations before eventual transport to ground or surface water systems. An understanding of the hydrology and biochemistry of soil water fluxes between a 50-cm depth and the bedrock surface is clearly needed to determine the eventual fate of agricultural contaminants. Our results regarding the use of magnetic induction resistivity as a remote-sensing tool for rapid assessment of near-surface stratigraphy were somewhat ambiguous. High correlations ($a<.01$, R^2 .64 - .94) were found between observed and predicted loess depths at the Sikkink site. However, poor correlations were found for the Lancaster Site. Data inconsistencies suggest that instrument error may have been significant at Lancaster, however, this has not been positively confirmed.

I. PROBLEM STATEMENT

The purpose of this portion of this project was to determine the near-surface stratigraphy at two research sites within the karst region of Southeastern Minnesota and eastern Wisconsin. Layers of glacial till, clayey residuum, and/or other soil materials, that are frequently present between the surface loess and the underlying limestone or dolomite bedrock, may significantly alter subsurface water flow paths and the eventual fate of manure-applied nitrogen. Because direct observation of soil stratigraphy to depths of several meters is both labor and time intensive using traditional soil coring methods (hydraulic probes), we investigated the use of magnetic inductance resistivity (MIR) for determining and mapping soil strata with contrasting electrical conductivities. MIR is a remote, geo-sensing technique that measures differences in the electrical conductivity of stratigraphic layers beneath the surface. Consequently, soil and geologic materials having sufficiently different particle size distributions such as loess, limestone bedrock, and glacial till are detectable with this technique. We evaluated the utility of MIR by comparing direct observations of stratigraphy with MIR recordings and use a combination of direct and indirect measurements to construct a 3-dimensional, GIS-database of near surface stratigraphy.

II. INTRODUCTION

Landscape Evolution

Karst Topography

Many portions of Southeastern Minnesota and Western Wisconsin are underlain by limestone or dolomite bedrock. Openings in the bedrock that occur along bedding plane partings, joints and fault zones increase the permeability and circulation of water within the bedrock (Ritter et al., 1995). The carbonate component of the bedrock is dissolved especially in areas of high permeability and circulation. The solution integrates spaces, allowing pronounced underground circulation of water that, which in turn, promotes further solution (Ritter et al., 1995).

As solution increases the size of a cavern or conduit, it may not be able to support the weight of the overlying bedrock and soil. Eventually, the cavern collapses, creating a doline (also called a sinkhole) or surface depression that often links surface waters directly to ground water. There are two types of dolines: solution and collapse. Solution dolines (Figure C1 - 1) form as water infiltrates into joints, enlarging at the surface by the above process (Ritter et al., 1995). As the zone of dissolution increases, material above the conduit slumps downward creating a closed depression. Collapse dolines are initiated by underground caverns whose ceiling is unable to support the rock and soil above (Figure C1 - 2). The collapse is often catastrophic. Postcollapse modifications often make it impossible to differentiate between the two types.

In karst topography, conduits and dolines have the potential to drain soil and surface waters directly into aquifers with little to no residence time within the soil. The high microbial population found in soil has the ability to break down harmful agrochemicals. If soil water carrying excess nitrates from manure or agrochemicals by-passes the soil, groundwater aquifers used for water supply could be adversely affected. However, the presence of karst features is not the sole factor involved in groundwater contamination susceptibility. The various constituents of the near surface stratigraphy can greatly affect the hydrology. The movement or impedance of water through a stratigraphic layer can be altered by large particle size discontinuities between adjacent materials, pedogenic structure, thickness and particle size class. Soil water reaching a highly impermeable layer will result in lateral flow towards lower hillslope positions or dolines, which increases the probability of direct flow into the groundwater system.

Regional Soil Stratigraphy

During interglacial periods, there is evidence that residual soils developed in the limestone bedrock and were later truncated by erosion events associated with the onset of continental glaciation. The erosion was more severe in Minnesota than in Wisconsin, presumably due to harsher periglacial environments. The lack of glacial tills throughout Southwestern Wisconsin and the patchy occurrence of tills and erratics in Southeastern Minnesota shows that the ice mass did not cover this region during the Wisconsinan glaciation. However, the climate and vegetation in these regions were affected by the close proximity to the ice mass. Earlier ice advances may have encroached on portions of southeastern Minnesota as evidenced by buried tills and erratics. The karstic bedrock in these regions is overlain by varying thicknesses of loess, creating potentially complex stratigraphy including remnants of paleosols (buried soils) associated with limestone residuum, glacial tills, paleosols formed in loess and the modern loess soil. While all of these materials are not usually found at a single site, they may be distributed across the landscape in spatially-complex patterns. This section briefly reviews the nature of soil parent materials and landscape evolution in Southeastern Minnesota and western Wisconsin.

Types of Soil Parent Materials

<u>Loess</u>

Four distinct loess formations can be found within in the Upper Midwest. From youngest to oldest they are: Peoria, Roxana, Loveland and Wyalusing. Leigh and Knox (1994) provide the general characteristics of the formations. The Peoria formation composes the present surface. It is a brownish-gray (2.5Y 6/2) to light-brownish-gray (10YR 5/4) calcareous silt loam (Leigh and Knox, 1994). The present soil contains multiple argillic horizons with illuvial clay skins on ped faces. It can reach up to 10 m thick in some areas (Mason et al., 1994). McKay (1979) estimated the range of the Peoria loess to be between 25,000 and 12,000 B. P. Leigh and Knox (1994) performed an accelerator mass spectrophotometer (AMS) radiocarbon date on material 25 cm from the base of the Peoria and determined a date of 24,250 ± 970 B.P. (GX-15888-AMS). The basal material is the oldest portion of the deposit, since it was deposited first.

The Roxana loess is a brown (10YR 4/3 to 10YR 4/4) non-calcareous silt loam that exhibits weak to moderate platy and blocky structure throughout (Leigh and Knox, 1994). Leigh and Knox (1993) set the age of the Roxana formation in the Driftless Area between 55,000 and 27,000 B.P. The oldest age (basal material) was estimated by extrapolation of (AMS) radiocarbon dates along with date-depth trendlines from other samples. The large timespan between the oldest and youngest dates indicates a slow depositional rate (~ 0.05 mm/yr).

The Loveland formation is a brownish-gray (2.5Y 6/2) to light-brownish-gray (10YR 5/4) silt loam (Leigh and Knox, 1994). Its maximum thickness is 3.0 m, but is normally < 2.0 m. The Sangamon paleosol which developed in the Loveland formation is a brown (7.5YR 4/4) to dark-yellowish-brown (10YR 4/4). Its solum is 1.5 to 2.0 m and profile development is similar to that of the modern Peoria loess soil. The age of the Loveland formation is estimated to be Illinoian or older (>125,000 B. P.) (H. E. Markewich, as cited in Liegh and Knox, 1993). Due to limitations on dating techniques, the absolute age of the Loveland formation can not be fixed with certainty, however an Illinoian age bracket is supported (Ruhe, 1969).

The Wyalusing is a brown (10YR 4/3 to 10YR 4/4) non-calcareous silt loam with weak to moderate platy structure and a maximum observed thickness of 2 m. The Wyalusing loess has not been positively dated, however, relative age can be inferred from superposition. The Wyalusing is positioned under the Illinoian-aged Loveland and therefor must be older than it.

Loess Patterns of the Midwest

For the most part, the major loess deposits of the Upper Midwest are found adjacent to major outwash-bearing river systems such as the Mississippi, Missouri, and Illinois. The overbank materials of these rivers provided a large supply of sediment for aeolian entrainment. After soil particles are entrained into the windstream, they are transported some distance downwind dependent upon grain size and available energy of the system. Larger sand-sized particles may only move meters, while silt sized particles may be transported many kilometers. As the energy of the wind decreases, the largest particles are deposited first followed by the smaller ones.

Early research by Leverett (1899) found thick loess belts parallel to the major river valleys with the thickest bands of loess on the eastern (downwind) side of the valleys. Studies of loess thickness and particle size trends in the Upper Midwest show a uni-directional thinning and fining of loess away from the outwash-bearing river systems (Krumbein, 1937; Smith, 1942; Waggoner and Bingham, 1961; Ruhe, 1969 and Fehrenbacher et al., 1986).

However, west of the Mississippi, in Southeastern Minnesota and northeastern Iowa the mechanisms of loess deposition were different. Two geomorphic regions are covered by loess, but within different thicknesses. The westernmost region, known as the Iowan Erosion Surface (Ruhe, 1969) is a highly weathered Pre-Illinoian till plain mantled by < 1m of loess. In Minnesota, it is bound on its western side by Wisconsinan aged Des Moines Lobe till and on its eastern side by the Thick Loess Province (Figure C1 - 3). The Thick Loess Province is situated between the Iowan Erosion Surface and the Mississippi River.

The loess thickness trend in the Thick Loess Province is opposite to the midwest archetype. Moving west from the Mississippi, the loess *increases* in thickness until an abrupt decrease at the Iowan Erosion Surface. On the western edge of the thick Loess Province, loess can reach up to 10 m thick (Mason et al., 1994). Loess along the western edge of the Thick Loess Province is often interbedded with sand (Personal observation, David De Bonis; Calvin, 1911; Leighton, 1917 and Ruhe, 1969) suggesting strong aeolian activity. The thickness trends and great distance from a major meltwater river system (capable of supplying the sediment) suggests that the loess was derived from Wisconsinan periglacial zones west of the Thick Loess Province (Mason et al., 1994). Some of the loess may have been derived from the Iowan Erosion Surface itself (Hanson, 1976).

Residuum

The Rountree formation is a residual clay composed of varying thicknesses. The formation is composed of an upper strata of dark reddish brown (5YR 4/3) clay with strong, fine, angular blocky structure and a lower strata of dark brown to strong brown (7.5YR 4/4 to 4/6) clay with strong, coarse, platy structure.

The red clay residuum of the Rountree formation contains chert pebbles and cobbles within the matrix (Frolking et al., 1983). The exact age of the Rountree formation is not known, however, superposition indicates that it is older than all of the previously mentioned loess deposits. Knox (1982) suggest that the Rountree is not likely to be very old (Pleistocene or younger) due to the extreme periods of erosion and mass wasting during Pleistocene periglacial environments.

Windrow Formation

The Windrow formation was first described by Thwaites and Twenhofel (1921) as "quartz and chert pebbles in a matrix of quartz sand and brown iron oxide, iron oxide cemented sandstone, concretionary limonite, an at some localities blue and white sticky clay." It is a Cretaceous fluvial deposit with patchy clay lenses presumably formed in lagoonal or backwater areas.

Till

Southwestern Wisconsin was not glaciated during the Quaternary. However, in Southcentral and Southeastern Minnesota, tills from at least two glacial periods can be found. In the southcentral portion of the state, Wisconsinan aged till from the Des Moines Lobe extends into central Iowa. East of the Des Moines Lobe, three zones of till are separated by roughly by north-south lines: Thick drift zone, thin-drift zone and old-drift zone (Hobbs, 1992). The thick-drift zone, which lies adjacent to the Des Moines Lobe till, is covered by a thick calcareous Pre-Illinoian till. The thin-drift zone is characterized by thin to patchy areas of Pre-Illinoian till. Till on the old-drift zone covers < 20% of the total area and may be from several different glaciations (Hobbs, 1992).

Landscape Evolution

West of the Mississippi (Sikkink study site)

Although the area west of the Mississippi in Southeastern Minnesota has often been included as part of the Driftless Area, evidence of Pre-Illinoian tills and erratics have been found a numerous locations. (Knox et al., 1992) suggest the Mississippi River as a reasonable western border of the Driftless Area.

In Southeastern Minnesota, the Peoria loess does not follow Upper Midwest loess paradigm. Both mean grain size (Figure C1 - 4) and thickness (Figure C1 - 5) *increase* with distance from the Mississippi River, indicating that the Mississippi was *not* the source of this loess. Its maximum thickness of 10 m occurs about 100 km west of the Mississippi at the eastern edge of the Iowan Erosion Surface. The Roxana loess follows the midwest paradigm of decreasing thickness and median grain size with distance from the river, suggesting that the Mississippi *was* the source of the loess. Its maximum thickness of < 1 m is found adjacent to the Mississippi River and thins towards its western extent near Caladonia in Houston County, Minnesota. While it is found on both sides of the Mississippi, it is less common in Southeastern Minnesota than in areas east of the river (Personal Observation, Ed Nater).

During the late-Wisconsinan glacial period, the landscapes of Southeastern Minnesota underwent numerous episodes of extreme periglacial erosion. In many areas, particularly in the western portion of the Thick Loess Province, the landscape was eroded to the underlying sandstone and limestone bedrock. Nearly all of the older loess units, glacial tills and residuum were removed. The Wyalusing and Loveland loesses have not clearly been identified in Southeastern Minnesota. However, paleosols formed in Pre-Wisconsinan materials have been described in Houston County (Lively et al., 1987). The residuum thickness is highly variable across the region. It tends to accumulate in sinkholes and bedrock lows and is thin on adjacent bedrock highs (Hobbs, 1992). The texture of the residuum ranges from clay to sandy clay. Areas of sandy clay are found over or downslope from sandstone bedrock.

East of the Mississippi (Lancaster study site)

The Driftless Area is confined to Southwestern Wisconsin and northwestern Illinois (Figure C1 - 6). This area was not overridden by Quaternary ice sheets, but was affected by periglacial processes including mass wasting and cryoturbation (Slater and McSweeny, 1992). The Rountree formation underlies the loess in most parts of the Driftless Area (Knox et al., 1990). The thickness and distribution varies with slope gradient, bedrock type and interfluve width. It is thickest on wide, flat upland interfluves (Knox, 1992) and on dolomitic bedrock containing high concentrations of chert (Knox et al., 1992). Erosion of the Rountree left stone lines which armored the residuum from further erosion. Frolking et al., (1983) observed that chert pebbles and resistant cobbles of dolomite are often present at the contact between the residuum and loess. In some cases, the stone lines can reach a thickness of 0.5 m. Knox et al. (1992) attribute the relationship between high chert content and thick Rountree to intense periglacial mass wasting and fluvial erosion during the repeated climate changes of the Pleistocene (Knox, 1992).

The existence or absence of each loess formation at a given point is dependent upon age, topographic position and distance from source. The thickest loess (12m) is found adjacent to the Mississippi (Leigh and Kn(1993). Loess thickness and median grain size systematic diminish eastward (Figure C1 - 7), suggesting that the Mississippi ver was the predominant source of the loess.

The Wyalusing, Loveland and Roxana were eroded from most of Wisconsin (Leigh and Knox, 1994). The maximum thicknesses of each unit are comparable: Wyalusing - 2. m; Loveland - 2.0 m and Roxana - 1.5 m. In a study conducted mainly in Southwestern Wisconsin, Leigh and Knox (1994) described 60 soil cores on the crests of convex interstream divides. The presence of the different loess deposits was as follows: Peoria 100%, Roxana 53%, Loveland 20% and Wyalusing 7%. The Peoria was the only loess found on steep hillslopes. The absence of the Wyalusing, Loveland and Roxana formations from steep hillslopes and their minimal presence on stable portions of the landscape indicates a highly erosional environment at some time since the deposition of these loesses. Leigh and Knox (1994) speculate that the absence of early and middle Pleistocene loess deposits (Wyalusing and Loveland) were a result of periglacial hillslope erosion caused by close proximity to the Laurentide ice sheet.

MAGNETIC INDUCTANCE RESISTIVITY

Theory

A separate objective of this study was to investigate the utility of magnetic inductance resistivity (MIR) a means for mapping the near surface stratigraphy. The following discussion ed upon Geonics Limited Technical Note TN-6 (Mc Neil, 1980).

The instrument contains a transmitter coil (Tx) and a receiver coil (Rx) which are separated by an intercoil spacing (s) of 3.67 m (Figure C1 - 8). The transmitter emits an alternating audio frequency that induces small magnetic currents within the earth. These currents generate a primary (Hp) and secondary (Hs) magnetic field that can be read by the receiver. The ratio of Hs to Hp is linearly related to the ground conductivity (σ) by:

$$\frac{Hs}{Hp} \cong \frac{i\omega\mu_0\sigma s^2}{4} \qquad (1)$$

where $\omega = 2\pi f$, f = frequency (Hz), μ_0 = permeability of free space, σ = ground conductivity (mho/m), s = intercoil spacing, and i = square root of -1. Using the relationship between Hs and Hp in equation 1, the apparent ground conductivity (σ_a) is given as:

$$\sigma_a = \frac{4}{\omega\mu_0 s^2}\left(\frac{Hs}{Hp}\right) \qquad (2)$$

and is measured in mmho/m.

The intercoil spacing (s) of 3.67 m ws the EM31 to measure conductivity throughout the entire profile to a maximum depth of ≈ 6 m in the vertical dipole mode and 3 m in the horizontal dipole mode. The depth of the reading is always measured at a constant distance from the instrument, depending on dipole configuration. The measurement depth in either dipole mode can be changed by lifting the instrument to specific heights above the ground. To measure 2 m below the surface with the vertical dipole, the instrument is raised 4 m above the ground. Similarly, to measure 3 m below the surface, the instrument is positioned 3 m above the ground (Figure C1 - 9).

The ability to remotely read ground conductivity at varying heights above the ground surface is due to two characteristics of the EM31: 1) all current flow is horizontal and 2) current flow is spatially independent. If the current flow were not spatially inde nt the current would not be ble to pass through air, which has a conductivity ≈ 0. Additionally, the elative contribution to the secondary magnetic field (Hs) from any depth (z) can be determined for the vertical and horizontal dipole modes by the functions ϕ_v (z) and ϕ_h (z) respectively (Figure C1 - 10, (a)).

Cumulative response curves (Figure C1 - 10, (b)) derived from ϕ_v (z) and ϕ_h (z) simplify calculations for a multi-layered earth (more than one strata present). The function

$$R_{V,H}(z) = \int_z^{\infty} \Phi_{V,H}(z)dz \qquad (3)$$

is defined as the relative contribution to the secon-' y magnetic field or apparent conductivity for all the material below a d' pth z. The cumulative response curves show the relative contribution of material below a certain point. For example, the relative contribution of all material below 2 intercoil spacings for the vertical dipole mode is ~5% Knowing the contribution at each depth to the total response pe. ts a determination of the thickness of each strata present.

Applications

The EM31's ability to detect small changes in ground conductivity has led to numerous applications (Table C1-1). The applications distinguish between materials or strata having differences in conductivity.

III. OBJECTIVES

There are two main objectives for this portion of the study:

1. Determine the near-surface stratigraphy for two study sites in the karst region and to construct a three dimensional spatial database of soil strata at detailed (~ 1:10,000) scale for interpretation of hillslope water movement within the vadose zone.

2. Assess the efficacy of magnetic indu ınce resistivity (MIR) as a means of rapidly determining the thickness and depths of major near-surface stratigraphic units.

IV. METHODS

Study Site Descriptions

Sikkink

The Sikkink farm is located in Fillmore County (Figure C1 - 11), Minnesota, 1.5 km east of Cherry Grove (Fi C1 - 12). This site was ' ·sen due to our knowledge of the soils on the site from previous studies.

The general Stratigraphy for Fillmore County is provide in (Figure C1 - 13). The Sikkink farm is situated at a geomorphic transition zone. The western half of the farm lies on the Iowan Erosion Surface (< 1 m of loess) and the eastern half in the Thick Loess Province (1 to 10 m of loess). Mason and Nater (1992) described soil profiles at the Sikkink site: one on the Iowan Erosion Surface (Figure C1 - 14) and one on in Thick Loess Province (Figure C1 - 15). A sharp contrast in topography and stratigraphy exists between the two regions. The topography of the Iowan Erosion Surface is characterized as flat to gently rolling with little stream incision, while the topography of the Thick Loess Province is characterized by deeply incised stream valleys with steep slopes and rocky bluffs (Farnham, 1954). The change in topography is evident in the areas surrounding the Sikkink farm (Figure C1 - 12).

On the western half of the farm, a thin l^ess cap (< 1 m) is underlain by a highly eroded Pre-Illinoian till plai: :h is underlain by the Cedar Valley limestone (Figure C1 - 13). The til. ın this area is often absent, especially on high slopes. The stratigraphy of the eastern half of the farm consists of up to 10 m of Peoria loess over residual clays over karstic Cedar Valley limestone. The residual clays are < 0.5 m thick and are discontinuous across the land. ıpe. A few sections of the farm contain the Windrow formation. It is found on stable landscape positions where periglacial erosion was less effective.

Lancaster

The second study site is located at the University of Wisconsin Agricultural Field Station in Grant County, Wisconsin (Figure C1 - 16). It is situated 6.5 km west of Lancaster, just off highway 35/81. This site was chosen to collaborate with the other researchers in the overall study.

Galena dolomite, Decorah dolomite and shale, and Platteville dolomite formations underlie most of the county (Figure C1 - 17). Geological maps by Heyl et al. (1955) and Hole (1952), show the Galena formation as the uppermost stratigraphic layer. The Galena formation characteristically contains a chert line between the dolomitic bedding planes. Inclusions of the St. Peter Sandstone are often close or adjacent to the bedrock/soil interface especially in deeply cut stream valleys. Weathering of the Galena dolomite has produced karst topography in much of the county.

The landforms are characterized as dissected plateaus with fairly broad, rolling ridges and steep-sided valleys (Grant County Soil Survey, 1951). Pleistocene fluvial erosion dissected the area producing ridge and ravine topography (Frolking, 1989). Some areas have over 90 m of relief (Grant County Soil Survey, 1951). A dendritic drainage pattern with short feeder streams has developed throughout the county. Many of these streams are intermittent, carrying water only during peak runoff. The hillslopes usually have a series of incised drainageways and interfluves that run parallel to the predominant slope direction (Figure C1 - 18). The general stratigraphy at the study site consists of 1 to 4 m of Peoria loess over 0 to 1 m of Roxana loess over 0.5 to 2 m of Rountree formation over karstic Galena dolomite.

Sampling Strategy

Soils

We sampled and described 28 soil profiles to a depth of 4.75 m during the summer of 1994. Sampling transects traversed a stream valley and included both thin and thick loess deposits (Figure C1 - 12). Soil cores were extracted at 30 m intervals along the sampling transects. These transects were designed to test of the MIR's ability to accurately discern differences in loess and residuum thickness. Both transects were run parallel to the slope. The soil was sampled and described to the effective depth range of hydraulic probe (4.75 m) or refusal, which ever came first. Refusal depth is the point at which the hydraulic probe can not further penetrate the profile. The refusal was either due to bedrock, in which case the entire core was sampled, or impedance by large rocks within the soil matrix. The later case is not a problem with in the loess formations as they are virtually rock free. However, chert bands, stone lines and limestone fragments associated with the residuum can obstruct the probe.

The following characteristics were described for each core: 1) depth of each major horizon 2) soil matrix color 3) size, type and grade of soil structure 4) size, abundance, contrast and color of soil color mottles features 5) soil texture and 6) effervescence with 1 M HCl. The profile descriptions were used to determine the depth and thickness of the Peoria loess and residuum. The Roxana, Loveland and Wyalusing were not found. In some cases, pedogenic mixing of the residuum with other materials produced clayey textures: sandy clay, sandy clay loam and clay loam. For the purposes of the MIR analysis, these strata were included with the residuum.

In the summer of 1994, 40 soil cores were sampled and described at the l [illegible]ster site with a truck mounted hydraulic probe. The core sampling pattern was laid out to cover the topographic variability found on hillslopes. Transects were laid out both parallel and perpendicular to the major hillslope elements. First, transects were run along the crests of the interfluves and the base of the drainages to provide data on the lowest and highest hillslope positions. Next, transects were run perpendicular to the interfluves and drains to provide data on the intermediate hillslope positions. The geographic coordinates of each soil sample was determined with a Differential Global Positioning System (DGPS). The hand held unit compares time signals received by multiple satellites to a highly accurate internal clock to calculate distances and triangulate its geographical location (Hunn, 1989).

Each soil core was described using the same characteristics as those at the Sikkink site. Major horizon depths from the profile descriptions were used to determine the thickness of the following stratigraphic layers for each core: 1) Peoria Formation 2) Roxana Formation and 3) Rountree Formation. The Loveland and Wyalusing Formations were not found. Determining the thickness of the clayey residuum was problematic. Refusal depth in many of the cores was due to impedance by a chert line, stone line or limestone fragment rather than the bedrock. For the purposes of the study, the lower boundary of the residuum is the point at which the probe was refused and may not accurately reflect the total thickness of this particular strata.

Topography

The elevation of the sampling transects were surveyed at the Sikkink Farm using a Geodimeter (electronic ground surveying device) (Figures C1 - 19 and C1 -20). All geographic coordinates were surveyed relative to one of the sampling locations.

A topographic survey of the Lancaster site was conducted in the spring of 1994 using a Geodimeter. Relative elevations were measured at 760 points across the 30-ha site. A topographically-referenced survey method was used to select specific survey locations as discuss by Carter (1988). Measurements were taken on major landforms and breaks in slope between them to insure that significant, but minor landforms were not omitted. The elevation observations were interpolated into a regular 10-m grid using a kriging procedure (Royle et al., 1981) to create a digital elevation model (DEM) of the topographic surface (Figure C1 -21). Using a USGS Geodetic Marker as a reference, the coordinates were transformed to Universal Transverse Mercator coordinates and elevations above mean sea level.

Three dimensional database

A three-dimensional, geographic, database of topographic and major stratigraphic surfaces was constructed to elucidate changes in near-surface stratigraphy as a function of hillslope position. This involved the generation of raster (cell-based) models for the following surfaces:

- topographic surface (as previously discussed)
- Upper boundary of the Roxana Loess (where present)
- Upper boundary of the clayey residuum (where present)
- Depth of auger refusal (bedrock or rock fragment contact)

The horizontal resolution of these interpolated surfaces was 10-m (grid-cell size) with a vertical resolution of 0.1 m. Information on the depths to soil stratigraphic layers was obtained from the 40 soil core that were described across the hillslope. The geographic coordinates of each soil core (obtained with a DGPS receiver) were used to determine the ground surface elevation by overlaying the sampling points with the digital elevation model of surface topography. Consequently, the relative elevation of each soil stratigraphic layer was found by subtracting the measured depth to a stratigraphic boundary from the surface elevation. A simple bilinear interpolation was used to generate the surfaces for the subsurface strata. A geostatistical approach was not used, as with the surface elevations, due to profound differences in the sampling density for surface elevations vs. soil core descriptions.

This three-dimensional, digital database was stored in file formats appropriate for the KHOROS image processing system and the Earth Resource Data Analysis System (ERDAS) to facilitate spatial analysis and data visualization. A profile sampling tool in KHOROS was used to sample the three-dimensional database along specific hillslope transects to provide two-dimensional views of soil stratigraphy both along and perpendicular to the drainageways and interfluves of the hillslope.

Magnetic Inductance Resistivity

Field Sampling

In the summer of 1994 and the spring of 1995, magnetic inductance resistivity measurements were taken for selected soil sampling locations and transects at the Sikkink and Lancaster sites. Two methods were used to gather the data. In each method, data were collected in the vertical dipole mode. The preference for the vertical dipole mode was made for three reasons. First, the EM-31 measures the same response (at a given depth) whether it is in the vertical or horizontal mode. Second, The horizontal dipole can not read conductivity at depths greater than 3 m and many of the profiles were deeper. Third, the ease of operation and data analysis was greatly increased since only one setting was used.

The point method was used to collect conductivities at 8 depths below a soil sampling site. The depths started at 6 m and decreased by 25 cm increments. To ensure the accuracy and consistency of the height which the EM-31 was lifted above the ground, a ladder was constructed. Holes were drilled into each side of a 10-ft section of PVC tubing in 25 cm increments. Two rubber bungee cords with 'S hooks' at each end were attached to the EM-31. At each soil sampling site, the PVC tubing was erected and the EM-31 was lifted to the desired height above the ground. To steady the instrument, the S hook of each cord was inserted into the corresponding set of holes for a particular height. A measurement was recorded with a digital data logger. This was repeated for the next 7 heights above the ground.

Using the auto method, the EM31 is lifted to a constant height above the ground and records a data point at a user defined time interval (1 data point/ # sec). The auto method allows a continuous conductivity measurement while walking along the transect. The time interval for all of the auto measurements was 1 data point/sec. The transect was walked at a steady pace and soil sampling sites were marked by the data logger as they were passed. This enabled us to relate the continuos data stream back to the soil sampling sites.

In 1994, the point method was used to collect data at each soil sampling site along two transects at the Sikkink site (Sikkink: Transects A94 and A95) and three transects at the Lancaster site (southern, southwest drainage and northwest drainage). At the Sikkink site the two transects traversed from the Thick Loess Province to the Iowan Erosion Surface. This provided a large difference in loess thickness across the transect. At the Lancaster site, two of the transects were traversed down drainages. This provided data on the areas where water is concentrated during rain events. The next transect was run perpendicular to the slope across the interfluves and drainages This provided a range of hillslope positions within the same transect. In 1995, the soil sampling sites along the two Sikkink transects were resampled using the point method (Transects A95 and B95). In addition, the entire length of each transect was sampled using the auto method (Transects A95-auto and B95-auto).

Data Analysis

The data was interpreted using Interpex EM34+ software. The software has the ability to calculate thicknesses and conductivities for a known number of strata. A first approximation of the conductivities for each strata is made by entering the known thicknesses of two or three cores along the transect. Once this is complete, the estimated conductivities are transferred to the remaining unknown cores. A forward iteration is performed and the percent fit of each core is checked to make sure it is less than 50%. The average conductivity of each strata is calculated and reapplied to each core along the transect. A series of iterations is performed to calculate the thicknesses of each strata. The measured results were compared to the MIR-predicted results to ascertain the accuracy of the application.

IV. RESULTS AND DISCUSSION

Evaluation of Near-Surface Stratigraphy

Sikkink

Topography

The regional topography near the Sikkink site was discussed in a previous section. Figure C1 - 20 depicts the relative elevations along soil sampling transects A and B. Elevation points were taken at each soil sampling location. Both transects have 25 m of relief and are asymmetrical in shape. Using the stream as a dividing line, the northern (transect A) and western (transect B) sections have a steeper slope gradients and lower slope curvatures than their corresponding southern and eastern sides. The western section has a steeper slope gradient and has a lower slope curvature than the eastern section.

Stratigraphy

The sampling transects cross two distinct geomorphic regions are represented at the Sikkink farm: the Iowan Erosion Surface (loess < 1 m) and the Thick Loess Province (loess > 1 m). Each transect starts from the Thick Loess Province and finishes on the Iowan Erosion Surface. The loess is thickest on the southern and eastern portions of Transects A and B respectively (Figures C1 - 22 and C1 - 23). Moving upslope on the southern and eastern portions of Transects A and B, the loess thickness remains relatively constant to a point where it sharply increases about midslope.

Just north of the stream on Transect A, the loess thickness increases. From about half way up the northern slope to about 15 m from the stream, limestone flags are found on the surface and within the loess matrix. The presence of the limestone flags within and on top of the loess indicates mixing by mass movement. The loess/colluvium deposit is most likely deeper than what was observed during the core descriptions due to the inability of coring devices to pass large limestone fragments within the matrix.

The residuum was composed of a yellow (10YR 7/6) clay to clay loam with massive structure. It is very thin (< 0.20 m) to absent on most portions of the Sikkink farm. Most of Transect A is devoid of residuum. Where it does occur, it is found in concave depressions in the bedrock topography (Figure C1 -22). These areas represent a change to lower slope environments that may have initiated deposition of the residuum during solifluction, creep or slopewash. The residuum in this case may not actually be formed *in situ*, but be reworked material from higher landscape positions. Much of the surviving residuum in this area has probably accumulated in dolines, bedrock fractures or on stable landscape positions such as summits and interfluves.

The residuum thickness is very thin (< 0.20 m) over most of transect B, but was found to be thicker (1.7 m, 0.8 m, 2.2 m (reworked clays) and 0.8 m) at four of the soil sampling sites. The thicker residuum was found on stable or accumulational areas of the landscape (Figure C1 -23) where erosion is lower due to a low (0-3%) slope gradients. On Transect B, a deposit sandy clays over a gravely clay loam is found just east of the stream. Given the location of this deposit, it is most likely alluvial materials, possibly reworked Windrow formation.

Hydrology

The transport and ultimate fate of potential agricultural contaminants is dependent upon the pathway and rate at which water moves through the soil and eventually encounters groundwater and/or surface water systems. Conceptual and analytical models that assume vertical, uniform soil water flow from the soil surface to the bedrock or water table surface may be grossly inaccurate and lead to false conclusions regarding contaminant transport. While the biogeochemical processes occurring in the upper few centimeters of soil are important in terms of chemical transformations, the stratigraphy of underlying soil materials can profoundly affect: (i) the redistribution and subsequent concentration of water-born contaminants within the landscape and (ii) the points of entry into surface and ground water systems.

Substantial changes in soil texture for adjacent soil strata frequently causes the development of a saturated soil zone above the contact. If the strata are inclined, then lateral flow is likely to develop causing a redistribution of the soil water and associated contaminants. At the Sikkink site, silty loess overlies a thin layer of clayey residuum. The clayey residuum has a massive structure and would transmit water at a much slower rate that the overlying silts. Hence, we would expect soil water to accumulate above the areas where the clayey residuum is present and to flow laterally in the downhill direction. This assumption is further supported by soil morphological evidence. Redoximorphic features, such color mottling, associated with periodically saturated soils were found in the silty loess directly above the clayey residuum contact suggesting that the silty loess had been periodically saturated. The clayey residuum may effectively seal the bedrock surface and prevent entry of the soil water into bedrock fissures where the clayey residuum is present. Therefore, areas without clayey residuum represent areas of possible contaminant entry into the bedrock fissures and associated groundwater systems.

Field investigations at the Sikkink site indicate that the clayey residuum is discontinuous across hillslopes (Fig. C1-23). As such, we would expect soil water to move vertically through the soil profile until the clayey residuum is encountered. Some degree of lateral flow is likely above the clay with possible entry into limestone bedrock (probably via fissures) on sections of the hillslope where the clayey residuum is absent. On areas of the hillslope where the clayey residuum is more consistent, we would expect that the lateral flow above the clay would cause direct discharge into the valley stream. If we generalize the extreme situations, for hillslopes with continuous clayey residuum beneath the loess, we would expect soil water to be diverted downslope via lateral flow above the clay and discharge (return flow) into surface stream systems. Alternatively, if no clayey residuum were present, we would expect soil water to enter bedrock fissures along the hillslope and flow into the groundwater systems associated with the karst bedrock. Direct measurements of soil hydrology were beyond the scope of this project, therefore, subsurface flow estimations are speculative and are based on our direct observations of near-surface stratigraphy. We also assume that the development of pedogenic soil horizons in the upper meter of the loess-derived soil do not cause significant later flow; this assumptions is supported by soil morphology as well (absence of large textural and/or structural discontinuities in upper horizons and absence of elluvial horizons).

Lancaster

Topography

The general topography of the Lancaster study site is similar to the surrounding network of incised valleys. The study site is located on a hillslope that has three interfluves separated by two drainages (Figure C1 - 21).

Stratigraphy

A 3-dimensional database of the hillslope stratigraphy relative to the topographic surface was created and stored in a geographic information system. In order to discuss specific hillslope-stratigraphic relationships, we sampled the transects as depicted in Figure C1 -21. The soil stratigraphy for these transects is shown in (Figures C1 - 24 through C1 - 29).

Peoria loess was found on every portion of the hillslope (Figure C1 - 30). It is thickest on the summit positions (Figure C1 - 29) and interfluves (Figure C1 - 25). It thins from these areas towards the lower hillslope positions. Roxana loess was found mainly on interfluves, heads of drainageways and summits (Figure C1 - 31), and was present in 30% of the soil samples (Figure C1 - 31). However, it was not found on the southwest interfluve or in the lower portions of drainages. Residuum was found at 90% of the core sites (Figure C1 - 32) and is thickest on upper portions of the northwest interfluve (Figure C1 - 26). Residuum thickness thins towards the footslope and in some places, such as the backslope of the northwest interfluve, it is totally absent. In contrast, the residuum thickness on the middle and southeast interfluves stays relatively constant from summit to toeslope with minor deviations at the toe slope (Figure C1 - 26 and C1 - 29).

Hydrology

Three major stratigraphic units were identified: (i) Peoria Loess, (ii) Roxana Loess, and (iii) clayey residuum. The Peoria and Roxana loess have similar particle size distributions and redoximorphic features (evidence of periodic saturation) were not found above the boundary between the Peoria and Roxana Loesses. This suggests that significant lateral flow did not develop at the contact of the two loess deposits. However, the profound differences in particle size between the silty loesses and the clayey residuum coupled with the presence of redoximorphic features above the clayey residuum contact suggest that lateral flow occurs above the clayey residuum, as at the Sikkink site. Additionally, the Peoria loess was saturated in some of the soil cores directly above the contact with the clayey residuum providing direct confirmation. As previously discussed, clayey residuum was found at approximately 90% of the 40 soil sampling sites on the hillslope (Fig. C1-30) and that the topography of the clayey residuum surface closely follows the modern surface topography (Figs. C1-24(a) - C1-29(a)). Hence, we would expect subsurface patterns of lateral flow above the clayey residuum to follow surface drainage patterns. This would tend to concentrate subsurface flow in the drainageways and shed flow from narrow interfluves. A general trend found in the drainageways was that the clayey residuum and Roxana Loess were not present in the lower reaches of some drainageways and on convex, shoulder positions (Fig. C1-24). This is probably due to fluvial erosion processes on the paleo-surfaces. Convex surfaces are inherently more erodible and as surface flow is concentrated in the drainageways the flow becomes more erosive and, over time, the residuum and Roxana loess were removed from these portions of the landscape. This removal would have occurred prior to the deposition of the Peoria Loess. The lack of residuum makes these areas potential points of entry into the groundwater system. The convex surfaces probably of little concern because significant flow does not accumulate in these areas, however, concave drainageways can accumulate a large portion of both the surface and subsurface flow.

Landscape Evolution

During the Pleistocene, episodes of fluvial erosion dissected the area producing ridge and ravine topography (Frolking, 1989). A clay-rich soil formed from the Galena dolomite included the Rountree Formation as a C horizon. Fluvial erosion and mass wasting removed the solum, leaving a truncated C horizon at some places in the landscape. This is the clayey residuum described in the previous section. The clayey residuum was preserv: d over much of the landscape. It is thickest on stable interfluves and areas with low slopes. The thinnest sections are at the ends of drainages and areas with steep slope. In some locations, a paleosol is evident by strong angular blocky structure in the top portion of the Rountree. It is important to realize that the current topography does not exactly correlate to the paleotopography of the underlying strata. However, in most cases, the larger features in the current topography do correlate to the bedrock topography. Features such as very small drainages may be current features.

Two different loess depositions occurred during the Illinoian. First, the Wyalusing and then the Loveland. Both were deposited over parts of the region, but much of the extent and thickness of each have been erased due to extreme erosion during the late Illinoian. Although deposits have been found on a handful of stable interfluves and divides, these deposits have been almost completely eroded. Over small distances, loess deposition is uniform. It can be inferred that up to several meters of each aeolian deposit was eroded from unstable hillslope positions such as drainages and backslopes.

The next deposit was the Roxana loess which was deposited between 55,000 and 27,000 B. P. The slow deposition of the Roxana allowed for two pedogenic events. First, a soil began to form within the Roxana loess. Second, it is likely that pedogenic processes were active upon the top portions of the Rountree, possibly contributing to the strong structure in the upper division.

Between 24,000 and 12,000 B. P, the Peoria loess was deposited over the entire area. Its thickness and distribution follows the general pattern of loess deposition in the Upper Midwest. Subsequent Holocene erosion has cut new drainages in the current topography that are not evident in the paleotopography.

Magnetic Inductance Resistivity

The observed near-surface stratigraphy was compared to the MIR-predicted loess and residuum thicknesses to assess the reliability and accuracy of MIR. A regression analysis was performed to quantify the relationship (Table C1 -2).

Sikkink

The correlations for the point method were variable between the loess and residuum (Table C1 - 2). All of the relationships between observed and MIR-predicted loess thickness were significant (a = 0.01), with R^2 values ranging between 0.66 and 0.94. The two transects sampled by the auto method, A95AUTO and B95AUTO, both showed significant relationships between the observed and MIR-predicted loess thickness with R^2 values of 0.64 and 0.91 respectively. Neither the point or auto method produced a significant relationship between the observed and MIR-predicted residuum thickness.

Observed versus MIR-predicted scatter plots for Transect A95 show that almost all of the MIR-predicted thicknesses for the residuum, and to a lesser extent for the loess, are higher than the observed values Figure C1 - 34). This relationship was seen in almost all of the other transects. No clear explanation can be given for the high MIR-predicted loess thicknesses. However, the higher MIR-predicted residuum thicknesses may be due to the inability of the coring device to break through a stone line or large limestone fragment within the residuum matrix. This would produce a thinner observed residuum thickness than what is actually present.

Lancaster

No significant relationships were found between the observed and MIR-predicted loess or residuum thickness. Measured versus MIR-predicted scatter plots for the southern transect showed no relationship (Figure C1 - 33).

Summary

The possible use of MIR for mapping near-surface stratigraphy is dependent upon its accuracy, reliability, ease of use, and time of operation. The accuracy of the MIR for predicting loess thickness was high at the Sikkink site (R^2 ranging between 0.64 and 0.94), but was low at the Lancaster site (R^2 ranging from 0.04 to 0.27). The MIR did not accurately predict the residuum thickness at either of the study sites. The reliability of the MIR-predicted stratigraphic thicknesses is unclear at this point due to very low correlations for both the loess and residuum at the Lancaster site compared to the Sikkink site. In contrast, the high correlations for loess thickness at the Sikkink site (R^2 ranging between 0.64

and 0.94) during 1994 and 1995 collections (transects A94 and A95; B94 and B95) supports the reliability of loess thickness prediction. The similarity between the stratigraphy at each site suggests that the correlations between observed and MIR-predicted strata thickness should be comparable.

The reason for the large inconsistency between the two sites is not clear. Two possibilities exist for explaining the inconsistencies. First, it is possible that the instrumentation was faulty during data collection at the Lancaster site. There was no way to check the validity of the data until it was processed by the EMIX 34+ software. The second possibility is that the MIR was functioning well, but was unable to measure the conductivities due to unknown characteristics of the stratigraphy. This seems unlikely due to the similarity between the three main strata at each site: Peoria loess, clayey residuum and dolomite or limestone.

Data interpretation suggests that loess thickness (in Southeastern Minnesota) can be determined with the MIR using either the point or auto method. There are two differences between the point an auto method. First, the point method takes 3-4 minutes per sampling station, while the auto method takes less than 2 seconds. Second, the point method is limited to discreet sampling points, while the auto method reads data at close intervals approximating a continuous measurement along an entire transect. At the Sikkink site, the correlations between the observed and MIR-predicted loess thicknesses were comparable for the point and auto methods. Transects A95 and A95AUTO both had significant relationships for the loess, with R^2 values of 0.64 and 0.67 respectively. Similarly, transects B95 and B95AUTO had significant relationships for the loess with R^2 values of 0.94 and 0.91 respectively. The auto method is easier to use, quicker and collects data over the entire transect.

VI. CONCLUSIONS

We determined the near-surface stratigraphy for one hillslope in Southeastern Minnesota (Sikkink site) and one hillslope in Western Wisconsin (Lancaster) that are underlain by karst bedrock. Direct observations of soil stratigraphy from deep soil cores indicated that the upper 1 to 5 meters were composed of deposits of loess (aeolian silts) which was underlain by a clayey residuum in most areas of the landscape and by limestone bedrock in other areas. Spatial patterns of the clayey residuum were discontinuous at both sites and evidence suggests that the residuum had been removed from the erodible portions of the paleosurface, which appeared to be very similar to the current topographic surface. Strong textural contrasts between the loess and residuum coupled with observations of soil redoximorphic features and the presence of saturated soils in some soil cores indicated that water was accumulating above the loess-residuum boundary. Because this boundary was frequently inclined on a hillslope, we speculated that soil water would be transported laterally and downslope above the clayey residuum resulting in a redistribution and concentration of soil water, and associated contaminants, to concave portions of the landscape. The extent of the residuum on a hillslope will determine the extent of lateral subsurface flow and whether soil water is diverted laterally to surface streams (continuous residuum) or moves vertically to the bedrock surface and enters bedrock fissures to the groundwater system (no residuum). Our observations indicate that near-surface stratigraphy can be quite variable in regions of karst bedrock (in Minnesota and Wisconsin) and may have significant impact on the pathways and residence time of water and associated contaminants in the soil and other unconsolidated sediments above bedrock. The development of ephemeral, shallow surficial aquifers, above the clayey residuum, may be quite widespread throughout the karst region. As such, in order to understand the eventual fate of agricultural contaminants, we must develop a clear understanding of the hydrology and potential biochemical transformations that may occur between the upper 50 cm of soil and the groundwater surface. This portion of the project determined the near-surface stratigraphy of each study site. Direct measurements of hydrology or biochemical transformations were beyond the scope of this research.

The use of magnetic induction resistivity (MIR) as a tool for rapid assessment of near-surface stratigraphy had mixed results. This approach appeared to be viable for predicting loess thickness at the Sikkink study site, but poor results were obtained at Lancaster. The correlations between observed and MIR-predicted loess thicknesses were comparable between the auto and point sampling methods.

LITERATURE CITED

Beven, B. B. 1983. Electromagnetics for mapping buried earth features. Archaeology 10:47-54.

Cameron, D. R., E. de Jong, D. W. L. Read and M. Oosterveld. Mapping salinity using resistivity and electromagnetic induction techniques. 1981. Canadian Journal of Soil Science 61:67-78.

de Jong, E., A. K. Ballantyne, D. R. Cameron and D. W. L. Read. 1979. Measurement of apparent electrical conductivity of soils by and electromagnetic induction probe to aid salinity surveys. Soil Science Society of America Journal 43:810-812.

Emilsson. G. R. and R. T. Wroblewski. 1988. Resolving conductive contaminant plumes in the presnce of irregular topography. Proc. of the Second National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. Las Vegas. pp 617-635.

Calvin, S. 1911. The Iowan drift. Journal of Geology 19:601-602.

Carter, J. R. 1988. Digital representations of topographic surfaces. Photogrammetric Engineering and Remote Sensing 54:1577-1580.

Farnham, R. S. 1954. Soil survey of Fillmore County, Minnesota. USDA-SCS, Washington, D. C.

Fehrenbacher, J. B., K. R. Olson and I. J. Jansen. 1986. Loess thickness in Illinois. Soil Science 141:423-431.

Frazee, C. J., J. B. Fehrenbacher and W. C. Krumbein. 1970. Loess distribution from a source. Soil Science Society of America Proceedings 34:296-301.

Frolking, T. A. 1989. Forrest soil uniformity along toposequences in the loess-mantled Driftless Area of Wisconsin. Soil Science Society of America Journal 53:1168-1172.

Frolking, T. A., M. L. Jackson and J. C. Knox. 1983. Origin of red clay in the loess-covered Wisconsin Driftless Uplands. Soil Science Society of America Journal 47:817-820.

Germeroth, R. M. and H. Schmerl. 1987. Jet-fuel from the ground up. Civil Engineering Feb-1987:64-66.

Hanson, B. V. 1976. The stratigraphy, provenance, age and depositional environment of east central iowa loesses. Unpublished Ph. D. dissertation. University of Iowa, Iowa City.

Hobbs, H. 1992. Paleozoic plateau of Southeastern Minnesota. In (E. A. Nater ed.) Soils geomorphology pre-conference tour book. Soil Science Society of America annual meeting, November, 1992.

Hobbs, H. C. and J. E. Goebel. 1982. Geologic map of Minnesota, quaternary geology, map S-1. Minnesota Geological Survery, Minneapolis.

Hunn, J. 1989. GPS: A guide to the next utility. Trimble Navigation, Sunnvale, Ca.

Kachanoski, R. G., E. G. Gregorich and I. J. van Wasenbeeck. 1988. Estimating spatial variations of soil water content using noncontacting electromagnetic inductive menthods. Canadian Journal of Soil Science 68:715-722.

Knox, J. C. 1982. Quaternary history of the Kickapoo and lower Wisconsin River valleys, Wisconsin. In (Knox, J. C. ed.) Quaternary history of the Driftless Area: 29th annual Midwest Friends of the Pleistocene meeting: Wisconsin Geological and Natural Survey Field Trip Guidebook 5, pp1-65.

Knox, J. C. and J. W. Attig. 1988. Geology of the pre-Illinoian sediment in the bridgeport terrace, lower Wisconsin river valley, Wisconsin.

Knox, J. C., D. S. Leigh and T. A. Frolking. 1990. Rountree formation (new). Appendix in "Geology of Sauk County Wisconsin" (L. Clayton and J. W. Attig, Eds.), pp 64-67. Wisconsin Geological Survey Information Circular 67.

Knox, J. C., D. S. Leigh and P. M. Jacobs. 1992. Modeling soil horizon stratigraphy, Pleasent Valley, Wisconsin. In (E. A. Nater ed.) Soil. geomorphology pre-conference tour book. Soil Science Society of America annual meeting, November, 1992.

Knuth, M. 1988. Complementary use of EM31 and dipole-dipole resistivity to locate the source of oil brine contamination: a case study. Proc. of the Second National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring, and Geophysical Methods. Las Vegas. pp 583-595.

Krumbein, W. C. 1937. Sediments and exponential curves. Journal of Geology 45:577-607.

Leigh, D. S. 1994. Roxana silt of the Upper Mississippi Valley: lithology, source and paleoenvironment. Geologic Society of America Bulletin 106:430-442.

Leigh, D. S. and J. C. Knox. 1993. AMS radiocarbon age of the Upper Mississippi Valley Roxana silt. Quaternary Research 39:282-289.

Leigh, D. S. and J. C. Knox. 1994. Loess of the Upper Mississippi Valley Driftless Area. Quaternary Research 42:30-40.

Leighton, M. M. 1917. The Iowan glaciation and the so-called Iowan loess deposits. Proc. Iowa Academy of Science 24:87-92.
Leverett, F. 1899. USGS Monograph 38.
Leverett, F. 1932. Quaternary geology of Minnesota and parts of adjacent states. Professional paper 161. U. S. Geological Survey, Washington, D. C.
Mason, J. A. and E. A. Nater. 1992. Loess stratigraphy in Southeastern Minnesota and northeastern Iowa. *In* E. A. Nater (ed.) "Soils geomorphology pre-conference tour book." Soil Science Society of America annual meeting, November, 1992.
Mason, J. A., E. A. Nater and H. C. Hobbs. 1994. Transport direction of Wisconsinan loess in Southeastern Minnesota. Quaternary Research 41:44-51.
McKay, E. D. 1979. *In* L. R. Follmer, E. D. McKay, J.A. Lineback and D. A. Gross (eds) Wisconsinan, Sangamonian, and Illinoian stratigraphy in Central Illinois,
McNeil, J. D. 1980. Technical Note TN-6: Electromagnetic terrain conductivity measurement at low induction numbers. Geonics Limited.
Mullern, C. R., L. Eriksson and C. Persson. Electromagnetic measurements for continuous or local assessment of depths and types of Quaternary deposits in profiles. In Proceedings of the international symposium on engineering geology and underground construction 71-80. Lisbon.
Peffer, J. R. and P. G. Robelen. 1983. Affordable overburden mapping using new geophysical techniques. Pit and Quarry Aug-1983.
R. S. Lively, E. A. Bettis III, G. R. Hallberg, and H. Hobbs. An exposure of the Sangamon soil in Southeastern Minnesota. Proc. Iowa Academy of Science 94:111-115.
Ritter, D. F., R. C. Kochel and J. R. Miller. 1995. Process geomorphology. Wm. C. Brown, Dubuuque, Iowa.
Royle, A. G., F. L. Clausen and P. Fredericksen. 1981. Practical universal kriging and automatic contouring. Geoprocessing 1:377-394.
Ruhe, R. V. 1969. Quaternary landscapes in Iowa. The Iowa State University Press. Ames, Iowa.
Ruhe, R. V., R. B. Daniels and J. G. Cady. 1967. Landscape evolution and soil formationin southwestern Iowa. Technical Bulletin 1349. United States Department of Agriculture, Washington, D. C. Simonson, R. W. and C. E. Hutton. 1954. Distribution curves for loess. American Journal of Science 252:99-105.
Sinah, A. K. and L. E. Stephens. 1983. Permafrost mapping over a drained lake by electromagnetic induction methods. Geological Survey of Canada Current Research Part A, Paper 83-1A:213-220.
Slater, B. K. and K. McSweeny. 1992. Modeling soil horizon stratigraphy, Pleasent Valley, Wisconsin. In (E. A. Nater ed.) Soils geomorphology pre-conference tour book. Soil Science Society of America annual meeting, November, 1992.
Smith, G. D. 1942. Illinois loess: variations in its properties and distribution. University of Illinois Agricultural Experiment Station Bulletin 490.
Thwaites, F. T., and W. H. Twenhofel. 1921. Windrow formation: an upland gravel formation of the Driftless and adjacent areas of the Upper Mississippi Valley. Geologic Society of America Bulletin 32:293-314.
Waggoner, P. E. and C. Bingham. 1961. Depth of loess and distance from source. The Connecticut Agricultural Experiment Station.
Worcester, B. K. 1973. Soil genesis on the primary divides of the southeastern Iowa loess province. Unpublished Ph.D. disertation, Iowa State University.
Zalasiewicz, J. A., S. J. Mathers and J. D. Cornwell. 1985. The application of ground conductivity measurments to geologic mapping. Quarterly Journal of Engineering Geology 18:139-148.

Figure C1 - 1 Cross-section of a solution doline From Ritter et al., (1995)

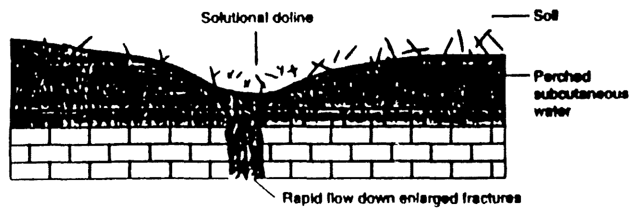


Figure C1 - 2 Formation sequence of a collapse doline From Ritter et al., (1995)

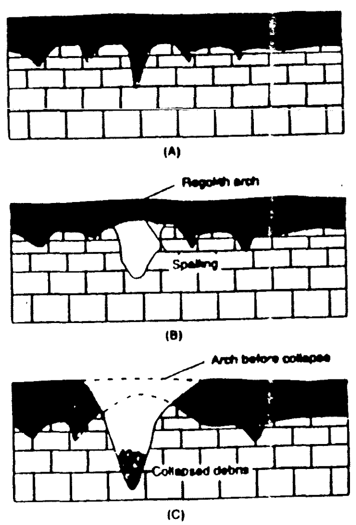


Figure C1 - 3. Des Moines Lobe, Iowan Erosion Surface and Thick Loess Province in southeastern Minnesota and northeastern Iowa. General loess thicknesses for each region is provided. Based on Leverett (1932), Ruhe, (1969), Hobbs and Goebel, (1982) and Mason et al., (1994).

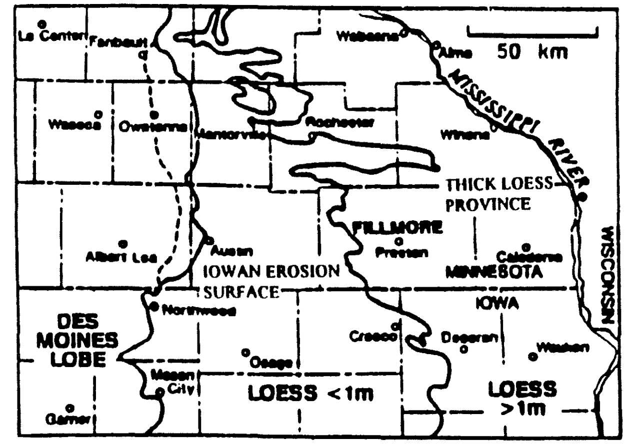


Figure C1 - 4 Coarse silt/total silt ratio for the Peoria loess in southeastern Minnesota. From Mason et al. (1994).

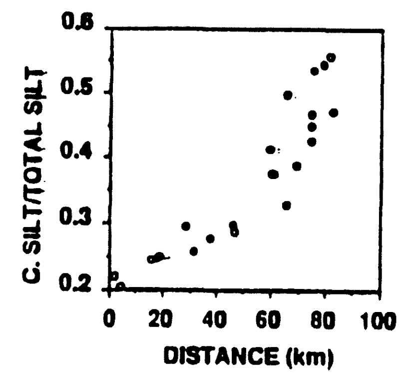


Figure C1 - 5 Peoria loess thickness as a funtion of distance from the Mississippi river.

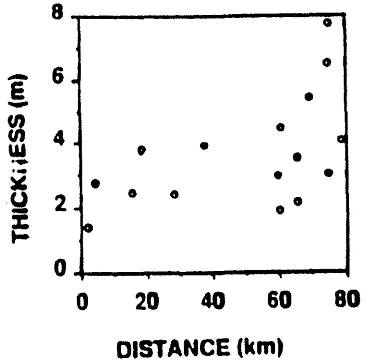


Figure C1 - 6 The Driftless Area in southwestern Wisconsin and northwestern Illinois. From Knox and Attig (1988).

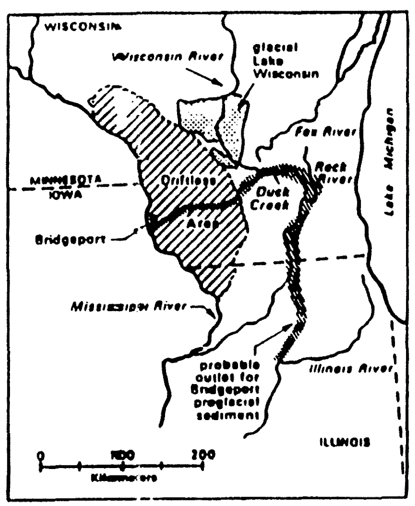


Figure C1 - 7. Loess thickness and median grain size east of the Mississippi river, Wisconsin. From Leigh and Knox (1994).

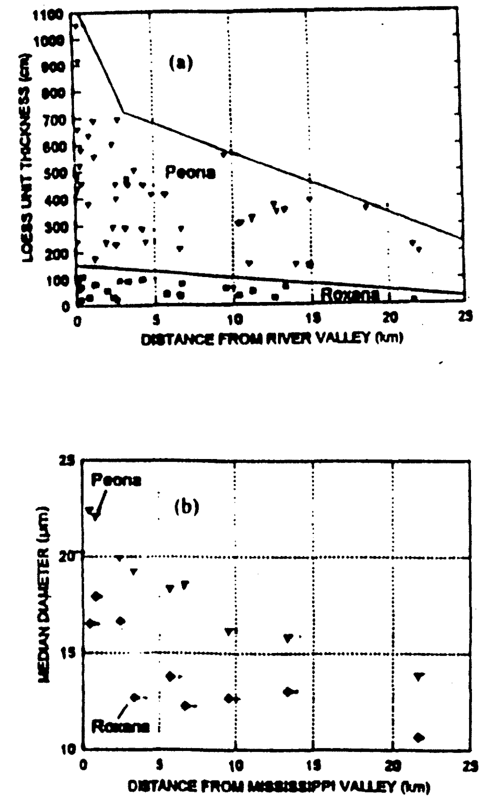


Figure C1 - 8. Diagram of the EM31.

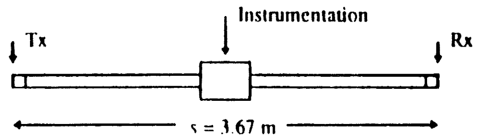


Figure C1 - 9. EM31 measuring depths. Notice the large differences in the conductivities of the four units: air, loess, residuum and bedrock.

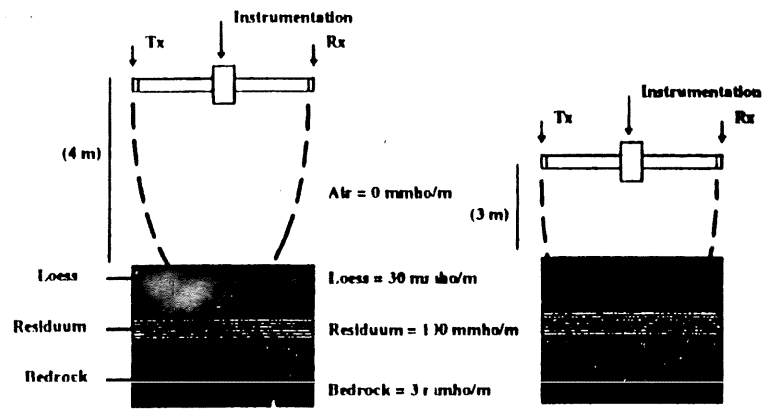


Figure C1 - 10. Comparison of the relative contributions (a) and the cummulative response with depth for for the verticle and horizontal dipoles. From McNeil (1980).

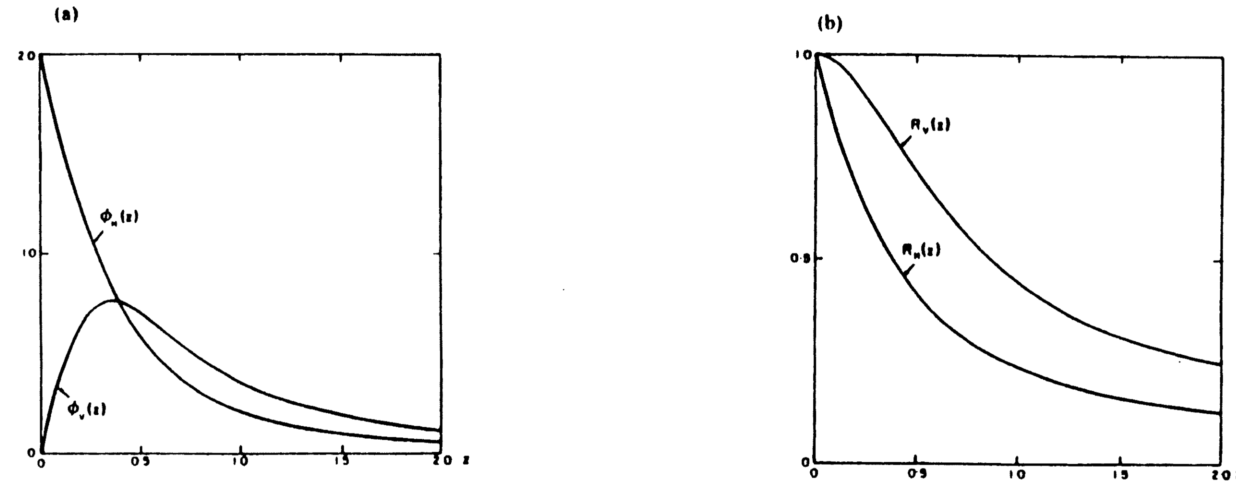


Figure C1 - 11. Location of Fillmore County, Minnesota.

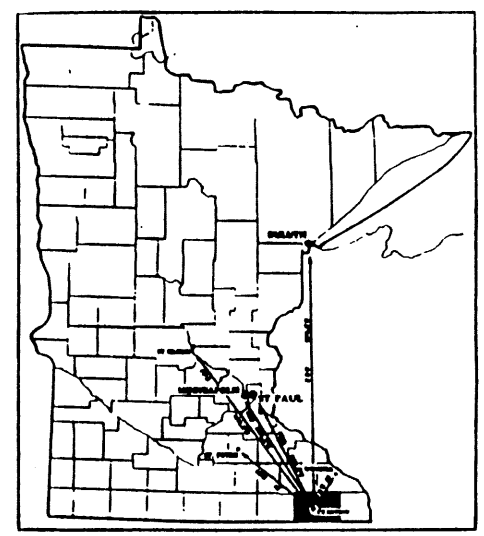


Figure C1 - 12. Topography and geomorphic regions near the Sikkink study site. Notice the sharp contrast in topography between the Thick Loess Province (TLP) and Iowan Erosion Surface (IES). Transect A and B are shown cross the stream valley paralell to slope. USGS Cherry Grove Quadrangle (1965)

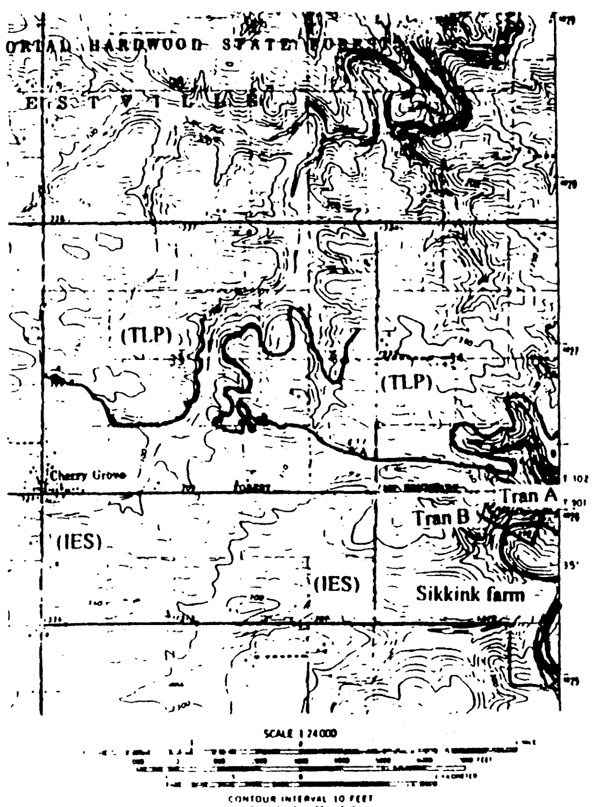


Figure C Geology and soils of Fillmore County, Minnesota. The general location of the Sikkink farm, Iowan Erosion Surface and Thick Loess Province are given. After Farnham (1954)

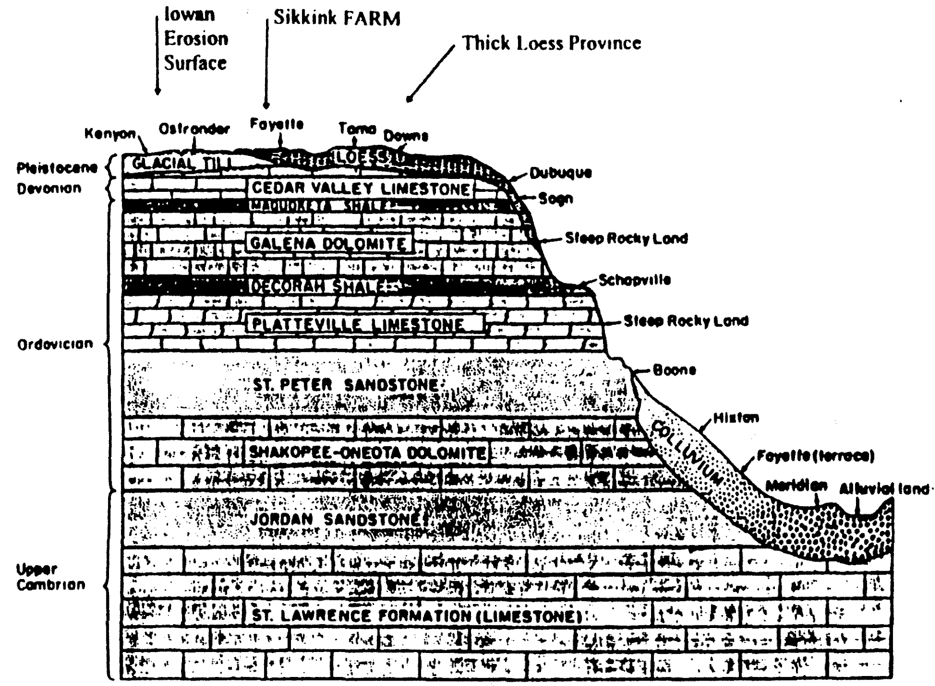


Figure C1 - 14. Soil profile at the Sikkink farm (Iowan Erosion Surface).

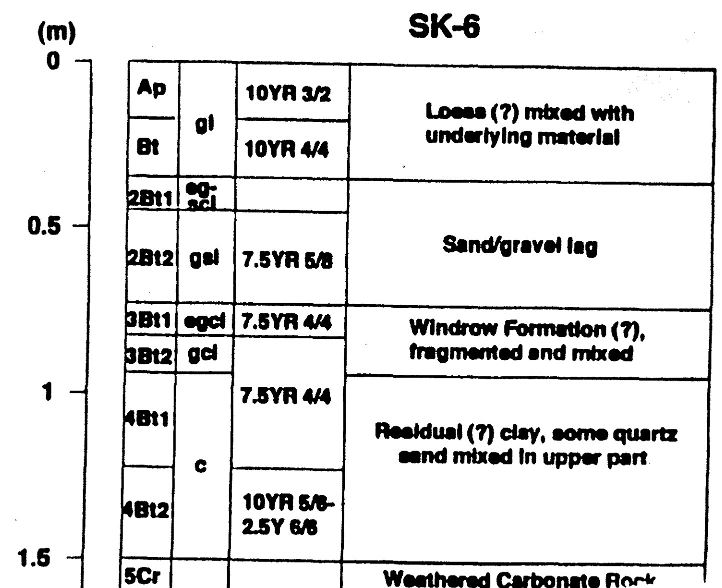


Figure C1 - 15 Soil profile at the Sikkink farm (Thick Loess Province).

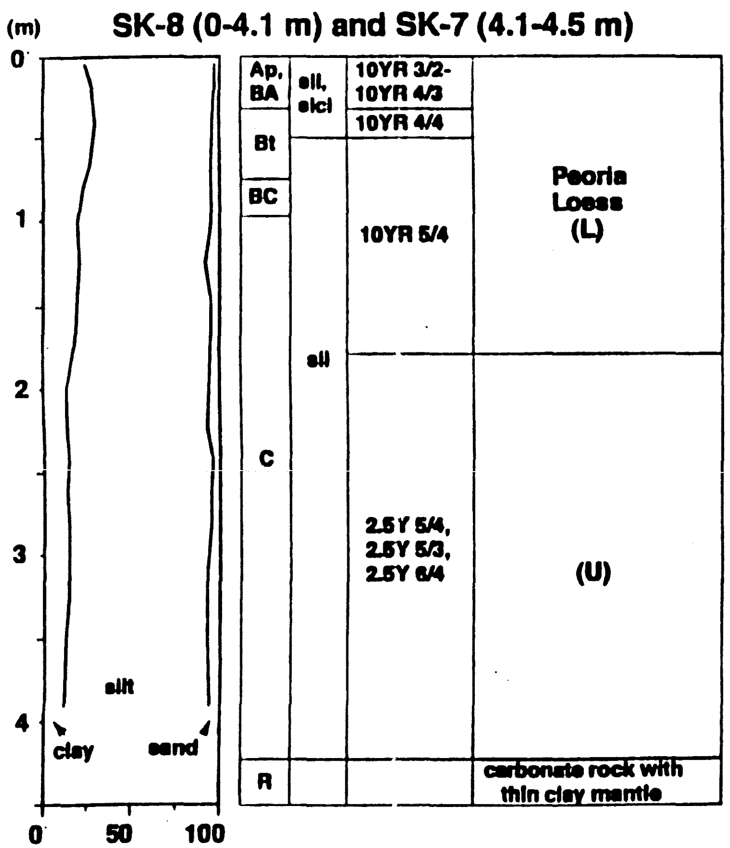


Figure C1 - 16. Grant County, Wisconsin.

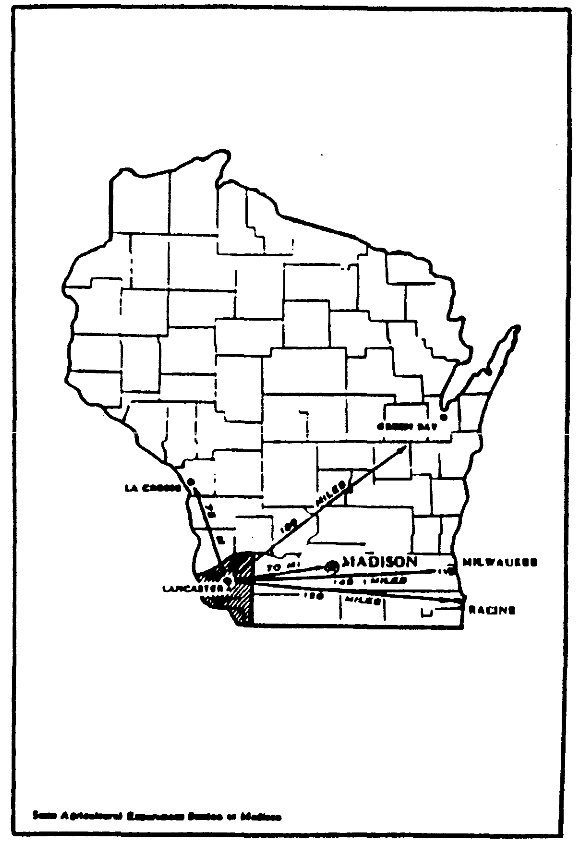


Figure C1 - 17. Geology of Grant County, Wisconsin.

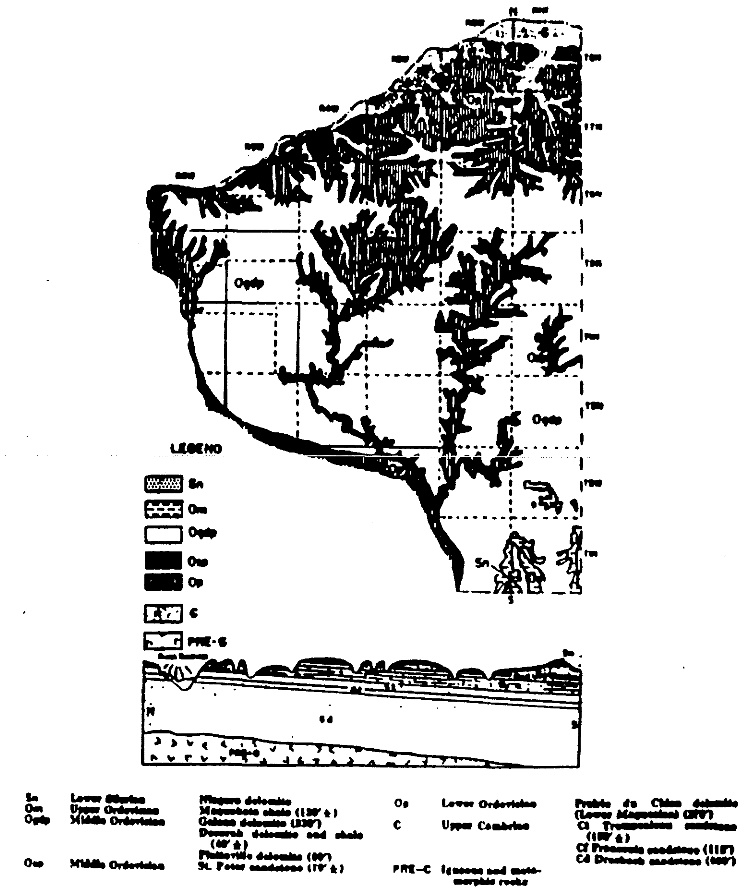


Figure C1 - 18 . ,aphy of the Lancaster study site. Hurricane Quadrangle (1962).

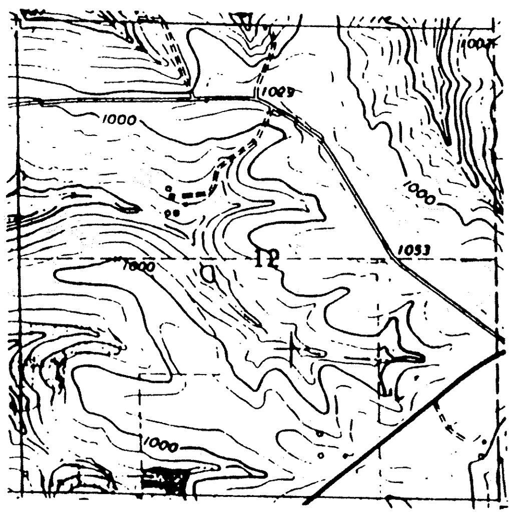
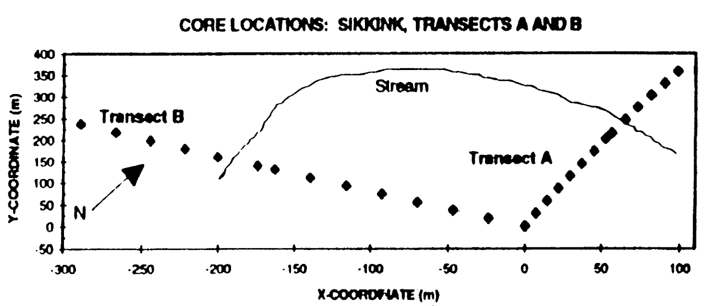


Table C1 - 1. EM31 applications.

APPLICATION	AUTHOR(S)
Geologic Mapping	• Beven (1983) • Peffer and Robelen (1983) • Zalasiewicz et al., (1985)
Ground Water Contamination	• Germeroth and Schmerl (1987) • Emilsson and Wroblewski (1988) • Martin (1988)
Permafrost Mapping	• Ajit et al., (1983)
Soil Mapping	• Mullern et al., (1983)
Soil Salinity	• de Jong et al., (1979) • Cameron et al., (1981) • Kachanoski et al., (1988)

Figure C1 - 19. Relative coordinates of Transects A and B at the Sikkink farm.



F 20. Topographic relief of Transects A (a) and B (b) at the Sikkink farm.

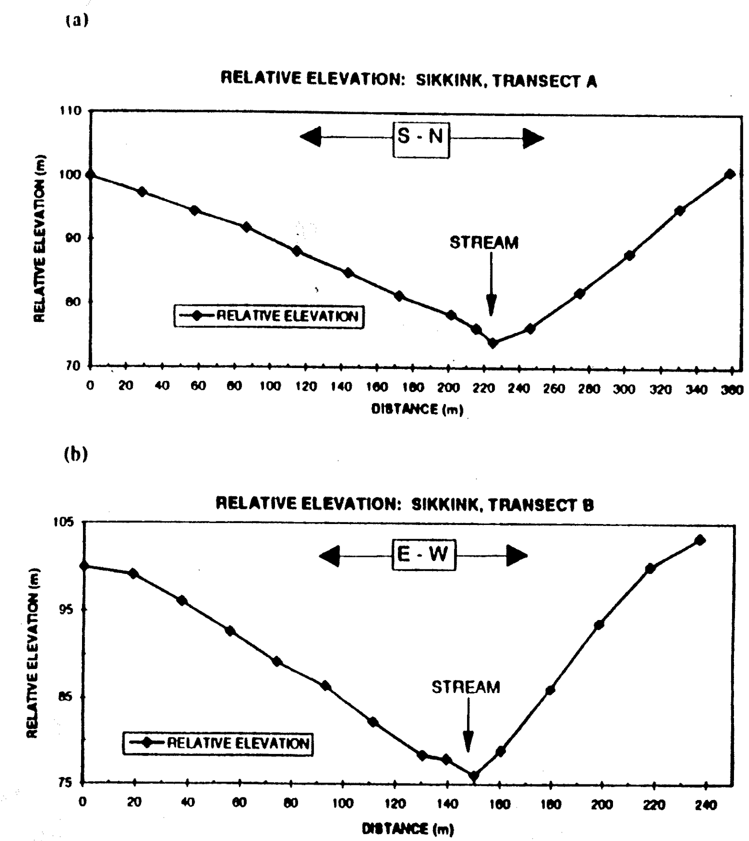


Figure C1 - 21. 10 m digital elevation model for the Lancaseter site showing transects taken from the 3-dimensional database.

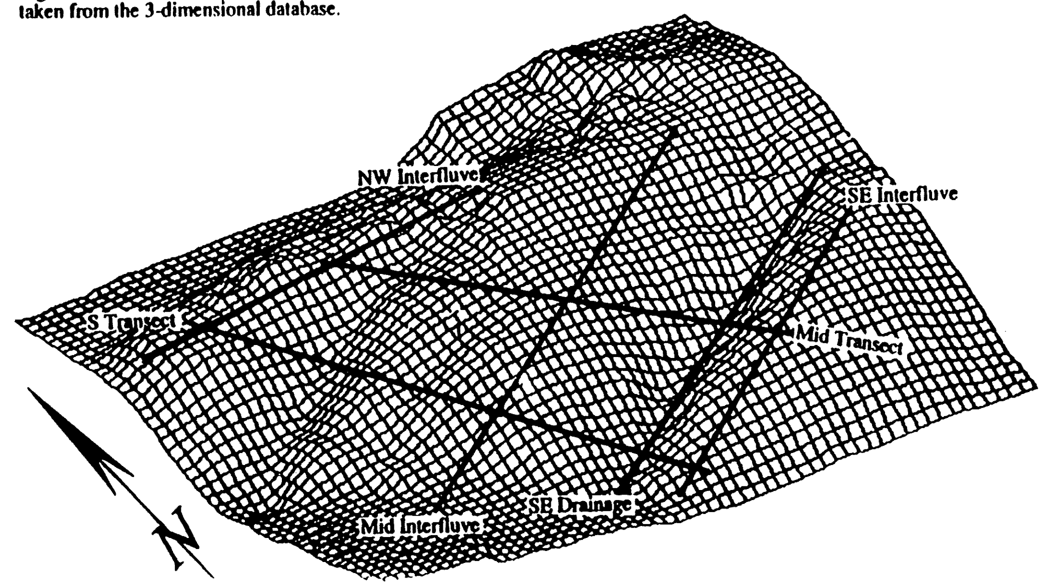


Figure C1 - 22. Near-surface stratigraphy of Transect A. The vacillation jag occurs partway up the southern hillslope. Colluvium has accumulated on the lower portions of the northern hillslope.

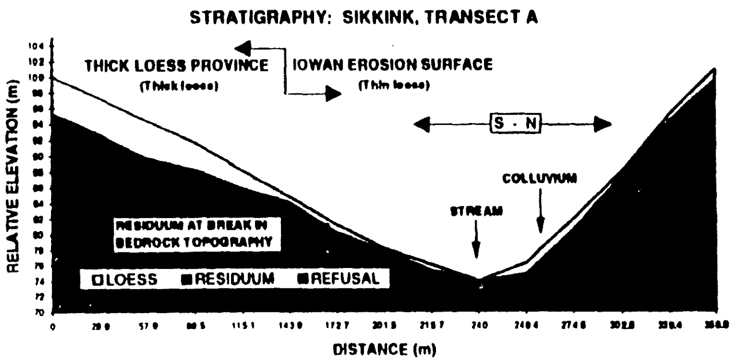


Figure C1 - 23. Near-surface stratigraphy of Transect B. 8 of the 14 cores were measured with a hydraulic probe or by hand auger. The remaining 6 were determined using the EM31. The correlation between the measured cores and the MIR-predicted values had an R^2 of 0.94.

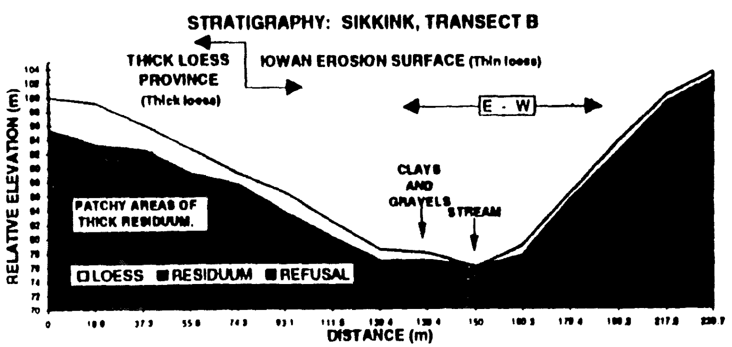
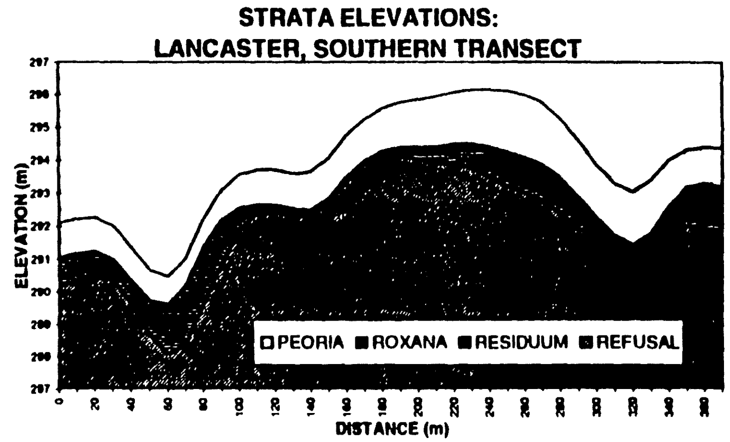


Figure C1 - 24. Near-surface stratigraphy (a) and cummulative profile thickness (b) for the Southern Transect, Lancaster.

(a)



(b)

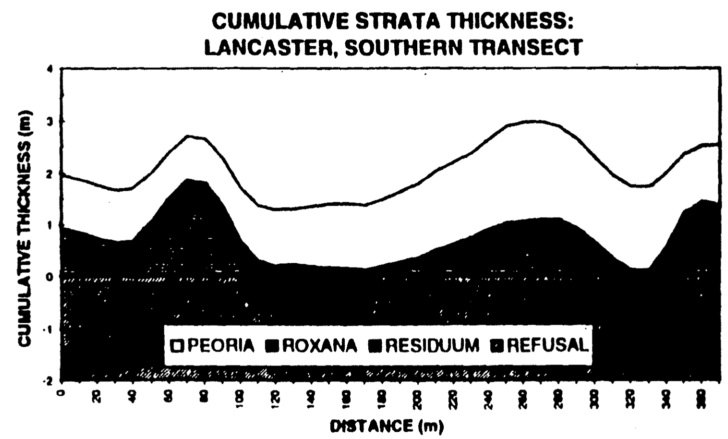
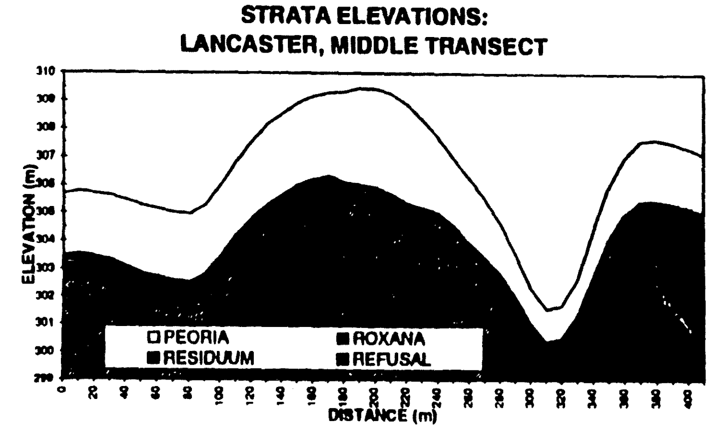


Figure C1 - 25. Near-surface stratigraphy (a) and cummulative profile thickness (b) for the Middle Transect, Lancaster.

(a)



(b)

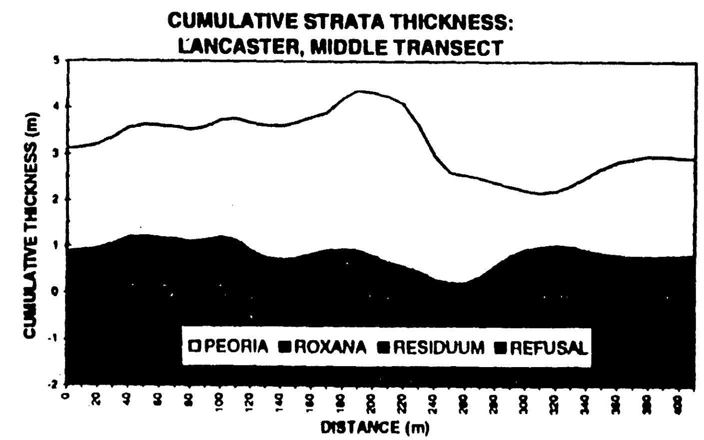
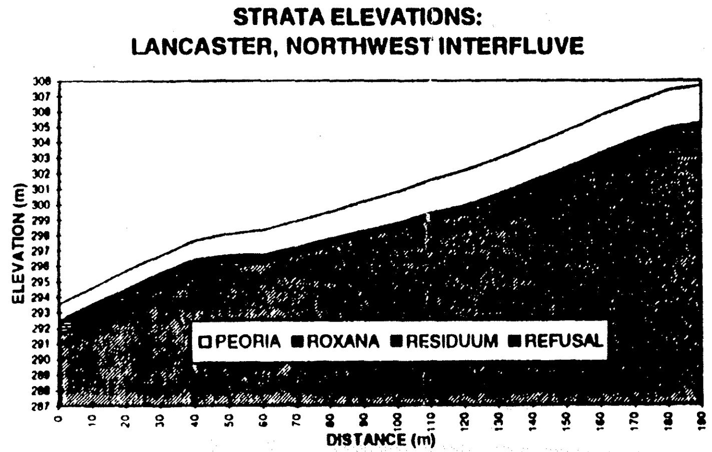


Figure C1 - 26. Near-surface stratigraphy (a) and cummulative profile thickness (b) for the Northwest Interfluve, Lancaster.

(a)



(b)

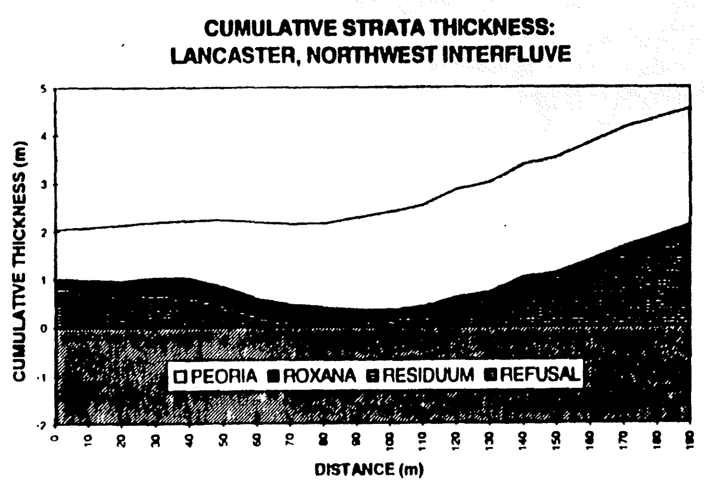
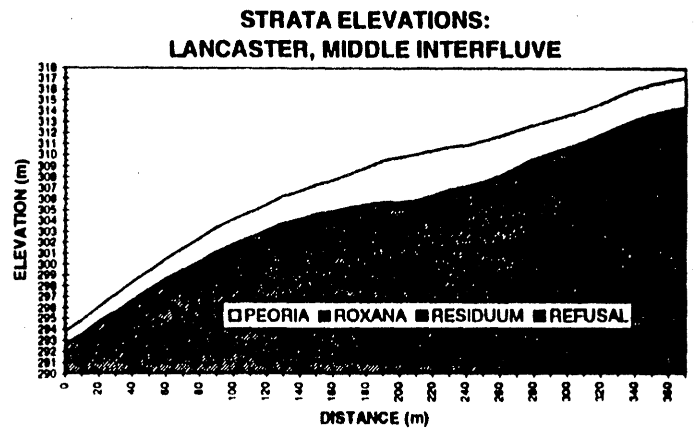


Figure C1 - 27. Near-surface stratigraphy (a) and cummulative profile thickness (b) for the Middle Interfluve, Lancaster.

(a)



(b)

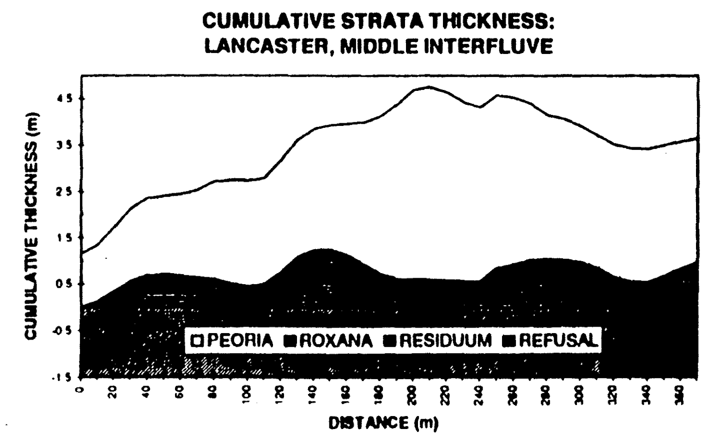
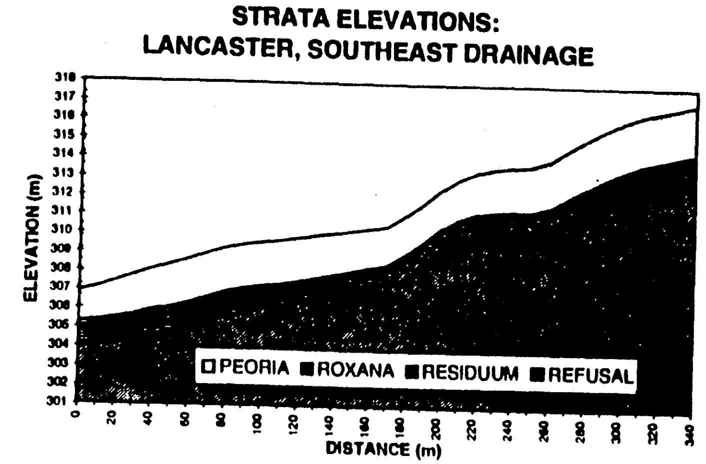


Figure C1 - 28. Near-surface stratigraphy (a) and cummulative profile thickness (b) for the Souteast Drainage, Lancaster.

(a)



(b)

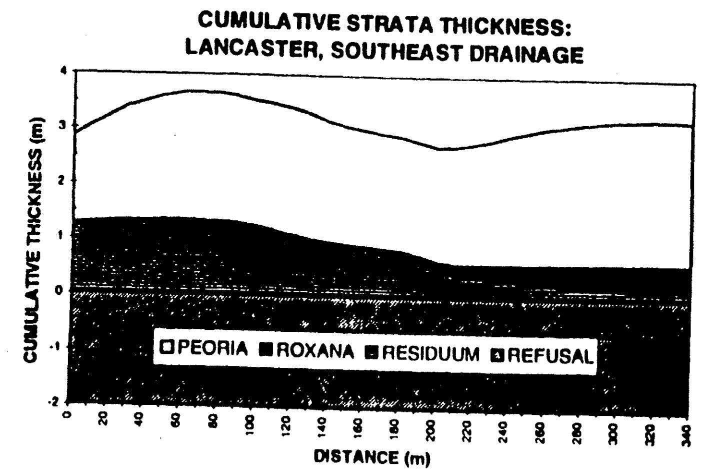
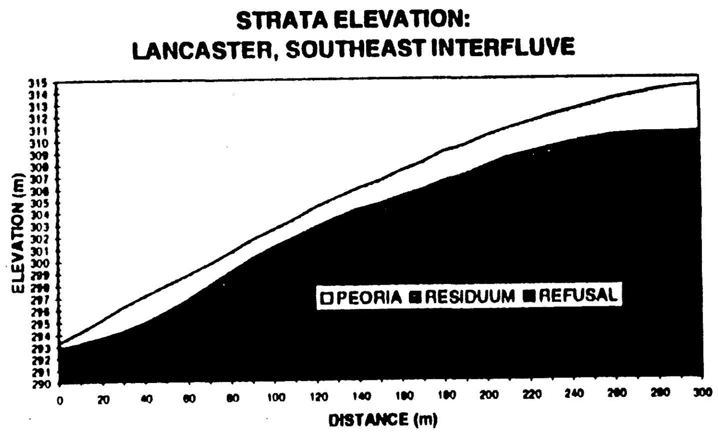


Figure C1 - 29. Near-surface stratigraphy (a) and cummulative profile thickness (b) for the Souteast Interfluve, Lancaster.

(a)



(b)

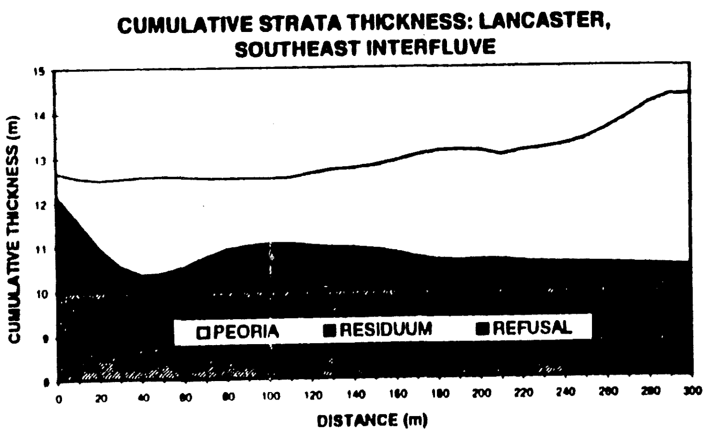


Figure C1 - 30. Percentage of each stratigraphic unit found at the Lancaster site (based on 40 soil cores).

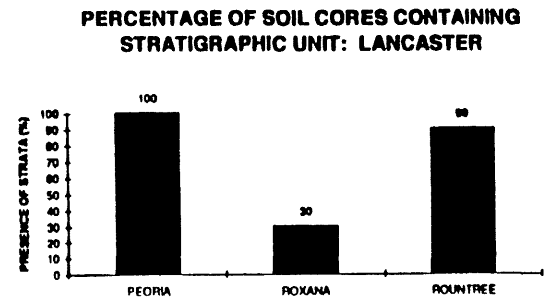


Table C1 - 2. Regression analysis results for the measured vs. MIR-predicted loess and residuum thicknesses.

		SURVEY	R^2 VALUE		F SIGNIF. AT α = .01	
LOCATION	TRANSECT	DATE	LOESS	RESIDUUM	LOESS	RESIDUUM
LANCASTER	SW-DRAIN	FALL 94	0.098	0.077	NA	NA
LANCASTER	NW-DRAIN	FALL 94	0.271	0.040	NA	NA
LANCASTER	SOUTHERN	FALL 94	0.043	0.270	NA	NA
SIKKINK	A94	FALL 94	0.659	0.046	0.0004	0.4268
SIKKINK	A95	SPRING 95	0.670	0.009	0.0003	0.7498
SIKKINK	A95AUTO	SPRING 95	0.638	0.026	0.0006	0.5849
SIKKINK	B94	FALL 94	0.731	0.386	0.0068	0.9610
SIKKINK	B95	SPRING 95	0.940	0.542	0.0000	0.0590
SIKKINK	B95AUTO	SPRING 95	0.911	0.322	0.0002	0.1424

Figure C1 - 31 Roxana thickness draped over surface topography

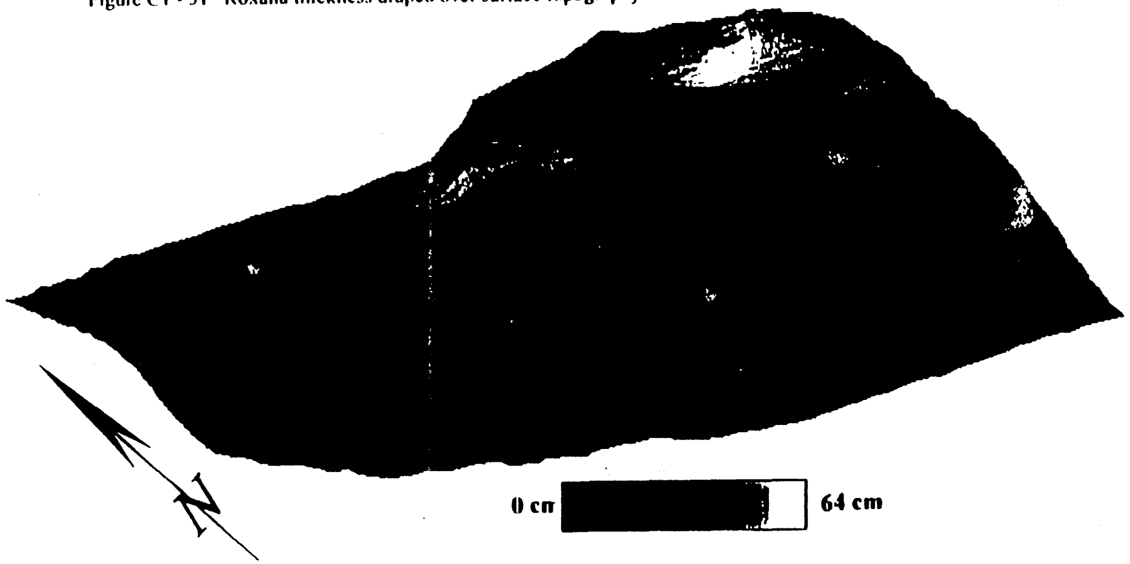


Figure C1 - 32. Residuum thickness draped over surface topography

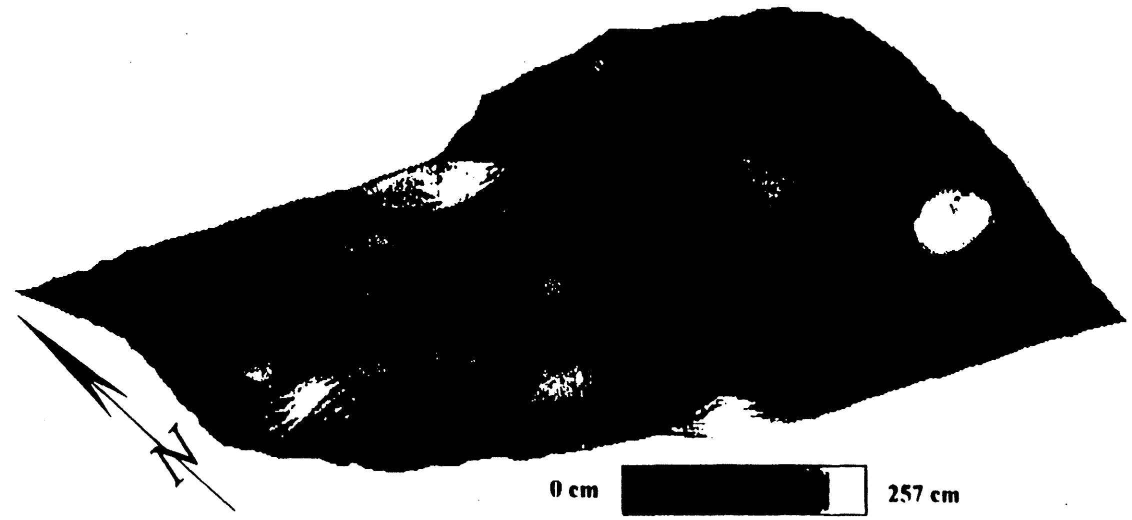
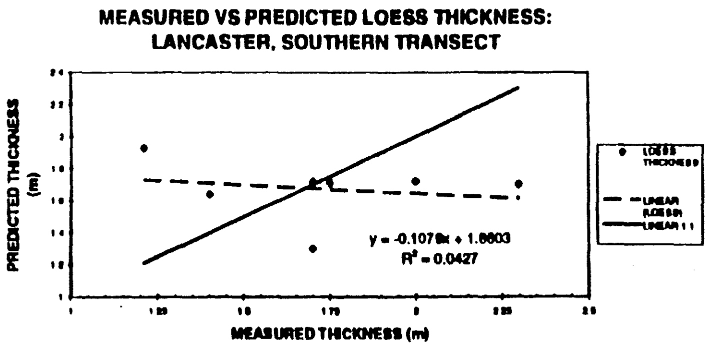


Figure C1 - 34. Measured versus predicted loess (a) and residuum (a) thickness along the Southern Transect.

(a)



(b)

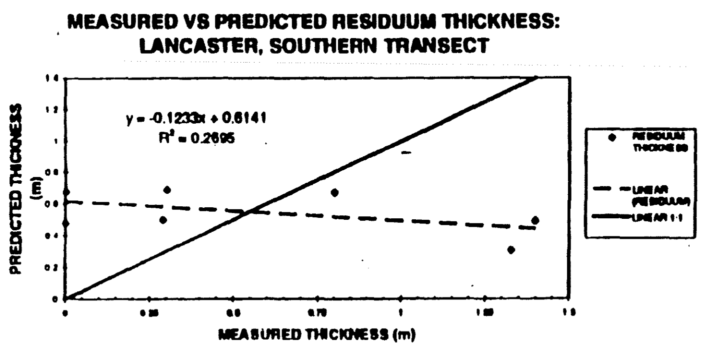
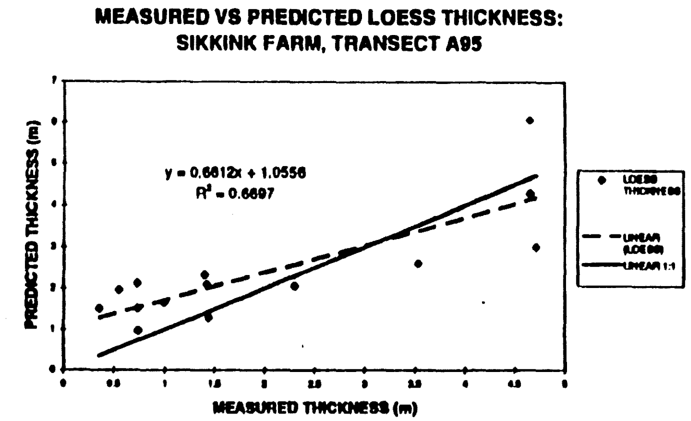
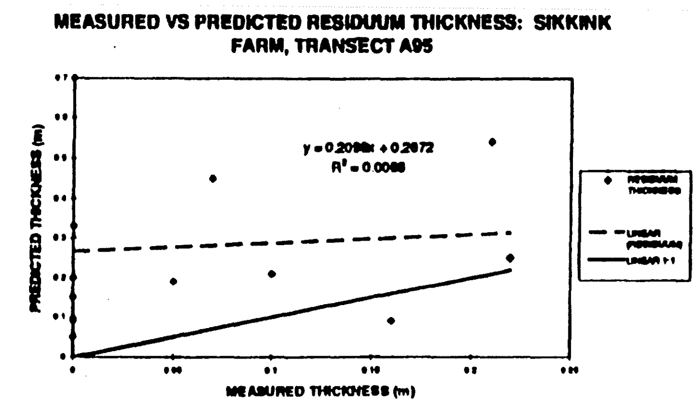


Figure C1 - 33. Measured versus MIR-predicted loess (a) and residuum (b) thickness along Transect A95.

(a)



(b)



D. Title of objective: Evaluation of manure management practices in the context of soil conservation techniques for southeastern Minnesota.

D.1.a. Activity: The focus of this study is to quantify the interactions of manure and tillage on nutrient (nitrogen and phosphorus) loading of runoff water for the karst areas of Minnesota.

D.1.b. Context within the project: A Minnesota survey by Klaseus et al. (1988) found pesticides and nitrate in 33% and 43%, respectively, of the 500 wells tested in 51 counties. In this survey, most of the contaminated wells were in the southeast (karst region) and central sand plain regions of Minnesota. Dairy and beef cattle are an important part of the economy in the karst area. Manure application to land is also an important management practice and generally manure is surface applied daily. Most of the soils have developed in loess and are underlain by fractured dolomitic bedrock. This silty loess material varies in thickness from .3 to over 6 meters. The terrain is rolling to steep and farming is done on contour strips. Chisel plowing and ridge tillage are common tillage systems. If manure is not incorporated there is danger of excessive runoff losses from manure supplied nutrients. If it is incorporated, there is more disturbance of soil and less cover by crop residue which may lead to increased erosion. Several studies have postulated that some of the wells in the karst area are contaminated from runoff water. This study will identify the best combinations of tillage type to minimize soil erosion and nutrient loss.

D.1.b. Methods: The experiment will quantify sediment loss and the nutrient loading (N and P) of surface runoff from 21m x 3m plots. Treatments will include two tillage (chisel and ridge tillage) systems; and two manure sources (poultry and dairy). The crop will be continuous corn and will be replicated twice. Plots will be isolated with corrugated steel borders. Sediment and runoff water will be collected on an individual storm basis. The sediment and runoff will be collected in a series of three 225 l barrels. The third barrel collects 1/9 of the runoff by the second which collects the overflow from the first. A representative sample of the suspension from each barrel will be collects after each rain storm and analyzed for nitrogen and phosphorus concentration. The analysis will include total, soluble and bio-available phosphorus. Chemical analysis will be done using standard methods. To quantify the nutrient cycling between the surface and subsurface layers in the tilled zone, plots will be sampled with soil depth at various times during the growing season. The soil samples will then be analyzed for total N and extractable phosphorus. The ridge till system will have soil N and P characterized relative to the ridge and furrow.

The runoff, sediment and nutrient loading data will be used to test a field scale model for the Chemical, Runoff, and Erosion for Agricultural Management Systems (CREAMS) model. Once validated the model will provide a tool to identify the management practices for other soils and slope conditions that will minimize sediment and nutrient loading of surface runoff.

D.1.c. Materials: Corrugated steel edging, 225 l barrels, PVC pipe, pumps, automated sampler, reagents, and glassware for chemical analysis.

D.1.d. Budget: 100,000 Balance $0

D.1.e. Timeline:

	7/93	1/94	6/94	1/95	1/95	6/95
Selection of field sites	xxxx					
Establishment of treatments	xxxx					
Collection of data	xxxxxxxxxxxxxxxxxxxxxxxxxxxx					
Validation of computer model			xxxx			
Extrapolation to other situations					xxxx	

D.1.f. Final Detailed Report

A study was undertaken in 1994 to measure the runoff and associated sediment and nutrient's losses in Goodhue county of Southeastern Minnesota. The soil is Seaton Silt Loam and has 12 percent slope. Four (10' X 70') runoff plots were set up in a no till field which has standing corn residues from a previous year. Liquid Hog manure was applied in plot one and three and urea was applied in plots two and four. A corn crop was grown in the plots. The summary of cultural practices and other information is given in Table D-1.

Table D-1. Summary of Cultural Practices and other Information.

Practice	Date	Rate	Type	Applied elem. N	P2O5
Manure	5/6/94	10,000 gal/a	liquid swine	Est. Aval. 121 lb/a	5.4 lb/a
Starter	5/12/94	15 gal/a	7-21-7	12 lb/a	35 lb/a
Planting	5/12/94	30,000 seed /a	Enestv-edtE560		
Herbicide	5/12/94	3 pt/a & 2/3 oz/a	Marksman		
Fertilizer	6/17/94	100 lb N/a	Urea		
Cultivation	6/22/94	by hand	steel plt forks		
Harvest	11/4/94	Yield			
		Plot 1	**Plot 2**	**Plot 3**	**Plot4**
		183 bu/a	182 bu/a	209 bu/a	215 bu/a
Residue cover	6/21/94	51 %	52 %	51 %	52 %
Residue cover	6/24/94	24 %	28 %	22 %	32 %

The GLEAMS (Groundwater Loading Effects of Agricultural Management System) model was used to simulate runoff and associated nutrients' losses for four experimental plots set up in Goodhue County. Since it was a year study only, storm by storm runoff and nutrients simulation option was chosen. The model run needs six input files which include a daily precipitation data file, average daily temperature file, hydrology parameter file, erosion parameter file, nutrient's parameter file, and pesticide nutrients file.

Daily rainfall records measured by an electronic raingauge at the experimental site were used to create the precipitation data input file. The average daily temperature and other climatic data were acquired from continuing long-term weather records at near by weather station. The detailed information on soil type and properties were collected from soil survey reports. The crop information, nutrients and pesticide input were derived from the detailed log book of the field work. The precipitation and temperature data input files and hydrology, erosion, nutrients, and pesticide parameters files are given in the Tables D-2 to D-8.

Figure D-1 shows the cumulative rainfall measured at the experimental site during the year 1994. Figures D-2, D-3, D-4, and D-5 show the comparison of measured and predicted cumulative runoff in each runoff plot. Except for plot four, the model under predicted the runoff for the first half of the season but over predicted for second half of the season. This could be due to the fact that the model did not consider the surface sealing because of the residue presence and allowed more infiltration in the beginning of the season. Cultivation was performed in the middle of the season which resulted in increased infiltration and less measured runoff. The model did not consider the effect of cultivation and over predicted the runoff in later half of the season. Plot four had unusually high runoff during the season so the model predictions are lower than the measured runoff.

Figures D-6, D-7, D-8, and D-9 show the comparison of measured and predicted total nitrogen in the runoff in each runoff plot. Since the total nitrogen predicted by the model depends on the runoff, the model predictions for total nitrogen are less for the first half of the season and more for the second half of the season. For the fertilizer treatment plots, model predictions for total nitrogen are more close to the measured values. For manure treatment plots, the model under predicted the total nitrogen in the first half of the season and over predicted the total nitrogen in second half of the season.

Figures D-10, D-11, D-12, and D-13 show the comparison of measured and predicted total phosphorus in the runoff in each plots. The model under predicted the total phosphorus in manure treatment plots. The total phosphorus predictions are close to measured values for fertilizer treatment plots except in the second of season of the plot four which had unusually high runoff.

Figure D-1. ;ured cumulative rainfall for Nords experi l plots.

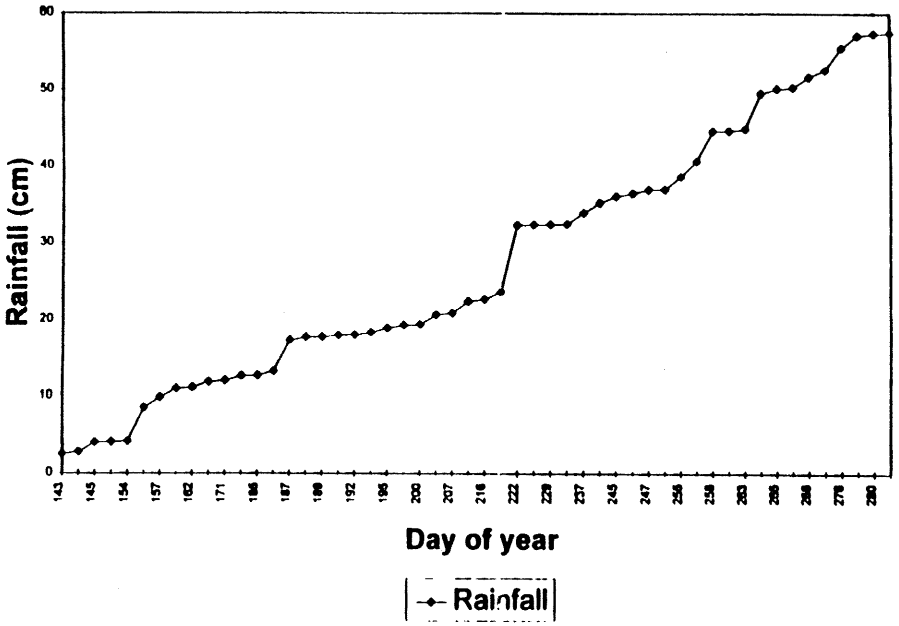


Figure D-2. PLOT 1: Manure Treatment. Comparison of measured and predicted runoff.

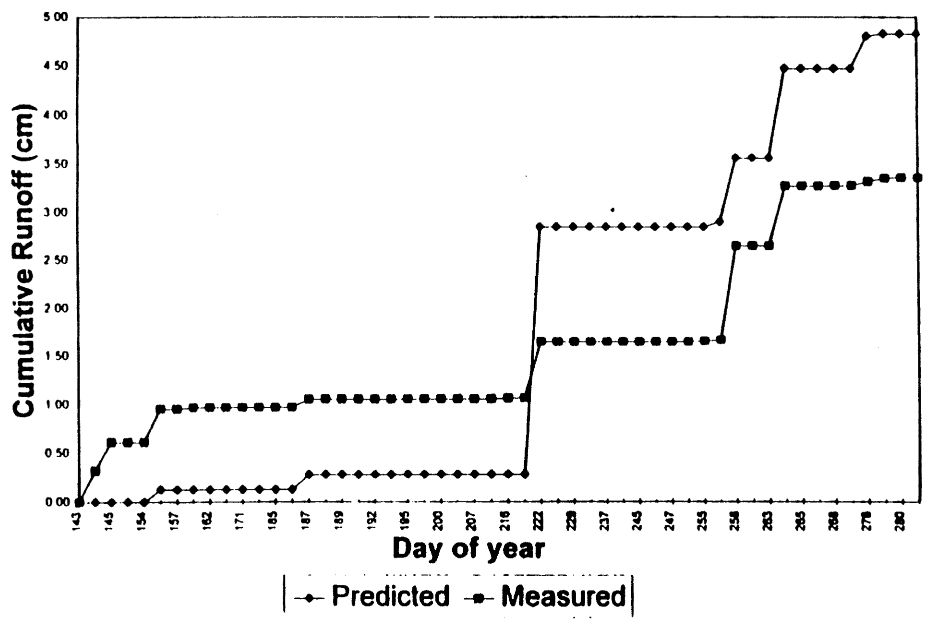


Figure D-3. PLOT 2: F izer Treatment. Comparison of measured and p ted runoff.

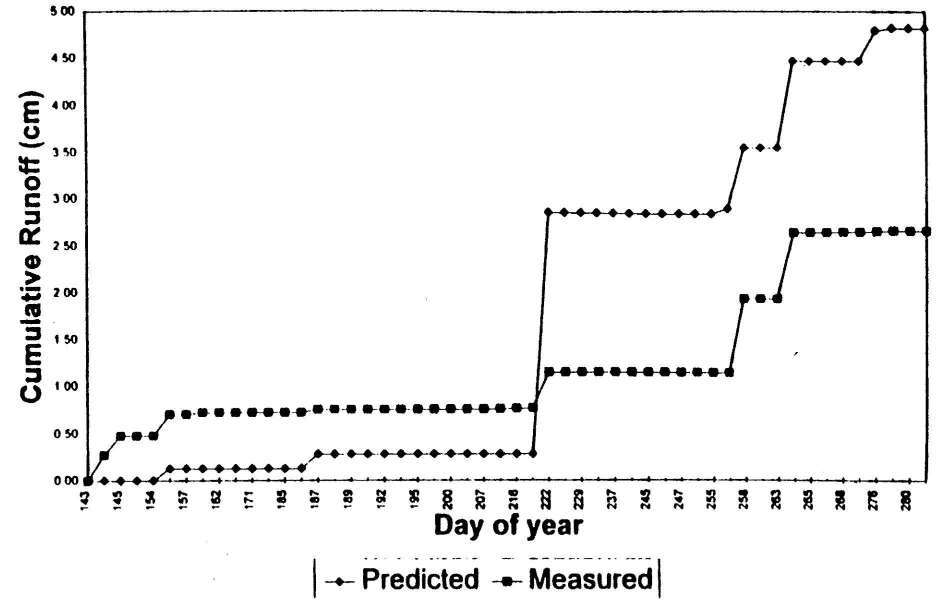


Figure D-4. PLOT 3: Manure Treatment. Comparison of measured and predicted runoff.

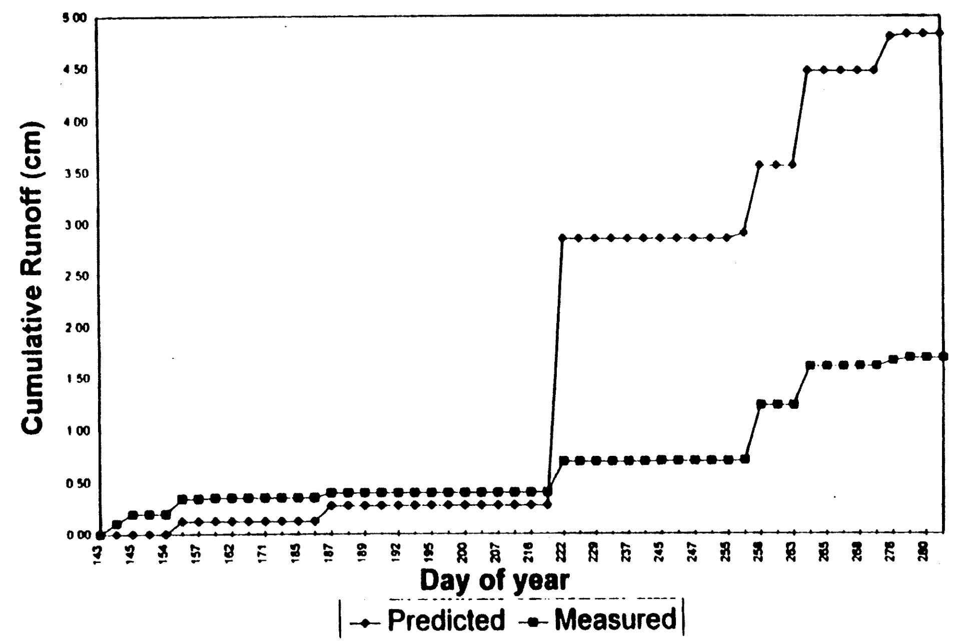


Figure D-5. PLO. .: Fertilizer Treatment. Comparison of measured and predicted runoff.

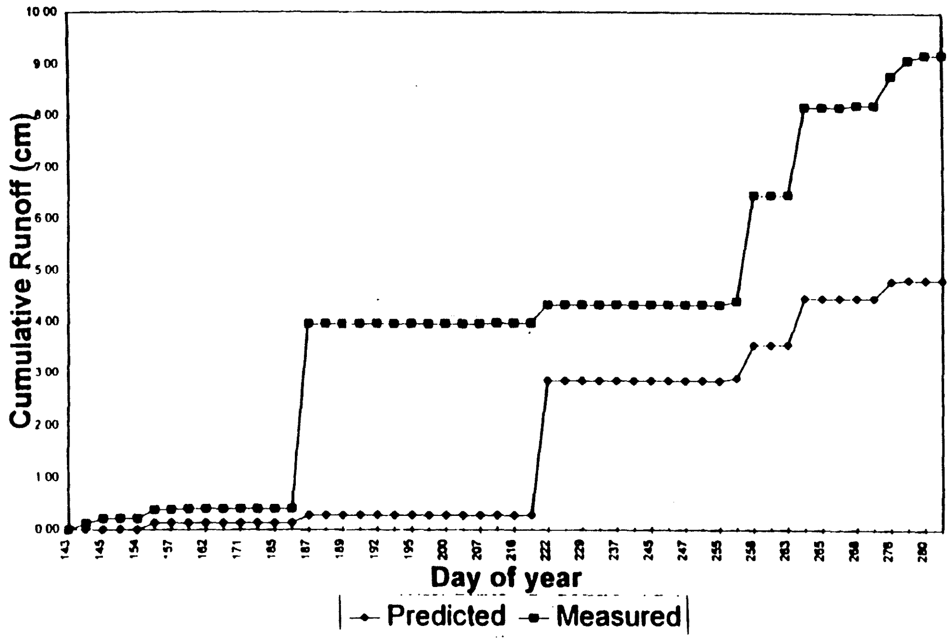


Figure D-7. PLOT 2: Fertilizer Treatment. Comparison of measured and predicted total N in runoff.

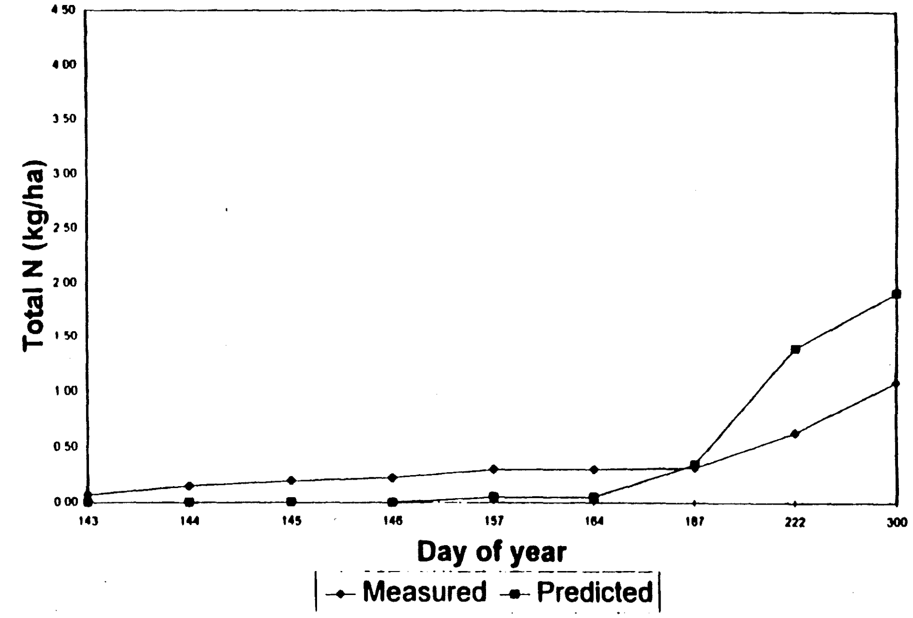


Figure D-6. PLOT 1: Manure Treatment. Comparison of measured and predicted total N in runoff.

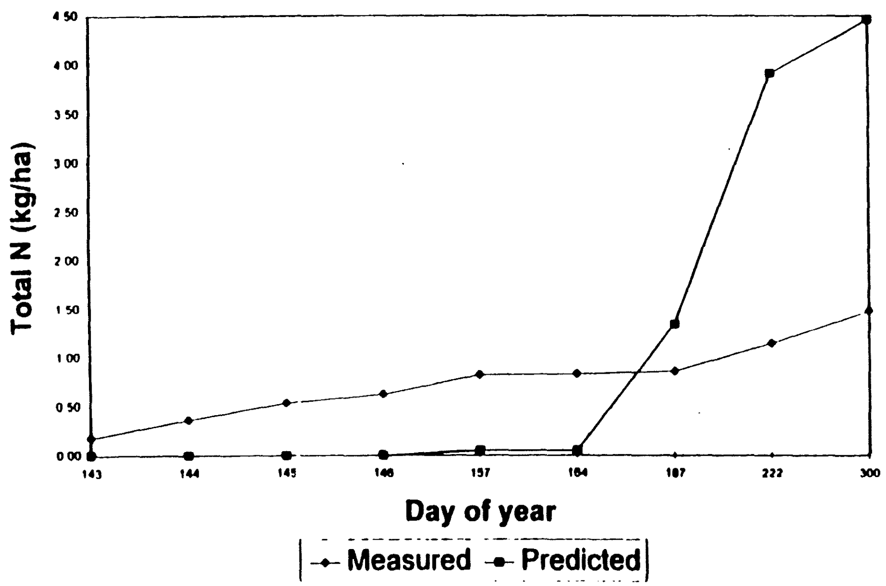


Figure D-8. PLOT 3: Manure Treatment. Comparison of measured and predicted total N in runoff.

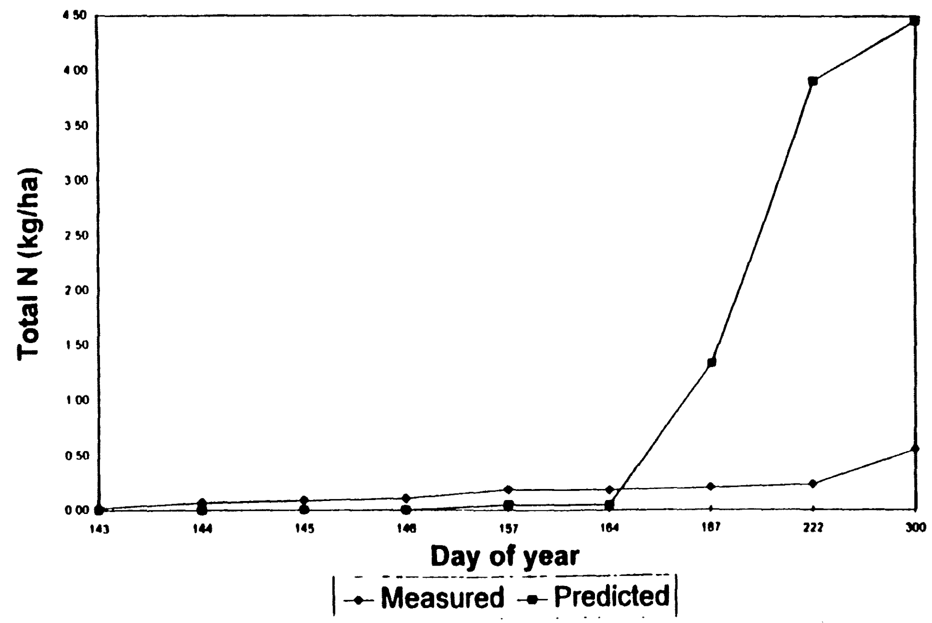


Figure D-9. [illegible]T 4: Fertilizer Treatment. Comparison of mea[illegible] and predicted [illegible]al N in runoff.

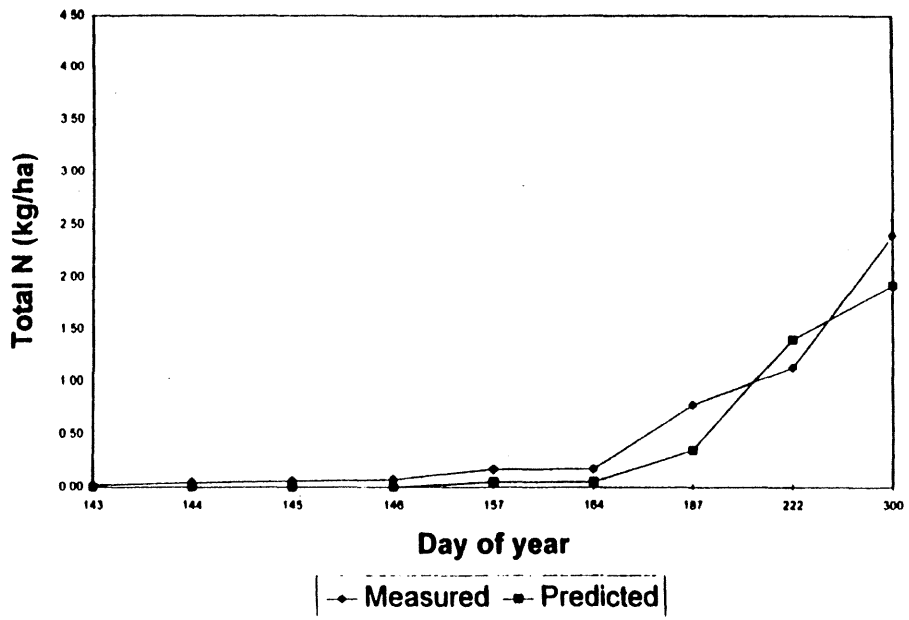


Figure D-11. PLOT 2: F[illegible]lizer Treatment. Comparison of measured and p[illegible]cted total P [illegible]noff.

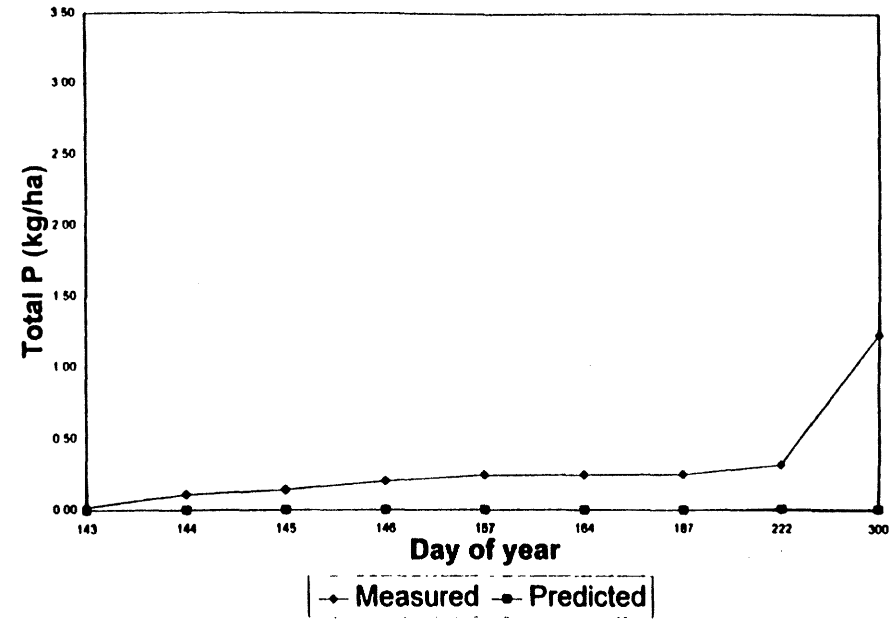


Figure D-10. PLOT 1: Manure Treatment. Comparison of measured and predicted total P in runoff.

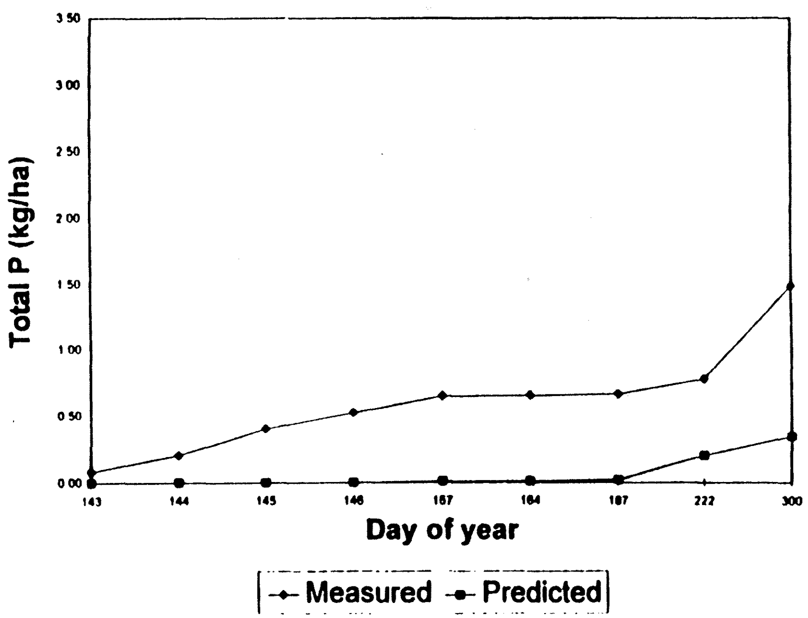


Figure D-12. PLOT 3: Manure Treatment. Comparison of measured and predicted total P runoff.

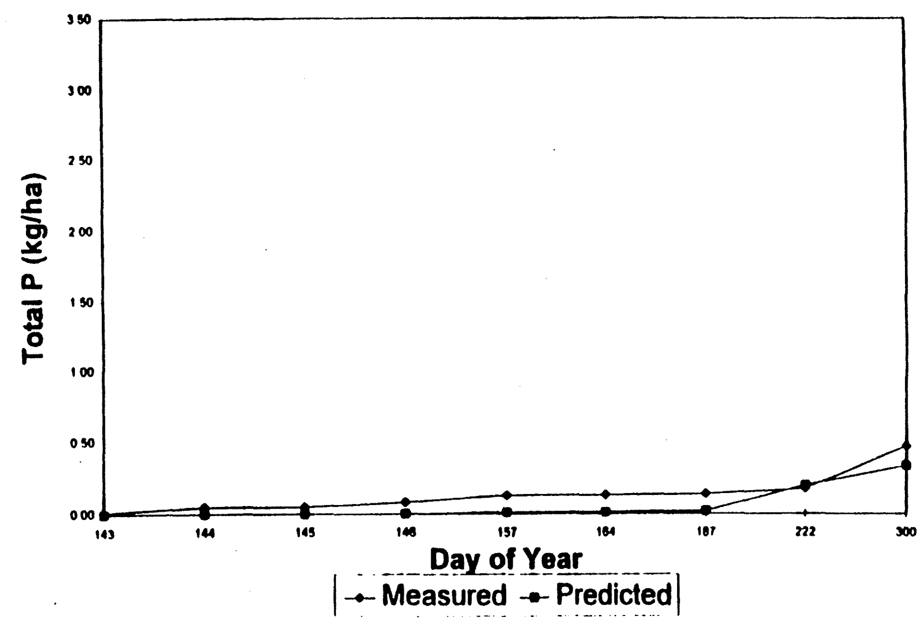


Figure D-13. PL[illegible] [illegible]izer Treatment. Comparison of measured and predicted tota[illegible] [illegible] runoff.

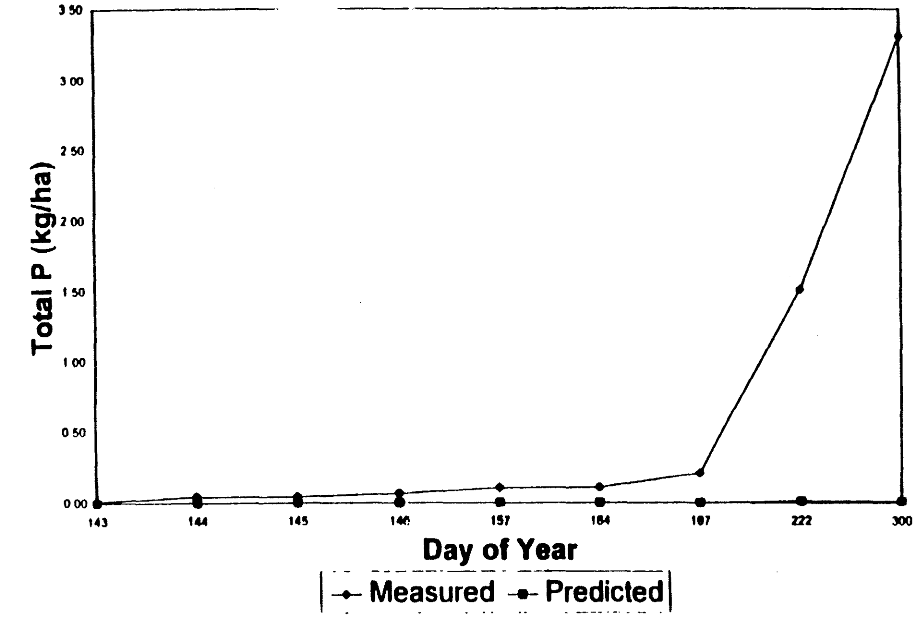


Table D-2. Precipitation data input file.

Nords	94	.	.	.	.	.	.	.	.	.	.	1
MN	94	.	.	.	.	.	.	.	.	.	.	2
1994	94	.	.	.	.	.	.	.	.	.	.	3
Preci-	94	.	.	.	.	.	.	.	.	.	.	4
pita-	94	.	.	.	.	.	.	.	.	.	.	5
tion	94	.	.	.	.	.	.	.	.	.	.	6
(In.)	94	.	.	.	.	.	.	.	.	.	.	7
	94	.	.	.	.	.	.	.	.	.	.	8
	94	.	.	.	.	.	.	.	.	.	.	9
	94	.	.	.	.	.	.	.	.	.	.	10
	94	.	.	.	.	.	.	.	.	.	.	11
	94	.	.	.	.	.	.	.	.	.	.	12
	94	.	.	.	.	.	.	.	.	.	.	13
	94	.	.	.	.	.	.	.	.	.	.	14
	94	.	.	0.99	0.11	0.49	0.02	.	.	.	.	15
	94	.	.	.	0.02	1.72	.	0.52	.	.	.	16
	94	0.45	0.05	0.29	.	.	.	.	.	.	.	17
	94	0.06	.	.	.	.	0.25	.	.	.	.	18
	94	.	.	.	.	0.01	0.22	1.60	0.16	0.01	0.09	19
	94	.	0.02	.	0.13	0.23	.	0.15	.	.	0.03	20
	94	.	0.51	.	.	.	.	0.09	.	.	.	21
	94	.	.	.	.	0.60	0.11	.	.	.	.	22
	94	0.36	3.42	.	0.02	.	.	.	.	0.01	.	23
	94	0.02	.	.	.	.	.	0.57	.	.	.	24
	94	.	0.51	.	.	0.33	0.14	0.20	0.02	.	.	25
	94	.	.	.	.	0.65	0.82	.	1.59	0.02	.	26
	73	.	.	0.09	1.81	0.23	0.07	.	0.53	.	.	27
	94	.	.	.	.	0.36	1.14	.	.	0.65	0.11	28
	94	0.04	.	.	.	.	.	.	.	0.14	0.41	29
	94	.	.	.	0.02	0.09	.	.	.	.	.	30
	94	.	.	.	.	.	.	.	.	.	.	31
	94	.	.	.	.	.	.	.	.	.	.	32
	94	.	.	.	.	.	.	.	.	.	.	33
	94	.	.	.	.	.	.	.	.	.	.	34
	94	.	.	.	.	.	.	.	.	.	.	35
	94	.	.	.	.	.	.	.	.	.	.	36
	94	.	.	.	.	.	.	.	.	.	.	37

Table D-3. Daily av[illegible]age temperature input file.

Nords	94	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	Mean Daily Tmp	1
MN	94	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0		2
1994	94	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0		3
Mean	94	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0		4
Daily	94	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0		5
Temp(F)	94	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0		6
	94	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0		7
	94	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0		8
	94	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	46.6		9
	94	45.8	37.7	34.5	35.6	23.3	24.8	38.1	43.2	41.4	47.0		10
	94	45.9	39.9	48.9	53.3	46.1	48.7	57.0	64.9	47.6	38.9		11
	94	48.0	49.6	61.5	66.8	57.9	57.0	39.3	33.4	34.0	38.5		12
	94	43.0	47.5	51.6	56.2	44.2	43.8	53.1	54.2	53.3	57.6		13
	94	60.7	55.2	62.6	61.0	59.3	55.4	61.0	64.0	67.0	68.0		14
	94	70.0	71.0	67.0	63.8	56.7	52.9	56.7	67.9	70.4	72.8		15
	94	63.7	58.7	57.2	66.6	67.4	66.6	73.4	61.2	55.3	60.1		16
	94	66.5	64.7	68.6	70.4	80.6	78.6	79.9	78.9	74.3	76.0		17
	94	75.6	69.3	70.3	63.2	68.9	70.1	69.0	68.1	68.3	66.4		18
	94	67.7	65.9	60.7	63.4	74.2	77.0	75.0	73.6	63.4	61.7		19
	94	64.1	73.0	67.3	61.1	64.5	66.2	68.1	68.0	66.9	75.5		20
	94	71.0	70.0	68.0	68.1	67.5	61.8	62.4	61.9	64.2	67.9		21
	94	69.3	73.7	72.0	70.5	73.9	58.7	63.0	61.4	66.8	58.5		22
	94	55.9	57.8	65.6	66.5	62.8	57.8	60.1	66.1	69.0	70.9		23
	94	70.6	62.3	63.5	65.3	70.3	73.5	75.9	69.7	74.3	60.7		24
	94	60.1	61.1	56.4	53.6	55.8	62.3	58.8	65.4	59.7	69.4		25
	94	67.6	71.9	73.0	73.1	69.2	74.2	75.6	72.8	60.8	60.8		26
	94	64.5	68.1	66.1	67.7	55.1	58.9	65.6	59.8	62.0	49.0		27
	94	51.9	55.6	58.6	55.3	48.7	47.3	50.2	58.4	62.3	56.0		28
	94	49.4	41.8	45.2	52.2	51.1	00.0	00.0	00.0	00.0	00.0		29
	94	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0		30
	94	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0		31
	94	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0		32
	94	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0		33
	94	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0		34
	94	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0		35
	94	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0		36
	94	00.0	00.0	00.0	00.0	00.0							37

Table D-4. Hydrology parameter input file.

GLEAMS Version 2.10, Hydrology parameters, Nords, MN
1994; Annual corn crop
Seaton Silt Loam; 12 slope; Hydrologic soil group C

94093	1	0	1	1	0	0	1	1	
3404	2080	771	2771	3771	772	2772	3772		
0.016	.15	0.2	4.5	78	0.12	7.00	60.0	950.	44.7
3	3	18.0	45.0	60.0					
0.43	0.43	0.43							
0.32	0.32	0.32							
0.12	0.12	0.12							
0.15	0.15	0.15							
1.00	0.01	0.01							
20.0	20.0	20.0							
60.0	60.0	60.0							
21.22	27.38	38.80	57.40	70.83	79.54	84.05	81.39	72.12	60.5
41.45	26.80								
2.25	7.98	19.56	33.81	45.46	55.18	59.95	57.60	48.23	37.4
23.46	10.30								
163.	253.	357.	419.	489.	530.	550.	478.	361.	236
145.	121.								
421.	421.	447.	496.	465.	417.	376.	368.	397.	422
452.	423.								
5.68	10.09	19.47	31.76	42.80	54.92	59.92	58.88	49.59	39.4
24.63	13.04								
94	94	1							
20	1132	1308	1173	12.0	6.0				
0									
-1		0	0						

Table D-5. sion parameter input file.

```
GLEAMS 2.1 Erosion Parameter, Nords, MN
1994 Annual Corn crop
Seaton Silt Loam, 12 percent slope, Hydrologic Soil Group C
      94        94         4         1         0
   400.0
       1     0.016
    70.0       .12
       1       1.0      0.54
       1
     001       132       173       308
       1       1.0
     .15       .15       .09       .09
     1.0       1.0       1.0       1.0
    0.05      0.05     0.045     0.045
```

Table D-6. Nutrient parameter input file (Manure application).

```
GLEAMS 2.10  Nutrients Parameter file for Nords, MN (Fertilizer application)
1994; Annual Corn Crop
Seaton Silt loam; 12 percent slope; Hydrologic soil group C
      94        94         2         1         1
  1000.0      2.66


    1001
       1         1      1308
      20
    1168         0         0
     0.0      42.0       0.0       0.0
    1132        21      5.00
       0
```

Table D-7. Nutrient meter input file (Fertilizer application).

```
GLEAMS 2.10  Nutrients Parameter file for Nords, MN (Manure Application)
1994; Annual Corn Crop
Seaton Silt loam; 12 percent slope; Hydrologic soil group C
      94        94         2         1         1
  1000.0      2.66


    1001
       1         1      1308
      20
    1168         1         0        14
     1.0       0.0       .28       .04       .23       .10       .02       .14         3
    1132        21       5.0
       0
```

Table D-8. Pesticide parameter input file.

```
GLEAMS Version 2.10 Pesticide parameters, Nords, MN
1994: Annual Corn Crop
Seation silt loam, 12 percent slope, Hydrologic Soil Group C
   94132     94365         1         1         2
       1           Harmony             0
       1    2400.0       3.0      45.0       0.0       .80                 1.0
    12.0
    1132         1
       1     0.046       1.0       0.0       1.0         0
       0
```

Figure D-13. PLOT 4: Fert reatment. Comparison of measured and predicted total P in ru

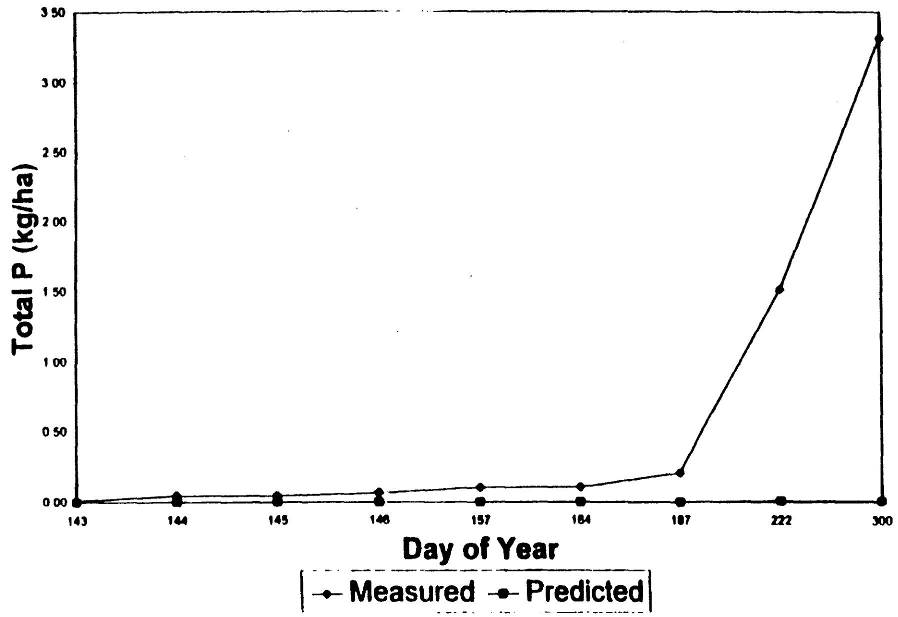


Table D-2. Precipitation data input file.

```
Nords   94   .    .    .    .    .    .    .    .    .    .       1
MN      94   .    .    .    .    .    .    .    .    .    .       2
1994    94   .    .    .    .    .    .    .    .    .    .       3
Preci-  94   .    .    .    .    .    .    .    .    .    .       4
pita-   94   .    .    .    .    .    .    .    .    .    .       5
tion    94   .    .    .    .    .    .    .    .    .    .       6
(In.)   94   .    .    .    .    .    .    .    .    .    .       7
        94   .    .    .    .    .    .    .    .    .    .       8
        94   .    .    .    .    .    .    .    .    .    .       9
        94   .    .    .    .    .    .    .    .    .    .      10
        94   .    .    .    .    .    .    .    .    .    .      11
        94   .    .    .    .    .    .    .    .    .    .      12
        94   .    .    .    .    .    .    .    .    .    .      13
        94   .    .    .    .    .    .    .    .    .    .      14
    94   .    .  0.99 0.11 0.49 0.02  .    .    .    .       15
    94   .    .    .  0.02 1.72  .  0.52  .    .    .       16
    94 0.45 0.05 0.29  .    .    .    .    .    .    .       17
    94 0.06  .    .    .    .  0.25  .    .    .    .       18
    94   .    .    .    .  0.01 0.22 1.60 0.16 0.01 0.09    19
    94   .  0.02  .  0.13 0.23  .  0.15  .    .  0.03    20
    94   .  0.51  .    .    .    .  0.09  .    .    .       21
    94   .    .    .    .  0.60 0.11  .    .    .    .       22
    94 0.36 3.42  .  0.02  .    .    .    .  0.01  .       23
    94 0.02  .    .    .    .    .  0.57  .    .    .       24
    94   .  0.51  .    .  0.33 0.14 0.20 0.02  .    .       25
    94   .    .    .    .  0.65 0.82  .  1.59 0.02  .       26
    73   .    .  0.09 1.81 0.23 0.07  .  0.53  .    .       27
    94   .    .    .    .  0.36 1.14  .    .  0.65 0.11    28
    94 0.04  .    .    .    .    .    .    .  0.14 0.41    29
    94   .    .    .  0.02 0.09  .    .    .    .    .       30
    94   .    .    .    .    .    .    .    .    .    .       31
    94   .    .    .    .    .    .    .    .    .    .       32
    94   .    .    .    .    .    .    .    .    .    .       33
    94   .    .    .    .    .    .    .    .    .    .       34
    94        .    .    .    .    .    .    .    .    .       35
    94        .    .    .    .    .    .    .    .    .       36
    94        .    .    .    .    .    .    .    .    .       37
```

Table D-3. Daily average temperature input file.

```
Nords    94  00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0  Mean Daily Tmp 1
MN       94  00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0                2
1994     94  00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0                3
Mean     94  00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0                4
Daily    94  00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0                5
Temp(F)  94  00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0                6
         94  00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0                7
         94  00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0                8
         94  00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 46.6                9
         94  45.8 37.7 34.5 35.6 23.3 24.8 38.1 43.2 41.4 47.0               10
         94  45.9 39.9 48.9 53.3 46.1 48.7 57.0 64.9 47.6 38.9               11
         94  48.0 49.6 61.5 66.8 57.9 57.0 39.3 33.4 34.0 38.5               12
         94  43.0 47.5 51.6 56.2 44.2 43.8 53.1 54.2 53.3 57.6               13
         94  60.7 55.2 62.6 61.0 59.3 55.4 61.0 64.0 67.0 68.0               14
         94  70.0 71.0 67.0 63.8 56.7 52.9 56.7 67.9 70.4 72.8               15
         94  63.7 58.7 57.2 66.6 67.4 66.6 73.4 61.2 55.3 60.1               16
         94  66.5 64.7 68.6 70.4 80.6 78.6 79.9 78.9 74.3 76.0               17
         94  75.6 69.3 70.3 63.2 68.9 70.1 69.0 68.1 68.3 66.4               18
         94  67.7 65.9 60.7 63.4 74.2 77.0 75.0 73.6 63.4 61.7               19
         94  64.1 73.0 67.3 61.1 64.5 66.2 68.1 68.0 66.9 75.5               20
         94  71.0 70.0 68.0 68.1 67.5 61.8 62.4 61.9 64.2 67.9               21
         94  69.3 73.7 72.0 70.5 73.9 58.7 63.0 61.4 66.8 58.5               22
         94  55.9 57.8 65.6 66.5 62.8 57.8 60.1 66.1 69.0 70.9               23
         94  70.6 62.3 63.5 65.3 70.3 73.5 75.9 69.7 74.3 60.7               24
         94  60.1 61.1 56.4 53.6 55.8 62.3 58.8 65.4 59.7 69.4               25
         94  67.6 71.9 73.0 73.1 69.2 74.2 75.6 72.8 60.8 60.8               26
         94  64.5 68.1 66.1 67.7 55.1 58.9 65.6 59.8 62.0 49.0               27
         94  51.9 55.6 58.6 55.3 48.7 47.3 50.2 58.4 62.3 56.0               28
         94  49.4 41.8 45.2 52.2 51.1 00.0 00.0 00.0 00.0 00.0               29
         94  00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0               30
         94  00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0               31
         94  00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0               32
         94  00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0               33
         94  00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0               34
         94  00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0               35
         94  00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0 00.0               36
         94  00.0 00.0 00.0 00.0 00.0                                        37
```

Table D-4. Hydrology parameter input file.

```
GLEAMS Version 2.10, Hydrology parameters, Nords, MN
1994; Annual corn crop
Seaton Silt Loam; 12 slope; Hydrologic soil group C
   94093       1       0       1       1       0       0       1       1
    3404    2080     771    2771    3771     772    2772    3772

   0.016     .15     0.2     4.5      78    0.12    7.00    60.0    950.   44.7
       3       3    18.0    45.0    60.0
    0.43    0.43    0.43
    0.32    0.32    0.32
    0.12    0.12    0.12
    0.15    0.15    0.15
    1.00    0.01    0.01
    20.0    20.0    20.0
    60.0    60.0    60.0
   21.22   27.38   38.80   57.40   70.83   79.54   84.05   81.39   72.12   60.5
   41.45   26.80
    2.25    7.98   19.56   33.81   45.46   55.18   59.95   57.60   48.23   37.4
   23.46   10.30
    163.    253.    357.    419.    489.    530.    550.    478.    361.    236
    145.    121.
    421.    421.    447.    496.    465.    417.    376.    368.    397.    422
    452.    423.
    5.68   10.09   19.47   31.76   42.80   54.92   59.92   58.88   49.59   39.4
   24.63   13.04
      94      94       1
      20    1132    1308    1173    12.0     6.0

       0
      -1               0       0
```

Table D-5. osion parameter input file.

```
GLEAMS 2.1 Erosion Parameter, Nords, MN
1994 Annual Corn crop
Seaton Silt Loam, 12 percent slope, Hydrologic Soil Group C
      94       94        4        1        0
   400.0
       1    0.016
    70.0      .12
       1      1.0     0.54
       1
     001      132      173      308
       1      1.0
     .15      .15      .09      .09
     1.0      1.0      1.0      1.0
    0.05     0.05    0.045    0.045
```

Table D-6. Nutrient parameter input file (Manure application).

```
GLEAMS 2.10  Nutrients Parameter file for Nords, MN (Fertilizer application)
1994; Annual Corn Crop
Seaton Silt loam; 12 percent slope; Hydrologic soil group C
      94       94        2        1        1
  1000.0     2.66

    1001
       1        1     1308
      20
    1168        0        0
     0.0     42.0      0.0      0.0
    1132       21     5.00
       0
```

Table D-7. Nutrien ameter input file (Fertilizer application)

```
GLEAMS 2.10  Nutrients Parameter file for Nords, MN (Manure Application)
1994; Annual Corn Crop
Seaton Silt loam; 12 percent slope; Hydrologic soil group C
      94       94        2        1        1
  1000.0     2.66

    1001
       1        1     1308
      20
    1168        1        0       14
     1.0      0.0      .28      .04      .23      .10      .02      .14        3
    1132       21      5.0
       0
```

Table D-8. Pesticide parameter input file.

```
GLEAMS Version 2.10 Pesticide parameters, Nords, MN
1994: Annual Corn Crop
Seation silt loam, 12 percent slope, Hydrologic Soil Group C
   94132    94365        1        1        2
       1          Harmony        0
       1   2400.0      3.0     45.0      0.0      .80               1.0
    12.0
    1132        1
       1    0.046      1.0      0.0      1.0        0
       0
```

E. Title of Objective: Evaluate alternative methods for utilizing poultry mortality and analyze the environmental and economic benefits of the compost as a nutrient source compared to other disposal methods and compared to raw manure and purchased fertilizers.

E.1. Activity: Evaluate the economic and environmental potential for various carbon sources in the composting of poultry mortality. **This will also be compared to other disposal methods.**

E.1.a Context: As manure is examined for effective usage back into various agricultural production systems, so should the application of other livestock production by-products such as mortality and various rural and urban carbon sources.

E.1.b. Methods: Various carbon sources/bulking agents will be used to evaluate their effect on the economics and efficiency of composting of dead birds. Temperature monitoring and testing information on odors, pest problems, killing of pathogens and nutrient content and stability of the final product. Grinding of the carcasses will be evaluated for enhancement of cold weather composting.

E.1.c. Materials: Materials used will be the producers bin composting site, various carbon sources (newspaper, sawdust, poultry litter, leaves), and thermometers to monitor biological activity, data collection sheets and sample containers. A portable dry extruder will be leased for 5 months.

E.1.d. Budget: $29,000 Balance: $0

E.1.e. TIMELINE:	7/93	1/94	6/94	1/95	6/95
Design substrate test	xxxx				
Set-up bin compost sites		xxxx	xxxx	xxxx	xxxx
Monitor/test sites	xxxx	xxxx	xxxx	xxxx	
Evaluate/redesign test		xxxx		xxxx	xxxx
Data summary					xxxx

E.1.f. Final Detailed Report

Standard bin composting of turkey mortality has used turkeys, turkey litter and straw layered to achieve a 20:1 carbon:nitrogen ration and approximately 60% moisture. Chopped newspaper, wood mulch and leaves were compared to the standard procedure to replace the straw as a carbon source to lower the cost of composting. Based on data and observation, newspaper and wood mulch appear to be acceptable substitutes for straw for quality of compost and are better than straw economically - waste newspaper and wood are generally free - transportation to the composting site is the only expense. Data is being collected from the third comparison using leaves. All alternative carbon sources were compared to straw using a) temperature as an indicator of biological activity; b) observations of odor and pest problems; c) nutrient testing to indicate the portion of the nutrients that were stabilized in the composting process; and, aerobic bacteria and pathogen testing.

In the newspaper/straw comparison, composting temperature in the primary bins were 140 degrees in the newspaper treatment and 150 degrees in the straw treatment; however, after turning the compost into the secondary bin, the newspaper compost rose to 160 degrees while the straw compost rose to 155 degrees. These measured temperatures are adequate to kill pathogens. There were no pest or odor differences between the treatments were observed. There was no seepage from either treatment. The newspaper compost was noticeably easier to turn.

Nutrient test of the compost showed that the straw compost had 67% of the total nitrogen content in an organic form and the newspaper compost had 74% of the total nitrogen in an organic form. The higher the percent in an organic form, the smaller the amount readily available for leaching or volatilization. Based on the following measurements and observations, newspaper worked as well as straw for composting turkey mortality at about 65% of the cost. Nutrient test results (unadjusted for moisture) are:

	Straw Compost	Newspaper Compost
Moisture	27.70%	31.90%
Total N	2.65	2.64
Organic N	1.78	1.96
Org N/Total N	67.20	74.23
Phosphorus	2.31	2.32
Potassium	2.54	2.65
Aerobic Bact. (Colonies/gram)	2.8×10^4	7.9×10^5

In the second comparison, waste wood mulch from a recycling center was substituted for straw in the compost. Nutrient tests comparing the straw and wood compost and the raw manure (unadjusted for moisture) used in the compost mix showed the following:

	Straw Compost	Wood Compost	Manure
Moisture	30.03%	37.96%	44.80%
Total N	3.19	3.20	2.43
Organic N	2.22	2.06	1.55
Org N/Total N	69.60	64.40	63.80
Phosphorus	1.31	1.32	1.31
Potassium	2.51	2.13	2.33
Aerobic Bact.	6.6×10^7	1.0×10^7	3.8×10^7

No salmonella or staphylococcus bacteria were detected in any treatments.

Results of these comparisons have been used by the cooperators at Jerome Foods to make recommendations to their turkey facility managers.

Extrusion of turkey/chicken mortality was investigated as an alternative to composting. Extrusion cooks, sterilizes, dehydrates and texturizes by creating heat through friction. Extrusion adds value to this waste product in combination with other low value materials and grain which can then be used as a small portion of the ration for ruminant animals. The extrusion process creates enough heat to dry out the product several percentage points so that is has a longer storage life and to kill most pathogens that could be a problem in the dead birds.

Several combinations varying the ratios of dead birds (ground to 1/2 inch pieces), soybeans, corn, foxtail from oat screenings and used vegetable oil from restaurants were used to determine the best mixtures for the extrusion process and for the , moisture and nutrient content and pathogen kill in the final product. The finished product in each combination was tested for microbiological organisms especially those pathogenic organisms of particular interest to the poultry producers (Salmonella and Pasteurella) as well as for feed value - moisture, crude protein, fat, crude fiber, total ash, calcium and phosphorus.

The mixtures tested in the first experiment and the nutrient test results from the various extrusion ratios were:

Mixture Content	Mixture 1	Mixture 2	Mixture 3	Mixture 4
%Birds	15	10	10	25
%Soybeans	10	8	8	20
%Corn	20	30	20	25
%Foxtail	50	50	60	30
%Veg. Oil	5	2	2	0
Moisture (%)	24	21	21	29
Extrusion Temp. (F)	260	300	310	210

End Product (Dry Matter Basis)	Mixture 1	Mixture 2	Mixture 3	Mixture 4
Moisture (%)	12.97	9.92	9.68	19.85
Crude Protein (%)	31.23	25.94	24.46	34.06
TDN (%)	79.70	86.80	76.90	79.90
Crude Fiber (%)	10.74	5.36	12.58	10.59
Fat (%)	13.60	4.84	4.76	12.24
Ash (%)	5.24	3.88	6.04	7.54
Calcium (%)	0.49	0.16	0.29	0.84
Phosphorus (%)	0.62	0.48	0.58	0.74

The nutrient value in dollars of the end product on a protein and energy basis was calculated for 2000 pounds of each mixture based on the nutrient tests and using the assumptions that

1) the cost of soybean protein is $0.205 per pound of protein; soybeans at $180 per ton and 44% protein; and,
2) the cost of the energy supplied by corn is $0.053 per pound of TDN; corn at $2.40 per bushel and 80% TDN.

Nutrient Value	Mixture 1	Mixture 2	Mixture 3	Mixture 4
Protein (%)	31.23	25.94	24.46	34.06
Protein value ($)	128.04	106.35	100.2	139.65
%TDN	79.7	86.6	76.9	79.9
TDN value ($)	84.50	91.79	81.62	84.7
Total Value ($)	212.54	198.14	181.90	224.35

The cost of producing the extrusion product including cost of ingredients and labor, and equipment costs was calculated and subtracted from the value of the nutrients to determine the net value of the end product.

Costs	Mixture 1	Mixture 2	Mixture 3	Mixture 4
Ingredients ($)	65.60	64.30	58.30	91.10
Extrusion ($/ton)	26.70	26.70	26.70	26.70
Total costs ($)	92.30	90.00	85.00	117.80
Net value ($)	120.24	108.14	96.90	106.55

The costs of the individual ingredients of the extrusion mixtures studied were:

Ingredient	Cost per pound
Ground dead birds	$0.050
Soybeans	$0.092
Corn	0.043
Foxtail	0.013
Used vegetable oil	0.020

Initial observations of the extrusion process and final product were used to fine tune. Moisture levels of 29% or above for the raw ingredients entering the extruder were too high and did not allow the extruder to reach optimal temperatures for pathogen elimination and for a drier end product. Also, at that moisture level, the extruder did not auger well. Also, grinding the corn for the mixture increases the surface area which changes the consistence of the mixture and improves the mixture for use in the extruder. The extrusion products produced in these experiments were fed to hogs without feed refusal.

E.2. Activity: Evaluate the agronomic and environmental impact of compost application to agricultural land.

E.2.a. Context: Composting will tighten up the cycle of livestock waste production, management, and reutilization with the potential to reduce feedlot waste pollution and agricultural non-point ground and surface water contamination. The project will reinforce the value of composting for stabilizing nitrates and other leachable elements from farm wastes and making use of community generated wastes as carbon sources.

E.2.b. Methods: On-farm plots (same cooperators identified in Objective F.1) will be established comparing compost and raw manure, in cooperators' existing crop rotations. Raw manure will be applied at recommended rates and compost at 75, 100 and 120% of recommended rates.

E.2.c. Materials: i) farm equipment, seed, manure supplied by farm; ii) sample bags, nutrients tests; iii) scales to determine application rates and yields, suction tubes, data collection sheets.

E.2.d. Budget: $40,000 Balance: $0

E.2.e. TIMELINE:

	7/93	1/94	6/94	1/95	6/95
Identify Cooperators	xxxx				
Design Demonstrators	xxxx				
Design Data Collection Sheets		xxxx		xxxx	
Implement Demo and Collect Data			xxxx		xxxx
Field Tours	xxxx		xxxx		
Prepare Data Summary		xxxx			
Farmer Workshops		xxxx		xxxx	

E.2.f. Final Detailed Report
Three demonstrations were designed and planted.
Siemon Farm: A demonstration was set up on a silt loam soil on the Siemon turkey farm at Altura. Treatments applied prior to fall tillage for corn production included: manure in the form of turkey litter applied at the U of M recommended rate using a two foot nitrate test;
compost including dead birds using same N criteria as manure; and a commercial fertilizer, urea, as control was applied in the spring. Treatments were replicated three times. A fall soil test was taken 10/18/93 showing:

pH - 6.6	Bray 1 P - 100+ lb./acre
Potassium - 300+ lb/acre	Organic Matter - Low
Nitrate N, 0-6 inch - 13ppm	Nitrate N, 0-24 inch - 74 lb./acre

Compost, turkey manure and urea were applied at the following amounts and with the following results on yield, moisture and test weight when the corn was harvested (10/17/94).

	Compost	Manure	Urea
Amnt. Applied	4 tons/acre	6 tons/acre	350 lb/acre
When Applied	11/8/93	11/8/93	5/22/94
Est. Avail. N	118.4 lb/acre	123.6 lb/acre	161.0 lb/acre
Yield 178.	7 bu/acre	173.0 bu/acre	170.0 bu/ac
Moisture	24.9	24.5	24.0
Test Wt.	51.8	51.6	51.6

	--------lbs/ton--------	
Total N	58.3	38.8
Organic N	41.0	26.0
Mineral N	17.3	12.8
Org. N Avail.		
1st Yr. (30%)	12.3	7.8
N Avail. 1st Yr	29.6	20.6

There were no significant differences among the treatments for yield, grain moisture or test weight, weed pressure, insects, lodging or color of the crop during the growing season.

Lingenfelter Farm: A similar design was used for the demonstration at the Lingenfelter farm at Dover to represent a sandy loam soil. Three replications of three treatments compared urea, compost and manure applied to chisel plowed corn stalks in the spring.

A fall soil test was taken 10/18/93 showing:

pH - 5.7	Bray 1 P - 100+ lb./acre
Potassium - 219 lb/acre	Organic Matter - Low
Nitrate N, 0-6 inch - 15ppm	Nitrate N, 0-24 inch - 66 lb./acre

Compost, turkey manure and urea were applied at the following amounts and with the following results on yield, moisture and test weight when the corn was harvested (11/7/94).

	Compost	Manure	Urea
Amnt. Applied	4.9 tons/acre	6.4 tons/acre	390 lb/acre
When Applied	4/20/94	4/20/94	-
Est. Avail. N	186.0 lb/acre	178.0 lb/acre	180.0 lb/acre
Yield	180 bu/acre	181 bu/acre	181.0 bu/acre
Moisture	17.1	17.2	18.5
Test Wt.	56.0	55.7	55.3

	lbs/ton	
Total N	56.2	52.8
Organic N	27.2	35.6
Mineral N	29.0	17.2
Org. N Avail. 1st Yr. (30%)	9.1	10.7
N Avail. 1st Yr	38.1	27.9

There were no significant differences among the treatments for yield, grain moisture or test weight, weed pressure, insects or color of the crop throughout the growing season. At harvest, the compost and manure treatments had approximately 1.5 lodged stalks per 1000 ft. of row while the urea treatment had approximately 6.0 lodged stalks per 1000 ft. of row. However, this difference did not affect yields because the combine was able to pick up lodged stalks.

Meyer Farm: A demonstration site was planted to study the effect of manure and compost on incidence of root rot pathogens in new seeded alfalfa. Treatments replicated three times included control plots (chemical fertilizer applied at U of M recommended rate for alfalfa production), plots receiving 154 lb. available nitrogen per acre in the form of 2.7 tons of turkey manure/acre and plots receiving 265 lb. available nitrogen per acre in the form of composted turkey manure and carcasses. Compost and manure for these plots were taken from the Siemon farm. Compost quality for this site was not good. There was adequate biological activity to kill turkey disease pathogens but not enough to stabilize nitrogen or reduce odor. Only 70% of total nitrogen was in the organic form and the bad odor indicated fermentation instead of aerobic digestion. The alfalfa stand was inspected and evaluated for root rot diseases in July and August. Disease incidence in the field was negligible across all treatments. Alfalfa yields were not significantly different among the treatments.

F. Title of objective: Educational program

F.1. Activity: Disseminate information gathered in objectives A through D with "on farm" demonstration, field days, winter meetings, and publications.

F.1.a. Context within the project: An information dissemination program will be focused in the six counties of southeastern Minnesota where soils overlay karstic topography. This will allow rapid technology transfer from this project to agency field staff and farmers.

F.1.b. Methods: The core of this educational program will be demonstrations on cooperating farmer fields. Demonstrations will have replicated manure management/conservation systems. The statistical design will be a randomized complete block split with subplots. Main plots will be two to three tillage systems. Subplots will be N source (manure type, fertilizer, etc.). Plots will be large enough to accommodate cooperator's equipment. Manure and fertilizer applications will be monitored with load cells. Samples will be taken for chemical characterization. Crop response will be characterized by measuring stand, early growth, weed density by species, total N of ear leaf, yield, and grain moisture. Soil test N, P, and K will be determined. Data will be organized in tables to illustrate significant treatment responses.

F.1.c. Materials: A vehicle will be purchased to allow for transportation to cooperating farms in the six counties in this project. It will be necessary to visit demonstration sites A freezer and oven will be purchased to store manure, soil, plant, and water samples or dry soil and plant tissue samples at a site located central to the study area until they can be transported to the St. Paul campus of the University of Minnesota for chemical analysis.

F.1.d. Budget: $63,000 Balance: $0

F.1.e. Timeline:	7/93	1/94	6/94	1/95	6/95
Identify Cooperators	xx				
Design Demonstration	xx				
Establish Treatments	xx				
Monitor Crop Response	xx		xx		
Field Tours	xx				
Organize Data		xx		xx	
Winter Meetings					xx
Publication					xx

F.1.f Final Detailed Report

INTEGRATION OF MANURE AND ALFALFA N SOURCES
INTO RESIDUE MANAGEMENT SYSTEMS
FOR KARST AREAS OF MN[1] 1993

J.F. Moncrief, B. A. Christensen, J. A. Tesmer,
N. R. Broadwater, C. R. Schwartau, T.L. Wagar,
B.J. Johnson, P M. Bongard, and C.G. Eide[2]

Seven studies on five farms in southeastern Minnesota were used to evaluate integration of manure into residue management systems. Aspect and timing of alfalfa kill dramatically affected no till corn growth and yield. There were relatively small differences in early growth and development of both corn and soybeans under high residue systems. The growth delay persisted through flowering and physiological maturity. Yield differences due to N source and tillage were variable.

This study was initiated in the spring of 1993 to evaluate manure utilization strategies within residue management systems in southeastern MN. Farmer cooperators were identified in five counties in the karst area of MN. Each demonstration was tailored to fit within the project guidelines and also address particular farmer interests. Residue management systems are the convention in this part of the state due to the erosive nature of the soils.

Daryl Highum Farm

Treatments at this site are tillage and N source. Tillage systems evaluated are chisel plowing followed by discing and a no till approach. Nitrogen sources are anhydrous ammonia and liquid hog manure. Manure application was made in the spring followed by tillage and planting. Anhydrous ammonia was applied side dress June 15. The results from this demonstration is presented in tables 1a-1g. Back ground information for is shown in table 1a.

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1 This study is supported by the Legislative Commission on Minnesota Resources the Minnesota Extension Service, and the Soil Conservation Service. Their support is greatly appreciated.

2 J.F. Moncrief and B.J. Johnson are Extension Soil Scientist and Assistant Scientist respectively; B.A. Christensen, J.A. Tesmer, N.R. Broadwater, C.R. Schwartau, T.L. Wagar, P.M. Bongard, are Extension Educators; C.G. Eide is an udergraduate research assistant.

The manure source at this site has a high concentration of N. As is characteristic of hog manure more of the nitrogen was in the ammonium form (60 vs 40% for mineral and organic respectively). Manure and anhydrous ammonia were applied at very similar rates.

Corn planted with only a fluted coulters resulted in a delay of the emergence rate and .3 leaves per plant in development (table 1b. Final stands were similar and at adequate levels. The delay in growth was the result of 3% vs 10% soil cover in the row with soybean residue (table 1c). Soil cover between the row was 6% and 20% for the chisel and no till systems respectively. Corn plants grown with the no till system tasseled and silked slightly later than with chisel plowing (table 1d).

Anhydrous ammonia resulted in higher levels of late season ammonium (table 1e). Total soil mineral N levels were similar between N sources and tillage, however. Soil nitrate was concentrated in the top foot of soil (table 1f). Soil mineral N in the row was inversely correlated with early growth (table 1g). Although corn phenology was affected by tillage and N source, differences were small and grain moisture was not affected (table 1h). Yields were relatively high and there was no affect of tillage or N source on grain yields. Grain N concentrations were higher with chisel plowing and the anhydrous ammonia source. This is consistent with other research.

Dan Graskamp Farm

Two rates of N as liquid hog manure were compared to anhydrous ammonia. The design is a randomized complete block with split plots. Main plots at this site were nitrogen source and rate. Subplots were row cultivation. Corn following soybeans was the test crop.

N source did not affect corn stands (table 2b). Row cultivation reduced stands by about 1,000 plants per acre. Soil cover with soybean residue was low. Cultivation reduced soil cover.

The high rate of manure increased the development of corn by about .2 leaves per plant. This affect carried through to silk emergence (table 2c).

The dominant weed at this site was wirestem muhly followed by velvet leaf. Horse tail numbers were reduced with cultivation by other species were not affected (tables 1d and e).

Soil ammonium and nitrate were similar between the low rate of manure and anhydrous ammonia. The high rate of manure increased mineral nitrogen concentrations in the row slightly and doubled concentrations between the row (table 2f). As expected, anhydrous ammonia, although applied at two thirds of the ammonium rate of the low rate of manure resulted in higher concentrations of late season ammonium due to the self inhibition of nitrification of this N source.

The manure N source resulted in a small but statistically significant increase in grain yields (3-5 bu/acre, table 2h). The low rate of manure and anhydrous ammonia (158 and 80 lbs N/acre, respectively) resulted in similar grain N concentrations. The high rate of manure (358 lbs N/acre) increased grain N significantly (table 2i).

Tony and Walter Hammel Farm

At this site corn was grown following alfalfa with a no till system. The treatments evaluated include: fall vs spring killed alfalfa; and north and south aspect. The design is a randomized complete block with timing main plots and aspect subplots. Data from this site are presented in tables 3a-k.

The time of the year that alfalfa was killed with herbicides did not affect corn stands (table 3b). Aspect and timing did affect early corn growth however (.2 and .6 leaves respectively). Spring killed alfalfa and northern aspect reduced growth.

Before row cultivation spring killed alfalfa resulted in about a 10% increase in soil cover (table 3c). Soil cover was not affected by aspect. After row cultivation soil cover was much reduced and northern aspect had slightly lower soil cover.

There was an interaction between aspect and timing of alfalfa kill on phenology later in the season (tassel and silk emergence, table 3d). Aspect was more important on spring killed alfalfa than fall killed.

Treatments did not affect weeds present in the row (table 3e). Between the row there was more foxtail and alfalfa with the spring killed alfalfa treatment (table 3f).

There was no affect of treatments on late season soil mineral nitrogen (table 3h).

Soils ranged in thickness from 32 to >69 inches (table 3j). The surface texture is silt loam with argillic horizons below.

Aspect affected grain moisture 4.1% at harvest. Earlier differences in development were greater at harvest due to aspect. Time of alfalfa kill resulted in a difference in grain moisture at harvest of 2.7%. This trend was opposite of the earlier affects of aspect and timing.

Fall killed alfalfa sod resulted in a yield increase of 30 bushels per acre over the spring kill treatment. Northern aspect reduced grain yields about 20 bushels per acre. Grain N concentrations were higher with the spring killed alfalfa, likely the result of dilution.

Jim Holty Farm

At this site there are three studies. The first is looking at the effect of aspect on corn response in a spring discing tillage approach. The design is a randomized complete block with two replications. The second study is evaluation of no till corn into corn. The design is a randomized complete block with two replications. The third study is evaluation of no till, drilled soybeans into corn stalks. The design is a randomized complete block with two replications.

The results of the aspect study are presented in tables 4b to 4d. Aspect did not affect stand establishment, early growth, or yield.

The results of the demonstration contrasting a disc/plant system to a no till approach for corn after corn are shown in tables 5a to 5d. Stand and early growth were not affected by tillage system. Weeds were higher with the no till system. The predominant weed species present was foxtail.

Corn grown no till after corn resulted in statistically similar yields. There is a trend for reduced yields with the no till approach that appears to be related to weed control.

The study evaluating tillage effects on soybeans grown after corn is summarized in tables 6a to 6c. The tillage evaluated were no till and chisel plowing systems. There was no difference in soybean stand due to tillage (table 6a). Early growth was delayed .4 nodes per plant under no till conditions. This due to the high "in row" cover with the no till system and the cool growing season in 1993.

Soybean yields were statistically similar between tillage treatments (table 6c).

Francis and Paul Kottshade Farm

The tillage approach at this site is light field cultivation for corn following soybeans. The N sources evaluated were liquid hog manure, anhydrous ammonia, and an unfertilized check. The design is a randomized complete block.

Soybean residue levels were at modest levels after the spring field cultivation (table 7a). The N sources did not affect stand establishment. Early corn growth was reduced with nitrogen stress (table 7b).

Although corn yields and N uptake tended to be higher with both N sources there was no statistically significant differences (table 7d).

Table 1a. Cultural practices used in the demonstration at the Daryl Highum Farm, 1993.

Experimental Design
Treatments at this site are tillage and N source. Tillage systems evaluated are chisel plowing followed by discing and a no till approach. Nitrogen sources are anhydrous ammonia and liquid hog manure. Plots were arranged in a completely randomized design. Manure application was made in the spring followed by tillage and planting. Anhydrous ammonia was applied side dress June 15.

Tillage Equipment
Chisel plow Land All, 4" twisted shovels at 7.5" spacing, straight coulters at 15"
Disc 19' Ford with 20" discs

Cropping history
Previous crop Soybeans; planting date 4/30/93; hybrid Cargill 4327 (105 day); rate 35,500 in 30" rows
Planter Allis Chalmers with 2" fluted coulters

Manure applications
Hog manure (pit storage) 2500 gal/A
Total N 203 lb/A
NH_4-N 126 lb/A
Estimated Avail. N 153 lb/A
Application Broadcast 5/4/93 (worked in except on no-till plots)

Liquid Hog Manure Analysis

Sample	Solids	NH_4^+	NO_3^-	Tot.Min.-N	Org.N[1]	Total N	Est.Avail.N[2]	Est.Avl.N applied[3]
5/19/93	---%---	------------------lbs/1000 gals.-----------------						--- lbs.N/a ---
1.	11.6	50.8	-	50.8	26.9	77.7	60.2	123
2.	6.6	50.3	-	50.3	34.5	84.8	62.3	
3.	10.4	50.8	-	50.8	31.6	81.4	61.9	
4.	12.5	49.9	-	49.9	32.6	82.6	61.4	
5.	8.6	51.1	-	51.1	30.5	81.6	61.8	
6.	8.6	50.4	-	50.4	29.1	79.5	60.5	
Avg.	**9.7**	**50.6**	**-**	**50.6**	**30.9**	**81.2**	**61.4**	

1.Organic nitrogen = Total nitrogen - Total mineral nitrogen (from laboratory analysis).
2.Estimated available nitrogen =(Org.-N x .35) + Tot.Min.-N. It is assumed that all of the mineral N and 30% of the Org.N is available during the first year of

application
3.The rate of manure applied for plot area was 2,000 gal./acre from a pit. Broadcasted on 5/4/93 and worked in on chisel plots and broadcast only on no till plots.

Fertilizer
82-0-0 125 lb N/A side-dressed 6/15/93; 9-23-30 180 lb/A applied as starter

Soil type Recent Alluvium, loam to sandy loam texture.

Weed control
2,4-D 1 pt/A applied 5/14/93
Lasso (alachlor) 2 qt/A applied 5/14/93
Bladex (cyanazine) 2 qt/A applied 5/14/93

Table 1b. Effect of tillage and nitrogen source on early season corn population and leaf numbers at the Daryl Highum farm demonstration near Rushford in Fillmore County, 1993.

		stand			early growth		
		6/12	7/2	avg.	6/10	7/2	avg.
tillage	N source	---plt/Ax 1000---			-leaves/plant-		
No-till	AN. NH_3	29.2a[1]	30.7a	30.0	4.9b	7.7c	6.3
	Hog Manure	28.8a	30.3a	29.6	4.9b	8.0bc	6.4
Chisel	An. NH_3	30.8a	29.6a	30.2	5.0b	8.1b	6.6
Plow	Hog Manure	29.4a	29.6a	29.5	5.4a	8.4a	6.9
No-till		29.0b	30.5a	29.8	4.9b	7.9b	6.4
Chisel Plow		30.1a	29.6a	29.9	5.2a	8.2a	6.7
An. NH_3		30.0a	30.2a	30.1	4.9a	7.9b	6.4
Hog Manure		29.2a	30.0a	29.6	5.2a	8.2a	6.7
Pr>F	tillage	<0.10	>>0.10		<0.10	<0.05	
	N Source	>0.10	>>0.10		>0.10	<0.05	
	tillagexN	>0.10	>>0.10		>0.10	>>0.10	

[1]Data followed by the same letter in the same column group are not significantly different at the 0.10 level.

Table 1c. Effect of tillage and nitrogen source on soybean residue at the Highum Farm demonstration, 1993.

		in row cover			between row cover		
		6/12	7/2	Avg.	6/10	7/2	Avg.
Tillage	N Source	----------	----------	----------	%	----------	----------
No-till	an. NH_3	11.2a[1]	10.0a	10.6	21.7a	15.0a	18.4
	Hog Manure	7.5b	10.4a	9.0	18.3a	16.7a	17.5
Chisel	An. NH_3	3.3c	3.8b	3.6	7.1b	5.8b	6.4
Plow	Hog Manure	2.5c	3.8b	3.2	4.6b	5.8b	5.2
No-till		9.2a	10.2a	9.7	20.0a	15.8a	17.9
Chisel Plow		2.9b	3.8b	3.4	5.8b	5.8b	5.8
An. NH_3		7.0a	6.9a	7.0	14.4a	10.4a	12.4
Hog Manure		5.0b	7.1a	6.0	11.4b	11.2a	11.3
Pr>F	Tillage	<0.01	<.05		<<.01	<0.01	
	N Source	<0.10	>>0.10		<0.10	>>0.10	
tillagexN Source		>0.10	>>0.10		>>0.10	>>0.10	

[1]Data followed by the same letter in the same column group are not significantly different at the 0.10 level.

Table 1d. Effect of tillage and nitrogen source on percent of corn plants tasselling and silking at the Highum Farm demonstration, 1993.

		Tasselling 7/26	Tasselling 7/30	Silking 7/26	Silking 7/30
		%			
No-till	An. NH_3	66.9a[1]	92.2a	21.6b	71.2b
	Hog Manure	75.8a	95.1a	29.2b	92.3a
Chisel Plow	An. NH_3	81.6a	91.6a	45.6a	82.0ab
	Hog Manure	84.1a	97.2a	41.4a	94.2a
No-till		71.4a	93.6a	25.4b	81.8a
Chisel Plow		82.8a	94.4a	43.5a	88.1a
An. NH_3		74.2a	91.9a	33.6a	76.6b
Hog Manure		80.0a	96.2a	35.6a	93.2a
Pr>F Tillage		>0.10	>>0.10	<0.05	>0.10
N Source		>>0.10	>0.10	>0.10	<0.05
tillagexNwource		>>0.10	>>0.10	>0.10	>0.10

[1]Data followed by the same letter in the same column group are not significantly different at the 0.10 level.

Table 1e. Effect of tillage and nitrogen source on total inorganic soil nitrogen concentrations to a 3 foot depth at the Highum farm demonstration, August 27, 1993.

		NH_4^++NO_3^-	NH_4^+	NO_3^-
		lb/A		
No-till	An. NH_3	130.4a[1]	70.3a	60.1a
	Hog manure	83.1a	48.9c	32.9a
Chisel plow	An. NH_3	105.9a	62.9ab	43.0a
	Hog manure	96.8a	57.2bc	39.6a
No-till		106.8a	59.6a	46.5a
Chisel plow		101.4a	60.0a	41.3a
An. Ammonia		118.2a	66.6a	51.6a
Hog manure		90.0a	53.0a	36.2a
In-row		101.5a	59.9a	40.9a
Between-row		106.6a	59.7a	46.9a
Pr>F Treatment		0.24	0.04	0.47
Tillage		0.53	0.69	0.55
N Source		0.34	0.17	0.46
Row position		0.60	0.96	0.44
Treatment*Row		0.73	0.81	0.78

[1]Data followed by the same letter in the same column group are not significantly different at the 0.10 level.

Table 1f. Effect of tillage and nitrogen source on inorganic nitrogen concentrations at three soil depths at the Highum farm, August 27, 1993.

	depth	NH_4^++NO_3^-	NH_4^+	NO_3^-
		--------lb/A----------		
No-till An. NH_3	0-12"	50.8a	20.3bcd	30.5a
	12-24"	39.3bc	23.0abc	16.3bcd
	24-36"	40.3abc	27.0a	13.3cde
Hog manure	0-12"	38.1bc	13.3e	23.5ab
	12-24"	22.8d	18.0d	4.8e
	24-36"	22.2d	17.5d	4.7e
Chisel An. NH_3	0-12"	42.9ab	16.8de	26.1a
	12-24"	31.4cd	22.5bc	8.8de
	24-36"	31.7cd	23.6abc	8.1de
Hog manure	0-12"	34.1bc	13.5e	20.6bc
	12-24"	32.0bcc	19.7cd	12.3cde
	24-36"	30.7cd	24.0ab	6.6e
Treatment				
No-till An. NH_3		43.5a	23.4a	20.0a
Hog manure		27.7a	16.3c	11.0a
ChiselAn. NH_3		35.3a	21.0ab	14.3a
Hog manure		32.2a	19.1bc	13.2a
Row position				
In-row		33.8a	20.0a	13.6a
Between-row		35.5a	19.9a	15.6a
Depth				
0-12"		41.4a	16.0b	25.2a
12-24"		31.4b	20.8a	10.6b
24-36"		31.2b	23.0a	8.2b
Pr>F Treatment		0.242	0.038	0.471
Row position		0.606	0.956	0.441
Depth		0.001	0.0004	0.0001
TreatmentxRow position		0.732	0.810	0.776
TreatmentxDepth		0.665	0.822	0.813
Row positionxDepth		0.424	0.374	0.821
TrtmentxRowxDepth		0.840	0.577	0.944

[1]Data followed by the same letter in the same column group are not significantly different at the 0.10 level.

Table 1g. Correlation of inorganic soil nitrogen concentrations at the 0-12" depth with corn phenology and yields at the Highum farm, 1993.

	leaf numbers		Silking		
Row position	6/11	7/12	7/26	7/30	Yield
In-row soil N	-0.631	-0.089	-0.282	0.069	-0.065
Between soil N	-0.284	0.115	-0.313	-0.033	0.131
Pr>F In row N	0.011	0.752	0.309	0.806	0.817
Between row N	0.304	0.683	0.256	0.908	0.643

Table 1h. Effect of tillage and nitrogen source on corn grain yields, moisture and nitrogen content at the Highum farm, October 28, 1993.

	moisture	yield	nitrogen
	--%--	-bu/a-	--%--
No-till an. NH_3	21.1a[1]	171a	1.20a
Hog manure	20.1a	163a	1.11b
Chisel An. NH_3	19.8a	176a	1.21a
plow hog manure	19.5a	175a	1.17a
Tillage			
No-till	20.6a	167a	1.16b
Chisel plow	19.6a	176a	1.19a
N source			
An. NH_3	20.4a	174a	1.21a
Hog manure	19.8a	169a	1.14b
Pr>F Treatment	0.41	0.56	0.01
Tillage	0.27	0.32	0.03
N Source	0.26	0.56	0.07

[1]Data followed by the same letter in the same column are not significantly different at the 0.10 level.

Table 2a. Cultural practices at the Dan Graskamp farm, 1993.

Tillage equipment
Field cultivator (21') 2" shanks at 6" spacing
Row cultivator 13' John Deere (4-38" row)
(6/27/93) 2-5" sweeps between rows

Cropping history
Previous crop Soybeans
Planting date 5/8/93
Variety McCurdies 5222 (110 day)
Planting population 28,500

Experimental Design

Two rates of N as liquid hog manure were compared to anhydrous ammonia. The design is a randomized complete block with split plots. Main plots at this site were nitrogen source and rate. Subplots were row cultivation.

Manure	High rate	Low rate
Hog manure	6300 gal/A	3145 gal/A
Total N	450 lb/A	226 lb/A
NH_4-N	243 lb/A	122 lb/A
Est. Avail. N	316 lb/A	158 lb/A

Application Broadcast 5/11/93 and worked in

Liquid Hog Manure Analysis

Sample applied[3]	Solids	NH_4^+	NO_3^-	Tot.Min.-N	Org.N[1]	Total N	Est.Avail.N[2]	Est.Avl.N
5/19/93	---%---	---------------lbs/1000 gals.					--------------------	--- lbs.N/a --
-								
1.	9.5	39.2	-	39.2	34.1	73.3	51.2	* Hi= 311
2.	8.5	43.6	-	43.6	28.7	72.3	53.6	* Lo= 156
3.	9.1	41.8	-	41.8	28.9	70.6	51.9	
4.	4.3	29.8	-	29.8	41.2	70.9	44.2	
Avg.	**10.4**	**38.6**	**-**	**38.6**	**33.2**	**71.8**	**50.2**	

1.Organic nitrogen = Total nitrogen - Total mineral nitrogen (from laboratory analysis).
2.Estimated available nitrogen = (Org.-N * .35) + Tot.Min.-N. It is assumed that all of the mineral N and 30% of the Org.N is available during the first year of application.
3.The rate of manure applied for plot area was 6,200 gal./acre for the Hi and 3,100 gal/acre for the Lo treatment. Storage was a pit, surface applied by broadcast on 5/11/93 and worked in.

Fertilizer 9-23-30 100 lb/A applied as starter; anhydrous 80 lb N/A

Soil Fayette silt loam 2-6% slope

Weed control
Prowl (3.3E)2.5 pt/A applied 5/17/93; Marksman2.5 pt/A applied 5/17/93; Bladex (4 F)1 lb/A applied 5/17/93

Table 2b. Effect of nitrogen source and cultivation (6/27/93) on early season plant population and soybean residue at the Dan Graskamp farm demonstration near Fountain in Fillmore County, 1993.

N source	N rate	cul[1]	stand 6/9	stand 6/29	in row 6/9	in row 6/29	between row 6/9	between row 6/29
	-lb/A-		--plt/A---		----------	%	----------	
An. NH_3	80	Yes	-	24.3A[1]	-	2.7B	-	3.3C
		No	-	25.4A	-	4.2AB	-	6.5AB
Hog manure	316	Yes	-	24.4A	-	5.8A	-	4.6BC
		No	-	26.0A	-	1.8B	-	8.8A
Hog manure	158	Yes	-	24.5A	-	4.0AB	-	4.4B
		No	-	26.2A	-	3.8AB	-	6.4AB
AA	80		24.6A	24.9A	7.9A	3.3A	12.9A	5.0A
Hog manure	316		25.4A	25.2A	9.0A	3.8A	13.8A	6.7A
Hog manure	158		24.3A	25.4A	7.6A	3.8A	13.8A	5.4A
Cultivation			-	24.4B	-	6.8A	-	4.1B
No cultivation			-	25.9A	-	6.8A	-	7.2A
Pr>F N Source			0.16	0.82	0.52	0.93	0.80	0.36
Cultivation			-	0.03	-	0.18	-	0.0002
NxCultivation			-	0.91	-	0.02	-	0.25

[1]Data followed by the same letter in the same column group are not significantly different at the 0.10 level.

Table 2c. Effect of nitrogen source and cultivation (6/27) on corn phenology at the Graskamp Farm, 1993.

N source		Cult	early growth 6/9	6/29	silking 8/13
	-lb/a-		-leaves/plant-		-score-
An. NH_3	80	Yes	-	6.7b[2]	1.5c
		No	-	6.8ab	1.6c
Hog manure	316	Yes	-	7.0a	2.6a
		No	-	6.9ab	2.4ab
Hog manure	158	Yes	-	6.8ab	2.0abc
		No	-	6.8ab	1.8bc
Aa	80		2.8a	6.7b	1.6b
Hog manure	316		2.8a	6.9a	2.5a
Hog manure	158		2.9a	6.8ab	1.9b
Cultivation			-	6.8a	2.0a
No cultivation			-	6.8a	1.9a
Pr>f n source			0.20	0.08	0.04
Cultivation			-	0.63	0.49
Nxcultivation			-	0.77	0.61

[1]Silking score based on color: 1=white or yellow (not pollinated) 5=brown (pollinated).
[2]Data followed by the same letter in the same column group are not significantly different at the 0.10 level.

Table 2d. Effect of nitrogen source and cultivation (6/27) on weed counts and species composition **in the row** at the Graskamp farm, July 19, 1993.

		Cult	Count	Wirestem Muhly	Horse Tail	Quack-Grass
	-Lb/a-		#/Ft^2	-------%-------		
AA. NH_3	80	Yes	1.1a[2]	91.7	8.3	-
		No	1.3a	54.3	45.7	-
Hog Manure	316	Yes	1.1a	67.5	27.5	5.0
		No	1.2a	86.6	13.4	-
Hog Manure	158	Yes	1.4a	95.8	4.2	-
		No	1.0a	94.5	5.6	-
AA	80		1.2a	73.0	27.0	-
Hog Manure	316		1.2a	77.1	20.4	2.5
Hog Manure	158		1.1a	95.1	4.9	-
Cultivation			1.2a	85.0	13.3	1.7
No Cultivation			1.2a	78.5	21.5	-
Pr>F N Source			0.97	0.11	0.33	
Cultivation			0.80	0.12	0.68	
NxCultivation			0.34	0.14	0.12	

[1]W.Muhly=Wirestem muhly; Vel.leaf=Velvetleaf.
[2]Data followed by the same letter in the same column group are not significantly different at the 0.10 level.

Table 2e. Effect of nitrogen source and cultivation (6/27) on weed counts and species composition **between the row** at the Graskamp farm, July 19, 1993.

		Cult	count	Wirestem Muhly	Horse tail	Vel. leaf	Common lambs
	-lb/A-		#/Ft²	--------	% cover	---------	
An. NH_3	80	Yes	5.8a[2]	94.1ab	1.7b	0.8	3.3
		No	6.5a	85.7b	10.2a	1.4	2.8
Hog Manure	316	Yes	5.4a	91.8ab	4.0ab	3.9	0.4
		No	6.4a	84.7b	6.7ab	1.1	7.3
Hog Manure	158	Yes	5.6a	98.2a	1.5b	0.4	-
		No	3.4a	91.7ab	7.2ab	1.1	-
AA	80	-	6.1a	89.9a	5.9a	1.1	3.0
Hog Manure	316	-	5.9a	88.3a	5.4a	2.5	3.8
Hog Manure	158	-	4.5a	94.9a	4.3a	0.7	-
Cultivation			5.6a	94.7a	2.4a	1.7	1.2
No Cultivation			5.4a	87.4b	8.0b	1.2	3.3
Pr>F N Source			0.52	0.31	0.89	0.17	0.42
Cultivation			0.89	0.08	0.02	0.60	0.38
NxCultivation			0.38	0.97	0.52	0.17	0.38

[1]W.Muhly=Wirestem Muhly; H.tail=Horsetail; V.leaf=Velvetleaf; Common Lambsquarters

[2]Data followed by the same letter in the same column group are not significantly different at the 0.10 level.

Table 2f. Effect of nitrogen source and cultivation (6/27) on total inorganic soil nitrogen concentrations to a 3 foot depth at the Graskamp farm, August 28, 1993[1].

			In-row			Between-row		
			NH_4^++NO_3^-	NH_4^+	NO_3^-	NH_4^++NO_3^-	NH_4^+	NO_3^-
		cult	------------		lb/A			--------------
Anhydrous	80	Yes	120	112	8.1	71	58.2	13.0
		No	121	104	16.5	101	91.0	10.3
Hog manure	316	Yes	147	113	33.6	147	102.0	44.9
(high rate)		No	183	132	50.8	218	159.0	58.5
Hog manure	158	Yes	91	73	17.7	85	57.7	27.2
(low rate)		No	163	152	11.4	74	58.1	15.6
Anhydrous	80		120	108	12.3	86	74.6	11.6
Hog manure	316		165	122	42.2	182	130.5	51.7
Hog manure	158		127	112	14.6	80	57.9	21.4
Cultivation			119	99	19.8	101	72.6	28.4
No Cultivation			156	129	26.2	131	102.7	28.1
In-row			138	114	23.0			
Between-row			116	88	28.2			

1. These data represent one replication which did not allow statistical analysis.

Table 2g. Effect of nitrogen source and cultivation (6/27) on inorganic soil nitrogen concentrations at three depths at the Graskamp farm, August 28, 1993.

N Source	Cult	Depth	In-row $NH_4^+ + NO_3^-$	In-row NH_4^+	In-row NO_3^-	Between-row $NH_4^+ + NO_3^-$	Between-row NH_4^+	Between-row NO_3^-
			--------	--------	--------	lb/A	--------	--------
Anhydrous	Yes	0-12"	83.1	77.9	5.26	45.6	35.6	10.01
		12-24"	36.9	34.1	2.82	25.6	22.6	3.03
		24-36"						
	No	0-12"	44.6	36.5	8.03	34.9	30.1	4.84
		12-24"	38.6	34.2	4.33	33.6	32.0	1.54
		24-36"	37.7	33.6	4.16	32.8	28.9	3.95
Hog manure (high rate)	Yes	0-12"	65.2	52.2	13.02	47.1	31.7	15.42
		12-24"	38.1	31.4	6.74	47.1	37.9	9.21
		24-36"	43.7	29.8	13.89	52.5	32.3	20.28
	No	0-12"	56.8	29.2	27.58	62.4	44.5	17.84
		12-24"	82.8	73.6	9.20	76.0	55.1	20.83
		24-36"	43.5	29.6	14.0	79.1	59.2	19.90
Hog manure (low rate)	Yes	0-12"	32.2	23.8	8.42	44.2	27.5	16.70
		12-24"	29.9	25.4	4.50	40.7	30.2	10.49
		24-36"	28.6	23.8	4.76	---		
	No	0-12"	73.7	69.1	4.60	35.2	25.0	10.20
		12-24"	51.0	49.5	1.44	7.0	6.0	0.91
		24-36"	38.6	33.3	5.36	31.6	27.1	4.45
Anhydrous			50.1	45.5	4.56	28.7	24.8	3.90
Hog manure (high rate)			55.0	40.9	14.07	60.7	43.4	17.25
Hog manure (low rate)			42.3	39.4	4.85	26.4	19.3	7.12
Cultivation			46.4	39.5	6.90	33.6	24.2	9.46
No Cultivation			51.9	43.2	8.74	43.6	34.2	9.38
0-12"			59.3	48.1	11.15	44.9	32.4	12.50
12-24"			46.2	41.3	4.84	38.3	30.6	7.67
24-36"			42.0	34.5	7.48	32.7	24.6	8.10
In-row			49.2	41.3	7.82			
Between-row sampling			38.6	29.2	9.42			

Table 2h. Effect of nitrogen source and cultivation (6/27) on corn grain yields, moisture contents, and nitrogen concentrations at the Graskamp farm, 1993.

	cult	moist.	yield	N
		--%---	-bu/A-	-%-
An. NH_3	Yes	25.4a[1]	114c	1.31a
	No	26.1a	115c	1.28b
Hog Manure (High Rate)	Yes	25.1a	119ab	1.34a
	No	25.1a	123a	1.34a
Hog Manure (Low Rate)	Yes	24.9a	119ab	1.30a
	No	25.4a	118bc	1.24b
An NH_3		25.8a	115b	1.30b
Hog Manure(high)		25.2a	121a	1.34a
Hog Manure(low)		25.2a	118a	1.27b
Cultivation		25.2a	117a	1.31a
No Cultivation		25.5a	119a	1.29b
Pr>F N Source		0.43	0.02	0.04
Cultivation		0.47	0.56	0.03
NxCultivation		0.50	0.29	0.17

[1]Data followed by the same letter in the same column group are not significantly different at the 0.10 level.

Table 3a. Cultural practices used at the Hammel Farm demonstration, 1993.

Tillage equipment
Row cultivator Dakon 4-38" rows (late June) 5 Danish tine/row

Cropping history
Previous crop Alfalfa
Planting date 5/8/93
Variety DeKalb 451 (100 day)
Planting population 29,900 seeds/A
Planter New Idea with Kinsey planting units & 2" fluted coulters

Experimental Design
The treatments evaluated at this site include: fall vs spring killed alfalfa; and north and south aspect. The design is a randomized complete block with timing main plots and aspect subplots.

Fertilizer
Urea 50 lb N/A

Soils
Black Hammer-Southridge silty clay loam
Nodine-Rollingstone silty clay loam

Weed control
Ranger (alfalfa kill) 3 pt/A

Aspect	avg.	std.	range
North slope	13%	(1.6)	10-14
South slope	16%	(3.2)	12-20

Table 3b. Effect of alfalfa-kill timing and aspect on early season plant population and corn leaf numbers at the Tony and Walter Hammel Farm demonstration near Caledonia in Houston County, 1993.

		stand			early growth		
sod		6/21	7/10	avg.	6/21	7/10	avg.
kill	aspect	---plt/A x1000---			-leaves/plant-		
Fall	North	26.7a[1]	28.6a	27.6	5.4a	7.8a	6.6
	South	28.3a	29.3a	28.8	5.5a	8.0a	6.8
Spring	North	26.1a	24.9a	25.5	4.7a	6.8b	5.8
	South	25.4a	25.9a	25.6	4.9a	7.3ab	6.1
Sod Kill							
Fall		27.5a	29.0a	28.2	5.4a	7.8a	6.6
Spring		25.8a	25.4a	25.6	4.8a	7.1b	6.0
Aspect							
North		26.4a	26.8a	26.6	5.0b	7.3a	6.2
South		27.0a	27.7a	27.4	5.2a	7.6a	6.4
Pr>F	Sod kill	0.47	0.38		0.17	0.08	
	Aspect	0.82	0.30		0.06	0.26	
SdkillxAspect		0.59	0.84		0.70	0.70	

[1]Data followed by the same letter in the same column group are not significantly different at the 0.10 level.

Table 3c. Effect of alfalfa-kill timing and aspect on alfalfa residue at the Hammel Farm, 1993[1].

		In Row			Between Row		
Sod		6/21	7/10	Avg.	6/21	7/10	Avg.
Kill	Aspect	--Plt/a X1000---			--------%---------		
Fall	North	14.6a[2]	4.2c	9.4	24.2c	2.6a	13.4
	South	20.4a	5.7bc	13.0	30.8bc	3.1a	17.0
Spring	North	23.3a	7.3ab	15.3	35.8ab	2.6a	19.2
	South	31.2a	8.3a	19.8	49.2a	5.2a	27.2
Sod Kill							
Fall		17.5b	5.0b	11.2	27.5b	2.9a	15.2
Spring		27.5a	7.5a	17.5	42.5a	3.9a	23.2
Aspect							
North		19.2a	5.8a	12.5	30.0a	2.6b	16.3
South		25.8a	7.0a	16.4	40.0a	4.2a	22.1
Pr>F							
Sodkill		0.00	0.04		0.03	0.69	
Aspect		0.32	0.14		0.16	0.05	
SodkillxAspect		0.86	0.73		0.57	0.13	

[1]Plots were cultivated between 6/21 and 7/10/93.
[2]Data followed by the same letter in the same column group are not significantly different at the 0.10 level.

Table 3d. Effect of sodkill and aspect on corn silking and tasselling at the Hammel Farm, 1993.

		Tasseling		Silking	
		7/30	8/4	7/30	8/4
Kill	Aspect	--------------%---------------			
Fall	North	89.0ab[1]	100.0a	67.2ab	97.4a
	South	92.4a	98.8a	70.6a	88.7a
Spring	North	55.9b	97.5a	5.0c	62.8b
	South	75.3ab	98.1a	42.0b	93.8a
Sodkill					
Fall		90.7a	99.4a	68.9a	93.0a
Spring		65.6b	97.8a	23.5b	78.3b
Aspect					
North		72.4a	98.8a	36.1a	80.1b
South		83.8a	98.4a	56.3a	91.2a
Pr>F	Sodkill	0.08	0.50	0.04	0.03
Aspect		0.31	0.42	0.13	0.08
SodkillxAspect		0.44	0.10	0.17	0.03

[1]Data followed by the same letter in the same column group are not significantly different at the 0.10 level.

Table 3e. Effect of sodkill and aspect on weed counts and species composition in the row (cultivation late June) at the Hammel farm, July 9-12, 1993.

Sod Kill		Weed Count #/Ft[1]	Species Composition[1] Qg	Fxt.sp.	Dand.	Yns	Alf.	Rrpw	Vele
			%						
Fall	North	3.7a[2]	74.9a	20.7	3.4	-	-	1.1	-
	South	3.6a	66.0a	-	34.0	-	-	-	-
Spring	North	15.8a	39.4a	50.0	-	6.3	4.4	-	-
	South	6.9a	74.4a	-	1.8	-	17.3	4.8	1.8
Sod Kill									
Fall		3.6a	70.4a	10.4	18.7	-	-	0.6	-
Spring		11.4a	56.9a	25.0	0.9	3.1	10.8	2.4	0.9
Aspect									
North		9.8a	57.1a	35.4	1.7	3.2	2.2	0.6	-
South		5.2a	70.2a	-	17.9	-	8.7	2.4	0.9
Pr>F	Sod kill	0.24	0.82						
	Aspect	0.44	0.62						
SodkillxAspect		0.45	0.46						

[1]QG=Quackgrass; Fxt.sp=Foxtail sp.; Dand.=Dandelion; YNS=Yellow nutsedge; Alf.=Alfalfa; RRPW=Redroot pigweed; Vele=Velvetleaf.
[2]Data followed by the same letter in the same column group are not significantly different at the 0.10 level.

Table 3f. Effect of sodkill and aspect on weed counts and species composition between the row (cultivation late June) at the Hammel farm, July 9-12, 1993.

Kill	Aspect	Weed Count #/Ft[2]	Species Composition[1] Qg	Fxt.sp.	dand.	Yns	Alf.	Rrpw
			%					
Fall	North	2.1ab[2]	88.2a	-	9.3	-	-	2.5
	South	1.5b	71.4a	-	28.6	-	-	-
Spring	North	5.1a	39.8a	48.4	-	5.3	5.3	1.4
	Spring	3.5ab	81.5a	-	-	-	16.3	2.3
Sod Kill								
Fall		1.8b	79.8a	-	19.0	-	-	1.3
Spring		4.3a	60.6a	24.2	-	2.6	10.8	1.8
Aspect								
North		3.6a	64.0a	24.2	4.7	2.6	2.6	1.9
South		2.5a	76.4a	-	14.3	-	8.1	1.2
Pr>F	Sodkill	0.03	0.65					
Aspect		0.40	0.65					
SodkillxAspect		0.69	0.34					

[1]QG=Quackgrass; Fxt.sp=Foxtail sp.; Dand.=Dandelion; YNS=Yellow nutsedge; Alf.=Alfalfa; RRPW=Redroot pigweed.
[2]Data followed by the same letter in the same column group are not significantly different at the 0.10 level.

Table 3g. Effect of sodkill and aspect on total soil N at 3-foot depth at the Hammel Farm, August 26, 1993.

Sod kill	aspect	$NH_4^+ + NO_3^-$	NH_4^+	NO_3^-
		lb/A		
Fall	North	141a[1]	88.2a	52.5a
	South	84a	69.8a	13.8a
Spring	North	134a	100.8a	32.2a
	South	144a	89.2a	54.5a
Fall		112a	79.0a	33.1a
Spring		139a	95.0a	43.4a
North		137a	94.5a	42.4a
South		113a	79.5a	34.1a
In-ro		129a	88.9a	40.4a
Between-row		121a	85.1a	36.1a
Pr>F	Sodkill	0.17	0.18	0.56
	Aspect	0.63	0.50	0.78
SodkillxAspect		0.50	0.87	0.36
Row position		0.52	0.72	0.34
Row pos.xSodkill		0.77	0.36	0.18
Row pos.xAspect		0.67	0.62	0.91
Rowpos*Sodkill*Aspect		0.46	0.79	0.16

[1]Data followed by the same letter in the same column group are not significantly different at the 0.10 level.

Table 3h. Effect of sodkill, aspect, and depth on soil nitrogen concentrations at the one- and two-foot depths at the Hammel farm, August 26, 1993.

sod kill	aspect	depth	$NH_4^+ + NO_3^-$	NH_4^+	NO_3^-
			--------lb/A---------		
Fall	North	0-12"	48.2a[1]	27.5a	20.7ab
		12-24"	46.6a	28.1a	18.4ab
	South	0-12"	41.0a	29.8a	11.4ab
		12-24"	41.8a	39.7a	2.1b
Spring	North	0-12"	45.6a	28.1a	17.6ab
		12-24"	43.0a	35.1a	8.1ab
	South	0-12"	50.0a	27.1a	23.0a
		12-24"	45.6a	29.4a	16.2ab
Fall			44.4a	31.3a	13.1a
Spring			46.2a	29.9a	16.2a
North			46.0a	29.7a	16.2a
South			44.6a	31.5a	13.2a
0-12"			46.3a	28.1a	18.2a
12-24"			44.3a	33.1a	11.2b
In-row			44.9a	30.0a	13.6a
Between-row			45.7a	31.2a	15.6a
Pr>F Sodkill			0.77	0.26	0.66
Aspect			0.93	0.77	0.76
SodkillxAspect			0.75	0.44	0.37
Row position			0.81	0.64	0.76
Depth			0.64	0.14	0.00
DepthxSodkill			0.60	0.91	0.45
DepthxAspect			0.96	0.68	0.50
SodkillxAspectxDepth			0.72	0.26	0.17

[1]Data followed by the same letter in the same column group are not significantly different at the 0.10 level.

Table 3i. Correlation of inorganic soil nitrogen concentrations at the 0-12" depth with corn phenology and yields at the Hammel farm, 1993.

	Leaf Numbers		Silking		
Row Position	6/21	7/10	7/30	8/4	Yield
In-row soil N	0.072	0.144	-.004	0.186	-0.245
Between-row soil N	-0.180	0.147	-0.042	0.087	-0.296
Pr>F					
In-row soil N	0.86	0.73	0.99	0.66	0.56
Between-row soil N	0.67	0.73	0.92	0.84	0.48

Table 3j. Soil core sampling data from the Hammel Farm, July 21, 1993.

Core	Sodkill	Aspect	Horizon	Depth	Soil Description
1	Spring	South	A	0-30"	Silt loam (Alluvium)
			B	30-55"	Si. clay loam, lt. brown (Argillic)
			C	55-69"	Mottled clay
				69"+	Rock
2	Spring	North	A	0-10"	Silt loam
			B_1	10-24"	Red clay (Argillic)
			B_2	24-38"	White clay
			C	38"+	Sandstone
3	Fall	North	A	0-8"	Silt loam
			B_1	8-30"	Brown clay
			B_2	30-42"	Clay (light color)
			C	42"+	Rock
4	Fall	South	A	0-8"	Silt loam
			B_1	8-20"	Silty clay loam
			B	20-42"	Brown clay
				42"+	Rock
5	Spring	South	A	0-8"	Silt loam
			B_1	8-15"	Fine sandy loam
			B_2	15-36"	Fine sand
			C	36"+	Sandstone
6	Spring	North	A	0-8"	Silt loam
				8-14"	Silt loam
			B	14-24"	Silty clay loam
				24-50"	Silt loam
			C	50-52"	Sand
				52"+	Sandstone

Table 3k. Effect of sodkill and aspect on corn grain yields, moisture contents, and nitrogen contents at the Hammel farm study.

Kill	Aspect	Moisture --%---	Yield --Bu/a--	Nitrogen --%--
Fall	North	27.2b[1]	160.8a	1.27a
	South	24.2d	177.7a	1.27a
Spring	North	30.6a	129.0b	1.33a
	South	25.5c	148.8ab	1.33a
Sodkill				
Fall		25.7a	169.2a	1.27b
Spring		28.0a	138.9b	1.33a
Aspect				
North		28.9a	144.9b	1.30a
South		24.8b	163.2a	1.30a
Pr>FSodkill		0.15	0.08	0.03
Aspect		0.01	0.04	0.98
SodkillxAspect		0.15	0.73	0.94

[1]Data followed by the same letter in the same column are not significantly different at the 0.10 level.

Table 4a. Cultural practices used in the demonstrations at Jim Holty's Farm, 1993.

Experimental design

At this site there are three studies. The first is looking at the effect of aspect on corn response in a spring discing tillage approach. The design is a randomized complete block with two replications. The second study is evaluation of no till corn into corn. The design is a randomized complete block with two replications. The third study is evaluation of no till, drilled soybeans into corn stalks. The design is a randomized complete block with two replications.

	Corn Aspect	Corn No-till	Soybean No-till
Tillage equipment			
Disc 14'	Case International	none	none
Cropping history			
Previous crop	Corn	Corn	Corn
Planting date	5/10/93	5/13/93	5/22/93
Variety	Pioneer 3563 (103 day)	Pioneer 3702 (101 day)	
Planting pop.	28,500	28,500	
Planter	Case IH 800 with Yetter rolling finger trash wipers	Case IH 800Case	IH Grain drill
Fertilizer			
82-0-0	131 lb N/A	131 lb N/A	-
9-23-30	150 lb/A	150 lb/A	-
Beef manure	40 ton/A	-	-
Soil			
Port Byron silt loam 3-6% slope at all three sites.			
Weed control	Confidence (2.08 lb/A) Atrazine (0.7 lb/A) Bladex (1.67 lb/A) May 17	Confidence (2.08 lb/A) Atrazine (0.7 lb/A) Marksman (1.3 qt/A) May 20	Pursuit (4 oz/A)
Insect control	Counter	Counter	-

Table 4b. Effect of aspect on early season plant population and crop residue, at the Richard and Jim Holty's Farm near Spring Grove in Houston County, 1993.

	Population			Cover with Corn Residue			
				In-row		Between Row	
	6/15	7/6	Avg.	6/15	7/6	6/15	7/6
Aspect	----1000s Plt/a----			-------------%-------------			
North Facing	25.3a[1]	23.2a	24.2	24.2a	29.2a	76.7a	81.2a
South Facing	24.8a	23.2a	24.0	27.5a	31.2a	81.2a	85.4a
Pr>F Aspect	0.82	0.98		0.84	0.75	0.50	0.50

[1]Data followed by the same letter in the same column are not significantly different at the 0.10 level.

Table 4c. Effect of aspect on common stalk borer damage, corn leaf numbers and corn silking at the Holty Farm, 1993.

	Common Stalk Borer Damage	Leaf Numbers			Silking[1]
		6/15	7/6	Avg.	8/13
Aspect	--%--	-Leaves/plant--			Score
North Facing	6.3a[2]	3.1a	6.4a	4.8	1.0a
South Facing	10.0a	3.0a	6.6a	4.8	1.2a
Pr>F Aspect	0.45	0.80	0.20		0.50

[1]Silking score based on color: 1=white or yellow (not pollinated), 5=brown (pollinated).
[2]Data followed by the same letter in the same column are not significantly different at the 0.10 level.

Table 4d. Effect of aspect on corn grain yield and moisture at the Holty farm, 1993.

Aspect	Grain Moisture	Corn Yield
Aspect	--%--	-Bu/a-
North	27.2a[1]	101a
South	26.5a	103a
Pr>F Aspect	0.96	0.46

[1]Data followed by the same letter in the same column are not significantly different at the 0.10 level.

Table 5a. Effect of tillage on early season corn population and corn residue at the Holty Farm near Spring Grove in Houston County, 1993.

	Population			In-row		Between Row	
	6/15	7/6	Avg.	6/15	7/6	6/15	7/6
	----Plt/a(x1000)--			------------%-------------			
No-till	27.6a[1]	27.3a	27.4	17.5a	12.9a	73.3a	66.7a
Disc/plant	27.0a	27.3a	27.2	10.0a	6.7a	22.5b	25.4b
Pr>F Tillage	0.66	1.0		0.55	0.50	0.08	0.03

[1]Data followed by the same letter in the same column are not significantly different at the 0.10 level.

Table 5b. Effect of tillage on corn leaf numbers and silking at the Holty Farm, 1993.

	Leaf Numbers			Silking[1]
	6/15	7/6	Avg.	8/13
	--Leaves/plant--			Score
No-till	2.6a[2]	6.8a	4.7	1.5a
Disc/plant	2.8a	7.1a	5.0	1.5a
Pr>F Tillage	0.30	0.50		1.0

[1]Silking score based on color: 1=white or yellow (not pollinated) to 5=brown (pollinated).
[2]Data followed by the same letter in the same column are not significantly different at the 0.10 level.

Table 5c. Effect of tillage on weed counts and species composition in and between the rows at the Holty Farm, July 12, 1993.

	Weed Counts		Species Composition			
			Foxtail Sp.		Velvetleaf	
	In-row	Between	In-row	Between	In-row	Between
	---No./ft^2----		------% ground cover--------			
No-till	10.8a[1]	2.6a	92.2a	100.0a	7.8a	-
Disc/plant	7.2a	0.7b	83.1a	70.0a	17.0a	30.0
Pr>F Tillage	0.59	0.03	0.47	0.50	0.47	

[1]Data followed by the same letter in the same column are not significantly different at the 0.10 level.

Table 5d. Effect of tillage on corn grain moisture, test weight, and yield, Holty Farm, 1993.

	tst.wt	moi.	yield
	lb/bu	-%-	bu/ac
No-till	47.2a	24.9a	89.6a
Disc/plant	47.5a	24.4a	96.8a
Pr>F	0.80	0.67	0.34

Table 6a. Effect of tillage on early soybean populations, node numbers and corn residue at the Holty Farm, Houston County, 1993.

	Soybean Population	Node Numbers

	6/15	7/6	Avg.	6/15	7/6	Avg.
	---Plt/a(x1000)----			--Nodes/plant---		
No-till	165a[1]	179a	172	2.7a	5.3b	4.0
Chisel Plow	187a	201a	194	2.9a	5.8a	4.4
Pr>F Tillage	0.40	0.65		0.20	0.07	

[1]Data followed by the same letter in the same column are not significantly different at the 0.10 level.

Table 6b. Effect of tillage on corn residue at the Holty Farm, Houston County, 1993.

	Corn Residue			
	In-row		Between Row	
	6/15	7/6	6/15	7/6
	--------------%-------------			
No-till	42.1a[1]	46.2a	40.8a	39.2a
Chisel Plow	17.5a	17.5b	20.4a	21.7a
Pr>F Tillage	0.22	0.10	0.15	0.20

[1]Data followed by the same letter in the same column are not significantly different at the 0.10 level.

Table 6c. The effect of tillage on soybean test weight, moisture, and yield, Holty Farm, 1993.

	tst.wt	moi.	yield
	lb/bu	-%-	bu/ac
No-till	57.8a	11.2a	33.4a
chisel plow	57.5a	11.6a	38.4a
Pr>F	0.50	0.30	0.27

Table 7a. Cultural practices used at the Kottschade Farm, 1993.

Experimental Design

The tillage approach at this site is light field cultivation for corn following soybeans. The N sources evaluated are liquid hog manure, anhydrous ammonia, and an unfertilized check. The design is a randomized complete block.

Tillage equipment
Field cultivator International
Row cultivator International

Cropping history
Previous crop soybeans; planting date 5/18/93; variety Pioneer 3751 (97 day); planting population 27,800
Planter John Deere 7000 (6-30" rows) with 1" fluted coulters

Manure applications
Hog manure
(stored pit under slots) 3,825 gal/A
Total N 236 lb/A
NH_4-N 137 lb/A
Estimated Available N 170 lb/A
Application Injected 5/9/93

Liquid Hog Manure Analysis

Sample applied[3]	Solids	NH_4^+	NO_3^-	Tot.Min.-N	Org.N	Total N	Est.Avail.N	Est.Avl.N
5/19/93	---%---	----------------lbs/1000 gals.---------------------						--- lbs.N/a ---
1.	7.8	37.3	-	37.3	24.3	61.6	44.6	170
2.	7.8	34.5	-	34.5	27.4	61.9	44.1	
Avg.	**7.8**	**35.9**	**-**	**35.9**	**25.8**	**61.8**	**44.4**	

1.Organic nitrogen = Total nitrogen - Total mineral nitrogen (from laboratory analysis).
2.Estimated available nitrogen =(Org.-N * .35) + Tot.Min.-N. It is assumed that all of the mineral N and 30% of the Org.N is available during the first year of application.
3.The rate of manure applied for plot area was 3,825 gal./acre on May 9,1993.

Storage is a pit under slots and injected with 3 inch straight shovels.

Fertilizer
82-0-0 100 lb N/A; 11-30-20 105 lb/A applied with planter.

Soil Fayette silt loam

Weed control Lasso (alachlor) 2 qt/A applied 5/18/93; Hi-Depth 1 pt/A applied 7/3/93

Table 7b. Effect of nitrogen source on early season corn population and crop residue at a demonstration on Paul Kottschade's farm near Plainview in Wabasha County, 1993.

	Corn Population			Soybean Residue			
				In-row		Between-row	
	6/25	7/20	Avg.	6/25	7/20	6/25	7/20
	---Plt/a(x1000)----			----------%------------			
Check	28.7a[1]	25.8a	27.2	3.8a	2.1a	5.8a	3.3a
Anh.NH_3	27.1a	26.2a	26.6	5.4a	3.8a	5.8a	4.0a
Hog Man.	27.2a	25.3a	26.2	3.1a	1.2a	6.7a	1.9a
Pr>f N Source	0.91	0.95		0.18	0.43	0.90	0.53

[1]data Followed by the Same Letter in the Same Column Are Not Significantly Different at the 0.10 Level.

Table 7c. Effect of Nitrogen Source on Corn Leaf Numbers and Silking at the Kottschade Farm.

	Leaf Numbers			Silking[1]
	6/25	7/20	Avg.	8/20
	--Leaves/plant--			Score
Check	4.3a[2]	6.2b	5.2	2.5a-
Anh.NH_3	4.4a	6.6a	5.5	2.7a
Hog Manure	4.2a	6.5a	5.4	2.8a
Pr>f N Source	0.50	0.04		0.90

[1]silking Score Based on Color: 1=white or Yellow (Not Pollinated) to 5=brown (Pollinated).
[2]data Followed by the Same Letter in the Same Column Are Not Significantly Different at the 0.10 Level.

Table 7d. Effect of nitrogen source on hand-harvested corn grain yields, moisture contents, and nitrogen concentrations at the Kottschade Farm, November 4, 1993.

	Moisture	Yield	Nitrogen
	--%---	bu/A	--%--
Check	20.4a[1]	117a	1.28a
Anhydrous	21.2a	134a	1.35a
Hog manure	21.4a	136a	1.36a

[1]Data followed by the same letter in the same column are not significantly different at the 0.10 level.

INTEGRATION OF MANURE AND ALFALFA N SOURCES
INTO RESIDUE MANAGEMENT SYSTEMS
FOR KARST AREAS OF MN, 1994[3]

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Abstract Tillage and N source were evaluated for corn and soybean production on four farms in southeastern MN. Generally "in row" cover with corn or soybean residue reduced corn development. Soybean growth was slowed in some instances but no yields. Tillage had variable effects on grain yields. Manure generally resulted in increased early growth and development compared to commercial fertilizer.

Introduction

This study was initiated in the spring of 1993 to evaluate manure utilization strategies within residue management systems in southeastern MN. The same farmer cooperators agreed to another year in three counties in 1994. Each demonstration was tailored to fit within the project guidelines and also address particular farmer interests. Residue management systems are the convention in this part of the state due to the erosive nature of the soils. This is the second and final year of this study.

Tony and Walter Hammel Farm

This site had first year corn following alfalfa in 1993. Treatments in 1993 included aspect and timing of alfalfa killing as variables. For a detailed description of treatments see the 1994 copy of this publication. In 1994 in addition to these two variables planter applied fertilzier was evaluated on second year corn. The design is a randomized complete block with split, split plots. Time of alfalfa kill are main plots, the first subplot is aspect, and the second subplot is starter fertilizer. The planter used was equipped with a 2 inch fluted coulter.

Residue levels are shown in table 1b. Killing the alfalfa in the spring of 1993 compared to the fall of 1992 resulted in higher levels of residue in the row after planting in 1994 (72 compared to 65%). This is largely due to higher densities of weed and alfalfa residues. Fluted coulters reduced "in row" cover from 74 to 63%. This is much higher than optimum for corn growth and development.

Early growth, stand, and tasselling rate are shown in table 1c. Starter fertilizer increased corn stands by about 1,600 plants per acre. Starter also increased early growth by .5 leaves per plant. None of the treatments affected the tasselling rate, however. The silking data shows an effect of aspect (table 1d). Southern aspect had about 25% more plants with silk emerged on 7/18 and 7/22.

Inadvertently one replication was lost by harvest by the cooperating farmer. For this reason yield parameters do not have a statistical analysis. Means of the remaining two replications are presented to show trends. No conclusions can be drawn however.

Jim Holty Farm

At the Jim Holty farm two studies were conducted. The first evaluated tillage and nitrogen source on corn response followig corn. The second evaluated tillage effects on soybean production. The corn study is shown in tables 2b-2d. In this study the two N sources (manure and anhydrous) and two tillage systems were evelauted (chisel and no till). Soil cover with corn residue was influenced strongly by the rolling finger type row cleaners. After planting there was about the same "in row" cover for both the no till and chisel systems (about 37%) although there was large differences between the row. At the second residue measurement (6/27) the residue had blown back into the row with the no till treatment. The increase was more with the manure application than with the anhydrous N source (20 vs 10%). These values are much to high for effective early corn growth and development.

Tillage and N source did not affect stands (table 2c). Both did affect early growth. The no till system reduced early growth 1.3 leaves per plant compared to the chisel system. The manure N source increased early growth by .4 leaves. The growth advantage of the corn grown with chisel plowing also hastened tasselling. The manure N source showed a similar trend. Development trends also carried through silk emergence (table 2d).

Chisel plowing resulted in a 45 bushel per acre yield advantage over the no till system. This is a greater difference than other studies have shown considering the size of the early growth differnces. There was a small yield advantage of the manure N source (7 bushels per acre).

The soybean study compared no till and chisel tillage system effects on soybean response (tables 2e and 2f). Corn residue levels were about 20% higher with no tillage. Chisel plowing followed with secondary tillage left greater than 30% cover.

Soybean stands were similar and more than adequate. Although there was a slight early growth difference (.2 nodes per plant) grain yields were identical. This is typical on these soils when weeds are effectively controlled.

Daryl Graskamp Farm

At this site two sources of N (liquid pig manure and anhydrous ammonia), two rates of manure (1,500 and 3,000 gallons per acre resulting in 80 and 160 pounds of estimated available N per acre), and row cultivation was evaluated on second year corn. Results are given in tables 3a-3c.

[3] This study is supported by the Legislative Commission on Minnesota Resources, the Midwest Soybean Growers Association, the Minnesota Extension Service, and the Soil Conservation Service. Their support is greatly appreciated.

[4] J.F. Moncrief and B J. Johnson are Extension Soil Scientist and Assistant Scientist respectively; B.A. Christensen, J.A. Tesmer, N.R. Broadwater, and T.L. Wagar are Extension Educators in Houston, Fillmore, Winona, and Southeast Area Office at Rochester respectively; P.M. Bongard is an independent data analysis specialist, Faribault, MN; T.L. Heiden is an udergraduate research assistant.

Corn residue levels were greater than 40% and slightly higher in the row (apparently the result of the planter mounted fluted coulters). It is also interesting that row cultivation tended to increase cover with corn residue. Soil cover in the row is much higher than recommended.

Stands, early growth and yield are shown in table 3c. The high rate of manure increased stands about 2,000 plants per acre. Cultivation reduced stands 1,000 plants per acre. Stand levels are high enough that it is unlikely that they affected yields. Cultivation decreased early growth by .4 leaves per plant. A similar trend was found in the rate of silk emergence and grain moisture.

Yields were not affected by N source, rate, or cultivation.

Daryl Highum Farm

Treatments at this site are tillage, corn hybrid, and N source. Tillage systems evaluated are chisel plowing followed by discing and a no till approach. Nitrogen sources are anhydrous ammonia and liquid hog manure. Manure application was made in the spring followed by tillage and planting. Anhydrous ammonia was applied side dress June 15. The results from this demonstration is presented in tables 4a-4d and figures 1-6. Back ground information for is shown in table 4a.

Soil cover with soybean residue was about 9% for both tillage systems after planting. The fluted coulters did an usually good job of removing residue from the row area with both tillage sytems. On the second date of residue measurment (only 9 days later) "in row" cover increased about 30% with the no till system. Manure increased soil cover slightly with the discing system but reduced it with no tillage.

The main effects of tillage, N source, and hybrid did not affect stands. There was a significant interaction between N source and tillage. Tillage surprisingly did not affect early growth. There was an effect of N source and corn hybrid. Manure and the Cargill hybrid increased early growth .3 leaves per plant. The manure N source and Cargill hybrid resulted in earlier tasselling and silk emergence. There were no significant main effects for grain moisture although there were several interactions. Grain yields were only affected by corn hybrid (P3578 was 10 bushels per acre higher than Cargill 4327).

Sigificant interactions are shown in figures 1-4. The Cargill hybrid tasselled much earlier than the Pioneer hybrid under the discing tillage system. Grain moisture showed an opposite trend which is expected. Grain yield differences between hybrids were greater under the discing tillage system.

The relationship between "in row" cover with corn residue and early growth for the two hybrids is shown in figures 5 and 6. Residue effects on early growth increased with time for the Cargill hybrid and decreased with time for the Pioneer hybrid.

Table 1a. Cultural practices used at the Hammel farm sodkill (1993), aspect (1993), and starter fertilizer (1994) corn study Houston County, MN, 1994.

Tillage system

No-till (not a variable)

Planting and harvest information

Crop	Hybrid	Planted	Seeds	Harvested
Corn	DK 451 (100 day)	4/20	29,000s/A	9/15/94

New Idea planter with Kinsey planting units and 2" fluted coulters

Crop history

1993 - Corn; 1992 Alfalfa

Fertilizer nutrients applied

Date	Analysis	N	P_2O_5	K_2O
		applied (lb/A)		
4/20/94	9-23-30	9	23	30

Liquid dairy manure applied

Manure Analysis (lb/1000 gallons)				
Total N	NH_4^+	Org. N	P_2O_5	K_2O
48	24	24	19	31

Nutrients applied Date	Rate	Total N	N_{avail}[1]	P_2O_5	K_2O
	gal/A	lb/A			
11/93	3000	145	94	56	93

1. Estimated available N from manure = 100% mineral N + 30% organic N (Assumes 50% org. and 50% inorg.) Liquid dairy manure stored in earthen lagoon.

Soils

Black Hammer-Southridge silty clay loam
Nodine-Rollingstone silty clay loam
(Typic Hapludalfs & Typic Paleudalfs respectively)

Weed control

Date	Herbicide	Rate lb ai/A
5/9/94	Acetachlor (Harness)	1.75
"	Dicamba (Banvel)	0.25
"	Flumetsulam (Broadstrike)	0.04

Fall '92 or Spring '93 glyphosate (Roundup) for alfalfa sod kill

Weed (6/27)	Whole site % cover
Foxtail sp.	40
Quackgrass	15
Com. lambsquarters	10
Dandelion	1.5
Alfalfa	1
Common milkweed	1
Blackseed plantain	1
Hedge bindweed	0.5

Aspect		Mean
North slope	14-22%	17.8
South slope	16-21%	17.2

Table 1b. Effect of sodkill, aspect, and starter fertilizer on corn residue in and between the rows at the Hammel farm demonstration, June 1994.

------------------% cover------------------

			Corn Residue						
			6/9/94		6/27/94		Mean		
Sodkill	Aspect	Starter	In	Between	In	Between	In	Between	
Fall	North	Yes	57.5a[1]	67.5a	67.5	72.5	62.5	70.0	
		No	62.5a	75.0a	62.5	72.5	62.5	73.8	
	South	Yes	62.5a	65.0a	55.0	67.5	58.8	66.2	
		No	52.5a	77.5a	50.0	72.5	51.2	75.0	
Spring	North	Yes	65.0a	70.0a	62.5	77.5	63.8	73.8	
		No	70.0a	80.0a	70.0	70.0	70.0	75.0	
	South	Yes	77.5a	82.5a	72.5	80.0	75.0	81.2	
		No	62.5a	77.5a	60.0	77.5	61.2	77.5	
Fall[2]			65.0a		65.0a		65.0a		
Spring			73.1a		71.2a		72.2b		
	North[2]		68.4a		69.4a		68.9a		
	South		69.7a		66.9a		68.3a		
		Starter[2]	68.4a		69.4a		68.9a		
		No starter	69.7a		66.9a		68.3a		
		Row pos.	63.8a	74.4a	62.5a	73.8b	63.1a	74.1a	
Pr>F									
Sodkill				0.190		0.186		0.028	
Aspect			0.728		0.314		0.808		
Sodkill*Aspect			0.508		0.116		0.238		
Starter				0.811		0.732		0.920	
Starter*Sodkill				0.637		0.863		0.763	
Starter*Aspect			0.315		0.863		0.586		
Starter*Sodkill*Aspect			0.558		0.732		0.654		
Row Position			0.174		0.064		0.108		
Row position*sodkill		0.799		0.817		0.803			
Row position*aspect			0.865		0.494		0.690		
Row position*starter			0.502		0.817		0.620		
Row pos.*sodkill*aspect			1.00		0.817		0.920		
Row pos.*sodkill*starter			0.865		0.645		0.765		
Row pos.*aspect*starter			0.672		0.494		0.586		
RowP.*sodkill*aspect*starter			0.799			0.645		0.	9 6 0

1. Data followed by the same letter in the same group (by date) are not significantly different at the 0.10 level, n=32.
2. Means are over row position.

Table 1c. Effect [illegible]kill, aspect and starter fertilizer on corn population, corn leaf numbers, and tasselling at the Hammel farm, 1994.

Sodkill	Aspect	Starter	Corn Population 6/9	6/27	Mean	Leaf Numbers 6/9	6/27	Mean	Corn Tasselling 7/18	7/22	Mean
			--plants/A x 1000----			----leaves/plant---			------% plants------		
Fall	North	Yes	18.6a[1]	19.2a	18.9ab	4.6a	7.2a	6.0a	55.8a	92.3a	74.0a
		No	19.9a	19.9a	19.9ab	4.2a	6.2a	5.2a	49.2a	81.2a	65.2a
	South	Yes	19.9a	21.3a	20.6ab	5.1a	8.4a	6.8a	88.3a	100.0a	94.2a
		No	17.9a	17.9a	17.9b	5.0a	8.0a	6.5a	95.4a	100.0a	97.8a
Spring	North	Yes	24.0a	24.7a	24.4a	5.0a	7.6a	6.4a	83.4a	100.0a	91.7a
		No	22.0a	22.0a	22.0ab	4.5a	8.4a	6.4a	85.0a	100.0a	92.5a
	South	Yes	20.6a	20.6a	20.6ab	5.5a	8.5a	7.0a	97.4a	100.0a	98.7a
		No	17.2a	19.2a	18.2b	4.9a	6.8a	5.8a	78.6a	85.7a	81.2a
Fall			19.1a	19.6a	19.3a	4.8a	7.4a	6.1a	72.2a	93.4a	82.8a
Spring			21.0a	21.6a	21.3a	5.0a	7.8a	6.4a	86.0a	96.4a	91.3a
	North		21.1a	21.5a	21.3a	4.6a	7.4a	6.0a	68.3a	93.4a	80.9a
	South		18.9a	19.8b	19.3a	5.1a	7.9a	6.5a	89.9a	96.4a	93.2a
	Starter		20.8a	21.5a	21.1a	5.1a	7.9a	6.5a	81.2a	98.1a	89.7a
	No Starter		19.2b	19.8a	19.5b	4.6a	7.3a	6.0a	77.0a	91.7a	84.4a
Pr>F											
Sodkill			0.500	0.442	0.471	0.153	0.667	0.549	0.228	0.775	0.429
Aspect			0.238	0.072	0.163	0.231	0.369	0.270	0.145	0.656	0.238
Sodkill*Aspect			0.294	0.072	0.187	0.793	0.193	0.322	0.194	0.226	0.199
Starter			0.027	0.142	0.069	0.143	0.155	0.113	0.639	0.159	0.400
Starter*Sodkill			0.057	0.734	0.306	0.522	0.794	0.856	0.614	0.841	0.663
Starter*Aspect			0.057	0.506	0.225	0.895	0.300	0.483	0.846	0.841	0.834
Starter*Sodkill*Aspect			0.320	0.218	0.225	0.696	0.089	0.176	0.356	0.159	0.254

1. Data followed by the same letter in the same column group are not significantly different at the 0.10 level, n=16.

Table 1d. Effect of sodkill, aspect, and starter fertilizer on corn silking, harvest population, grain moisture and corn yield at the Hammel farm, September 9, 1994.

Sodkill	Aspect	Starter	Corn silking 7/18	Corn silking 7/22	Corn silking Mean	Harvest Pop.	Harvestable Ears	Moisture	Yield
			-------% plants--------			plts/Ax1000	%	%	bu/A
Fall	North	Yes	0.0a	42.0a	21.0a	17.9	100.0	30.8	76.1
		No	0.0a	31.9a	16.0a	16.5	100.0	30.4	75.2
	South	Yes	36.6a	96.2a	66.4a	19.2	78.6	47.4	54.2
		No	32.2a	90.9a	61.6a	16.5	100.0	29.4	73.6
Spring	North	Yes	20.1a	96.6a	58.4a	20.6	96.2	29.4	116.2
		No	24.6a	78.2a	51.4a	19.2	95.6	34.1	94.3
	South	Yes	37.3a	90.2a	63.8a	19.6	95.3	28.0	107.1
		No	35.7a	67.8a	51.8a	21.3	85.0	29.4	110.4
Fall			17.2a	65.2a	41.2a	17.5	94.6	34.5	69.8
Spring			29.4a	83.2a	56.4a	20.2	93.0	30.2	107.0
	North		11.2a	62.2b	36.7b	18.6	98.0	31.2	90.4
	South		35.5a	86.3a	60.9a	19.2	89.7	33.4	86.3
	Starter		23.5a	81.3a	52.4a	19.3	92.5	33.9	88.4
	No Starter		23.1a	67.2a	45.2a	18.4	95.2	30.8	88.4
Pr>F									
Sodkill			0.609	0.468	0.533				
Aspect			0.142	0.042	0.037				
Sodkill*Aspect			0.428	0.024	0.047				
Starter			0.955	0.225	0.399				
Starter*Sodkill			0.783	0.550	0.784				
Starter*Aspect			0.694	0.982	0.883				
Starter*Sodkill*Aspect			0.949	0.834	0.871				

1. Data followed by the same letter in the same column group are not significantly different at the 0.10 level, n=16.

Table 2a. Cultural practices used at the Holty farm corn and soybean tillage studies, Houston County, 1994.

Tillage systems

1. No-till
2. Spring disced (4/20/94) 14' Case IH; chisel plowed (4/23/94) Case IH with 2" shovels;

Planting and harvest information

Crop	Hybrid/Var.	Plant	Population	Harvest
Corn	Keltgen 2550	4/23	29,000s/A	11/16
Sybn	Asgrow 2234	4/26	210,000s/A	11/16

Corn planted with Case IH 800 with Yetter rolling finger row cleaners.

Soybeans planted with Case IH grain drill equipped with a Yetter coulter cart.

Crop history

1993 - Corn at both demonstration sites

Fertilizer nutrients applied (corn only)

Date	Analysis	N	P_2O_5	K_2O
		applied (lb/A)		
4/18/94	82-0-0	131	0	0
4/20/94	9-23-30	12	30	39

Beef manure nutrients applied

Manure Analysis (lb/ton)

Total N	NH_4^+	Org. N	P_2O_5	K_2O
16	3	13		

Date	Rate	Total N	N_{avail}[1]	P_2O_5	K_2O
		Nutrients applied			
	ton/A	-----------lb/A-----------			
4/12/94	21	336	158		

1. Estimated available N from manure =100% mineral N + 35% organic N Solid beef manure from cement lot.

Soils

Port Byron silt loam 3-6% slope (Typic Hapludoll)

Weed control

Corn

Date	Product	Rate lb ai/A
5/15/94	Dicamba+Atrazine (Marksman)	1.0
"	Metolachlor (Dual)	1.3
"	Atrazine	0.6
6/3 & 6/16	Row cultivator- Case IH 4-38" rows & 5 Danish tines/row	

Soybean

Rep 1		lb ai/A
5/3	Imazethapyr + Pendimethalin (Pursuit Plus)	0.9
"	Pendimethalin (Prowl)	0.5
Rep 2		
6/21/94	Imazethapyr (Pursuit)	0.063
"	Thifensulfuron (Pinnacle)	0.001

Weeds present	Whole site % cover
Corn	
Foxtail sp	4.0
Quackgrass	2.0
Horsetail	0.5
Velvetleaf	0.1
Dandelion	0.5
Soybean	
No-till plots	
Quackgrass	2.0
Horsetail	0.5
Red clover	0.05
Maple trees	0.05
Chisel plots	
Quackgrass	1.0
Velvetleaf	1.0

Table 2b. Effect of tillage and manure on corn residue (6/9 and 6/27) in the corn demonstration at the Holty farm, 1994.

		Corn Residue 6/9		Corn Residue 6/27		Corn	
	N	Row Position		Row Position		Residue Mean	
Tillage	Source	In	Between	In	Between	In	Between
		% cover					
No-till	Manure	38.2bc[1]	70.8a	63.2a	65.5a	51.0ab	68.2a
	An.NH$_3$	40.8bc	60.0ab	49.5a	60.5a	45.2ab	60.2ab
Chisel/disc	Manure	32.5c	40.8bc	43.8a	46.0a	38.2b	43.5ab
	An.NH$_3$	35.8bc	38.8bc	55.2a	55.0a	45.5ab	47.0ab
No-till[2]		52.4a		59.7a		56.2a	
Chisel/disc		36.9a		50.0a		43.6a	
	Manure[2]	45.6a		54.6a		50.2a	
	An.NH$_3$	43.8a		55.1a		49.5a	
	Row position	36.8b	52.6a	52.9b	56.8a	45.0b	54.8a
Pr>F							
Tillage			0.136		0.267		0.184
N Source		0.619		0.941		0.776	
Tillage*N Source		0 512		0.203		0.118	
Row position		0 003		0.053		0.006	
Row position*tillage		0.013		0.115		0.025	
Row position*N Source		0.124		0.327		0.456	
Row pos*tillage* N Source		0.449		0.115		0.847	

1. Data followed by the same letter in the same column or row group (by date) are not significantly different at the 0.10 level, n=16.
2. Means within row position.

Significant interactions from Table 2b.

	Residue 6/9		Residue 6/27		Corn	
	Row position		Row position		Residue means	
Tillage	In	Between	In	Between	In	Between
	%cover					
No-till	39.5b	65.4a	56.4	63.0	48.1	64.2
Chisel	34.2b	39.8b	49.5	50.5	41.9	45.2

Table 2c. Effect of tillage and N source on corn population, leaf numbers, tasselling, silking and harvest data in the corn demonstration at the Holty farm, 1994.

Tillage	N Source	Corn Population 6/9	6/27	Mean	Leaf Numbers 6/9	6/27	Mean	Tasselling 7/13	7/17	Mean
		---plants/A x 1000---			------leaves/plant------			-------% plants--------		
No-till	Manure	21.2a[1]	20.4a	20.9a	4.9b	7.4bc	6.2b	16.6a	72.7a	44.6a
	An.NH_3	20.9a	20.3a	20.6a	4.9b	7.2c	6.1b	6.8a	69.6a	38.2a
Chisel/	Manure	23.3a	23.5a	23.4a	5.6a	9.8a	7.8a	50.4a	92.1a	71.2a
disc	An.NH_3	23.6a	24.2a	24.0a	5.2ab	9.2ab	7.2ab	32.8a	84.4a	58.6a
No-till		21.0a	20.4a	20.7a	4.9a	7.3b	6.2b	11.7b	71.1a	41.4a
Chisel/disc		23.5a	23.8a	23.4a	5.4a	9.5a	7.5a	41.6b	88.2b	65.0a
	Manure	22.2a	22.0a	22.1a	5.3a	8.6a	7.0a	33.4a	82.4a	58.0a
	An.NH_3	22.2a	22.3a	22.3a	5.1a	8.2a	6.6a	19.8a	77.0a	48.4a
Pr>F										
Tillage		0.451	0.407	0.426	0.114	0.080	0.084	0.291	0.073	0.168
N Source		1.00	0.795	0.916	0.057	0.226	0.137	0.113	0.586	0.245
Tillage*N		0.838	0.752	0.755	0.057	0.457	0.237	0.521	0.812	0.652

1. Data followed by the same letter in the same column group are not significantly different at the 0.10 level, n=8.

Table 2d. Effect of tillage and N source on corn silking, grain moisture, and corn yield in the demonstration at the Holty farm, 1994.

Tillage	Source	Corn Silking 7/13	7/17	Mean	Grain Moisture	Corn Yield
		------% plants------			%	bu/A
No-till	Manure	0.0a	15.2a	7.6a	19.2a	117a
	An.NH_3	0.0a	22.4a	11.2a	19.4a	102a
Chisel	Manure	11.0a	79.0a	45.0a	19.8a	154a
	An.NH_3	4.8a	47.4a	26.1a	19.4a	153a
No-till		0.0a	18.8a	9.4a	19.3a	109a
Chisel		7.9a	63.2a	35.6a	19.6a	154a
	Manure	5.5a	47.0a	26.3a	19.6a	135a
	An.NH_3	2.4a	34.9a	18.7a	19.4a	127a
Pr>F						
Tillage		0.202	0.141	0.150	0.644	0.114
N Source		0.280	0.252	0.158	0.168	0.117
Tillage*N Source		0.280	0.126	0.082	0.038	0.135

1. Data followed by the same letter in the column group are not significantly different at the 0.10 level, n=8.

Table 2e. Effect of tillage on corn residue in and across the rows in the soybean study at the Holty farm, 1994.

	Residue (6/17)		Residue (6/24)		Residue means	
	Row Position		Row Position		Row Position	
Tillage	In	Across	In	Across	In	Across
	---------------	-----------	-----%cover	----------	-----------	-----------
No-till	52.5a[1]	54.3a	62.5a	52.2a	57.5a	53.2a
Chisel	30.0a	30.7a	33.3a	34.3a	31.7a	32.6a
No-till[2]	53.4a		57.3a		55.4a	
Chisel	30.4a		33.8a		32.1a	
RowPos.	41.2a	42.5a	47.9a	43.2a	44.6a	42.9a
Pr>F						
Tillage	0.146		0.160		0.153	
RowPos.	0.775		0.263		0.660	
Till*RPos.	0.899		0.202		0.523	

1. Data followed by the same letter in the column group are not significantly different at the 0.10 level, n=8.
2. Means over row position.

Table 2f. Effect of tillage on soybean population, node numbers and harvest data in the soybean demonstration at the Holty farm, June 1994.

	Soybean Population			Node Numbers			Harvest	Soybean
Tillage	6/8	6/24	Mean	6/8	6/24	Mean	Moisture	Yield
		plt/Ax1000			nodes/plant		--%--	bu/A
No-till	206a	192a	199a	3.1b	6.8a	5.0a	14.2a	57.4a
Chisel/Disc	227a	220a	224a	3.3a	7.0a	5.2a	14.6a	57.4a
Pr>F								
Tillage	0.747	0.683	0.713	0.052	0.205	0.126	0.395	1.00

1. Data followed by the same letter in the same column are not significantly different at the 0.10 level, n=4.

Table 3a. Cultural practices used in the Graskamp farm nitrogen source and cultivation corn study near Fountain in Fillmore County, 1994.

Tillage systems

1. Coulter-Chisel plow (fall) 13' John Deere with straight discs at 7" spacing in front of 3" shanks at 18" spacing in back followed by a feld cultivator (5/2/94) 21' w/ 2" shanks at 6" spacings

2. No till

Planting and harvest information

Crop	Hybrid	Plant	Population	Harvest
Corn	Agrigene 3965	5/2	25,500s/A	11/9

Corn planted with John Deere 7000 with 2" fluted coulters

Crop history

1993 - Corn

Soil

Fayette silt loam 2-6% slope
(Typic Hapludalf)

Insect Control

5/2 Terbufos (Counter) 1.2 oz ai/1000' row (1.0 lb ai/A)

Nutrients applied

Date	Analysis	Actual applied (lb/A)	N	N_{avail}[1]	P_2O_5	K_2O
4/20/94	82-0-0	125	0	0		
5/2/94	8-20-27	10		25	34	

Liquid hog manure applied

Manure Analysis (lb/1000 gallons)

Total N	NH_4^+	Org. N	P_2O_5	K_2O
57.1	51.0	6.1		

Date	Rate	Total N	N_{avail}[1]	P_2O_5	K_2O
	gal/A	---------------lb/A---------------			
11/93	3000	171	160		
"	1500	86	80		

1. Estimated available N from manure =
100% mineral N + 35% organic N Liquid hog manure stored in a pit.

Weed control

Date	Control	Rate
		lb ai/A
5/12/94	Dicamba + Atrazine (Marksman)	1.0
	Pendimethalin (Prowl)	1.25
	Cyanizine (Bladex)	0.9
6/16/94	Row cultivator 13' John Deere (4-38"rows) w/ 4-2" sweeps between rows	

Weeds present	% cover
Foxtail sp	1.5
Quackgrass	1.0
Velvetleaf	1.0

Table 3b. Effect of nitrogen source and cultivation on corn residue in and between the rows at the Graskamp farm, 1994.

N		Corn residue					
		5/31/94		6/21/94		Means	
Source	Cultivation	In	Between	In	Between	In	Between
		---------------	%cover	----------------			
Anhyd. NH_3	No	46.2a[1]	43.4ab	40.4a	39.2a	43.5a	39.8abc
	Yes			45.4a	44.2a		
Manure	No	43.9a	30.2c	45.8a	40.8a	44.8a	35.6c
1500g/A	Yes			52.0a	43.6a		
Manure	No	45.2a	33.8bc	39.1a	40.1a	42.2ab	37.0bc
3000g/A	Yes			42.2a	38.4a		
Anhyd. NH_3[2]		43.5a	42.3a		41.7a		
Manure (1500g/A)		37.1a	45.5a		40.2a		
Manure (3000g/A)		39.5a	40.0a		39.6a		
No Cultivation[2]				40.9a			
Cultivation				44.3a			
Row position		45.2a	34.8b	44.1a	41.1a	43.5a	37.4b
Pr>F							
N Source		0.296		0.166		0.674	
Cultivation				0.141			
N Source*Cultivation				0.669			
Row Position		<0.001		0.118		0.004	
Row pos.*N Source		0.237	0.414		0.360		
Row pos.*Cultivation				0.473			
Row pos*N*Cultivation				0.864			

[1]Data followed by the same letter in the same group (by date) are not significantly different at the 0.10 level. n=24 (before cultivation); n=48 (after cultivation)
[2]Means over row position.

Table 3c. Effect of nitrogen source and cultivation on corn population, corn leaf numbers, silking score (7/25), and harvest data (11/9) at the Graskamp farm, 1994.

N Source	Cultiva-tion	Corn Population[1] 5/31	6/21	Mean	Leaf Numbers 5/31	6/21	Mean	Silk Score[2]	Grain Moisture	Corn Yield
		----plants/Ax1000----			------leaves/plant------			score	%	bu/A
An. NH_3	No		24.[illegible]bc[3]			6.9a		1.2a	13.7a	140a
	Yes		24.8abc			6.5abc		1.2a	13.2b	143a
Manure	No		22.9c			6.9a		1.2a	13.6a	148a
1500g/A	Yes		25.4ab			6.4bc		1.0a	13.4a	146a
Manure	No		26.4a			6.8ab		1.4a	13.3ab	150a
3000g/A	Yes		26.5a			6.2c		1.1a	13.1b	152a
An. NH_3		23.8b	24.4b	24.1b	2.4a	6.7a	4.6a	1.2a	13.4a	142a
Man.-1500g/A		24.3b	24.2b	24.2b	2.4a	6.6a	4.6a	1.1a	13.5a	147a
Man.-3000g/A		26.4a	26.4a	26.4a	2.4a	6.5a	4.4a	1.2a	13.2a	151a
No Cultivation			24.5b			6.8a		1.3a	13.5a	146a
Cultivation			25.5a			6.4b		1.1a	13.2b	147a
Pr>F										
N Source		0.010	0.056	0.016	0.831	0.632	0.584	0.670	0.195	0.341
Cultivation			0.094			0.001		0.117	0.031	0.542
N*Cultivation			0.266			0.681		0.500	0.501	0.584

[1]Late emergence noted in heavy residue areas.
[2]Silking score based on color: 1=white or yellow (not pollinated) 5=brown (pollinated).
[3]Data followed by the same letter in the same column group are not significantly different at the 0.10 level. n=12 (before cultivation) n=24 (after cultivation).

Table 4a. Cultural practices used in the Highum farm tillage, nitrogen source, and corn variety study near Rushford in Fillmore County, 1994.

Tillage systems

1. Disc (4/22/94) 19' Ford with 20" discs
2. No till

Planting and harvest information

Crop	Hybrid	Plant	Pop.	Harvest				
Corn	P3578	4/23&29	30,000s/A	10/24	"	Cg4327	"	"
	"							

105 day RM for both corn hybrids
Corn planted with Allis Chalmers with
2" fluted coulters

Crop history

1993 - Soybeans

Soils

Alluvial soil

Nutrients applied

		Actual applied (lb/A)					
Date	Analysis		N	N_{avail}[1]	P_2O_5	K_2O	
4/23&29	9-23-30	14		34	45		
6/6/94	82-0-0	102		0	0		

Liquid hog manure applied

Manure Analysis (lb/1000 gallons)

Total N	NH_4^+	Org. N	P_2O_5	K_2O
70.3	44.1	26.1		

		Nutrients applied			
Date	Rate	Total N	N_{avail}[1]	P_2O_5	K_2O
	gal/A	---------------	lb/A	--------------	
11/93	2500	176	133		

1. Estimated available N from manure =100% mineral N + 35% organic N Liquid hog manure stored in a pit.

Weed control

Date	Control	Rate
		lb ai/A
5/6/94	Dicamba + Atrazine (Marksman) +	1.2
"	Metolachlor (Dual)	2.0
6/2/94	Nicosulfuron (Accent)	0.03

Weeds present	% cover
Velvetleaf	1.0

Table 4b. Effect of tillage, nitrogen source, and hybrid on soybean residue, corn population, and corn leaf numbers at the Highum Farm, 1994.

			Soybean Residue					
	Nitrogen		6/1/94		6/18/94		Means	
Tillage	Source	Hybrid	In	Between	In	Between	In	Between
			%cover					
Disc	An.NH_3	Cg4327	7.5	14.4	8.1	15.6	8.0	15.1
		P3578	7.5	16.9	11.9	19.4	9.8	18.2
	Manure	Cg4327	16.2	16.9	15.6	23.1	16.0	20.1
		P3578	6.9	12.5	10.0	21.2	8.6	17.0
No-till	An.NH_3	Cg4327	38.1	51.9	39.4	53.8	38.8	52.9
		P3578	26.2	48.8	36.9	48.8	31.6	48.8
	Manure	Cg4327	21.9	56.9	37.5	59.4	29.9	58.2
		P3578	29.4	58.1	36.9	53.1	33.2	55.8
Disc[1]			12.3b[2]		15.6b		14.1b	
No-till			41.4a		45.7a		43.6a	
	An.NH_3[1]		26.4a		29.2a		27.9a	
	Manure		27.3a		32.1a		29.9a	
		Cg4327[1]	28.0a		31.6a		29.9a	
		P3578	25.8a		29.8a		27.9a	
		Row pos.	1[illegible].2b	34.5a	24.5b	36.8a	22.0b	35.8a
Pr>F								
Tillage			0.008		0.005		0.006	
N Source			0.703		0.264		0.404	
Tillage*N			0.798		0.727		0.764	
Hybrid			0.416		0.584		0.454	
Hybrid*Tillage			0.814		0.584		0.822	
Hybrid*N			0.724		0.584		0.878	
Tillage*N*Hybrid			0.078		0.552		0.208	
Row position		<0.001		<0.001		<0.001		
Row position*Tillage			<0.001		0.018		<0.001	
Row position*N			0.235		0.205		0.131	
Row position*Hybrid			0.494		0.718		0.796	
Row position*Tillage*N			0.015		0.505		0.041	
Row position*Tillage*Hybrid			0.731		0.332		0.428	
Row position*N*Hybrid			0.393		0.959		0.575	
Row position*Tillage*N*Hybrid			0.235			0.572		0.

2 7 6

[1]Means over row position.

[2]Data followed by the same letter in the same group (by date) are not significantly different at the 0.10 level. n=64

Significant interactions from Table 4b.

Tillage	N	Residue 6/9 Row position In	Residue 6/9 Row position Between	Means Row Pos. In	Means Row Pos. Between
		---------%cover------------			
Disc	NH_3	7.5	15.6	8.9	16.6
	Manure	11.6	14.7	13.0	18.6
No-till	NH_3	32.2	50.3	35.2	50.8
	Manure	25.6	57.5	31.6	57.0

Tillage	Residue 6/9 Row position In	Residue 6/9 Row position Between	Residue 6/18 Row position In	Residue 6/18 Row position Between	Residue means Row position In	Residue means Row position Between
	------------------%cover-------------------					
Disc	9.5	15.2	11.4	19.8	10.6	17.6
No-till	8.9	53.9	37.6	53.8	33.4	53.9

Table 4c. Effect of tillage, nitrogen source, and hybrid on corn population, and corn leaf numbers at the Highum farm, 1994.

Tillage	N Source	Hybrid	Corn Population 6/1	Corn Population 6/18	Corn Population Mean	Leaf Numbers 6/1	Leaf Numbers 6/18	Leaf Numbers Mean
			----plants/Ax1000----			-----leaves/plant-----		
Disc	An.NH_3	Cg4327	19.8a[1]	20.0a	19.9a	4.6abc	8.2a	6.4ab
		P3578	20.7a	21.8a	21.2a	4.4abc	7.9ab	6.2ab
	Manure	Cg4327	21.8a	22.4a	22.1a	4.9a	8.3a	6.6a
		P3578	24.4a	25.0a	24.7a	4.7abc	8.1ab	6.4ab
No-till	An.NH_3	Cg4327	22.6a	23.5a	23.1a	4.4abc	7.4b	6.0ab
		P3578	23.5a	22.6a	23.1a	4.1c	7.6b	5.9b
	Manure	Cg4327	19.6a	20.2a	20.0a	4.7ab	8.1ab	6.4ab
		P3578	22.4a	21.6a	22.0a	4.3bc	7.9ab	6.2ab
Disc			21.7a	22.3a	22.0a	4.6a	8.1a	6.4a
No-till			22.0a	22.0a	22.1a	4.4a	7.7a	6.1a
	An.NH_3		21.7a	22.0a	21.9a	4.4b	7.8b	6.1b
	Manure		22.0a	22.3a	22.2a	4.6a	8.1a	6.4a
		Cg4327	21.0a	21.6a	21.3a	4.7a	8.0a	6.4a
		P3578	22.8a	22.8a	22.8a	4.4b	7.9a	6.1b
Pr>F								
Tillage			0.895	0.923	0.989	0.445	0.305	0.388
N Source			0.756	0.806	0.784	0.006	0.022	0.014
Tillage*N			0.082	0.097	0.087	0.651	0.138	0.363
Hybrid			0.172	0.270	0.201	0.003	0.515	0.088
Hybrid*Tillage			0.966	0.362	0.688	0.408	0.400	0.642
Hybrid*N			0.468	0.476	0.459	0.939	0.694	0.717
Tillage*N*Hybrid			0.966	0.758	0.863	0.939	0.474	0.570

[1]Data followed by the same letter in the same column group are not significantly different at the 0.10 level. n=32

Significant interactions from Table 4c.

Tillage	Populaction 6/1 N Source NH_3	Populaction 6/1 N Source Manure	Population 6/18 N Source NH_3	Population 6/18 N Source Manure
	--------------plants/A x 1000------------			
Disc	20.2	23.1	20.9	23.7
No-till	23.1	21.0	23.1	20.9

Table 4d. Effect of tillage, N source, and hybrid on corn tasselling , silking and grain moisture and yield (10/24) at the Highum Farm, 1994.

Tillage	Source	Hybrid	Tasselling 7/11	Tasselling 7/15	Tasselling Mean	Silking 7/11	Silking 7/15	Silking Mean	Grain Moisture	Corn Yield
			---------------% plants--------------						--%--	bu/A
Disc	An.NH_3	Cg4327	46.9ab[1]	93.0a	70.0ab	9.0ab	63.5ab	36.3ab	21.1ab	173.0a
		P3578	3.5c	46.5a	25.0c	2.1b	19.6bc	10.8bc	20.7ab	194.0a
	Manure	Cg4327	62.7a	95.5a	79.1a	20.8a	83.4a	52.1a	20.6ab	180.0a
		P3578	14.9bc	67.3a	41.1abc	2.8b	35.7bc	19.2a	20.6ab	193.4a
No-till	An.NH_3	Cg4327	7.8bc	75.1a	41.5abc	1.2b	38.2bc	19.8bc	19.6b	187.2a
		P3578	3.6c	52.7a	28.2bc	0.0b	10.0c	5.0c	22.8a	189.6a
	Manure	Cg4327	30.1abc	90.8a	60.5abc	2.7b	60.0ab	31.4abc	20.4b	185.8a
		P3578	6.2bc	41.0a	23.6c	1.8b	15.9c	8.9bc	20.2b	190.5a
Disc			32.0a	75.6a	53.8a	8.6a	50.4a	29.6a	20.7a	185.1a
No-till			11.9a	64.9a	38.5a	1.4a	31.0a	16.2a	20.8a	188.3a
	An.NH_3		15.5b	66.8a	41.2b	3.1b	32.8b	18.0b	21.0a	186.0a
	Manure		28.4a	73.7a	51.1a	7.0a	48.7a	27.9a	20.4a	187.4a
		Cg4327	36.8a	88.6a	62.8a	8.4a	61.3a	34.9a	20.4a	181.5b
		P3578	7.0b	51.9b	29.5b	1.7b	20.3b	11.0b	21.0a	191.9a
Pr>F										
Tillage			0.271	0.642	0.452	0.334	0.355	0.343	0.966	0.707
N Source			0.014	0.310	0.007	0.062	0.005	<0.001	0.410	0.538
Tillage*N Source			0.878	0.465	0.319	0.231	0.592	0.162	0.695	0.477
Hybrid			<0.001	<0.001	<0.001	0.023	<0.001	<0.001	0.151	0.025
Hybrid*Tillage			0.018	0.924	0.046	0.047	0.284	0.078	0.071	0.117
Hybrid*N Source			0.319	0.736	0.282	0.325	0.280	0.193	0.107	0.756
Tillage*N*Hybrid			0.519	0.110	0.060	0.289	0.498	0.980	0.049	0.549

[1]Data followed by the same letter in the same column group are not significantly different at the 0.10 level. n=32

Significant interactions from Table 4d.

	Tasselling 7/11		Silking 7/11		Grain Moisture		Corn Yield	
	Hybrid		Hybrid		Hybrid		Hybrid	
Tillage	Cg4327	P3578	Cg4327	P3578	Cg4327	P3578	Cg4327	P3578
	%plants				%		bu/A	
Disc	54.8	9.2	14.9	2.4	20.8	20.6	176	194
No-till	19.0	4.9	2.0	0.9	20.0	21.5	186	190

	Grain Moisture	
N	Hybrid	
Source	Cg4327	P3578
NH_3	20.4	21.7
Manure	20.5	20.4

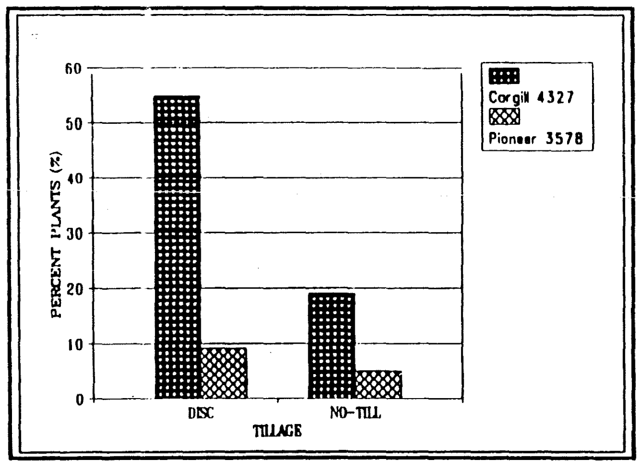

Figure 2. Effect of tillage and hybrid on corn tasselling at the Highum farm, July 11, 1994.

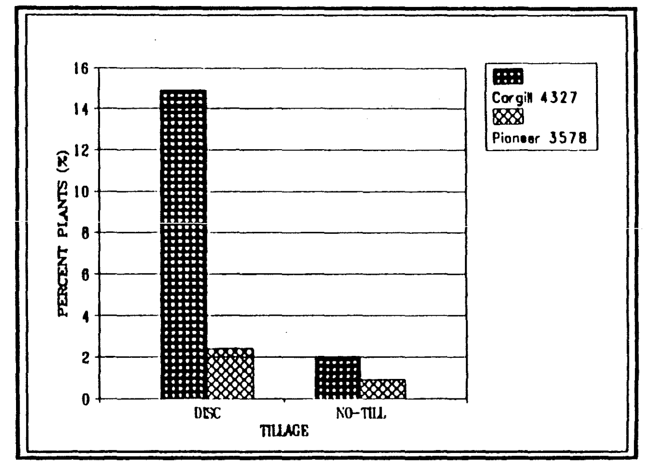

Figure 1. Effect of tillage and hybrid on corn silking at the Highum farm, July 11, 1994.

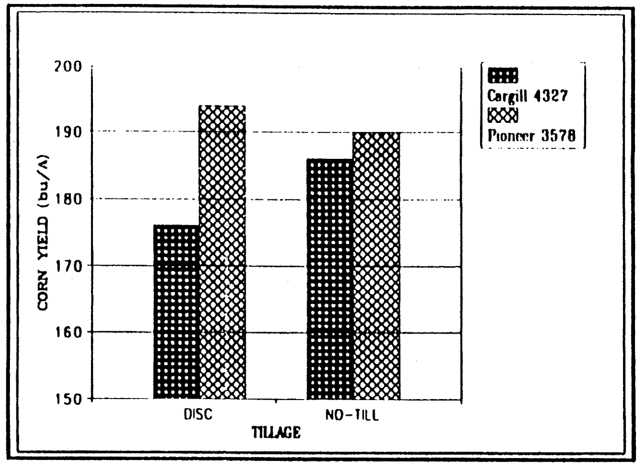

Figure 4. Effect of tillage and hybrid on corn yield at the Highum farm, October 24, 1994.

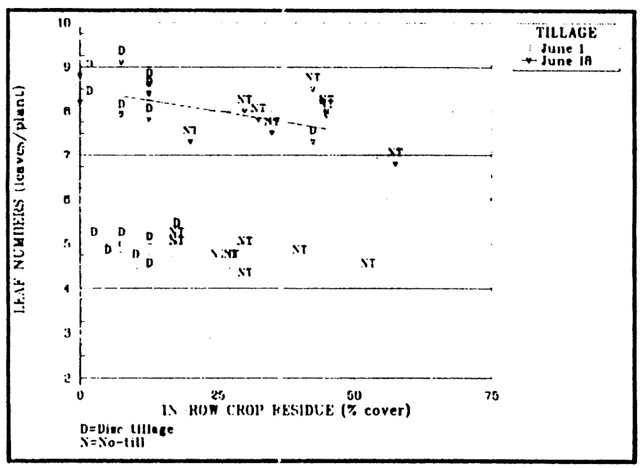

Figure 6. Effect of in-row crop residue on corn leaf numbers (**Cg4327**) June 1 and 18 at the Highum farm, 1994.

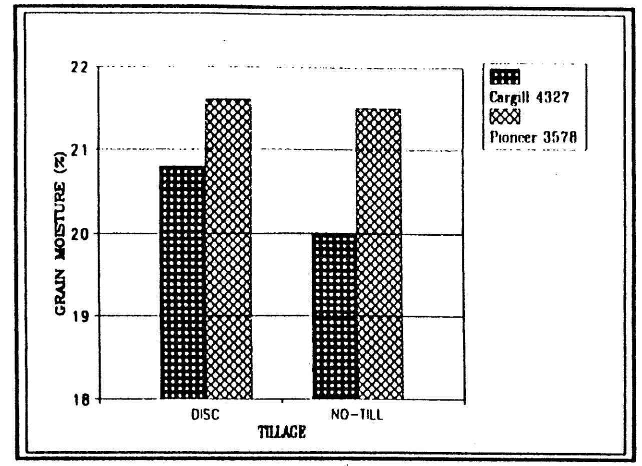

Figure 3. Effect of tillage and hybrid on grain moisture at the Highum farm, October 24, 1994.

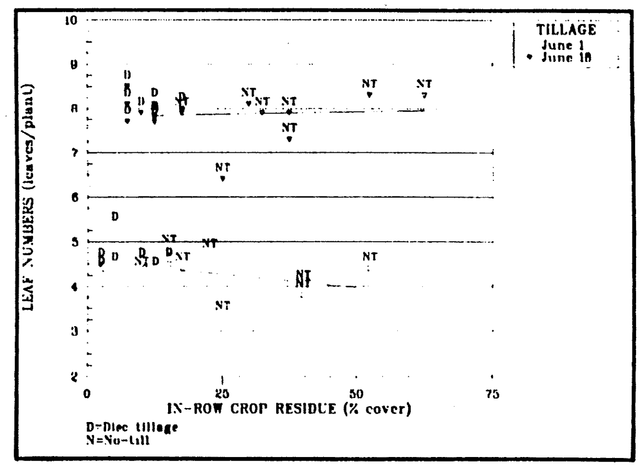

Figure 5. Effect of in-row crop residue on corn leaf numbers **(P3578)** June 1 and 18 at the Highum farm, 1994.

F.2. Activity: Develop and implement a soil fertility management component to educate farmers about the value of on-farm nutrient sources.

F.2.a. Context within the project: On-farm nutrient sources have been under valued and under utilized. Development and implementation of soil fertility management plans that properly credit nutrients from manure, compost, and legumes and utilize other management criteria such as timing, tillage, etc. would reduce nutrient losses from agricultural activities to surface and ground water. Individualized development of plans with peer follow-up and support has proven very effective in accelerating changes in agricultural practices.

F.2.b. Methods: Local ag professionals will receive training on nutrient management basics including the use of manure management planning software and workshop and manure clinic skills. These local trainers will receive audio-visual materials (slide sets and videotapes) to supplement farm nutrient management packets for use at farmer workshops and field days. Manure management field days in the six targeted counties will provide basic information on sampling, testing, calibration, and distribution of manures and composts. These will be held in conjunction with the on-farm demonstrations in Activity F.1 above, where possible. Workshops involving extension, SWCDs, farming associations, and agricultural specialists, will assist participating farmers in developing soil fertility management plans using the data that they have collected.

F.2.c. Materials: Sample containers for manure and soil, use of existing assorted laboratory equipment for analyzing soil and manure samples, scales for determining manure application rates, data forms, plastic sheets for manure calibration, field markers, tape measure, other plot related miscellany, fact sheets, field maps and advertising flyers.

E.2.d. Budget: $50,000 Balance: $0

F.2.e. Timeline:

	7/93	1/94	6/94	1/95	6/95
Design soil fertility packets				*****	
Manure management field days/ Distribute packets			****		*****
Trainer Workshops			****	*****	
Implementation support	********	********	********	********	********
Evaluation/redesign				******	******

F.2.f. Final Detailed Report: Soil fertility packets were designed and assembled and distributed to and through local NRCS and SWCD staff trained in nutrient management in cooperation with a Section 319 USEPA grant. Farm nutrientmanagement packets include information on how to take nutrient credits for manure, legumes, crop rotations, and organic matter, soil and manure sampling and spreader calibration instructions and data sheets to record specific information for their operation such as cropping history, soil type, soil test history, legume plant population, manure analysis, yield potential, etc. Approximately 30 people attended the first 2-day training seminar in Rochester last winter (1994). Initial participant evaluations indicated the need for additional training to increase confidence to begin training and working with farmers to development nutrient management plans.

Additional surveys were sent out this fall (1994) to facilitate more specific planning of winter events to meet local ag-professionals' training needs. (Survey included in Appendix). Based on the survey, sessions this winter (Feb. 1995) provided additional skill training (how to do manure workshops, calibration, communication skills, manure planning software, etc.) to field staff and local government staff from eleven counties. (Meeting agenda, presenters, training evaluation, etc. included in the Appendix). These local trainers received audio-visual materials (slide sets on nitrogen BMPs and fertilizer basics and videotapes on manure calibration and application) to supplement farm nutrient management packets for use at farmer workshops and field days planned for this spring and summer. Nutrient management packets including easy-to-use laminated reference guides have also been distributed at conferences, workshops, farm shows, field days, etc. throughout the state. Almost 1,000 packets and 3,000 laminated swine manure guides were distributed. Nutrient management informational display materials were distributed to trainers to use at farm shows, meetings, at field days and other events. Packets and slide sets have also been distributed for use by farm services companies for use in the client training workshops. Additional training on-site in county offices in the use of Manure Application Planner (MAP) software is scheduled for this summer.

Appendix: Educational and informational material.

1995 Farm Nutrient Management
for Southeastern Minnesota

A Nutrient Management Technical Assistance Project

sponsored by:

Minnesota Extension Service
Minnesota Department of Agriculture
Minnesota Association of Soil and Water Districts
United States Natural Resources Conservation Service

Funding for this project approved by the Minnesota Legislature, 1993 MN Laws, Ch. 172, Sec. 14, Subd. 3j as recommended by the Legislative Commission on Minnesota Resources from the MN Future Resources Fund. Matching funds provided from the USEPA, Section 319 of the Water Quality Act of 1987, "Nonpoint Source Management" grant.

Table of Contents for Farm Nutrient Management Notebook

Manure Management Workshop Agenda
Riverland Technical College, Rochester
February 22, 1995

Time	Subject (Instructors)	Location
10:00 - 12:00	Practical Aspects of Manure Management (Tim Wagar, Jack McGill, Rich Fisher, MES) -Manure Sampling and Testing (Wagar) -Manure Spreader Calibration (McGill) -Concepts of Developing a MAP (Wagar) -Practical Examples of MAP (Fisher)	Auditorium
12:00 - 1:00	Working lunch/development of follow-on training needs and recommendations.	Cafeteria
1:00 - 1:30	Soil Testing Lab Certification Program (Ed Kaiser, MDA)	Auditorium
1:30 - 2:30	MPCA Issues and Concerns With Manure Management (Ed Weir, Lee Ganske, MPCA) -Impacts of Agricultural Phosphorous on Surface Waters (Ganske) -Potential Impacts of Manure Runoff on Streams (Weir).	Auditorium
2:30 - 3:00	Working With the Public on Manure Issues (Duane Johnson, Dodge County Planning Department)	Auditorium

Minnesota Department of Agriculture
90 West Plato Boulevard
Saint Paul, Minnesota 55107
(612) 297-1629

News Relea...

FOR IMMEDIATE RELEASE: Tuesday, February 7, 1995
CONTACT: Jackie Renner, MDA Communications Director, 612-297-1629

Southeastern Minnesota Manure Management Workshop for Local Government Officials on February 22

A manure management workshop is being offered at Riverland Technical College in Rochester on Wednesday, February 22 for southeastern Minnesota local government officials. Soil & Water Conservation District staff, local water planners, Natural Resources Conservation Service staff and other interested parties are invited to attend. The workshop will be held in the Auditorium (Room B-117) and will run from 10:00 AM to 3:00 PM. There is no cost to participate in this manure management workshop.

Topics to be discussed include manure sampling, application rates and methods, calibration of spreaders and soil testing laboratory certification.

Environmental issues continue to be important in agriculture. Manure application practices can play a role in these environmental issues. This fact, combined with the current trend of rising costs of commercial fertilizers, requires agricultural producers to understand the relationship between farm nutrient application practices, realistic yield goals and water quality. It is also critical that the local government officials who interact with and advise producers understand these relationships.

This manure management workshop is a cooperative educational effort by the Minnesota Department of Agriculture, Riverland Technical College, the Minnesota Extension Service, the Minnesota Pollution Control Agency and the Minnesota Association of Soil and Water Conservation Districts. Funds are provided under a federal Clean Water Act, Section 319, non-point source management grant and a grant from the Legislative Commission on Minnesota Resources.

For further information on this workshop, contact John Wagner, Agricultural Chemical Adviso at (612) 297-7122.

NEEDS ASSESSMENT FOR
NUTRIENT MANAGEMENT TRAINING
SURVEY SUMMARY
AREA SEVEN-SOUTHEAST MINNESOTA

A total of 20 Needs Assessment surveys were returned. There were 10 from SCS employees and 10 from SWCD employees. The following statistics are a combination of those from area seven, the southeast corner of Minnesota.

Experience and Educational Background

High school degree (5)
2 year college degree (4)
4 year college degree (11)
(Only highest level of education is counted)

Types of 4 year degrees listed:
- Soil Science (5)
- Agricultural Economics
- Technical Agriculture-Soil and Crop Science
- Agronomy
- Natural Resources
- Water Resources
- Agricultural Education

Were you raised on a farm? (11)

Are you actively involved in farming as a worker, owner, or manager? (10)

How many years experience with the SCS or SWCD?
0-5 (3)
6-10 (7)
>10 (10)

Nitrogen-Best Management Practices (by region)	Interest--L--M--H
Nitrogen rates (N), sources and timing of applications for the soils and conditions in your area	(1) (6) (13)
Selection of fertilizer N rates as influenced by yield goals and N credits from manure and legumes	(4) (6) (10)
Application recommendations and precautions as influenced by tillage, N source, soil pH, etc.	(1) (3) (16)
Review of key N processes in soil (nitrification, denitrification, mineralization, immobilization, leaching of nitrate)	(5) (6) (9)

NEEDS ASSESSMENT FOR
NUTRIENT MANAGEMENT TRAINING
SURVEY SUMMARY
AREA SEVEN-SOUTHEAST MINNESOTA (cont.)

Irrigation	**Interest--L--M--H**		
Types of irrigation systems	(19)		(1)
Scheduling principles and tools for soil moisture monitoring	(18)	(2)	
Fertigation	(16)	(3)	(1)
Leaching and the management factors affecting it	(16)	(3)	(1)
Nitrification Inhibitors			
Principles of use, rates, length of effectiveness	(4)	(8)	(8)
Manure			
Fertilizer Credits for N and P (other nutrients?)	(1)	(5)	(14)
Storage and associated N losses	(1)	(9)	(10)
Application methods and associated N losses	(2)	(5)	(13)
Volatilization and the factors affecting it	(2)	(7)	(10)
Calibration of applicators	(4)	(7)	(8)
Strategies for minimizing runoff from feedlots and storage facilities	(1)	(2)	(17)
How to take a sample for manure analysis	(3)	(9)	(8)
Factors affecting nutrient release from manure (i.e., from organic forms to plant available forms)	(2)	(7)	(11)

NEEDS ASSESSMENT FOR
NUTRIENT MANAGEMENT TRAINING
SURVEY SUMMARY
AREA SEVEN-SOUTHEAST MINNESOTA (cont.)

Fertilizer Basics	Interest--L--M--H
Reactions and movement of N and P in soil (chemistry, nutrient cycling in soil)	(1) (7) (8)
Fertilizer analysis or guarantee (oxide and elemental basis)	(6) (8) (4)
Calculations (e.g., fert. application rates, converting from ppm to lbs/a)	(5) (4) (9)
Soil Science Basics	
Cation exchange capacity	(8) (8) (3)
Soil texture	(6) (7) (6)
Soil components (mineral, organic matter, pore space)	(7) (6) (6)
Water holding capacity vs. plant available water holding capacity	(8) (6) (5)
Soil pH	(7) (6) (6)
Soil Testing	
Reasons for soil testing	(8) (8) (2)
Soil tests that are recommended for your area	(5) (7) (9)
Interpretations of results	(2) (12) (6)
Field sampling procedures	(9) (8) (4)
Sample handling procedures	(9) (8) (3)
Costs	(11) (9)

NEEDS ASSESSMENT FOR NUTRIENT MANAGEMENT TRAINING SURVEY SUMMARY AREA SEVEN-SOUTHEAST MINNESOTA (cont.)

	Interest--L--M--H
Tillage	
Discussion of the various types (plow, chisel, ridge, no-till, etc.)	(10) (7) (3)
Runoff vs. infiltration comparisons	(4) (8) (8)
Residue remaining and associated with nutrient placement (stratification)	(11) (3) (6)
Potential problems with nutrient placement (stratification)	(3) (7) (10)
Plant Recovery of Applied Fertilizers (i.e., efficiency)	
Plant uptake vs. soil residual vs. leaching vs. denitrification	(1) (12) (7)
Phosphorus	
Fertilizer sources and rates, placement	(2) (9) (9)
Eutrophication	(5) (9) (6)
Soil test target values, buildup and maintenance	(4) (8) (8)
New Concepts in Nutrient Management	
Variable rate technology (i.e., "on the go" fertilizer applications)	(7) (7) (6)
Plant tissue monitoring (chlorophyll meter, field sampling, etc.)	(8) (9) (3)
New computer software for making manure management plans and decisions	(5) (3) (12)
Information on how you can help train, or better inform, farmers on nutrient management	(3) (3) (14)
Feedlot management and related issues	(2) (4) (14)

NEEDS ASSESSMENT FOR NUTRIENT MANAGEMENT TRAINING SURVEY SUMMARY AREA SEVEN-SOUTHEAST MINNESOTA (cont.)

Rank the following for what you feel would be the most effective way for you personally to communicate information on nutrient management to farmers. **1=best, 3=worst**

	1	2	3	Average
a. In person, one-on-one discussions	94%	6%		
b. Small group meetings	5%	65%	30%	
c. Mailings and phone calls	7%	16%	77%	

What general time of the summer is best for you to schedule a two-day training session? Give a numerical ranking next to the letter below. **1=best, 6=worst**

	1	2	3	4	5	6	Average
A. Early June				11%		88%	
B. Late June	22%	11%	11%		55%		
C. Early July	31%	6.5%	31%	15%	6.5%		
D. Late July	40%	26%	20%	6%		6%	
E. Early August	36%	18%	18%	27%			
F. Late August	8%	31%	15%	23%	23%		

If these times are all bad, what other time frame would work for you?:

"December, January, February" (2)
"January, February, March"
"December"

What types of educational materials would you find most useful in facilitating your educational efforts with farmers that we might provide for you (e.g., visual aids such as slide sets on nitrogen BMP's)? Note: the Minnesota Department of Agriculture has the funds available to create these materials for you if there is a need for them:

"S.C.S. Ag. Waste Management Field Handbook, dated February 25, 1992"
"M.P.C.A. Feedlot Training Course"
"Brochure or pamphlet for public (easy reading)" (6)
"Photos of BMP's and alternatives to conventional systems"
"Overhead transparencies" (2)
"Visual aids/slides/videotape" (8)
"News articles"

NEEDS ASSESSMENT FOR NUTRIENT MANAGEMENT TRAINING SURVEY SUMMARY AREA SEVEN-SOUTHEAST MINNESOTA (cont.)

Useful educational materials that we could provide (cont.):

"On farm demonstrations"
"Public TV. commercials"
"Simple fact sheet-colorful"
"Charts comparing application methods/effectiveness (yield), tillage systems and placement/timing/farm nutrient applications"
"Slide sets of Nitrogen and fertilizer BMP's"
"Form for Nitrogen/fertilizer calculations for farmers to use at home"
"Additional staff-incentive $ for ICM"
"Education directed at Co-op/elevator consultants"

Please list three things you would most hope to gain from a two-day training session on nutrient management:

"Variable Rate Technology" (2)
"Working knowledge of plant recovery of applied fertilizer"
"Plant tissue monitoring technique"
"Nitrogen BMP's" (2)
"Waste utilization" (3)
"Feedlot management"
"Fertilizer sources and rates"
"Fertilizer basics" (2)
"P build-up and affect on surface water quality"
"How to incorporate manure on HEL and achieve 30% residue cover when the manure is applied to bean stubble and upcoming crop is corn"
"How to deal with a producer who has too much livestock waste for treatment of land available (i.e. How do we prevent the recommendation to not incorporate so that N volatilizes so that more can be applied)"
"Manure basics" (4)
"Design of storage pits" (3)
"Feedlot runoff control measures" (2)
"Fertilizer benefits"
"Broiler compost mix (S.C.S. Ag. Waste Handbook-section 10)
"Explanation of the complaint process to M.P.C.A."
"Information about the D.N.R. Enforcement law that passed in Feb. '93-N.O.V., etc."
"Nitrogen utilization"
"Interpretation of soil test results"
"Application recommendations" (3)
"Fertilizer credits for N and P" (2)
"Nutrient release in manure" (2)
"Fertilizer analysis"
"Available Nitrogen by using crop rotation"
"Plowing for Nitrogen use" (2)
"N, P, K vs. CEC /texture/drainage, etc."
"Manure handling/ value of a sample"
"Area specific recommendations, soil variables when working with fertilizer management techniques"

NEEDS ASSESSMENT FOR NUTRIENT MANAGEMENT TRAINING SURVEY SUMMARY AREA SEVEN-SOUTHEAST MINNESOTA (cont.)

Are there any topics you care to have covered, or concerns you may have about dealing with nutrient management questions?:

"When you should be managing for P rather than N, and when the economical and environmental threshold can differ"
"Innovative ideas on N, P, K application for no-till (emphasis on incorporating manure into no-till operation)"
"How to use animal waste in a crop rotation using Hay (applying manure *before* oats/seeded often causes lodging of oats)"
"Winter spreading of manure and its affect on surface water"
"We generally concentrate on erosion control engineering practices and on FSA/Management activities. There is often not time to also know about and assist farmers with nutrient management, even though this is important. It is hard enough to keep up with and do the things we already do, so this training would be very interesting but perhaps not used alot"
"Where can farmers get $ assistance for manure handling systems?"

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Summary of Evaluations and Final Report

Manure Management Workshop

Riverland Technical College, Rochester, Minnesota
February 22, 1995

Prepared by

John Wagner
Information and Certification Unit
Minnesota Department of Agriculture

May 18, 1995

MINNESOTA EXTENSION SERVICE

UNIVERSITY OF MINNESOTA

For more information, contact your local Minnesota Extension office. REV. 2/95

Nitrogen Availability and Loss Per Application Method For Swine Manure

	% N Availability		% N Loss
	YEAR 1	YEARS 2-3	TOTAL
BROADCAST:			
No incorporation	30	30	40
Incorporation within 12 hours	65	25	10
Incorporation within 4 days	45	30	25
INJECTION:			
Sweep	65	30	5
Knife	50	35	15

Table shows average losses and availability of nitrogen under normal conditions.
Soil organic matter, time of application, soil texture, rainfall, and temperature are all factors affecting nitrogen availability and loss.

Producers must balance their crop fertilizer management program of manure and commercial fertilizer with their soil test recommendations and their manure/nutrient analysis.

			Nutrient Analysis (Lbs./1,000 Gals.)		% Available		
________ (Gals./A Applied)	÷ 1,000 Gals.	x	________ Lbs. N	x	________ *	=	Lbs. N / A
		x	________ Lbs. P_2O_5	x	.80	=	Lbs. P_2O_5 / A
		x	________ Lbs. K_2O	x	.90	=	Lbs. K_2O / A

*** Refer to nitrogen availability chart above**

Producers need to be aware of the manure/nutrients that are being applied so that excessive amounts of commercial fertilizer can be avoided, thus reducing crop expense.

Average Nutrient Analysis of Liquid and Solid Manure
*includes lot runoff water

Form	*Specie*	*Bedding/Storage*	*% Dry Matter*	*Total N*	P_2O_5	K_2O
LIQUID:			Lbs./1,000 Gals.			
	Swine	Anaerobic pit/lagoon*	4/1	36/5	25/3	22/4
	Dairy	Anaerobic pit/lagoon*	8/1	31/4	15/3	19/4
	Beef	Anaerobic pit/lagoon*	9/1	29/4	18/3	26/4
SOLID:			Lbs./Ton.			
	Swine	No bedding	18	11	8	5
		With bedding	18	9	7	7
	Dairy	No bedding	18	9	3	6
		With bedding	21	9	3	6
	Beef	No bedding-dirt	15	11	7	10
		No bedding-concrete	52	21	14	23
		With bedding	50	21	18	26
	Turkey	No bedding	20	20	40	17
		With bedding	25	22	45	18

Data Excerpted From Livestock Waste Facilities Handbook, Midwest Plan Service, April, 1993.

Production and printing paid for by the Minnesota Department of Agriculture for the Nutrient Management Technical Assistance Project, under Section 319 of the Water Quality Act of 1987.

PRINTED ON RECYCLED PAPER WITH AT LEAST 10% POST-CONSUMER WASTE

Useful Nutrient Management Data

Crop Nutrient Removal

CROP	N	P_2O_5	P	K_2O	K
	NUTRIENT (lbs. per unit of indicated yield)				
Corn[1]					
Grain, 100 bu	90	36	16	26	22
Stover, 1 ton (dry)	22	8	4	32	26
Corn silage[2], 10 tons	83	36	16	83	69
Sorghum silage, 1 ton	40	15	7	58	48
Soybeans[1], Grain, 50 bu	188	44	19	69	58
Beans[1], dry, Grain, 50 bu	125	42	18	42	35
Wheat[1]					
Grain, 50 bu	63	31	14	19	16
Straw, 1 ton	13	3	1	40	19
Barley[1]					
Grain, 50 bu	44	19	9	13	11
Straw, 1 ton	15	5	2	30	25
Oats[1]					
Grain, 100 bu	62	25	11	19	16
Straw, 1 ton	12	8	3	40	33
Sunflower[2], Grain, 10 cwt	36	17	7.5	11	9.1
Sugarbeets[2], Beet, 10 tons	42	5	2.2	83	69
Alfalfa hay[3], 1 ton	45	10	4	45	37
Timothy hay[3], 1 ton	24	10	4	38	32
Potatoes, Tubers, 500 cwt	175	75	33	280	232

[1] Grain crops cannot be compared on a bushel basis because the weight per bushel varies among crops.
[2] Numbers taken from Potash and Phosphate Institute publications.
[3] Composition, especcially nitrogen, varies with maturity of the crop.
All other numbers taken from the "Modern Corn Publication", S. R. Alsdrich et al., 1986.

Weights of Crops Per Bushel

CROP	*LBS./BU.*
Corn	56
Sorghum	56
Soybeans	60
Wheat	60
Barley	48
Oats	32
Rye	56
Sudangrass	40
Potatoes	60
Sweet Potatoes	55
Sunflower	25

Fertilizer Conversion Factors

$P_2O_5 \times 0.44 = P$
$P \times 2.29 = P_2O_5$
$K_2O \times 0.83 = K$
$K \times 1.20 = K_2O$
1 gal. of water = 8.328 lbs.
1 gal. of UAN (28% N) = 10.6 lbs.

Common Fertilizer Analyses

FERTILIZER	ANALYSIS	CHEMICAL FORMULA
N		
Anhydrous ammonia	82-0-0	NH_3
Ammonium nitrate	34-0-0	NH_4NO_3
Urea	46-0-0	$(NH_2)_2CO$
UAN solution (Urea ammonium nitrate)	28 to 32-0-0	NH_4NO_3 plus $(NH_2)_2CO$ in water
Aqua ammonia	20-0-0	NH_3 in water
Ammonium sulfate	21-0-0-24(S)	$(NH_4)_2SO_4$
P		
Triple superphosphate (TSP)	0-44 to 46-0	$Ca(H_2PO_4)_2$
Diammonium phospahate (DAP)	18-46-0	$(NH_4)_2HPO_4$
Monoammonium phosphate MAP)	11-48-0	$NH_4H_2PO_4$
Ammonium polyphosphate liquid (APP)	10-34-0	$NH_4H_2PO_4$ plus $(NH_4)_3HP_2O_7$
Ammonium polyphosphate dry (APP)	15-62-0	*Same as liquid*
K		
Potassium chloride (Muriate of potash)	0-0-60	KCl
Potassium sulfate	0-0-50-18(S)	K_2SO_4
Potassium-magnesium sulfate (Sul-fo-mag)	0-0-22-22(S)-11(Mg)	$K_2SO_4 \cdot 2MgSO_4$
Potassium nitrate	13-0-44	KNO_3

Nutrient Analysis of Beef, Dairy, Swine and Poultry Manure

	Total N	P_2O_5	K_2O
BEEF			
Solid:	*Lbs. / Ton*		
No bedding-dirt	21	14	23
No bedding-concrete	11	7	10
With bedding	21	18	26
Liquid:	*Lbs. / 1,000 Gals.*		
Anaerobic storage	29	18	26
DAIRY			
Solid:	*Lbs. / Ton*		
No bedding	9	3	6
With bedding	9	3	6
Liquid:	*Lbs. / 1,000 Gals.*		
Anaerobic storage	31	15	19
SWINE			
Solid:	*Lbs. / Ton*		
No bedding	11	8	5
With bedding	9	7	7
Liquid:	*Lbs. / 1,000 Gals.*		
Anaerobic storage	36	25	22
POULTRY			
Solid:	*Lbs. / Ton*		
No bedding	33	48	34
With bedding	47	48	30

Numbers taken from Minnesota Extension Service publications.

Per Animal Daily Manure Production And Pounds of Nutrients[1]

	LBS.	GALS.	N	P_2O_5	K_2O
	Lbs.				
Beef (1,000 lbs.)	60	7.5	0.34	0.25	0.29
Dairy (1,400 lbs.)	115	13.9	0.57	0.24	0.46
Swine (200 lbs.)	13.1	1.5	0.09	0.07	0.07
Turkey	0.7		0.009	0.008	0.00
Chicken (layer)	0.2		0.003	0.003	0.00

[1] Adjust proportionately for different animal weights
Numbers taken from Minnesota Extension Service publications.

Nitrogen Availability For 3 Years As Affected By Method of Application and Total N Loss

	Broadcast - Incorporated[1] 0-1/2 day	1/2-4 days	None	*Injection*[2] Sweep	Knife
	% Total N				
Year 1	65	45	25	60	45
Year 2	20	20	20	25	30
Year 3	10	10	10	10	15
Lost	5	25	35	5	10

[1] Averaged over 4 species: Beef, Dairy, Swine and Poultry.
[2] Averaged over 3 species: Beef, Dairy and Swine.
Numbers taken from Minnesota Extension Service publications.

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News Relea...

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Manure Management Workshop
Riverland Technical College
Rochester, Minnesota
February 22, 1995

Summary of Evaluations and Final Report

Prepared by the

Minnesota Department of Agriculture
90 West Plato Boulevard
St. Paul, Minnesota 55107-2094

Compilation and Summary..........................John Wagner
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Telephone: (612) 296-1277

Cover Layout and Design............................Linda Haiby
Division Operations Unit

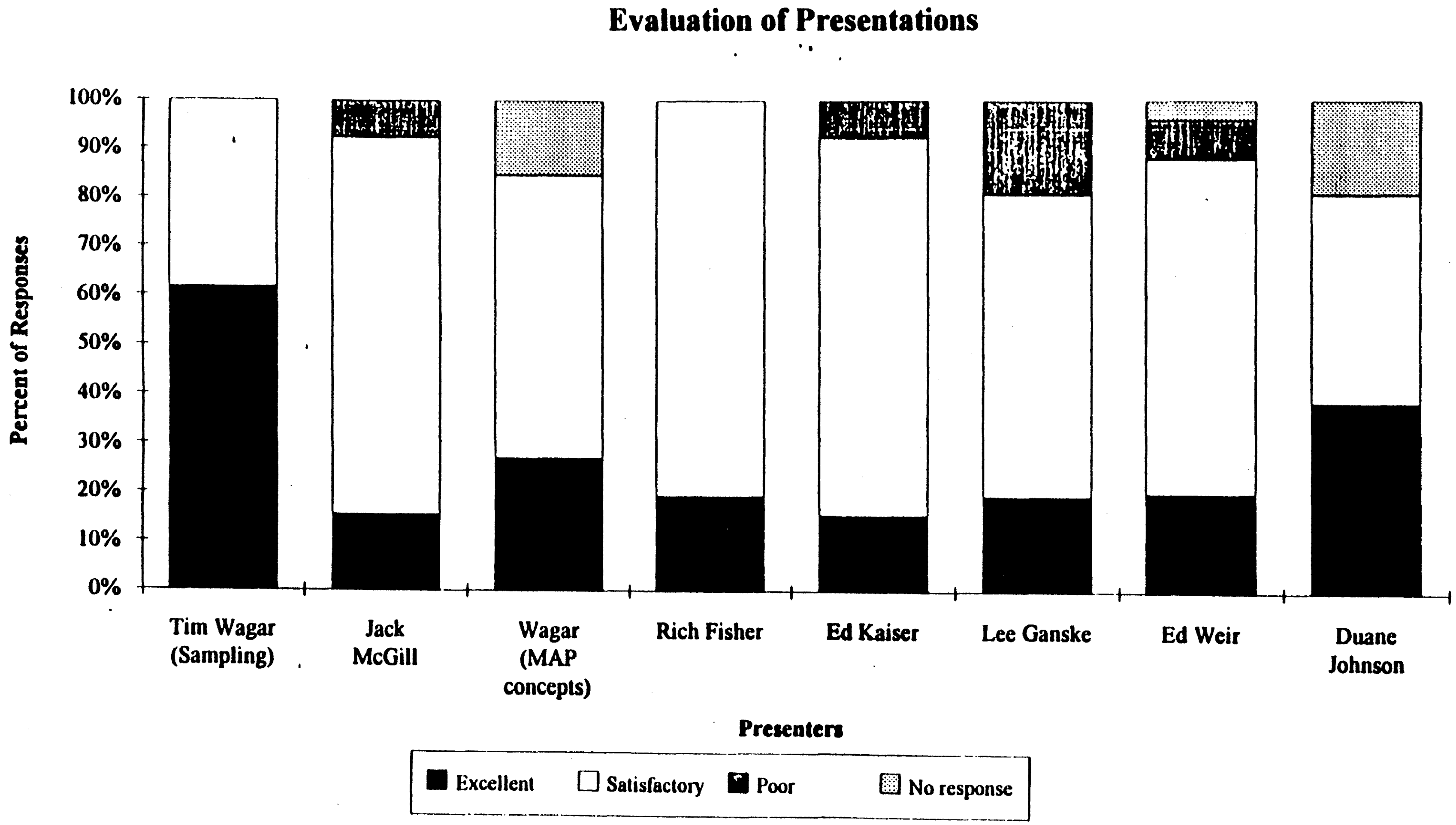
Funding for this project approved by the Minnesota Legislature, 1993 MN Laws, Ch. 172, Sec. 14, Subd. 3j as recommended by the Legislative Commission on Minnesota Resources from the MN Future Resources Fund and by matching funds from the USEPA, Section 319 of the Water Quality Act of 1987, "Nonpoint Source Management" grant. This was a cooperative educational effort of the Minnesota Department of Agriculture (MDA), the Minnesota Extension Service (MES), the Minnesota Pollution Control Agency (MPCA) and the Dodge County Planning Department.

Comments by Course Participants

Results of the survey of participants in the Manure Management Workshop offered at Riverland Technical College are presented later in graphic and tabular form. In addition to the numerical tabulations, a number of general comments were submitted. These comments are presented below:

- May have been helpful to run through a couple examples of soil tests, manure tests and recommendations for a sample farm operation.
- Develop some sample manure management plans as a training exercise, perhaps using some farmers as examples.
- Each extension office could use a spreader calibration video.
- We really did not need the GIS portion.
- Stay away from dry statistics and stay more with practical application.
- Excellent advice. The workshop was fine.
- The information presented by MPCA in the afternoon relative to phosphorous concerns was good to know but was an extreme change of pace from more practical information presented in the morning. Possibly work through a requirement plan for manure. Have more information on working with phosphorous build-up in soils and how to address this in manure management planning. The information in binders, etc is very handy. We did take advantage of getting materials.
- Coffee and doughnuts for break.
- Well organized.
- Give reasons why we need manure management. Could have given examples on how to go about it. Go through a few more examples of calculation of manure spreading based on a variety of environmental conditions.
- Too quick; nice informative film (spreader calibration).
- Professional entry handouts.
- Odor issues: why can't they plant trees around the buildings and the areas.
- More handouts of lecture material.

Rochester Manure Management Workshop



Feb 22, 1995
Total Number of Responses = 26

Attachments

1. Class Schedule.
2. Press Release.
3. Evaluation Form.
4. Letter of Invitation.
5. Instructor Letter of Instruction.
6. Request for Special Expense for Cost of Working Lunch.

Rochester Workshop Summary of Evaluations

1. Conference evaluations

Item	Excellent/yes	Good/somewhat	Poor/no	No response
Facility	11	13	0	2
Overall conference rating	4	20	0	2
Content suitable for audience	16	8	0	2
Well paced	20	4	0	2
Well managed/coordinated	20	4	0	2

2. Evaluation of presentations

Name	Excellent	Satisfactory	Poor	No response
Tim Wagar (Sampling)	16	10	0	0
Jack McGill	4	20	2	0
Tim Wagar (Concepts of MAP)	7	15	0	4
Rich Fisher	5	21	0	0
Ed Kaiser	4	20	2	0
Lee Ganske	5	16	5	0
Ed Weir	5	17	2	1
Duane Johnson	10	11	0	5

3. Evaluation of Program Usefulness

Subject	Very	Somewhat	Not	No response
Manure Sampling and Testing	16	8	0	2
Manure Spreader Calibration	12	12	0	2
Concepts of Developing a MAP	7	15	0	4
Practical Examples of MAP	5	21	0	0
Soil Testing Lab Certification	2	15	6	3
Impacts of Agricultural P	3	17	4	2
Manure Runoff Impacts	5	15	3	3
Working with the Public	11	8	0	7

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Celebrate Minnesota

News Release

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A manure management workshop is being offered at Riverland Technical College in Rochester on Wednesday, February 22 for southeastern Minnesota local government officials. Soil & Water Conservation District staff, local water planners, Natural Resources Conservation Service staff and other interested parties are invited to attend. The workshop will be held in the Auditorium (Room B-117) and will run from 10:00 AM to 3:00 PM. There is no cost to participate in this manure management workshop.

Topics to be discussed include manure sampling, application rates and methods, calibration of spreaders and soil testing laboratory certification.

Environmental issues continue to be important in agriculture. Manure application practices can play a role in these environmental issues. This fact, combined with the current trend of rising costs of commercial fertilizers, requires agricultural producers to understand the relationship between farm nutrient application practices, realistic yield goals and water quality. It is also critical that the local government officials who interact with and advise producers understand these relationships.

This manure management workshop is a cooperative educational effort by the Minnesota Department of Agriculture, Riverland Technical College, the Minnesota Extension Service, the Minnesota Pollution Control Agency and the Minnesota Association of Soil and Water Conservation Districts. Funds are provided under a federal Clean Water Act, Section 319, non-point source management grant and a grant from the Legislative Commission on Minnesota Resources.

For further information on this workshop, contact John Wagner, Agricultural Chemical Advisor at (612) 297-7122.

Manure Management Workshop Agenda
Riverland Technical College, Rochester
February 22, 1995

Time	Subject (Instructors)	Location
10:00 - 12:00	Practical Aspects of Manure Management (Tim Wagar, Jack McGill, Rich Fisher, MES) -Manure Sampling and Testing (Wagar) -Manure Spreader Calibration (McGill) -Concepts of Developing a MAP (Wagar) -Practical Examples of MAP (Fisher)	Auditorium
12:00 - 1:00	Working lunch/development of follow-on training needs and recommendations.	Cafeteria
1:00 - 1:30	Soil Testing Lab Certification Program (Ed Kaiser, MDA)	Auditorium
1:30 - 2:30	MPCA Issues and Concerns With Manure Management (Ed Weir, Lee Ganske, MPCA) -Impacts of Agricultural Phosphorous on Surface Waters (Ganske) -Potential Impacts of Manure Runoff on Streams (Weir).	Auditorium
2:30 - 3:00	Working With the Public on Manure Issues (Duane Johnson, Dodge County Planning Department)	Auditorium

over

What is your highest level of education?

8th grade   High school   2 yr college/technical   4 yr college   more than 4 yrs college

How many previous workshops have you attended?

0   1-3   4-6   7-10   11-15   16-20

Comments: ____

____

How could we make the workshop better?____

____

____

letters\revbd\standardevalform

MANURE MANAGEMENT EVALUATION FORM

Manure Management Workshop
Rochester, MN
February 22, 1995

Please take a few moments to complete this workshop evaluation form. Your opinions are important to us, and we will take them into account as we plan future nutrient management training. Please rate each of the following items by circling the appropriate response.

Please rate each session based both on how well the topics were presented and usefulness to your work.

SESSION	PRESENTATION EXCELLENT	 SATISFACTORY	 POOR		USEFULNESS VERY USEFUL	 SOMEWHAT USEFUL	 NOT USEFUL
Manure Sampling and Testing *Tim Wagar*	3	2	1		3	2	1
Manure Spreader Calibration *Jack McGill*	3	2	1		3	2	1
Concepts of Developing a Manure Application Plan *Tim Wagar*	3	2	1		3	2	1
Practical Examples of MAP *Rich Fisher*	3	2	1		3	2	1
Soil Testing Lab Certification Program *Ed Kaiser*	3	2	1		3	2	1
Impacts of Agricultural Phosphorous *Lee Ganske*	3	2	1		3	2	1
Potential Impacts of Manure Runoff on Streams *Ed Weir*	3	2	1		3	2	1
Working With the Public on Manure Issues *Duane Johnson*	3	2	1		3	2	1

Please rate the facility .... *Excellent* *Good* *Poor*
Overall, how would you rate the conference? .... *Excellent* *Good* *Poor*
Content was suitable for my background and experience .... *Yes* *Somewhat* *No*
Conference was well-paced within allotted time .... *Yes* *Somewhat* *No*
Conference was well-managed and coordinated .... *Yes* *Somewhat* *No*

letters\revbd\standardevalform

(612) 297-7122

February 8, 1995

name
address
Post Office Box xxx
city, MN 5xxxx

Dear name,

As we discussed on February 7, the rest of this letter contains detailed information concerning the Manure Management Workshop scheduled for February 22 at Riverland Technical College. Some of it may not apply very well to your subject but it will fill you in on what the other instructors have been told I really appreciate your agreeing to participate. If you have any questions, please let me know.

General: This is to confirm the schedule for the Manure Management Workshop to be held at Riverland Technical College (Room B-117) in Rochester on February 22, 1995 and to provide more detailed information. Some of the requirements I will be discussing are required by the provisions of the grant that is paying for the workshop while others are intended to provide as much reference information as possible for the attendees . You can help me with fund matching by keeping an informal record of the time you spend on this course. Additionally, any written information (lesson outlines, lesson plans, copies of slides, handouts, etc.) you can provide will help in the planning and conduct of any repeat training at other locations.

Class Schedule: The workshop is scheduled to begin at 10 AM and run until 3 PM, with an hour break for lunch. The first two hours will cover practical aspects of manure management with instruction shared by three extension educators.

10:00 - 12:00 (Tim Wagar, Chuck Fick, Rich Fisher, MES):

1. Manure Sampling.
    a. Proper manure sample collection.
    b. Sample preparation and storage.
    c. Manure analysis.

COMMENTS:
    a. Use a probe and agitation factor/discuss range between analysis & table values.
    b. Collection of manure from different types of livestock.
    c. Collection in various storage systems, including short term storage systems.

(612) 297-7122

January 13, 1995

name
xxxxxxxx County
address
PO Box xxxx
city, MN 56xxx

Dear name,

I would like to invite you and other interested people in your office to attend a Manure Management Workshop in Rochester on February 22. The course will be held in Auditorium B-117 at the Riverland Technical College, 1926 College View Road SE, from 10 AM until 3 PM.

This session will be oriented towards providing NRCS, SWCD and MES people as well as local Water Plan Coordinators and other interested officials in the Southeastern Minnesota area with current information on all aspects of practical manure management procedures. The intent is to provide you with the knowledge you need to answer questions about manure best management practices that allow producers to effectively use this valuable nutrient resource without adversely affecting water quality. The instructors will be Minnesota Extension Service educators who have been doing a lot of work in the area of manure management.

Please contact me at (612) 297-7122 to let me know if you can attend and how many from your office will be coming. If you prefer, you can reply in writing, send a fax to (612) 297-2271 or send an internet note to jwagner@mda-ag.mda.state.mn.us.

For your information, I have also enclosed a list of available nutrient management publications that you can get by contacting me in case you can't make the training.

Sincerely,

John Wagner, Agricultural Chemical Advisor
Information & Certification Unit
Agronomy Services Division

JW:xm

Enclosures

1:30 - 2:30 (Ed Weier, Lee Ganske, MPCA)

6. Phosphorous buildup and transport to surface waters.

7. Effects of over-application of manure.

2:30 - 3:00 (Duane Johnson, Dodge County Planning Department)

8. Working with the public on manure issues.

Course Evaluation: I will develop a questionnaire for the participants to complete at the end of the workshop. The results will be used as one means of evaluating the effectiveness of the course and to help refine the development of future courses. Your comments as instructors will also be solicited. A copy of the final report will be sent to all instructors.

Test Questions: No grade or pass/fail criteria will be applied to this workshop but the grant does require that the participants should be able to demonstrate their understanding of some basic concepts as a result of attending the workshop. To accomplish this, I need to have some type of test or evaluated exercise at the conclusion of the workshop. If you like, I can assemble a short test from questions you provide. I would appreciate your thoughts on how to best accomplish this. Again, this is intended to be a very nc threatening, low-stress affair for the participants and specific scores will go only to me but it is requirement that I must satisfy.

Lesson Plans: In order to apply some standards of consistency to future courses where other instructors will be involved and to facilitate the development of these future sessions, I would like to have a written lesson plan from each instructor for the subjects they teach. If a complete lesson plan is not possible given the time remaining, at least give me an outline along with copies of any slides or other audiovisual materials you will use.

Student Handouts: I will be compiling a 3 ring binder with a collection of brochures and other reference information that each participant can take home with him/her at the conclusion of the training. I would also like to include copies of your class outlines, slides and other materials you deem appropriate for the students to use for note-taking and future reference.

Deadlines: I would like to have copies of all lesson plans/course outlines, slides, other handout materials and the test questions by Thursday, February 16 .

2. Using analysis data to determine application rates.
   a. Soil testing: strengths and weaknesses/when should it be done?
   b. How accurate are the tables? or the analysis results?
   c. Crop history and use of records.

COMMENTS:
   a. Make sure proper credit for N in manure is given to avoid over application with commercial N.
   b. Convince producers of the N credit in manure; avoid safe-siding; show $ savings from less commercial N.
   c. Can testing labs help with answering questions about accuracy of testing?
   d. Recommendations should be based on <u>both</u> soil tests and manure nutrient values.

3. Selecting an application method.
   a. Time of application.
   b. N loss considerations.
   c. Broadcast vs. incorporation.

COMMENTS:
   a. Explain morning and evening application times. What is the pay back time of incorporation equipment? "Real world ideas".
   b. Conflicts/compatibility with conservation tillage systems.

4. Calibration of manure spreaders application rate.
   a. Load cells.
   b. Plastics sheets.
   c. Variables (speed, width, homogeneity).

COMMENTS:
   a. Can we develop a rate adjustment fact sheet?
   b. How do you make adjustments to the rate?

<u>12:00 - 1:00 Lunch</u>

<u>1:00 - 1:30 (Ed Kaiser, MDA)</u>

5. Soil Testing Lab Certification Program.

MINNESOTA FINANCE DEPARTMENT
400 Centennial Building
658 Cedar Street
St. Paul, MN 55155

REQUEST FOR APPROVAL TO INCUR SPECIAL EXPENS[E]

1. Name and Title of Requestor	1a. Agency/Department Name
John F. Wagner, Agricultural Chemical Advisor	Agriculture
2. Phone (612) 297-7122	3. Date this form prepared February 9, 1995

4. APPROVAL IS REQUESTED FOR THE FOLLOWING: ("X" all that apply):

(a) [ ] Meal(s) which exceed maximum state allowance
(b) [ ] Meal(s) within work area
(c) [ ] Refreshments (coffee, tea, or soft drinks)
(d) [ ] Conference and registration fee(s)
(e) [ ] Lodging within work area
(f) [x] Other Special Expense (Specify)
Working lunch meal expenses at Riverland Technical College

5. FULL NAME OF CONFERENCE, MEETING, ORGANIZATION, ETC. (No Acronyms, Initials, etc.)
Manure Management Workshop

6. LOCATION OF EVENT (NAME AND ADDRESS OF HOST FACILITY)
Riverland Technical College, Rochester, MN

7. DATE(S) AND TIME(S) OF EVENT
February 22, 1995; 10 AM - 3 PM

8. DESCRIBE WHY THE STATE SHOULD PAY THESE EXPENSES:
As part of this workshop for local government officials in the Southeastern Minnesota area, the time from 12 AM to 1 PM will be set aside for informal small group discussions to develop ideas for follow on nutrient management training. To achieve maximum participation, the intent is to hold these discussions over lunch in the college cafeteria. By paying for the meal expenses, atten[dees] will be further motivated to participate rather than seeking lunch at some other location.

9. ITEMIZATION OF COSTS:

DESCRIPTION	QUANTITY	$ UNIT COST	$ TOTAL
Lunch expense at Riverland Technical College cafeteria.	70	$5.00	$350.00

10. NAME OF SPONSOR OR MEETING, CONFERENCE, OR WORKSHOP
Minnesota Department of Agriculture

TOTAL REQUESTED FOR APPROVAL → $350.00

11. FOR WHOM IS APPROVAL OF SPECIAL EXPENSE BEING REQUESTED?

a. REQUESTOR ONLY ("X")
STATE EMPLOYEES (List Names and Titles If Other Than Requestor)
John Wagner
Rick Hansen, Supervisor, Ag Chem Information & Certification
Mary Hanks, Supervisor, Energy & Sustainable Ag
Ed Kaiser, Ag Lime/Anhydrous Ammonia Advisor

b. OTHER PARTICIPANTS
Local government officials from Southeastern Minnesota area counties (NRCS, SWCD, MES, Water Plan Coordinators and other county & local officials). Preliminary list of name[s] attached.

12. DEPARTMENT APPROVALS: DATE

APPROVED FOR AN AMOUNT NOT TO EXCEED $ ______

NOT APPROVED BECAUSE:

FI-00023-07 (1-91)

Classroom Support: The auditorium should have most normal audiovisual support available for your use. If you do have any questions concerning the facilities, just let me know what you need and I will handle the coordination.

Directions: I have enclosed a map of the Rochester area and Riverland Technical College to assist you in locating the auditorium

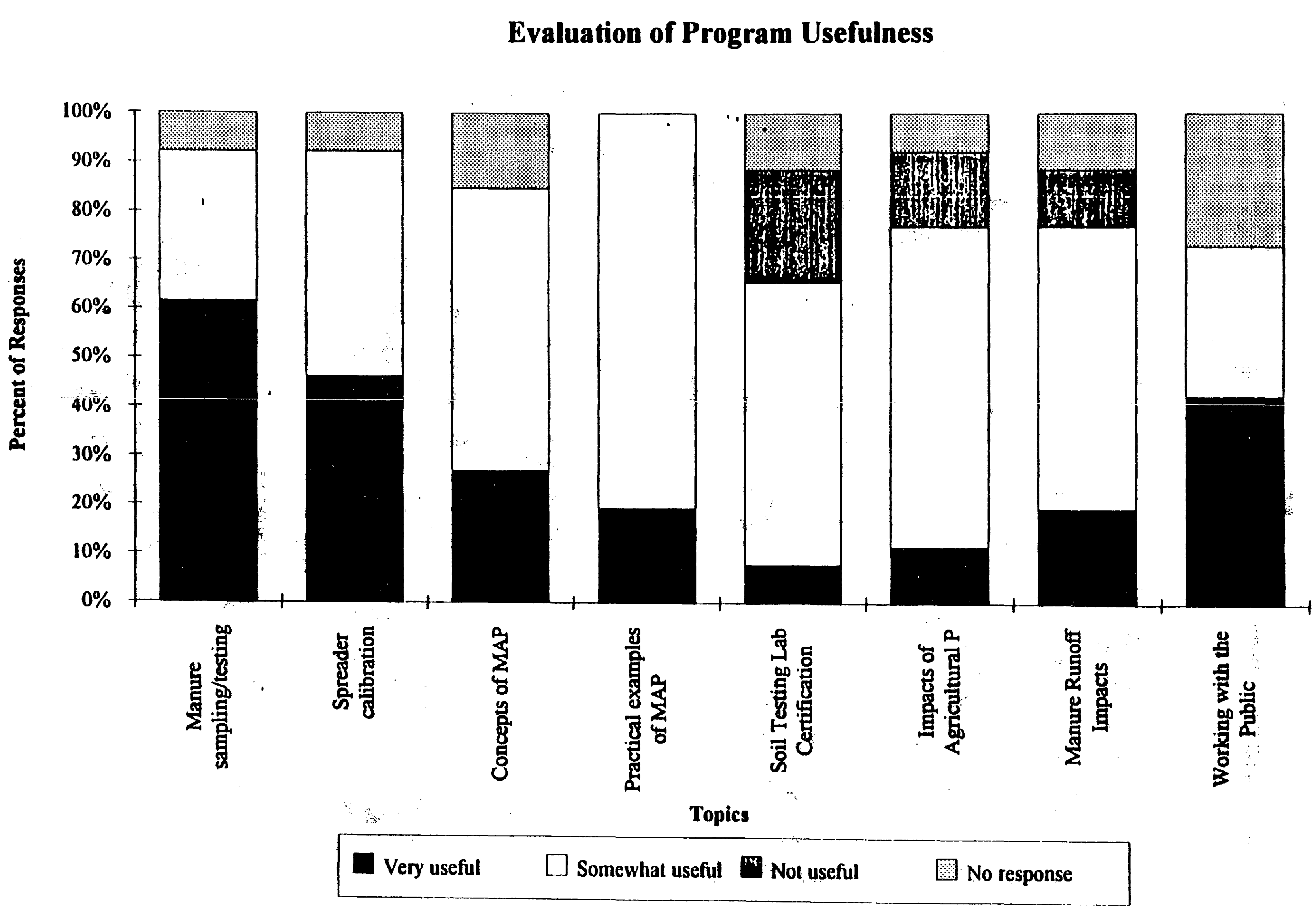
Questions: If you have any questions please contact me at (612) 297-7122 or use the internet: jwagner@mda-ag.mda.state.mn.us. My fax number is (612) 297-2271.

Sincerely,

John Wagner, Agricultural Chemical Advisor
Information & Certification Unit
Agronomy Services Division

JW:sc

Rochester Man) Management Workshop



Feb 22, 1995
Total Number of Responses = 26