1993 Research Project Abstract
For the period ending June 30, 1995
This project was supported by the MN Future Resources Fund

Title:	Nutrient Recycling Through Plants and Animals
Program Manager:	Samuel D. Evans
Organization:	University of Minnesota
Legal Citation:	M.L. 93, Chpt. 172, Sect. 14, Subd. 3(k)
Approp. Amount:	$260,000

STATEMENT OF OBJECTIVES

A. Assess existing soil and plant tests under West Central Minnesota conditions as "Plant N availability predictors" from two manure sources.
B. Integrate weather, soil, and climatic factors to estimate N availability and develop a predictive computer model for West Central Minnesota.
C. Assess tillage and manure application technique effects on N and P losses from manure during the snowmelt and growing season periods in West Central Minnesota.
D. Identify economic risk of using "plant available N" estimation.
E. Conduct a farm nutrient and cost inventory and disseminate information to producers.

RESULTS

Soil nitrate-N tests to a 2-foot depth on manured and fertilized plots either at corn emergence or at the 5-leaf stage were fairly well correlated with corn grain yield. Chlorophyll meter readings, basal stalk nitrate-N at maturity, and fall soil nitrate-N concentrations were of little value in determining the crop N status soon enough to take corrective action. There appeared to be some effect of soil texture on N mineralization, but the data were quite variable.

In the modeling effort an existing computer model, NCSWAP, was used to simulate soil nitrate-N status and corn yield and compared to a long-term study at Morris. The model worked quite well for the check treatment and the solid beef manure treatment. This model could be used to simulate various manure management scenarios. In the other modeling phase of the study, a crop simulation model, CROPSYST, used actual Morris, MN soil temperatures, soil moisture, plant available N, and corn yield. This model did not work well due to the high year-to-year variability in 1993-1994. An N-stress function predicted by the model could be used to predict the effect of mid-season N applications.

In the tillage and manure application phase of the study on a 12% slope, the relatively shallow soil disturbance created by ridge tillage proved more effective than deep moldboard plowing at containing erosive losses of sediment and phosphorus. In fact, the manure reduced runoff, sediment, and total phosphorus during the growing season. Ridge tillage however released more phosphorus during the spring thaw than moldboard plowing. On the moldboard plowing the surface roughness reduced runoff and on the ridge tillage phosphorus losses were much higher due to the exposed residue.

In the risk assessment phase of the study, analysis of model farms showed that use of manure testing could improve the use of the nutrients contained in the manure. Economic analysis compared the benefits of using manure testing compared to errors in nutrient application (overapplication or underapplication) when testing was not used.

A survey of 23 farms in west central Minnesota was completed. In general, the farmers surveyed were using very good fertilizer management practices, but manure was not given adequate credit. The greatest deviation between N applied and N needs for corn was corn following manured legumes (130 lb/ac excess N). However, when acreage is combined with the excess N for various management scenarios, three scenarios make up 86% of the excess N; corn following soybeans, corn following manured legumes, and corn following corn or small grains. So educational efforts need to be directed at application of N at proper rates and proper crediting of manure and legumes.

In the on-farm demonstration effort, experimental sites were established on three cooperating farms. Data from these sites were valuable in demonstrating the value of proper management of manure and will be used at other manure management meetings.

PROJECT RESULTS USE AND DISSEMINATION

The field experiments were used two years during Field Days at the West Central Experiment Station to demonstrate proper manure handing techniques. Two of the on-farm demonstrations were sites for farmer meetings covering improved manure management techniques. Parts of the runoff phase of the study have been presented as two papers at the American Society of Agronomy. Information from the studies was presented to farmer workshops at Staples and Alexandria. Information from these studies will be given to the Minnesota Extension Service Specialists for use in their winter meetings.

The computer modeling phase of the study expanded the use of two existing computer models in managing nitrogen in manure more efficiently.

A draft extension bulletin has been prepared addressing the value of manure testing. Two journal articles will be prepared from the runoff phase of the study and one journal article will be prepared summarizing the "plant N availability predictor" phase of the study after one more year of data is collected by the fall of 1995.

July 1, 1995

LCMR Research Work Program 1993 - Summary - Research

I. Project Title: Nutrient Recycling Through Plants and Animals

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A. Legal Citation: M.L. 1993 Chpt. 172, Sect. 14, Subd. 3(k)

Total Biennial LCMR Budget: $260,000
Balance: $2,315.94 remaining on 6/26/95

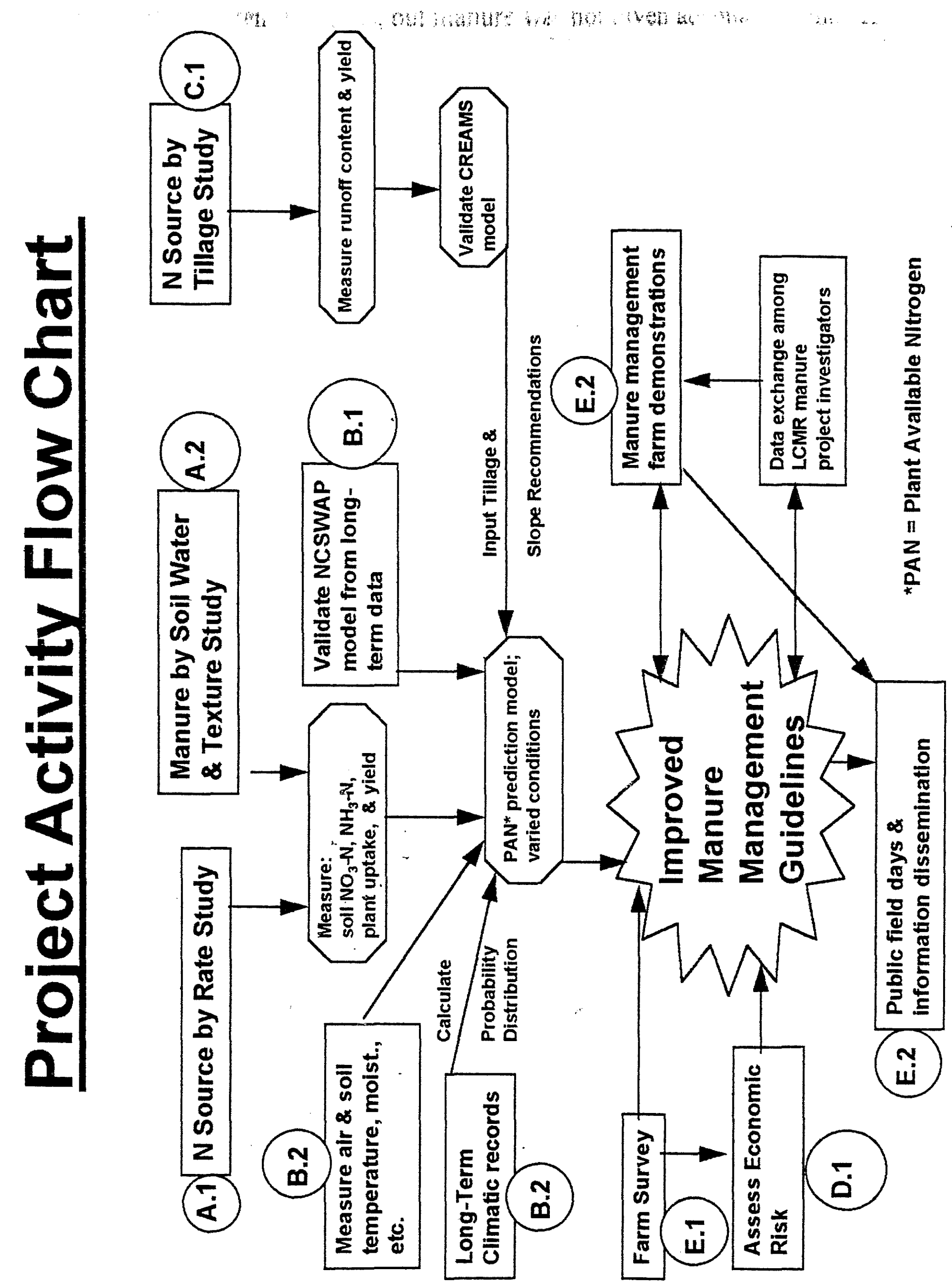
Appropriation Language as drafted 7/27/92: This appropriation is from the future resources fund to the commissioner of agriculture for a contract with the University of Minnesota to improve techniques to predict nitrogen mineralization from manure and soil organic matter in west central Minnesota.

B. LMIC Compatible Data Language: Not applicable.

C. Status of Match Requirement: Not applicable

II. Project Summary:

The ultimate goal of this project is to develop improved methods to use animal manure in West Central Minnesota so that manure use efficiency is increased and the probability of N and P losses to the environment is decreased. This will be done by improving techniques to predict plant available nitrogen from applied manure, assessing the N carryover from previously applied manure, and measuring tillage effects on N and P losses from manured sloping land during the growing season and snowmelt periods. Soil and climatic parameters will be measured to characterize their effect on soil N changes. Plant available nitrogen will be calculated and ultimately integrated into existing computer models. An estimate of changes in income due to manure management changes will help in developing a risk assessment model. A farmer inventory will be conducted to assess manure sources, handling methods, and fertilization practices. An on-farm demonstration effort will be developed to show good manure mangement techniques and will include results from this project as they become available. Finally, information from all phases of this project will be disseminated at field days, workshops, and through publications.



III. Statement of Objectives:

A. Assess existing soil and plant tests under West Central Minnesota conditions as "Plant N availability predictors" from two manure sources.
B. Integrate weather, soil, and climatic factors to estimate N availability and develop a predictive computer model for West Central Minnesota.
C. Assess tillage and manure application technique effects on N and P losses from manure during the snowmelt and growing season periods in West Central Minnesota.
D. Identify economic risk of using "plant available N" estimation.
E. Conduct a farm nutrient and cost inventory and disseminate information to producers.

IV. Research Objectives

A. Title of Objective: Assess existing soil and plant tests under West Central Minnesota conditions as "Plant N availability predictors" from two manure sources.

A.1. Activity: Measure the direct and residual availability of N from applied liquid dairy and swine manure to corn in West Central Minnesota and compare that with N applied as inorganic fertilizer. S. D. Evans will spend 15% of his time over the next two years supervising this activity. A.E. Olness and P.R. Goodrich will spend 1% of their time over the next two years on this activity.

A.1.a: Context within the project: Measured amounts of liquid dairy and swine manure and inorganic N fertilizer will be applied to an Aastad silty clay loam soil at Morris. The N changes in the soil and N uptake by the crop will be measured over a 2-year period. The hypothesis is that N available to the crop over the growing season can be determined by early season plant and/or soil tests. Determination of N early in the season will allow the farmer to apply manure at rates more closely matching crop need, but still have the opportunity to apply additional N fertilizer if N release is slower than expected. Detailed climatic and soil measurements will be made on selected plots in activity B.2 so that N release to the crop can be related to the probability of occurrence of critical soil temperature and soil moisture conditions.

A.1.b. Methods: Field plots will be established in the fall of 1992. Varying rates of liquid dairy and swine manure will be applied along with control treatments of inorganic N fertilizer. The experimental design will be four replications of a randomized complete block. A second identical study (time split) will be started one year later. The inorganic N fertilizer treatments will consist of four rates of broadcast fall-applied urea plus a control treatment (no manure or N fertilizer). The manure will be injected at four rates. The manure will be analyzed for dry matter, total N, NH_4-N, total P, and total K. The NO_3-N and NH_4-N content of the soil in each main treatment block will be measured to a depth of 150 cm (6 subsamples/block) prior to treatment application. Before treatment application, soil borings will be taken on a grid across each replication to determine soil properties and samples of the surface soil will be saved for further analysis. Soil samples will be collected to a depth of 60 cm in 30-cm increments on all treatments at VE-V1 (emergence) and V4-V5 (defined for the pre-sidedress NO_3-N soil test) stages and analyzed for NO_3-N and NH_4-N. At the V4-V5 stage, chlorophyll meter readings will also be taken on each treatment in order to assess the N status of the crop. Following physiological maturity, stover and grain samples will be collected to determine dry matter yield, grain yield, and N uptake. Following this, 10 basal stalk samples (from 15-36 cm above the soil surface) will be collected from each plot for NO_3-N analysis. Following removal of the remainder of the grain from the plots, the soils will again be sampled to a depth of 150 cm in 30-cm increments for NO_3-N and NH_4-N analysis (3 subsamples/plot). Manure and N fertilizer will avoided in this portion of the study so that residual effects can be measured in 1994 and 1995. The entire study will be chisel plowed in preparation for the 1994 season. In 1994 and 1995 the same measurements will be made as in 1993.

Apparent N mineralization rates will be calculated from plant and soil data and will be compared to published guidelines for each type of manure. The apparent N mineralization rates will then be incorporated into N recommendation adjustments for manure application in West Central Minnesota.

A.1.c. Materials: Field materials necessary to accomplish this objective include soil sampling equipment, tractors, spreaders, tillage equipment, planters, cultivators, drying equipment, soil & plant grinders, and plot combine. Laboratory equipment needed includes glassware, laboratory supplies, and analytical instruments.

A.1.d. Budget: $332.09 remaining on 6/26/95

A.1.e. Timeline:

In order to properly carry out this activity, plots must be established in the fall of 1992, manure applied, and plots planted and sampled during the 1993 growing season before July,1993.

	7/93	1/94	6/94	1/95	6/95
Take base soil samples	***				
Apply manure		*			
Till and plant plots			*		
Take treatment soil samples	***	***		***	
Take plant samples	****	****			
Take chlorophyll readings		*		*	
Harvest stover & grain	***	***			
Take basal stalk samples		*	*		
Analyze soil & plant samples	*****************************				
Enter data into computer files	*************************				
Analyze data statistically		****	****	****	****
Calculate apparent mineralization rates	***	***			
Compare with published data		*		*	
Prepare annual summary			**		**
Develop new manure adjustment guidelines					**
Prepare final report					**

A.1: Status

This study was set up to assess various soil and plant tests as "Plant N Availability Predictors". Such tests would enable a farmers to measure the N status of the crop or soil and relate it to corn grain yield.

The effects of liquid swine and liquid dairy manure applied to an Aastad clay loam at four rates on soil NO_3-N content and various crop parameters were evaluated for one and two years following fall manure injection and compared to four rates of urea and a check. The first year following application, all but the lowest manure rates increased soil NO_3-N levels at emergence, V5, and post-harvest over the check treatment. Soil NO_3-N levels from the 2nd year following manure application were significantly higher than the check treatment at emergence and V5 only with the highest manure rate from both sources. Post-harvest soil NO_3-N levels of the two highest rates of both manures were higher than the check in the 0-5 ft depth zone.

Differences in chlorophyll meter readings on the residual manure study were significant only on July 11, the pre-tassel stage. On the study the first year after manure application, chlorophyll meter readings were affected by treatment at both V5 and pre-tassel stages. On both studies the range in readings was wider at pre-tassel than at V5. Therefore, it appears that chlorophyll meter readings would have very limited value in determining the need for additional sidedressed N fertilizer.

Total N uptake, grain N removal, silage yield, and grain yield were all significantly affected by treatment on both studies. The effects were much larger on the 1st year following manure application as compared to the 2nd year.

At the emergence corn stage the correlation between soil NO_3-N to a 2 ft depth and corn grain yield was 0.62 in 1993 and 0.73 in 1994. It required 15-20 ppm NO_3-N at this corn stage to maximize yield. There was a positive relationship between soil NO_3-N to a 2-ft depth at corn stage V5 and corn grain yield ($r^2 = 0.59$ in 1993 and 0.83 in 1994). The amount of NO_3-N (0 to 2 ft) at stage V5 needed to maximize yield was 10-15 ppm in both years following fall manure application. In the one residual manure year measured (1994) yields were not maximized with the NO_3-N levels measured. However, it appeared that yields were approaching a maximum when soil NO_3-N levels exceeded 10 ppm.

We found a wide range in basal stalk NO_3-N values in both 1993 and 1994 the fall following manure application. The highest values found each year were associated with the highest manure N applied, but the plot-to-plot variation was quite high. It was not possible to accurately calculate apparent N mineralization rates because of the unusual season and the limited time frame of this study. Evaluation of the present University of Minnesota manure availability guidelines showed their limitation in regard to varying N content of the manure and environmental effects following manure application.

The most promising "Plant N Availability Predictor" was soil NO_3-N measured to a 2-ft depth. The best correlation with grain yield was with soil samples taken at the V5 stage. However, the correlation was also quite good at the emergence stage. Further work needs to be done to establish supplemental N fertilizer rates to apply when the soil NO_3-N levels are below the optimum level. This study does indicate that when soil NO_3-N levels at the V5 stage are above 15 ppm, no additional N fertilizer would be needed.

A.2. Activity: Establish an experimental site where one rate of liquid dairy manure will be applied on soils of three textural classes and plant available N measured on sub-plots maintained at 5 soil moisture levels. One of the textural sites will be on the same soil type as in activity A.1.
A.E. Olness will spend 4% of his time over the next two years on this activity. P.R. Goodrich will assist on this activity.

A.2.a. Context within the project: In this phase soil and plant data will be collected to assess the effect of soil moisture level on the rate of apparent N mineralization. This will provide data on the N provided to the crop and test the hypothesis that N mineralized from manure applications is sensitive to both soil moisture level and soil texture.

A.2.b. Methods: Field plots will be established in the fall of 1992. The NO_3-N and NH_4-N will be measured to a depth of 150 cm prior to manure application. Dairy manure will then be applied to provide 180 kg N/ha to the following crop. The soil moisture level will then be measured, multiple lines of flat perforated sprinkler tubing installed, and plots covered with plastic. Irrigation water will then be applied to establish five soil moisture levels. During plot establishment soil samples will be collected for soil characterization. The following spring the plots will be uncovered, tilled, and planted to corn. The soils will be sampled to 60 cm in 30-cm increments for NO_3-N and NH_4-N content and distribution. Irrigation will again be used to maintain differential soil moisture levels. Soil samples will be taken weekly from planting to June 30 to a depth of 30 cm for nitrogen and moisture monitoring. One sampling will be scheduled at the V4-V5 stage which is specified for the pre-sidedress (PSD) NO_3-N soil test. When mature in the fall, stover and grain samples will be collected in order to determine total N uptake. When ready for combine harvest, four rows 12.2 m long will be harvested for grain yield. This entire process will be repeated for a second year on the same soils. The effect of soil moisture on plant available nitrogen over the early season will be examined using standard correlation methods.

A.2.c. Materials: Field materials necessary to carry out this project include soil probes, tillage equipment, plastic plot covers, flat sprinkler tubing, water tanks & pumps, manure applicators, corn planters, soil moisture monitoring equipment, plot combine, and miscellaneous plot care equipment. Laboratory equipment needed includes glassware, laboratory supplies, and analytical equipment.

A.2.d. Budget: This activity will be carried out cooperatively with the USDA-ARS research group at Morris and funds necessary for this phase of the project will be provided by that unit.

A.2.e. Timeline:

In order to properly carry out this activity, the first year of the experiment must be started in the fall of 1992, measurements made and data collected in the fall of 1992 and spring of 1993, plots planted, and planting thru June 30 samples collected before July, 1993.

	7/93	1/94	6/94	1/95	6/95
Take base soil samples	**				
Apply manure		*			
Establish differential soil moisture levels and cover plots		*			
Till and plant plots		**			
Sample plots weekly		****			

A.2.e. Timeline: (continued)

	7/93	1/94	6/94	1/95	6/95
Maintain soil moisture levels		****			
Correlate NO_3-N levels with soil moisture levels	***		***		
Correlate crop yields with PSD NO_3-N soil levels	***		***		
Harvest plots	**	**			
Complete final analysis and interpretation					****

A.2. Status:

Nitrate-nitrogen produced by the mineralization of manure is expected to be affected by the same environmental factors affecting mineralization of indigenous organic matter. One of these factors, aeration, is affected by soil water content which in turn is largely controlled by soil clay content. To examine this affect in more detail, plots were established on a Aastad clay loam, a Kranzburg silt loam, and a Sioux sandy loam soil by applying 7,700 L of liquid dairy manure/acre (equivalent to application of about 160 lbs of available N/acre). Plots were then irrigated with different amounts of water to establish different soil water contents.

Excessive rainfall in the spring and early summer of 1993 and the cool growing season precluded a continuation of the fall water application rates. Therefore attempts to constrain water contents were discontinued. The Sioux sl site was under control of the Minnesota Department of Natural Resources and a contractor; who applied anhydrous ammonia uniformly over the area, including the plot area at the rate of about 160 lbs/ac after planting. As a consequence, data were collected but the site was subsequently abandoned. No attempt was made to continue the controlled soil water characteristic after 1992-93. Therefore, the focus of the study was the effect of soil texture on N mineralization under rainfed moisture conditions.

Soil samples were collected and analyzed for nitrate-N and water content. Rather large amounts of nitrate-N developed in the surface depth increments at all three sites and some tendency of texture and water content developed but was inconclusive in establishing the effect of aeration on development of nitrate-N. Corn grain yields averaged 115.3 bu/ac, 91.0 bu/ac, and 62.9 bu/ac on the silt loam, clay loam, and sandy loam sites, respectively in 1993; these yields were competitive with applications of conventional inorganic N-fertilizer at recommended rates of application. Manure applications showed clear effects of advancing the rate of corn development; flowering was advanced by as much as 2 to 4 days on sites receiving liquid dairy manure in the previous fall.

B. Title of Objective: Integrate weather, soil, and climatic factors for N mineralization prediction and develop a predictive computer model for West Central Minnesota.

B.1. Activity: Integrate weather, soil, and climatic factors to simulate carbon and nitrogen dynamics in the soil/plant system for West Central Minnesota. The scope of this activity has been reduced because of the budget reduction. Therefore, modeling will be carried out only on data from a long-term manure study previously conducted at Morris. J.A.E. Molina will spend 5% of his time on this activity over the next two years. P.R. Goodrich will assist in this activity.

B.1.a. Context within the project: Plant available N is at the crossroad of many microbe-mediated transformations: it is biologically produced by N mineralization of the soil organic matter, N rich plant residues, and manure; it is also sought after by microbes during immobilization, a process which competes with the plant for N. An estimate of plant available N during the growing season has to account for the balance between all the processes cited above. This can now be achieved with simulation models, such as Nitrogen and Carbon Simulation in the Soil, Water, Air, and Plant System (NCSWAP), which integrate abiotic and biotic N transformations within the context of farm managerial practices.

B.1.b. Methods: The model NCSWAP will be calibrated to account for the data collected from the "long-term manure study" performed at Morris from 1970 to 1991. This study documents the residual effect on continuous corn of two heavy applications of 1) solid beef manure, 2) liquid beef manure, and 3) liquid hog manure. Two additional treatments (control: no manure or fertilizer and fertilized: NPK applied annually) complete the study.

A stepwise calibration will be performed. Initially the active soil organic matter will be obtained by calibration against results from the first year (1970) control treatment. Once this information has been obtained, the model will be tested on its ability to account for the control and fertilizer experimental results from 1971 to 1991. Data available are: (1) above ground production; (2) total soil C and N; and (3) soil NO_3-N in the top 120 cm at harvest. After completion of this calibration/validation procedure, the manure treatments will be considered. Simulations (1970 to 1991) will be performed for each type of manure. Amounts of inorganic and organic N added to the soil in 1970 and 1971 with the manure will be taken into consideration. Experimental and simulated data (as listed above) will be compared. If needed, the fit between simulated and experimental results will be improved by adjustment of the rate constant of manure (organic matter) decomposition. This will provide the N mineralization rate over a 21-year period.

Once calibration/validation has been achieved, the model will be exploited. The model will be used as a tool to foster dialogues between scientists and field practitioners. In general, the model can be used to 1) predict, and 2) advise.
B.1.c. Materials: The data from the long-term manure study is in a database file and is readily accessible. Computers are available for the simulation runs.
B.1.d Budget: $193.39 remaining on 6/26/95

B.1.e. Timeline:

	7/93	1/94	6/94	1/95	6/95
Carry out stepwise calibration	******				
Make computer simulation runs	*****				
Fit simulated & experimental data	******				
Exploit model		*******			
Prepare final report					**

B.1. 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).

NCSWAP simulated 20 years (1971-1989) continuous corn for 3 contrasted treatments: zero-N, fertilizer, and solid beef manure additions. The overall performance of the model as well as differences between treatments could be best vizualized by considering the cumulative dry matter production. The manure applications made in fall 1970 and 1971 were sufficient to maintain dry matter production to a level identical to the one achieved with a yearly addition of fertilizer. Dry matter production did not crash with the zero-N treatment, but stabilized to 6 - 8 metric tons per hectare after year 1975. The model gave a good estimate of cumulative dry matter production for the zero-N and fertilizer treatments. It over-estimated by about 15 percent the measured yields for the manure treatments between year 1976 and 1986. Simulated and experimental data for the average nitrate concentration in the soil top 4 feet were in accord for the zero-N and manure treatments. From 1971 to 1985, the model underestimated nitrate concentrations for the fertilizer treatments. The half-life of the manure's organic fraction was calibrated to 115 days (.006 day-1 decay rate).

The model was used to find out management alternatives to (1) manure application; (2) the long term (28 years) behaviour of continuous corn; and (3) causes for observed diffences between the treatments in terms of changes in the soil organic fractions (active vs. passive SOM). A triennial low rate of manure application was simulated. While nitrate concentrations in soil were lowered, dry mass production was maintained to that found with the fertilizer. Further simulations indicated that the low manure load applied every four years was not sufficient to sustain maximum yields. Simulation of crop yields from 1971 to 1999 showed that the residual effect of manure was felt for 16 years. Subsequently, dry matter production dropped to that observed for the zero-N treatment. The 28 years simulation confirmed a slow downward trend of yields for the zero-N treatment. Differences between the treatments could be best explained by changes in the active soil organic matter.

B.2. Activity: Field experiments to assess soil and climatic impacts on plant available nitrogen. The scope of this activity has been reduced because of budget reduction. The funds will permit detailed measurement on only 8 plots. C.F. Reece and M.W. Seeley will spend 10% and 5% of their time respectively over the next two years working on this activity and supervising graduate students.

B.2.a. Context within the project: Detailed soil and climatic measurements can be used to develop simple predictive models for plant available N. Weather conditions can then be used to estimate the occurrence of above- or below-normal N availability from manure or native soil organic matter. With such a tool, producers could better determine optimum side-dress N rates to meet their yield goals, reducing input costs and preventing application of excess manure or inorganic N fertilizers.
B.2.b. Methods: Eight of the plots used in the experimental design for activity A.1 will be instrumented to measure temperature and moisture profiles in the soil. The plots will encompass two replications of four treatments (base rates of liquid dairy and swine manure, urea to provide 135 kg N/ha, and the control treatment). Soil measurements will be made at the 1, 15, 30, and 60 cm depths using heat dissipation sensors. In addition, rainfall, solar radiation, wind speed and direction, air temperature and humidity will be recorded on a daily basis. Pre-manure application measurement of NO_3-N and NH_4-N at 30-cm increments to 150 cm (taken in activity A.1) will be supplemented with biweekly measurement to a depth of 60 cm in 30-cm increments in all eight plots until stage V4-V5. The sum of NO_3-N and NH_4-N will define the plant available N and will be related to soil temperature and moisture measurements using time-series analysis. Using the West Central Experiment Station climatological data (dating from 1885) in conjunction with the climatic data measured during the field experiment, predictive models of soil temperature and moisture will be run over the compete time series to determine distribution frequencies for soil temperature and moisture. Weekly probability distributions for critical soil temperature and moisture conditions which relate closely to the measured plant available N will then be estimated.
B.2.c. Materials: Campbell Scientific data loggers, multiplexers and sensors will be used. Two data loggers will be required. Data will be stored in the field and transferred to computers using storage modules on at least a weekly basis during the growing season. Data loggers will be used year round to record depth and duration of the soil frost in the four treatments, as this relates to the start of the field season each spring. NO_3-N and NH_4-N measurements in 30-cm increments will be taken using three probes/plot on a biweekly basis.
B.2.d. Budget: $535.06 remaining on 6/26/95

B.2.e. Timeline:
In order to properly carry out this activity, equipment must be installed at the experimental site in the fall of 1992 and measurements continued until the official start of the project on 7/93.

	7/93 1/94 6/94 1/95 6/95
Inventory historical data	**********
Field measurements	*****************************
Modeling	
plant available N changes	**************************
Probability distributions from long-term weather data	***********

B.2. Status:

Plant available nitrogen (sum of nitrate and ammonium) was monitored on a biweekly basis from emergence to V5 stage on plots supported in activity A.1. Soil temperature and moisture were also monitored on these plots. While nitrogen source and treatment significantly affected plant available nitrogen levels, soil temperature and moisture did not vary much from plot to plot due to N source. Soil nitrate levels typically accounted for 98 percent of the plant available nitrogen. Since growers rarely request ammonium analysis of their soil, soil nitrate became the primary indicator of plant available nitrogen in our analyses.

Soil temperature and moisture measurements were related to plant available nitrogen measurements and corn yields using the simulation model, CROPSYST (Cropping Systems Simulation Model, Washington State University). CROPSYST is a process-oriented model for simulating crop growth and yield, soil water budget, soil-plant nitrogen budget, and residue production and decomposition. The model allows simulation of management practices such as tillage, fertilization, and crop rotations. CROPSYST was calibrated for conditions at Morris, MN using the soil temperature, moisture, plant available nitrogen, and yield data obtained in 1993 and 1994.

Historical weather data since 1900 was used in conjunction with CROPSYST to simulate 93 years of crop yields and plant available nitrogen levels. Dairy manure, swine manure and urea fertilizer treatments were simulated in this procedure. Probability distributions of plant available nitrogen and yield were calculated from this data set.

Yield was not well correlated with various measures of plant available nitrogen, soil temperature, growing degree days, or precipitation. A weak negative correlation was found between yield and soil nitrate. The positive correlation between soil nitrate and yield within a year was overwelmed by year to year variability in yield due to other factors in the environment such as timing of temperature and moisture. In other words, in years with favorable growing conditions, plants took up N early in the season and reduced mid-season levels of soil nitrate. In years with poor growing conditions, N uptake was depressed which increased residual nitrate in the soil.

We concluded that weekly probabilities of plant available nitrogen would not be good predictors of yield unless the growing conditions to the end of the season were known in advance. Therefore, a second analysis was performed which attempted to isolate the nitrogen effect on yield by normalizing year to year variability in crop yields due to other environmental factors. This approach depended on calculating a yield reduction due to nitrogen limitations. Yield reduction was calculated as the difference between yield predicted for a given treatment and yield predicted for the same year under conditions of unlimited N supply divided by the yield associated with unlimited N supply.

Yield reduction was strongly correlated with N-stress as calculated by CROPSYST ($r = 0.97$) for all nitrogen sources. Although N-stress predicted by the model is not a measureable variable, the relationship to yield reduction was exploited by relating N-stress to real soil variables. Correlations between N-stress and a number of soil variables were calculated. Based on these results, a regression model was developed which used the following variables to predict N-stress: soil nitrate two weeks after planting, cumulative precipitation since fertilization in the fall, and prepitation in the first and second weeks after planting. Urea fertilizer and swine manure treatments exhibited the same response over all years, whereas dairy manure exhibited less N-stress. This is most likely due to the higher percentage of solid organic matter in the dairy manure. Using this regression model and the historical weather record, probability tables of N-stress and yield reduction were calculated based on whether cumulative precipitation and soil nitrate levels are below-average, average, or above-average. These tables indicate that mid-season sidedress applications of nitrogen could avert yield reductions when soil nitrate levels are below-average and/or cumulative precipitation since fertilizing is above-average.

C. Title of Objective: Assess tillage and manure application effects on N and P losses from manure during the snowmelt and growing season periods in West Central Minnesota.

C.1. Activity: Tillage system and manure application effects on losses of N and P due to surface runoff, both from rain and snow will be quantified under West Central Minnesota soil and climatic conditions. Budget reduction in this activity will be accomplished by coordinating analyses with other similar projects. J.F. Moncrief and S.C. Gupta will spend 5% of their time over the next two years assisting on this activity and supervising a graduate student.

C.1.a. Context within the project: Livestock operations are an important part of the economy in West Central Minnesota. Environmentally sound manure utilization from these farming enterprises is imperative. Some soils are steeply sloping, have moderate permeability, and can subsequently pose a hazard to surface water contamination with N and P in water runoff. The shallow incorporation of applied manure with crop residue management systems designed for erosion control (resulting in lower sediment losses) may result in higher losses of N and P. The purpose of this objective is to quantify the net effect of crop residue management systems on N and P losses.

C.1.b. Methods: This experiment will quantify sediment loss and the nutrient loading (N and P) of surface runoff from 3 m by 21 m runoff plots under natural precipitation conditions with continuous corn. The experimental design is a randomized compete block of three replications with tillage main plots split with N and P source subplots. Nitrogen and P fertilizer will be spring applied anhydrous ammonia or ammonium polyphosphate applied as a band with the planter. Manure will be broadcast applied once as solid beef manure with the rate based on soil test P levels. Residue management will be accomplished with either 1) fall moldboard plowing with secondary tillage in the spring with a field cultivator, or 2) a ridge tillage system with planting and row cultivation the only tillage. Plots will be isolated with corrugated steel borders. Runoff will be collected and a representative sample of the suspension will be collected after each rain storm and analyzed for N and P concentrations. Chemical analysis will include total, soluble, and bio-available P as well as total N, NO_3-N, and NH_4-N. The runoff, sediment, and nutrient loading data will be used to test a field scale model for the Chemical, Runoff, and Erosion form of the Agricultural Management Systems (CREAMS) computer model.

C.1.c. Materials: Corn planters, tillage equipment, cultivators, harvesters, corrugated steel edging, 225 liter barrels, PVC pipe, pumps, reagents, and glassware and laboratory supplies. Microcomputers and the CREAMS model will be used in the model test phase.

C.1.d. Budget: $880.17 remaining on 6/26/95

C.1.e. Timeline: This activity will be carried out on plots established in the spring of 1992 and some measurements will be made before July, 1993.

	7/93	1/94	6/94	1/95	6/95
Establish treatments		****		****	
Collect runoff data		****		****	
Prepare annual summary		****			
Validation of CREAMS model			****		
Prepare final report					***

C.1. Status:

I. Tillage and Manure Interactions on Sediment and Phosphorus Transport

A problem of agricultural non-point source pollution is the necessary cultivation to maximize the use of nutrients from manure for crop production. This study was conducted to evaluate the effects of tillage system in combination with solid beef (*Bos taurus* L.) manure application on surface water quality. The effects of ridge till (RT) and moldboard plowing (PL) combined with one time surface application of manure on the transport of sediment, total P (TP), particulate P (PP), and dissolved molybdate reactive P (DMRP) during the snowmelt and rainfall runoff in 1992-94 were investigated on a Barnes loam (fine-loamy mixed Udic Haploboroll) with 12% slope planted to corn (*Zea mays* L.).

In 1992 the runoff, sediment, TP, and DMRP in the PL was 18.5, 162, 30, and 12 times, respectively, greater than from the RT plots. Manure treatment increased DMRP concentration and thus higher DMRP loss in runoff. For the RT plots, the main source of the annual runoff, TP, PP, and DMRP in 1993 and 1994 was snowmelt, whereas in the PL plots it was rainfall. In 1993, runoff, sediment, TP, and PP from the PL was 15, 70, 7, and 8 times, respectively, greater than from the RT plots.

Runoff and sediment loss reduction due to manure application was 50 and 71% respectively. Manured RT resulted in 52% greater DMRP loss compared to non-manured RT plots. In 1994 the sediment, TP, and PP from the PL was 12, 2, and 4 times, respectively, greater than from the RT plots, however, DMRP was 3.8 times greater in RT than PL plots. Manure application had no significant influence on runoff, sediment, phosphorus loss. Relative to PL, the RT reduced runoff, sediment, TP, and PP loss. DMRP loss from corn residue during snowmelt was greater in RT than PL plots. Manure reduced runoff and erosion but increased DMRP loss in RT plots.

II. Tillage and Manure Interactions on Soil Phosphorus Dynamics, Yield and Phosphorus Uptake of Corn

Manure incorporation into soil is necessary in order to maximize the nutrient availability for crop production. The specific objective of this study was to evaluate the effects of ridge till (RT)and moldboard plowing (PL)tillage treatments with and without beef cattle (*Bos taurus* L.) manure application on the soil-P dynamics, corn (*Zea mays* L.) yield, and corn P-uptake. Beef manure was applied one time at the rate of 56 Mg ha^{-1}. Dynamics of $NaHCO_3$ extractable-P (Olson-P) in soil at 0-5, 5-10, and 10-15 cm depth, corn yield, and corn P-uptake were evaluated on Barnes loam (fine-loamy mixed Udic Haploboroll) with 12% slope from 1992-94. Corn was planted up and down the slope.

Manure application in the RT system resulted in Olson-P stratification with soil depth. at 0-15 cm depth between the plant rows, manure application increased Olson-P by 4.5 and 12.5 mg kg^{-1} in RT treatments and by 6.5 and 9.5 mg kg^{-1} in PL plots one and two years after its application, respectively. Incubation studies of soil and manure in the laboratory showed that Olson-P decreased exponentially with time.

In 1993 grain yield was significantly greater in the PL treatment (7.4 Mg ha^{-1}) than in RT plots (6.2 Mg ha^{-1}). In 1994 tillage effects were not significant. In 1993, manure had no significant effect on grain yield whereas in 1994 manure increased grain yield by 0.5 Mg ha^{-1}. Tillage had no significant influence on P uptake in 1993 and 1994, but in each year manure significantly increased corn P-uptake by 4.7 kg ha^{-1}. Grain yield in the PL plots was either greater or similar to the RT plots, depending on the year. Tillage had no significant effect on corn P-uptake. Manure influence on grain yield was not consistent.

III. Validation of GLEAMS Model to Predict Runoff, Sediment, and P Transport

The objective of this part of the study was to test the GLEAMS (Ground Water Loading Effects of Agricultural Management Systems) model against the measured data from the preceding field experiments. The GLEAMS model simulated surface runoff and the associated sediment and total P, particulate P (PP) and dissolved molybdate reactive P (DMRP) from the erosion plots in 1993 and 1994.

Since the standing residue trapped and kept the snow in place in the ridge tillage system, the model predictions of snowmelt runoff from the ridge till system were good. The model predictions of the snowmelt runoff in the absence of residue (moldboard plowing) were not close to the measured values. It is hypothesized that since the model did not consider snowdrifts, there may have been some loss of snow due to the snow drifts, thus resulting in an overestimation of the snowmelt runoff in bare soils. In general, the model predictions of rainfall runoff were good for both the moldboard and ridge tillage systems when the rainfall intensity was not high. For the high intensity rainfall, the model overestimated and underestimated the surface runoff for the ridge tillage and moldboard plow systems, respectively.

The model overestimated sediment loss in snowmelt runoff for both the ridge tillage and the moldboard systems. In general, the model predictions of the sediment loss from rainfall were close to the measured values for both the ridge till and moldboard plow systems. Only for a high intensity rainfall, the model predictions of sediment loss were higher and lower for ridge till and the moldboard systems, respectively.

Since the PP and TP greatly depends upon the sediment loss, the overprediction of sediment loss in the snowmelt runoff resulted in an overestimation of TP and PP losses. Similarly, the model predictions of DMRP were good as long as the predictions of runoff were also reasonable. Field representation of snowmelt is not very well represented in the model, especially where snow drifts may occur extensively. The model needs to be improved in sediment loss for both snowmelt and high intensity rainfall conditions.

D. Title of Objective: Identify economic risk of using plant available N estimation.

D.1. Activity: Measure economic and risk related impacts of using PAN estimates. This activity will use the demonstration farms in activity E.2 as part of the database in order to reduce expenses. Coordination will also be carried out between this activity and that in E.1. R.D. Alderfer will spend 3% of his time over the next two years on this activity.

D.1.a. Context within the project: This phase of the project draws on all other parts of the project to measure economic and risk related financial impacts of N management in the farm environment.

D.1.b. Methods: Costs of commercial inorganic N fertilizers and their application, will be compared to costs and production results using organic N sources on surveyed farms. Emphasis will be on measuring the costs and benefits of N management when yields and prices are uncertain. The climatic model in activity B.2 will be used to compute historical yields and estimated income over variable costs, using the long-term weather data from the West Central Experiment Station. Final results must be expressed in a form that most producers would be able to understand. Through the work in activities A and B, it will also be possible to estimate a value for swine and dairy manure.

D.1.c. Materials: Part-time clerical help will be hired to gather, and format electronic data during the last two months of the first year of the project. A masters student research assistant will be hired in the second year of the project to assist with analysis of economic and risk-related data.

D.1.d. Budget: $375.23 remaining on 6/26/95

D.1.e. Timeline:

	7/93	1/94	6/94	1/95	6/95
Gather first year results in electronic form			*****		
Analyze research and economic results			****	****	****
Write up final report					****
Prepare extension-type publication					****

D.1. Status:

The Plant Available Nutrient portion of this study, generated promising results, but at the culmination of the first year of the project, it was not evident where the crop income risks were involved, that were a part of section D. As a result, in the 3rd quarter of the project, methods were revised and the focus turned to the value of managing all manure nutrients rather than just PAN. Two reasons for focusing on N, P and K, were (1) that all nutrients are joint products in manure and jointly needed in crop production and (2) that a common failure in manure management is sampling and testing manure, when nutrient content can be incredibly variable (30 to 300 percent of the average nutrient levels).

A preliminary draft of the extension-type publication was completed. The title of that paper was "The value of Manure Sampling and Testing for Central Minnesota Dairy and Swine farms.

The nutrient content of dairy and swine manure can vary greatly, depending upon handling, storage and a number of factors. Livestock producers are strongly encourage to take manure samples in order to measure actual manure nutrient content prior to application to crop land. The number of producers who have their manure tested is generally agreed to be low. In a survey of more than 400 hog producers, roughly 80 percent had not done a manure analysis in the last 5 years, and most of those who had sampled, indicated they sampled only one time. From 1991 data Montgomery indicated that the number of Minnesota livestock producers testing manure varied from 4 to 8.5 percent depending on the area of the state.

When farmers under applied nutrients it was assumed that crop losses were equal to the value of the nutrients not applied. This is a very conservative estimate, when one considers most crop yield response functions to N, P, and K. The economic losses from over application of manure nutrients do not include potential crop damage loss nor any environmental benefits which farm families and society would jointly benefit.

When a swine producer(100 sow farrow-to-finish and 900 tillable acres) assumes an average table value for nutrient content in their manure, this study shows that reasonable economic errors are $1200 to $2500 on an annual basis, not including potential environmental impacts and their costs. Similarly, dairy farms (80 cows and 400 tillable acres) could save $54 to $1197 annually, by testing their manures. Errors much larger are likely to occur (but with less frequency), since the values for high and low manure nutrient analysis were very conservative compared to the possible range of error that could potentially occur. With 15,000 hog farms and 13,500 dairy farms, the Minnesota pork industry could conservatively save $1000 per farm or $15 million dollars on an annual basis, and the dairy industry with 13,500 farms could annually save $500 per farm or $6.75 million dollars.

E. Title of Objective: Conduct farm nutrient and cost inventory and disseminate information to producers.

E.1. Activity: Conduct farm nutrient and cost inventory of fertilizer and manure use patterns on selected farms in west central Minnesota. The scope of this activity has been reduced (fewer number of farmers to be contacted) and coordinated with activity D.1. Bruce Montgomery will spend 4% of his time over the next two years on this activity. R.D. Alderfer will spend 1% of his time on this activity over the next two years.

E.1.a. Context within the project: Data from participating demonstration farms and other similar livestock/crop farms in West Central Minnesota will be will be gathered for analysis in activity D.1.

E.1.b. Methods: On-farm nutrient inventories coordinated through the Minnesota Department of Agriculture will be conducted by their designee, with assistance from R.D. Alderfer at the West Central Experiment Station. Some station support for travel and miscellaneous expenses will be paid with station funds. Data includes soil and manure analysis, crop acreage, crop yield and farm plans. This will form the basis for farm-level simulation and analysis for measuring economic and risk related impacts.

E.1.c. Materials: Soil and manure tests on surveyed farms as needed. Soil maps and recorded farm-level data. Hired or contracted person will assist in on-farm data collection, and Richard Alderfer will assist when possible.

E.1.d. Budget: $9,800

E.1.e. Timeline:

	7/93	1/94	6/94	1/95	6/95
Identify potential farms for survey effort	***				
Contact farms and make final selection	****				
Collect on-farm data		****		****	
Summarize data					**
Prepare final report					**

E.1 Status:

Twenty-three farms, covering over 13,000 acres, participated in the FArm Nutrient Management Assessment Program (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.

Producers in this study appeared to be using the correct timing of N fertilizer for fall and spring applications. Although just based on one year of information, fall-applied N was applied correctly based on long-term soil temperature data. Nitrogen sources were dominated by ammonium-based products which is particularly important in fall applications. Use of the soil nitrate test was limited only covering 16% of the corn acres, however, the previous wet season may have limited the usefulness of the test. Manure testing was very limited.

Manure accounts for approximately 15% of the 'first year available' N- legumes account for another 11 %. Organic contributions are less than other regions of the state where FANMAP was used. Obviously proper crediting of both of these sources is needed to successfully manage N in any cropping system. On corn acres where no previous manure or legume credits existed to confound the rate selection process, producers appear to be in agreement with recommendations that were made by UM/MES four to five years ago. Recommended rates have been reduced a minimum of 20 lb/A. Consequently due to the development of more conservative recommendations, producers are over-applying fertilizer inputs by 28 lb/N/A. Roughly 89% of the acreage in this particular scenario were above UM recommendations.

Producers were reducing N fertilizer inputs following soybeans by 20 lb/A. Soybean crediting may have been less than normal due to the poor 1993 crop. Using the one pound N credit per bushel, which is typical in western Minnesota, producers were taking the appropriate credits. Statewide recommendations give soybeans a 40 lb/A credit.

Producers were basically reducing commercial N inputs by 75 lb/A in scenarios where previous manure applications were made to non-legume crops such as corn. Producers were underestimating the value of the manure by approximately 40 lb/A. A common practice is to apply manure to soybean acres which are followed by corn in the rotation. In this scenario, producers were found to reduce their commercial inputs by approximately 60 lb/A. However the combination of legume and manure credits, coupled with the fertilizer (average of 66 lb/A), creates a situation where over-applications in excess of 130 lb/A develops. In these situations, only a starter N application should be applied and would trim 40 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 over 70% of the "first year" available N was applied to corn in this study, only 25% of the corn acres received annual applications of manure. For a water quality perspective, the most significant impacts could be made by improving the N crediting process in this particular cropping scenario.

The process of manure crediting is greatly simplified with manure storage systems that allow for a minimal number of land application events. In general, most of the storage facilities of the selected farms in West Central Minnesota allowed some flexibility in storage capabilities and thus timing of application. Approximately 75% of the N retained after storage originated from a variety of systems that allowed for some storage benefits. Scrape and haul collection systems, a type of system which demands frequent applications, accounted for 25% of the N available for land application. In previously studies by the MN Extension Service, the nutrient value from manure has been found to be highly variable. Manure testing needs continual promotion as a fundamental part of a nutrient management plan. None 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. Producers can make significant reductions by using the most recent recommendations. Producers have made significant progress in the crediting of organic contributions although there are certain cropping sequences where large improvements need to be made.

E.2 Activity: Develop a network of on-farm demonstrations, field days, winter meetings and publications to serve as the core of the educational effort. The scope of this activity has been cut in half because of the budget reduction. Data collected on the demonstration farms will also be used in activities D.1 and E.1. Doug Gunnink will spend 8% of his time on this activity over the next two years. R.D. Alderfer will spend 1% of this time on this activity over the next two years. P.R. Goodrich will assist in this activity. Mary Hanks will also allocate 2% of her time to this activity.

E.2.a. Context within the project: One of the most effective methods for disseminating management information to farmers is quality, local, on-farm demonstrations. The adoption of new guidelines presented in the on-farm demonstrations will decrease losses of NO_3-N while maintaining profitable farming. Information from the on-farm demonstrations and other project objectives will be summarized at field days, workshops, and through publications.

E.2.b. Methods: The core of this education program is three strategically placed on-farm demonstrations of fertilizer and manure management strategies to reduce and/or make more efficient use of N for corn. Cooperators and sites will be evaluated for demonstration suitability by on-site visits. Treatments and crop responses will be characterized in enough detail to determine probable cause and effect on yield differences and inputs tallied to assess influences on profitability.

The on-farm demonstrations will focus on the more efficient use of manure N sources through examination of the use of split N applications based on the presidedress NO_3-N test. Using cooperator manure and soil testing records, manure will be applied at varying rates up to a maximum of approximately 168 to 180 kg N/ha available to the corn crop (may be modified to fit realistic yield goals). Treatments will vary the amount of additional inorganic N fertilizer to be applied as sidedress N based on the presidedress NO_3-N test. Crop response will be used to evaluate the effectiveness of the NO_3-N test. Sites will be selected in areas that are representative of typical soil types in the west central part of Minnesota.

Field days will be scheduled at each demonstration site. All cooperators, including farmers, will meet to evaluate the data collected and to determine the program for farmer and field staff workshops. One workshop per year will be held at a location to be determined at that time. Data from the demonstrations and other research components will be summarized into workshop presentation materials and fact sheets for general distribution in the west-central area of the state.

E.2.c. Materials: Materials necessary to accomplish this activity will consist of : 1) farm equipment, seed, fertilizer/manure supplied by farmer cooperators; 2) sample bottles and bags, use of existing assorted laboratory equipment for analyzing soil, water, plant tissue and manure samples; 3) scales for determining manure application rates, data forms, field markers, tape measure, other plot related miscellany, fact sheets, field maps and advertising flyers.

Data collected during the 2 years of the project as well as information obtained from previous projects and complementary projects will be integrated to produce the fact sheets and workshop presentation materials.

E.2.d. Budget: $0.00

E.2.e. Timeline:

	7/93	1/94	6/94	1/95	6/95
Identify cooperators		****			
Assess farming operation and design demonstration			****		****
Implement demonstrations and collect data			****		****
Field tours held in cooperation with local agency advisors		****		****	
Prepare data summaries and fact sheets			********		*******
Field staff and farmer training workshop			****		****

E.2. Status:

Three on-farm demonstrations of efficient nitrogen and manure management were successfully completed. Two field tours were held in July, 1994 on the Steve Sunderland and Gordon Johnson Farms in cooperation with The University of Minnesota Extension Service at Montevideo and Fergus Falls. Manure management fact sheets were assembled from U of M and MDA sources, bound in easy to use three ring binders and passed out at the field days. Manure management information was presented by Sam Evans, U of M soil scientist at Morris at winter meetings at Staples Technical College on December 6, 1994, at Alexandria Technical College onon February 10, 1995 and at the Morris West Central Experiment Station field tours on July 8, 1993 and July 14, 1994. Extension staff including agents and Manure Application Planner specialists are meeting in mid-June to review the demonstration summaries and schedule further farmer meetings. These summaries are a valuable addition to the existing manure management literature, providing a regional and farm-based experience.

The three on-farm demonstrations provided good local examples of refined manure management practices. There was strong interest in these farm communities to use this information to save money on fertilizer where manure is already being spread. The demonstrations showed that manure can be a dependable, environmentally sound sole source of nitrogen when combined with lab analysis and spreader calibration. The use of the basal stalk nitrogen test shows promise but needs to have threshold values developed for total nitrogen. The in-season chlorophyll meter test for crop nitrogen status did not predict nitrogen stress early enough for a late nitrogen sidedress but did detect nitrogen status at tassel.

V. Evaluation: This program will be evaluated by its ability to: 1) predict N availability from manure sources under varying climatic conditions by using the in-season soil and plant N status, 2) identify management practices to reduce sediment and nutrient runoff, 3) identify the risk on farm income of using manure as an N source, and 4) improve manure utilization on farms in West Central Minnesota.

VI. Context within field: Animal production is an important part of the agriculture in West Central Minnesota. Field studies started at Morris in the early 70's showed the benefit of manure on crop production (Evans et al., 1977; Evans, 1979). Manure applications were detectable for at least 15 years following treatment (unpublished data). Present University of Minnesota fertilizer recommendations contain provisions for manure credits, but these changes are based on 1) general manure analysis guidelines or 2) manure analyses from a specific manure source.

Farmers tend to give less credit to manure than suggested because 1) N fertilizer is cheap and 2) a little extra N gives them a cushion in case of N losses or less N available from manure than predicted. At the present time there are no in-season plant or soil tests to evaluate the N status. Activities A.1, A.2, C.1, and C.2 address this problem. The soil NO_3-N test has been useful for over 15 years in predicting N needs in western Minnesota. At the present time a large study is being completed assessing various soil tests in their ability to predict N availability in eastern Minnesota under higher rainfall conditions. Some of these tests involve early season soil tests. Fall NO_3-N tests on the long-term manure plots at Morris did not correlate with yields the following year. In this project, early season soil and plant tests will be used to evaluate the apparent N mineralization rate and N status of the corn crop. Climatic variables will also be measured so that apparent N mineralization can be modeled. This study will be the first in West Central Minnesota where detailed soil and climatic measurements will be made to explain variable apparent N mineralization rates.

The soil NO_3-N test in the top 30 cm of soil 4 to 5 weeks after emergence has been used (Fox et al., 1989) to separate N responsive from nonresponsive sites. Jokela (1992) found that the presidedress NO_3-N test reflected N availability with manure sources showing similar or slightly lower soil profile NO_3-N levels than agronomically equivalent rates of fertilizer N. Basal corn stalk samples collected after black layer and analyzed for NO_3-N have been used to characterize degree of N excess during corn production.

In an effort to reduce wind and water erosion, farmers are turning to tillage practices which involve less soil tillage and which leave more crop residue on the soil surface. Activity C.1 addresses manure management under these reduced tillage conditions. It has been shown that surface runoff carries nutrients off the land which contributes to lake and stream degradation (Römkens et al., 1973). The most critical element is phosphorus, but runoff of nitrogen can also cause problems. This phase of the project will assess tillage systems on their effect on nutrient runoff from manure and fertilizer sources.

VII. Benefits: If this effort is successful, the use efficiency of nutrients contained in manure will increase, producer costs for fertilizer will decrease, and the potential for movement of N and P into surface and sub-surface water will decrease.

VIII. Dissemination: The results obtained from this study will be presented to farmers in activity E.2, will be presented to peers at scientific meetings, and will be published in extension folders and scientific journals.

IX. Time: Due to the nature of the research in this project, additional funding might be needed in the future in assessing climatic variability effects and test validation of the computer models. The opportunity to measure the residual effect of manure is limited because of the 2-year length of this project.

X. Cooperation

A. Dr. Richard Alderfer, Production Economist. West Cent. Expt. Station, UM, will carry out the risk assessment phase (D.1), assist in the survey effort (E.1), and advise 1 graduate student.
B. Dr. Samuel D. Evans, Soil Scientist, West Cent. Expt. Station, UM, will act as project manager and direct the field experiment in activity A.1.
C. Dr. Philip R. Goodrich, Extension Agrcultural Engineer-Animal Waste, Agr. Eng. Dept, UM, will assist in the manure application studies (A.1 & A.2), adapt the model NCSWAP to run under the expert system (Smart Pitchfork) (Activity B.1), and will assist with informational meetings.
D. Dr. Satish Gupta, Soil Physicist, Soil Science Dept., UM, will act as a resource person on the N and P runoff phase of the study, activity C.1..
E. Dr. John Moncrief, Extension Soil Management Specialist, Soil Science Dept., UM, will assist in activities A.1 and C.1. He will act as primary advisor of 1 graduate student
F. Dr. J.A.E. Molina, Soil Microbiology-Soil Fertility, Soil Science Dept., UM, will incorporate the 1970-91 Manure Type Study data into the model NCSWAP, activity B.1. He will require the help of a post-doctorate fellow for a 6-month period.
G. Dr. Clive Reece, Soil Physics-Climatology, Soil Science Dept., UM will assist in characterizing the soil and climatic environment and make estimates of N plant available N, activity B.2. He will act as primary advisor of 1 graduate student.
H. Dr. Mark W. Seeley, Climatology, Soil Science Dept., UM, will assist in monitoring the soil and climatic parameters and developing weekly distributions of soil temperature and moisture conditions from long-term WCES weather data, activity B.2. He will act as primary advisor of 1 graduate student who will spend one-half time on this study.
I. Dr. Alan E. Olness, Soil Scientist, Soil Conservation Research Laboratory, USDA-ARS, will be responsible for monitoring NO3-N concentrations which develop as a function of soil water content and soil texture (Activity A.2). He will also assist in determining analysis procedures for Activity A.1.
J. Bruce Montgomery Special Projects Coordinator, Planning Division, Minnesota Department of Agriculture will collect information on manure and fertilizer use practices in West Central Minnesota (in coordination with Alderfer), activity E.1.
K. Doug Gunnink, On-Farm Demonstration Coordinator, Agronomy Services Division,Minnesota Department of Agriculture, will be in charge of developing on-farm demonstration plots and carrying out informational meetings in West Central Minnesota, activity E.2.
L. Dr. Mary Hanks, Director, Energy and Sustainable Agriculture Program, Agronomy Services Division, Minnesota Department of Agriculture, will review and supervise the demonstration activity E.2. She

will also participate in planning sessions with cooperators, prepare reports, and manage the budget for this project.

XI. Reporting Requirements

Semiannual status reports will be submitted not later than January 1, 1994, July 1, 1994, January 1, 1995 and a final status report by June 30, 1995.

XII. Literature Cited

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<u>**1993 Research Project Abstract**</u>
For the period ending June 30, 1995
This project was supported by the MN Future Resources Fund

Title:	Nutrient Recycling Through Plants and Animals
Program Manager:	Samuel D. Evans
Organization:	University of Minnesota
Legal Citation:	M.L. 93, Chpt. 172, Sect. 14, Subd. 3(k)
Approp. Amount:	$260,000

STATEMENT OF OBJECTIVES

A. Assess existing soil and plant tests under West Central Minnesota conditions as "Plant N availability predictors" from two manure sources.
B. Integrate weather, soil, and climatic factors to estimate N availability and develop a predictive computer model for West Central Minnesota.
C. Assess tillage and manure application technique effects on N and P losses from manure during the snowmelt and growing season periods in West Central Minnesota.
D. Identify economic risk of using "plant available N" estimation.
E. Conduct a farm nutrient and cost inventory and disseminate information to producers.

RESULTS

Soil nitrate-N tests to a 2-foot depth on manured and fertilized plots either at corn emergence or at the 5-leaf stage were fairly well correlated with corn grain yield. Chlorophyll meter readings, basal stalk nitrate-N at maturity, and fall soil nitrate-N concentrations were of little value in determining the crop N status soon enough to take corrective action. There appeared to be some effect of soil texture on N mineralization, but the data were quite variable.

In the modeling effort an existing computer model, NCSWAP, was used to simulate soil nitrate-N status and corn yield and compared to a long-term study at Morris. The model worked quite well for the check treatment and the solid beef manure treatment. This model could be used to simulate various manure management scenarios. In the other modeling phase of the study, a crop simulation model, CROPSYST, used actual Morris, MN soil temperatures, soil moisture, plant available N, and corn yield. This model did not work well due to the high year-to-year variability in 1993-1994. An N-stress function predicted by the model could be used to predict the effect of mid-season N applications.

In the tillage and manure application phase of the study on a 12% slope, the relatively shallow soil disturbance created by ridge tillage proved more effective than deep moldboard plowing at containing erosive losses of sediment and phosphorus. In fact, the manure reduced runoff, sediment, and total phosphorus during the growing season. Ridge tillage however released more phosphorus during the spring thaw than moldboard plowing. On the moldboard plowing the surface roughness reduced runoff and on the ridge tillage phosphorus losses were much higher due to the exposed residue.

In the risk assessment phase of the study, analysis of model farms showed that use of manure testing could improve the use of the nutrients contained in the manure. Economic analysis compared the benefits of using manure testing compared to errors in nutrient application (overapplication or underapplication) when testing was not used.

A survey of 23 farms in west central Minnesota was completed. In general, the farmers surveyed were using very good fertilizer management practices, but manure was not given adequate credit. The greatest deviation between N applied and N needs for corn was corn following manured legumes (130 lb/ac excess N). However, when acreage is combined with the excess N for various management scenarios, three scenarios make up 86% of the excess N; corn following soybeans, corn following manured legumes, and corn following corn or small grains. So educational efforts need to be directed at application of N at proper rates and proper crediting of manure and legumes.

In the on-farm demonstration effort, experimental sites were established on three cooperating farms. Data from these sites were valuable in demonstrating the value of proper management of manure and will be used at other manure management meetings.

PROJECT RESULTS USE AND DISSEMINATION

The field experiments were used two years during Field Days at the West Central Experiment Station to demonstrate proper manure handing techniques. Two of the on-farm demonstrations were sites for farmer meetings covering improved manure management techniques. Parts of the runoff phase of the study have been presented as two papers at the American Society of Agronomy. Information from the studies was presented to farmer workshops at Staples and Alexandria. Information from these studies will be given to the Minnesota Extension Service Specialists for use in their winter meetings.

The computer modeling phase of the study expanded the use of two existing computer models in managing nitrogen in manure more efficiently.

A draft extension bulletin has been prepared addressing the value of manure testing. Two journal articles will be prepared from the runoff phase of the study and one journal article will be prepared summarizing the "plant N availability predictor" phase of the study after one more year of data is collected by the fall of 1995.

Nutrient Recycling Through Plants and Animals

M.L. 1993, Chpt. 172, Sect. 14, Subd. 3(k)

Final Detailed Report Submitted to the Legislative Commission on Minnesota Resources

July 1, 1995

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LCMR Final Report - Detailed for Peer Review - Research

I. Project Title: Nutrient Recycling Through Plants and Animals

Program Manager:	Samuel D. Evans
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A. Legal Citation: M.L. 1993 Chpt. 172, Sect.14, Subd. 3(k)

Total Biennial LCMR Budget:	$260,000
Balance:	$2,315.94 remaining on 6/26/95

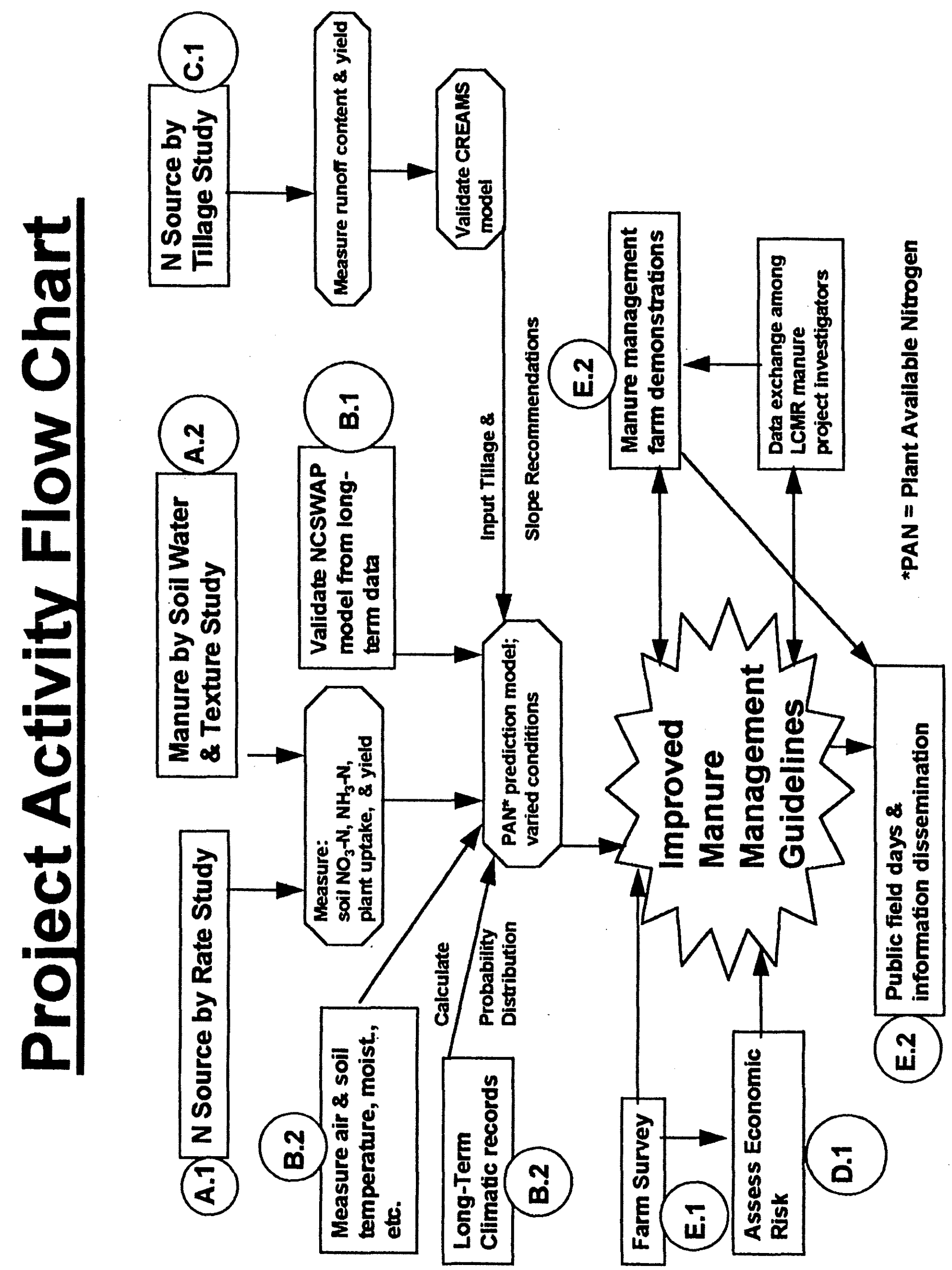
Appropriation Language as drafted 7/27/92: This appropriation is from the future resources fund to the commissioner of agriculture for a contract with the University of Minnesota to improve techniques to predict nitrogen mineralization from manure and soil organic matter in west central Minnesota.

B. LMIC Compatible Data Language: Not applicable.

C. Status of Match Requirement: Not applicable

II. Project Summary:

The ultimate goal of this project is to develop improved methods to use animal manure in West Central Minnesota so that manure use efficiency is increased and the probability of N and P losses to the environment is decreased. This will be done by improving techniques to predict plant available nitrogen from applied manure, assessing the N carryover from previously applied manure, and measuring tillage effects on N and P losses from manured sloping land during the growing season and snowmelt periods. Soil and climatic parameters will be measured to characterize their effect on soil N changes. Plant available nitrogen will be calculated and ultimately integrated into existing computer models. An estimate of changes in income due to manure management changes will help in developing a risk assessment model. A farmer inventory will be conducted to assess manure sources, handling methods, and fertilization practices. An on-farm demonstration effort will be developed to show good manure mangement techniques and will include results from this project as they become available. Finally, information from all phases of this project will be disseminated at field days, workshops, and through publications.



III. Statement of Objectives:

A. Assess existing soil and plant tests under West Central Minnesota conditions as "Plant N availability predictors" from two manure sources.

B. Integrate weather, soil, and climatic factors to estimate N availability and develop a predictive computer model for West Central Minnesota.

C. Assess tillage and manure application technique effects on N and P losses from manure during the snowmelt and growing season periods in West Central Minnesota.

D. Identify economic risk of using "plant available N" estimation.

E. Conduct a farm nutrient and cost inventory and disseminate information to producers.

IV. Research Objectives (continued)

A. Title of Objective: Assess existing soil and plant tests under West Central Minnesota conditions as "Plant N availability predictors" from two manure sources.

A.1. Activity: Measure the direct and residual availability of N from applied liquid dairy and swine manure to corn in West Central Minnesota and compare that with N applied as inorganic fertilizer. S. D. Evans will spend 15% of his time over the next two years supervising this activity. A.E. Olness and P.R. Goodrich will spend 1% of their time over the next two years on this activity.

A.1.a: Context within the project: Measured amounts of liquid dairy and swine manure and inorganic N fertilizer will be applied to an Aastad silty clay loam soil at Morris. The N changes in the soil and N uptake by the crop will be measured over a 2-year period. The soil will be sampled over time to determine inorganic N levels. The hypothesis is that N available to the crop over the growing season can be determined by early season plant and/or soil tests. Determination of N early in the season will allow the farmer to apply manure at rates more closely matching crop need, but still have the opportunity to apply additional N fertilizer if N release is slower than expected. Detailed climatic and soil measurements will be made on selected plots in activity B.2 so that N release to the crop can be related to the probability of occurrence of critical soil temperature and soil moisture conditions.

A.1.b. Methods: Field plots will be established in the fall of 1992. Varying rates of liquid dairy and swine manure will be applied along with control treatments of inorganic N fertilizer. The experimental design will be four replications of a randomized complete block. A second identical study (time split) will be started one year later. The inorganic N fertilizer treatments will consist of four rates of broadcast fall-applied urea (45, 90, 135, and 180 kg N/ha) plus a control treatment (no manure or N fertilizer). The manure will be injected at four rates. The base rate of each manure will calculated from previous analyses of the manure sources to provide N adequate for a corn yield of 9.4 Mg/ha based on the assumption that all the inorganic N and 30% of the organic N in the manure will be available in the first year after application. The other three rates would consist of 0.5, 1.5, and 2.0 times the base rate of each manure. The experiment will consist of four replications. Plot size will be six rows (4.6 m) wide by 12.2 m long. The manure and fertilizer treatments will be field cultivated within 12 hours of application. The manure will be analyzed for dry matter, total N, NH_4-N, total P, and total K. The NO_3-N and NH_4-N content of the soil in each main treatment block will be measured to a depth of 150 cm (6 subsamples/block) prior to treatment application. Before treatment application, soil borings will be taken on a 9.2-m x 12.2-m grid across each replication to determine the depth of the surface soil, depth to carbonates, and depth to mottling if present. Samples of the surface soil will be saved for pH and organic matter determination. Corn will be planted at an optimal date in the spring of 1993 with recommended population, herbicides, and insecticides. Soil samples will be collected to a depth of 60 cm in 30-cm increments on all treatments (3 subsamples/plot) at VE-V1 (emergence) and V4-V5 (defined for the pre-sidedress NO_3-N soil test) stages and analyzed for NO_3-N and NH_4-N. At the V4-V5 stage, chlorophyll meter readings will also be taken on eaeh treatment in order to assess the N status of the crop. Following physiological maturity, stover and grain samples will be collected on one 11.6-m row for yield and total N uptake. When the corn is ready for combine harvest, two 11.6-m rows will be harvested for grain yield. Following this, 10 basal stalk samples (from 15-36 cm above the soil surface) will be collected from each plot for NO_3-N analysis. Following removal of the remainder of the grain from the plots, the soils will again be sampled to a depth of 150 cm in 30-cm increments for NO_3-N and NH_4-N analysis (3 subsamples/plot). Manure and N fertilizer will avoided in this portion of the study so that residual effects can be measured in 1994 and 1995. The entire study will be chisel plowed in preparation for the 1994 season. In 1994 and 1995 the same measurements will be made as in 1993.

An additional set of plots will be initiated in the fall of 1993. All operations carried out on the plots started in 1992 will be carried out on these plots. Residual manure effects on these plots will be measured only in 1995.

All soil and plant samples will be analyzed by standard laboratory techniques.

The data will be entered into a PC using the DBASE III Plus program. The data will be analyzed by a multi-variate regression analysis using SAS PROC-REG. The dependent variable will be "plant available N" and the independent variables include urea rate, manure source, initial NO_3-N and NH_4-N levels, mollic epipedon thickness, soil organic matter level, soil temperature, and soil moisture. The specific regression model will be determined after the data distribution is evaluated. A best fit model will be selected upon the ability of the individually tested independent variables to concurrently improve the overall correlation coefficient and F ratios. The plant available N will then be correlated with final grain yield.

Apparent N mineralization rates will be calculated from plant and soil data and will be compared to published guidelines for each type of manure. The apparent N mineralization rates will then be incorporated into N recommendation adjustments for manure application in West Central Minnesota.

A.1.c. Materials: Field materials necessary to accomplish this objective include soil sampling equipment, tractors, spreaders, tillage equipment, planters, cultivators, drying equipment, soil & plant grinders, and plot combine. Laboratory equipment needed includes glassware, laboratory supplies, and analytical instruments.

A.1.d. Budget: $332.09 remaining on 6/26/95.

A.1.e. Timeline:

In order to properly carry out this activity, plots must be established in the fall of 1992, manure applied, and plots planted and sampled during the 1993 growing season before July,1993.

	7/93	1/94	6/94	1/95	6/95
Take base soil samples	*				
Apply manure	*				
Till and plant plots		*		*	
Take treatment soil samples	*	**	*	**	
Take plant samples	*		*		
Take chlorophyll readings		*		*	
Harvest stover & grain	*		*		

A.1.e. Timeline: (continued)

Take basal stalk samples	* *
Analyze soil & plant samples	**************************
Enter data into computer files	*************************
Analyze data statistically	**** ****
Calculate apparent mineralization rates	* *
Compare with published data	* *
Prepare annual summary	** **
Develop new manure adjustment guidelines	*
Prepare final report	**

A.1 Status:

INTRODUCTION

Animal production is an important part of the agriculture in West Central Minnesota. Field studies started at Morris in the early 70's showed the benefit of manure on crop production (Evans et al., 1977; Evans, 1979). Manure applications were detectable for at least 15 years following treatment (Evans et al., 1988). Present University of Minnesota fertilizer recommendations contain provisions for manure credits (Rehm and Schmitt, 1992), but these changes are based on 1) general manure analysis guidelines or 2) manure analyses from a specific manure source.

Farmers tend to give less credit to manure than suggested because 1) N fertilizer is cheap and 2) a little extra N gives them a cushion in case of N losses or less N available from manure than predicted. At the present time there are no in-season plant or soil tests to evaluate the N status with manure N sources. The soil NO_3-N test has been useful for over 15 years in predicting N needs in western Minnesota. A spring preplant soil nitrate-N test has been established (Schmitt and Rehm, 1992a, 1992b) to predict N availability in eastern Minnesota under higher rainfall conditions. This test can also be used in western Minnesota. Fall NO_3-N tests on the long-term manure plots at Morris did not correlate with yields the following year (Evans et al., 1988). In this project, early season soil and plant tests will be used to evaluate the apparent N mineralization rate and N status of the corn crop.

The soil NO_3-N test in the top 12 in of soil 4 to 5 weeks after emergence has been used (Fox et al., 1989) to separate N responsive from nonresponsive sites. Jokela (1992) found that the presidedress NO_3-N test reflected N availability with manure sources showing similar or slightly lower soil profile NO_3-N levels than agronomically equivalent rates of fertilizer N. Chlorophyll meter readings have been used (Blackmer and Schepers, 1995) to monitor corn nitrogen status under irrigation. Basal corn stalk samples collected after black layer and analyzed for NO_3-N have been used (Binford et al., 1990) to characterize degree of N excess for corn production.

Experimental Procedures

The experimental site was established in the fall of 1992 on a predominately Aastad clay loam soil (Pachic Udic Haploboroll, fine loamy, mixed) located on the West Central Experiment Station, Morris, MN. The 1992 crop was corn and was harvested as corn silage on October 2, 1992. Two trial sites were established; one to commence with manure and fertilizer applications in the fall of 1992 (Site 1) and the other to commence with manure and fertilizer applications in the fall of 1993 (Site 2).

Treatment areas were staked out on both sites on October 5, 1992. The design for each site was a randomized complete block with 4 replications. One replicate from Site 1 was discarded because it tended to be wetter than all other replicates. Plot size was 15 ft wide (6 rows) by 47.5 ft long. Thirteen treatments included a check, 4 rates of urea, 4 rates of liquid swine manure, and 4 rates of liquid dairy manure (Table A.1.2). Site 1 was grid sampled on October 6, 1992 on the corners of every second plot to determine the depth of topsoil, soil pH, soil organic matter content, and depth to carbonates. The same measurements were made on Site 2 on September 1, 1994. Samples were air dried and saved for analysis. Fertilizer was applied broadcast to Sites 1 and 2 on October 14, 1992 to provide 75 lb/ac P_2O_5 and 75 lb/ac K_2O to mask P and K effects.

Manure treatments were applied to Site 1 on October 20, 1992 and to Site 2 on October 22, 1993. Target application rates were 80, 160, 240, and 320 lb N/ac. The rates were based on pre-application samples taken from manure storage structures. All manure treatments were applied with an experimental Agricultural Engineering Department manure applicator. Samples of each manure were taken directly from the applicator in the field for subsequent analysis. The N contents of the manures are given in Table A.1.1. The applicator was weighed using portable load cells before and after each treatment to calculate the applied manure rates (Table A.1.2). The manure was metered through 4 hydraulically driven pumps, one for each injector, to provide a uniform application. The applicator was outfitted with 4 18-inch sweeps, 24 inches on center, for a total applicator width of 7.5 feet. Manure was applied at a 4-5 inch depth for all manures and rates except for the 320-lb dairy rate in 1992 which was applied at 5-6 inches on the first pass and 3-4 inches on the second pass. Inorganic fertilizer as urea was applied to provide 40, 80, 120, and 160 lb N/ac. Urea was applied to Site 1 on October 21, 1992 and to Site 2 on October 18, 1993 and then field cultivated to incorporate the urea and remove wheel tracks from the manure applicator. Urea was also applied to urea treatments in Site 1 in the fall of 1993.

<u>1st Year Direct Availability - Site 1 (1993)</u>

In the spring of 1993 the study was field cultivated (April 28) parallel to the manure applicator bands and future row direction. The study was planted on April 28 to Ciba-Geigy 4172 at 30,000 seeds/ac. Counter 15G was applied at 10 lb/ac at seeding with the planter. Lasso @ 3 lb/ac active ingredient (a.i.) + Bladex @ 2.2 lb/ac a.i. was broadcast preemergence on April 29. The study was sprayed with a postemergence application of Atrazine @ 2 lb/ac a.i. + 1 qt/ac Crop Oil Concentrate on June 18 for additional grass control. The study was cultivated on June 28.. Urea was applied on October 18 for the 1994 growing season to the same plots and rates as in the fall of 1992. The study was chisel plowed on October 18.

All plots were soil sampled in 0-1 and 1-2 ft increments for soil N content on May 17 at the emergence stage (EMNT) of corn. Each soil sample was a composite of 6 subsample probes (two in one of the two center corn rows, two 7.5 inches from that same row, and two 15 inches from the same row). At the V5 stage (PSNT) of corn growth all plots were soil sampled on June 25 using the same procedures as at the emergence stage. Post harvest soil samples were taken on October 15 to a depth of 5 ft in 1-ft increments. The plots were sampled using the same procedures as at the emergence stage. All soil samples at emergence, V5 and post harvest were dried at 95°F, ground, and analyzed for NH_4-N and NO_3-N.

Chlorophyll meter readings (SPAD 502 chlorophyll meter) were taken at V5 stage on June 25 and again on July 26, just prior to tasseling. Meter readings were taken on 10 plants in each plot halfway between the midrib and the leaf edge, halfway between the stalk and the end of the leaf, on the most recently fully extended leaf.

Corn was hand harvested for silage yields from one 45-ft of row on September 16. Ears and stover were weighed separately and 5 stalks and the center 3/4 inch of 10 ears were saved for moisture and N analysis. Silage samples were dried at 150°F for 48 hours and saved for N analysis. Basal stalk samples from 10 plants (an 8-inch section from 6 to 14 inches from the soil surface) were collected on October 1, dried, and saved for NO_3-N analysis. Grain yields were taken from two 45-ft rows on October 11 with a plot combine and a grain sample was saved for test weight and N analysis.

2nd Year Residual Availability - Site 1 (1994)

For the second year of the study on Site 1 the site was field cultivated for seedbed preparation on May 9, 1994. Ciba-Geigy 4172 corn was seeded at 30,000 seeds/ac on May 9. Force 1.5G was applied at seeding at 10 lb/A. A tank mix of Lasso @ 3 lb/ac a. i. + Bladex @ 2.2 lb/ac a. i. was applied broadcast preemergence on May 16. On June 1 Accent @ 2/3 ounce/A was applied broadcast for grass control. On June 8 the plots were cultivated.

The plots were soil sampled at the emergence stage of corn on May 25, V5 stage on June 14, and post harvest stage on October 11 for soil N content. The sampling procedure, sample handling, and analysis procedures were the same as in 1993.

Chlorophyll meter readings were taken on June 16 at V5 stage and on July 11 just prior to tasseling using the same procedures as in 1993.

Co[illegible] [illegible]ge yields, basal stalk samples, and grain yields were taken on September 15, 22, and 22 respectively. S[illegible] [illegible]ction procedures and handling were the same as in 1993.

[illegible]lability - Site 2 (1994)

[illegible] the field procedures, planting dates, hybrids, herbicides, plant and soil [illegible]as in Site 1 (1994) with the following exceptions: emergence soil [illegible]rvested on September 15, and fall soil samples were taken on

Results and Discussion

Manure Application

The total, organic, ammonium, and available N contents of the swine and dairy manures in 1992 and 1993 are shown in Table A.1.1. The swine manure had a much higher N content in 1993 than in 1992. Dairy manure N values were slightly lower in 1993 as compared to 1992. These values along with the weight of manure applied were used to calculate available N rates from the two applications (Table A.1.2). Because of differences between estimated manure analysis and the actual values obtained from samples during application, only the dairy manure in 1992 was fairly close to target levels. However, in all cases a good range in application rates was achieved.

Grain Yield Response to Applied Manure

Grain yields in 1993 were much lower than in 1994 (Tables A.1.3, A.1.4, and A.1.5). There was a good response to applied inorganic fertilizer on all sites. In 1993 the top yield with urea was 94.7 bu/ac, while in 1994 the top urea yield was 171.4 bu/ac. In 1993 corn yields increased with each added increment of added manure. Grain yields in 1994 on site 2 increased with each added increment of dairy manure, but did not increase above the third increment of swine manure on treatment S3. The residual effect of the 1992 applied manure on 1994 yields is shown in Table A.1.4. The lowest rates of manure, S1 and D1, were not significantly different in yield from the CK treatment. All other manure treatments showed a carryover effect in increasing corn yields. The effect was greater with the dairy manure primarily due to the much higher N levels applied. The yield with treatment S4 was lower than the 40-lb urea treatment. The yield with treatment D4 was slightly higher than the 120-lb urea treatment. Therefore, when manure was applied to supply more than crop N requirements, substantial yield increases were evident the following year. In both 1993 and 1994 on plots receiving applications the previous fall, grain moisture was decreased slightly as N rates increased both with urea and manure. On the residual manure plots in 1994 there were no significant differences in grain moisture. Grain weight was significantly affected by treatment in 1993 (Table A.1.3), but there was no clear trend due to N source or rate. In 1994 there was no treatment effect on grain weight.

Silage Yield Response to Applied Manure

There were highly significant effects of treatment on silage DM yield on all sites (Tables A.1.3, A.1.4, and A.1.5). In 1993 yields increased with each added increment of urea and swine manure. The yields on the dairy manure treatments did not increase above level D2. In 1994 on the direct effect study (Site 2) silage yields increased with all added levels of N except D4. On the residual effect plots in 1994 (Site 1) yields again increased with all levels of added N. Yields on S4 were about midway between the 40-lb and 80-lb urea treatments, while yields on D4 were about equal to the 120-lb urea treatment. This is further evidence of the carryover effect of manure when applied at high rates.

Evaluation of EMNT and PSNT for N Sufficiency Prediction

There were significant effects of urea and manure treatments on EMNT NO_3-N concentration at both soil depth combinations the first year and the second year following manure application (Tables A.1.8. A.1.9, and

A.1.10). At emergence the NO_3-N concentrations with both swine and dairy manure for the 0-1 and 0-2 ft depths generally increased as N rates increased. In 1993 the highest concentration was with the 370-lb dairy treatment while in 1994 the highest concentration was with the 466-lb swine treatment. Values were quite variable as indicated by the high C.V.'s.

A tanh function was used by Olness et al, 1995, to describe the relationship between grain yield and fertilizer N rate. In this study the same function was used to describe the relationship between soil NO_3-N at two growth stages and grain yield. The function used was as follows:

$$Y = Y_o*(1 + (e^{k*(F-Q)} - e^{-k*(F-Q)}) * (e^{k*(F-Q)} + e^{-k*(F-Q)})^{-1}),$$

where Y = grain yield, bu ac^{-1}; F = N rate, lb ac^{-1}; Q = N rate at which marginal N response begins to diminish, lb ac^{-1}; k = a coefficient of N use (ac lb^{-1}); and Y_o = a yield coefficient, bu ac^{-1};(about equal to yield without added N).

The correlation between EMNT and grain yield in 1993 was 0.62 (Fig A.1.1). In 1994 the correlation was 0.73 on the direct site(Fig. A.1.3) and 0.50 on the residual site (Fig. A.1.2). There were significant treatment effect on PSNT NO_3-N concentrations (stage V5) at all depth combinations (Tables A.1.8, A.1.9, and A.1.10). At stage V5 in 1993 the NO_3-N concentrations were much lower than at emergence (Tables A.1.8 and A.1.9), but there were still significant treatment effects. In 1993 precipitation between the May 17 sampling date and June 25 was 9.03 in (long-term average = 4.72 in). This probably resulted in a large amount of leaching of NO_3-N below the 2-ft depth and large reductions in NO_3-N concentration in most of the treatments. In 1994 precipitation between emergence and V5 was close to the long-term average, so reductions in NO_3-N were much smaller. The correlation between PSNT and grain yield in 1993 was 0.59 (Fig A.1.1). In 1994 the correlation was 0.82 on the direct site (fig A.1.3) and 0.61 on the residual site (Fig A.1.2).

Following harvest in 1993 the only treatments with NO_3-N concentrations above 5 ppm in the 0-1 and 0-2 ft zones were the high N manure treatments (Table A.1.8). In 1994 only treatments S3 and S4 had concentrations above 5 ppm for these two soil zones (Table A.1.9). The average NO_3-N concentration for the 0-5 ft zone was higher in the fall of 1993 than in 1994, indicating considerable leaching of N below the 2-ft depth.

The residual effects of the 1992 manure applications on 1994 soil NO_3-N are shown in Table A.1.10. There were significant effects of treatment on soil NO_3-N for emergence and V5 sampling stages and all depth combinations. The post harvest sampling date treatment NO_3-N concentrations were significant only at the 0-5 ft depth, indicating that 2 years after manure application the mineralized N had either been used up or leached out of the 0-1 and 0-2 ft increments.

There were no significant effects of treatment on soil NH_4-N concentrations either in the year following application or the following year at emergence, V5, or post harvest stages in either 1993 or 1994 (data not shown).

Evaluation of Chlorophyll Leaf Meter

Chlorophyll meter readings were significantly affected by treatment on all dates except for the early date at Site 1 in 1994 (Tables A.1.3, A.1.4, and A.1.5). In all cases the range in values was greater at the later date as compared to the earlier date. In some cases the readings on the highest manure treatments exceeded that on treatment F4.

The linear correlation between chlorophyll meter reading and grain yield in 1993 was 0.35 and 0.72 for the June 25 and June 26 dates respectively. The following year the same correlation was 0.44 and 0.71 for the June 16 and July 11 dates respectively for the direct site. For the residual site in the 1994 the values were 0.29 and 0.66 for the June 16 and July 11 dates respectively. From this data it appears that using chlorophyll meter readings at stage V5 to assess the need for additional N fertilizer would not be very useful because of the relatively narrow range of readings. At the pre-tassel stage the correlation between readings and grain yield were much higher, so this tool might be useful at this later plant stage. However, at the pre-tassel stage methods to apply additional N under non-irrigated conditions are limited.

Evaluation of Late-Season Stalk NO_3-N Test

We found a wide range in basal stalk NO_3-N values in both 1993 and 1994 (Table A.1.6) the fall following manure application. The highest values found each year were associated with the highest manure N applied. In 1993 treatment D4 had a value of 666 ppm and in 1994 treatment S4 had a value of 977 ppm. This was the only average treatment value above the critical level of 700 ppm suggested by Blackmer et al. (1992). The C.V.'s were quite high on all sites. It appears that on soils of this texture and drainage characteristics, micro-relief differences can have quite large effects on this value. However, the yield 132.1 bu/ac on the residual D4 treatment in 1994 (Table A.1.4) followed a 1993 fall basal stalk NO_3-N value of 666 ppm (Table A.1.6), not significantly different from the yield of 139.5 bu/ac on the highest urea treatment, F4. The F4 treatment had a stalk NO_3-N concentration of only 7.1 ppm.

Stove and Grain N Concentration and Uptake

Stover N concentration was significantly affected by treatment only in 1994 on site 2 (Table A.1.6). Grain N concentration was significantly increased by both urea and manure on the direct application sites in 1993 and 1994 (Table A.1.6). Grain N uptake and total N uptake were significantly affected by treatment in both years (Table A.1.7). The curvilinear relationships, $U = a + bx^{-1}$, between soil NO_3-N at emergence or V5 and N uptake are given in Table A.1.11. The r^2 values in 1993 showed very little difference between the two growth stages. The r^2 values were slightly higher for grain N uptake as compared to total N uptake. In 1994 the correlations were slightly higher for V5 as compared to emergence stage. In 1994 there was no consistent pattern of higher correlation with grain or total N uptake.

Effect of Soil Properties on EMNT and PSNT

The variation in pH, organic carbon, and depth to mollic epipedon are shown in figures A.1.4 and A.1.5. Values were calculated for each plot and a SAS backward regression procedure used to identify significant factors affecting soil NO_3-N concentrations at emergence and V5. On all sites the most important factors affecting the NO_3-N in each plot were the N source and rate. Soil pH, organic matter content, and mollic epipedon depth were minor factors in influencing soil NO_3-N levels.

Apparent Mineralization Rates

Soil NO_3-N concentrations in the 0-2 ft soil zone (Tables A.1.8, A.1.9, and A.1.10) showed no increases between emergence and V5 stages in 1993 and 1994. The changes in soil NO_3-N concentrations between fall 1993 for the 0-2 ft zone in Site 1 (Table A.1.8) were not greatly different from the spring 1994 concentrations (Table A.1.10) on the same plots. Therefore, with the limited number of sampling dates during the growing season and the unusually wet season in 1993, it was not possible to calculate the apparent mineralization rates. This was the only year when we could observe the residual effect of the manure applications in the 2-year span o the study.

Comparison with Published Data

The present University of Minnesota guidelines for swine manure (Schmitt and Rehm, 1992a) and dairy manure (Schmitt and Rehm, 1992b) were used to calculate available N in the manure based on volume applied (Table A.1.12). For swine manure the present guidelines arer slightly higher in 1993 and considerably lower in 1994 than the estimates used in this study. For dairy manure the present guidelines are considerably lower than those used earlier in this study. It appears that variations in the N content of the manures from average values greatly changed the available N values. The residual N predicted by the present guidelines is greater in all cases than the estimates used in this study. This inconsistency points to the need to develop an in-season test which can account for variation in manure volume used, manure N content, N losses, and seasonal effects on manure mineralization.

Summary

The effects of liquid swine and liquid dairy manure applied at four rates on soil NO_3-N content and various crop parameters were evaluated for one and two years following fall manure injection and compared to four rates of urea and a check. The first year following application, all but the lowest manure rates increased soil NO_3-N levels at emergence, V5, and post-harvest over the check treatment. Soil NO_3-N levels from the 2nd year following manure application were significantly higher than the check treatment at emergence and V5 only with the highest manure rate from both sources. Post-harvest soil NO_3-N levels of the two highest rates of both manures were higher than the check in the 0-5 ft depth zone. Differences in chlorophyll meter readings on the residual manure study were significant only on July 11, the pre-tassel stage. On the study the first year after manure application, chlorophyll meter readings were affected by treatment at both V5 and pre-tassel stages. On both studies the range in readings was wider at pre-tassel than at V5. Total N uptake, grain N removal, silage yield, and grain yield were all significantly affected by treatment on both studies. The effects were much larger on the 1st year following manure application as compared to the 2nd year. There was a positive relationship between soil NO_3-N to a 2-ft depth at corn stage V5 and corn grain yield. The amount of NO_3-N (0 to 2 ft) at stage V5 needed to maximize yield was 10-15 ppm in both years following fall manure application. In the one residual manure year measured (1994) yields were not maximized with the NO_3-N levels measured. However, it appeared that yields were approaching a maximum when soil NO_3-N levels exceeded 10 ppm. We were not able to accurately calculate apparent N mineralization rates because of the extremely cold and wet season in 1993 and the short time span of the study. Comparison of present University of Minnesota manure N content guidelines with estimates used in this study shows the importance of developing an in-season N monitoring technique such as the V5 soil NO_3-N test.

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Table A.1.1. Nitrogen content of manure used.

	Site 1, Applied fall 1992					Site 2, Applied fall 1993			
Manure Source	Total N	Org. N	NH_4-N	Avail. N(93)[b]	Avail. N(94)[c]	Total N	Org. N	NH_4 N	Avail. N(94)[b]
	lb/1000 gallons								
Swine	31.6	18.2	13.4	18.9	1.91	54.0	9.6	44.4	47.3
Dairy	35.6	17.4	18.3	23.5	1.83	31.4	13.2	18.2	22.2

[a] Sampled from the manure applicator just prior to application.
[b] Available N 1st year = NH_4-N + 30% of organic N.
[c] Available N 2nd year = 15% of remaining organic N.

Table A.1.2. Treatments, target N rates, manure applied, and available N estimates, 1992 & 1993.

			Site 1, Applied fall 1992			Site 2, Applied fall 1993	
Trt.	N Source	Target N Rates	Manure Applied	93 Avail. N Rates[a]	94 Avail. N Rates[b]	Manure Applied	94 Avail. N Rates[a]
		-ib/ac-	-gal/ac-	-lb/ac-	-lb/ac-	-gal/ac-	-lb/ac-
CK	None	0	0	0	0	0	0
F1	Urea	40	0	40	40	0	40
F2	Urea	80	0	80	80	0	80
F3	Urea	120	0	120	120	0	120
F4	Urea	160	0	160	160	0	160
S1	Swine manure	80	2440	46	5	1742	82
S2	Swine manure	160	4880	92	9	5074	240
S3	Swine manure	240	7180	136	14	7398	350
S4	Swine manure	320	9740	184	19	9858	466
D1	Dairy manure	80	3880	91	7	2293	51
D2	Dairy manure	160	7860	185	14	4906	109
D3	Dairy manure	240	11320	266	21	6832	151
D4	Dairy manure	320	15730	370	29	8681	192

[a] Based on actual weight of manure applied and available N values from Table 1.
[b] Based on actual weight of manure applied and residual N values from Table 1.

Table A.1.3. Influence of nitrogen source and rate on chlorophyll readings, grain yield, grain moisture, grain weight, and silage yield, Site 1, 1993.

Trt.	Chlorophyll June 25	Chlorophyll July 26	Grain Yield	Grain Moisture	Grain weight	Silage DM Yield
	-SPAD reading -		-bu/ac-	--%--	-lb/bu-	-lb/ac-
CK	40.0	32.7	51.7	25.7	50.7	8142
F1	39.3	36.6	66.0	24.3	51.1	9165
F2	40.2	40.9	71.8	24.4	49.3	10688
F3	42.3	42.1	94.7	21.0	51.8	10994
F4	40.5	45.6	91.5	21.1	52.0	11829
S1	39.5	37.9	59.1	25.6	49.7	9651
S2	40.3	40.5	74.0	23.2	50.5	11917
S3	40.7	45.9	99.3	21.2	52.2	13087
S4	41.6	46.6	102.8	21.5	51.2	13690
D1	38.4	35.6	63.8	25.7	49.5	9637
D2	39.4	43.8	97.6	23.5	50.8	12919
D3	40.5	44.2	95.9	22.6	52.2	12630
D4	41.6	45.7	106.4	21.3	51.3	12653
Pr > F	.0358	.0040	.0001	.0002	.0570	.0001
BLSD(.05)	2.5	7.6	22.2	2.4	2.5	1896
C.V. (%)	3.0	10.0	16.0	6.0	2.3	10.2

Table A.1.4. Influence of nitrogen source and rate on chlorophyll readings, grain yield, grain moisture, grain weight, and silage yield, Site 1, 1994.

Trt.	Chlorophyll June 16	Chlorophyll July 11	Grain Yield	Grain Moisture	Grain weight	Silage DM Yield
	- SPAD reading -		-bu/ac-	--%--	-lb/bu-	-lb/ac-
CK	38.6	34.3	75.8	27.7	53.1	8048
F1	42.7	40.0	101.2	25.4	52.9	9602
F2	41.7	44.7	122.2	24.0	53.7	11741
F3	44.2	44.6	127.4	25.3	53.7	12980
F4	43.2	46.8	139.5	25.2	53.8	13386
S1	37.9	36.7	70.7	26.1	53.8	8565
S2	38.4	35.7	92.6	25.9	53.6	9595
S3	40.2	39.5	94.1	24.8	53.9	10085
S4	39.9	39.5	98.1	24.4	53.8	10389
D1	37.9	37.2	75.3	25.2	53.1	8827
D2	40.1	43.1	108.4	23.7	54.3	11055
D3	40.8	43.7	104.8	24.5	53.9	11577
D4	41.7	43.8	132.1	26.1	53.3	12598
Pr > F	.1253	.0020	.0100	.6720	.4609	.0006
BLSD(.05)	NS	6.2	42.4	NS	NS	2394
C.V. (%)	6.7	6.7	21.4	8.3	1.3	12.9

Table A.1.5. Influence of nitrogen source and rate on chlorophyll readings, grain yield, grain moisture, grain weight, and silage yield, Site 2, 1994.

	Chlorophyll		Grain			Silage
Trt.	June 16	July 11	Yield	Moisture	weight	DM Yield
	- SPAD reading -		-bu/ac-	--%--	- lb/bu -	-lb/ac-
CK	38.8	38.9	108.5	27.7	53.2	10966
F1	39 0	40.9	117.4	25.6	52.6	11531
F2	43.0	47.3	142.4	24.7	53.2	14017
F3	43.2	46.6	160.0	22.8	53.6	15694
F4	43.9	51.2	171.4	24.9	52.9	16514
S1	42.4	45.2	128.3	24.6	53.5	13677
S2	42.6	48.2	180.6	24.8	53.0	17286
S3	44.6	50.3	188.4	25.8	52.1	17837
S4	43.6	50.5	187.2	26.6	52.8	19237
D1	38.6	40.3	116.3	26.9	52.5	11956
D2	42.4	46.3	147.2	26.3	53.4	15041
D3	41.3	47.2	166.6	25.9	52.9	16472
D4	43.6	49.8	174.2	23.6	53.5	16295
Pr > F	.0015	.0001	.0001	.0413	.1322	.0001
BLSD(.05)	3.3	2.4	14.9	3.3	NS	1780
C.V. (%)	5.1	4.0	7.5	7.2	1.3	8.9

Table A.1.6. Influence of nitrogen source and rate on total N content of stover, total N content of grain, and NO_3-N concentration of plant basal stalk.

	1993, Site 1			1994, Site 1			1994, Site 2		
	Stover Total	Grain Total	Basal Stalk	Stover Total	Grain Total	Basal Stalk	Stover Total	Grain Total	Basal Stalk
Trt.	N	N	NO_3-N	N	N	NO_3-N	N	N	NO_3-N
	- -%- -		-ppm-	- -%- -		-ppm-	- -%- -		-ppm-
CK	0.37	1.17	2.7	0.36	0.85	1.1	0.30	0.85	7.1
F1	0.33	1.19	2.9	0.38	0.89	0.8	0.32	0.90	1.8
F2	0.35	1.26	3.3	0.47	0.93	5.6	0.36	1.02	1.6
F3	0.25	1.38	4.3	0.39	0.95	12.9	0.42	1.05	2.4
F4	0.31	1.32	7.1	0.39	1.05	18.1	0.44	1.20	11.7
S1	0.36	1.22	3.0	0.33	0.89	1.0	0.38	0.98	0.8
S2	0.33	1.31	3.5	0.33	0.90	0.8	0.50	1.18	215
S3	0.32	1.33	168	0.38	0.94	1.4	0.47	1.30	511
S4	0.33	1.48	324	0.41	1.00	4.2	0.55	1.24	977
D1	0.38	1.19	5.3	0.37	0.87	0.7	0.37	0.88	0.8
D2	0.31	1.39	16.8	0.35	0.84	1.9	0.33	1.04	1.9
D3	0.31	1.46	182	0.37	0.98	1.8	0.36	1.07	1.4
D4	0.32	1.43	666	0.41	1.07	5.6	0.47	1.25	22
Pr>F	.4154	.0062	.0223	.7244	.1052	.1666	.0001	.0001	.0001
BLSD(.05)	NS	0.19	422	NS	NS	NS	0.09	0.12	180
C.V. (%)	17.5	7.7	197	20.4	10.0	172	15.7	8.6	101

Table A.1.7. Influence of nitrogen source and rate on total N uptake and total N removed in the grain.

	1993 Site 1		1994 Site 1		1994 Site 2	
Trt.	Total N Uptake	Total N in Grain	Total N Uptake	Total N in Grain	Total N Uptake	Total N in Grain
			- lb/ac -			
CK	55	34	49	37	67	52
F1	66	44	66	51	75	60
F2	78	51	87	64	103	82
F3	97	73	89	67	121	95
F4	99	68	105	82	146	115
S1	63	40	48	36	92	70
S2	82	55	60	47	154	119
S3	109	76	66	49	171	138
S4	128	85	74	57	175	130
D1	66	43	51	36	77	57
D2	112	77	68	51	107	86
D3	114	79	76	58	123	100
D4	127	85	103	81	153	122
Pr>F	.0001	.0001	.0080	.0141	.0001	.0001
BLSD(.05)	21.7	17.7	35	31	18	16
C.V. (%)	14.8	17.6	25.7	28.6	11.5	13.2

Table A.1.8. Effect of N source and rate on NO_3-N concentration in the soil profile at emergence stage, V5 stage, and post harvest stage of corn, Site 1, 1993.

	Emergence		V5		Post Harvest		
Trt.[a]	0-1 ft	0-2 ft	0-1 ft	0-2 ft	0-1 ft	0-2 ft	0-5 ft
				- - pm NO_3-N - -			
CK	6.5	5.4	4.8	4.9	3.4	2.2	2.4
F1	9.3	9.0	5.5	5.8	3.5	2.3	3.4
F2	15.8	12.7	7.4	8.3	4.5	3.2	5.6
F3	19.8	16.0	10.5	11.2	4.6	2.9	5.1
F4	22.1	15.7	11.7	11.0	4.4	3.3	7.9
S1	6.9	7.4	4.6	5.2	3.5	3.6	6.5
S2	16.6	16.6	8.2	9.7	3.4	2.7	7.6
S3	24.2	23.3	15.3	16.1	6.9	5.4	9.5
S4	22.3	25.1	11.9	15.2	7.8	7.4	10.4
D1	7.7	6.2	9.1	7.3	3.8	2.4	4.3
D2	15.7	15.6	11.0	12.2	6.6	4.2	5.6
D3	17.5	16.0	11.0	10.9	6.9	4.9	6.9
D4	41.2	29.8	18.9	21.2	8.1	10.6	11.5
Pr > F	.0001	.0001	.0385	.0006	.0140	.0067	.0078
BLSD(.05)	9.2	5.4	9.7	6.6	3.6	4.4	5.0
C.V. (%)	32.7	22.6	46.9	35.6	35.3	55.1	39.2

[a] Manure and inorganic N were applied in the fall of 1993.

Table A.1.9. Effect of N source and rate on NO_3-N concentration in the soil profile at emergence stage, V5 stage, and post harvest stage of corn, Site 2, 1994.

Trt.[a]	Emergence 0-1 ft	Emergence 0-2 ft	V5 0-1 ft	V5 0-2 ft	Post Harvest 0-1 ft	Post Harvest 0-2 ft	Post Harvest 0-5 ft
				- - ppm NO_3-N - -			
CK	6.0	4.8	4.3	4.1	2.3	1.3	2.0
F1	7.2	6.2	6.2	5.8	2.0	1.2	2.6
F2	9.9	9.1	8.2	8.3	2.2	1.4	2.3
F3	13.0	11.2	10.3	9.8	2.0	1.3	1.9
F4	19.1	16.6	14.8	12.9	3.4	2.0	3.4
S1	7.4	7.2	5.9	6.4	2.6	1.6	2.8
S2	15.8	15.9	13.7	12.7	4.2	2.6	3.6
S3	23.9	20.4	19.9	17.8	6.1	5.4	5.9
S4	33.7	29.0	30.2	25.1	13.2	11.9	8.2
D1	6.2	6.0	5.2	5.2	2.0	1.1	1.7
D2	10.2	9.7	8.3	8.2	2.1	1.2	2.7
D3	10.1	9.9	10.2	9.9	3.1	1.8	3.2
D4	13.2	12.1	11.9	10.8	2.9	1.7	2.9
Pr > F	.0001	.0001	.0001	.0001	.0001	.0001	.0001
BLSD(.05)	5.9	3.5	7.6	4.9	3.8	2.2	1.6
C.V. (%)	32.6	22.0	47.4	34.4	71.5	59.2	34.2

[a] Manure and inorganic N were applied in the fall of 1993.

Table A.1.10. Effect of N source and rate on NO_3-N concentration in the soil profile at emergence stage, V5 stage, and post harvest stage of corn, Site 1, 1994.

Trt.[a]	Emergence 0-1 ft	Emergence 0-2 ft	V5 0-1 ft	V5 0-2 ft	Post Harvest 0-1 ft	Post Harvest 0-2 ft	Post Harvest 0-5 ft
				- - ppm NO_3-N - -			
CK	5.2	3.9	4.9	3.6	2.3	1.2	1.1
F1	6.2	5.5	5.1	4.5	1.3	0.9	1.5
F2	12.4	9.5	7.9	7.4	2.2	1.2	1.8
F3	7.9	8.7	7.5	8.6	1.2	0.8	3.4
F4	12.5	12.4	9.6	9.1	2.3	1.5	3.1
S1	4.6	3.5	4.4	3.6	1.9	1.1	1.4
S2	4.9	3.8	4.5	3.4	1.6	1.0	1.8
S3	6.7	5.4	5.1	4.1	3.2	1.8	2.4
S4	5.6	4.4	4.1	4.0	2.4	1.3	4.4
D1	6.1	4.7	5.3	4.2	1.8	1.0	1.5
D2	6.0	4.5	4.9	3.7	2.4	1.3	2.6
D3	6.0	4.9	4.7	3.8	2.5	1.4	3.3
D4	7.4	6.5	7.0	6.6	2.1	1.2	4.8
Pr > F	.0001	.0001	.0019	.0001	.1019	.1406	.0001
BLSD(.05)	2.9	2.0	2.6	1.9	NS	NS	1.1
C.V. (%)	24.8	20.8	25.2	23.1	32.1	30.6	24.5

[a] Manure was applied in the fall of 1992, inorganic N was applied both in fall of 1992 and fall of 1993.

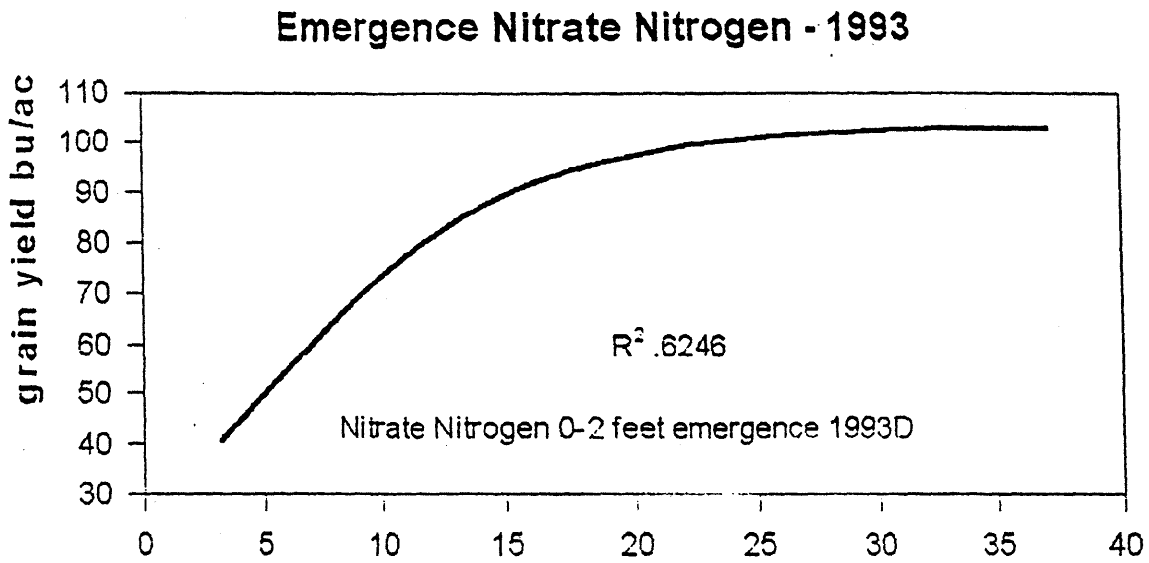
Table A.1.11. Correlation of grain N uptake (GNU) and total N uptake (TNU) with emergence and V5 soil NO_3-N ($U = a + bx^{-1}$, where U = GNU or TNU and b = soil NO_3-N at emergence or V5).

Plant Stage	1993, Direct GNU	1993, Direct TNU	1994, Residual GNU	1994, Residual TNU	1994, Direct GNU	1994, Direct TNU
			- - - - - r^2 - - - - -			
Emergence	0.54	0.48	0.46	0.51	0.60	0.67
V5	0.55	0.48	0.58	0.59	0.77	0.66

Table A.1.12. Comparison of available N from two manure sources estimated by two methods at Morris, MN in 1993 and 1994.

Trt.	Site 1, 1993 Available N A[†]	Site 1, 1993 Available N B[‡]	Site 1, 1994 Available N A	Site 1, 1994 Available N B	Site 2, 1994 Available N A	Site 2, 1994 Available N B
	--- lb/ac ---					
S1	57	46	13	5	41	82
S2	114	92	26	9	119	240
S3	168	136	39	14	173	350
S4	228	184	53	29	231	466
D1	51	91	19	7	30	51
D2	104	185	38	14	54	109
D3	149	266	54	21	90	151
D4	203	370	74	29	115	192

[†] A = Available N estimated by using guidelines from Schmitt and Rehm, 1992a and 1992b.
[‡] B = Available N estimated in Table A.1.2.



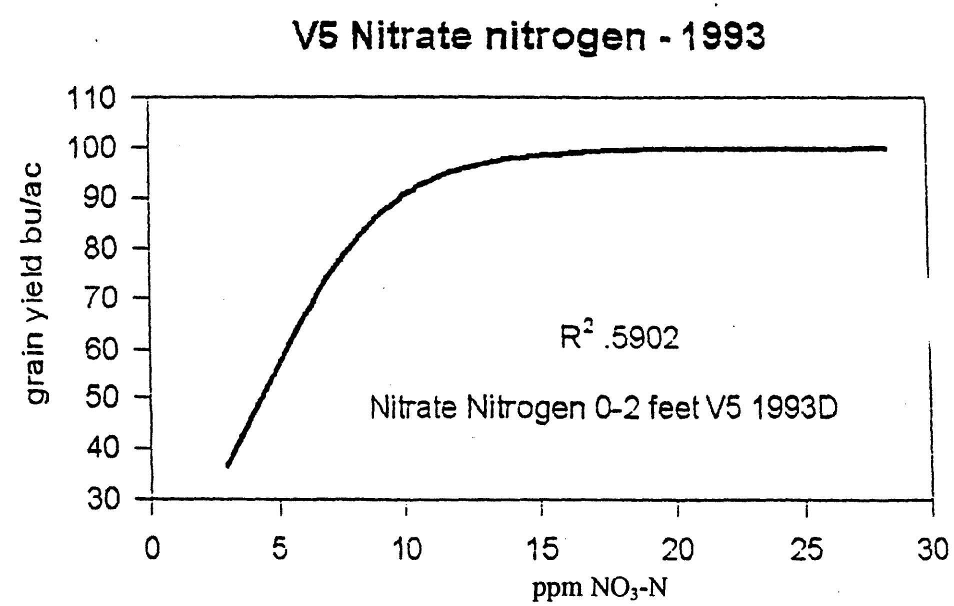


Fig. A.1.1. Effect of soil NO_3-N at emergence and V5 on corn grain yield in 1993.

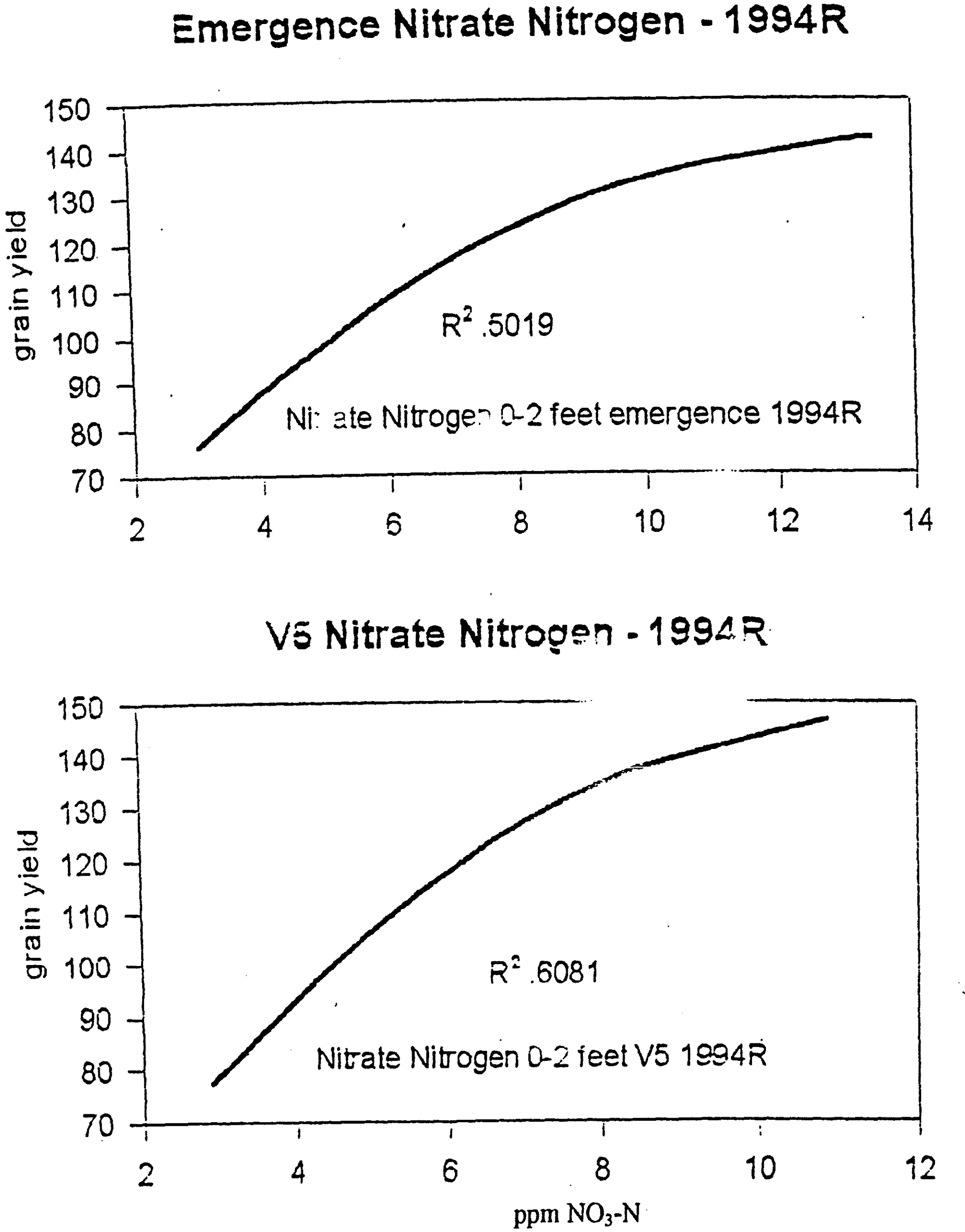


Fig. A.1.2. Effect of soil NO_3-N at emergence and V5 on corn grain yield on the residual manure plots in 1994.

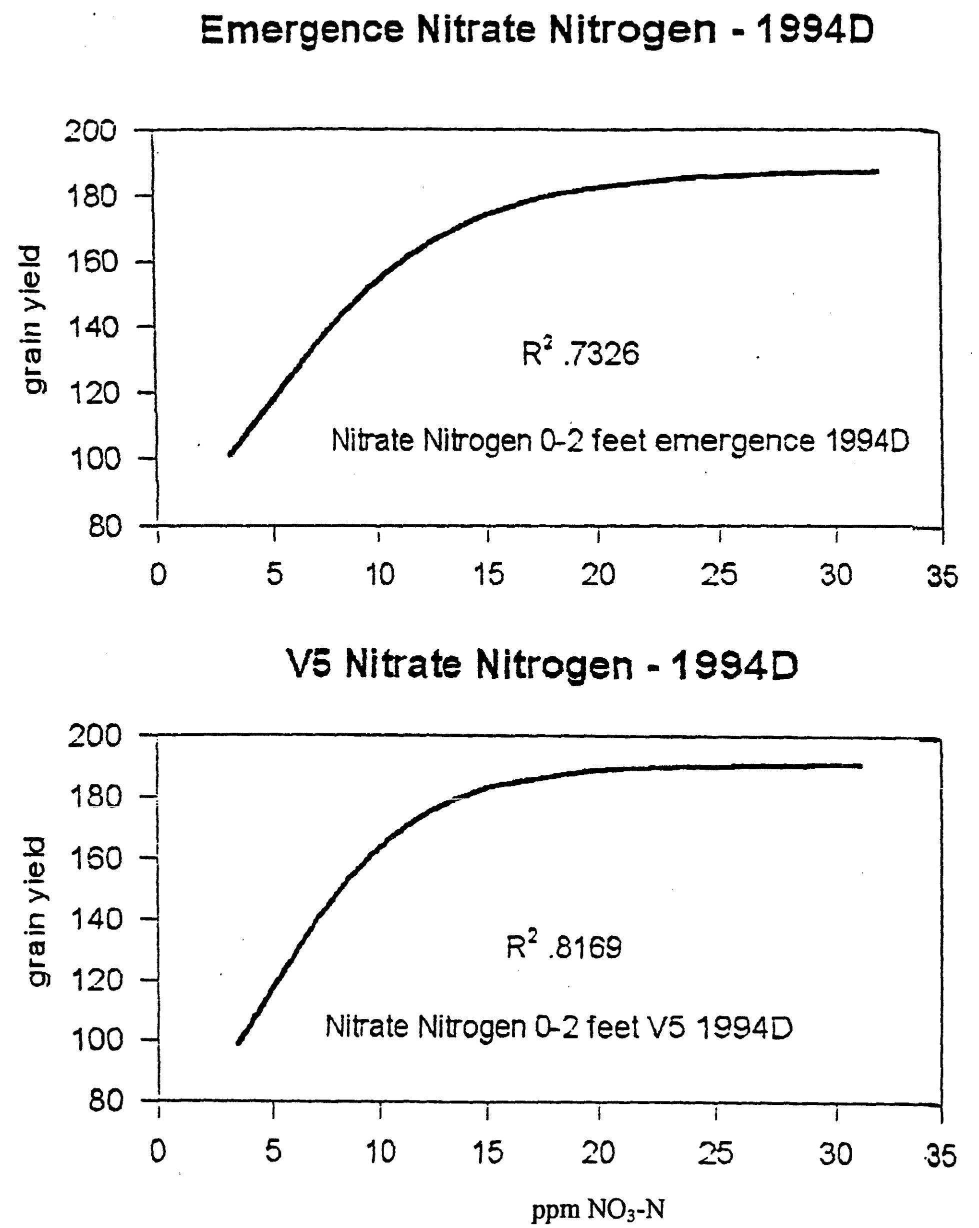


Fig. A.1.3. Effect of soil NO_3-N at emergence and V5 on corn grain yield on the direct manure plots in 1994.

Nu ent Recycling Studies: Si 1

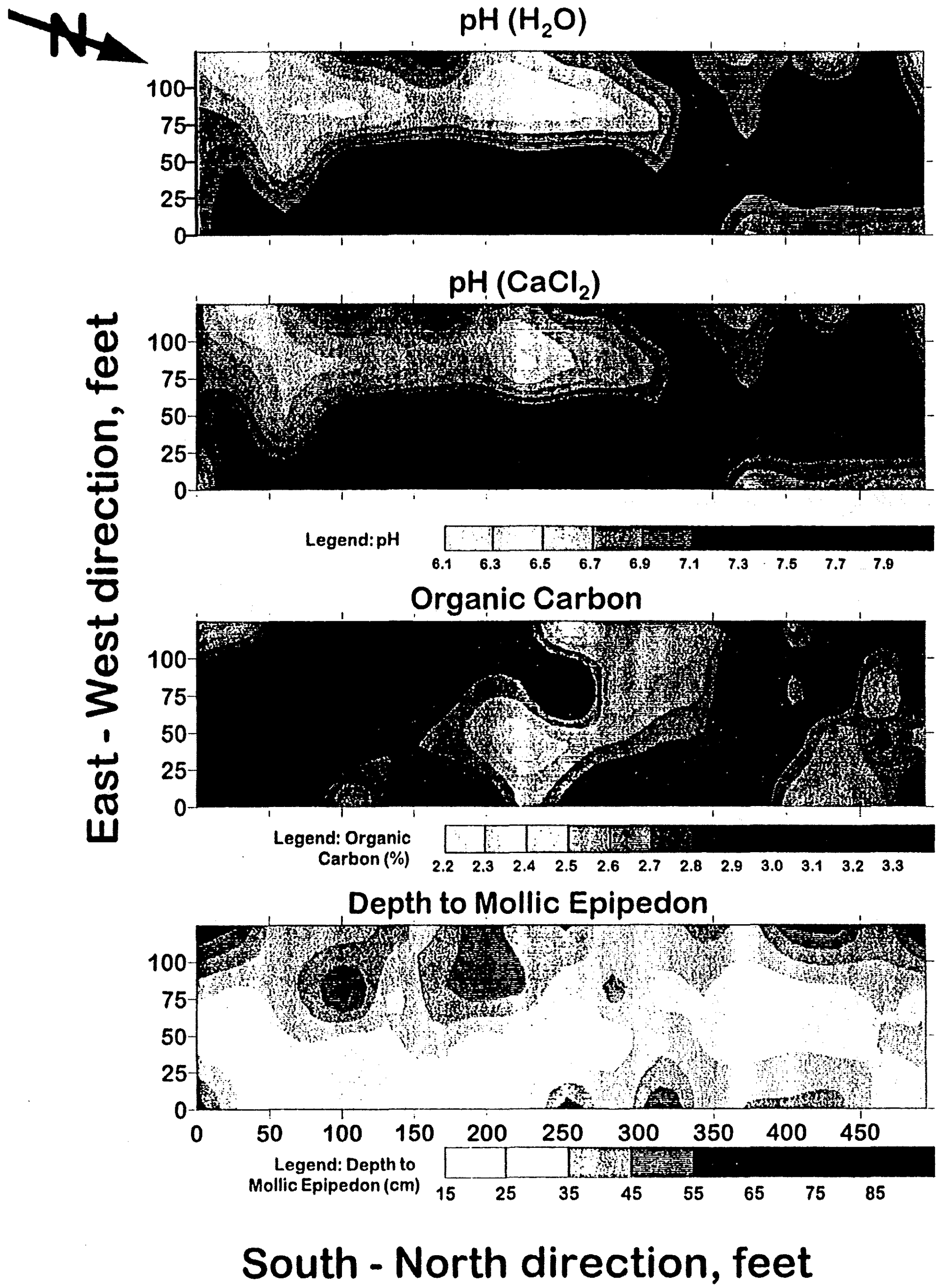


Fig. A.1.4. Interpolated map of pH, organic carbon, and mollic epipedon depth on Site 1.

Nutri Recycling Studies: Site

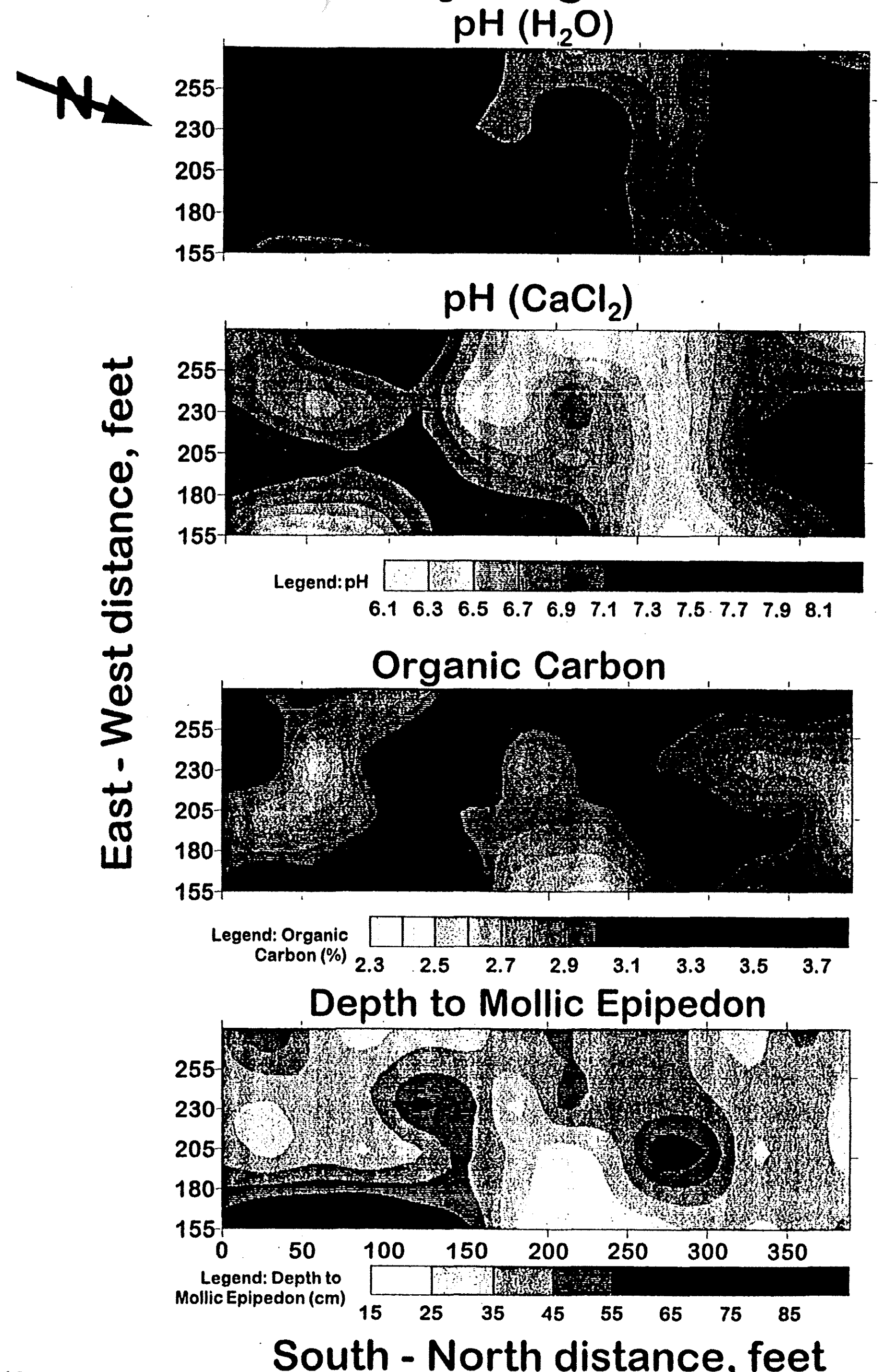


Fig. A.1.5. Interpolated map of pH, organic carbon, and mollic epipedon depth on Site 2.

IV. Research Objectives (continued)

A. Title of Objective: Assess existing soil and plant tests under West Central Minnesota conditions as "Plant N availability predictors" from two manure sources.

A.2. Activity: Establish an experimental site where one rate of liquid dairy manure will be applied on soils of three textural classes and plant available N measured on sub-plots maintained at 5 soil moisture levels. One of the textural sites will be on the same soil type as in activity A.1. A.E. Olness will spend 4% of his time over the next two years on this activity. P.R. Goodrich will assist on this activity.

A.2.a. Context within the project: In this phase soil and plant data will be collected to assess the effect of soil moisture level on the rate of apparent N mineralization. This will provide data on the N provided to the crop and test the hypothesis that N mineralized from manure applications is sensitive to both soil moisture level and soil texture.

A.2.b. Methods: Field plots will be established in the fall of 1992. The NO_3-N and NH_4-N will be measured to a depth of 150 cm prior to manure application. Dairy manure will then be applied to provide 180 kg N/ha to the following crop. The soil moisture level will then be measured, multiple lines of flat perforated sprinkler tubing installed, and plots covered with plastic. Irrigation water will then be applied to establish five soil moisture levels. During plot establishment soil samples will be collected and the soil characterized as to pH, texture, available P and K, total N, and NO_3-N and NH_4-N content and distribution. The following spring the plots will be uncovered, tilled, and planted to corn. The soils will be sampled to 60 cm in 30-cm increments for NO_3-N and NH_4-N content and distribution. Irrigation will again be used to maintain differential soil moisture levels. Soil samples will be taken weekly from planting to June 30 to a depth of 30 cm for nitrogen and moisture monitoring. One sampling will be scheduled at the V4-V5 stage which is specified for the pre-sidedress (PSD) NO_3-N soil test. When mature in the fall, stover and grain samples will be collected in order to determine total N uptake. When ready for combine harvest, four rows 12.2 m long will be harvested for grain yield. This entire process will be repeated for a second year on the same soils. The effect of soil moisture on plant available nitrogen over the early season will be examined using standard correlation methods. This will be done for each of the three soil textures.

A.2.c. Materials: Field materials necessary to carry out this project include soil probes, tillage equipment, plastic plot covers, flat sprinkler tubing, water tanks & pumps, manure applicators, corn planters, soil moisture monitoring equipment, plot combine, and miscellaneous plot care equipment. Laboratory equipment needed includes glassware, laboratory supplies, and analytical equipment.

A.2.d. Budget: This activity will be carried out cooperatively with the USDA-ARS research group at Morris and funds necessary for this phase of the project will be provided by that unit.

A.2.e. Timeline:

In order to properly carry out this activity, the first year of the experiment must be started in the fall of 1992, measurements made and data collected in the fall of 1992 and spring of 1993, plots planted, and planting thru June 30 samples collected before July, 1993.

	7/93	1/94	6/94	1/95	6/95
Take base soil samples	**				
Apply manure	*				
Establish differential soil moisture levels and cover plots	*				
Till and plant plots		**			
Sample plots weekly		****			
Maintain soil moisture levels		****			
Correlate NO_3-N levels with soil moisture levels	***		***		
Correlate crop yields with PSD NO_3-N soil levels	***		***		
Harvest plots	**	**			
Complete final analysis and interpretation					****

Status:

Nutrient Cycling Through Plants and Animals: The Effect of Texture on Formation of Nitrate-Nitrogen from Liquid Dairy Manure

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ABSTRACT:

Nitrate-nitrogen produced by the mineralization of manure is expected to be affected by the same environmental factors affecting mineralization of indigenous organic matter. One of these factors, aeration, is affected by soil water content which in turn is largely controlled by soil clay content. To examine this affect in more detail, plots were established on a Aastad clay loam, a Kranzburg silt loam, and a Sioux sandy loam soil by applying 7,700 L of liquid dairy manure/acre (equivalent to application of about 160 lbs of available N/acre). Plots were then irrigated with different amounts of water to establish different soil water contents. Soil samples were collected and analyzed for nitrate-N and water content. Rather large amounts of nitrate-N developed in the surface depth increments at all three sites and some tendency of texture and water content developed but was inconclusive in establishing the effect of aeration on development of nitrate-N. Corn grain yields averaged 115.3 bu/ac, 91.0 bu/ac, and 62.9 bu/ac on the silt loam, clay loam, and sandy loam sites, respectively in 1993; these yields were competitive with applications of conventional inorganic N-fertilizer at recommended rates of application. Manure

applications showed clear effects of advancing the rate of corn development; flowering was advanced by as much as 2 to 4 days on sites receiving liquid dairy manure in the previous fall.

INTRODUCTION

Nitrate-Nitrogen (NO_3-N) is the main form of N accumulated by corn (Warncke and Barber, 1973). Most NO_3-N is microbially produced from ammonium-N (NH_4-N) which in turn is usually generated from organic sources such as manure and urea through the decay process. Because it is microbially generated, the amount of NO_3-N in the soil at any time is dependent on those conditions which favor aerobic microbial activity. Recently, Doran et al (1990) have shown that maximal development of NO_3-N under aerobic conditions occurs when 1/3 of the soil pore space is filled with air.

The amount of soil pore space filled with air is function of soil clay content (texture), climate, and the potential to lose water by drainage or evapotranspiration. Thus, the conversion of NH_4-N to the NO_3-N form depends on soil texture. Fine textured soils seldom have less than half of the pore space filled with water even under the driest conditions and even modest rainfall will cause the total water filled pore space to exceed the desired level rather quickly. Coarse textured soils cannot hold enough water even under the most humid climates to achieve adequate moisture content and NO_3-N produced can be easily and quickly leached from the soil. As a consequence, we expect the relative efficiency of an organic N source to vary considerably but systematically as a function of soil texture.

The objective of this study was to determine 1) the relative efficiency of manure as an N source for production of adequate levels of NO_3-N and 2) the effect that different moisture levels would have on the concentration of NO_3-N that would develop in a given soil texture as a result of addition of manure.

MATERIALS AND METHODS

Plots measuring 60 ft by 30 ft were established on a Aastad clay loam (Pachic Udic Haploboroll; fine-loamy, mixed), a Sioux sandy loam (Udorthentic Haploboroll; sandy-skeletal, mixed) and a Kranzburg silt loam (Udic Haploborall; fine-silty mixed); all soils were located within 15 miles of Morris, MN in the fall ... All plots were uniformly treated with 7,700 gal/ac liquid dairy manure on Oct. 21 and 22, 1992 ...ut 160 lbs of N/acre and to a single plot at each site on Oct. 22, 1993.

...lastic and 0.0, 0.12, 0.25, 0.50, 0.75, or 1.0 inches of water were applied during ...nerate different moisture levels and to the Kranzburg sil plots on April 26, ...y 5 and 21, 1993. Spring rains precluded further water treatments in ...nter.

...d 4172 (92-94 day Minnesota maturity rating) on the ...nd 3965A (90 day Minnesota maturity rating). ...anzburg sil sites and 23,000 seeds/ac ...he Aastad cl site and 25,000 seeds/ac at the Kranzburg sil site. Physiological development was monitored throughout the growing season for flowering characteristics and grain samples were collected at harvest.

Soil moisture levels and soil NO_3-N concentrations were monitored periodically throughout the growing season to a depth of 2 ft in the Aastad and Kranzburg soil sites and to a depth of 1 ft in the Sioux soil site; soil at the Sioux site was about 12 inches deep over gravel. Cores taken to a depth of 60 inches for insertion of soil moisture determinations using a neutron meter in late May 1993 were sectioned in 6 inch segments (Sioux sl site excepted) and analyzed for moisture content and NO_3-N concentration.

RESULTS AND DISCUSSION

Excessive rainfall in the spring of 1993 and the cool growing season precluded a continuation of the fall water application rates. Therefore attempts to constrain water contents were discontinued. The Sioux sl site was under control of the Minnesota Department of Natural Resources and a contractor; who applied anhydrous ammonia uniformly over the area, including the plot area at the rate of about 160 lbs/ac after planting. As a consequence, data were collected but the site was subsequently abandoned. No attempt was made to continue the controlled soil water characteristic after 1992-93.

Grain yields in 1993 were significantly different between the three sites (Table A.2.1). Climate in 1993 was generally adverse for grain production with a much cooler than average growing season and ample to excessive moisture in April through June. The grain yields were markedly different between textural sites with the Kranzburg (average = 115 bu/ac) being much greater than the Aastad cl (average = 91 bu/ac which in turn was much greater than the yields obtained from the Sioux sl (average = 63 bu/ac).

Benefits of previous application of manure were obvious at both the Aastad cl and the Kranzburg sil sites in 1993 (Table A.2.2). On the Aastad cl in 1994, grain yields from plots which had received manure only in 1992 were generally only about 24 bu/ac less than the plot receiving a manure application in 1992 and 1993. Yields at the Kranzburg sil site appear to show less benefit from the second application of manure in 1993; yields at this site, however, were undoubtedly affected by a severe hailstorm which removed at least 50 % of the foliage on July 3, 1994 (shortly before flowering).

In 1993, the spring soil NO_3-N concentrations were large in the surface 0 to 12 inch depths at all three sites and plot averages ranged from 5.1 to 90.3 (Table A.2.3.). Below the 12 inch depth, the concentrations of in the Kranzburg sil and Sioux sl decreased quite sharply; however, the concentrations in the Aastad cl decreased only over the 12 to 24 inch depth and then increased in the 24 to 48 inch depth and in some cases exceeded 20 ppm at the 60 inch depth. The Aastad cl site had been a research site for a number of years and the increased N below the 12 inch depth may have been a residual effect of earlier studies. Concentrations of NO_3-N of between 15 to 20 ppm in the upper foot of the profile are regarded as optimal for non-N limiting corn production and the manure applications were clearly adequate to reach this level in 1993.

Microbial production of NO_3-N proceeds at a maximal rate under optimal moisture and temperature conditions. The attempt to effect some differences in the soil water status was partially successful and spring soil measurements showed a range of water contents which only partially reflected the irrigation treatments. In spite of the variances observed, NO_3-N concentrations showed a complex relationship with soil water content in the surface 0 to 6 inch depth increment. At the Kranzburg sil site, NO_3-N concentrations tended to increase with water content in the range of 26 to 32 % water content (Fig. A.2.1). At the Aastad cl site, NO_3-N concentrations tended to decrease with water content in the range of 28 to 34 % water content (Fig. A.2.2). At the Sioux sl site, NO_3-N concentrations show a week tendency to reach a maximum at around 27 % water content (Fig. A.2.3). Depending on the surface bulk density, a gravimetric water content of 30 % would fill about 60 to 70 % of the void space in the soil; this is about an optimal degree of aeration to effect maximal mineralization and nitrification. Of course, the content of water in soil at the time of sampling fails to reflect the antecedent conditions which were responsible for the development of NO_3-N, but they may be indicative of relative wetness during that period.

The concentrations of NO_3-N in the surface foot of soil are consistent with other observations. Water is the main soil thermal buffer and because finer textured clay loam soils hold more water, they warm more slowly in the spring than coarser textured silt loam or sandy loam soils. The order of NO_3-N concentrations in the surface 0- to 6-inch increment was sandy loam (mean = 71.6 ppm) > silt loam (mean = 29.5 ppm) > clay loam (mean = 17.0 ppm); even with the added N applied to the sandy loam, this soil probably mineralized more manure N than the other soils.

Aeration in the subsoil is normally less than that in the surface increments and NO_3-N concentrations in the Kranzburg sil and the Sioux sl were less than were much less than those obtained in the surface 0- to 6-inch increments. In the Aastad cl, the NO_3-N concentrations in the 6- to 12-inch increment exceeded those in the surface increment on average by about 12 ppm. It is possible that the manure was injected to a slightly greater depth in the clay loam than at the other sites. Also, NO_3-N in the 6- to 12-inch depth increment may have formed within the depth increment or been leached from the 0- to 6-inch depth zone. As a consequence, little or no relationship between soil moisture and NO_3-N concentration is readily apparent except in the Aastad cl site (Figs. A.2.4, 5, and 6).

In 1994, only a single plot at each site had received manure the previous fall and NO_3-N concentrations were much less than in the first spring after manure application (Table A.2.4). In fact, no evidence of manure application could be found at the silt loam site and very little evidence of manure application is noted at the clay loam site. These concentration levels are usually inadequate to achieve maximal grain yield. No relationship between soil moisture and NO_3-N concentrations is apparent in the 1994 sampling (Figs. A.2.7, 8, 9, and 10); however, the moisture ranges would not seem to have been great enough to extended through the optimal soil water contents for aerobic microbial activity.

While the results of the textural portion of this study are inconclusive, they are consistent with theory and observations of a number of studies involving application of commercial nitrogen sources. The spring NO_3-N concentrations suggest two important considerations in the use of manure to satisfy plant N needs. First, a texture effect will often occur as an indirect result of effects of water content on aeration and temperature of the soil. Secondly, spring climatic conditions may slow mineralization of N early in the season; this makes the spring pre-plant or emergence NO_3-N test less reliable on sites which have received manure than on sites which have received only ammonium forms of commercial fertilizer. As a consequence, recommendations for use of liquid dairy manure as an N source should be tailored to soil texture and subsequent crop need.

Little or no response is usually obtained to additions of N to soil which has NO_3-N concentrations of > 15 to 20 ppm in the upper two feet of the profile. The NO_3-N concentrations which developed at both the Aastad cl site and the Kranzburg sil should have exceeded the levels required to achieve maximal yield (if only N is limiting). The NO_3-N concentrations in both the Aastad cl and Kranzburg sil sites exceeded 20 ppm in the upper 1.5 ft of the profile throughout the entire early vegetative growth stage for the corn crop (Figs. A.2.11 and A.2.12). The excessive NO_3-N concentrations which developed in the Sioux sl site clearly reflect both the manure and anhydrous N applications; the concentrations in the upper foot represent almost 300 to 350 lbs of NO_3-N in the upper foot (Fig. A.2.13). In view of the excessive NO_3-N concentrations, it is particularly surprising that the grain yields from this site were relatively poor.

Physiological development on the Kranzburg sil and the Sioux sl was relatively unaffected by treatment in 1993 (Figs. A.2.14 and A.2.15). Development on the Aastad cl was much less uniform and a weak tendency to delayed development with increasing soil water content is suggested by the relative tasseling and silking developments (Fig. A.2.16). In contrast, tasseling and silking were significantly advanced in the two plots receiving manure additions again in 1993 when compared to those which only received manure in 1992 (Figs. A.2.17 and A.2.18). Inadequate accumulation of zinc and perhaps early season iron have been observed in this region of Minnesota in both corn (zinc) and soybean (iron) and it seems possible that manures could be a source of nutrients which are otherwise in temporary or marginal sufficiency for optimal crop development. Advancement of flowering is normally associated with advancement in grain maturation and dry down so some additional economic benefit should be realized from manure applications in grain drying costs at harvest.

SUMMARY AND CONCLUSIONS.

Nitrate nitrogen concentrations which develop in the soil profile after application of liquid dairy manure show evidence of soil textural effects. These textural effects are indirect expressions of soil moisture and temperature effects on microbial mineralization of organic sources of nitrogen and subsequent nitrification. A more rigorous study is needed to verify the textural (water content) effect on nitrification. Some benefit in addition to N is apparent in the advancement of plant physiological development in manured soils. The cause of this advancement is uncertain and further research on this phenomenon is desirable.

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Doran, J.W., L.N. Mielke, and J.F. Power. 1990. Microbial activity as regulated by soil water-filled pore space. Trans. 14th Intl. Congr. Soil Sci. Symp. III-3; Ecology of soil microorganisms in the microhabitat environment. Aug. 12-18, 1990, Kyoto, Japan. III:94-99.

Warncke, D.D., and S.A. Barber. 1973. Ammonium and nitrate uptake by corn (*Zea mays* L.) as influenced by nitrogen concentration and NH_4^+/NO_3^- ratio. Agron. J. 65:950-953.

Table A.2.1. Corn grain yields from three thextural classes to which manure was applied in 1992.

Soil	Water Treatment	Grain Yield† Mean	Grain Yield† Std. Dev.	Moisture Content Mean	Moisture Content Std. Dev.
	- - in/ac - -	- - - - - - - Bu/ac - - - - - - -		%	
Aastad cl	0.0	106.3		23.1	
	0.125	104.2		21.1	
	0.25	99.6		20.1	
	0.50	74.5		23.8	
	0.75	75.9		22.6	
	1.0	85.3		23.7	
		91.0 ±	14.2	22.4 ±	1.49
Kranzburg sil	0.0	116.3		22.9	
	0.25	116.9		23.5	
	0.5	102.8		26.2	
	0.75	116.2		25.6	
	1.0	124.4		24.9	
		115.3 ±	7.8	24.6 ±	1.41
Sioux sl	0.0	62.6		27.5	
	0.125	70.1		23.5	
	.25	65.2		25.2	
	0.5	58.6		30.1	
	0.75	61.4		25.4	
	1.0	59.5		24.3	
		62.9 ±	4.2	26.0 ±	2.42

† Grain yield is given at 15.5% moisture content.

Table A.2.2. Corn grain yields from three textural classes to which manure was applied in 1993.

Soil	Manure Treatment	Grain Yield† Mean	Grain Yield† Std. Dev.	Moisture Content Mean	Moisture Content Std. Dev.
		- - - - - - - Bu/ac - - - - - - -		%	
Aastad cl	Applied '92, '93	183.8		23.8	
	Applied '92 only	162.3		26.1	
		136.9		26.0	
		108.7		22.7	
		110.4		24.5	
		105.6		24.4	
		124.8 ±	24.4	24.7 ±	1.4
Kranzburg sil‡	Applied '92, '93	133.3		21.0	
	Applied '92 only	119.0		19.8	
		123.6		19.6	
		145.5		19.8	
		122.7		21.2	
		127.7 ±	12.0	20.1 ±	0.7

† Grain yield is given at 15.5% moisture content.
‡ This site received severe hail damage on Juy 3, 1994.

Table A.2.3. Spring profile nitrate-N concentrations in 1993.

Site	Depth	Water Treatment (in) 0.0	0.125	0.25	0.5	0.75	1.0
	-- in --			-- ppm --			
Kranzburg sil	0 to 6	40.4±38.5		41.4±8.6	23.5±14.1	17.3±7.7	25.0±13.7
	6 to 12	25.5±8.0		15.5±8.9	19.1±7.1	11.5±2.9	7.6±4.2
	12 to 18	12.8±6.5		5.8±5.5	6.1±1.8	7.0±6.6	4.0±3.1
	18 to 24	6.4±0.4		3.3±3.3	3.3±1.5	3.0±1.8	5.8±0.6
	24 to 36	4.3±0.3		2.1±1.4	1.8±0.6	2.7±3.0	5.9±0.2
	36 to 48	2.8±0.1		2.7±0.6	1.2±0.9	1.4±1.1	6.2±0.4
	48 to 60	3.8±0.7		3.6±0.9	2.0±1.2	1.7±0.6	7.2±0.5
Aastad cl	0 to 6	18.6±9.0	14.9±9.3	32.8±15.0	5.1±2.2	16.1±10.1	14.3±7.6
	6 to 12	25.7±9.3	32.7±13.9	54.0±15.0	19.3±6.7	38.7±9.5	27.9±17.1
	12 to 18	7.7±3.3	19.0±14.1	11.7±6.6	20.2±4.4	8.1±7.0	12.5±11.0
	18 to 24	5.9±2.4	17.3±12.1	11.6±2.6	20.5±6.2	6.6±7.7	4.8±2.1
	24 to 36	13.1±5.9	28.8±24.8	12.8±4.8	20.0±10.1	7.1±6.4	5.4±2.5
	36 to 48	24.0±1.0	18.3±20.7	15.4±6.4	12.6±9.5	15.8±9.4	7.4±5.8
	48 to 60	22.5±6.7	26.1±19.1	16.8±3.7	14.3±7.0	23.5±7.2	11.0±11.1
Sioux sl	0 to 6	90.3±41.4	52.3±11.7	67.4±21.1	64.0±40.8	85.8±47.3	69.9±51.5
	6 to 12	25.2	36.3± 8.4†	42.4± 11.3‡	39.2± 26.0§	31.6± 31.2††	19.5± 16.2‡‡
	12 to 24	10.3±7.3	6.0±1.7	7.1±0.8	6.3±0.5	5.7±1.5	4.3±1.5
	24 to 60	6.4±1.6	2.9±0.4	3.0±0.2	4.5±1.7	4.3±0.2	4.4±1.2

† Mean of two observations to a depth of 12 inches.
‡ Mean of three observations to a depth of 9 inches.
§ Weighted mean of two observations to a depth of 9 inches and one observation to a depth of 12 inches.
†† Weighted mean of two observations to a depth of 9 inches and two observations to a depth of 12 inches.
‡‡ Weighted mean of one observation to a depth of 9 inches and two observations to a depth of 12 inches.

Table A.2.4. Spring profile nitrate-N concentratons in 1994†.

Site	Depth	Manured Fall of 1992 and 1993	Manured Fall of 1992
	-- in --		
Kranzburg sil	0 to 6	9.0 ± 0.1	8.7 ± 1.6
	6 to 12	8.9 ± 1.7	7.2 ± 2.0
	12 to 18	9.4 ± 1.2	8.5 ± 2.1
	18 to 24	6.1 ± 1.5	7.2 ± 2.2
	24 to 36	5.5 ± 0.9	6.9 ± 2.9
	36 to 48	5.2 ± 0.4	7.1 ± 3.2
	48 to 60	5.1 ± 1.5	5.1 ± 0.8
Aastad cl	0 to 6	11.6 ± 3.6	8.3 ± 1.6
	6 to 12	12.2 ± 2.7	8.4 ± 10.0
	12 to 18	7.7 ± 0.9	4.3 ± 2.0
	18 to 24	7.4 ± 1.4	6.1 ± 1.5
	24 to 36	9.0 ± 0.5	6.3 ± 2.5
	36 to 48	11.1 ± 1.0	7.1 ± 3.4
	48 to 60	13.1 ± 1.5	8.5 ± 3.8

† N = 2 for 1993 manured sites and 8 for Kranzburg site and 10 for Aastad site manured in 1992 and 1993.

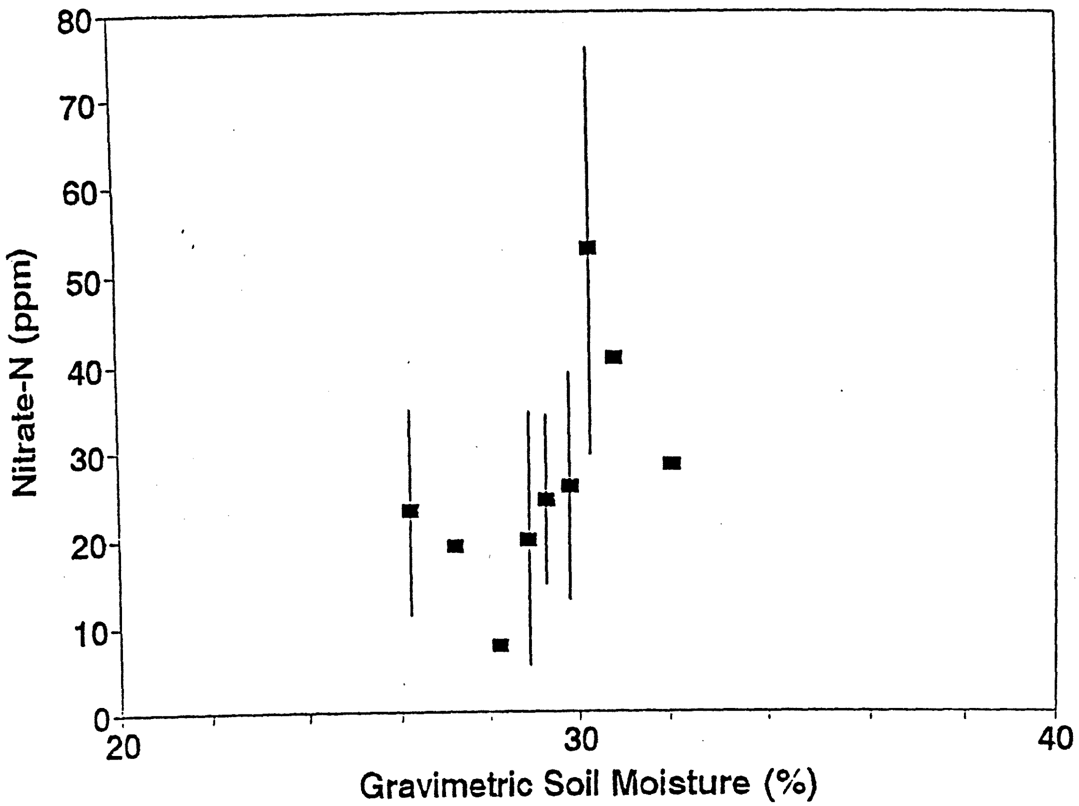

Fig A.2.1. Nitrate nitrogen concentrations in the 0- to 6-inch increment on a Kranzburg silt loam soil in 1993 after fall (1992) application of liquid dairy manure. Vertical bars represent standard deviations about the mean for two or more samples, having nearly identical moisture contents. Samples were collected on May 7 and 11, 1993.

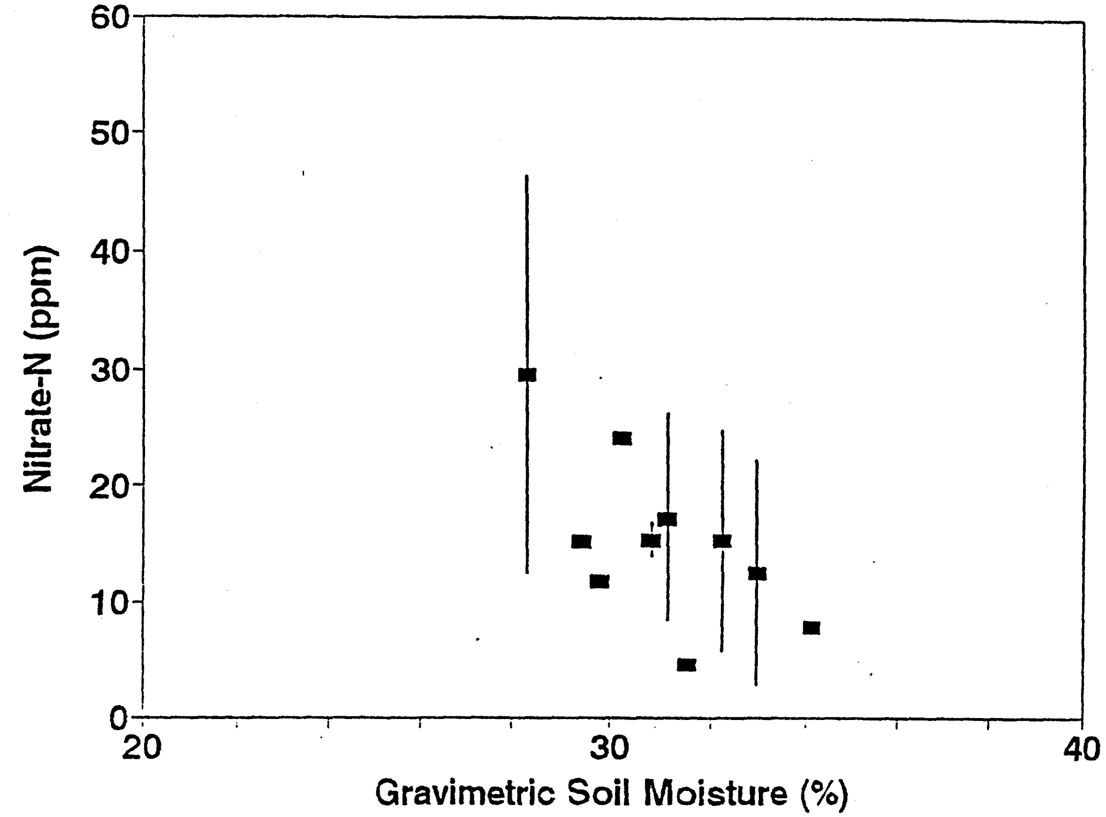

Fig A.2.2. Nitrate nitrogen concentrations in the 0- to 6-inch increment on a Aastad clay loam soil in 1993 after fall (1992) application of liquid dairy manure. Vertical bars represent standard deviations about the mean for two or more samples, having nearly identical moisture contents. Samples were collected on May 11 and 12, 1993.

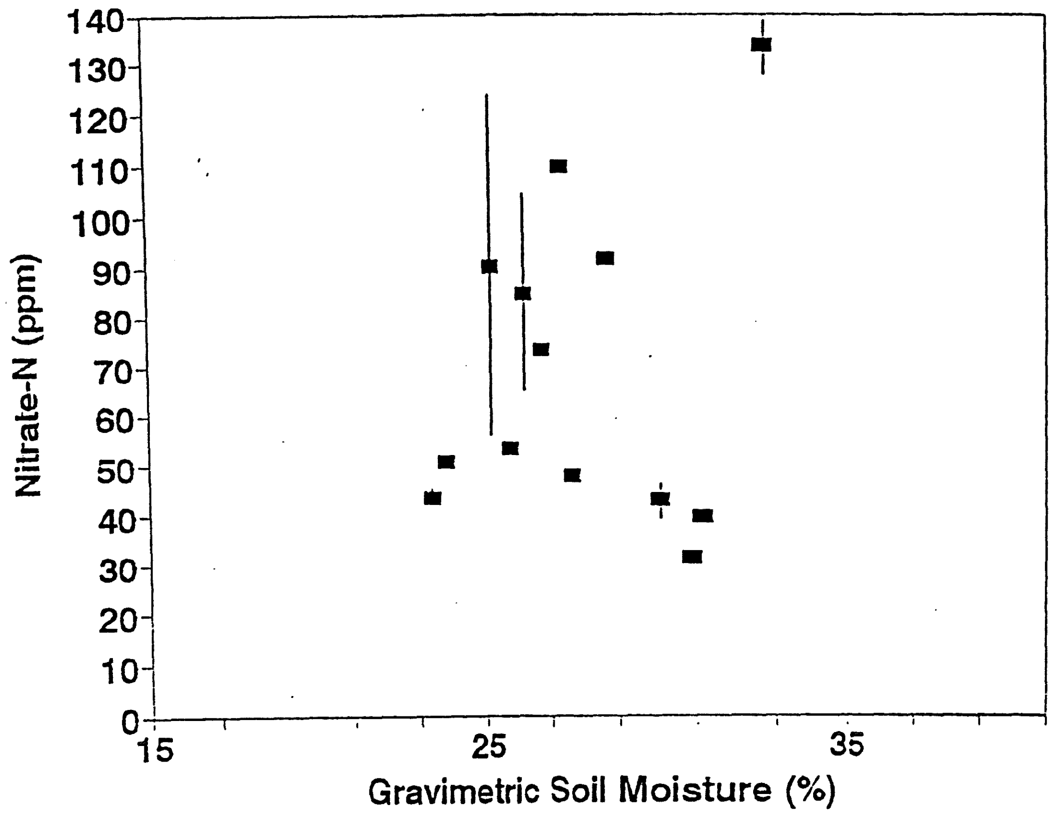

Fig A.2.3. Nitrate nitrogen concentrations in the 0- to 6-inch increment on a Sioux sandy loam soil in 1993 after fall (1992) application of liquid dairy manure. Vertical bars represent standard deviations about the mean for two or more samples, having nearly identical moisture contents. Samples were collected on May 18, 1993.

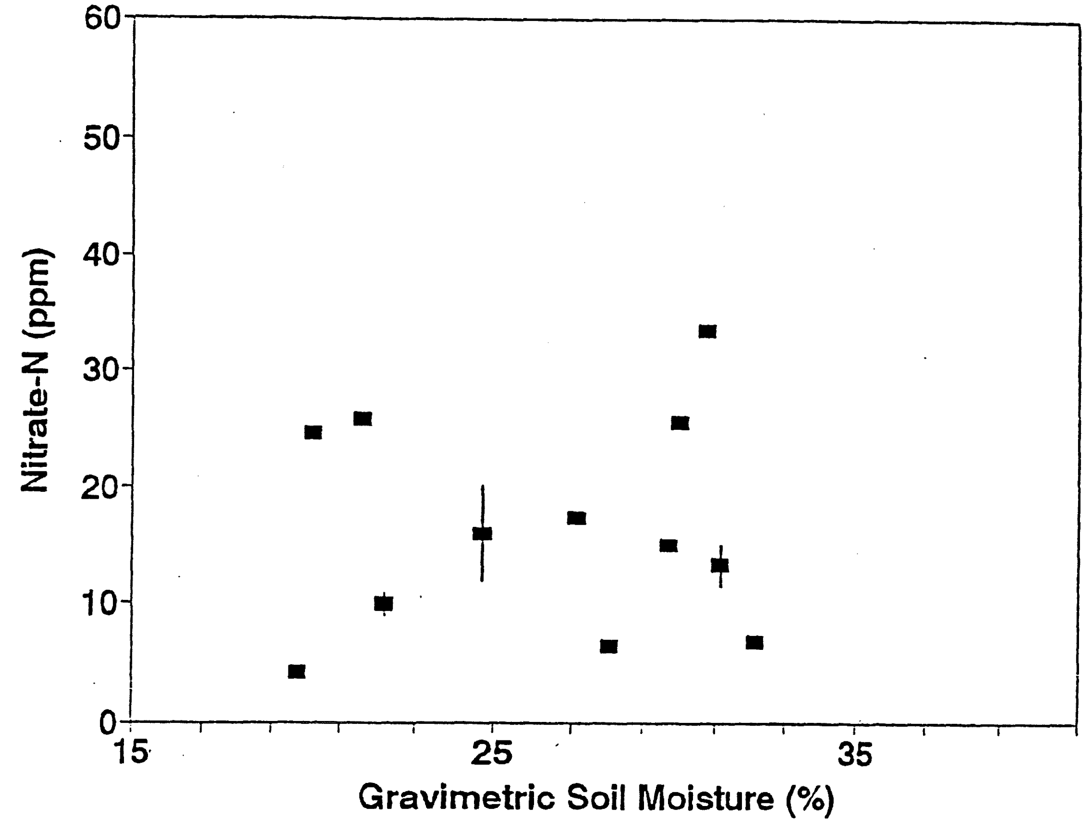

Fig A.2.4. Nitrate nitrogen concentrations in the 6- to 12-inch increment on a Kranzburg silt loam soil in 1993 after fall (1992) application of liquid dairy manure. Vertical bars represent standard deviations about the mean for two or more samples, having nearly identical moisture contents. Samples were collected on May 7 and 11, 1993.

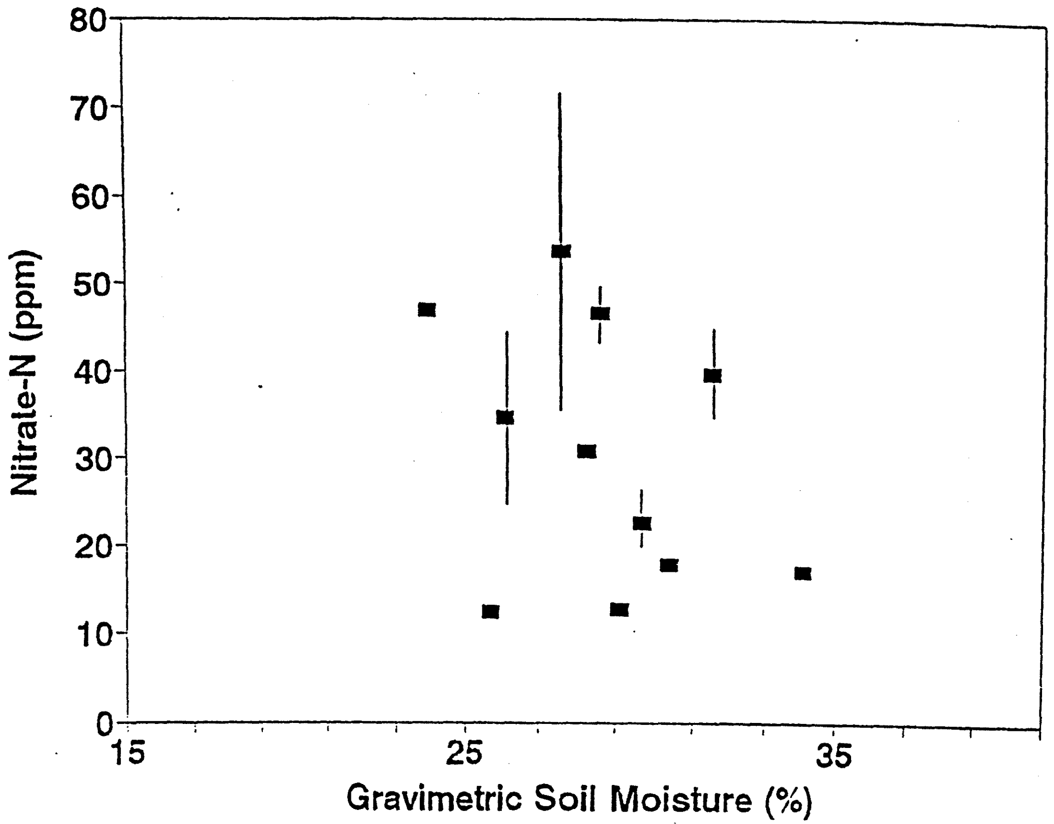

Fig. A.2.5. Nitrate nitrogen concentrations in the 6- to 12-inch increment on a Aastad clay loam soil in 1993 after fall (1992) application of liquid dairy manure. Vertical bars represent standard deviations about the mean for two or more samples, having nearly identical moisture contents. Samples were collected on May 11 and 12, 1993.

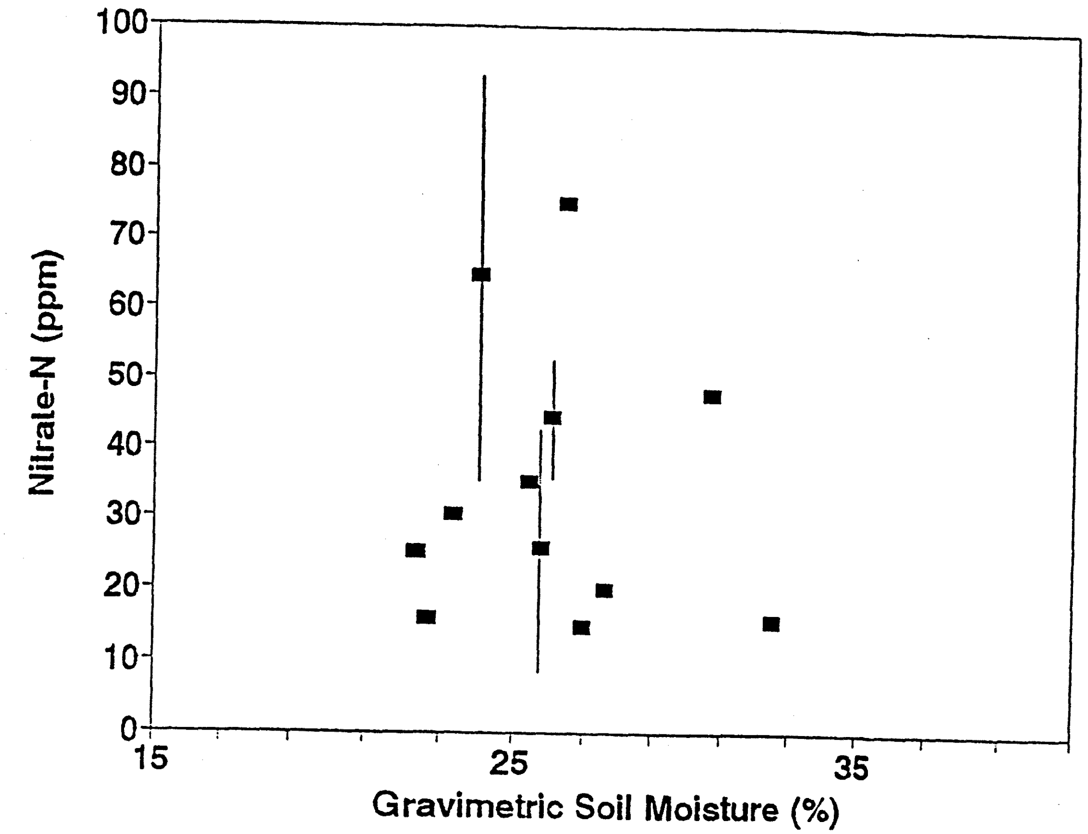

Fig. A.2.6. Nitrate nitrogen concentrations in the 6- to 12-inch increment on a Sioux sandy loam soil in 1993 after fall (1992) application of liquid dairy manure. Vertical bars represent standard deviations about the mean for two or more samples, having nearly identical moisture contents. Samples were collected on May 18 1993.

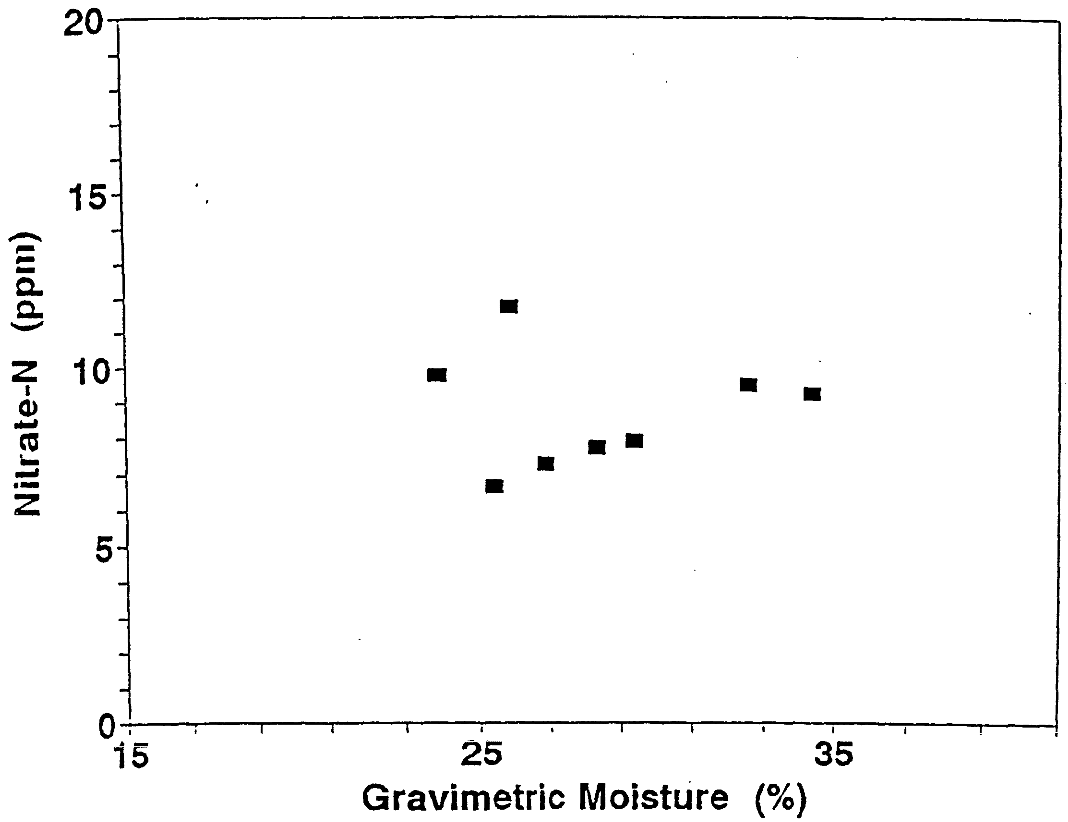

Fig. A.2.7. Nitrate nitrogen concentrations in the 0- to 6-inch increment on a Aastad clay loam soil in 1994 after fall (1992) application of liquid dairy manure. Vertical bars represent standard deviations about the mean for two or more samples, having nearly identical moisture contents. Samples were collected on May 17, 1994.

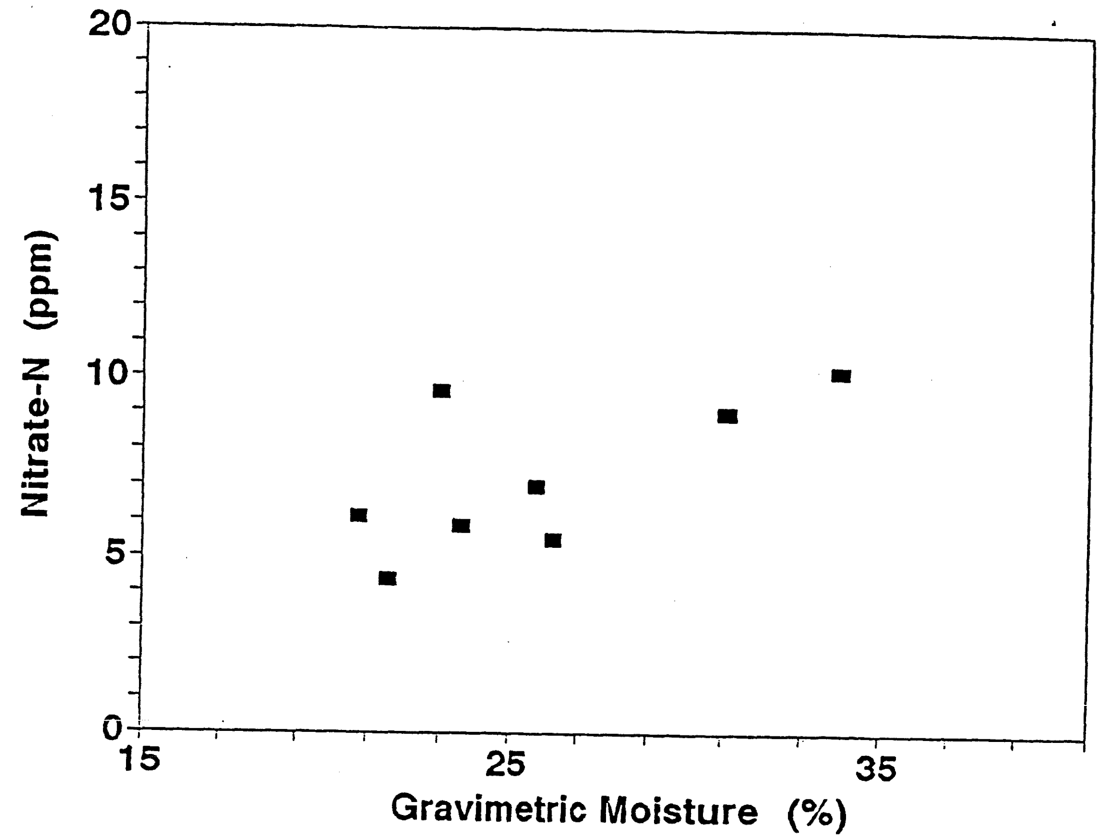

Fig. A.2.8. Nitrate nitrogen concentrations in the 0- to 6-inch increment on a Aastad clay loam soil in 1994 after fall (1992) application of liquid dairy manure. Vertical bars represent standard deviations about the mean for two or more samples, having nearly identical moisture contents. Samples were collected on May 19, 1994.

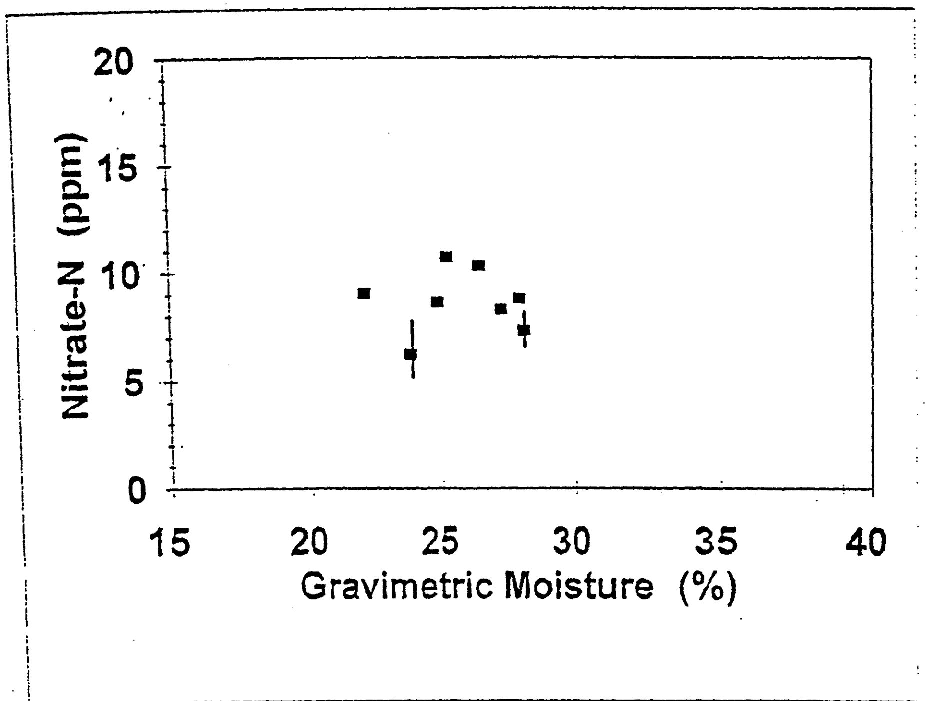

Fig. A.2.9. Nitrate nitrogen concentrations in the 6- to 12-inch increment on a Kranzburg silt loam soil in 1994 after fall (1992) application of liquid dairy manure. Vertical bars represent standard deviations about the mean for two or more samples, having nearly identical moisture contents. Samples were collected on May 17, 1994.

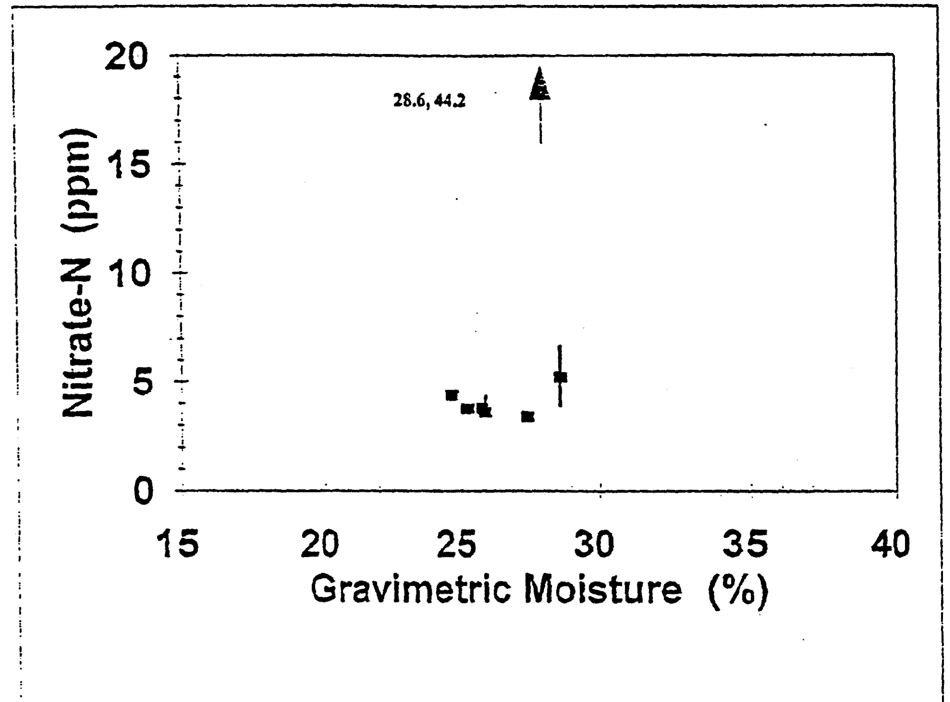

Fig. A.2.10. Nitrate nitrogen concentrations in the 0- to 6-inch increment on a Aastad clay loam soil in 1994 after fall (1992) application of liquid dairy manure. Vertical bars represent standard deviations about the mean for two or more samples, having nearly identical moisture contents. Samples were collected on May 19, 1994.

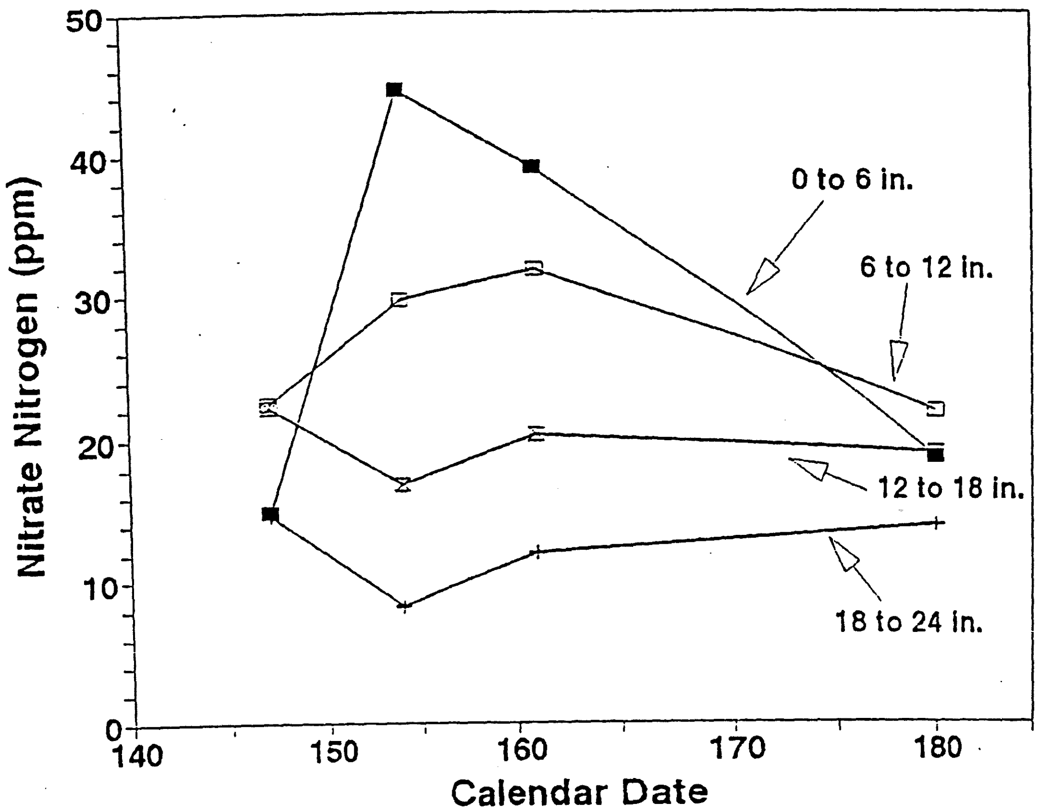

Fig. A.2.11. Early 1993 season nitrate-N concentrations in a Kraznzburg silt loam soil treated with liquid dairy manure in the fall of 1992. Data points are the means of 15 observations.

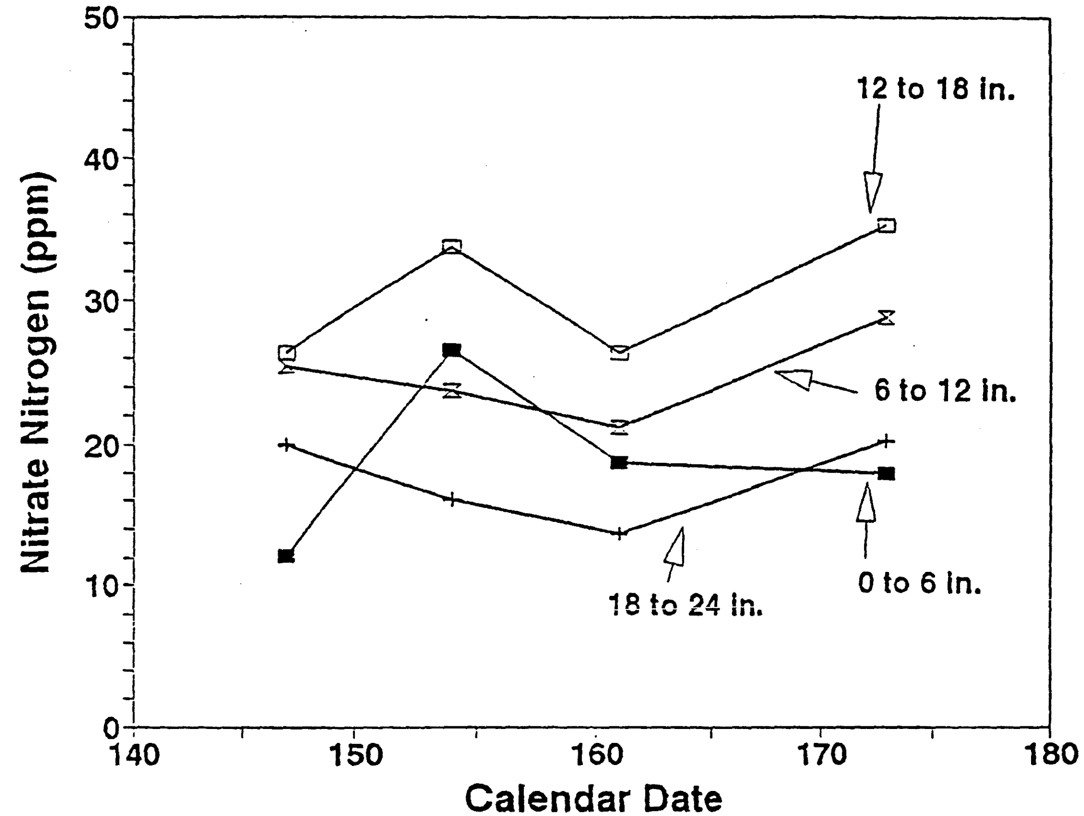

Fig. A.2.12. Early 1993 season nitrate-N concentrations in a Asatad clay loam soil treated with liquid dairy manure in the fall of 1992. Data points are the means of 18 observations.

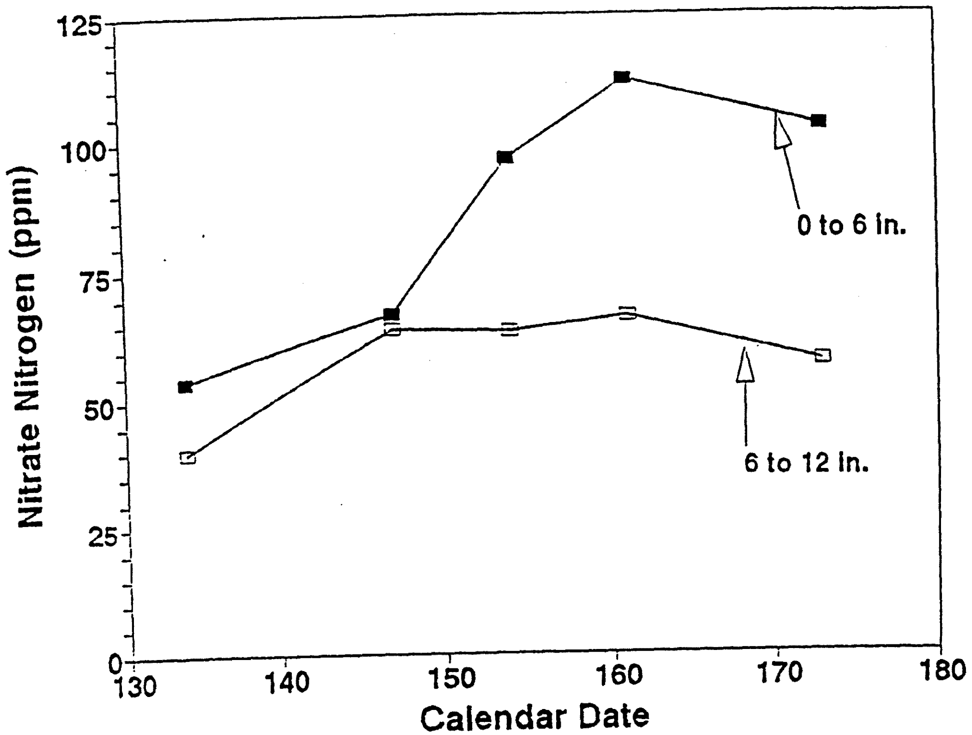

Fig. A.2.13. Early season nitrate-N concentrations which developed in a Sioux sandy loam soil treated with liquid dairy manure in the fall of 1992. Data points are the means of 18 observations.

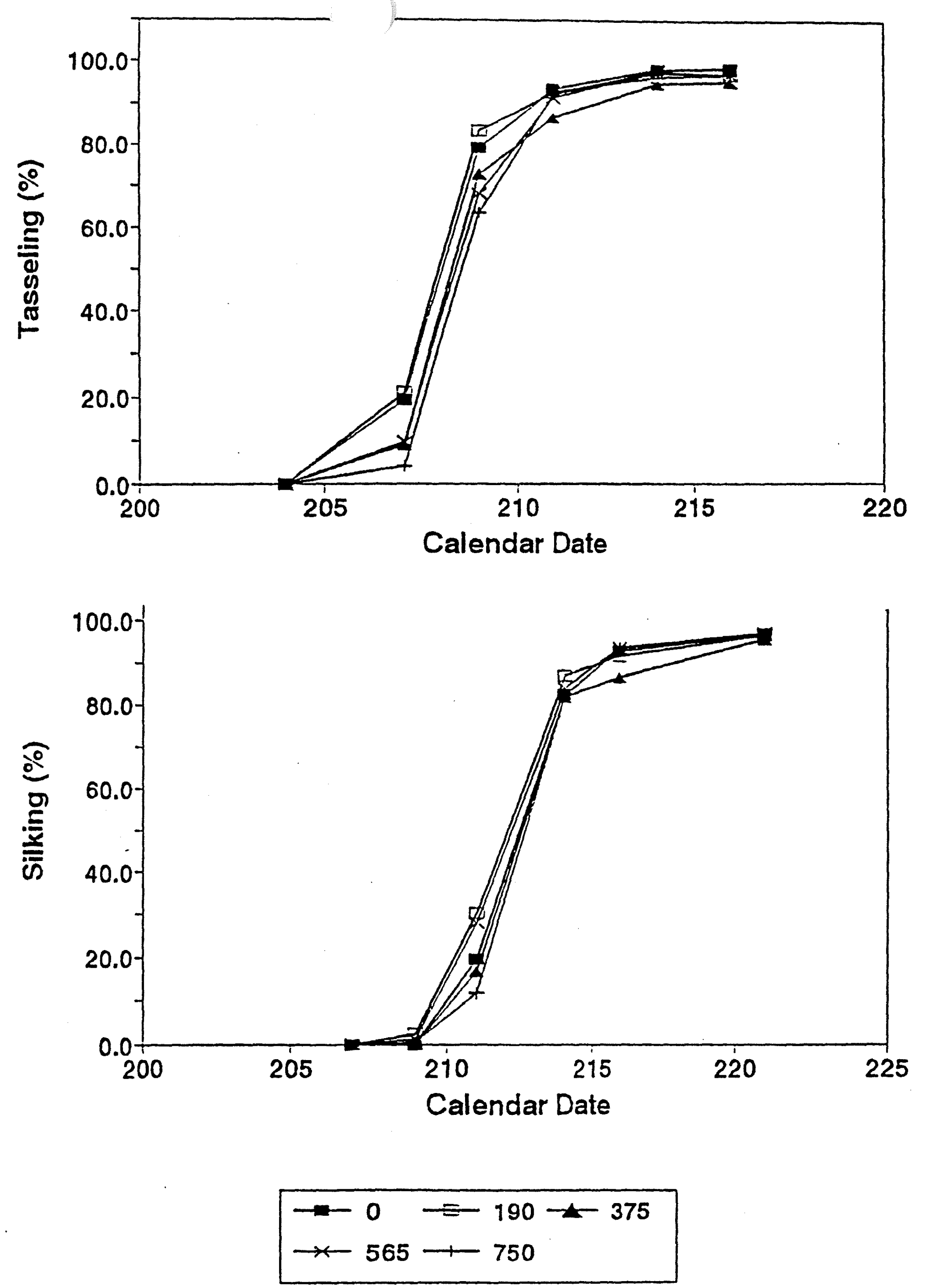

Fig. A.2.14. Flowering of corn on manured Kranzburg silt loam in 1993 as a function of water treatments applied to plots which had received liquid dairy manure in the fall 1992.

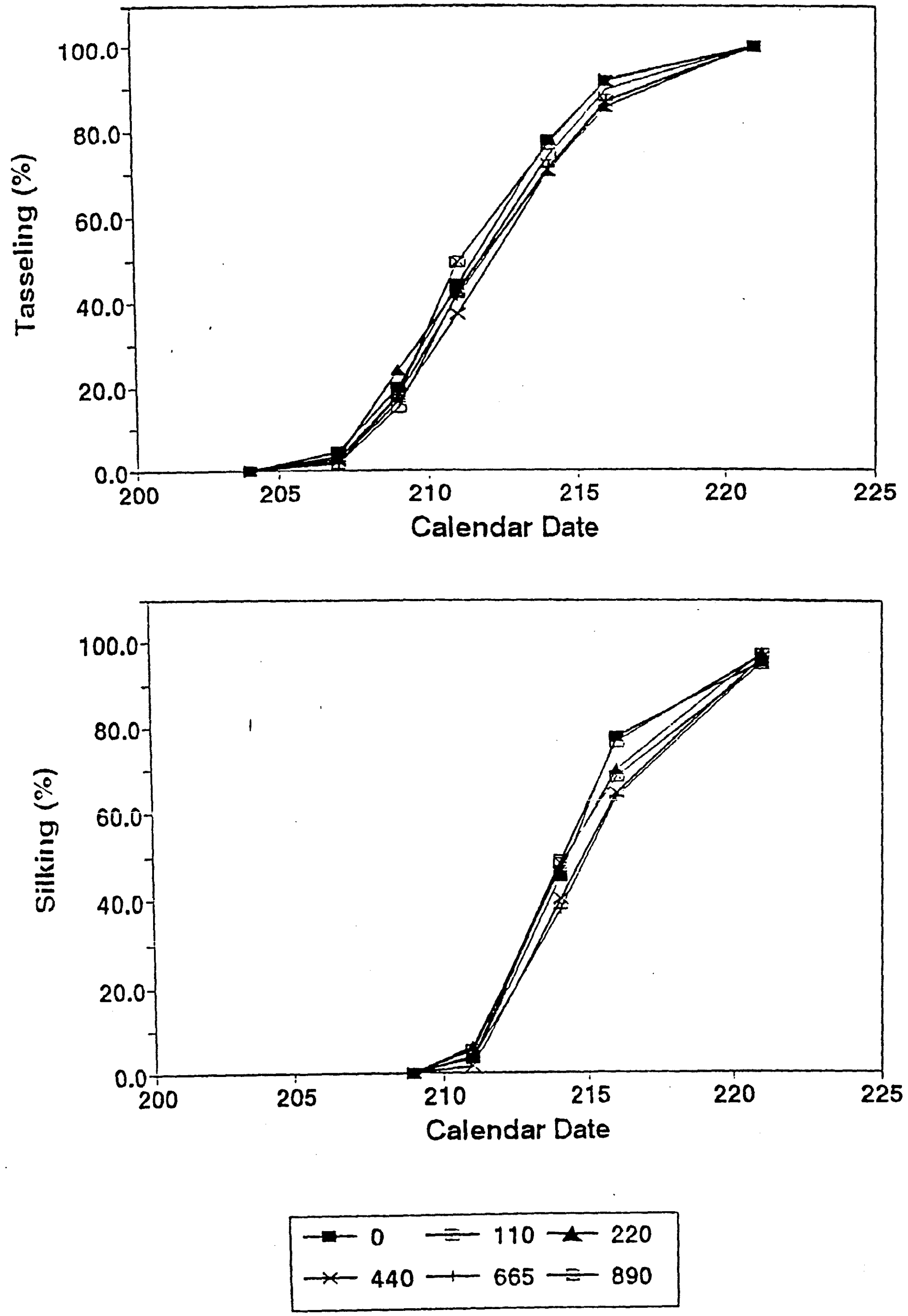

Fig. A.2.15. Flowering of corn on manured Sioux sandy loam in 1993 as a function of water treatm... applied to plots which had received liquid dairy manure i... fall 1992.

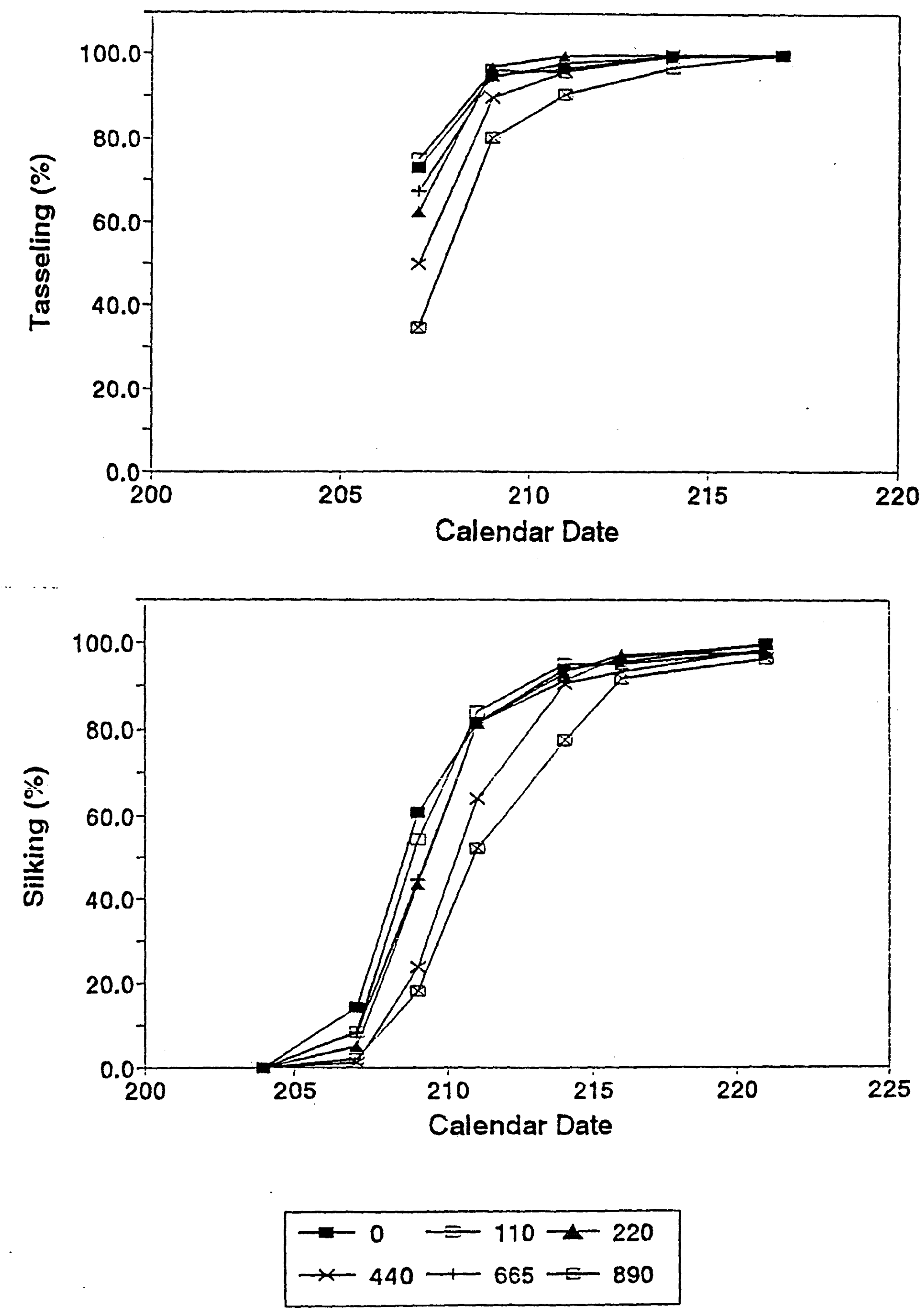

Fig. A.2.16. Flowering of corn on manured Aastad clay loam in 1993 as a functi... of water treatments applied ...ts which had received liquid dairy manure in the fall 1...

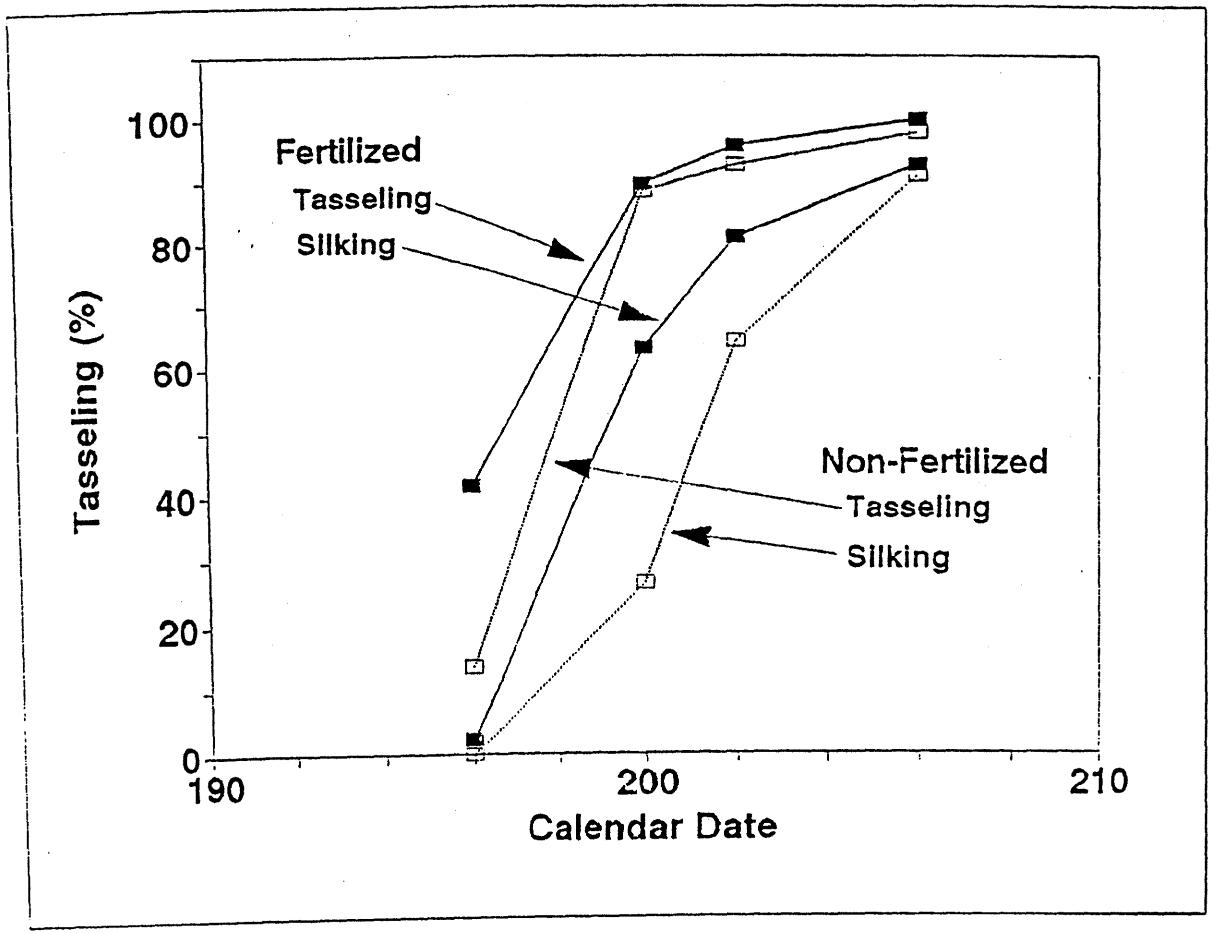

Fig. A.2.17. Effect of manure applicatins on the relative physiological development of corn ona Kraznzburg silt loam soil in 1994.

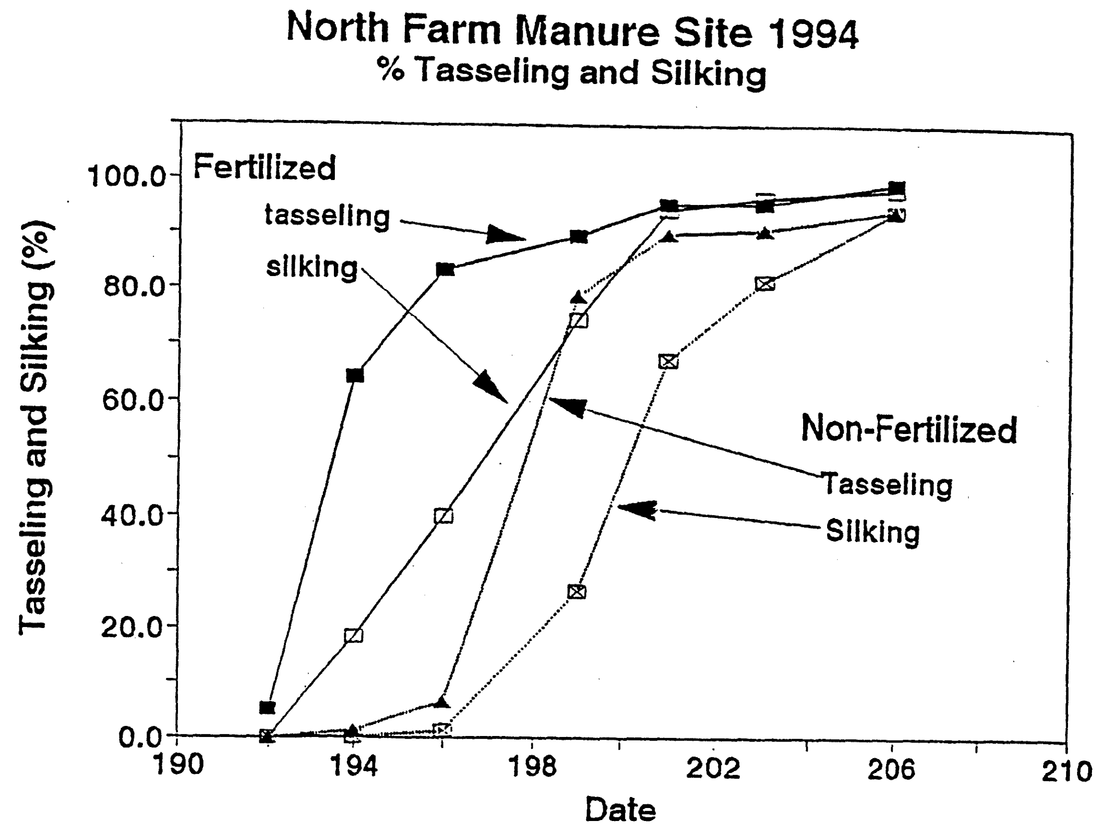

Fig. A.2.18. Effect of manure applicatins on the relative physiological development of corn ona Aastad clay loam soil in 1994.

IV. Research Objectives (continued)

B. Title of Objective: Integrate weather, soil, and climatic factors for N mineralization prediction and develop a predictive computer model for West Central Minnesota.

B.1. Activity: Integrate weather, soil, and climatic factors to simulate carbon and nitrogen dynamics in the soil/plant system for West Central Minnesota. The scope of this activity has been reduced because of the budget reduction. Therefore, modeling will be carried out only on data from a long-term manure study previously conducted at Morris. J.A.E. Molina will spend 5% of his time on this activity over the next two years. P.R. Goodrich will assist in this activity.

B.1.a. Context within the project: Plant available N is at the crossroad of many microbe-mediated transformations: it is biologically produced by N mineralization of the soil organic matter, N rich plant residues, and manure; it is also sought after by microbes during immobilization, a process which competes with the plant for N. An estimate of plant available N during the growing season has to account for the balance between all the processes cited above. This can now be achieved with simulation models, such as Nitrogen and Carbon Simulation in the Soil, Water, Air, and Plant System (NCSWAP), which integrate abiotic and biotic N transformations within the context of farm managerial practices.

B.1.b. Methods: The model NCSWAP will be calibrated to account for the data collected from the "long-term manure study" performed at Morris from 1970 to 1991. This study documents the residual effect on continuous corn of two heavy applications of 1) solid beef manure, 2) liquid beef manure, and 3) liquid hog manure. Two additional treatments (control: no manure or fertilizer and fertilized: NPK applied annually) complete the study.

A stepwise calibration will be performed. Initially the active soil organic matter will be obtained by calibration against results from the first year (1970) control treatment. Once this information has been obtained, the model will be tested on its ability to account for the control and fertilizer experimental results from 1971 to 1991. Data available are: (1) above ground production; (2) total soil C and N; and (3) soil NO_3-N in the top 120 cm at harvest. After completion of this calibration/validation procedure, the manure treatments will be considered. Simulations (1970 to 1991) will be performed for each type of manure. Amounts of inorganic and organic N added to the soil in 1970 and 1971 with the manure will be taken into consideration. Experimental and simulated data (as listed above) will be compared. If needed, the fit between simulated and experimental results will be improved by adjustment of the rate constant of manure (organic matter) decomposition. This will provide the N mineralization rate over a 21-year period.

Once calibration/validation has been achieved, the model will be exploited. The information which can be extracted from running scenarios is unlimited. The best return can be obtained when the model is used as a tool to foster dialogues between scientists and field practitioners. In general, the model can be used to 1) predict, and 2) advise. For example, prediction about N behavior at the site of the "long-term study" could consider: NO_3-N leaching; N loss by denitrification; and residual manure effect (beyond 1992) on yield. Advise could be extended to other sites by taking into consideration different soil and climatic conditions.

B.1.c. Materials: The data from the long-term manure study is in a database file and is readily accessible. Computers are available for the simulation runs.

B.1.d Budget: $193.09 remaining on 6/26/95

B.1.e. Timeline:

	7/93	1/94	6/94	1/95	6/95
Carry out stepwise calibration		******			
Make computer simulation runs		*****			
Fit simulated & experimental data		******			
Exploit model		*******			
Prepare final report					**

B.1 Status:

Abstract

Statement of Objectives:
To validate NCSWAP and to show that the model can be used as a tool to help divise management strategies for the application of manure to soil for conditions corresponding to West Central Minnesota.

Overall Project Results:
Experimental data documenting 20 year (1971-1989) of continuous corn for 3 contrasted treatments (zero-N, fertilizer, and solid beef manure additions) were used to validate the model. The model gave a good estimate of cumulative dry matter production for the zero-N and fertilizer treatments. It over-estimated by about 15 percent the measured yields for the manure treatments between year 1976 and 1986. Simulated and experimental data for the average nitrate concentration in the soil top 4 feet were in accord for the zero-N and manure treatments. From 1971 to 1985, the model underestimated nitrate concentrations for the fertilizer treatments. A triennial low rate of manure application was simulated. While nitrate concentrations in soil were lowered, dry mass production was maintained to that found with the fertilizer. Further simulations indicated that the low manure load applied every four years was not sufficient to sustain maximum yields. Simulation of crop yields from 1971 to 1999 showed that the residual effect of manure was felt for 16 years. Subsequently, dry matter production dropped to that observed for the zero-N treatment. The 28 years simulation confirmed a slow downward trend of yields for the zero-N treatment. Differences between the treatments could be best explained by changes in the active soil organic matter. The half-life of the manure's organic fraction was calibrated to 115 days (.006 day-1 decay rate).

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 NH_4-N and NO_3-N, and (2) organic N which may become plant available upon conversion to NH_4-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 West Central 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.

Experimental Data

A 20 year, continuous corn experiment was started in 1971 by Drs. S. Evans, P.R. Goodrich, R.C. Munter, and R.E Smith. Results from the first four years were reported in the Journal of Environmental Quality (1977). Data covering the period 1971-1989 were used for this study. The experiment was conducted at the University of Minnesota Experimental Station at Morris. Three of the 5 treatments were used for this report: zero-N; fertilizer (about 110 kg N . ha-1. year-1); and solid beef manure added in fall 1970 and 1971 at the annual rate of 1876 kg N-inorganic plus 2412 kg N-organic (C/N=20) . ha-1. Three replication plots were established per treatments. Above-ground dry matter production and nitrate concentration in the top 4 feet of the soil were measured.

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 and nitrate concentration in soil. The model was used to find out (1) management alternatives to manure application; (2) the long term (28 years) behaviour of continuous corn; and (3) c*auses for observed diffences between the treatments in terms of changes in the soil organic fractions (active vs. passive SOM).

Validation and Differences between Treatments:
Experimental and simulated data are shown for the above ground dry matter production in Figures B.1.1, B.1.2, and B.1.3. Simulated data were closest to the experimental data for the zero-N treatment. Validation was achieved for some years for the fertilizer and manure treatments, but failed (at least within the range defined by one standart deviation) for other years, e.g. 1987. The overall performance of the model as well as differences between treatments could be best vizualized by considering the cumulative dry matter production (Figure 4). The 2 manure applications made in fall 1970 and 1971 were sufficient to maintain dry matter production to a level identical to the one achieved with a yearly addition of fertilizer. Dry matter production did not crash with the zero-N treatment, but stabilized to 6 - 8 metric tons per hectare after year 1975. The model gave a good estimate of cumulative dry matter production for the zero-N and fertilizer treatments; but over-estimated by about 15 percent the measured yields for the manure treatments between year 1976 and 1986.

The average soil nitrate concentration in the top 4 feet are shown in Figures B.1.5, B.1.6, and B.1.7. Simulated and experimental data were in accord for the zero-N and manure treatments. From 1971 to 1985, the model underestimated nitrates concentrations for the fertilizer treatments. Notice the extremely high levels of average nitrate concentration (80 ug N . ha-1) in the soil profile for the manure treatment. This level was maintained for 5 years before it started to subside. By 1985, the levels were similar to those found in the zero-N treatment.

The half-life of the manure's organic fraction was calibrated to 115 days (.006 day-1 decay rate).

Simulated Scenarios:
A triennial rate of manure application was simulated. The load of application was also reduced to 313 kg N-inorganic plus 402 kg N-organic (C/N=20) . ha-1. Comparison of the 2 manure management strategies is shown in Figure B.1.8 for the cumulative dry mass production; and Figure B.1.9, for the average nitrate concentration in the soil profile. While the nitrate concentration was lowered, the dry mass production was maintained to that found with the fertilizer. Further simulations indicated that the low manure load applied every four years was not sufficient to sustain maximum yields.

Notice (Figure B.1.9) that 14 years after manure application, the cumulative dry mass declined, suggesting that the residual effect of manure started to subside. This was confirmed by extending the simulation of the high load manure treatment, for another 9 years (climatic conditions were assumed to be the same as those observed for the period 1980-1989). Figure B.1.10 shows that by 1990, the dry matter production had decreased to those levels observed for the zero-N treatment. It also confirms a slow downward trend of yields for the zero-N treatment.

Differences between Treatments Explained by the Kinetics of the SOM:

Figure B.1.11 compares the simulated changes in the total and active SOM for the various treatments. The SOM is expressed in terms of its N content in the top 30 cm. The active SOM corresponds to the potentially mineralizable N of Stanford and Smith (1972). It is represented in the model by the sum of Pool I and Pool II (Houot et al., 1989). Exerimental data for the total SOM were available and are shown in Figure B.1.11 by the vertical lines. They represent the range of values measured: (1) for the soil before the experiment (to the left of the year=0 line) ; and (2) for the manure treatment (to the right of the year=0 line). The increase in total SOM for the manure treatment was large enough to be measured. Five years after manure application, the difference in total SOM between the treatments was too small to be detectable experimentally (in the order of 75/2000 or about 4 percent).

Differences between the treatments could be best explained by changes in the active SOM (Figure B.1.12). On year 7 of the experiment, the active SOM for the fertilizer treatment had stabilized. By contrast, the active SOM for the manure and zero-N treatments continued to decrease. By year 13, the active SOM of the manure treatment became lower than the one for the fertilizer treatment; and converged towards the level of the zero-N treatment. This pattern of changes followed that which had been observed for the dry matter production (Figure B.1.10). Notice that the difference in active SOM between the fertilizer and zero-N treatments is in the order of 75/150 or 50 per cent. This difference should be accessible to experimental determinations. It confirms that methods to measure the active soil organic matter would give access to a direct estimate of soil health.

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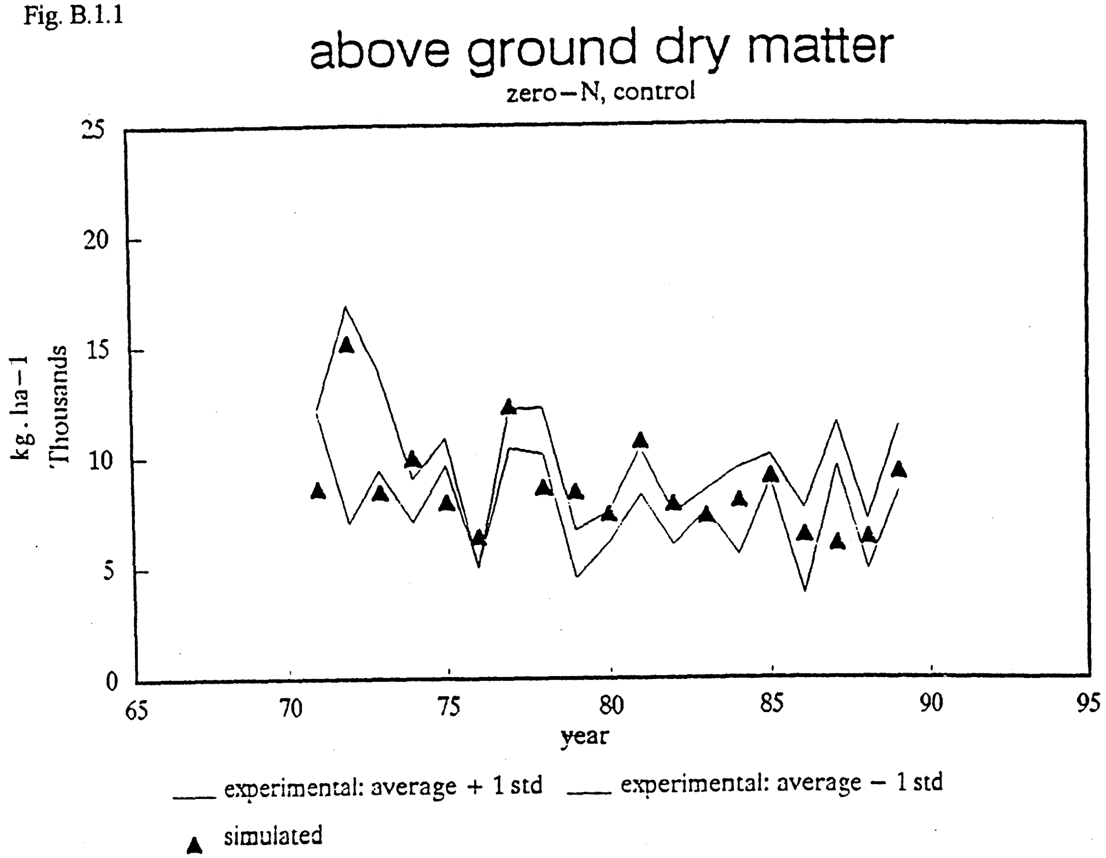
Fig. B.1.1



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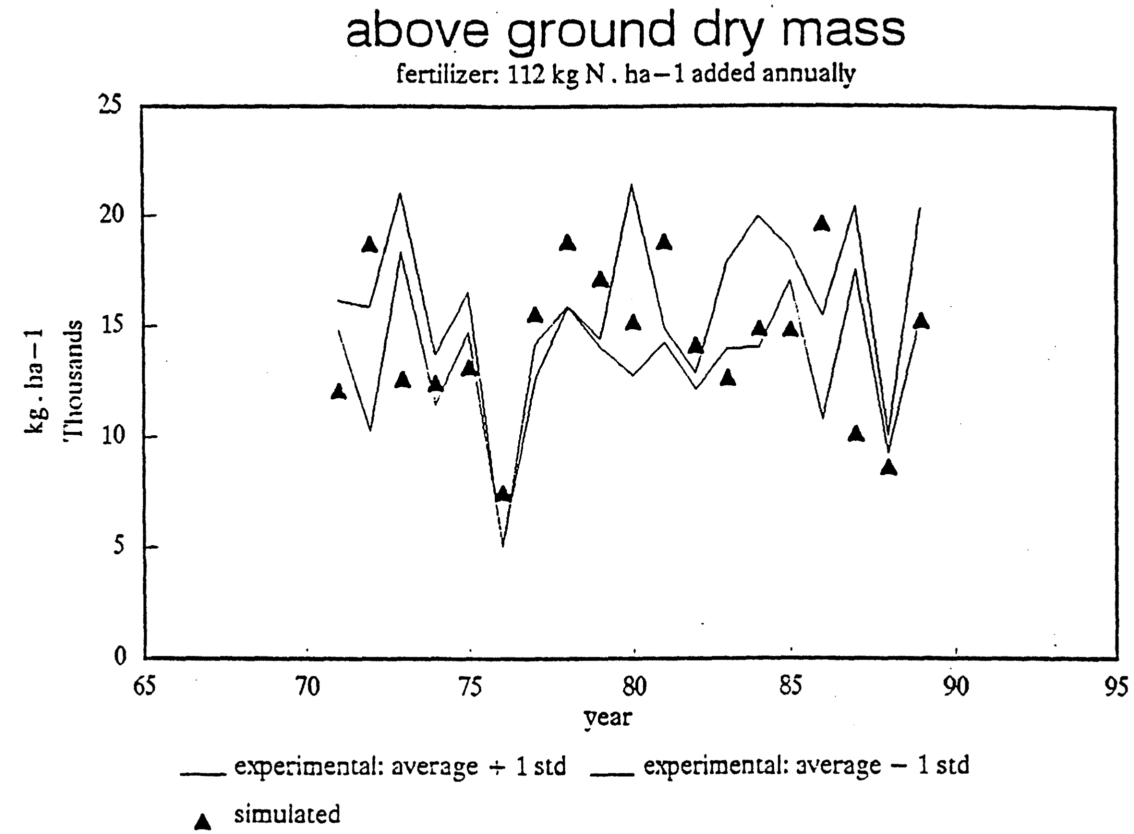

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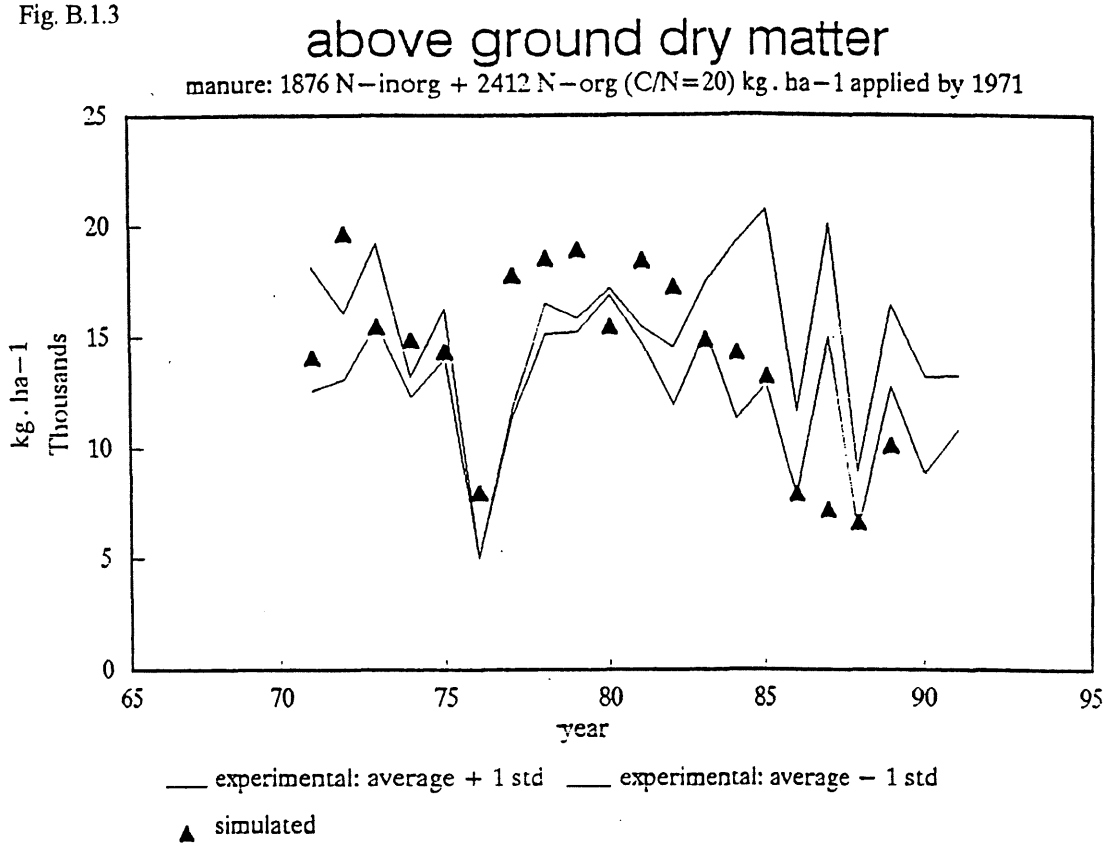

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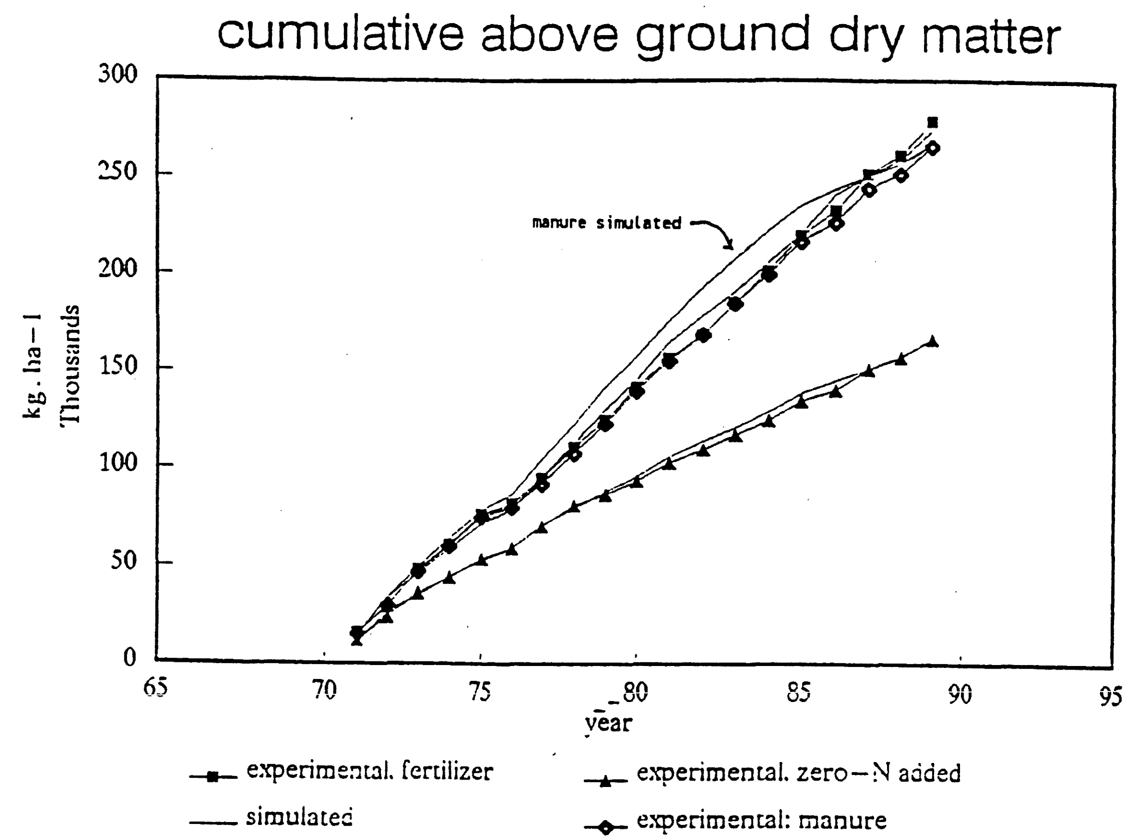

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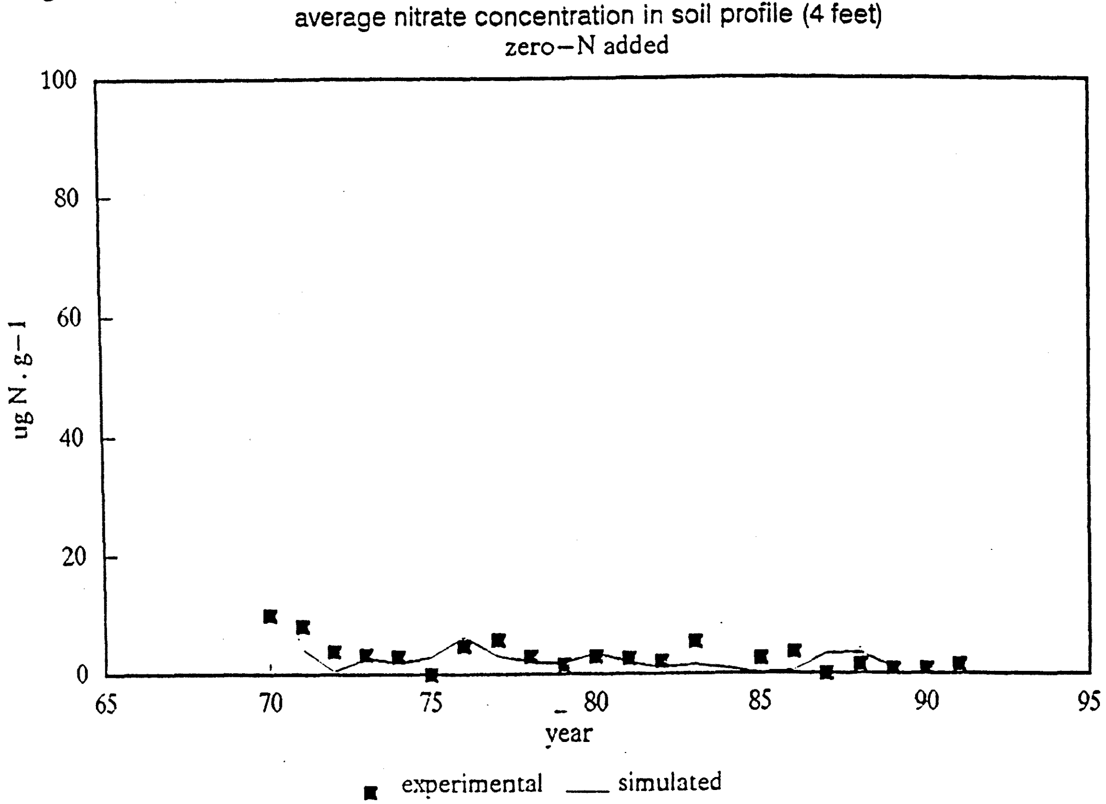
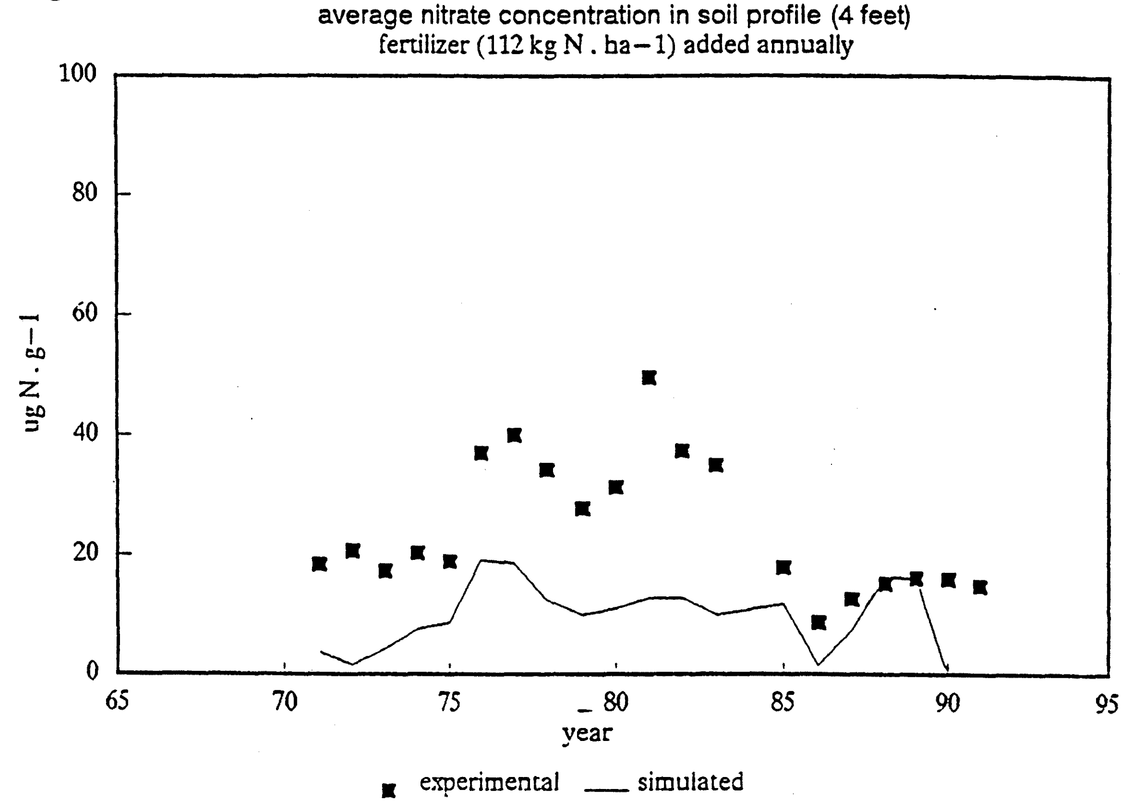


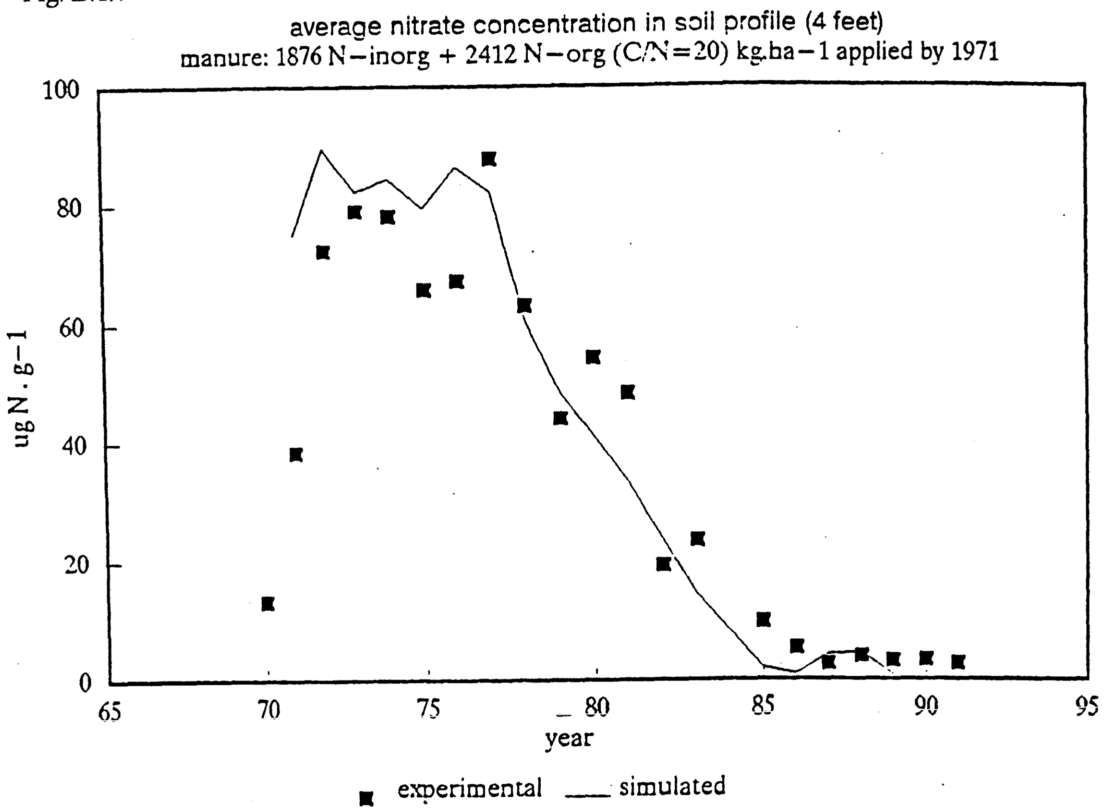
soil samples taken in fall after harvest

Fig. B.1.6



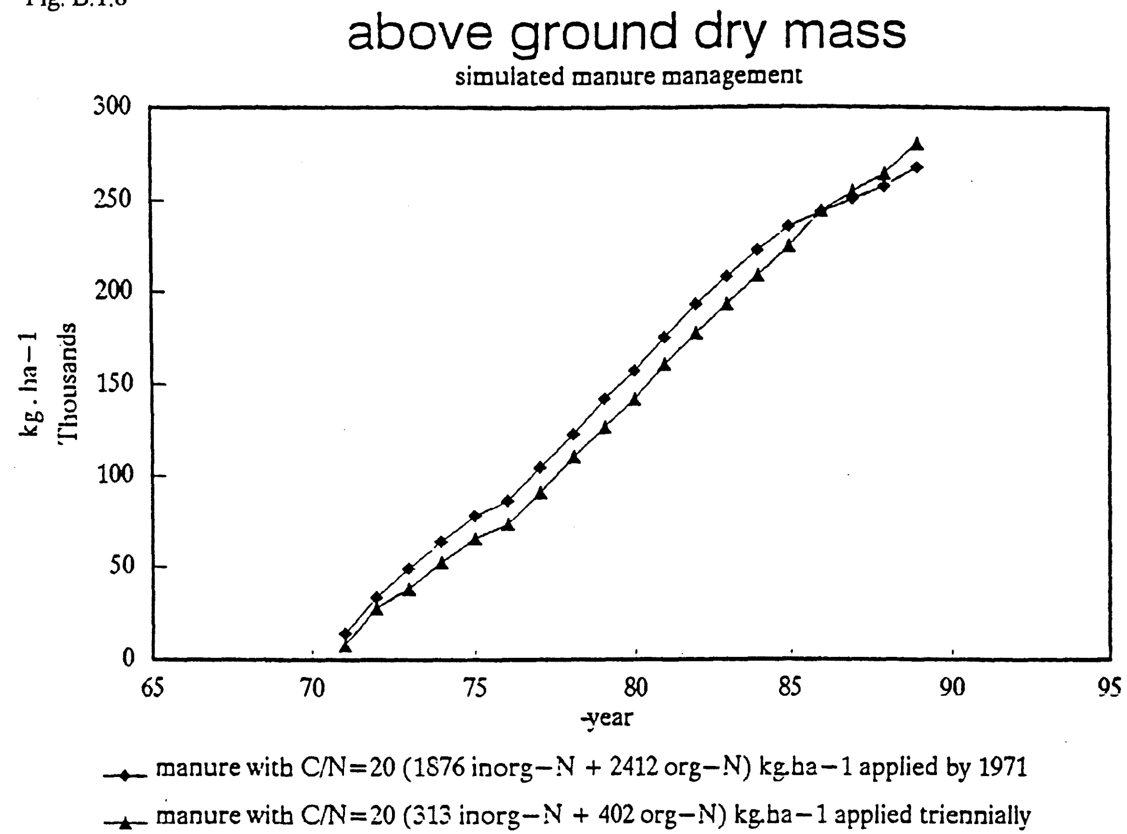
soil samples taken in fall after harvest

Fig. B.1.7



soil samples taken in fall after harvest

Fig. B.1.8



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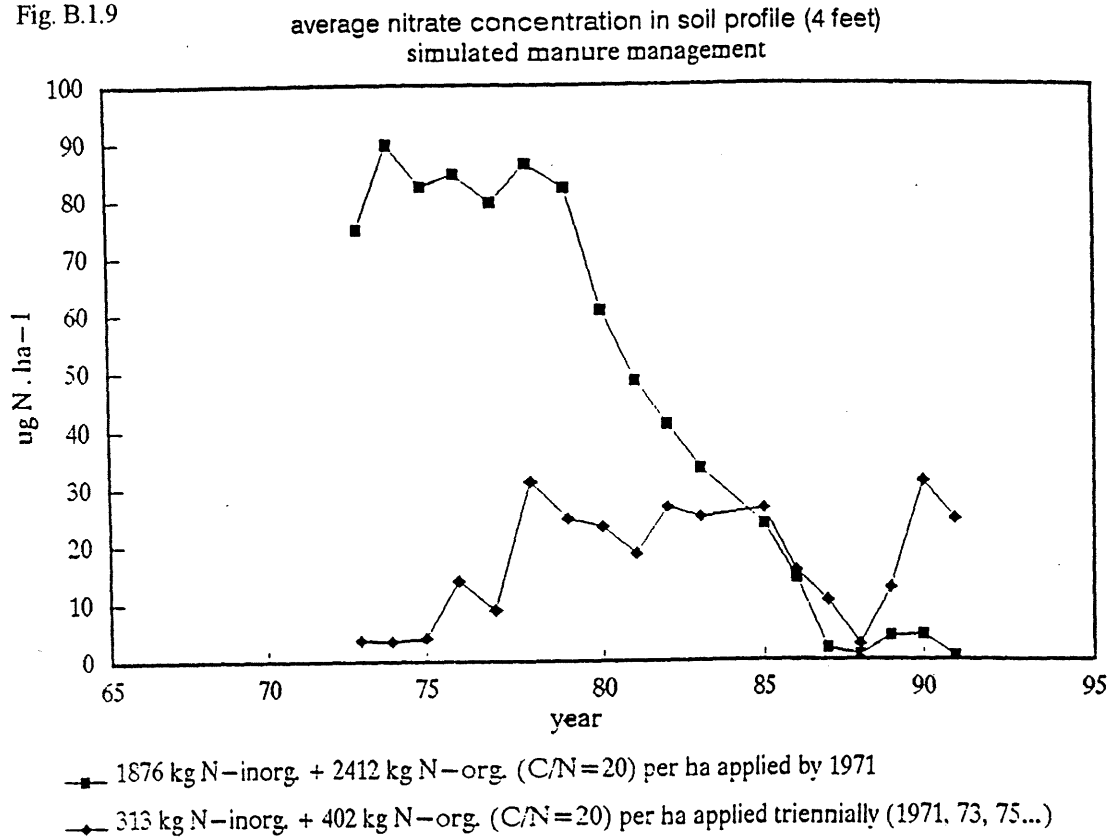

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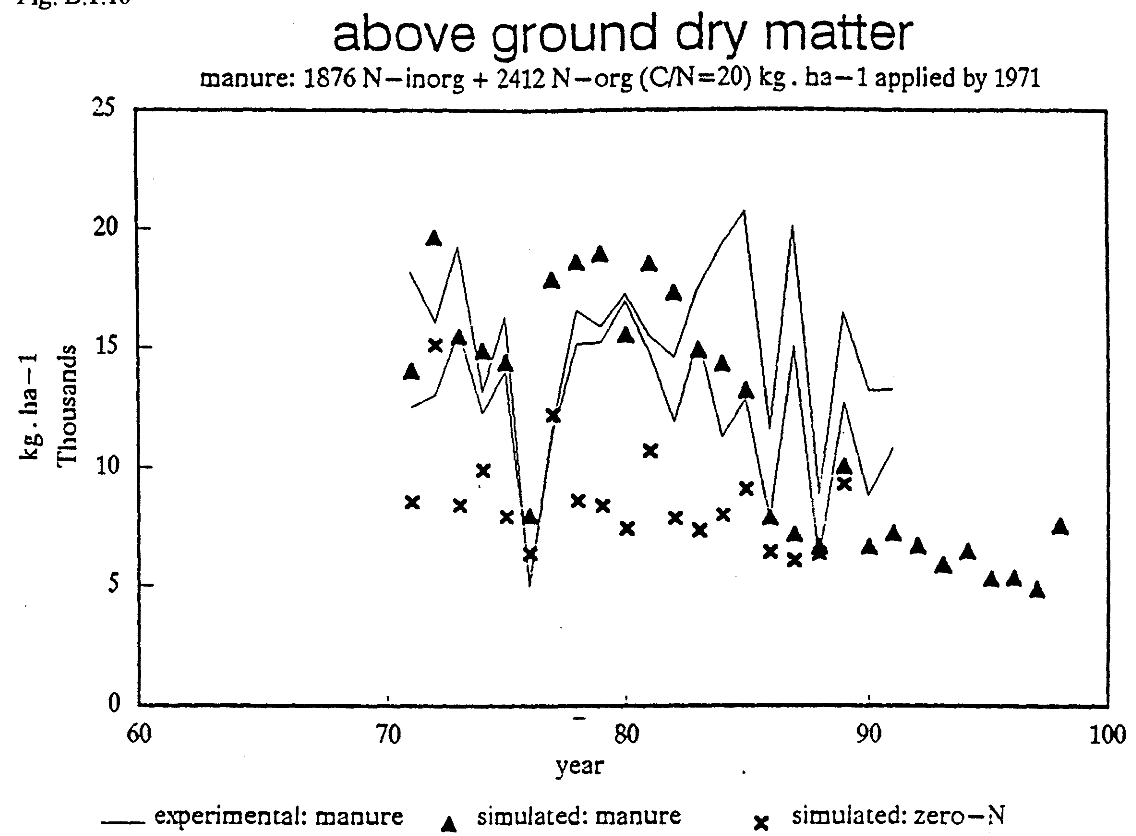


Fig. B.1.11

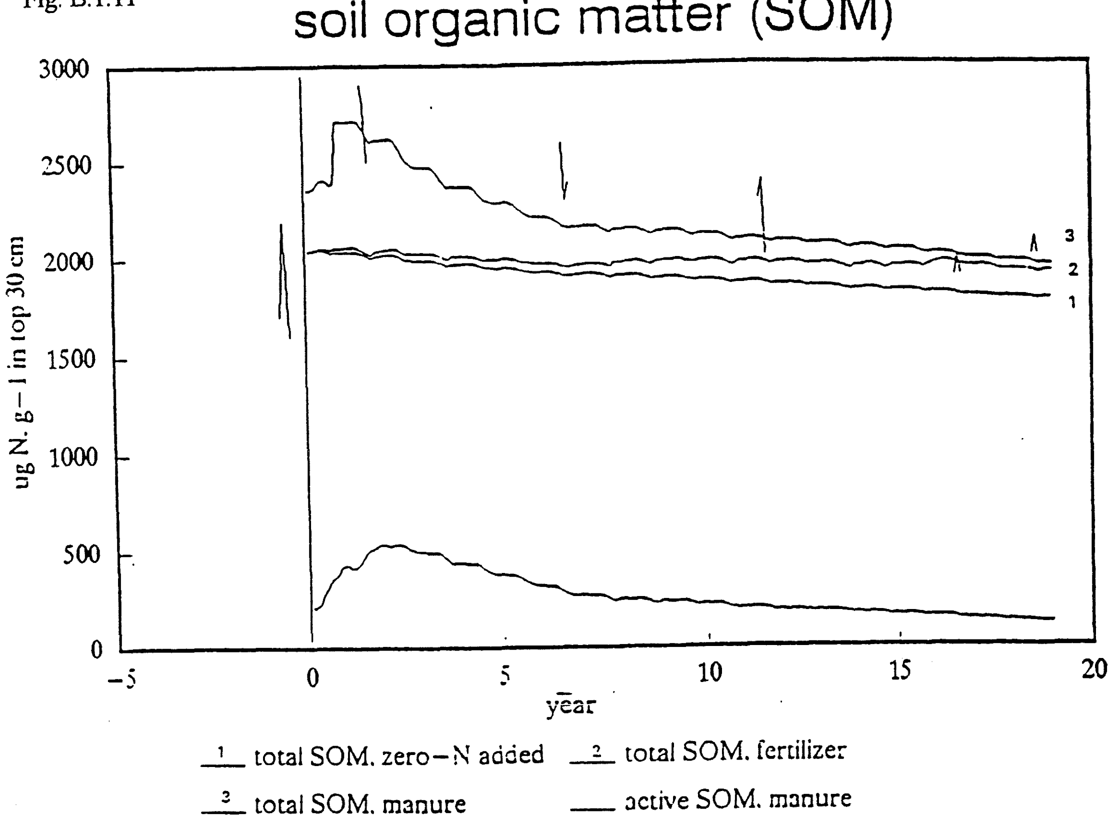
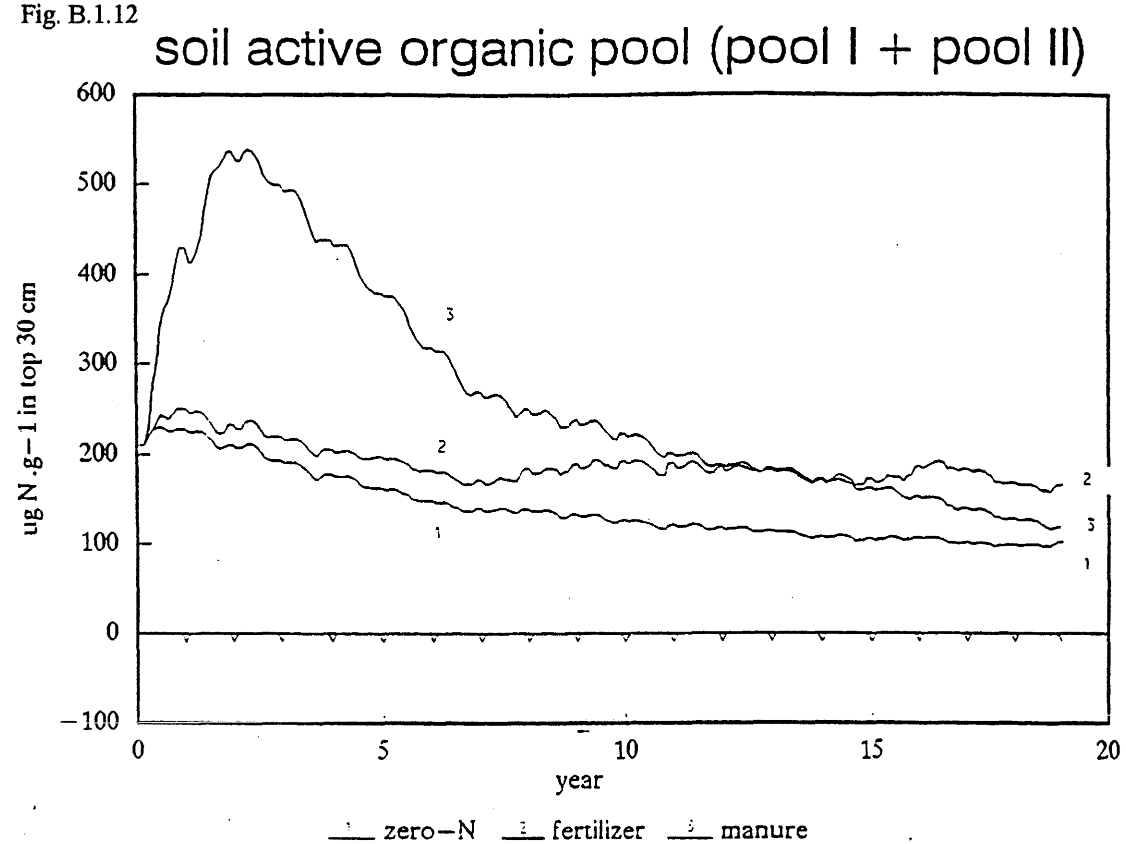


Fig. B.1.12



IV. **Research Objec... es (continued)**

B. Title of Objective: Integrate weather, soil, and climatic factors for N mineralization prediction and develop a predictive computer model for West Central Minnesota.

B.2. Activity: Field experiments to assess soil and climatic impacts on plant available nitrogen. The scope of this activity has been reduced because of budget reduction. The funds will permit detailed measurement on only 8 plots. C.F. Reece and M.W. Seeley will spend 10% and 5% of their time respectively over the next two years working on this activity and supervising graduate students.

B.2.a. Context within the project: Nitrogen available to plants from manure in the soils of West Central Minnesota is regulated by highly variable soil and climatic conditions, particularly in the early spring. To date, soil and climatic measurements in this part of the state have been too few and insufficient in detail to derive explanations for varying N availability indicated by soil testing. Sufficiently detailed soil and climatic measurements can be used to develop simple predictive models for plant available N. Weather conditions can then be used to estimate the occurrence of above- or below-normal N availability from manure or native soil organic matter. With such a tool, producers could better determine optimum side-dress N rates to meet their yield goals, reducing input costs and preventing application of excess manure or inorganic N fertilizers.

B.2.b. Methods: Eight of the plots used in the experimental design for activity A.1 (4.5-m x 12.2-m) will be instrumented to measure temperature and moisture profiles in the soil. The plots will encompass two replications of four treatments (base rates of liquid dairy and swine manure, urea to provide 135 kg N/ha, and the control treatment). Soil measurements will be made at the 1, 15, 30, and 60 cm depths using heat dissipation sensors. In addition, rainfall, solar radiation, wind speed and direction, air temperature and humidity will be recorded on a daily basis. Pre-manure application measurement of NO_3-N and NH_4-N at 30-cm increments to 150 cm (taken in activity A.1) will be supplemented with biweekly measurement to a depth of 60 cm in 30-cm increments in all eight plots until stage V4-V5. The sum of NO_3-N and NH_4-N will define the plant available N. Plant available N will be related to soil temperature and moisture measurements using time-series analysis (Krupa and Nosal, 1989a,b). Using the West Central Experiment Station climatological data (dating from 1885) in conjunction with the climatic data measured during the field experiment, predictive models of soil temperature and moisture (Campbell, 1985) will be run over the compete time series to determine distribution frequencies for soil temperature and moisture. Weekly probability distributions for critical soil temperature and moisture conditions which relate closely to the measured plant available N will then be estimated. Field days will be utilized to publicize results. These results will be synthesized in extension publications for use by growers and county agents..

B.2.c. Materials: Campbell Scientific data loggers, multiplexers and sensors will be used. Two data loggers will be required. Data will be stored in the field and transferred to computers using storage modules on at least a weekly basis during the growing season. Data loggers will be used year round to record depth and duration of the soil frost in the four treatments, as this relates to the start of the field season each spring. NO_3-N and NH_4-N measurements in 30-cm increments will be taken using three probes/plot on a biweekly basis.

B.2.d. Budget: $535.06 remaining on 6/26/95

B.2.e. Timeline:

In order to properly carry out this activity, equipment must be installed at the experimental site in the fall of 1992 and measurements continued until the official start of the project on 7/93.

	7/93	1/94	6/94	1/95	6/95
Inventory historical data	**********				
Field measurements	*****************************				
Modeling plant available N changes		******************************			
Probability distributions from long-term weather data				***********	

Status:

Field experiments were conducted at the West Central Experiment Station in Morris during the 1993 and 1994 crop seasons for the purpose of studying the effects of soil moisture and temperature on the release of plant available nitrogen (PAN) from manure sources (dairy and swine manure) and traditional urea fertilizer. Soil samples for nitrate-N and ammonium-N were taken frequently during both growing seasons. The climatic elements measured included soil temperatures, soil water potential, air temperature, relative humidity and precipitation.

A summary of the temperature and moisture characteristics of each year in the study was compiled. 1993 was one of the coolest growing seasons in the historical record at Morris (1886-1994) and also one of the wettest. Because of these features, measured mineralization rates of N were much lower during 1993 than during 1994, which was characterized by very favorable conditions in late April and May for mineralization of nitrogen.

Because year to year variability is so great in western Minnesota, an inventory and summary of the standard climatic variables (temperature and precipitation) were done for the complete station record (1886-1993). Weekly probability distributions associated with maximum and minimum temperature, as well as precipitation were computed (see detailed report Tables B.2.4.1 through B.2.4.3). There is a 50 percent probability for maximum temperatures to reach 50 degrees F or greater during the week of April 12-18. This corresponds to the average time (April 10-15) when the last of the soil frost goes out and microbiological activity in the soil begins to accelerate. This also corresponds to a period when the weekly probability of significant precipitation begins to climb. From the third week of April through the balance of the spring, climatological probabilities increase in favor of more rapid mineralization of nitrogen. However, there is a high degree of variability in both temperature and moisture conditions during the early spring in evidence by the relatively large standard deviations in weekly values. Likewise, large standard deviations in climatic parameters can be noted in the fall, starting in September. Because of this high degree of climatic variability, N mineralization rates in the early spring and the early fall can be expected to vary greatly as well. Manure applied in the late fall or during the winter on occasion will be subject to significant mineralization rates in late March or early April, while manure applied in the early fall may be subject to relatively high mineralization rates even as late as mid November.

The climatology of soil temperatures at Morris (1983-1993) shows a similar trend in variability associated with the spring and fall. Average four inch soil temperatures reach 50 degrees F about the last week of

April, with standard deviations of 5 to 6 degrees. The average four inch soil temperatures drop below 50 degrees F in the fall about mid October, with standard deviations of 5 to 6 degrees. 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. Manure applied to the soil after October 15 would be subject to little mineralization in most years. Average soil freezup is on or about November 29 at which point most biological and chemical activity within the soil all but cease for the winter.

Using a soil moisture submodel taken from the CERES-Maize model of corn growth and development published by Jones and Kiniry (1986), soil moisture estimates were made from the Morris historical climatic records (1886-1994) in order to derive the temporal distribution characteristics for the relevant layer of soil where the majority of mineralization occurs. The model was run using the water holding characteristics for a Hamerly silty clay loam, one of the soil series on the West Central Experiment Station. This soil is capable of holding 2.52 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 examined. At the 50 percent probability level, soil moisture is at 1.2 inches or greater for the period from April to mid July. After mid July, soil moisture values fall to less than one inch and reach the lowest level in late August and early September. Thus the lack of soil moisture becomes a limiting factor to continued high mineralization rates during this time. For 70 percent of the years examined soil moisture values remain below 1 inch in the top foot for much of the September, October and November period as well.

Though both mineralization and leaching potential of nitrogen are primarily a function of N source as well as soil temperature and moisture conditions, specific heavy rainfall events trigger more rapid movement within the soil profile and can produce large leaching loss by themselves. For this reason, an analysis of the frequency of heavy rainfalls, ranging from 1 inch to greater than 3 inches was done on the Morris climatic record (1886-1994). On average, five rainfall events of 1 inch or greater are measured each year at Morris, while two inch rainfalls occur with a frequency of about once each year.. The frequency distribution shows that the largest number of these heavy rainfall events occur in June and July, a time when mineralization rates are relatively high. August shows slightly less frequency. Both May and September show a frequency of one and two inch rains which is approximately half that of June and July. A temporal analysis by decade shows that the frequency of heavy rainfall has increased at Morris over what it was earlier this century. For example the smoothed decadal frequency of 1 inch rains at the present time is approximately 150 percent of what it was during the decades of the 1920s and 30s. An examination of the extreme precipitation events shows that a seven inch rainfall is possible even in April when spring applications of nitrogen (as manure or inorganic fertilizer) are often made.

Benefits: Historical climatic probabilities derived from this work can be used to evaluate best management practices for the application of manure and inorganic fertilizers. The temporal probability distributions for temperature and moisture provide indications of relative N mineralization rates and the risks of losing significant amounts of nitrogen to denitrification and leaching.

Detailed Reports on Activity B.2 Field experiments to assess soil and climatic impacts on plant available nitrogen (PAN).

Contents of Detailed Reports:

B.2.1 Inventory of h al climatic data for the West Central Experiment Sta Morris, MN

Introduction: The National Weather Service established a cooperative climate station at the West Central Experiment Station (formerly West Central Agricultural School) in April of 1885. Since that time a daily record of maximum and minimum temperatures, along with precipitation has been kept by the personnel of the experiment station. In more recent decades, observations and measurements of solar radiation, evaporation, wind speed and direction, humidity, soil temperatures, and soil moisture have been added to the climatic records. For the purpose of examining the long term temporal variability of climatic parameters, the Morris site is the single best climatic record in west central Minnesota, with less than 2 percent of the historical data missing from the state data base.

Results: The complete digitized daily historical data are available through the computer data base maintained by the Minnesota State Climatology Office (DNR-Division of Waters). Summaries of this historical data base can be found in Tables B.2.1.1 through B.2.1.7. The most extreme climatic conditions found in these distributions cannot be compensated for by any particular best management practices for handling manure and fertilizer applications, however these distributions provide a context for interpreting the results of the field experiments conducted during the 1993 and 1994 growing seasons to study plant available nitrogen released from manure and urea sources.

Table B.2.1.1 Distribution of daily and monthly temperature values at Morris, MN (1886-1994).

Averages: 1886-1995 Extremes: 1886-1995

	Averages			Daily Extremes				Mean Extremes				#Day-Max		#Day-Min	
MO	Max	Min	Mean	High	Date	Low	Date	High	Yr	Low	Yr	=> 90	<= 32	<= 32	<= 0
Ja	18.2	-1.7	8.3	60	25/1981	-40	21/1888	25.9	44	-8.5	'87	0.0	25.3	30.8	17.2
Fe	23.0	2.9	13.1	60	25/1902	-41	16/1936	30.0	31	-6.7	36	0.0	20.4	28.0	12.8
Ma	36.4	17.4	27.1	83	23/1910	-30	11/1948	43.1	10	12.7	'88	0.0	11.6	28.1	3.9
Ap	54.6	32.6	43.8	98	22/1980	-2	7/1936	53.0	15	33.2	50	0.0	1.1	15.5	0.0
Ma	68.2	44.4	56.5	106	31/1934	18	3/1907	67.0	34	46.0	7	0.8	0.0	2.9	0.0
Jn	77.0	54.8	66.1	104	28/1931	27	1/1929	75.4	33	59.1	69	2.5	0.0	0.1	0.0
Jl	82.4	59.3	71.0	109	18/1940	37	12/1927	78.4	36	63.2	92	4.9	0.0	0.0	0.0
Au	80.5	56.7	68.8	110	20/1916	31	30/1931	76.3	0	63.7	85	4.1	0.0	0.0	0.0
Se	70.8	46.9	59.1	106	10/1931	20	29/1899	66.9	31	50.2	65	1.2	0.0	1.8	0.0
Oc	58.6	35.3	47.2	93	5/1947	1	29/1895	57.3	63	35.9	25	0.1	0.4	11.8	0.0
No	38.8	20.3	29.8	76	1/1938	-27	28/1891	39.7	'99	15.9	'96	0.0	9.3	26.5	2.1
De	24.3	6.3	15.4	69	6/1939	-34	29/1887	27.2	59	-1.2	83	0.0	21.6	30.5	11.0
An	52.8	31.4	42.3	110	8/20/16	-41	2/16/36	48.5	31	38.2	78	13.6	89.7	176.0	47.0
Wi	21.9	2.6	12.4	69	12/ 6/39	-41	2/16/36	25.7	31	-1.9	'87	0.0	67.3	89.2	41.0
Sp	53.0	31.5	42.5	106	5/31/34	-30	3/11/48	49.6	77	33.9	'88	0.8	12.7	46.5	3.9
Su	79.9	56.9	68.6	110	8/20/16	27	6/ 1/29	73.4	88	63.5	15	11.5	0.0	0.1	0.0
Fa	56.2	34.3	45.5	106	9/10/31	-27	11/28/91'	51.8	53	38.3	'96	1.3	9.7	40.1	2.1

Table B.2.1.2 Distri on of Daily and Monthly Precipitation Values at Morris, MN (1886-1994).

Averages: 1886-1995 Extremes: 1886-1995

	Total Precipitation							Snow			#Days Precip		
	Mean	High	Yr	Low	Yr	1-Day Max		Mean	High	Yr	=>.10	=>.50	=>1.
Ja	0.68	2.70	75	0.00	42	1.21	31/1926	9.3	33.7	75	2.4	0.2	0.0
Fe	0.66	3.20	22	0.00	34	1.15	14/1926	7.7	20.0	62	2.2	0.3	0.0
Ma	1.19	3.82	40	0.00	'95	1.93	28/1940	10.0	46.5	51	3.5	0.7	0.1
Ap	2.27	8.54	54	0.12	26	6.90	26/1954	3.5	13.2	66	5.2	1.6	0.4
Ma	2.94	8.89	42	0.20	28	3.64	31/1959	0.1	4.0	54	6.3	2.0	0.5
Jn	3.94	12.53	14	0.32	0	5.20	26/1914	0.0	0.0	0	7.4	2.6	1.0
Jl	3.64	9.77	49	0.34	36	4.84	8/1929	0.0	0.0	0	5.8	2.3	1.1
Au	2.98	11.68	'99	0.14	49	4.34	18/1935	0.0	0.0	0	5.3	1.9	0.7
Se	2.26	7.49	21	0.22	79	3.00	12/1897	0.0	0.5	65	4.8	1.4	0.5
Oc	1.67	9.21	84	0.00	'89	3.60	15/1984	0.8	9.5	51	3.8	1.0	0.3
No	0.98	4.05	30	0.01	4	1.92	20/1930	5.8	20.9	77	2.7	0.5	0.1
De	0.65	3.48	68	0.00	'94	1.00	3/1891	7.4	34.6	68	2.1	0.3	0.0
An	23.78	34.10	84	8.36	76	6.90	4/26/54	44.8	89.2	51	52.0	14.8	4.8
Wi	1.99	6.67	69	0.40	42	1.21	1/31/26	24.5	64.5	69	6.8	0.7	0.1
Sp	6.41	14.74	'96	2.10	76	6.90	4/26/54	13.5	51.2	51	15.1	4.2	1.0
Su	10.59	17.66	'99	4.85	36	5.20	6/26/14	0.0	0.0	0	18.6	6.9	2.8
Fa	4.91	11.68	71	0.58	35	3.60	10/15/84	6.4	24.2	71	11.5	3.0	0.9

Table B.2.1.3 Average Monthly and Annual Growing Degree Days for Various Base Temperature Values at Morris, MN (1886-1994).

Growing Degree Days to Selected Base Temperatures (F)

Base		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
40	M	0	1	23	182	504	769	951	884	566	259	28	1	4168
	S	0	1	24	206	710	1479	2430	3314	3880	4139	4167	4168	
45	M	0	0	9	104	363	621	796	729	422	157	9	0	3210
	S	0	0	9	113	476	1097	1893	2622	3044	3201	3210	3210	
50	M	0	0	3	53	237	474	642	575	289	84	2	0	2359
	S	0	0	3	56	293	767	1409	1984	2273	2357	2359	2359	
55	M	0	0	1	23	138	332	487	422	177	36	0	0	1616
	S	0	0	1	24	162	494	981	1403	1580	1616	1616	1616	
60	M	0	0	0	8	69	205	336	276	94	13	0	0	1001
	S	0	0	0	8	77	282	618	894	988	1001	1001	1001	

Corn Growing Degree Days

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
50	M	0	1	19	120	303	481	622	568	343	164	21	1	2643
	S	0	1	20	140	443	924	1546	2114	2457	2621	2642	2643	

M = Monthly Data S = Running Sum of Monthly Data

Table B.2.1.4 Spring and Fall Minimum Temperature Distribution and Length of Growing Season Characteristics for Morris, MN (1886-1994).

Base Temp	Date of Last Spring Occurrence Median	Early	90%	10%	Late	#yrs	Date of First Fall Occurrence Median	Early	10%	90%	Late	#yrs
32	5/11	4/04	4/27	5/26	6/07	108	9/25	8/22	9/13	10/10	10/28	108
30	5/07	4/05	4/20	5/21	6/07	108	9/30	9/03	9/19	10/17	11/02	108
28	4/30	4/04	4/10	5/15	6/06	108	10/06	9/03	9/21	10/23	11/02	108
24	4/16	3/20	4/03	5/04	5/21	108	10/16	9/12	9/27	11/03	11/10	108
20	4/08	3/10	3/23	4/27	5/12	108	10/30	9/22	10/12	11/13	11/27	108
16	3/31	2/25	3/18	4/13	4/30	108	11/08	10/07	10/20	11/18	12/01	108

Base Temp	Length of Season (Days) Median	Shortest	10%	90%	Longest	#yrs
32	137	99	119	158	180	108
30	148	109	127	171	184	108
28	160	109	136	185	202	108
24	183	134	161	206	218	108
20	203	168	180	223	236	108
16	220	182	201	241	253	108

Table B.2.1.5 Probability Distribution for Daily Maximum Temperatures at Morris, MN (1886-1994).

MO	Low	5%	10%	25%	50%	75%	90%	95%	High
Ja	-25	-6	-2	8	20	30	36	40	60
Fe	-22	0	4	14	25	34	40	45	60
Ma	-12	16	21	29	36	44	54	60	83
Ap	18	34	37	45	54	64	73	77	98
Ma	30	49	53	60	69	77	83	87	106
Jn	47	62	65	71	77	83	89	91	104
Ju	57	70	73	77	82	87	92	95	109
Au	54	67	70	75	81	86	91	93	110
Se	39	53	56	63	71	78	85	89	106
Oc	18	38	42	50	59	68	75	80	93
No	-3	19	24	31	39	48	56	61	76
De	-25	0	5	16	26	34	40	43	69
An	-25	9	18	33	56	75	84	88	110
Wi	-25	-3	2	12	24	33	39	43	69
Sp	-12	24	30	39	54	67	77	82	106
Su	47	65	69	75	80	86	91	93	110
Fa	-3	27	32	43	58	70	79	83	106

Table B.2.1.6 Probability Distribution for Daily Minimum Temperatures at Morris, MN (1886-1994).

MO	Low	5%	10%	25%	50%	75%	90%	95%	High
Ja	-38	-24	-21	-12	-2	10	19	23	37
Fe	-41	-21	-17	-8	4	15	24	28	39
Ma	-30	-6	0	10	20	28	32	35	54
Ap	-2	18	21	27	32	38	44	48	66
Ma	18	30	33	38	44	50	56	59	76
Jn	27	41	44	50	55	60	64	66	92
Ju	37	48	51	55	59	64	68	70	83
Au	31	45	48	52	57	62	65	68	90
Se	20	32	35	40	47	53	58	62	79
Oc	2	20	23	29	35	42	48	52	68
No	-20	-1	5	14	22	29	33	36	52
De	-32	-18	-13	-4	8	17	24	27	54
An	-41	-12	-3	15	33	51	60	63	92
Wi	-41	-22	-18	-9	3	15	22	26	54
Sp	-30	4	12	24	32	42	50	54	76
Su	27	44	47	52	57	62	66	68	92
Fa	-20	9	15	25	34	45	52	57	79

Table B.2.1.7 Probability Distribution for Monthly Precipitation at Morris, MN (1886-1994).

MO	1%	5%	10%	25%	50%	75%	90%	95%	99%
Ja	0.00	0.08	0.14	0.29	0.57	0.98	1.48	1.84	2.66
Fe	0.00	0.09	0.15	0.30	0.56	0.93	1.37	1.69	2.40
Ma	0.00	0.23	0.37	0.65	1.07	1.64	2.28	2.73	3.71
Ap	0.23	0.49	0.69	1.14	1.87	2.85	3.99	4.78	6.53
Ma	0.39	0.76	1.04	1.67	2.63	3.91	5.36	6.37	8.56
Jn	0.54	1.04	1.41	2.24	3.51	5.19	7.10	8.42	11.30
Ju	0.60	1.06	1.40	2.13	3.21	4.60	6.16	7.23	9.54
Au	0.33	0.69	0.96	1.60	2.59	3.94	5.49	6.58	8.96
Se	0.24	0.51	0.72	1.21	1.99	3.05	4.26	5.12	7.00
Oc	0.00	0.13	0.25	0.60	1.28	2.36	3.71	4.73	7.11
No	0.03	0.08	0.15	0.36	0.77	1.44	2.30	2.94	4.56
De	0.00	0.03	0.09	0.23	0.50	0.91	1.43	1.81	2.68
An	14.14	16.60	18.03	20.59	23.71	27.13	30.48	32.61	36.84
Wi	0.36	0.63	0.82	1.24	1.85	2.64	3.52	4.12	5.41
Sp	2.07	2.94	3.49	4.58	6.05	7.79	9.62	10.84	13.37
Su	4.56	5.90	6.71	8.25	10.21	12.46	14.75	16.24	19.29
Fa	1.19	1.88	2.35	3.32	4.68	6.37	8.19	9.43	12.05

Field measurements during the 1993 and 1994 growing seasons and the subsequent modeling of plant available nitrogen (PAN) are described in sections B.2.2 and B.2.3, respectively. The standard climatic summaries for this two growing seasons are shown in Table B.2.1.8. 1993 was one of the coolest growing seasons in the historical record at Morris (1886-1994) and also one of the wettest. Because of these features measured mineralization rates of N were much lower during 1993 than during 1994, which was characterized by very favorable conditions in late April and May for mineralization of nitrogen. The corn yields were lower and maturity was later in 1993 due to the persistent cool temperatures and abundant moisture, while the 1994 yields were quite high with near normal maturity.

Table B.2.1.8 Precipitation, temperature and growing degree days (base 50/86 F) in the 1993 and 1994 growing seasons at Morris, MN.

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Total Precipitation (in)													
1993	0.89	0.36	1.68	1.85	6.18	5.47	7.91	2.84	2.14	1.06	1.66	0.77	32.81
1994	1.00	0.71	0.78	5.57	1.12	2.50	6.16	2.16	1.98	3.13	0.73	0.41	26.25
AVE	0.74	0.70	1.36	2.23	2.78	3.73	3.37	3.25	2.39	2.17	1.08	0.70	24.50
Mean Daily Temperature (F)													
Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1993	7.4	10.7	23.9	43.0	56.4	62.6	68.1	68.4	53.2	43.9	26.3	14.8	39.9
1994	-2.5	5.1	29.5	43.9	60.2	67.9	68.1	66.2	62.6	49.3	34.6	19.4	42.0
AVE	7.1	12.9	26.5	43.1	56.3	65.9	70.8	68.2	57.8	45.9	29.5	13.5	41.5
Corn Growing Degree Days (Base:50F Ceiling: 86F)													
Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
1993	0	0	13	83	285	399	569	575	232	131	1	0	2288
1994	0	0	4	121	394	542	570	517	421	166	27	0	2762
AVE	0	1	15	109	302	481	626	558	316	151	21	1	2581

Summary: The historical climatic record at Morris is compiled in a form which is suitable to evaluate selected best management practices not only associated with manure and fertilizer applications but planting, variety selection, herbicide use, harvesting and storage. The specific study of plant available nitrogen released from manure and inorganic fertilizer during the 1993 and 1994 growing seasons represents far ends of the climatic spectrum at Morris according to the historical records. Because of the degree and persistence of cool temperatures as well as the above normal precipitation, 1993 represents one of the most unfavorable years for mineralization, nitrogen uptake, yield and crop maturation. Conversely, adequate moisture and temperature, combined with the absence of any climatic stress make the 1994 growing season one of the most favorable for mineralization, nitrogen update and yield. Extrapolation of the field measurements of plant available nitrogen (PAN) and their relationship to climatic parameters may be somewhat limited since neither year is particularly representative of the larger population of growing seasons in the historical record at Morris.

B.2.2. Field Measurements on the Experimental Site

Analysis of soil extracts showed that nitrate represented the bulk of plant available nitrogen. Soil nitrate was used as the primary indicator of plant available nitrogen, since farmers routinely ask for soil nitrate analysis alone. Plant available nitrogen was monitored from emergence to V5 stage and at harvest in 1993 and 1994 on selected plots supported in activity A.1. Treatments monitored were check (C), dairy manure at the second rate (D2), urea fertilizer at the third rate (F3), and swine manure at the second rate (S2). Plant available nitrogen was much higher in 1993 than in 1994 on all measurement dates (Figs. 1 and 2). However, corn yields were much lower than average in 1993 compared with above average corn yields in 1994. The poor growing conditions in 1993 caused in less plant uptake of N which resulted in higher soil nitrate levels compared to 1994 where the favorable growing conditions enhanced plant uptake of N which resulted in lower soil nitrate levels. These results indicate that year to year changes in nitrate levels are negatively correlated with corn yields from year to year. This does not mean that less plant available nitrate is better. More available nitrate within in a year has a strongly increases yields (cf. Activity A.1.). Our results underline the difficulty in determining whether soil nitrate levels are high or low within a specific year without a priori knowledge of yields at the end of the growing season.

Soil temperature and moisture were also monitored on these plots. While nitrogen source and treatment significantly affected plant available nitrogen levels, soil temperature and moisture did not vary much from plot to plot due to N source. Consequently, one may assume in the future that soil temperature and moisture profiles are the same among plots which differ in N sources.

The soil temperature measurements confirm that growing conditions were extremely favorable in 1994, while in 1993, growing conditions were depressed due to cool conditions. In 1993, soil temperatures did not reach 20°C (especially at depth) until late in the growing season (Fig. B.2.2.3) whereas in 1994, soil temperatures throughout the top 2 ft. (60 cm) quickly rose to near 20°C and stayed there for the duration of the growing season (Fig. B.2.2.4). A comparison of soil moisture between 1993 and 1994 growing seasons also confirms that besides being cool in 1993, the soil was also very wet. Soil moisture in 1993 never dried above 0.1 bar for except for the top 15 cm (6 in.). This means that the soil was near saturation for the entire growing season. In 1994, however, soil moisture was always favorable for plant growth. In the second half of the growing season, there was a dry spell where soil moisture in the top foot would start to limit plant growth, however, soil moisture at depth was available during this period which should have supplied plants with adequate moisture.

Fig. B.2.2.1. Plant available nitrogen 1993.

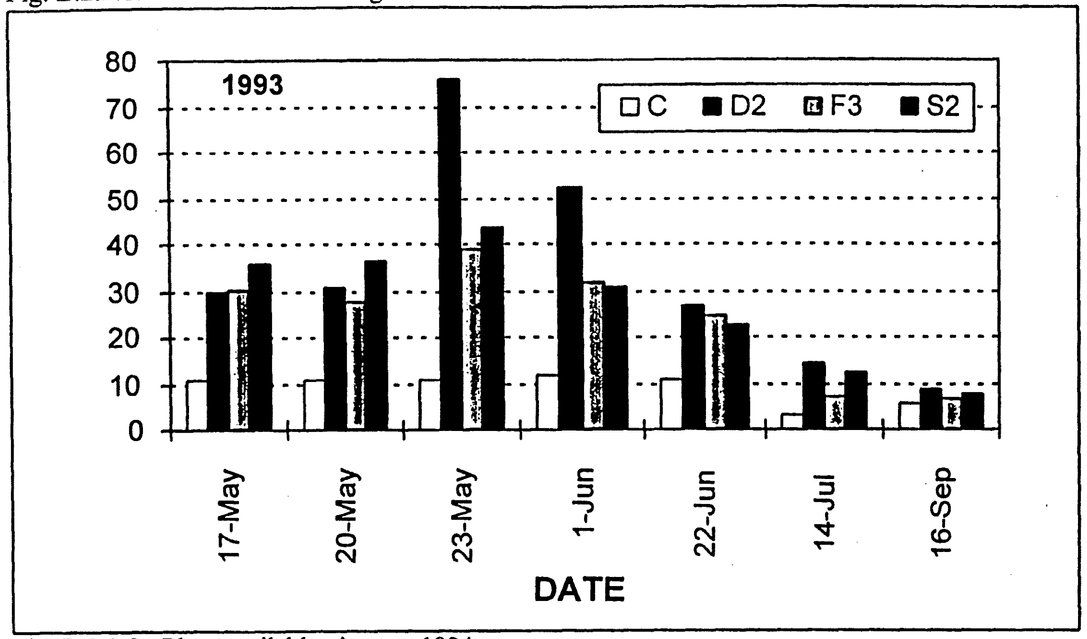


Fig. B.2.2.2. Plant available nitrogen 1994.

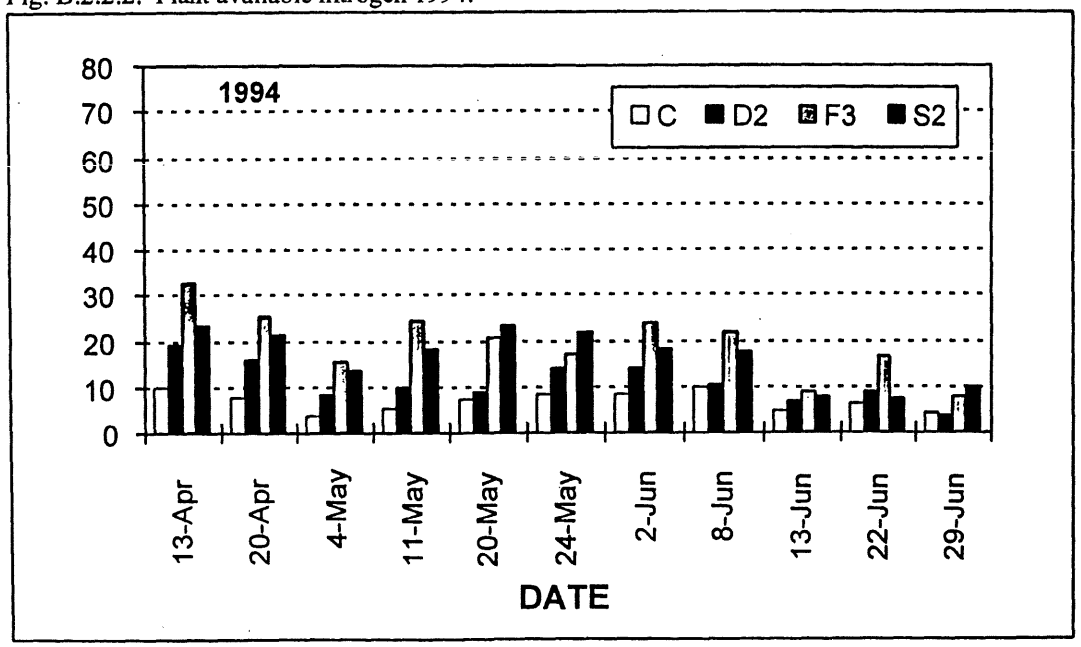


Fig. B.2.2.3. Soil temperatures in 1993.

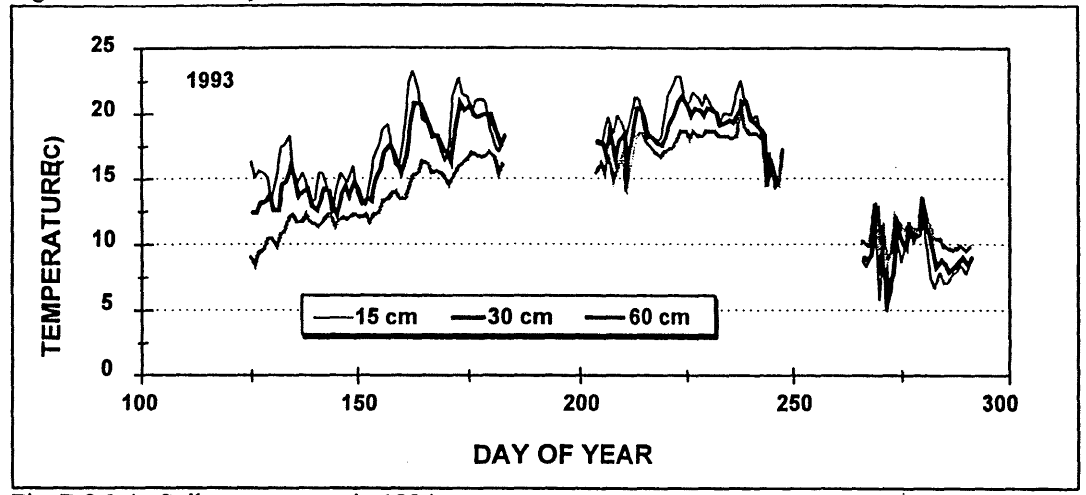


Fig. B.2.2.4. Soil temperatures in 1994.

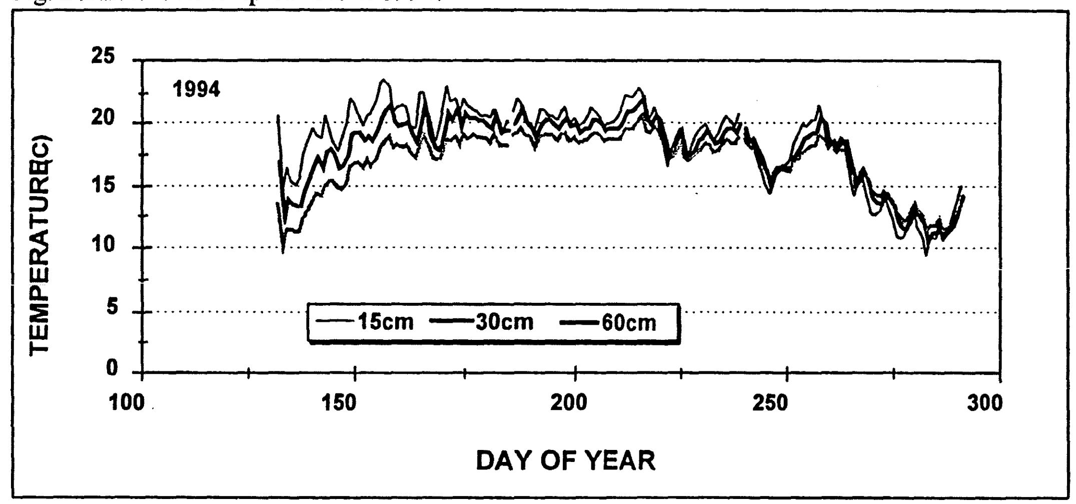


Fig. B.2.2.5. Soil mo. in 1993.

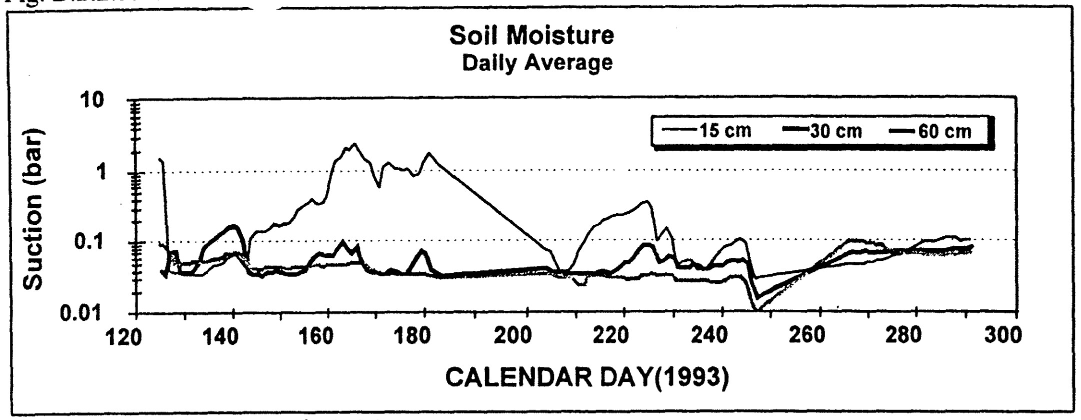
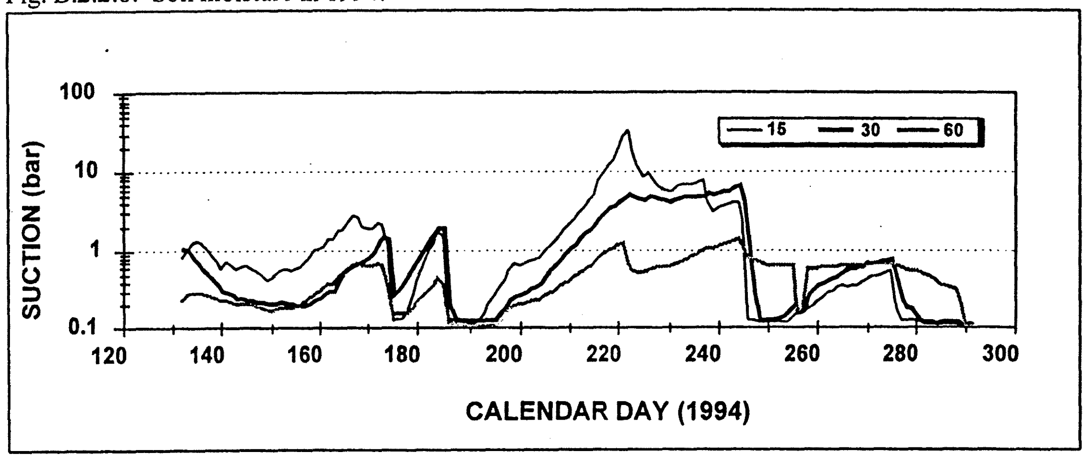


Fig. B.2.2.6. Soil moisture in 1994.



B.2.3. Modeling Plant Available N (PAN) Changes

Soil temperature, moisture measurements were related to plant available nitrogen measurements and corn yields using the simulation model, CROPSYST (Cropping Systems Simulation Model, Washington State University). CROPSYST is a process-oriented model for simulating crop growth and yield, soil water budget, soil-plant nitrogen budget, and residue production and decomposition. The model allows simulation of management practices such as tillage, fertilization, and crop rotations.

CROPSYST was calibrated for conditions at Morris, MN using soil temperature, moisture, plant available nitrogen, and yield data obtained in 1993 and 1994. Calibration of the model was performed in a number of steps. First, files describing the soil and crop conditions were created. The model was then run to simulate a corn crop with no nitrogen limitations for the weather conditions of 1993 and 1994. Plant growth parameters were adjusted so that the model predicted the maximum yields seen on the high nitrogen plots from Activity A.1. Soil temperatures and moistures predicted from the model were close to the soil temperatures and moistures observed in the . .d during those years. Next, the four urea fertilizer treatments were simulated in the model for 1993 and 1994. Model parameters related to N uptake and assimilation within the corn plant were adjusted so that the model predicted the range in yield and N uptake observed in the corresponding treatments in the field. After this, manure treatments were simulated and N mineralization, immobilization, and denitrification parameters were adjusted so that the model predictions of yield, N uptake, and soil nitrate agreed with field observations on the corresponding manure treatments. We considered the model to calibrated to the site at Morris after these steps were completed.

Historical weather data since 1900, in conjunction with CROPSYST, was used to simulate 93 years of crop yields and plant available nitrogen levels. Dairy manure, swine manure and urea fertilizer treatments were simulated. The model predicted yield, N uptake, N stress, and soil available nitrate, temperature and moisture for each year in the simulation.

Yield was not well correlated with various measures of plant available nitrogen, soil temperature, growing degree days, weekly precipitation, or cumulative precipitation since fertilizing or planting (Fig. B.2.3.1). A weak negative correlation was found between yield and soil nitrate (Fig. B.2.3.2). Within a particular year, however, more soil nitrate increased yields (results shown for 1994). This confirms our field measurements of PAN and yields in 1993 and 1994. The positive correlation between soil nitrate and yield within a year was overwhelmed by year to year variability in yield due to other factors in the environment such as timing of temperature and moisture. In other words, in years with favorable growing conditions, plants took up N early in the season and reduced mid-season levels of soil nitrate. In years with poor growing conditions, N uptake was depressed resulting in increased residual nitrate in the soil.

We concluded that weekly probabilities of plant available nitrogen would not be good predictors of yield unless the growing conditions to the end of the season were known in advance. Therefore, a second analysis was performed which attempted to isolate the nitrogen effect on yield by normalizing year to year variability in crop yields due to other environmental factors. This approach depended on calculating a yield reduction due to nitrogen limitations. Yield reduction was calculated as the difference between yield predicted for a given treatment and yield predicted for the same year under conditions of unlimited N supply divided by the yield associated with unlimited N supply.

Yield reduction was strongly correlated with N-stress as calculated by CROPSYST ($r^2 = 0.91$) for all nitrogen source treatments (Fig. B.2.3.3). Although N-stress predicted by the model is not a measurable variable, the relationship to yield reduction was exploited by relating N-stress to real soil variables. Correlations between N-stress and soil variables on climatological weeks 9 through 16 were calculated (The climatological year starts on March 1). Soil variables included soil nitrate in the top two feet, average soil temperature in the top two feet, growing degree days (base 10°C), precipitation, and cumulative precipitation since fertilizing or planting. Results indicate moderate correlations of N-stress (rÅ0.5) with soil nitrate in week 11 and cumulative precipitation in week 11 for all N sources (Fig. B.2.3.4). Week 11 corresponds with May 10 to May 16 which is approximately two weeks after planting.

Based on these results, a regression model was developed which used the following variables to predict N-stress: soil nitrate two weeks after planting, cumulative precipitation since fertilization in the fall prior to planting, and precipitation in the first and second weeks after planting. Urea fertilizer and swine manure treatments exhibited the same response over all years yielding the regression equation:

$$NS_{fert\,/\,swine} = -0.136 + .00126 \times P_{cf,11} + 0.00932 \times N_{11} - 0.000079 \times P_{cf,11} \times N_{11} \quad [B.2.3.1]$$

where $NS_{fert/swine}$ represents the expected N stress at the end of the season for urea fertilizer or swine manure treatments, $P_{cf,1}$ represents cumulative precipitation (mm) since fall fertilization, and N_{11} represents soil nitrate in the top two feet with both variables measured approximately two weeks after planting. Dairy manure exhibited less N-stress and different regression coefficients with the same regression model:

$$NS_{dairy} = -0.136 + .00126 \times P_{cf,11} + 0.00658 \times N_{11} - 0.000061 \times P_{cf,11} \times N_{11} \qquad [B.2.3.2]$$

The difference in coefficients between Eq. [B.2.3.1] and Eq. [B.2.3.2] is most likely due to the higher percentage of solid organic matter in the dairy manure which contributed to less N stress.

Using these regression models and the historical weather record, probability tables of N-stress and yield reduction were calculated based on whether cumulative precipitation and soil nitrate levels are below-average, average, or above average (Tables B.2.3.1 and B.2.3.2). Average values of cumulative precipitation since fertilizing and soil nitrate typically cause yield reductions of around 5 to 6 percent (Table B.2.3.2). High cumulative precipitation since fertilizing coupled with lower than average soil nitrate cause the most N stress and yield reduction. These tables indicate that mid-season sidedress applications of nitrogen could avert yield reductions when soil nitrate levels are below-average and/or cumulative precipitation since fertilizing is above-average. When soil nitrate levels are average and cumulative precipitation since fertilizing is average, yield reductions appear to be acceptable and supplemental N fertilization is probably not needed.

Fig. B.2.3.1. Correlation coefficients between corn yield and selected soil and microclimate variables.

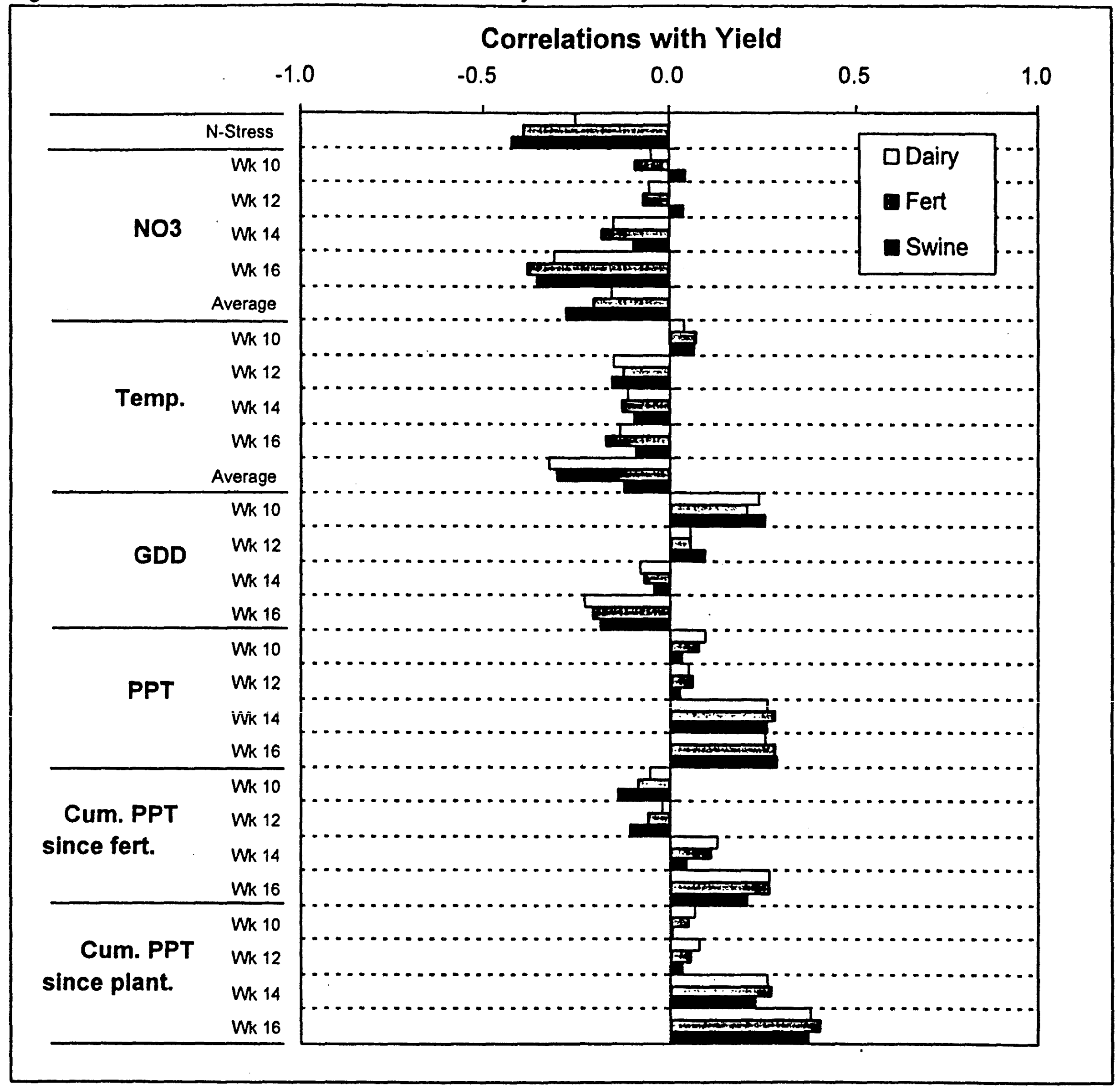


Fig. B.2.2.2. Plant av… …e nitrogen 1994.

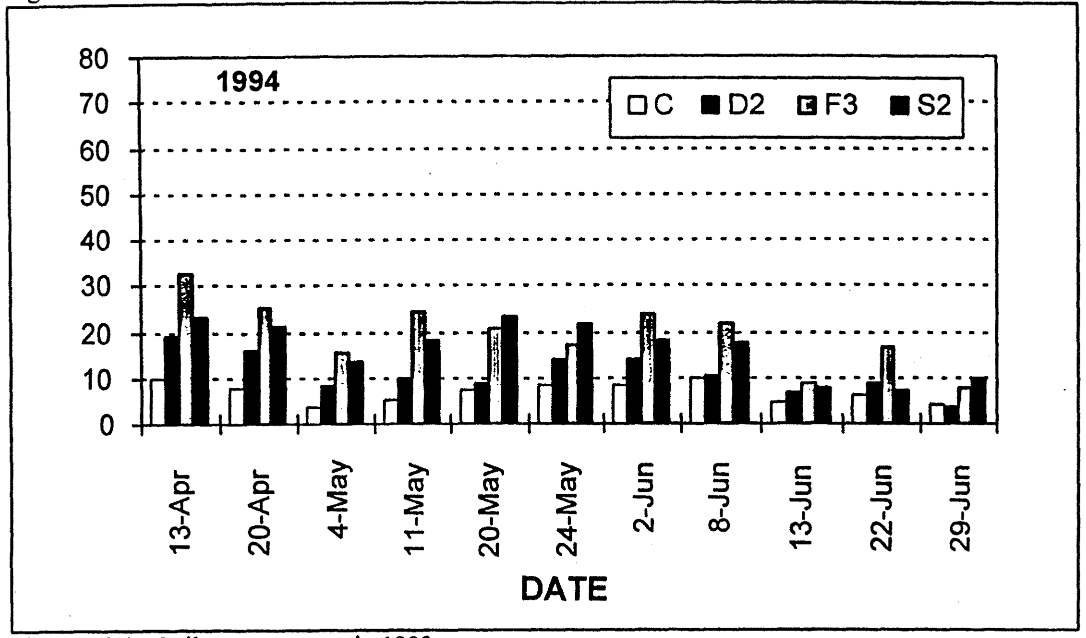


Fig. B.2.2.3. Soil temperatures in 1993.

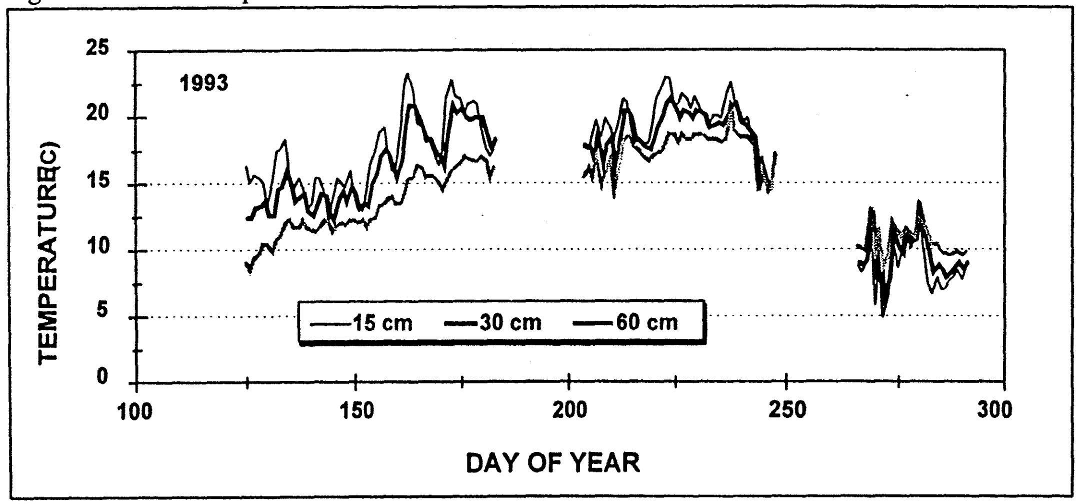


Fig. B.2.3.4. Correlation coefficients between N-Stress and selected soil and microclimate variables.

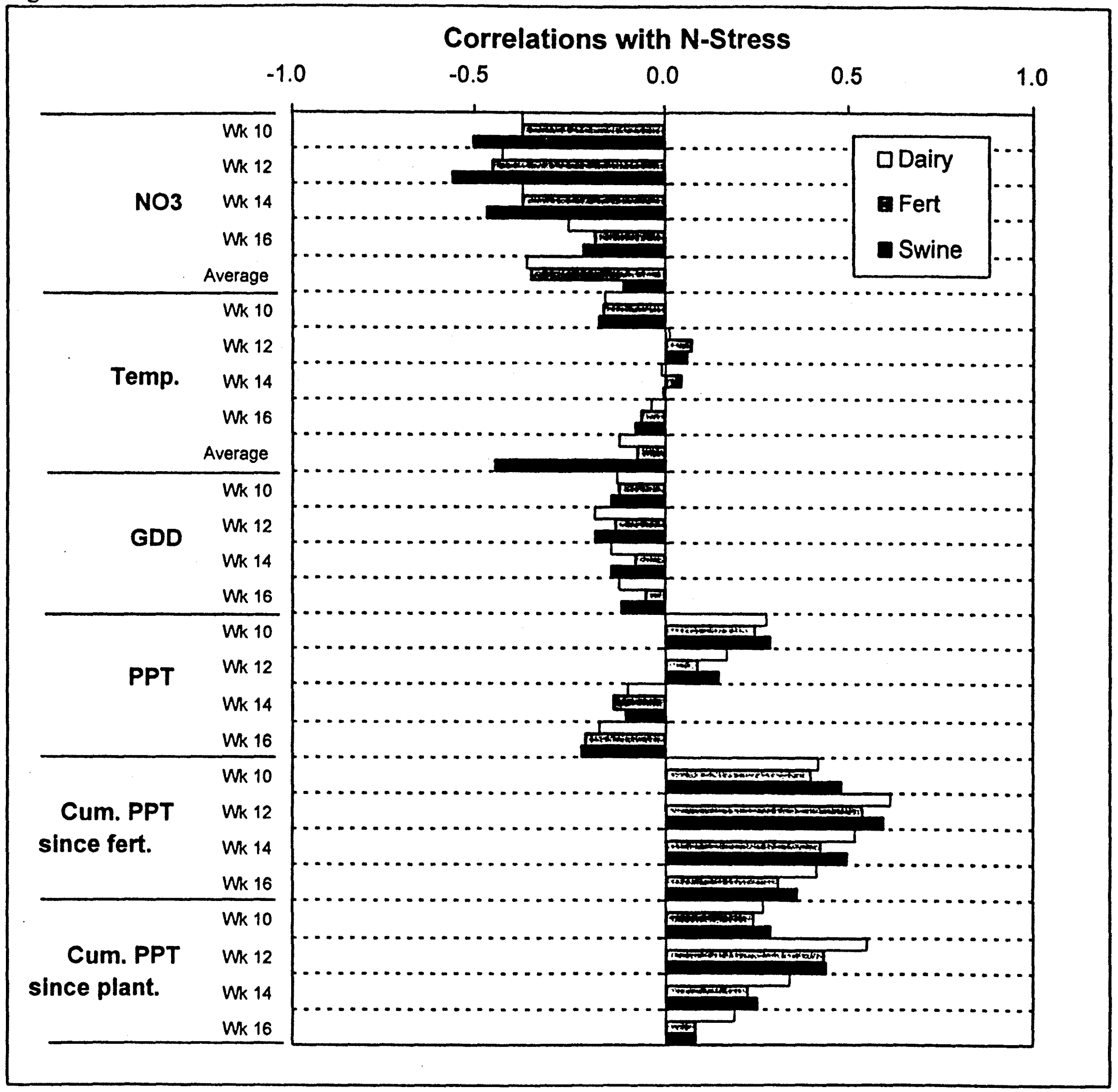


Table B.2.3.1. Conditional probability of nitrogen stress for corn grown with different nitrogen sources.

Soil nitrate in top 2 ft.	Urea Fertilizer and Swine Manure			Dairy Manure		
	Cumulative precipitation since fertilizing					
ppm	in.			in.		
< 7	2%	5%	14%	0%	5%	15%
7 to 12	1%	4%	9%	1%	4%	10%
> 12	1%	2%	2%	0%	1%	3%

Table B.2.3.2. Conditional probability of yield reduction due to nitrogen stress for corn grown with different nitrogen sources.

Soil nitrate in top 2 ft.	Urea Fertilizer and Swine Manure			Dairy Manure		
	Cumulative precipitation since fertilizing					
ppm	in.			in.		
< 7	2%	8%	20%	0%	8%	21%
7 to 12	2%	5%	13%	2%	6%	15%
> 12	2%	2%	3%	0%	2%	5%

B.2.4 :Probability Distributions of Climatic Parameters from the Long-Term Records

Introduction: Because of the high degree of variability shown in the historical climatic records at Morris, probability distributions were computed on weekly intervals for selected climatic parameters related to mineralization of nitrogen from various sources in the soil environment. Distributional characteristics for average weekly maximum temperature, minimum temperature and precipitation were computed from the entire 108 year record. The weekly distribution of soil temperatures at the four and eight inch depths were computed from the 1983-1993 records, for which a complete series of thermistor based measurements existed. Soil moisture estimates for the uppermost one foot of soil were computed using the CERES-Maize simulation model for corn grown and development (1986). This model has been validated by the Midwest Climate Center and is used to make operational assessments of regional soil moisture throughout the growing season. The distributional characteristics of daily soil moisture estimates were derived a Hamerly silty clay loam soil series using the complete record period of 108 years. Lastly, in order to evaluate the risks of leaching mineralized N from the soil profile, the distribution of heavy rainfall events was analyzed for the complete historical record period, examining the temporal patterns for the occurrence of 1 and 2 inch rainfalls, as well as the maximum 24 hour rainfalls by month.

Results: Tables B.2.4.1 to B.2.4.3 show the probability characteristics for weekly maximum air temperature, minimum air temperature, and precipitation respectively. Each week in the year starting with March 1-7 is shown. Figures B.2.4.1 to B.2.4.3 depict the temporal pattern in the 75th, 50th and 25th percentiles for these three climatic parameters during the crop season (April through October). Figure B.2.4.2 shows that there is a 50 percent probability for maximum temperatures to exceed 50 degrees F during the week of April 12-18. This corresponds to the average time (April 10-15) when the last of the soil frost goes out and microbiological activity in the soil begins to accelerate. Figure B.2.4.1 shows that this also corresponds to a period when the weekly probability of significant precipitation begins to climb. From the third week of April through the balance of the spring, climatological probabilities increase in favor of more rapid mineralization of nitrogen from manure sources applied in the late fall or early spring, or from inorganic fertilizer applications made in the early spring.

There is a high degree of variability in both temperature and moisture conditions during the early spring in evidence by the relatively large standard deviations in weekly values. Standard deviations of weekly precipitation shown in Table B.2.4.3 are all 0.50 inches or greater beginning in mid April, with peak variability shown in late April, early June, early July and mid August. Standard deviations of weekly maximum temperature are on the order of 8 to 9 degrees F in early April, but gradually diminish to only 5 degrees by early July. Standard deviations of maximum and minimum temperatures begin to increase again in the fall, starting in September. Because of this high degree of climatic variability, N mineralization rates in the early spring and the early fall can be expected to vary greatly as well. Manure applied in the late fall or during the winter on occasion will be subject to significant mineralization rates in late March or early April with some frequency, while manure applied in the early fall may be subject to relatively high mineralization rates even as late as mid November sometimes. Fall application of nitrogen fertilizer usually occurs after soil temperatures have fallen below the 50 degree F mark and therefore potential losses due to mineralization, denitrification and or leaching are usually minimized. Extreme climatic conditions which have occurred in the historical record and would cause large nitrogen losses to take place, such as average maximum temperatures of 75 degrees F during the first week of April or weekly precipitation of over 8 inches during the last week of April cannot be ameliorated by existing best management practices.

Figures B.2.4.4 and B.2.4.5 show the climatology of soil temperatures at Morris (1983-1993). The temporal patterns of the average and standard deviation values for both the four inch and eight inch depths during the growing season are show. Soil temperatures show a high degree of variability (larger standard deviation) associated with the spring and fall. Average four inch soil temperatures reach 50 degrees F about the last week of April, with standard deviations of 5 to 6 degrees. 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.

The average four inch soil temperatures drop below 50 degrees F in the fall, about mid October, with standard deviations of 5 to 6 degrees. 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 November 29 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, [illegible] soil temperature records in west central Minnesota should [illegible] examined as well since they would likely represent different soil series.

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 Morris historical climatic records (1886-1994) was run. The resulting 108 year record of daily soil moisture 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 Hamerly silty clay loam, one of the soil series on the West Central Experiment Station. This soil is capable of holding 2.52 inches of available moisture in the top foot. Figure B.2.4.6 shows the temporal distribution of the 70th, 50th and 30th 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 1.2 inches or greater for the period from April to mid July. After mid July, soil moisture values fall to less than one inch and reach the lowest level in late August and early September. Thus the lack of soil moisture becomes a limiting factor to continued high mineralization rates during this time. On the average, soil moisture values remain below 1 inch in the top foot for much of the September, October and November period as well (at least 70 percent of the time), helping to limit mineralization rates from fall applied manures and fertilizer.

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 west central region. Optimal conditions for mineralization and uptake of nitrogen usually occur in 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. Fall applications of nitrogen which occur after October 15 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 addition to compiling probability statistics for climatic parameters related to nitrogen mineralization, distributions of heavy precipitation events were examined in the Morris record to assess the temporal risks of leaching events which tend to either carry nitrate nitrogen deeper into the soil profile or cause losses by runoff. Figure B.2.4.7 shows the maximum 24 hour precipitation events by month. The large values of over 4 inches in July and August are expected because of the seasonal trend for higher dew points and therefore greater precipitable water available during these months. Crops at full canopy can usually withstand and recover from such rains. However, the large maximum values in April (6.9 inches) and October (3.6 inches) are of greater concern because they occur at times when the soil is typically free of vegetative cover and may be tilled with little crop residue present. Events of this magnitude would lead to substantial losses of nitrogen through deep percolation and runoff.

Table B.2.4.4 Distribution of 24 hr precipitation events of 1 inch or greater in the Morris climatological records (1886-1994). Number of events by month.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
3	3	11	39	56	105	116	80	53	31	13	4

Total 1 inch events = 514

Table B.2.4.4 shows the distribution of 24 hr 1 inch precipitation events at Morris, with the expected highest frequencies in June and July. Though 1 inch rainfall events may trigger more rapid movement of nitrate nitrogen within the soil profile, they tend to be more frequent at a time when mineralization and uptake are occurring at higher rates and a protective crop canopy helps reduce rain drop impact on the soil surface and slows the infiltration process. On average, five rainfall events of 1 inch or greater are measured each year at Morris. August shows slightly less frequency than June or July, while both May and September show a frequency which is approximately half that of June and July.

Figure B.2.4.8 shows the frequency distribution for 2 inch precipitation events at Morris over the growing season period. These events occur with a frequency of about one per year. The seasonal distribution mimics the pattern of 1 inch precipitation events, but shows less frequency. There have been 95 such events in the historical record at Morris. Nineteen of these events have occurred in the months of April, May, and October when spring or fall applied nitrogen sources would be most susceptible to loss by deep percolation or runoff.

Since best management practices for nitrogen need to be geared to the long term climatic characteristics, an examination of climatic trends and cycles is sometimes useful to see if the relative frequency of specific events is increasing or decreasing. This was done with respect to the frequency of 1 inch precipitation events at Morris, using smoothed (running mean) decadal frequencies across the entire historical record. Figure B.2.4.9 shows the pattern in decadal frequencies to be quite interesting. Today's frequency of 50 to 60 events per decade is roughly 150 percent greater than it was in the 1920s and 1930s, and is roughly equivalent to what it was during the 1890s. The trend toward increased frequency of this type of climatic event seems to be diminishing in recent years, but may only be temporarily tempered by the dry seasons of 1987 and 1988. Should this trend toward greater frequency of heavier rainfall events continue, more attention to timing nitrogen applications will be required.

Summary: Probability distributions of temperature and moisture parameters were derived for the complete climatic record at Morris, MN. These 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.

Climatic probabilities support the practice of late fall applications of nitrogen as a low risk option despite somewhat increasing variability in the climate of the soil at that time. Soil temperatures generally fall below 50 degrees F on or about October 15th.

The spring and summer probabilities 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 mid April in most years. Timely planting is critical to fully utilize the mineralization rate increases typically seen in May and June.

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Table B.2.4.1 Probability distribution of average weekly maximum air temperature (°F) at Morris, MN (1886 to 1993).

Period of			Average	Std. Dev.	Maximum	75%	50%	25%	Miniumum
01-Mar	to	07-Mar	30.1	8.8	48.3	37.1	30.3	24.1	11.3
08-Mar	to	14-Mar	33.6	8.6	59.1	39.3	33.9	29.4	14.9
15-Mar	to	21-Mar	37.2	9.1	62.9	43.1	35.9	31.1	21.0
22-Mar	to	28-Mar	41.6	10.0	68.0	47.3	40.6	35.3	18.4
29-Mar	to	04-Apr	45.2	9.1	66.1	50.6	45.7	38.1	23.1
05-Apr	to	11-Apr	50.2	9.0	75.1	55.6	49.6	43.7	32.6
12-Apr	to	18-Apr	55.6	8.4	76.1	61.0	55.3	50.9	38.3
19-Apr	to	25-Apr	58.8	8.4	78.1	64.9	59.1	53.0	35.9
26-Apr	to	02-May	61.1	9.2	84.1	68.3	61.3	55.3	35.3
03-May	to	09-May	64.7	9.1	84.4	71.1	65.6	58.0	45.4
10-May	to	16-May	67.1	7.5	85.3	72.6	66.3	62.4	49.9
17-May	to	23-May	70.5	7.2	85.6	75.3	70.1	65.6	53.1
24-May	to	30-May	71.9	6.2	91.0	76.1	71.4	67.3	59.7
31-May	to	06-Jun	74.0	6.3	90.3	77.7	74.1	69.9	57.4
07-Jun	to	13-Jun	75.6	6.1	92.7	79.4	75.9	71.7	57.7
14-Jun	to	20-Jun	77.9	5.7	97.9	81.9	77.0	74.3	64.1
21-Jun	to	27-Jun	78.7	5.7	91.7	82.9	79.1	75.1	66.6
28-Jun	to	04-Jul	80.5	5.1	93.7	84.0	80.4	77.4	68.3
05-Jul	to	11-Jul	82.2	4.8	99.6	84.6	81.9	79.0	68.0
12-Jul	to	18-Jul	82.6	4.8	100.3	85.7	82.3	79.7	72.0
19-Jul	to	25-Jul	83.4	5.2	98.6	86.7	83.3	79.7	71.9
26-Jul	to	01-Aug	83.2	5.2	97.7	86.1	83.3	79.9	69.7
02-Aug	to	08-Aug	82.6	5.0	93.9	85.9	82.9	79.7	70.4
09-Aug	to	15-Aug	81.1	5.2	92.4	84.7	81.4	77.6	68.3
16-Aug	to	22-Aug	80.6	4.6	91.1	83.6	80.7	77.9	67.1
23-Aug	to	29-Aug	78.6	6.1	91.0	83.3	79.0	73.7	62.7
30-Aug	to	05-Sep	77.3	6.0	89.1	81.4	76.9	72.6	64.7
06-Sep	to	12-Sep	73.6	6.4	97.0	77.9	73.0	69.4	60.0
13-Sep	to	19-Sep	70.3	6.6	86.9	73.9	70.9	65.1	55.7
20-Sep	to	26-Sep	67.3	6.9	83.1	70.6	66.7	62.7	48.9
27-Sep	to	03-Oct	66.0	7.2	85.6	71.1	64.6	60.6	50.6
04-Oct	to	10-Oct	62.8	7.0	78.6	68.0	62.3	57.6	49.6
11-Oct	to	17-Oct	60.2	8.0	79.0	66.6	59.3	55.3	40.1
18-Oct	to	24-Oct	55.8	8.5	74.3	62.0	56.6	49.3	37.7
25-Oct	to	31-Oct	52.1	8.2	71.7	57.4	52.0	47.4	33.7
01-Nov	to	07-Nov	47.1	8.3	65.0	53.1	48.0	41.4	21.1
08-Nov	to	14-Nov	40.7	8.0	63.7	45.7	40.7	35.4	21.6
15-Nov	to	21-Nov	38.1	8.7	58.3	43.9	38.4	32.1	19.6
22-Nov	to	28-Nov	32.4	8.1	49.3	37.4	32.7	27.3	10.9
29-Nov	to	05-Dec	28.7	9.0	50.0	33.9	30.0	23.4	6.4
06-Dec	to	12-Dec	25.4	10.3	60.3	33.0	25.7	20.4	-4.6
13-Dec	to	19-Dec	23.6	10.1	46.9	31.3	24.9	17.3	0.9
20-Dec	to	26-Dec	22.8	9.5	40.7	30.0	23.7	16.4	-8.6
27-Dec	to	02-Jan	21.0	8.8	38.7	27.6	21.3	15.7	-4.3
03-Jan	to	09-Jan	18.7	10.8	39.4	27.1	18.3	11.7	-9.6
10-Jan	to	16-Jan	18.6	11.0	38.9	27.7	20.6	11.3	-10.7
17-Jan	to	23-Jan	18.7	12.1	46.9	28.0	20.0	11.3	-11.1
24-Jan	to	30-Jan	18.1	11.2	47.6	26.0	19.1	10.7	-8.0
31-Jan	to	06-Feb	18.6	11.6	42.6	27.3	18.1	11.3	-8.1
07-Feb	to	13-Feb	21.0	10.9	44.4	30.0	21.7	14.0	-8.3
14-Feb	to	20-Feb	23.7	9.4	49.3	30.1	24.1	17.6	-5.6
21-Feb	to	27-Feb	27.2	9.4	48.6	34.1	25.9	19.3	9.1

Table B.2.4.2 Prob istribution of average weekly minimum air temperature (°F) at Morri (1886 to 1993).

Period of			Average	Std. Dev.	Maximum	75%	50%	25%	Miniumum
01-Mar	to	07-Mar	10.8	10.0	34.6	17.7	12.0	4.1	-8.6
08-Mar	to	14-Mar	15.0	9.6	31.3	21.7	16.6	8.6	-10.1
15-Mar	to	21-Mar	18.3	8.7	40.9	25.0	18.0	13.3	-4.9
22-Mar	to	28-Mar	22.4	8.3	39.6	28.0	23.4	17.3	0.6
29-Mar	to	04-Apr	25.8	6.9	38.7	30.0	27.3	22.0	1.9
05-Apr	to	11-Apr	29.5	5.0	39.4	33.9	30.0	26.0	17.7
12-Apr	to	18-Apr	32.7	5.8	48.0	36.4	32.7	29.0	16.4
19-Apr	to	25-Apr	35.5	5.7	50.0	39.1	35.1	32.4	20.9
26-Apr	to	02-May	38.4	5.8	54.6	41.9	38.9	35.0	25.1
03-May	to	09-May	40.3	5.9	58.9	43.7	40.0	36.7	25.0
10-May	to	16-May	42.6	5.5	57.1	46.0	42.1	38.3	31.3
17-May	to	23-May	46.3	5.0	59.4	49.9	46.0	42.7	33.9
24-May	to	30-May	49.0	5.1	59.7	52.7	48.4	45.4	37.3
31-May	to	06-Jun	51.5	5.2	63.9	55.1	51.7	48.4	40.1
07-Jun	to	13-Jun	53.4	4.8	65.4	56.6	52.9	50.0	42.6
14-Jun	to	20-Jun	55.8	4.7	70.7	59.0	56.0	53.3	44.1
21-Jun	to	27-Jun	56.6	4.8	71.1	59.7	56.3	53.4	45.9
28-Jun	to	04-Jul	58.2	4.7	70.0	61.4	58.4	54.1	48.1
05-Jul	to	11-Jul	59.3	4.1	70.4	62.0	59.1	56.6	50.0
12-Jul	to	18-Jul	59.7	4.0	70.1	62.3	59.4	56.9	51.1
19-Jul	to	25-Jul	59.5	4.2	69.3	62.3	59.4	56.1	51.0
26-Jul	to	01-Aug	59.1	4.0	69.6	61.6	58.4	56.4	46.4
02-Aug	to	08-Aug	58.6	4.0	67.4	61.6	58.3	56.3	50.6
09-Aug	to	15-Aug	57.0	4.2	67.6	59.6	57.4	54.0	48.4
16-Aug	to	22-Aug	56.7	4.2	68.4	59.4	56.3	54.0	47.6
23-Aug	to	29-Aug	54.8	4.9	66.9	58.3	54.7	51.9	42.4
30-Aug	to	05-Sep	53.0	5.4	67.1	57.1	52.9	48.9	38.0
06-Sep	to	12-Sep	50.4	5.2	67.4	53.4	49.9	47.7	37.7
13-Sep	to	19-Sep	47.0	5.1	61.6	50.3	47.0	43.6	35.7
20-Sep	to	26-Sep	43.3	5.4	59.1	46.9	43.4	39.3	32.9
27-Sep	to	03-Oct	40.9	5.0	54.6	44.1	41.0	37.9	29.6
04-Oct	to	10-Oct	38.5	5.5	53.9	41.4	39.1	34.7	24.1
11-Oct	to	17-Oct	36.6	6.3	52.1	41.3	35.7	32.1	23.4
18-Oct	to	24-Oct	33.2	6.2	52.7	37.4	32.6	29.0	19.3
25-Oct	to	31-Oct	30.3	5.9	44.6	33.9	30.3	27.4	14.6
01-Nov	to	07-Nov	26.7	6.4	40.9	30.7	27.7	23.6	3.6
08-Nov	to	14-Nov	22.2	6.7	36.3	26.4	23.6	18.6	2.7
15-Nov	to	21-Nov	20.0	8.0	35.0	26.4	21.0	14.0	1.6
22-Nov	to	28-Nov	14.7	8.5	32.3	21.1	16.1	8.4	-6.1
29-Nov	to	05-Dec	11.2	10.1	33.6	18.4	11.4	4.3	-12.6
06-Dec	to	12-Dec	7.9	10.4	28.1	16.1	8.6	0.6	-17.4
13-Dec	to	19-Dec	5.6	10.7	23.1	14.9	7.1	-2.0	-25.1
20-Dec	to	26-Dec	4.4	10.3	27.9	11.9	5.4	-2.9	-23.3
27-Dec	to	02-Jan	1.7	9.6	27.0	7.7	1.1	-4.4	-23.1
03-Jan	to	09-Jan	-0.7	11.6	22.7	7.9	-1.0	-8.6	-29.4
10-Jan	to	16-Jan	-1.2	11.2	20.1	7.4	-1.3	-8.0	-30.0
17-Jan	to	23-Jan	-1.5	12.0	24.3	7.9	-1.4	-10.0	-26.4
24-Jan	to	30-Jan	-2.4	11.5	25.4	5.9	-3.6	-11.4	-23.4
31-Jan	to	06-Feb	-1.1	12.8	23.9	8.3	-2.6	-9.0	-27.4
07-Feb	to	13-Feb	1.2	11.8	24.7	11.6	2.1	-8.4	-28.0
14-Feb	to	20-Feb	3.5	11.0	27.1	10.1	2.6	-3.4	-28.4
21-Feb	to	27-Feb	6.9	11.2	28.7	15.1	6.4	-1.7	-12.4

Table B.2.4.3. I ity distribution of average weekly precipitation (inches) at Morris, M 5 to 1993).

Period of			Average	Std. Dev.	Maximum	75%	50%	25%	Miniumum
01-Mar	to	07-Mar	0.26	0.41	2.05	0.30	0.10	0.00	0.00
08-Mar	to	14-Mar	0.21	0.30	1.69	0.33	0.10	0.00	0.00
15-Mar	to	21-Mar	0.24	0.33	1.46	0.31	0.11	0.00	0.00
22-Mar	to	28-Mar	0.32	0.45	2.07	0.45	0.15	0.00	0.00
29-Mar	to	04-Apr	0.34	0.45	1.97	0.55	0.12	0.00	0.00
05-Apr	to	11-Apr	0.38	0.48	2.29	0.60	0.22	0.05	0.00
12-Apr	to	18-Apr	0.45	0.56	2.45	0.75	0.23	0.00	0.00
19-Apr	to	25-Apr	0.57	0.64	2.78	0.85	0.39	0.07	0.00
26-Apr	to	02-May	0.80	1.10	8.14	1.17	0.47	0.16	0.00
03-May	to	09-May	0.51	0.61	2.72	0.77	0.26	0.04	0.00
10-May	to	16-May	0.67	0.80	3.55	0.99	0.46	0.08	0.00
17-May	to	23-May	0.69	0.75	4.36	1.13	0.45	0.12	0.00
24-May	to	30-May	0.71	0.82	4.28	0.97	0.45	0.11	0.00
31-May	to	06-Jun	0.95	1.01	4.64	1.35	0.60	0.12	0.00
07-Jun	to	13-Jun	0.87	0.84	3.39	1.41	0.58	0.25	0.00
14-Jun	to	20-Jun	0.98	0.99	5.35	1.34	0.78	0.18	0.00
21-Jun	to	27-Jun	0.94	1.07	6.86	1.23	0.70	0.21	0.00
28-Jun	to	04-Jul	1.06	1.11	5.31	1.51	0.74	0.24	0.00
05-Jul	to	11-Jul	0.99	1.31	6.29	1.05	0.61	0.14	0.00
12-Jul	to	18-Jul	0.73	0.82	3.76	1.00	0.45	0.17	0.00
19-Jul	to	25-Jul	0.63	0.70	3.39	0.93	0.38	0.10	0.00
26-Jul	to	01-Aug	0.71	0.93	4.52	1.15	0.40	0.05	0.00
02-Aug	to	08-Aug	0.69	0.71	4.01	1.14	0.47	0.13	0.00
09-Aug	to	15-Aug	0.57	0.70	3.41	0.75	0.37	0.06	0.00
16-Aug	to	22-Aug	0.78	1.17	7.91	0.98	0.34	0.10	0.00
23-Aug	to	29-Aug	0.59	0.76	4.74	0.91	0.32	0.01	0.00
30-Aug	to	05-Sep	0.58	0.76	4.03	0.84	0.32	0.05	0.00
06-Sep	to	12-Sep	0.69	0.80	3.56	0.88	0.50	0.14	0.00
13-Sep	to	19-Sep	0.55	0.74	4.90	0.84	0.26	0.07	0.00
20-Sep	to	26-Sep	0.48	0.61	2.58	0.69	0.22	0.04	0.00
27-Sep	to	03-Oct	0.35	0.55	2.60	0.46	0.12	0.00	0.00
04-Oct	to	10-Oct	0.47	0.69	3.40	0.63	0.21	0.01	0.00
11-Oct	to	17-Oct	0.36	0.67	5.32	0.38	0.12	0.00	0.00
18-Oct	to	24-Oct	0.31	0.46	2.77	0.52	0.09	0.00	0.00
25-Oct	to	31-Oct	0.35	0.65	3.53	0.37	0.07	0.00	0.00
01-Nov	to	07-Nov	0.24	0.40	1.78	0.31	0.05	0.00	0.00
08-Nov	to	14-Nov	0.24	0.43	2.58	0.30	0.05	0.00	0.00
15-Nov	to	21-Nov	0.28	0.51	3.81	0.36	0.06	0.00	0.00
22-Nov	to	28-Nov	0.18	0.29	1.90	0.21	0.07	0.00	0.00
29-Nov	to	05-Dec	0.19	0.28	1.31	0.26	0.06	0.00	0.00
06-Dec	to	12-Dec	0.12	0.22	1.20	0.19	0.01	0.00	0.00
13-Dec	to	19-Dec	0.13	0.23	1.32	0.17	0.04	0.00	0.00
20-Dec	to	26-Dec	0.17	0.30	1.80	0.20	0.05	0.00	0.00
27-Dec	to	02-Jan	0.14	0.25	1.55	0.13	0.04	0.00	0.00
03-Jan	to	09-Jan	0.14	0.24	1.47	0.18	0.02	0.00	0.00
10-Jan	to	16-Jan	0.17	0.24	1.43	0.24	0.07	0.00	0.00
17-Jan	to	23-Jan	0.15	0.22	1.21	0.20	0.06	0.00	0.00
24-Jan	to	30-Jan	0.14	0.19	0.96	0.19	0.07	0.00	0.00
31-Jan	to	06-Feb	0.15	0.22	1.21	0.21	0.06	0.00	0.00
07-Feb	to	13-Feb	0.16	0.25	1.30	0.20	0.05	0.00	0.00
14-Feb	to	20-Feb	0.19	0.26	1.15	0.30	0.07	0.00	0.00
21-Feb	to	27-Feb	0.16	0.27	1.77	0.20	0.05	0.00	0.00

Figure B.2.4.1
Morris, MN Probability Distribution of Precipitation (1886 - 1993)

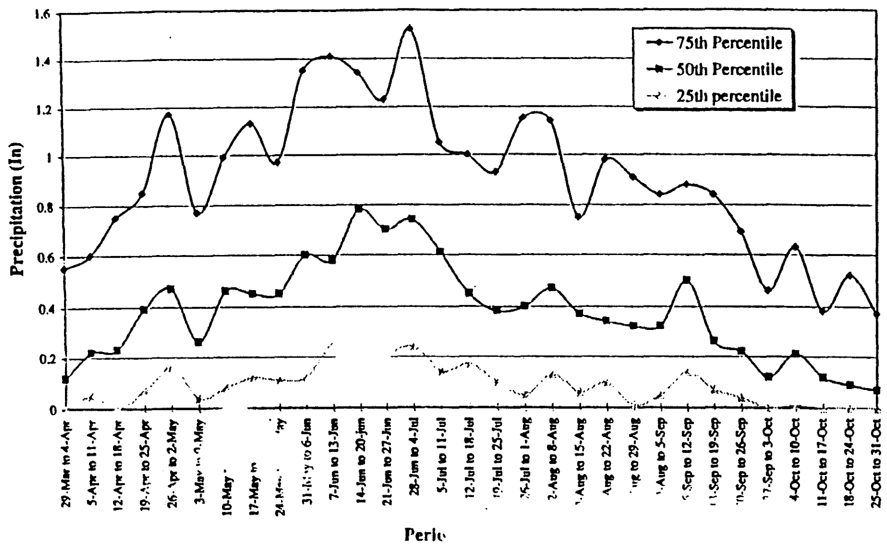


Figure B.2.4.2
Morris, MN Probability Distribution of Minimum Air Temperatures (1886 - 1993)

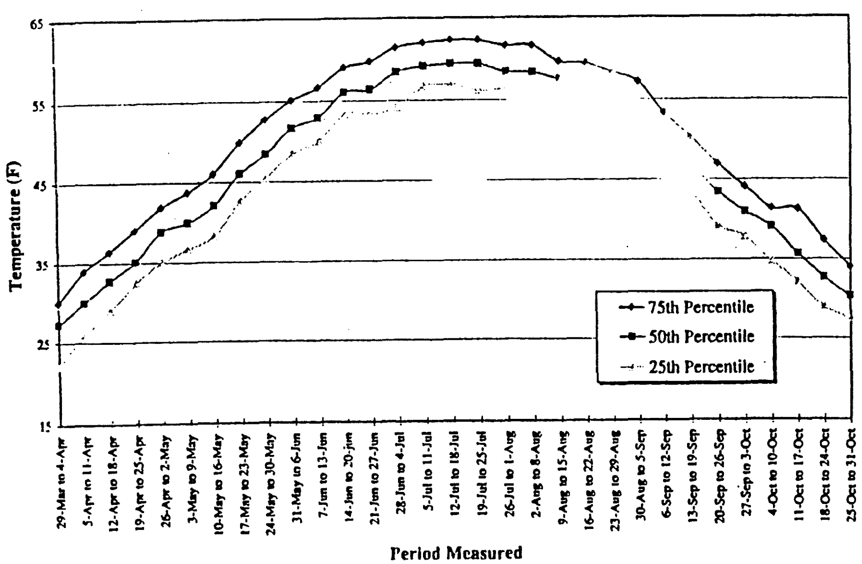


Figure B.2.4.3
Morris, MN Probability Distribution of Maximum Air Temperatures (1886 - 1993)

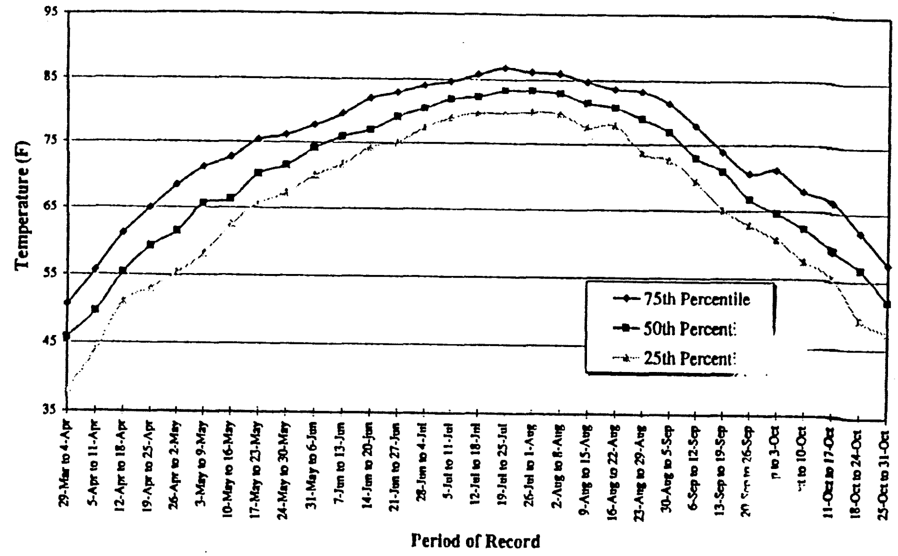


Figure B.2.4.4
MORRIS 10 YEAR 4" SOIL TEMP DATA (1983 - 1993)

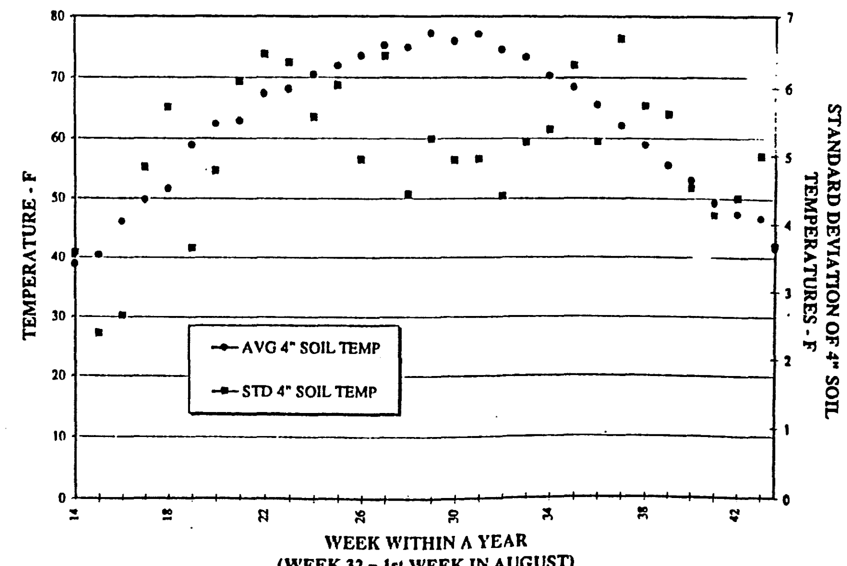


Figure B.2.4.5
MORRIS 10 YEAR 8" SOIL DATA
(1983 - 1993)

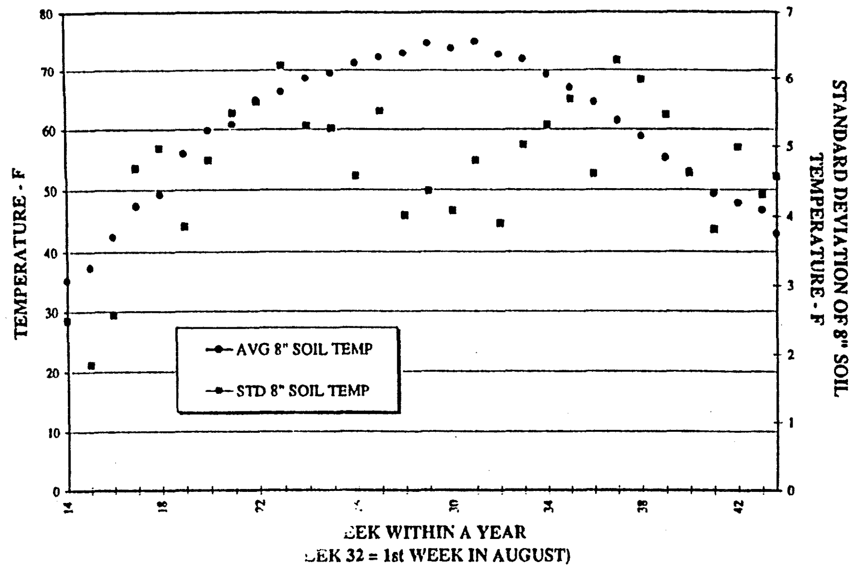


Figure B.2.4.7
Maximum 24 hr Precipitation by Month
Morris, MN (1886-1994)

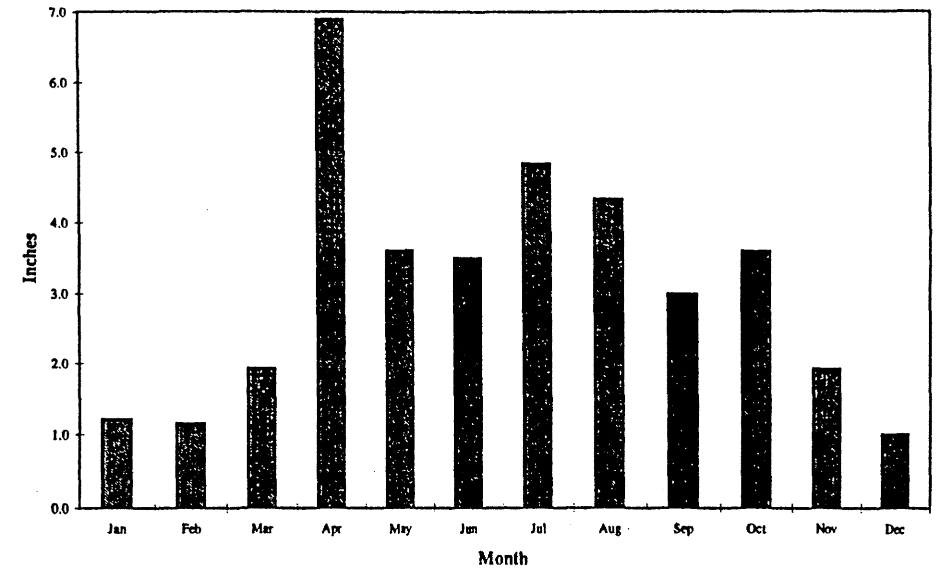


Figure B.2.4.6
:ris, MN 1886 - 1994
:s Depth; Hamerly Soil Series
Soil Moisture Data

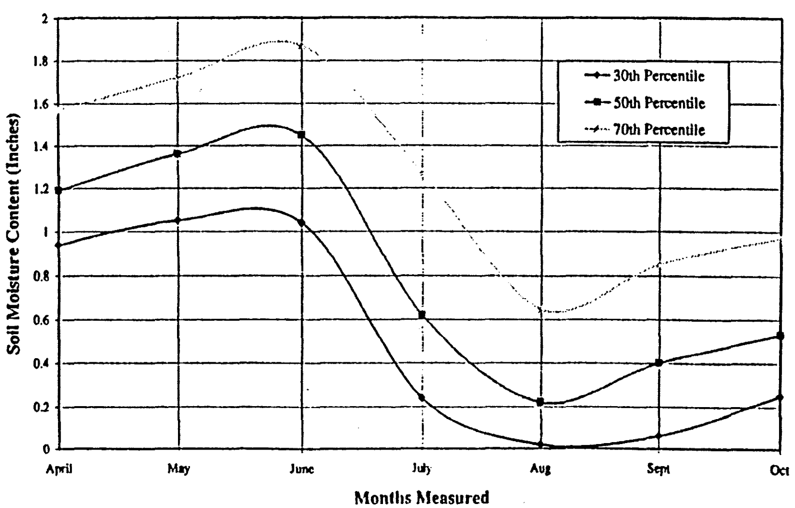


Figure B.2.4.8
Frequency of 2 Inch Rains by Month
Morris, MN (1886-1994)

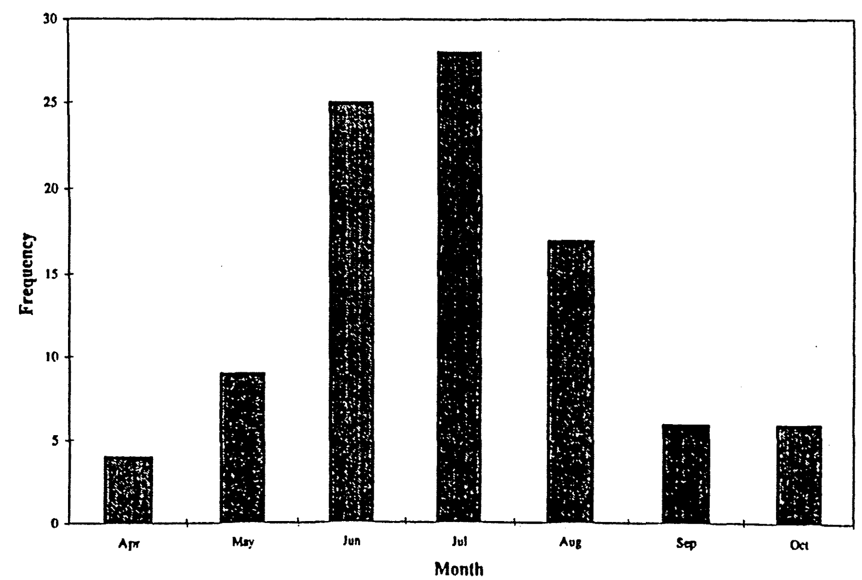
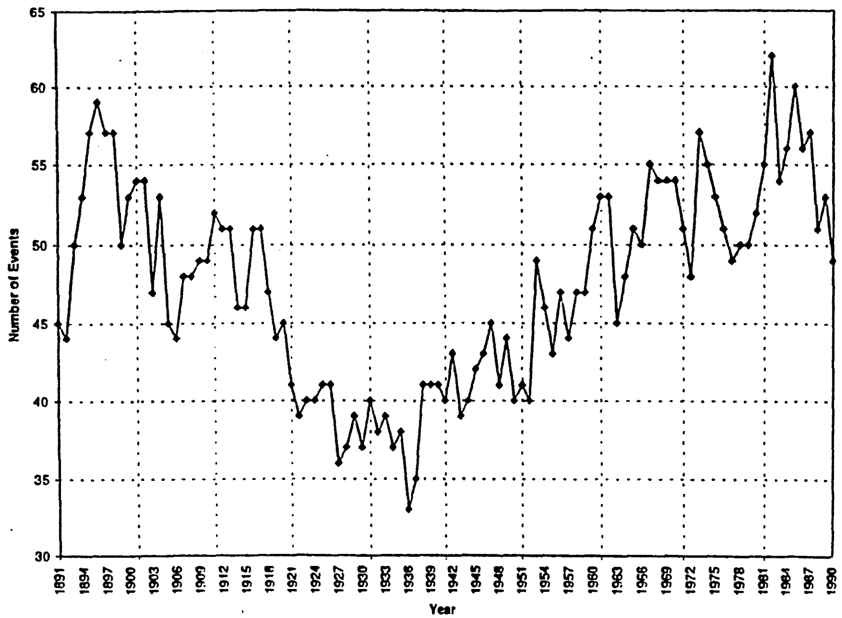


Figure B.2.4.9
Smoothed Decadal Frequencies of One Inch or Greater Precipitation Events at Morris, MN (1886 - 1994)



IV. Research Objectives (continued)

C. Title of Objective: Assess tillage and manure application effects on N and P losses from manure during the snowmelt and growing season periods in West Central Minnesota.

C.1. Activity: Tillage system and manure application effects on losses of N and P due to surface runoff, both from rain and snow will be quantified under West Central Minnesota soil and climatic conditions. Budget reduction in this activity will be accomplished by coordinating analyses with other similar projects. J.F. Moncrief and S.C. Gupta will spend 5% of their time over the next two years assisting on this activity and supervising a graduate student.

C.1.a. Context within the project: Livestock operations are an important part of the economy in West Central Minnesota. Environmentally sound manure utilization from these farming enterprises is imperative. Some soils are steeply sloping, have moderate permeability, and can subsequently pose a hazard to surface water contamination with N and P in water runoff. The shallow incorporation of applied manure with crop residue management systems designed for erosion control (resulting in lower sediment losses) may result in higher losses of N and P. The purpose of this objective is to quantify the net effect of crop residue management systems on N and P losses.

C.1.b. Methods: This experiment will quantify sediment loss and the nutrient loading (N and P) of surface runoff from 3 m by 21 m runoff plots under natural precipitation conditions with continuous corn. The experimental design is a randomized compete block of three replications with tillage main plots split with N and P source subplots. Nitrogen and P fertilizer will be spring applied anhydrous ammonia or ammonium polyphosphate applied as a band with the planter. Manure will be broadcast applied once as solid beef manure with the rate based on soil test P levels. Residue management will be accomplished with either 1) fall moldboard plowing with secondary tillage in the spring with a field cultivator, or 2) a ridge tillage system with planting and row cultivation the only tillage. Plots will be isolated with corrugated steel borders. A collector will direct runoff to three 225 liter barrels in series. The third barrel will collect 1/8 of the overflow from the second. A representative sample of the suspension from each barrel will be collected after each rain storm and analyzed for N and P concentrations. Chemical analysis will include total, soluble, and bio-available P as well as total N, NO_3-N, and NH_4-N. The runoff, sediment, and nutrient loading data will be used to test a field scale model for the Chemical, Runoff, and Erosion form of the Agricultural Management Systems (CREAMS) computer model.

C.1.c. Materials: Corn planters, tillage equipment, cultivators, harvesters, corrugated steel edging, 225 liter barrels, PVC pipe, pumps, reagents, and glassware and laboratory supplies. Microcomputers and the CREAMS model will be used in the model test phase.

C.1.d. Budget: $880.17 remaining on 6/26/95

C.1.e. Timeline: This activity will be carried out on plots established in the spring of 1992 and some measurements will be made before July, 1993.

	7/93	1/94	6/94	1/95	6/95
Establish treatments		****		****	
Collect runoff data		****		****	
Prepare annual summary			****		
Validation of CREAMS model				****	
Prepare final report					***

C.1. Status:

The detailed report starts on the next page.

TILLAGE AND MANURE INTERACTIONS ON CORN RESPONSE
AND EROSIVE LOSSES OF SEDIMENT AND PHOSPHORUS

A THESIS
SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF THE UNIVERSITY OF MINNESOTA
BY

DANIEL GINTING

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

JUNE 1995

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ABSTRACT

Incorporation of manure into soil is important for both better surface water quality and greater crop production. This study evaluated the interaction of ridge tillage and moldboard plowing with solid beef (*Bos taurus* L.) manure on surface runoff and associated sediment, total P (TP), particulate P (PP) and dissolved molybdate reactive P (DMRP) loss; soil $NaHCO_3$ extractable-P (Olson-P); corn (*Zea mays* L.) yield; and P-uptake in 1992-1994 on Barnes loam (fine-loamy mixed Udic Haploboroll) with 12 % slope. In 1992 the runoff, sediment, TP, and DMRP in the moldboard treatment (PL) was 18.5, 162, 30 and 12 times, respectively, greater than from ridge tillage (RT) treatment. In 1992, manure treatment increased DMRP loss. In 1993, runoff, sediment, TP, and PP from the PL treatment was 15, 70, 7, and 8 times, respectively, greater than from the RT plots. Manure reduced runoff and sediment yield by 50 and 70 percent, respectively. However, manure increased DMRP loss from RT treatment by 52 percent. In 1994, the sediment, TP, and PP from the PL treatment was 12, 2, and 4 times, respectively, higher than from the RT treatment. On the other hand, the DMRP loss was 3.8 times greater from RT than PL treatment. In 1994, manure had no effect on runoff, sediment, and P loss. Manure increased Olson P both one and two year after its application. In 1993 grain yield in PL treatment (7.42 Mg ha^{-1}) was greater than in RT plots by 1.23 Mg ha^{-1}. In 1994 tillage effects were not significant. In 1993, manure had no significant effect on yield but in 1994 manure increased yield by 500 kg ha^{-1}. Tillage had no significant influence on P uptake in 1993 and 1994, whereas manure significantly increased P-uptake by 4.7 kg ha^{-1} in each year. Relative to PL, the RT reduced runoff, sediment, TP, and PP loss, however there was greater DMRP loss during snowmelt in the RT plots due to corn residue. Manure reduced runoff and erosion but increased DMRP loss in the RT plots. In both RT and PL plots, manure application increased soil Olson-P and P uptake whereas grain yield in the PL plots was either greater or similar to the RT plots, depending on the year.

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Chapter 1. Tillage and Manure Interactions on Sediment and Phosphorus Transport

Tillage and Manure Interactions on Sediment and Phosphorus Transport

ABSTRACT

A problem of agricultural non-point source pollution is the necessary cultivation to maximize the use of nutrients from manure for crop production. This study was conducted to evaluate the effects of tillage system in combination with solid beef (*Bos taurus* L.) manure application on surface water quality. The effects of ridge till (RT) and moldboard plowing (PL) combined with one time surface application of manure on the transport of sediment, total P (TP), particulate P (PP) and dissolved molybdate reactive P (DMRP) during the snowmelt and rainfall runoff in 1992-1994 were investigated on a Barnes loam (fine-loamy mixed Udic Haploboroll) with 12 % slope planted to corn (*Zea mays* L.). In 1992 the runoff, sediment, TP, and DMRP in the PL was 18.5, 162, 30, and 12 times, respectively, greater than from the RT plots. Manure treatment increased DMRP concentration and thus higher DMRP loss in runoff. For the RT plots, the main source of the annual runoff, TP, PP, and DMRP in 1993 and 1994 was snowmelt, whereas in the PL plots it was rainfall. In 1993, runoff, sediment, TP, and PP from the PL was 15, 70, 7, and 8 times, respectively, greater than from the RT plots. Runoff and sediment loss reduction due to manure application was 50 and 71 %, respectively. Manured RT resulted in 52 % greater DMRP loss compared to non-manured RT plots. In 1994 the sediment, TP, and PP from the PL was 12, 2, and 4 times, respectively, greater than from the RT plots, however, DMRP was 3.8 times greater in RT than PL plots. Manure application had no significant influence on runoff, sediment, and phosphorus loss. Relative to PL, the RT reduced runoff, sediment, TP, and PP loss. DMRP loss from corn residue during snowmelt was greater in RT than PL plots. Manure reduced runoff and erosion but increased DMRP loss in RT plots.

INTRODUCTION

There is considerable concern regarding the contamination of surface and ground waters from land applied agricultural chemicals (Hallberg, 1984; CAST, 1985; Baker, 1985; Nielsen and Lee, 1987). Baker (1988) showed that lake and river contamination from surface runoff is a serious problem in the Lower Great Lake region. Contaminants in the surface runoff include nutrients (NO_3^-, P) and herbicides. Baker (1985) concluded that adoption of conservation tillage practices that reduce sediment and P loading to surface water are necessary.

Based on the measured water quality at 300 locations on the major US rivers, Smith et al. (1987) reported that suspended sediments and nutrients from agricultural sources are the most damaging non-point source (NPS) pollutants. The importance of the NPS lies in the significant association between TP increase in natural water bodies and various measures of agricultural land use, including fertilized acreage and cattle population density. Sediment is the most visible of agriculturally derived pollutants. Sediments not only contribute to costly dredging requirements at lake, ports, and marinas but also carry sediment-bound pollutants, such as PP, to surface waters such as lakes (Smith et al., 1987).

The concern over P with respect to water quality is mainly with stimulation of algae and other aquatic plant growth. For most water bodies, P is the key limiting nutrient for aquatic plant growth (Lee et al., 1978). However, focusing only on TP for eutrophication control may result in no improvement in water quality. It is recommended that eutrophication control measures be directed toward controlling algal available P (Lee et al., 1978). Long term water quality studies of the Ohio rivers draining to Lake Erie have shown that reducing sediments has not necessarily lead to a reduction in eutrophication (Baker, 1985).

Definitions

Researchers have used different terms to describe types of P in surface water quality. To avoid ambiguity, it is felt necessary to define the terminologies used in this thesis presentation. The TP refers to the P in soluble or insoluble form. The TP analysis requires the conversion of insoluble material to soluble material and organic to inorganic phosphorus. One of the two most widely used for extracting the TP from runoff suspension is digestion with $HClO_4$ (USEPA, 1981).

The TP in runoff suspension consists of sediment associated (insoluble) P, soluble organic P and soluble inorganic P. The soluble inorganic P that is usually detected with ammonium molybdate is referred to as dissolved molybdate reactive P (DMRP). The difference of TP and DMRP is called particulate P (PP) (Sharpley et al., 1991b). The DMRP for the most part is readily bioavailable for algal growth whereas the majority of PP (which consisted of the sediment associated P and organic material in runoff) constitute a long term source of potentially bioavailable P. Bioavailable P (BP) represents DMRP and a variable portion of PP that can be taken up by algae (Sharpley et al., 1991b and Sharpley et al., 1994). The portion of PP that was bioavailable involves the extraction of P with NaOH (Sharpley et al., 1991a)

Chemical Concentration in Surface Runoff

In surface runoff, chemicals are transported both in solution phase and along with the sediments. Factors that determine the chemical concentration in surface runoff are (a) adsorption and desorption process, (b) the amount of chemical in the surface soil, and (c) the interactions of the rainfall, runoff, and soil.

Adsorption and Desorption of Chemicals

Current models used to quantify adsorption-desorption of reactive solutes by soils are grouped into the equilibrium and kinetics models (Travis and Etnier, 1981). Since no one model is suitable for all soils and conditions, the choice depends on the problem under consideration. In the runoff process, the actual kinetics of adsorption-desorption within the first few minutes is important (Ahuja, 1985). Desorption of soil P during a short time period (labile P) is a low activation energy process and it has been proposed to be diffusion limited (Kuo and Lotse, 1974; Evans and Jurinak, 1976; Cooke, 1966). For the intermediate time, the linear reversible kinetic model does not adequately describe P desorption (Amer et al., 1955; Evans and Jurinak, 1976). Instead, a power-form of time dependence has been proved quite successful for P desorption (Kuo and Lotse, 1974; Barrow, 1979; Chien and Clayton, 1980).

Sharpley et al. (1981a) successfully used a power function of time and soil-water ratio to describe P desorption. This power function was successfully used by Sharpley et al. (1981b) and Ahuja et al. (1982) to describe P concentration in surface runoff from soil boxes under simulated rainfall. The parameters of the power function may not be the same between the field and the laboratory. Ahuja et al. (1983) concluded that aggregates and clods substantially influence the desorption process in the field.

The Amount of Chemical

The amount of soil available-P determines the available-P in the sediments. The concentration of inorganic P in runoff has been shown to be linearly related to available P in sediment (Romkens and Nelson, 1974; Sharpley et al., 1981b). McDowel et al. (1980) found that the average dissolved-P concentration in runoff was related to the equilibrium soil-P concentrations by a factor of 2 to 3. These observations suggest that accumulation of nutrients at the soil surface may lead to significantly higher P losses in surface runoff.

Interactions of the Rainfall, Runoff, and Soil

During rainfall and runoff events, rainfall mixes with the soil and water in a thin mixing zone at the soil surface zone. From the mixing zone at the soil surface, chemicals are transferred to overland flow. The processes involved in this transfer are: (a) the mixing of rainwater with soil solution, (b) dissolution of the chemical partly present in solid form, (c) desorption of chemical from the soil particles and crop residues, and (d) desorption of the chemical from eroded sediment (Bailey et al., 1974). Sharpley et al. (1978) indicated that the concentration of dissolved inorganic-P in surface runoff was linearly related to 0.1M NaCl extractable inorganic-P in the top 1-cm soil prior to a runoff event.

The transfer of chemicals to overland flow is accelerated with an increase in kinetic energy of rainfall and runoff because of increased mixing of soil and water. Slope and rain intensity modify the effect of kinetic energy by changing the thickness of the surface water layer (depth of overland flow) prevalent during rainfall (Ingram and Woolhiser, 1980). Ahuja et al. (1982) showed that the relationship between kinetic energy and average P concentration in runoff was approximately linear for a given soil slope. According to Sharpley (1985) slope length increases P desorption to surface runoff by affecting on soil-water ratio. The effects of soil hydraulic conductivity on chemical transfer are through its effects on infiltration rate, especially when subsurface hydraulic conductivity is low (Ahuja and Lehman, 1983).

Modeling the Release of Chemicals to Runoff

Before the 1980s, it was generally assumed that rainfall mixed completely with the soil and the soil water in a thin zone of surface soil. It was during this mixing that chemicals from the soil were apportioned among infiltration, runoff, and soil water (Frere et al., 1975; Donigian et al.1977). Frere et al. (1980) and Leonard and Wauchope (1980) assumed a 1-cm thick mixing zone and also that only a fixed fraction of the available chemicals in this zone mixed with runoff water.

In modeling the release of P in surface runoff, Ahuja et al. (1981) assumed a complete mixing in the "effective depth of interaction (EDI)". The complete mixing in EDI implied that the concentration of chemical in runoff water or water infiltrating below the EDI was equal. Ahuja et al. (1981) determined the

EDI by using ^{32}P. The authors noted that the EDI increased with time but the time-averaged EDI appeared adequate for P release under free infiltration conditions.

Ahuja and Lehman (1983) conducted a more critical test of the concept of EDI with a non-adsorbing chemical, Br^-, by varying the infiltration rates under a constant rainfall rate. Measured Br^- concentration in runoff was non-linearly related to time on the semi-logarithmic plot thereby indicating that the complete mixing concept within EDI was not strictly valid.

The weakness of the EDI concept lead Ahuja (1985) to develop a "Nonuniform Mixing Model", in which the author assumed that the degree of mixing of rainfall and runoff with soil decreases exponentially with depth. During the mathematical simulation, soil is divided into many small depth increments and the numerical computations are made separately for each combination of depth and time increments. At each depth increment, a suitable adsorption-desorption model is used to represent the adsorption-desorption process.

Baker at al. (1982) and Baker and Laflen (1982) used the non-uniform mixing concept to model the field scale transport of pesticides, nitrate, ammonium and P in runoff with varying amounts of surface residue. For all these chemicals, the model gave a reasonably good fit between the predicted and measured values. These authors concluded that the residue cover greatly shielded the chemicals at the soil surface from mixing with rainfall. In addition, these authors also observed that there was also less degree of mixing with soil depth at reduced raindrop energy. The concept of non-uniform mixing in N and P transfer to overland flow has also been shown to be satisfactory in a box (Ashraf and Borah, 1992) and small watershed studies (Borah and Ashraf, 1992).

Sharpley et al. (1981b) presented an "empirical kinetic model" to describe chemical release in surface runoff. The empirical model was based on the amount of chemical before rain, the duration of rain, and the soil-water (amount of rain) ratio. The effects of rain intensity, slope, and slope length were included in the soil-water ratio. A test of the empirical equation on six replicated bare and medium residue cover field plots showed that the concentration and time relationship were linear on a log-log scale as indicated by Baker, et al. (1982). From this, the authors concluded that the empirical kinetic model was a reasonably good descriptor of chemical release in surface runoff.

Tillage and Manure Interactions on Chemical Transport

Tillage

Tillage affects on soil physical properties occurs in two zones: (a) the zone where soil has been fractured and then turned over leading to rough surface conditions, and (b) the zone which is compacted due to machinery weight (Gupta et al., 1991). Surface rougness affects runoff volume and its chemical makeup through its influence on soil hydrology such as infiltration and runoff. The extent of tillage effects on chemical transport in runoff is a function of soil, slope, surface cover, and the concentration of chemicals in a shallow soil depth (Baker and Laflen, 1983).

Conservation tillage has been known to reduce erosion and the sediment associated chemicals in surface runoff. However, as the chemical accumulates at the soil surface under conservation tillage, loss of chemicals in runoff solution may be higher (Romkens et al., 1973; Barissa et al., 1978; Baker et al., 1978; McDowell et al., 1980; Laflen and Tabai-Tabai, 1984). Since in conservation tillage systems a substantial amount of plant residue is left at the soil surface, leached chemicals from the residue also contribute to an increased chemical losses in runoff water (McDowell and McGregor, 1984; Schreiber, 1985; Schreiber and McDowell, 1985; Timmons et al., 1970). This is especially true during a snowmelt period when soil is frozen. Most of the P in the runoff is from crop residue. Timmons and Holt (1977) showed that on an annual basis, snow melt transported an average of 89, 86 and 82 percent of organic-P, inorganic-P and total P, respectively.

Manure

The manure effluent guidelines for animal feedlot implicitly encourage the land application of manure as a way to dispose manure as well as a way to provide nutrients to crops (Shuyler and Meek, 1989). The important question is how to dispose of agricultural manure such that it does not pollute water resources and at the same time its nutrients are maximally utilized by plants.

Manure application influences transport of nutrients in surface runoff through its influence on soil chemical and physical properties. Manure application has been known to improve soil chemical and physical properties (Sweeten and Mathers, 1985; Sommerfeld and Chang, 1985; Weil and Kroonje, 1979). In general, surface application of manure increases nutrient concentration in runoff but nutrient losses are reduced because manure at the soil surface retards runoff and soil loss (Young and Mutchler, 1976).

The degree to which manure increases nutrient concentration in runoff depends on nutrient content of the manure and the utilization of nutrients by plants. A few factors that influence manure nutrient content (Klausner, 1989, Minnesota Extension Service, 1985) are: (1) composition of food ration fed to cattle, (2) amount of bedding and water added, (3) method of manure collection and storage, (4) method and timing of land application, (5) characteristic of the soil and the crop to which manure is applied, and (6) climate. The availability and utilization of nutrients in manure nutrient by plants greatly depends upon biological activities that break down organic material.

Substantial research has been conducted to evaluate the influence of method and timing of manure application on surface runoff. Several plot studies have documented that winter or fall applications of manure on hay land results in greater concentration and export of P and N in snow melt runoff as compared to non-manured hayland (Steenhuis et al., 1981; Young and Mutchler, 1976). Converse et al. (1976), on the other hand, observed no significant differences. Studies on summer application of manure (Long, 1979; Reese at al., 1982) have shown an increase of N and P concentration in runoff from manured hayland. Occurrence of rainfall closer to the time of application increases P concentration in runoff (King and Clausen, 1989). Runoff from manured haylands has been reported to be less than from the non-manured land (Converse, at al., 1976; Young and Mutchler, 1976, Wendt and Corey, 1980).

Minnesota has nine major river basins, 81 major watersheds, and 25,000 miles of rivers and streams. While pollution from point sources is decreasing, storm water from agricultural NPS continues to be an important pollution source for sediment, nutrients, pesticides, and other wastes (Minnesota Environmental Quality Board, 1991). Confounding the problem of the agricultural NPS in the Minnesota River Basin is the extensive hog, dairy, and poultry farming in the area.

Manure application to land is a regular practice for crop production in the Minnesota River Basin. To maximize the nutrient benefits of manure to plants, it needs to be incorporated in the soil. The dilemma is what degree of soil cultivation is necessary to incorporate manure while maintaining enough residue to prevent excessive erosive losses of sediment and P. Alternatively stating, can conservation tillage like ridge tillage, be effective with manure application such that the nutrient value of the manure is maximized without greatly affecting the runoff water quality. Specifically, the objective of this study was to evaluate the effects of moldboard vs. ridge tillage systems in combination with and without manure application on P and sediment transport in surface runoff both during frozen and unfrozen periods.

MATERIALS AND METHODS

Field Runoff Study

A field study on tillage and manure interactions on sediment and phosphorus transport in surface runoff was undertaken from 1992 through 1994 at the West Central Experiment Station Morris, MN. The soil at the experimental site is Barnes loam (fine-loamy mixed Udic Haploboroll) on a 12 % slope with a south-eastern aspect. The soil had been previously cropped with alfalfa. The initial (1992) soil test for pH water (1:1), Olson-P, Bray-P and ammonium acetate extractable K were 8.0, 17 mg kg^{-1}, 23 mg kg^{-1}, and 155 mg kg^{-1} respectively (Table 1 in Appendix A1).

Twelve erosion plots, each sized 22 m by 3 m (to accommodate four rows of corn) were marked and isolated using corrugated steel plates. Plot layout and experimental set up are shown in Fig. 1-1. At the end of each plot the runoff was directed to a trough made of a polyvinyl chloride (PVC) sheet (3 m by 0.3 m) and then routed through a 7.6-cm diameter PVC pipe to a collecting system. The collecting system consisted of three barrels of 210 L each. The first barrel collected coarse sediments. The overflow from the first barrel was channelled to the second barrel. At the second barrel, nine adjacent openings of 3.8-cm diameter were drilled near the rim of the barrel (Fig. 1-2). One of the openings was connected to the third barrel with a 3.8-cm diameter PVC pipe which channelled the excess runoff from the second barrel. This set up allowed 1/9 of the overflow from the second barrel to be collected in the third barrel. The runoff collecting system was designed for a 3.5-cm runoff (10-year 24-hour rainfall of 9.7 cm) considering a curve number of 71 (USDA-SCS, 1972). Corrugated roofing was placed over the trough at the end of the plots to prevent entrance of direct precipitation into the collecting system. The sketch showing the collecting system is given in Fig. 1-2. The treatments were arranged in a randomized complete block with split plots and three replications (tillage main plots and manure subplots). Tillage treatments were ridge till (RT) and moldboard plowing (PL). Tillage was up and down slope. Each tillage block was split into 'with manure' and 'without manure' treatments. The manure treatment is defined as a one time application of solid beef manure at the rate of 56 Mg ha^{-1}. The application provided approximately 161 kg total-P ha^{-1} containing 64 kg ha^{-1} of inorganic P. Manure analysis is given in Table 2 of Appendix A1. Detailed procedures for manure analysis are given in Appendices A2 and A3. The treatments were: Ridge till system with manure (RTM), Ridge till system without manure (RTNM), Moldboard plow system with manure (PLM), and Moldboard plow system without manure (PLNM).

In the spring 1992, solid beef manure was applied with box type manure spreader on manure plots. The PL treatment involved the moldboard plowing of the previous year alfalfa (PLNM) and previous alfalfa plus manure (PLM). The moldboard plowing was followed by disking and planting. In the RT plots, ridges were established on 21 July 1992 with a Hiniker row cultivator. Thus in the RTM plots, manure remained at the soil surface prior to 21 July 1992. In other words, the RT treatment prior to 21 July 1992 were more like a no-till treatment.

Corn (Pioneer-3571) was planted up and down the slope at a rate of 79,000 seeds ha^{-1} with a Hiniker 4 row planter equipped with a 5-cm fluted coulter at 76-cm row spacing. In 1992, because of gophers, corn (Pioneer-3617) was replanted at a rate of 99,000 seeds ha^{-1} on 26 May 1992. Due to continuous gopher (*Citellus* sp.) damage, corn (Pioneer-3921) was again reseeded on 15 June 1992 at a rate of 148,000 seeds ha^{-1}. Both replantings were done using an Almaco planter equipped with a 2.5-cm fluted coulter set at 76-cm row spacing. In 1992 no corn grain or plants were harvested from the plots. Corn plants in moldboard systems were chopped and plowed into the soil with fall moldboard plowing. Due to poor corn stands, baled dry corn stalks were spread on the RT plots at a rate of 5.6 Mg ha^{-1}. This corn stalk application was done to simulate residue cover that exist in the ridge tillage after harvest.

On 16 July 1993 NH_4NO_3 was broadcast applied to the non-manured plots (RTNM and PLNM), at a rate of 45 kg ha^{-1} N to achieve similar N available level among all treatments. This amount was based on the anticipated available N from the organic nitrogen of manured plots (RTM and PLM). In 1994 N was applied at a rate of 111 kg ha^{-1} and 134 kg ha^{-1}, respectively, to PLM and PLNM plots. The corresponding N rate for RTM and RTNM was 134 kg ha^{-1} and 157 kg ha^{-1}, respectively, to the RTM and RTNM plots. In 1994, the NH_4NO_3 was hand broadcast and incorporated with cultivation on 6 June 1994. Pesticides were applied at the recommended rate (Appendix A1).

Tillage operations in 1993 and 1994 were: (1) the moldboard plowing in the fall followed by field cultivation and planting in the spring, (2) a direct planting in the previous year ridges in the spring followed by row cultivation in the summer. Row cultivation formed ridges around the growing corn plants. Detailed field operations during 1992 to 1994 are given in Appendix A1.

A few days in the winter on 2, 3, and 4 March 1994, soil temperatures were measured in the interrow area at 5-cm depth in one RT and one PL plot. The temperature was measured using copper-constantan thermocouples hooked to a data logger.

Snow depth and density was measured on 1 and 7 March 1994 with a snow tube. The snow tube was made of an aluminum tube 4.8-cm in diameter. The leading end of the tube were jagged and sharpened. The snowtube was pushed into the snow gently (with a turning motion to avoid compaction) and the snow depth was recorded. The tube was pulled and then cleaned from soil or plant material (usually at the jagged end). The length of the snow in the tube was recorded (to determine snow volume) and snow was emptied to a preweighed plastic bag and weighed in the laboratory. The snow density was derived by dividing the snow weight with its volume. Equivalent water depth of snow was derived from the snow density and snow depth data.

The runoff volume from snowmelt and rain was measured with a calibrated dip stick. On 31 March 1994 pressure transducers (with specification of 0-15 MPa) were installed in the first barrel and hooked to a data logger. The pressure transducer and data logger provided the change of water volume (in depth) in the first barrel with time. This was intended for relating runoff flow rate and rainfall rate in a runoff hydrograph. Because ten out of 12 transducers were not working properly on 11 July 1994, the pressure transducers were replaced with transducers with a narrower range of specification (0-5 MPa).

After volume measurement, the runoff suspension was thoroughly stirred and samples were taken for sediment and P fractionation (TP, BP, and DMRP). Subsamples for sediment and P analysis were taken from the first, second, and third barrels. Sediments were measured by evaporating 200 mL of runoff suspension followed by drying at 105 °C.

Total P was measured using perchloric acid digestion as described in EPA standard procedure (US EPA, 1981). For TP analysis 20 mL of runoff suspension was pipetted while magnetically stirring the runoff sample in a bottle to homogenize the suspension. The detailed procedure on TP analysis is given in Appendix A4. The BP was measured using extraction of the 20 mL of runoff suspension mixed with 180 mL of 0.11 N NaOH to make a final concentration of 0.1 N NaOH (Sharpley et al., 1991). Extraction with NaOH was done by shaking for 18 hours on a reciprocating shaker (Appendix A5). Dissolved molybdate reactive P was measured from the solution after separation of the solid phase from the runoff suspension (Wendt and Corey, 1980). The detailed procedures for DMRP measurement is given in Appendix A6. All phosphorus fractions were determined with the ascorbic acid method of Murphy and Riley (1962). For BP and DMRP analysis, liquid and solid phase were separated by centrifugating at 15,000 rpm (22,700 × *g*) for 5 minutes (10 minutes total time including acceleration and deceleration stages) at 25 °C.

Residue Cover

Soil residue cover was measured using line transect procedure (Laflen et al., 1981) in both row and interrow area. "Row area" was defined as a 10-cm wide strip centered over the row and the "interrow" area was the remainder. A line used had 25 markings at 25-cm interval. The line was stretched across the inrow or interrow area and the markings (touching the residue or perpendicularly over the residue) were counted. The residue cover (expressed in percent) is derived from the number of markings counted multiplied by four. Residue cover measurement was made in quadruplets in each plot before and after planting, before and after cultivation, and after ridging.

Bulk Density

Bulk density was measured a week after planting on 5 May 1994. Soil samples were taken with a soil probe of 3-cm in diameter. The probe was hand driven into the soil vertically to a 7.5-cm depth and the soil in the probe was emptied into a moisture can, brought back to the laboratory, and oven dried at 105 °C. Bulk density was determined by dividing soil dry weight by soil volume (Blake and Hartge, 1986). Soil bulk density was measured in triplicate at the up slope, center and down slope positions in each plot.

Steady State Infiltration

Cumulative infiltration and steady state infiltration rate (regarded as field saturated hydraulic conductivity) were measured with a double ring infiltrometer (Bower, 1986) after fall harvest but before fall tillage on 28 October 1994. Duplicate infiltration measurement were made (10 m apart) between plant rows in each plot. The double ring infiltrometer consists of inner and outer rings approximately 33 and 50-cm in diameter, respectively.

The soil surface was cleaned from plant residues and both the inner and outer ring were driven approximately 15 cm into the soil. A metal wire with a sharp point was set at 4 to 5 cm (representing water head) above the soil at the center of the inner ring. A piece of glass fiber was placed on top of the soil in the inner ring (to avoid soil disturbance when pouring water). Water height was maintained at the preset head by adding 0.5 L when the wire pierced water surface (water in both inner and outer ring was maintained at the same level). Cumulative water depth added and time (60 minutes) were recorded and plotted. Steady state infiltration rates were calculated from the linear part of the curve of cumulative infiltration (mm) vs. time (minutes). The slope of the regression line (SAS, 1982) of the linear part is taken as the steady state infiltration rate (mm/minute). The depth of water infiltrated during the first 10, 30 and 60 minutes was also determined from the curve showing the cumulative infiltration vs. time.

Phosphorus Leaching from Corn Residue

Field Study on TP Leaching

The 1992-1993 snowmelt runoff analysis showed that TP concentration was higher in the RT compared to PL plots. It was suspected that higher TP concentration was a result of P release from surface residues ruptured during freezing and thawing. Since there is no information on the release of P from corn residue in the field during snowmelt, a field residue leaching study was undertaken in the winter of 1993-1994.

Mature corn leaves were taken from five RT plots after harvest on 28 October 1993. A portion of the leaves was sampled for moisture content and initial TP analysis. For the winter TP leaching study, about 25 g of leaves was placed in each of the ten perforated bags. The leaf-bags were then returned to the RT plots. In each RT plot (at up-hill side), two bags were pinned between the plant rows on 29 October 1993. The bags were collected on 31 March 1994 after all the snow had melted. The leaves in each bag were dried at 60 °C and then analyzed for final TP. The loss of TP from crop residue due to snow melt was determined from the difference between the initial TP and final TP for each bag.

Laboratory Study on DMRP Leaching from Corn Residue

A majority of the daily snowmelt analysis during 1993-1994 indicated that TP and DMRP concentrations were higher from RT plots. Since TP leaching from leaves by snowmelt had already been conducted in the field, an additional study was undertaken in the laboratory to evaluate DMRP leaching from both leaves and stover.

Residue Preparation: Corn leaves used in the DMRP laboratory experiment were from the same source as the ones used in the field leaf-TP leaching study. Dry corn leaves were cut to about 15-cm length. About 12 g of cut leaves were inserted lengthwise blade by blade, in a 1-L polyethylene bottle.

The corn stover used was subsampled from chopped stover collected after corn harvesting on October 28 1994. The dry chopped-stover was sieved to collect the fraction 1-cm or greater. About 12 g of dry residue was placed in a 1-L polyethylene bottle. Both leaf and stover residue leaching experiment was done in triplicate.

Residue Leaching: Residue was subjected to different leaching-cycle treatments. Each treatment involved three cycles of either freezing-thawing-leaching or soaking-leaching. The description of treatments is given in Table 1-1. In each leaching cycle, 350 mL of cold (4 °C) deionized distilled water was added. To speed the thawing of ice in treatment A (Table 1-1), the bottles containing residue were placed in flowing air from a fan for about 5 hours at room temperature.

Before leaching, each bottle was hand-shaken 15 times end over end to ensure contact of cold water with residue. To avoid loss of residue in decantation, a piece of parafilm was stretched to cover the bottle mouth and pierced with a needle. The leachate was then poured to the last drop into a beaker, filtered through a Whatman # 42 filter paper, then stored at 4 °C prior to DMRP analysis as given in Appendix A6.

Only a few drops of water were left in the bottle before the next leaching cycle (Table 1-1). The three cycles of leaching, each with 350 mL deionized-distilled water, simulated the ratio of total residue weight to total cumulative snowmelt runoff during 1993-1994 winter. The ratio was equivalent to 1050 mL snowmelt for each 12 g of corn residue.

Phase Separation for Runoff Suspension

Phase separations by filtration have been replaced by centrifugation for various reasons including the fact that filters are able to retain some solute of interest (USEPA, 1987). Calculation of centrifugation for removing particles of a desired radii and time can be facilitated by the equations (USEPA, 1987):

$$\omega^2 = \frac{4\pi^2(rpm)^2}{60}$$

$$t = \frac{9\eta \ln(R_b/R_t)}{2\omega^2 r^2(\rho_p-\rho)}$$

where

t =time in (minutes)

η =viscosity of water (8.95×10^{-3} g $sec^{-1}cm^{-1}$ at 25 °C)

r = particle radius (in cm)

ρ_p =particle density (g cm^{-3})

ρ =density of solution (g cm^{-3})

rpm =revolution per minute.

R_t =distance (in cm) from the center of the centrifuge rotor to the top of solution in centrifuge tube.

R_b =distance (in cm) from the center of the centrifuge rotor to the bottom of centrifuge tube.

The routine procedure of phase separation for BP and DMRP of runoff is: centrifugation at 15,000 rpm (Sharpley at al., 1981a) or 27,160 *g* (Sharpley, 1983) plus filtration through a 0.45 µm membrane filter. The filtration is a laborious, time consuming and costly procedure, especially when involving a large number of runoff samples. By calculation using the formula above with R_b and R_t is 12.3 and 5.6, centrifugation to 15,000 rpm (22,700 *g*) for 5 minutes at 25 °C removes the particles down to 0.05 µm. Therefore it is hypothesized that filtering after 5 minute centrifugation at 15,000 rpm (22,700 *g*) is not necessary. To justify this elimination of filtering step in the BP and DMRP measurements, we conducted an additional study on comparison of centrifugation vs. centrifugation plus filtering on 55 runoff samples.

The samples represented different runoff events containing a range of P and sediment concentrations. From each sample a pair of subsamples were taken. All subsamples were centrifuged at 15,000 rpm (22,700 *g*) for five minutes (10 minutes total time). After centrifugation, the supernatant of one subsample from each pair of subsamples was filtered through a 0.45 µm membrane filter and then analyzed for DMRP determination (Appendix A6). In the other subsample, DMRP was also determined in the supernatant without filtration. A first order regression line correlating the P concentration between filtered and non-filtered supernatant was determined (SAS, 1982). Paired comparison of P concentration of filtered and non-filtered supernatant was also conducted with a paired student-t test (SAS, 1982). A similar procedure was used on 25 runoff samples for BP determination with and without filtration

RESULTS AND DISCUSSION

Precipitation

Precipitation data were taken from a weather station at the West Central Exp. Stn., Morris, MN about 1 km from the plots. Daily precipitation records from 1992, 1993, and 1994 are presented in Fig. 1-3 and summarized in Table 1-2. Daily precipitation data showed that events with precipitation higher than 2.0 cm were more frequent in 1993 compared to 1992 or 1994. Daily precipitation in early spring in the month of April was greater in 1994 than 1992 or 1993. The highest daily precipitation occurred in the month of July of each year (Fig. 1-3). Total snowfall (water equivalent) during 1992-1993 and 1993-1994 was 10.6 and 12.5 cm, respectively. Total rainfall during 1992, 1993 and 1994 was 43.2, 73.0 and 57.0 cm, respectively.

The 1992 Rainfall Runoff, Erosion, and Phosphorus Loss

Runoff Volume and Sediment Loss

Three rainfall-runoff events occurred from 7.4 cm precipitation during May-June 1992. Although the ridges were not yet formed in the RT treatment, total runoff from the RT plots was significantly less (25 times) than the PL plots (Table 1-3). This is because the dried alfalfa stalk residues from the previous year's crop and straw material in the beef manure in the RT plots reduced rainfall energy impacting at the soil surface (less soil detachment) as well as retarded the flow of runoff (allowing greater infiltration into the soil). As expected, sediment concentrations were significantly higher in PL than RT plots. Greater runoff volume and higher sediment concentration in PL plots lead to a greater (163 times) total sediment loss from the PL plots compared to the RT plots. There were no significant differences in runoff volume and sediment loss either due to manure or tillage by manure interaction (Table 1-3).

Phosphorus Loss

Losses in TP, BP, and DMRP in rainfall runoff (May-June 1992) were significantly higher from the PL compared to the RT plots (Table 1-4). This was mainly due to a larger runoff volume and greater sediment load from the PL than the RT plots (Table 1-3). The concentration of TP, BP, and DMRP in runoff was always higher in RT compared to PL plots for individual events. However, the runoff volume being higher from the PL plot overshadowed the differences in concentration. The PP was a major component of TP in runoff water from both RT and PL plots.

The BP was dominated by DMRP in runoff water from both the RT and PL plots. In runoff from RT plots, 56 percent of BP was DMRP, whereas from PL plots, 51 percent of BP was DMRP (Table 1-4). Bioavailable portion of PP in runoff varied with tillage. In runoff from RT plots, 41 percent of PP was BP whereas 12 percent of PP was BP in runoff from PL plots. Since sediment concentration was low in runoff from the RT plots, a majority of bioavailable PP was soluble organic P. Conversely, since the sediment concentration was significantly greater in runoff from the PL plot, a majority of the bioavailable PP must be sediment associated P.

Manure application had no significant influence on TP, PP or BP loss in surface runoff, however, DMRP loss in surface runoff was significantly influenced by manure application (Table 1-4). Since runoff volume was not significantly influenced by manure application, the greater loss of DMRP was mainly due to greater DMRP concentration in manured plots.

The 1993 Runoff, Erosion, and P Loss

The 1992-1993 Winter Snowmelt

Runoff: The 1992-1993 snowmelt runoff, sediment and P measurements were taken on 29 March 1993 at the end of snow thaw period. Therefore, these measurements represent a composite of all snowmelt during this winter.

Tillage and manure significantly influenced snowmelt runoff but tillage by manure interaction was not significant (Table 1-5). Snowmelt runoff from the RT plots was 5.7 times higher than the snowmelt runoff from the PL plots. This was due to due to a lack of depressional storage in the RT plots compared to the PL plots. The 1992 fall moldboard plowing resulted in the depressional storage. During the 1992-1993 winter no in situ snow depth measurement was taken. As stated earlier, baled corn residue was spread on the RT plots because of poor corn stands to simulate residue cover often found in ridge tillage after fall harvest. It was assumed that this residue did not significantly influence snow depth in RT compared to PL plots.

Manure application significantly reduced the snowmelt runoff. Reduced runoff from the manured plots was presumed to be the result of improved soil conditions and thus increased infiltration as a result of fecal and straw material from manure addition.

Sediment Load: Tillage significantly influenced the total sediment loss due to snowmelt (Table 1-5). The RT plots had 8.2 times higher sediment loss than PL plots. The increase of sediment loss was mainly due to an increase in runoff volume from RT plots, since there was no significant influence of tillage on sediment concentration (Table 1-6).

Manure application alone did not significantly influence sediment loss due to snowmelt runoff. However, there was a significant interaction between tillage and manure on sediment loss by snowmelt runoff. In RT plots, manure application reduced sediment loss whereas in PL plots there was no difference in sediment loss between manure and no manure treatment. Since there was no tillage by manure interaction on sediment concentration, the interaction effects on the reduction of sediment loss were mainly due to runoff reduction with manure application in RT plots.

TP: Runoff from the RT plots resulted in a significantly higher TP loss than PL plots. This difference was due to both higher runoff volume (Table 1-5) and higher TP concentrations in the runoff from the RT plots (Table 1-6). Higher TP concentrations in the runoff from the RT plots are presumed to be from the P leached from corn residues by snowmelt. Timmons and Holt (1977) reported that freezing and thawing enhances the leaching of P from plant materials.

Manure application alone had no significant influence on TP loss but tillage by manure interaction was significant (Table 1-5). Manure application reduced snowmelt TP loss by 1.2 kg ha^{-1} from RT plots whereas in PL plots the TP loss slightly increased by 0.05 kg ha^{-1} with manure application. The reduction in TP loss from manured applied RT plots was mainly due to a reduction of volume and TP concentration. TP concentration in snowmelt runoff from manured RT plots was lower by 3.5 mg L^{-1} than the non-manured plots (Table 1-6). The increase of TP loss from manure applied PL plots was due to an increase of TP concentration by 2.6 mg L^{-1} with manure application.

PP: There was a trend in greater PP loss from the RT plots compared to the PL plots (Table 1-5). Since the sediment concentration was low in the snowmelt, most of the PP in snowmelt must be organic P released from corn residue. Greater PP loss in RT compared to PL plots was mainly due to greater runoff volume from the RT plots because the difference in PP concentration due to tillage was not significant (Table 1-6).

There was no significant influence of manure on PP loss in snowmelt runoff, however, there was a significant tillage by manure interaction on snowmelt PP loss (Table 1-5). In the RT plots, PP loss was reduced by 1.3 kg ha^{-1} with manure application, whereas in PL plots, PP loss was slightly increased by 0.04 kg ha^{-1} with manure application. Reduction in snowmelt PP loss in manure applied RT plots was due to a reduction of both runoff volume (Table 1-5) and its PP concentration (Table 1-6). The increase of PP loss in manure applied PL plots was due to an increase of PP concentration by 2.4 mg L^{-1} with manure application.

DMRP: Tillage influence on DMRP loss was significant (Table 1-5). Ridge tillage resulted in greater DMRP loss mainly due to a significantly greater runoff volume (Table 1-5) because the DMRP concentrations were not significantly different between the tillage systems (Table 1-6).

Manure effects on DMRP loss were not significant, even though manure application significantly increased DMRP concentration in the snowmelt runoff. Reduced volume of snowmelt runoff balanced the higher DMRP concentration in manure applied plots resulting in no significant difference in DMRP loss. The tillage by manure interaction was significant for DMRP concentration (Table 1-6). Increased DMRP concentration by 1.1 mg L^{-1} in the snowmelt runoff from manured RT plots, suggested that partially incorporated manure resulted in higher DMRP concentration than no manure application. However, due to a reduction of runoff volume, higher concentration of DMRP did not result in higher DMRP loss. In Table 1-5, it is shown that in RT plots, higher TP or PP loss is not necessarily followed by higher DMRP loss. On the contrary in the manured RT plots, 47 percent of TP loss in snowmelt is in the form of DMRP, whereas in non-manured RT plots only 5.5 percent of TP loss is DMRP. This again suggests that the DMRP losses were mainly due to partially incorporated manure in RT plots.

The 1993 Rainfall Runoff

Runoff: There were 15 individual rainfall-runoff events during the months of May through August 1993. The total runoff from the 15 events was significantly different between the two tillage systems. The total runoff from the PL plots was 15.5 times higher than the runoff from the RT plots (Table 1-7). For nine of the 15 daily events RT plots had significantly lower runoff volume. For the other five events, runoff was similar (Appendix A10). Higher residue cover in RT plots presumably increased the infiltration by reducing the runoff velocity and by protecting the soil from surface sealing due to rainfall impact. The reduction in runoff from RT plots compared to PL plots was great, especially in a long and high intensity rain. For example, in a 2-hour 10-cm rain event on 4 July 1993, there was only 0.3 cm runoff from the RT plot compared to 3.4 cm from PL plots (Appendix A10).

Manure reduced runoff caused by rainfall (Table 1-7) although the difference was not significantly at 10 % probability. For eight of the 15 runoff events, manure significantly reduced the runoff volume. On average, the manured plots resulted in runoff reduction by 50 percent compared to the non-manured plots (Table 1-7). This reduction in runoff volume was presumably due to improved aggregate stability on infiltration.

Although overall there was no significant interaction between tillage and manure on runoff (Table 1-7), seven out of the 15 runoff events showed significant interactions (Appendix A10). In these seven runoff events, manure reduced runoff significantly from the PL system. This suggests that even in the absence of residues, manure application can reduce runoff from the PL plots.

Sediment Loss: Both tillage and manure application significantly influenced the sediment loss from May to August 1993. Sediment loss was 70 times greater from the PL than RT treatment (Table 1-7). Thirteen of the 15 events indicated that the PL plots resulted in significantly higher sediment loss. Higher sediment loss was due to both higher runoff volume and sediment concentration. Seven of the 13 daily events showed a significant influence of tillage on sediment concentration (Appendix A11). In most events, the RT plots resulted in lower sediment concentration. For example, in the biggest rainfall event (2-hour 10-cm rain) in 1993, the PL plots resulted in sediment loss of 15.1 Mg ha-1 compared to 0.2 Mg ha^{-1} from RT plots (Appendix A10).

Manure significantly reduced the total sediment loss from May to August 1993. Non manured plots resulted in 3.4 times greater sediment loss compared to manured plots. This translated to a sediment loss reduction of 11.3 Mg ha^{-1} in manured PL plots compared to the non-manured PL plots (Table 1-7). Similarly, the reduction in the sediment loss from manured compared to the non-manured RT plots was 0.46 Mg ha-1. Seven of the 15 runoff events showed that manure application reduced sediment loss (Appendix A10), mainly as a result of the reduction in runoff volume and not due to lower sediment concentrations in the runoff (Appendix A11). This suggests that the manure effects on increased water infiltration is due to improved soil aggregation or stability.

TP: Tillage significantly influenced the cumulative TP loss in the runoff during May through August, 1993. The PL system resulted in 6.8 times greater TP loss than the RT system (Table 1-7). In 12 of the 15 runoff events, TP from PL plots was significantly greater than RT plots (Appendix A10). However, in two of the 12 events there was an increase in TP concentration in PL plots (Appendix A11). Therefore, the greater TP loss in PL plots was mainly due to a significantly greater runoff volume.

There was a trend in TP loss reduction with manure application. In two out of the 15 events, non-manured plots resulted in higher TP loss, but in neither of these two was there a higher TP concentration in non-manured plots. This suggests that greater TP loss in these two events was mainly due to greater runoff and not due to increased TP concentration. There were five out of 15 events where manure application significantly influenced the TP concentration (Appendix A11), however, the concentration of TP in runoff from manured plots was not consistently lower or higher compared to non-manured plots.

There was no tillage by manure interaction on cumulative TP loss from May to August, 1993 (Table 1-7). However, for three runoff events, there was a significant tillage by manure interaction on TP loss (Appendix A10). In these three events, manure application significantly reduced TP loss from the PL plots whereas there was no effect of manure on TP loss in RT plots. This reduction was mainly due to a reduction of runoff volume from manure application.

PP: There was a significant influence of tillage on cumulative PP loss from May through August, 1993 (Table 1-7). The PL system resulted in 7.9 times greater PP loss compared to the RT treatment. The PP was the predominant form of P which was mostly associated with sediment. For the RT treatment, the PP was 84 percent of the TP whereas for the PL treatment, PP was 96 percent of the TP. Twelve of 15 runoff events had a significantly higher TP loss from PL than RT plots (Appendix A10). Four of the 12 events had a higher concentration of PP from PL than RT plots (Appendix A11). This suggests that the greater PP loss from the PL treatment was mainly due to greater runoff volume than the RT treatment.

Although manure significantly reduced runoff volume and sediment loss, cumulative PP loss from May through August 1993 was similar between manure and no manure treatment (Table 1-7). Thirteen of the 15 events showed that PP loss was similar between manure and no manure treatment. There was no significant interaction of tillage by manure on cumulative PP loss (Table 1-7). Only two runoff events showed significant tillage by manure interaction on the concentration of PP in runoff (Appendix A11). In both events, manure application reduced PP concentration.

DMRP: For both tillage treatments, cumulative DMRP loss from May through August 1993 was a smaller portion (compared to PP) of TP loss in runoff. In RT plots, DMRP loss was 16 percent of TP loss, whereas in the PL plots DMRP loss was 4 percent of TP (Table 1-7). Cumulative DMRP loss from May through August 1993 was not significantly influenced by tillage or manure application (Table 1-7). Six of the 15 events showed that PL treatment consistently resulted in higher DMRP loss in runoff (Appendix A10) even though three of these six events had consistently lower DMRP concentration in the runoff.

Manure had no significant influence on cumulative DMRP loss from May through August 1993 (Table 1-7). Six of the 15 runoff events showed a significant influence of manure in increasing concentration of DMRP (Appendix A11) but only one of these events showed greater DMRP loss with manure application (Appendix A10). This suggests that in most runoff events, manure increased the concentration of DMRP but at the same time reduced the runoff volume which results in reduced DMRP loss. However for a particular event, such as on 4 July 1993 (2-hour 10-cm rain), the reduction of runoff volume was overshadowed by a greater concentration of DMRP in manured plots which resulted in greater DMRP loss (Appendix A10).

There was a significant tillage by manure interaction for cumulative DMRP loss from May through August 1993. In RT treatment, manure increased DMRP loss whereas in the PL plots DMRP loss was similar (Table 1-7). This interaction was mainly from the largest runoff event (2-hour 10-cm rain) on 4 July 1993. Although the runoff was lower for the manured RT plots, higher concentration of DMRP with manure application resulted in greater DMRP loss. Higher concentration of DMRP in manured RT treatment was because manure and residue had not been well incorporated in the soil. The presence of residues and manure retarded the runoff flow allowing greater contact time for runoff to react with soil, residue and manure resulting in a greater release of P to runoff and consequently higher concentration.

The 1993 Annual Runoff, Erosion and P Loss

Tillage Effects: For the RT system, annual runoff was dominated by snowmelt runoff (77 percent of annual runoff), whereas in the PL system, rainfall runoff was the predominant component (95 percent) of the annual runoff. Annual runoff volume from the PL treatment was significantly higher than the RT treatment (Table 1-8). However this difference between two tillage treatments was mainly due to one major runoff event (Fig. 1-4). The contribution of this single largest runoff event was 3.4 cm for the PL treatment compared to 0.3 cm for the RT treatment. If it was not for this 2-hour 10-cm rain (10 year 24-hour storm for Morris), the annual runoff would be similar for the tillage systems.

Sediment loss from snowmelt runoff was negligible compared to the sediment load due to rainfall runoff. Sediment losses from RT and PL treatments were 0.3 and 16.0 Mg ha^{-1}, respectively (Table 1-8). For the PL treatment 95 percent of the sediment load was from one major runoff event. Sediment loss followed a similar distribution as the runoff loss (Fig. 1-4).

For the RT system, TP in snowmelt runoff was the predominant component (64 percent) of annual TP loss whereas for the moldboard system, TP in rainfall runoff was the main component (97 percent) of the annual TP loss (Fig. 1-5). There was no significant difference in annual TP loss between RT and PL treatments (Table 1-8). A majority of the annual TP loss for the PL treatment was mainly due to one major runoff event (Fig. 1-5). The pattern of annual TP loss distribution was similar to the distribution of runoff and sediment loss (Fig. 1-4 and 1-5).

Since the sediment concentration was low in runoff from snowmelt, the PP in the snowmelt runoff was mainly in organic P form. For the RT system, snowmelt was the main source (64 percent) of annual PP losses whereas for the PL system, rainfall runoff was the main source (98 percent) of annual PP losses. The annual PP loss was significantly greater from the PL treatment, again mainly due to one major rain event (Fig. 1-5). If it was not due to this major event, the annual PP loss from the snowmelt would have been greater in RT treatment compared to PL treatment.

For the RT treatment, DMRP in snowmelt runoff was the predominant component (66 percent) of the annual DMRP loss whereas for the PL treatment, DMRP in rainfall runoff was predominant (84 percent) component of the annual DMRP loss. These opposite factors contributing to DMRP losses resulted in a non-significant differences in annual DMRP loss between the two tillage systems (Table 1-8). For both RT and PL treatments, the annual DMRP loss was a small portion of the annual P loss. For the RT system, annual DMRP loss was 15 percent of the annual TP loss, whereas for the PL system, the DMRP loss was 4 percent of the annual TP loss. Greater TP loss in PL treatment was not necessarily followed by greater DMRP loss. In spite of the increase in TP loss from largest rainfall in 1993, the DMRP loss did not significantly increased from the PL plots (Fig. 1-5).

Manure Effects: Manure application significantly reduced the annual runoff due to snowmelt and rainfall. Manure effects on runoff reduction was greater during rainfall than snowmelt (Fig. 1-6). Compared to non-manured treatment, manure treatment reduced rainfall runoff by 51 percent and snowmelt runoff by 35 percent.

Manure application also significantly reduced the annual sediment loss (Table 1-8). The manured treatment resulted in 67 percent reduction in total sediment loss compared to the non-manured treatment. The significant difference between manured and non-manured plots was mainly during the biggest runoff event caused by the 2-hour 10-cm rainfall (Fig. 1-6). Presumably, manure application improved soil aggregation and increased infiltration, thus reducing runoff and erosion.

Total P in runoff from non-manured plots was 2.5 times higher than manured plots (Table 1-8). Higher TP loss from non-manured plots was mainly in the rainfall runoff (Fig. 1-7). Compared to non-manured plots, manured plots reduced cumulative TP loss by 62 percent during rainfall runoff. The significant reduction in the annual TP loss from the manured plots was mainly during the biggest runoff event. This suggests a close relationship between TP (Fig. 1-7) and sediment loss (Fig. 1-6) during the rainfall runoff events.

Manure tended to reduce annual PP loss (Table 1-8). The reduction of PP loss was due to the influence of manure on reduction in both runoff and sediment transport during the rainfall runoff events. The cumulative TP in rainfall runoff was reduced by 64 percent in manure compared to the no manure treatment (Table 1-7). A significant difference in PP between manured and non-manured plots was largely from the biggest runoff event (2-hour 10-cm rainfall) on 4 July 1993 (Fig. 1-7).

Although loss of DMRP was greater from the manured than the non-manured plots during the biggest runoff event (Appendix A10), the annual DMRP loss was not influenced by manure application (Table 1-8). The tillage and manure interactions were absent for annual runoff and associated sediment, TP, PP and DMRP losses.

The 1994 Runoff, Sediment and P Loss

The 1993-1994 Snowmelt Runoff

Snow Characteristic: During the 1994 snowmelt period, 15 daily events of snowmelt runoff were observed. The daily snowmelt events occurred periodically between 22 February through 26 March 1994. In-situ snow depth and snow density, measured on 1 March and 7 March 1994, are given in Table 1-9.

Snow depth in the RT plots was much higher than snow depth in the PL plots. Over a period of a week, there was a significant reduction in the snow depth (from 26.9 to 18.1 cm) as well as in the equivalent water content (7.9 to 5.7 cm). There was a tendency of equivalent water content to be slightly greater in the RT compared to the PL treatment. Although there was a significant decrease in snow depth, snow bulk density did not change over a period of one week.

Soil Temperature: Air temperature 10 cm above ground and in-situ soil temperature at 5 cm depth between plant rows in one RT and one PL plot were measured for three days in March 1994. The soil and air temperature are graphed in Fig. 1-8. On the first day of measurement (2 March), the soil temperature at 5-cm depth in a RT plot was lower than a PL plot because of insulation from thicker snow and the presence of surface residues. However, on the second day (3 March) when maximum air temperature reached 8 °C, soil temperature at 5-cm depth in the RT plot was similar to the value as that of the PL plot. On the third day (4 March) when the air temperature reached a maximum 8 °C, soil temperatures for both RT and PL plots was 1 °C (Fig. 1-8). This suggests that soil periodically thawed at a 5-cm depth in spite of the presence of snow in both RT and PL plots.

Runoff: Air temperature and snowmelt runoff hydrograph from 13 through 15 March are plotted in Fig. 1-9. In general, the variation in the rate of snowmelt runoff followed the pattern of variation in ambient air temperature 1 m above the ground. Also, the flow rate was greater in the RT plots than the PL plots. There was a time difference in the peaks of runoff. The time to peak rate of runoff was slower (2 hours) in the RT than the PL plots. This was mainly due to a greater snow depth in the RT plots. In the PL plot, the snowmelt runoff slowed earlier with the drop in the air ambient temperature because thinner snow depth in PL plot provide less insulation.

Although not significantly different, the RT plots resulted in greater total snowmelt runoff during 22 February through 26 March 1994 (Table 1-10). In three of the 15 snowmelt runoff events, tillage significantly influenced the runoff volume (Appendix A12). In these three events, the RT treatments consistently resulted in higher runoff compared to PL treatment. This higher runoff was mainly due to greater snow trapping by the standing corn residue and a lack of depressional storage in the RT treatment. Since in the PL treatment there were no standing residues, snow depth was relatively small. On the other hand, the PL plots had a greater depressional storage from the moldboard primary tillage and thus more infiltration and less runoff.

Manure application had no significant influence on cumulative snowmelt runoff from 22 February through 26 March 1994 (Table 1-10). For only one event, manure application significantly reduced runoff (Appendix A12). In contrast to the 1992-1993 winter snowmelt runoff data, manure application had no significant influence on total snowmelt runoff during the 1993-1994 winter. Variability in snow depth among treatments with standing residue may have caused this non-significant effect of manure application. There was also no tillage by manure interaction on total snowmelt runoff during 1993-1994 winter.

Sediment: Total sediment loss in snowmelt runoff during 22 February through 26 March 1994 was significantly influenced by tillage systems. Total sediment loss from the RT and PL plots was 45.0 and 28.4 kg ha^{-1} respectively (Table 1-10). Four of the 15 runoff events showed a significant influence of tillage (Appendix A12). In these four events, the RT plots resulted in greater sediment loss, however, in none of these 4 events was there a significant influence of tillage on sediment concentration in the snowmelt runoff (Appendix A13). This suggest that the greater sediment loss from the RT plots during winter was mainly due to greater snowmelt runoff.

Manure or tillage by manure interactions were not significant for the sediment loss by snowmelt runoff (Table 1-10). Only in one snowmelt event, manure application reduced sediment loss (Appendix A12), and for this event manured plots had a similar sediment concentration compared to the non-manured plots.

TP: Cumulative TP loss in snowmelt runoff, from 22 February through 26 March 1994 was significantly influenced by the tillage systems. The RT treatment resulted in 5 times greater TP loss compared to the PL treatment (Table 1-10). This was also true for most individual snowmelt runoff events. Eight of the 15 snowmelt runoff events indicated a significant influence of tillage (Appendix A12). The daily snowmelt hydrograph and the rate of TP load in runoff event on 13 March 1994 (Fig. 1-10) and 15 March 1994 (Fig. 1-11) showed TP loss was greater in RT than PL plot and also the rate of TP loss was closely related to flow rate. The change of TP concentration with time in both runoff events is given in Appendix A14.

Greater TP loss from the RT plots was also due to a significantly greater TP concentration (Appendix A13) regardless of low sediment concentration. The cumulative TP loss was dominated by DMRP loss both from the RT and the PL plots (Table 1-10). Similar to 1992-1993 snowmelt runoff data, these results also suggested that the higher TP concentration and TP loss from the RT system was due to a release of phosphorus from the surface corn residues.

The cumulative TP loss due to snowmelt was not significantly influenced either by manure or tillage by manure interaction (Table 1-10). Thirteen of the 15 runoff events showed no significant influence of manure on TP loss (Appendix A12), and only 6 events showed any significant influence of manure application on TP concentration (Appendix A12).

PP: Tillage had a significant influence on cumulative PP loss in snowmelt runoff from 22 February through 26 March 1994. The RT treatment resulted in four times cumulative PP loss compared to the PL treatment (Table 1-10). In eight of the 15 runoff events, there was a significant effect of tillage on PP loss (Appendix A12). Out of these eight events, six events had greater concentration of PP and 4 events had greater snowmelt runoff from the RT than the PL plots (Appendix A13). Since the sediment concentration in snowmelt runoff was low, loss of PP in the snowmelt runoff was mainly in the organic form. The cumulative PP loss from the RT and PL plots was 34 and 40 percent of the cumulative TP loss, respectively.

The cumulative PP loss in the snowmelt runoff was not significantly influenced either by manure or tillage by manure interaction (Table 1-10). This non-significance of manure or tillage by manure interactions was also evident for PP concentration (Appendix A13) or PP loss for individual snowmelt runoff events (Appendix A12).

DMRP: Cumulative DMRP loss in the snowmelt runoff, from 22 February through 26 March 1994 was significantly influenced by the tillage systems. Cumulative DMRP loss from the RT treatment was 5.5 times higher than the PL treatment (Table 1-10). Ten of the 15 snowmelt runoff events showed that tillage significantly influenced the DMRP loss (Appendix A12). In these ten events, the DMRP loss was significantly greater from the RT plots compared to the PL plots. The snowmelt hydrograph and the rate of TP load in runoff event on 13 March 1994 (Fig. 1-10) and 15 march, 1994 (Fig. 1-11) showed that DMRP loss was greater in the RT plots and also, DMRP loss was closely related to flow rate. The change of DMRP concentration with time in both runoff events is given in Appendix A14.

Eight of the ten runoff events mentioned previously, had significantly higher DMRP concentration in the snowmelt runoff from the RT plots than the PL plots (Appendix A13). This suggests that DMRP release from corn residue contributed significantly to DMRP loss in snowmelt runoff.

The cumulative DMRP loss in the snowmelt runoff from 22 February through 26 March 1994 was not influenced by manure or tillage by manure interaction applications (Table 1-10). Only one snowmelt runoff event showed a significant influence of manure on DMRP loss (Appendix A12). In this event, concentration of DMRP was not significantly influenced by manure application. In general, manure application increased DMRP concentration in seven of the 15 events. In five of these seven events, tillage by manure interaction were significant for the concentration of DMRP in the snowmelt runoff (Appendix A13). In all these five runoff events, concentration of DMRP was significantly greater in manured RT than non-manured RT or PL treatment. This suggests that higher DMRP concentration must be due to an increase in P content of the surface soil in the manured treatments.

The 1994 Rainfall Runoff

Runoff: Total runoff due to rainfall from 25 April through 26 August 1994 was significantly influenced by tillage (Table 1-11). During this period there were eight runoff events. One event on 29 April 1994 was a snowfall. Because of small quantity of the snowmelt runoff and the fact soil condition did not reflect winter conditions, this event was regarded as a rain event of low intensity.

The PL treatment had three times higher runoff volume compared to RT treatment (Table 1-11). Four of the eight individual runoff showed that tillage significantly influenced runoff volume (Appendix A15). Three of the four events occurred in early spring (April), before secondary tillage and the other event occurred in July. In these four events the PL plots resulted in significantly greater runoff than the RT plots (Appendix A15).

A daily runoff hydrograph of an early spring rain (25 April 1994) is plotted in Fig. 1-12. The plot showed runoff from PL plot started after the first 4 hours of rain (1.9 cm). Runoff flow rate was greater in PL than RT plot. The presence of surface residue in RT plots not only increase the infiltration thus less runoff, but also caused runoff to start later and stop earlier (Fig. 1-12). The rainfall ceased for 30 minutes before the peak rainfall occurred which caused the peak rainfall did not followed by peak runoff.

Manure also significantly influenced the cumulative rainfall runoff from 25 April through 26 August 1994. Runoff from the manured plots was 80 percent of that from the non-manured plots. In four of the eight runoff events, manured plots had a significantly lower runoff than the non-manured plots (Appendix A15). Similar to the 1993 season, manure application reduced runoff and increased infiltration presumably by enhancing the aggregate stability and thus decreasing soil detachment and dispersion. Tillage by manure interaction was not significant for the cumulative rainfall runoff Table 1-11). Only one event in early spring indicates a significant interaction of tillage by manure (Appendix A15) which showed that manure in the PL plots reduced runoff volume.

Sediment Loss: Tillage significantly affected cumulative sediment loss in rainfall runoff from 25 April through 26 August 1994. Sediment loss from the PL plots was 1.8 times higher than from the RT plots (Table 1-11). In four runoff events describe earlier, the PL plots resulted in significantly greater sediment loss than the RT plots (Appendix A15). In three of four events, runoff had a significantly higher sediment concentration from the PL than the RT treatment (Appendix A16). These three events occurred in early spring before secondary tillage when soil in the PL plots was bare. Significantly greater sediment loss from the PL compared to RT plots was caused by both greater runoff volume and higher sediment concentration due to the absence of surface residue cover and crop canopy.

Manure also significantly influenced the cumulative sediment loss through its influence on three rainfall runoff events in early spring. Sediment loss in the manured plots was 65 percent of that from the non-manured plots (Table 1-11). In the three of four runoff events described earlier, manure application reduced sediment loss significantly (Appendix A15). However, only for one event, manure application significantly reduced sediment concentration in the runoff (Appendix A16). This suggests that the influence of manure on sediment loss was mainly due to its influence on increased infiltration and reduced runoff.

The tillage by manure interaction was not significant for cumulative sediment loss. Only one of the eight runoff events showed a significant interaction; i. e. manure application in the PL plots reduced the runoff volume.

TP: The cumulative TP loss in runoff due to rainfall from 25 April through 26 August 1994 was significantly influenced by tillage. The PL plots resulted in 6.3 times greater TP loss compared to the RT plots (Table 1-11). Three early spring runoff events showed that PL plots resulted in significantly higher TP loss compared to the RT plots (Appendix A15). Only one of the three events showed that PL plots had a significantly greater TP concentration in the runoff. This suggests that greater cumulative TP loss was mainly due to greater runoff volume from the PL than the RT plots.

Manure had no significant influence on cumulative TP loss in runoff due to rainfall during 25 April through 26 August 1994 (Table 1-11). In one runoff event, manure application significantly reduced TP loss (Appendix A15), due to a decrease in runoff volume and not a decrease in TP concentration. There was no tillage by manure interaction on cumulative TP loss in rainfall runoff (Table 1-11). In two runoff events, the tillage by manure interaction was significant (Appendix A15). In these both events, manure application compared to no manure application reduced TP loss in the PL plots.

PP: Tillage significantly influenced the cumulative PP loss in rainfall runoff from April 25 through 26 August 1994 (Table 1-11). Four of the eight runoff events had greater PP loss from the PL compared to the RT plots (Appendix A15). Greater PP loss from the PL plots was mainly during early spring. Also, the greater PP loss from the PL plots was mainly due to greater runoff volume from the PL compared to the RT plots. Only one early spring runoff event showed that the concentration of PP was significantly greater in the PL compared to the RT plots (Appendix A13). The cumulative PP was a dominant component of cumulative TP losses in the rainfall runoff for both RT and PL treatments. The cumulative PP in the RT and PL plots was 60 and 96 percent of the cumulative TP, respectively.

Manure or the tillage by manure interaction was not significant for cumulative PP loss in rainfall runoff from 25 April through 26 August, 1994 (Table 1-11). However, two of eight runoff events showed a significant influence of manure on PP loss (Appendix A15). In these two events, manure application reduced PP loss which mainly due a reduction in runoff volume. These same two events showed a tillage by manure interaction; manure application reduced PP loss in PL plots.

DMRP: Both the PL and RT treatments resulted in similar total DMRP loss in rainfall runoff during 25 April through 26 August 1994 (Table 1-11). In two runoff events, where tillage was significant, the RT had either higher or lower DMRP loss (Appendix A15 and A16). In four (including the two events described earlier) events, the DMRP concentration was higher in RT plots compared to the PL plots. This suggest that higher DMRP concentration in runoff was due to greater P content of the surface soil in the RT treatments.

There was no influence of manure application on the cumulative DMRP loss in runoff from rainfall during 25 April through 26 August 1994 (Table 1-11). For one event, DMRP loss was greater from non-manured than the manured plots, mainly due to greater runoff volume, because for this particular event, runoff from the non-manured plots had a lower concentration of DMRP. For other event, the tillage by manure interaction was significant; manure application to RT plots increased DMRP losses.

The 1994 Annual Runoff, Erosion and P-Loss

Tillage Effects: There was no significant difference in the annual runoff between the RT or PL treatment (Table 1-12). For the RT treatment, snowmelt runoff was 3.5 times greater than the rainfall runoff, conversely for the PL treatment, rainfall runoff was 1.9 times greater than the snowmelt runoff (Fig. 1-13).

The PL system resulted in 11.8 times higher annual sediment loss compared to the RT system (Table 1-12). Contribution of the annual snowmelt was negligible. For the PL plots, sediment loss in rainfall runoff was 62 times greater than the sediment loss from the snowmelt. On the other hand, the sediment loss in rainfall runoff from the RT plots was 2.1 times greater than the sediment loss in the snowmelt runoff. Two sequential rain events in early spring had the largest contribution to the annual sediment loss (Fig. 1-13). During these events, there was no standing crop and the surface residue cover was low in the PL plots. In RT plots, the surface residue cover increased infiltration by slowing runoff and also protected the soil against raindrop detachment, thus reducing the sediment loss significantly. Although a heavier daily rainfall (3-hour 2.8-cm rain in the morning and 5-hour 7.3-cm rain around midnight) occurred on 5 July, there was only a slight increase in sediment loss from both RT and PL treatments. This was because the corn canopy had fully developed and reduced the impact of rain on soil detachment.

Total P losses were two times greater from the PL compared to RT plots (Table 1-12). Higher TP losses were mainly due to rain that occurred in early spring (Fig. 1-14). For the PL plots, the main source of annual TP loss was rainfall runoff and not snowmelt runoff. For the RT plot it was the other way around. For the PL treatment, annual TP losses in rainfall runoff were 15.8 times greater than the annual TP losses in the snowmelt runoff. For the RT treatment, annual TP losses were two times greater in snowmelt runoff than the rainfall runoff.

Annual PP losses, were significantly influenced by tillage (Table 1-12). Particulate-P from the PL plots was 3.9 times higher than that from the RT plots. Annual PP losses were 46 and 92 percent of the annual TP losses from the RT and PL plots, respectively. For the RT treatment, snowmelt and rainfall contributed similar amounts of PP to the annual PP losses. On the other hand, for the PL plots, rainfall runoff was the main source of annual PP loss. For the PL plots, PP loss in rainfall runoff was 38 times greater than PP losses in snowmelt runoff. For the PL plots, the PP loss was mainly from the two early spring runoff events (Fig. 1-14).

Tillage significantly influenced annual DMRP loss. The RT treatment resulted in 3.7 times higher annual DMRP load compared to the PL system (Table 1-12). For the RT treatment, 54 percent of the TP losses were DMRP whereas for the PL treatment, 8 percent of the TP losses were DMRP. For the RT system, DMRP losses in the snowmelt runoff were three times greater than the DMRP losses in rainfall runoff (Table 1-10 and 1-11). On the other hand for the PL plots, DMRP losses in snowmelt and rainfall runoff were similar (Fig. 1-14).

Manure Influence: Annual runoff and associated sediment, TP, PP, and DMRP loss were not influenced by manure or tillage by manure interaction (Table 1-12; Fig. 1-15 and 1-16). The influence of manure application was observed mainly on individual rainfall runoff events.

Soil Bulk Density and Hydraulic Properties

Soil Bulk Density

Soil bulk density measurements were taken to evaluate the influence of tillage and manure application on soil porosity and indirectly on the infiltration and runoff during the growing season. Soil bulk densities were taken between plant rows at three positions in each plot, namely up slope, center and down slope. The measurements were taken on 5 May 1994, a week after corn planting.

Tillage and the one time manure application in spring 1992 did not significantly influence the between row soil bulk density on 5 May 1994 (Table 1-13). This further suggests that the effect of tillage or manure on between the row porosity a week after planting were negligible.

Infiltration and Saturated Hydraulic Conductivity

Infiltration measurements were taken on 28 October 1994 after the fall harvest but prior to the primary tillage. Initial soil moisture content was measured before infiltration measurements. Water content at the time of infiltration measurements were slightly greater in RT (0.32 g g^{-1}) than in the PL plots (0.28 g g^{-1}). Infiltration measurements were intended to assess the improvements (if any) in soil hydraulic properties under the two tillage systems in the absence of residue cover or surface roughness. This is important because it is difficult to separate the influence of residue cover and surface roughness on infiltration from the runoff measurements.

The geometric mean of cumulative infiltration and saturated hydraulic conductivity (Ksat) is given in Table 1-13. First 10-minute infiltration (C10) was significantly greater in the RT than the PL treatment. Tillage had no significant effects on cumulative 30-(C30) or 60-(C60) minute infiltration (Table 1-13). Ksat as calculated form the steady state infiltration rate was not significantly influenced by tillage treatments. Differences in C10 between the tillage systems are mainly due to the differences in surface porosity. The absence of significant differences in cumulative infiltration and Ksat between the tillage systems suggests that the lower rainfall runoff from the RT than the PL plot was mainly due to the presence of higher surface residue cover in the RT compared to PL plots. Effects of manure or tillage by manure interaction on cumulative infiltration or saturated hydraulic conductivity were absent (Table 1-13).

Residue Cover

In 1993 residue cover in the inrow area before planting was 69 and 8 percent for the RT and PL treatments, respectively (Fig. 1-17). After planting, the inrow residue cover for the RT and PL system was 13 and 4 percent, respectively. Reduction in surface residue from 69 to 13 percent before and after planting in the RT treatment was significant. Residue cover in the interrow area was significantly greater in the RT than PL treatments (Fig. 1-17). In the RT plots, residue cover in the interrow area after planting and before cultivation was 50 and 48 percent, respectively. In the PL plots, residue cover in the interrow area did not change greatly with field operations. The residue cover in PL plots was 9 and 4 percent from planting to before cultivation, respectively.

In 1994, residue cover between rows was 50 percent after cultivation and decreased significantly to 15 percent after ridging in the RT treatment. This decrease in residue cover was due to the moving of the soil and residues from between row area to the row area. In PL treatment, residue cover decrease slightly (not significant), from 6 percent after cultivation to 4 percent after ridging (Fig. 1-17).

For both 1993 and 1994, residue cover in the RT system was above 30 percent before ridging, a minimum requirement for soil conservation. Ridging usually took place in the middle of the growing season when the corn canopy was well developed. Thus although residue cover reduced to 15 percent after ridging in the RT plots, the canopy cover absorbed rainfall impact, thereby reducing runoff, soil erosion and P losses.

Phosphorus Leaching from Corn Residue

TP Leached by Snowmelt in the Field.

Snowmelt runoff data suggested that corn residues contributed significantly to the TP losses in 1993-1994. The TP loss in the snowmelt from RT and PL plots was 212 and 43 g ha^{-1}, respectively. Besides surface roughness, RT and PL plots had different amounts of residue cover. Residue cover in RT plots was 91 percent greater than the 14 percent cover in PL plots. Since sediment loss by the snowmelt runoff was low, it is assumed that the difference in TP between RT and PL treatment (169 g ha^{-1}) was a result of TP leached from corn residues.

The field leaf leaching study indicated that on the average, 3.5 percent of TP was leached from leaves. TP measurement based on corn stover of ten plants after harvest in 1993 resulted in estimated TP of 3.6 kg ha^{-1}. Using this value and assuming that the leaching of P from corn stover is similar to leaching of P from corn leaves (3.5 percent), the contribution of stover to P-loss is 126 g ha^{-1}. This value represented 74 percent of the TP leached from corn residue during snowmelt in 1993-1994 winter. The closeness of the estimated TP leached (126 g ha^{-1}) and the difference in snowmelt TP between RT and PL plots (169 g ha^{-1}) suggests that corn residue is a major source of TP loss in the snowmelt runoff.

Laboratory Study of DMRP Leached from Corn Leaves

The DMRP leached (as a percent of TP in the residue) from corn leaves and stover is given in Table 1-14. Cumulative DMRP leached from the residue is given in Fig. 1-18. The rate of leaching of DMRP was lower in leaves than stover for all treatment and order of leaching cycle. DMRP leached from residue decreased with an increase in number of leaching cycles.

For leaves and stover, the freezing and thawing cycles (Compare pretreatment C and D in Table 1-14) did not increase the release of DMRP from the residues, presumably because the residues used in the experiment were dry (7 % moisture) mature residues. For the first leaching cycle, DMRP leached from residue was consistently higher when soaked for 20 h than when not soaked. However, there was no consistent trend relative to two other preleaching treatment (B, C and D). Freezing followed by soaking (treatment A) did not consistently enhance the release of DMRP in all leaching cycles. For stover, the total DMRP leached by soaking (treatment B) was greater compared to the other pretreatments (A, C and D).

Pretreatment C is more representative of freezing and thawing cycles (no soaking) in the field during winter. Data on DMRP loss in snowmelt runoff during 1993-1994 suggests that corn residues contributed significantly to the TP losses (Table 1-10). The TP loss in the snowmelt from RT and PL plots was 141 and 26 g ha^{-1}, respectively. Residue cover in the RT plots was much higher than the residue cover in PL plots. Again, since the sediment loss in the snowmelt runoff was low, it is assumed that the differences in TP losses from RT and PL plots (116 g ha^{-1}) are from DMRP leaching from corn residue. As mentioned earlier, estimated TP in corn stover is equivalent to 3.6 kg P ha^{-1}. Using the leaching values of 38.1 % from leaves and 55.0 % from stover, estimated DMRP leached from corn residues was in 1.4 kg ha^{-1} and 2.0 kg ha^{-1}, respectively. These DMRP values are 12 and 18 times greater than the differences in DMRP loss measured between RT and PL plots in the snowmelt runoff. This suggests that the laboratory residue leaching procedure overestimate the DMRP loss in the snowmelt runoff. The greater surface contact between residue and water in the laboratory studies might have caused the overestimation. However, the data from laboratory leaching studies of residues suggests that corn residue is an important source of P during the snowmelt period.

Phase Separation of Runoff Sample

The routine procedure of phase separation for DMRP and BP determination is centrifugation for 5 minutes at 15,000 rpm plus filtration through a 0.45 μm membrane filter. The results of this experiment with DMRP and BP in runoff samples showed that the difference between centrifugation and centrifugation plus filtering were not significant at the 5 percent probability level using a paired t-test. Also, the regression line between the filtered vs. non-filtered is the same as the 1:1 line at 5 percent probability level. This is especially true for non-filtered DMRP values lower than 4 mg L^{-1} which was the case for a majority of the runoff samples (Fig 1-19 A). Negligible differences in filtered vs. non-filtered samples also applied to BP measurements (Fig 1-19 B). These suggest that centrifugation alone was sufficient for the separation of particles from solution for both DMRP or BP determinations.

SUMMARY AND CONCLUSION

Snowmelt Runoff

Tillage

During the 1992-1993 snowmelt events, RT treatment resulted in higher runoff and associated sediment or TP losses compared to the PL treatment. Sediment concentration in the snowmelt runoff was low. Higher TP losses were due to greater runoff volume and TP concentration in the snowmelt from the RT than PL plots. Higher runoff was due to a lack of surface depressional storage whereas higher TP concentration was from P that leached from surface residues. For the RT plots, PP was the dominant portion of TP lost in the runoff. Although not significant at 10 percent probability, there was a tendency of a greater PP loss from the RT than the PL plots. Since the sediment concentration was low in the snowmelt, PP in surface runoff must be the organic form of P. Tillage alone had no significant influence on DMRP loss.

During the 1993-1994 winter, total snowmelt runoff was not significantly influenced by tillage although 26 percent of the daily snowmelt events indicated that the RT system consistently resulted in a greater snowmelt runoff, because of greater snow depth and lack of depressional storage. Standing residue cover trapped significantly greater snow depth and thus higher equivalent water depth in RT plots. Snow density was not different between the tillage treatments in spite of the snow depth differences. Despite the presence of snow and residue cover in the RT plots, soil temperature at 5-cm depth reached 1 °C during the afternoon, when air temperature was 8 °C. There were a significantly greater sediment, TP, PP and DMRP loss in RT plots compared to PL plots. Greater cumulative loss of TP and DMRP was due to both higher runoff volume and higher P concentration in the snowmelt runoff.

Manure

In 1992-1993, manure application significantly reduced total snowmelt runoff but had a very little influence on TP, PP or DMRP losses in snowmelt runoff. Although concentration of DMRP in the snowmelt runoff was greater from the manure applied treatments, a significant reduction of runoff from the manure applied treatment lead to no difference between the tillage treatments. There was a significant tillage by manure interaction on sediment, TP, PP, and DMRP losses in snowmelt runoff. In manure applied RT plots, there was a sediment reduction mainly due to a reduction in runoff. Both TP and PP losses in the snowmelt runoff decreased in manure applied RT plots. This reduction was due to a reduction in runoff amount as well as a reduction in the concentration of PP and TP. In PL plots, sediment and TP losses were similar with or without manure application. Tillage by manure interaction was significant for concentration of DMRP and this resulted in greater DMRP loss from the RT plots. Higher DMRP concentration in snowmelt runoff from the RT plots was due to the shallow incorporation of manure at the soil surface.

During 1993-1994 winter snowmelt, manure application had no significant influence either on cumulative loss of runoff, sediment, TP, DMRP or losses of these constituents from majority of the individual events. The same was also true for tillage by manure interaction. This lack of significance was not consistent with the 1992-1993 snowmelt runoff data. It is suspected that the variability of snow depth among plots may have overshadowed the influence of manure on runoff, sediment and P during 1993-1994 snowmelt. Forty percent of the individual events showed that DMRP concentration was higher in manured RT plots. This higher DMRP concentration was due to the presence of manure and residue at the soil surface in the RT plots.

Rainfall Runoff

Tillage

In 1992, the RT treatment resulted in significantly lower runoff, as well as a decrease in sediment, TP, BP and DMRP losses. The presence of residue retarded runoff flow and rainfall energy, thus reducing runoff and sediment losses. The RT system resulted in significantly lower total TP, BP and DMRP although the concentration of TP, BP and DMRP were significantly greater in rain runoff from the RT plots. Greater P concentration in RT (which was more like no till) plots was due to the presence of manure on alfalfa residues prior to ridging on 21 July, 1992. Greater runoff from PL plots resulted in greater TP, BP and DMRP losses.

In 1993, runoff amounts, as well as sediment, TP and PP losses were greatly reduced from the RT compared to PL plots. Greater sediment loss in PL system was both due to the greater runoff volume and greater concentration of sediment particularly in the largest runoff event (from a 2-hour 10-cm rainfall). Higher TP losses from PL than RT plots were mainly due to higher runoff volume. In both RT and PL treatments, PP was the dominant portion of TP losses. Greater PP losses from PL than RT plots were due to greater runoff volume from a single largest rain event mentioned earlier. Cumulative DMRP losses in rainfall runoff were not significantly influenced by tillage although the concentrations of DMRP were higher from the RT system. Presence of surface residues in the RT plots resulted in these higher concentrations. Residue retarded runoff flow, thus increasing contact time releasing more DMRP into the runoff.

In the 1994, PL treatment resulted in greater total sediment loss both due to higher runoff volume and its associated sediment concentration in individual events. Cumulative TP and PP losses were greater from the PL treatment, mainly due to greater runoff volume. Cumulative DMRP losses were not influenced by tillage although in individual events DMRP concentration was higher in rainfall runoff from the RT plots. Greater concentration of DMRP in rainfall runoff was due to the presence of residues that retarded runoff, thereby increasing runoff contact time with residues and thus releasing DMRP in runoff.

Manure

In 1992 , manure addition had no significant influence on runoff volume, and sediment, TP, PP and BP losses. However, manure treatment significantly increased DMRP losses mainly due to an increase of DMRP concentration in the rainfall runoff. Beef manure applied contained 64 kg ha^{-1} DMRP.

In 1993, manure application significantly reduced cumulative sediment loss by rainfall runoff. Both cumulative and DMRP losses were not influenced by manure application. In the largest rainfall runoff event (from 2-hour 10-cm rainfall) DMRP losses were greater from manured than non-manured plots because of greater DMRP concentration.

Although the tillage by manure interaction was not significant for total runoff, 47 percent of the individual events showed that manure significantly reduced runoff from the PL plots. Tillage by manure interaction was significant for cumulative DMRP losses in rainfall runoff. In manured RT plots, although manure reduced runoff volume, greater DMRP concentration in rainfall runoff resulted in higher DMRP losses.

In 1994, manure application significantly reduced total rainfall runoff volume which resulted in less sediment loss. Manure application had no significant effect on TP, PP and DMRP losses in rainfall runoff. In 50 percent of the individual events, manure addition resulted in significantly higher DMRP concentration in rainfall runoff.

The Annual Erosion and Phosphorus Loss

Year of 1993.

Tillage Effects: For RT plots, snowmelt was the main source of annual runoff, whereas for PL plots, rain runoff was the dominant portion of the annual runoff. Higher annual runoff in PL plots was primarily due to one rainfall event of a 2 hour 10-cm storm in July 1993. If it was not due to this particular event, the annual runoff would be similar between RT and PL plots. Sediment loss in snowmelt runoff was negligible compared to sediment loss in rainfall runoff. Sediment losses from rainfall runoff in RT treatments was negligible compared to that from PL treatments. In PL plots, 95 percent of the sediment loss was from the largest runoff event described earlier.

In RT plots, snowmelt runoff was also the dominant source of annual TP losses, whereas in PL plots, rainfall runoff was the dominant source of TP losses. Although not significant at 10 percent probability level, annual TP loss tended to be greater for the PL than the RT treatments. This trend was mainly due to the TP contribution from one major runoff event.

Since sediment concentrations were low in snowmelt runoff, PP must have resulted from organic-P in the solution. Annual PP losses in snowmelt runoff were the dominant part of the annual PP losses from RT plots. Conversely, PP losses in rainfall runoff were the main source of annual PP losses from PL plots. Greater annual loss of PP from PL compared to RT treatment was mainly due to one large runoff event describe earlier.

Annual DMRP losses were not a predominant component of the annual P loss. Snowmelt runoff was the main source of annual DMRP losses from both RT and PL plots. The contribution of rainfall runoff on DMRP loss was small despite a large runoff event that caused greater loss of annual sediment TP, PP, and runoff from the PL plots.

Manure Effects: Manure application resulted in significant reduction of runoff volume both from snowmelt and rainfall. Manure application also resulted in reduction of sediment loss but this reduction was mainly due to a reduction of sediment loss from one large runoff event.

Manure application reduced annual TP losses through its influence on the reduction of annual PP losses. A significant difference in annual PP or TP losses between manured and non-manure plots was mainly due to one large event. Annual DMRP loss were similar between manured and non-manured plots.

Year of 1994

Tillage Effects: Snowmelt was the dominant source of annual runoff for RT plots compared to PL plots where rainfall was the dominant source of the annual runoff. However, annual runoff was not different between RT or PL systems. Contribution of snowmelt to the annual sediment loss was negligible. PL treatment resulted in significantly greater sediment loss, primarily due to rain events that occurred in early spring when PL plots were bare. For RT treatment snowmelt runoff was the dominant source for annual TP loss, whereas for PL treatment rainfall runoff was the main source of the annual TP loss. Higher TP loss from PL plots mainly occurred from early spring rainfall when soil was bare. For RT plots, PP losses in snowmelt runoff were the main source of the annual PP loss and this PP was mainly in organic form. For PL plots, sediment associated PP from rainfall runoff was the dominant source of the annual TP. For RT plots, annual DMRP loss is the dominant source of annual TP loss whereas for PL plots annual PP loss was the dominant source of annual TP loss. Annual DMRP loss was greater from RT plots compared to the PL plots. This suggests that DMRP loss in snowmelt runoff could still occur despite a reduction in runoff and the sediment associated TP or PP losses in early spring.

Manure Effects: Annual runoff, and sediment, TP, PP, and DMRP losses were not significantly influenced by manure application. Differences due to manure application were only on individual event or seasonal basis but not on annual basis.

Soil Bulk Density and Hydraulic Properties

Soil bulk densities taken between plant rows to a depth of 7.5 cm in May 1994 were not significantly influenced by tillage or manure application. This suggests that soil surface porosity was similar between tillage or manure treatments a week after planting. The ridge tillage system resulted in greater cumulative infiltration during the first 10 minutes. The lack of significant difference in cumulative 30 and 60 minute infiltration and steady state infiltration between tillage systems suggests that surface residue played greater role in reducing rainfall runoff compared to soil hydraulic conductivity and surface roughness differences between tillage system.

Surface Residue

In RT system, surface residue cover between the row where erosion and runoff concentrated were greater than 80 percent before and after planting. This protected soil from direct raindrop impact until the corn crops provides canopy protection. Although, surface cover residue decreased to 30 percent after ridging, there was enough canopy cover that protected soil from direct rainfall impact. In PL plots, residue cover was less than 30 percent during the whole year which resulted in greater susceptibility of soil to direct impact from rain drops and thus higher sediment loss.

Phosphorus Leached from Corn Leaves

The field study indicated that 3.5 percent (126 g ha^{-1}) of TP was leached from corn leaves which represented 74 percent of TP in the snowmelt runoff (169 g h^{-1}) during the winter of 1993-1994. The closeness of estimated TP leached from residue in the field and the TP losses in snowmelt runoff suggests that corn residue is a major source of TP loss in snowmelt.

A laboratory study indicated that the majority of DMRP leached from corn residues takes place in the first leaching. Freezing and thawing cycles did not increase the release of DMRP from residue. Also, freezing-soaking cycles did not consistently result in greater DMRP release compared to soaking alone. The DMRP leached from corn residue in the laboratory was 15 times greater than the DMRP loss in the snowmelt runoff. The laboratory leaching data also suggest that DMRP leached from residue contributes significantly to DMRP loss in the snowmelt runoff.

Phase Separation in DMRP and BP Determination

Phase separation experiment for DMRP and BP determination shows that there was no significant difference between centrifugation or centrifugation plus filtering at 5 percent probability level. This suggests that filtration after centrifugation at 15,000 rpm (22,700 *g*) for 5 minutes was not necessary for runoff samples in this study.

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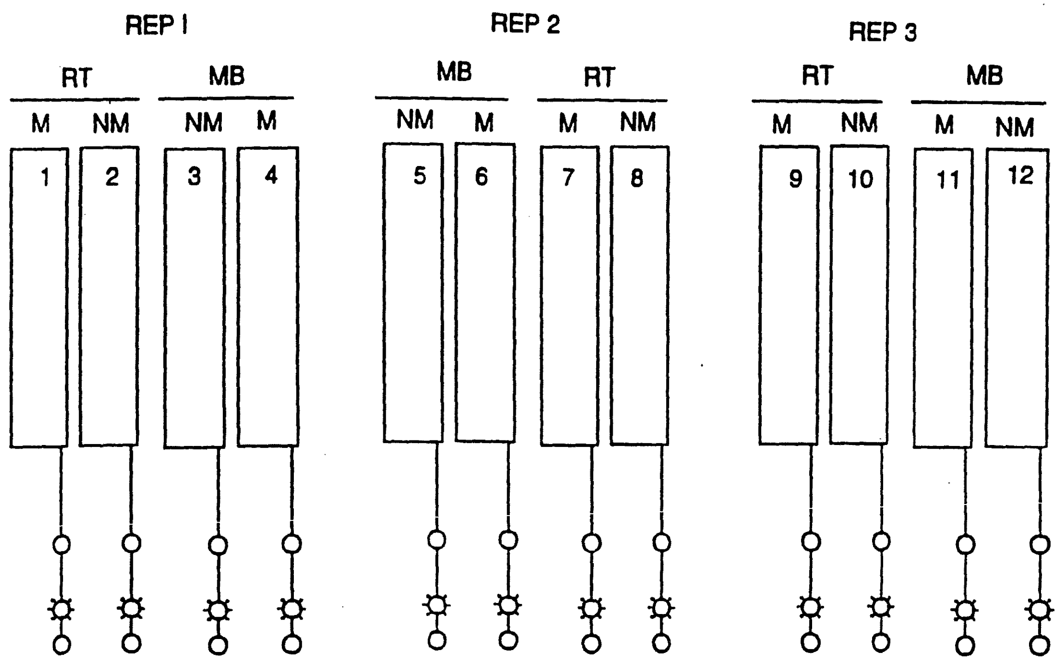

Key:
RT = Ridge Tillage
MB = Moldboard Plow
M = Solid Beef Manure
NM = No Manure

Fig. 1-1. Layout of runoff plots at Morris, MN. Tillage was done up and down the slope.

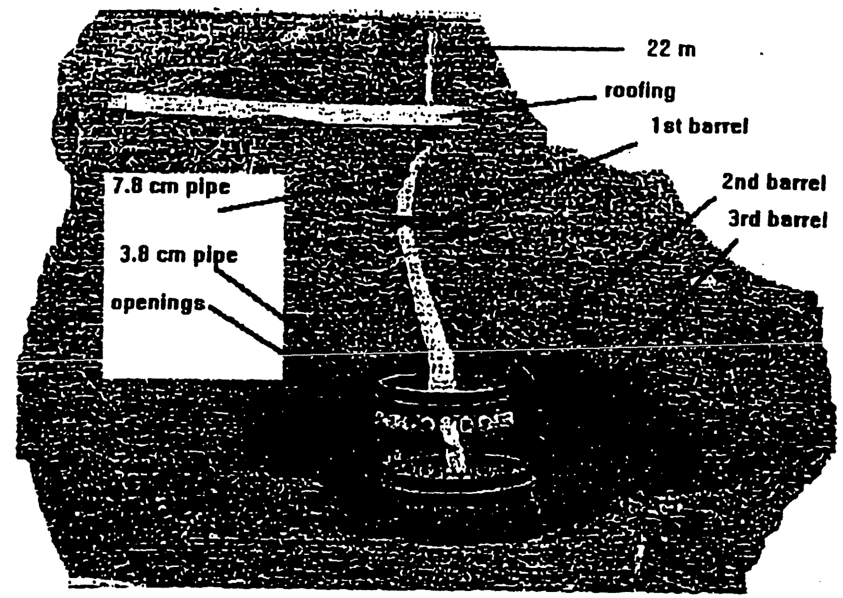

Fig. 1-2. The experimental set up showing the runoff and sediment collecting system.

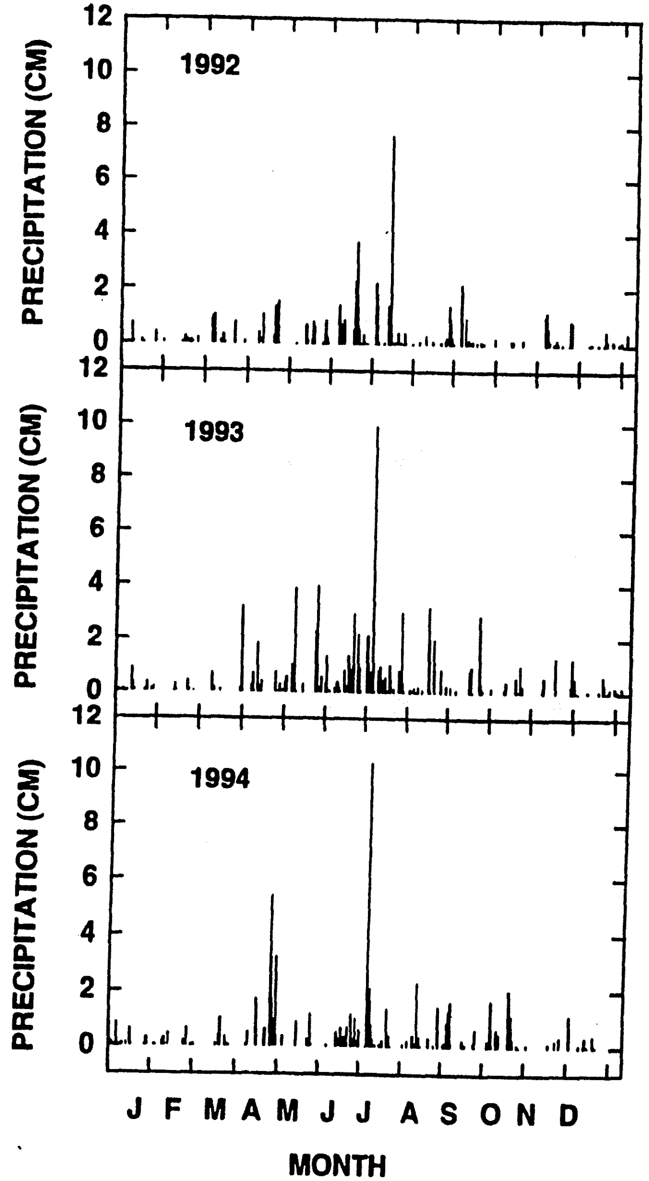

Fig. 1-3. Daily precipitation recorded at the West Central Exp. Stn., Morris, MN 1 km from the study site (1992-1994)

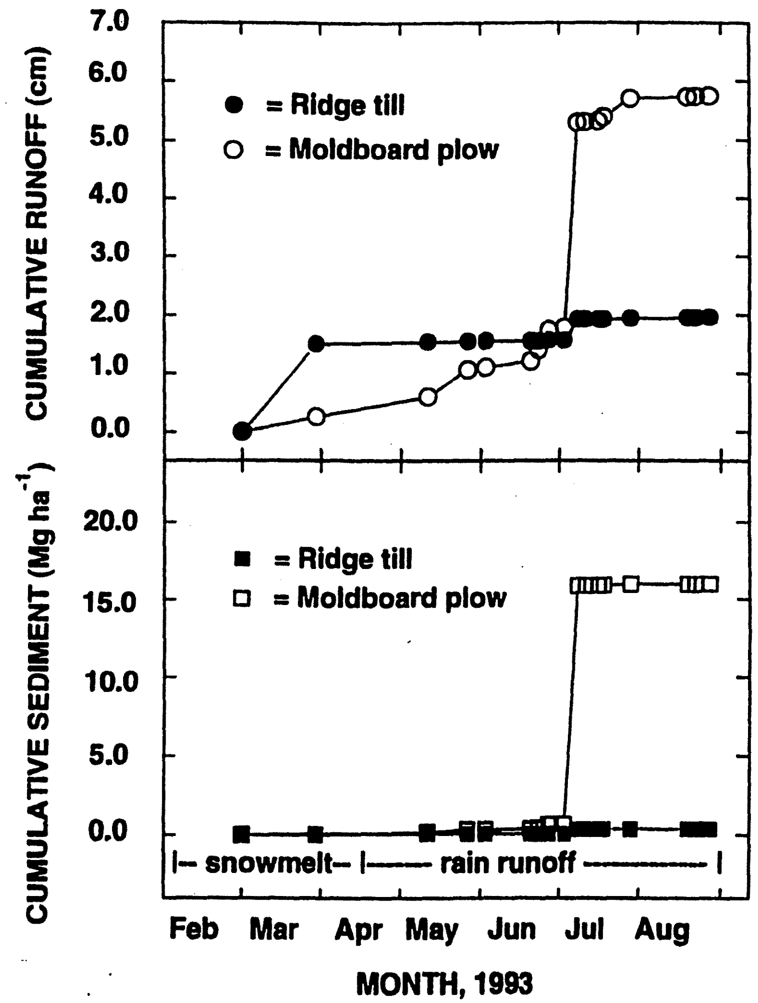

Fig. 1-4. Effect of tillage on cumulative runoff and associated sediment losses from Barnes loam from 29 March through 24 August 1993 at the West Central Exp. Stn., Morris, MN.

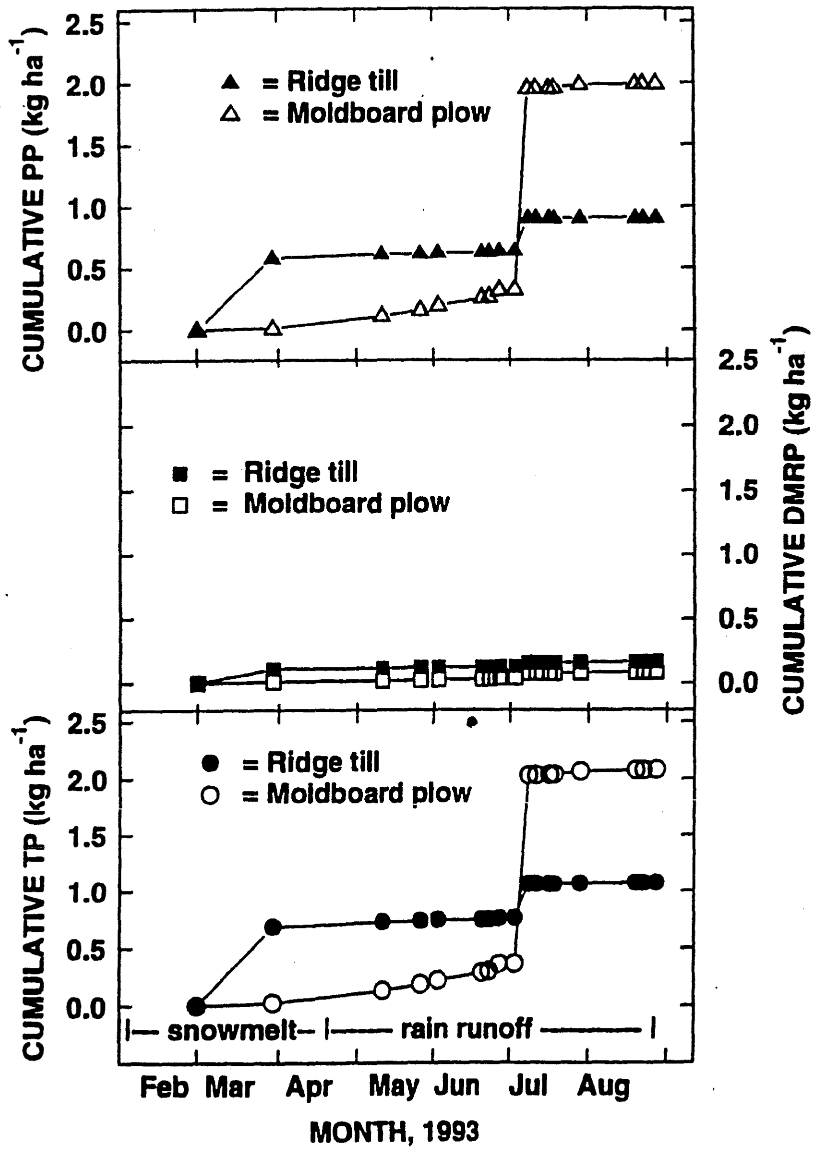

Fig. 1-5. Effects of tillage on cumulative particulate P (PP), dissolved molybdate reactive P (DMRP) and Total-P (TP) in surface runoff from Barnes loam from 29 March through 4 August 1993 at the West Central Exp. Stn., Morris, MN.

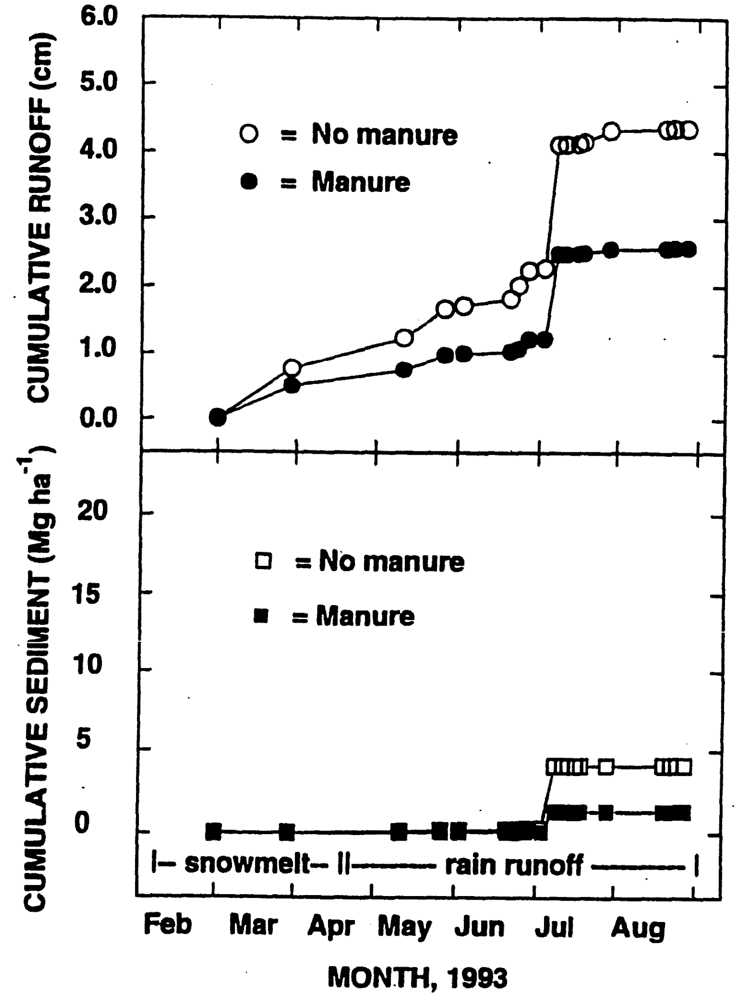

Fig. 1-6. The effects of manure on cumulative runoff and associated sediment losses from Barnes loam from 29 March through 24 August 1993 at the West Central Exp. Stn., Morris, MN.

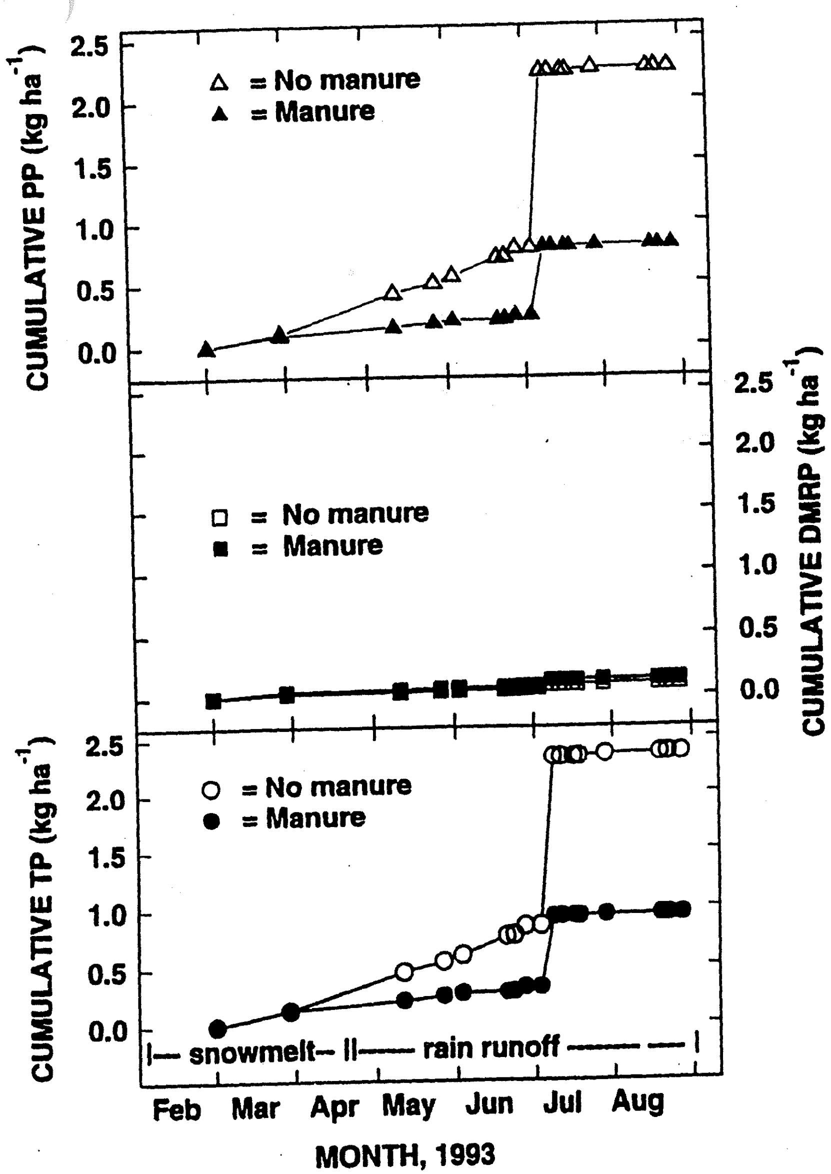

Fig. 1-7. Effects of manure on cumulative particulate P (PP), dissolved molybdate reactive P (DMRP) and Total-P (TP) in surface runoff from Barnes loam from 29 March through 4 August 1993 at the West Central Exp. Stn., Morris, MN.

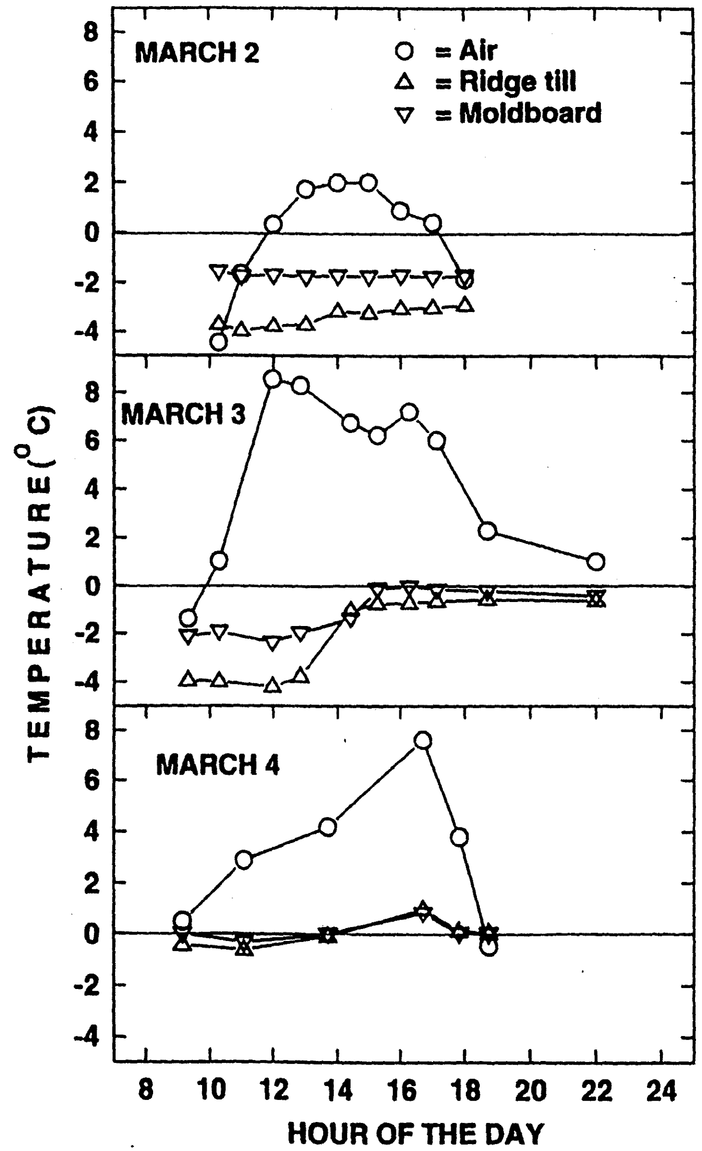

Fig. 1-8. Soil and air temperature on 12, 13, and 14 March 1994 at the experimental site at Morris, MN.

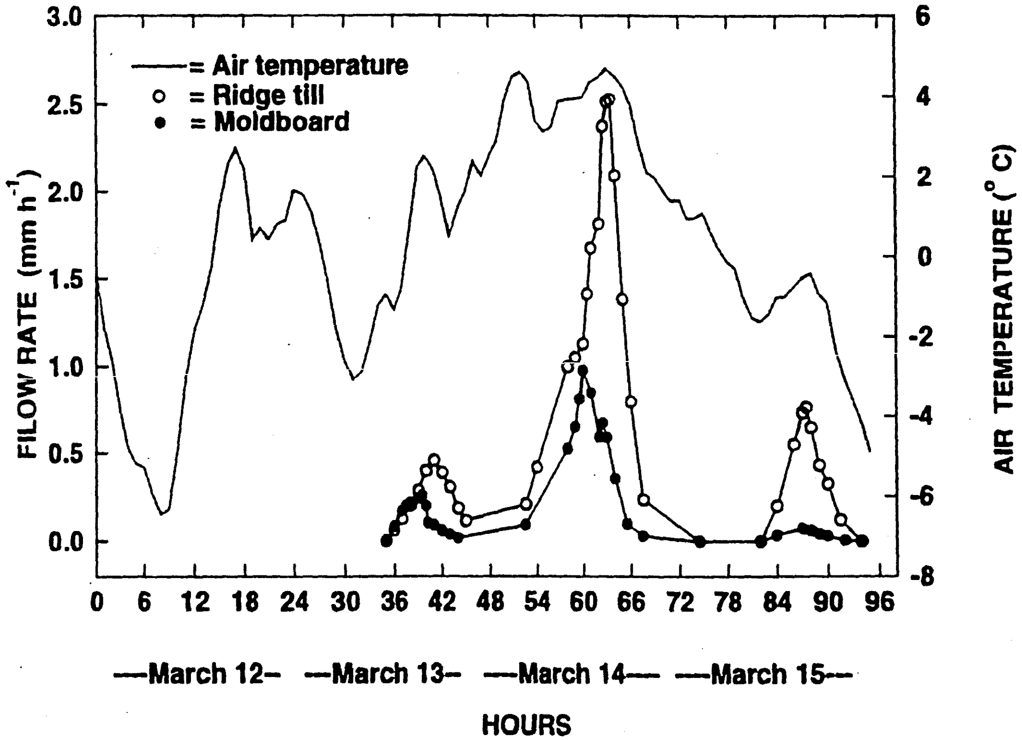

Fig. 1-9. Snowmelt runoff hydrograph on 13, 14, and 15 March 1994 at the experimental site, Morris, MN.

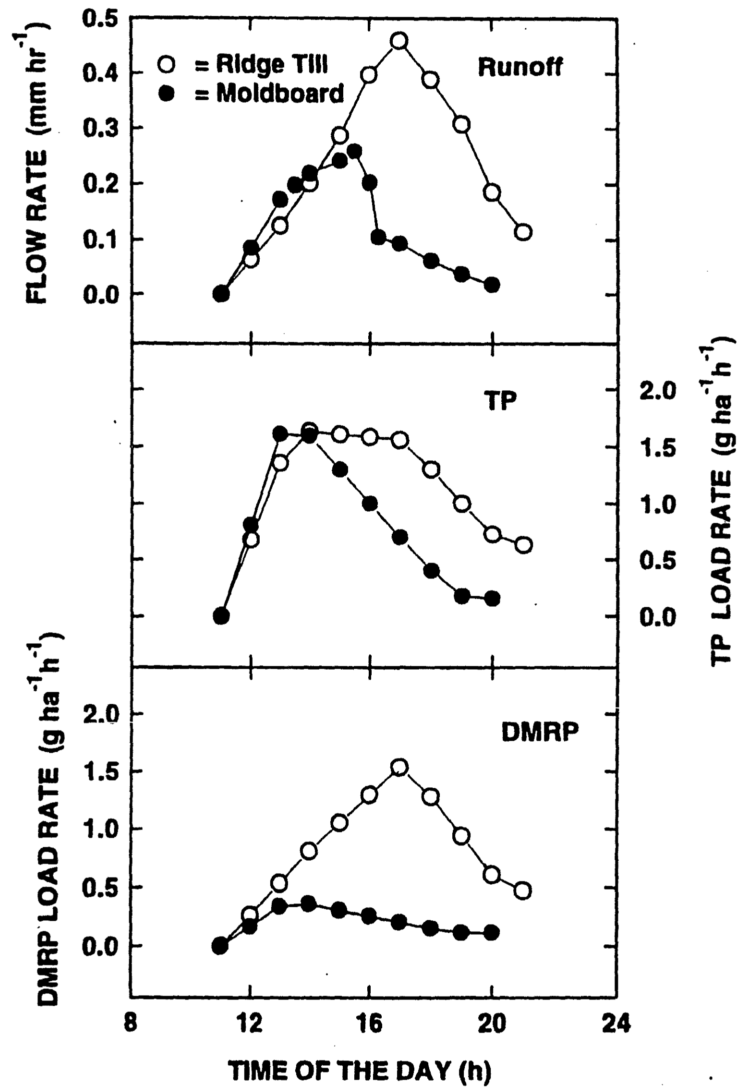

Fig. 1-10. The effect of tillage on snowmelt runoff flow rate and associate total P (TP) and dissolved molybdate reactive P (DMRP) load rate from Barnes loam on 13 March 1994.

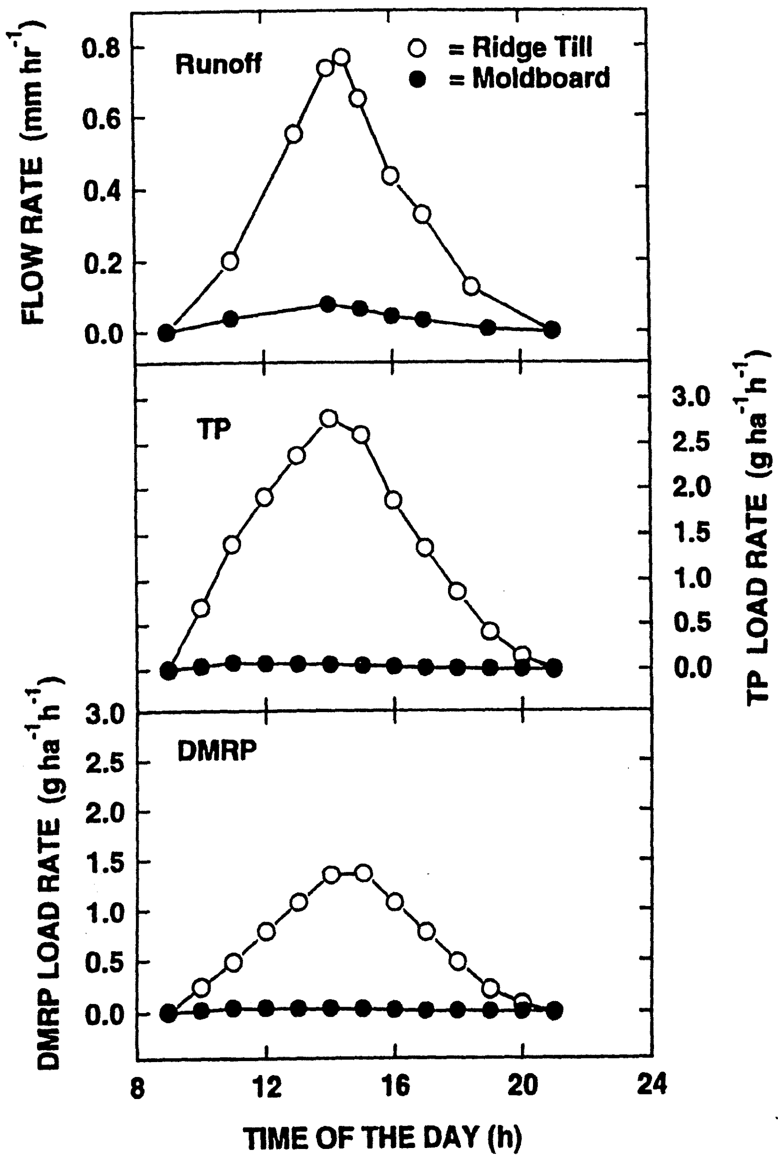

Fig. 1-11. The effect of tillage on snowmelt runoff flow rate and associate total P (TP) and dissolved molybdate reactive P (DMRP) load rate from Barnes loam on 15 March 1994.

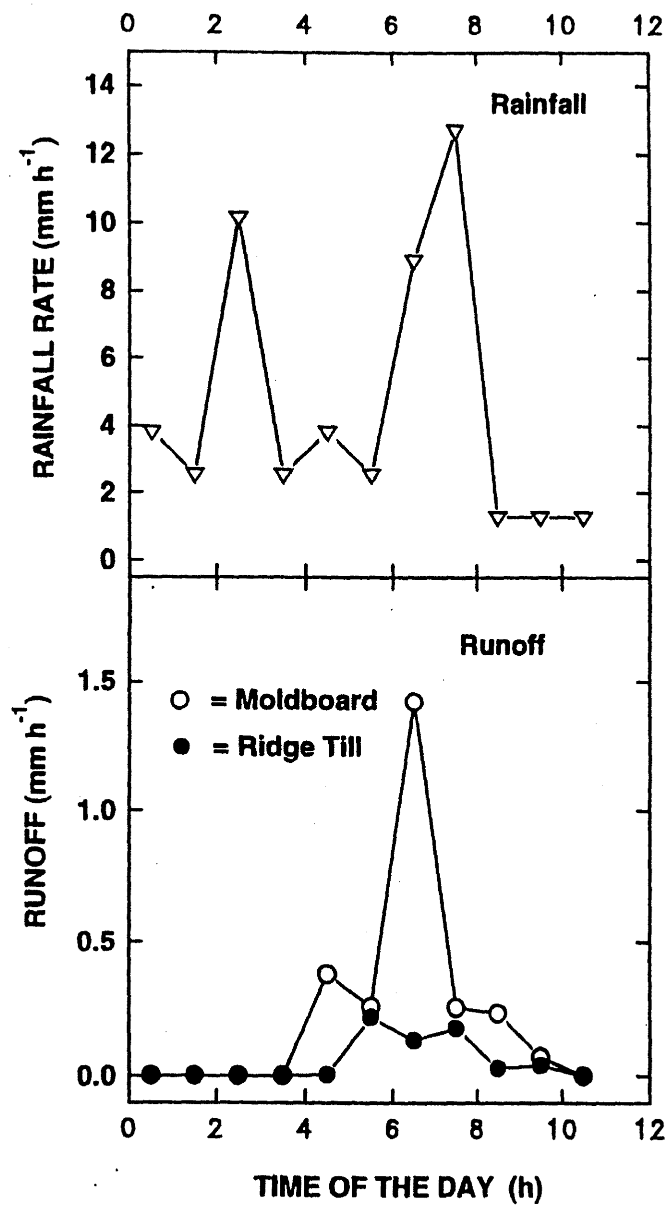

Fig. 1-12. The effect of tillage and rainfall intensity on runoff rate from Barnes loam on 25 April 1994.

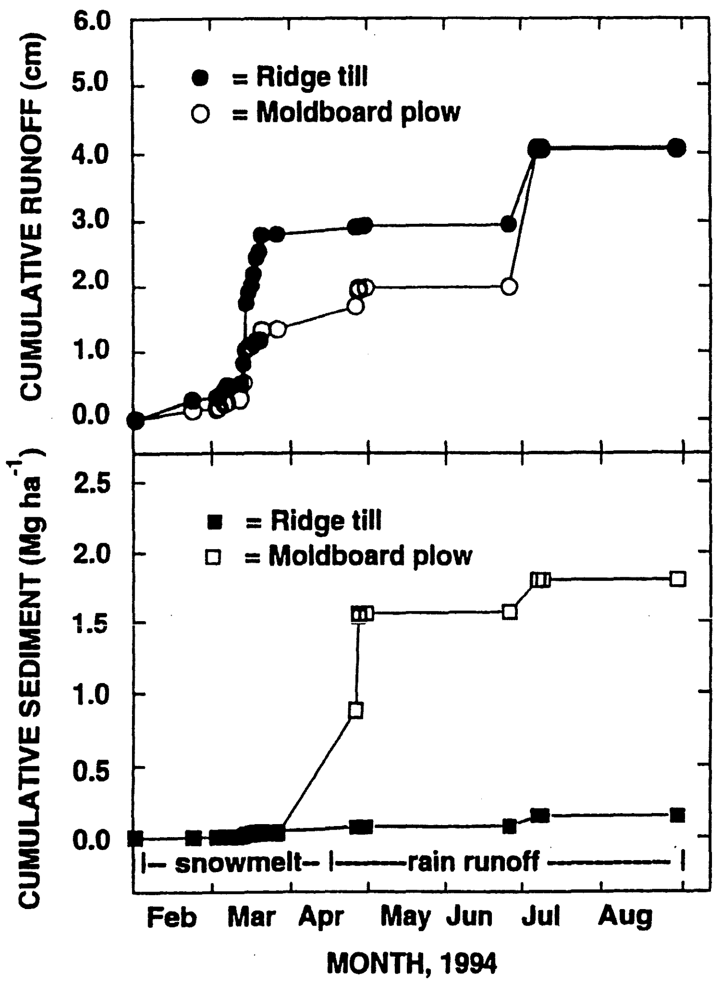

Fig. 1-13. The effects of tillage on runoff and associated sediment loss from 22 February through 26 August 1994 on Barnes loam at the West Central Exp. Sta., Morris, MN.

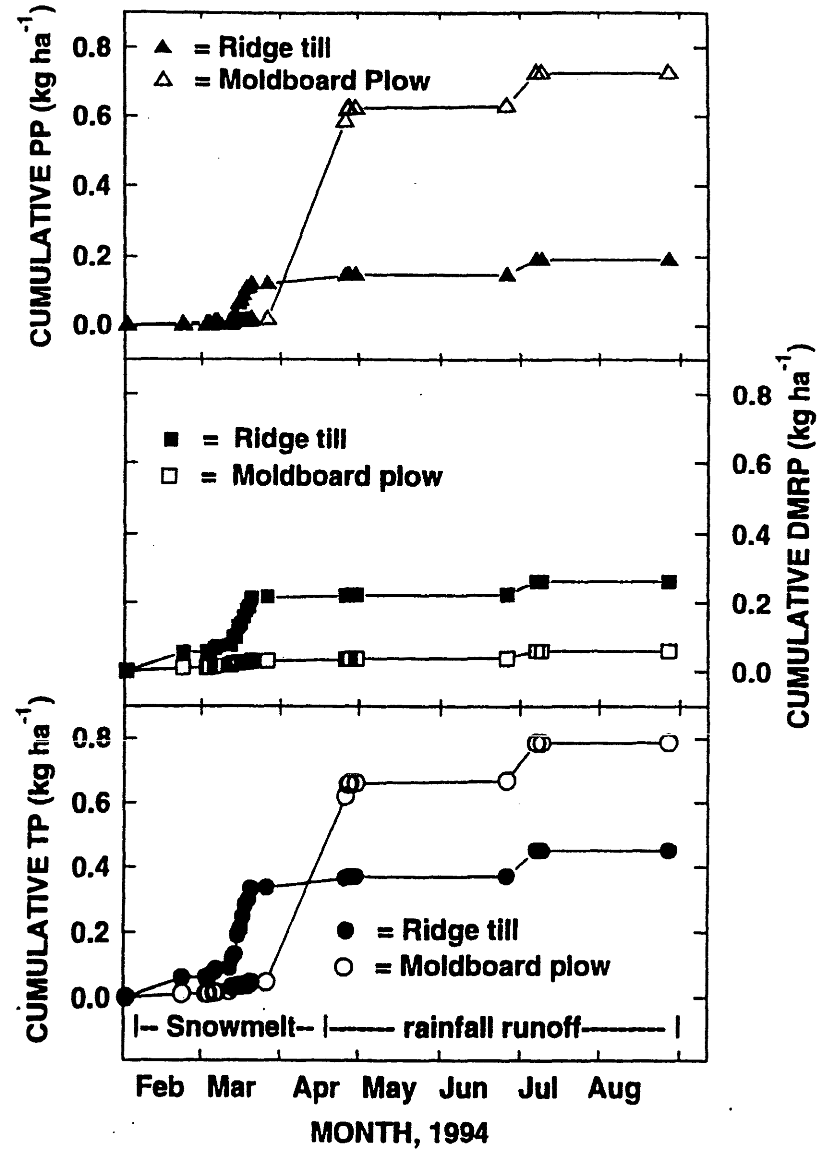

Fig. 1-14. Effects of tillage on particulate P (PP), dissolved molybdate reactive P (DMRP) and total P (TP) losses in surface runoff from 22 February through 26 August 1994 on Barnes loam at the West Central Exp. Sta., Morris, MN.

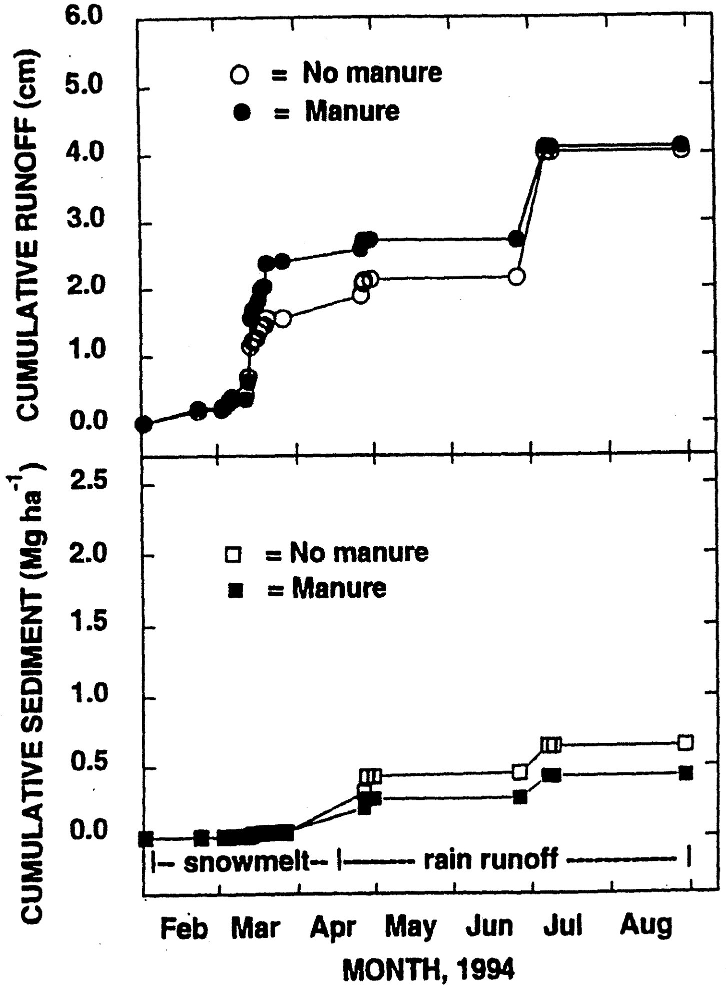

Fig. 1-15. The effects of manure on runoff and associated sediment loss from 22 February through 26 August 1994 on Barnes loam at the West Central Exp. Sta., Morris, MN.

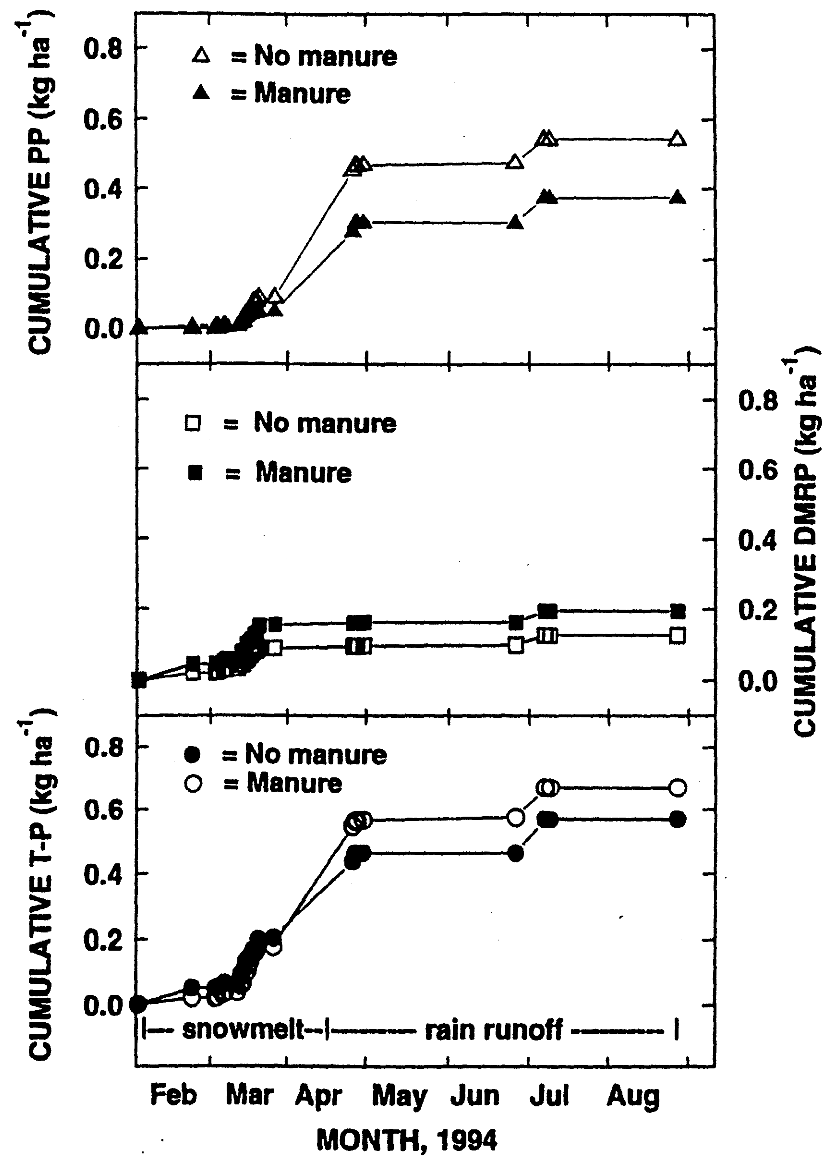

Fig. 1-16. Effects of manure on particulate P (PP), dissolved molybdate reactive P (DMRP) and total P (TP) losses in surface runoff from 22 February through 26 August 1994 on Barnes loam at the West Central Exp. Sta., Morris, MN.

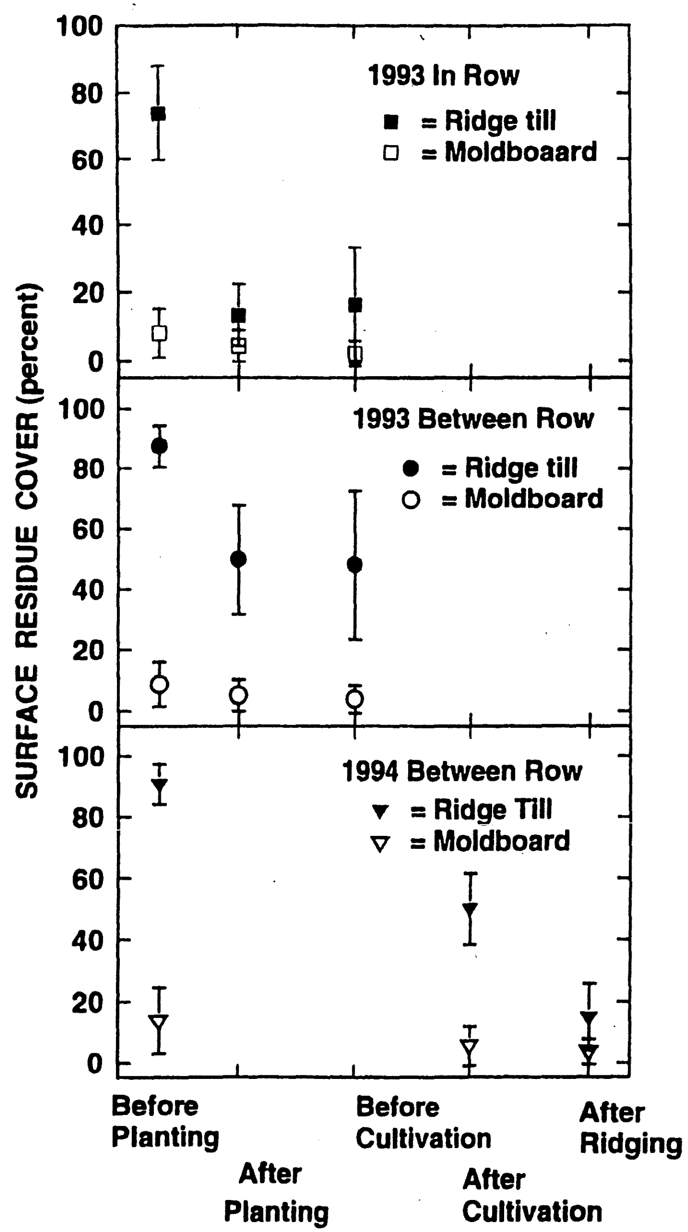

Fig. 1-17. Effect of field operations on residue cover in the ridge tilled and moldboard plowed plots during the 1993 and 1994 growing season at the West Central Exp. Sta., Morris, MN.

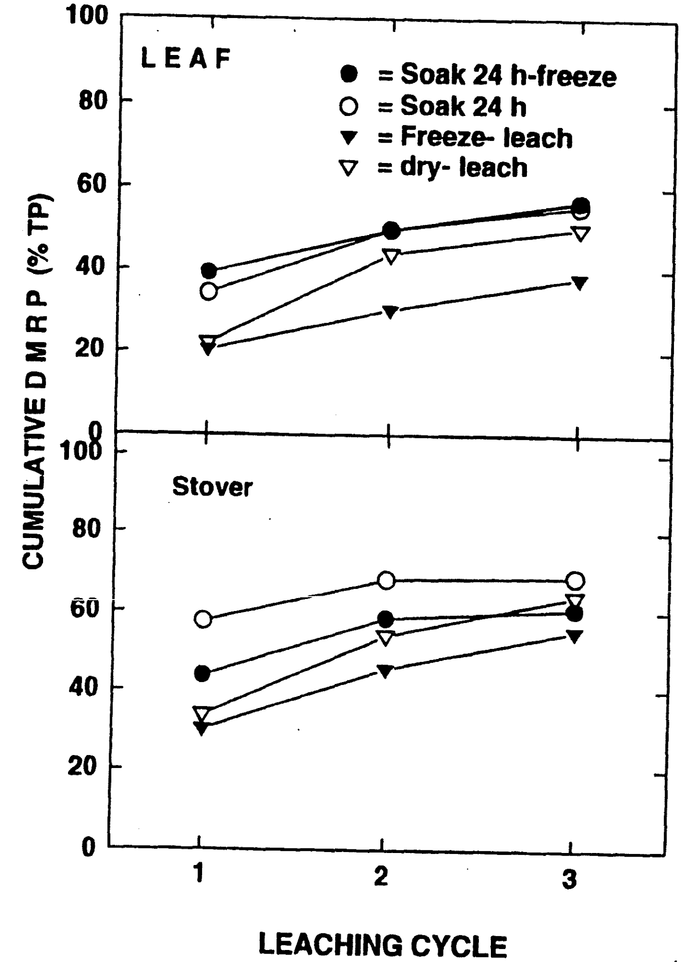

Fig. 1-18. Effects of pretreatments (soaking, freezing and thawing cycles) on dissolved molybdate reactive P (DMRP) leached from corn leaves and stover.

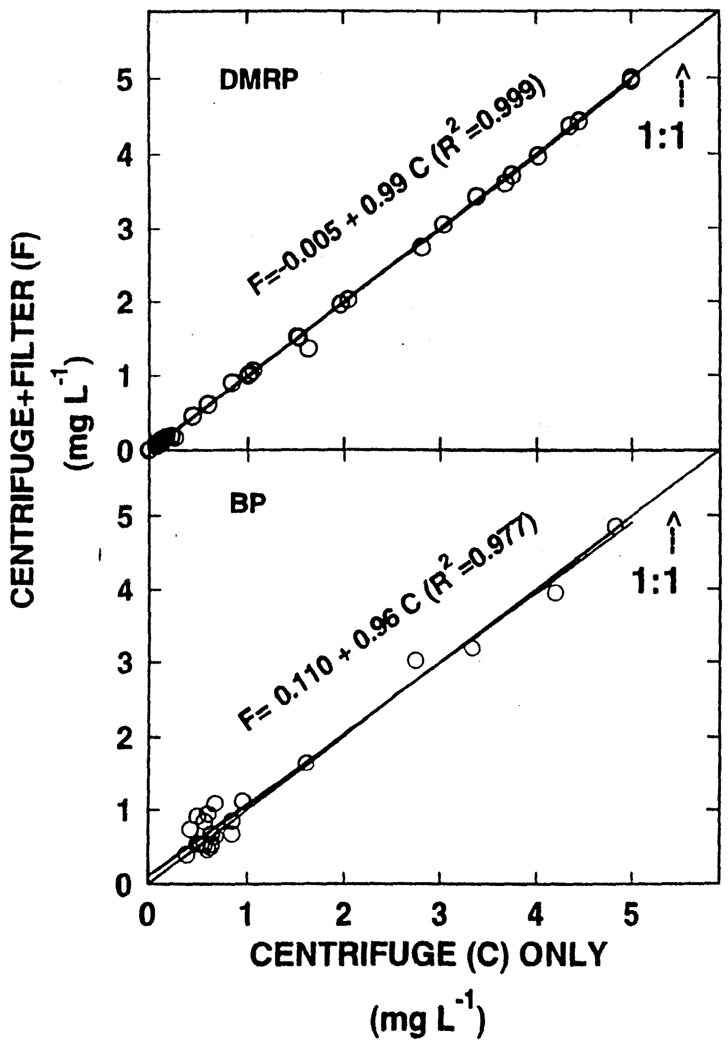

Fig 1-19. A comparison of centrifugation and centrifugation plus filtration to separate solid and solution phase before dissolved molybdate reactive P (DMRP) and bioavailable P (BP) determination.

Table 1-1. Description of the procedure for the laboratory residue leaching experiment.

Treatment	Cycle	Description
A	1	Plant material was frozen for 20 hours.
	2	Cold distilled water added and refrozen immediately for 20 hours, thawed, hand-shaken and decanted.
	3	Cold distilled water added after the 1st leaching and refrozen immediately for 20 hours, thawed, hand-shaken and decanted.
	4	Cold distilled water added after the 2nd leaching, and refrozen immediately for 20 hours, thawed, hand-shaken and decanted.
B	1	Residue was cooled (4 °C) for 20 hours.
	2	Cold distilled water added, stored for 20 hours at 4 °C, hand-shaken and decanted.
	3	Cold distilled water added after the 1st leaching, stored for 20 hours at 4 °C, hand-shaken and decanted.
	4	Cold distilled water added after the 2nd leaching, stored for 20 hours at 4 °C, hand-shaken and decanted.
C	1	Plant material was frozen for 20 hours, thawed for 15 minutes, cold water added, hand-shaken and decanted.
	2	Plant material was refrozen for 20 hours after the first leaching, thawed for 15 minutes, cold water added, hand-shaken and decanted.
	3	Plant material was refrozen for 20 hours after the 2nd leaching, thawed for 15 minutes, cold water added, hand shaken and decanted.
D	1	Plant material was stored at 4 °C for 20 hours, cold water added, hand-shaken and decanted.
	2	Restored at 4 °C for 20 hours after the 1st leaching, cold water added, hand-shaken and decanted.
	3	Restored at 2 °C for 20 hours after the 2nd leaching, cold water added, hand-shaken and decanted.

Table 1-2. Seasonal precipitation during 1992, 1993 and 1994 at the West Central Exp. Stn., Morris, MN.

Year	Period	Form	Amount (cm)
1992	Apr. 1-Oct. 31	Rain	43.2
	Nov. 1-Dec. 31	Snow†	6.5
1993	Jan. 1 Mar. 29	Snow	4.1
	Apr. 1-Oct. 31	Rain	73.0
	Nov. 1-Dec. 31	Snow	6.2
1994	Jan. 1-Mar. 28	Snow	6.3
	Apr. 1-Oct. 31	Rain	57.0
	Nov. 1-Dec. 31	Snow	2.9

†=water equivalent

Table 1-3. The effects of tillage and manure on cumulative rainfall runoff and associated sediment loss from May to June 1992 on Barnes loam at the West Central Exp. Sta., Morris, MN.

Treatments	Runoff (mm)	Sediment (kg ha^{-1})
Ridge till		
No Manure	0.20	4.13
Manure	0.10	2.10
Average	0.15	2.99
Moldboard		
No Manure	3.87	626
Manure	3.55	381
Average	3.71	488
Average		
No Manure	1.41	55.7
Manure	1.24	33.4
P>F values		
Tillage (T)	0.002	0.004
Manure (M)	0.499	0.185
T by M	0.937	0.994

Table 1-4. The effect of tillage and manure on cumulative loss of total P (TP), particulate P (PP), DMRP and bioavailable P (BP) in rainfall runoff from May through June 1992 on Barnes loam at the West Central Exp. Sta., Morris, MN (June, 1992).

Event	TP	PP	DMRP	BP
	g ha^{-1}	g ha^{-1}	g ha^{-1}	g ha^{-1}
Ridge till				
No Manure	6.1	4.3	1.8	2.8
Manure	6.4	3.6	2.7	5.0
Average	6.2	4.0	2.1	3.8
Moldboard				
No Manure	158	147	11.1	39.2
Manure	295	246	49.1	55.0
Average	216	193	23.6	46.4
Average				
No Manure	32.5	27.7	4.8	11.3
Manure	45.7	33.0	12.7	17.4
P > F Values				
Tillage (T)	0.024	0.153	0.022	0.040
Manure (M)	0.347	0.524	0.044	0.170
T by M	0.405	0.648	0.130	0.788

Table 1-5. The effect of tillage and manure on cumulative snowmelt runoff, and associated sediment, total phosphorus(TP), Particulate-P (PP) and DMRP losses on 29 March 1993 on Barnes loam at The West Central Exp. Stn., Morris, MN.

	Runoff	Sediment	TP	PP	DMRP
	(mm)	(kg ha^{-1})	g ha^{-1}	g ha^{-1}	g ha^{-1}
Ridge till					
No Manure	22.8	80.9	1537	1453	85
Manure	2.5	25.3	308	163	145
Average	15.0	45.2	688	577	111
Moldboard					
No Manure	2.6	4.2	11.7	<0.1	11.6
Manure	2.5	7.2	58.0	43.4	14.6
Average	2.6	5.5	26.1	13.0	13.1
Average					
No Manure	7.7	18.5	134	102	31.5
Manure	5.0	13.5	134	88.0	46.0
P > F Values					
Tillage (T)	0.030	0.023	0.042	0.116	0.031
Manure (M)	0.098	0.389	0.994	0.985	0.456
T by M	0.255	0.058	0.034	0.053	0.735

Table 1-6. The effects of tillage and manure on concentration of sediment (CSED), TP (CTP) and DMRP (CDMRP) in snowmelt runoff during 1992-1993 winter on Barnes loam at the West Central Exp. Stn., Morris, MN.

Concentration	RT		PL		P>F		
	NM	M	NM	M	T	M	T*M
CSED (g L^{-1})	0.37	0.32	0.17	0.29	.213	.634	.334
CPP (mg L^{-1})	6.37	1.81	0.03	2.45	.496	.837	.068
CDMRP (mg L^{-1})	0.39	1.45	0.45	0.62	.240	.023	.061
CTP (mg L^{-1})	6.76	3.26	0.48	3.07	.102	.627	.103

T=Tillage; RT=Ridge Tillage; PL=moldboard Plowing; NM=no manure; M=Manure

Table 1-7. Cumulative 1993 rainfall runoff, sediment, total phosphorus (TP), particulate P (PP) and DMRP loss as influenced by tillage and manure at The West Central Exp. Stn., Morris, MN (10 May-24 Aug., 1993).

	Runoff	Sediment	TP	PP	DMRP
	(mm)	(Mg ha^{-1})	kg ha^{-1}	kg ha^{-1}	g ha^{-1}
Ridge till					
No Manure	6.5	0.550	0.614	0.575	38.9
Manure	1.9	0.093	0.142	0.084	58.6
Average	3.5	0.227	0.295	0.248	47.8
Moldboard					
No Manure	60.6	22.6	2.53	2.46	73.4
Manure	49.5	11.3	1.61	1.54	68.3
Average	54.8	15.9	2.02	1.95	70.7
Average					
No Manure	19.8	3.53	1.25	1.19	53.5
Manure	9.8	1.03	0.478	0.432	46.0
P > F Values					
Tillage (T)	0.017	0.032	0.004	0.008	0.187
Manure (M)	0.103	0.037	0.130	0.246	0.153
T by M	0.207	0.251	0.375	0.793	0.064

Table 1-8. The effect of tillage and manure on cumulative annual runoff and associated sediment, and total phosphorus (TP), particulate-P (PP), and DMRP losses from 29 March through 24 August 1993 from Barnes loam at The West Central Exp. Stn., Morris, MN.

	Runoff	Sediment	TP	PP	DMRP
	mm	Mg ha^{-1}	kg ha^{-1}	kg ha^{-1}	g ha^{-1}
Ridge till					
No Manure	29.8	0.746	2.18	2.06	123
Manure	12.8	0.161	0.525	0.309	216
Average	19.5	0.346	1.07	0.906	165
Moldboard					
No Manure	63.6	22.6	2.55	2.47	85.4
Manure	52.0	11.3	1.69	1.61	83.2
Average	57.5	16.0	2.08	1.99	84.3
Average					
No Manure	43.5	4.11	2.36	2.25	104
Manure	25.8	1.35	0.942	0.808	134
P > F Values					
Tillage (T)	0.029	0.012	0.161	0.091	0.160
Manure (M)	0.097	0.029	0.070	0.105	0.496
T by M	0.255	0.283	0.248	0.343	0.455

Table 1-9. Snow depth, equivalent water content and snow density measured on 1 and 7 March 1994 at the experimental site, Morris, MN.

Date	Tillage	Snow Depth	Water Content	Density
		(cm)	(cm)	Mg m^{-3}
1 March	Ridge till	33.0	9.9	0.30
	Moldboard	20.8	5.9	0.28
	Average	26.9	7.9	0.29
7 March	Ridge till	25.5	7.7	0.31
	Moldboard	10.7	3.7	0.24
	Average	18.1	5.7	0.28
	P > F Value			
	Date (D)	0.001	0.013	0.465
	Tillage (T)	0.032	0.119	0.519
	D by T	0.822	0.649	0.295

Table 1-10. Effects of tillage and manure on cumulative snowmelt runoff and associated sediment, Total-P (TP), Particulate-P (PP) and dissolved molybdate reactive P (DMRP) losses from 22 February through 26 March 1994 on Barnes loam at The West Central Exp. Stn., Morris, MN.

	Runoff	Sediment	TP	PP	DMRP
	mm	kg ha^{-1}	g ha^{-1}	g ha^{-1}	g ha^{-1}
Ridge till					
No Manure	23.9	43.6	159	69.6	89
Manure	32.9	46.5	284	62.2	222
Average	28.0	45.0	212	71.6	141
Moldboard					
No Manure	10.1	22.7	30.8	13.8	17.0
Manure	17.8	36.6	59.7	20.7	39.0
Average	13.4	28.4	42.9	17.2	25.7
Average					
No Manure	15.5	31.4	120	30.9	39.0
Manure	24.2	40.6	142	37.2	93.1
P > F Values					
Tillage (T)	0.309	0.090	0.044	0.093	0.041
Manure (M)	0.560	0.686	0.407	0.323	0.250
T by M	0.868	0.759	0.954	0.527	0.953

Table 1-11. Effects of tillage and manure on cumulative rainfall runoff and associated sediment, total P (TP), and dissolved molybdate reactive P (DMRP) losses from 25 April through 26 August 1994 from Barnes loam at The West Central Exp. Stn., Morris, MN.

	Runoff	Sediment	TP	PP	DMRP
	(mm)	(Mg ha^{-1})	g ha^{-1}	g ha^{-1}	g ha^{-1}
Ridge till					
No Manure	8.5	0.106	99.1	62.4	36.7
Manure	7.6	0.898	117	65.3	51.7
Average	8.0	0.979	107	64.1	43.6
Moldboard					
No Manure	30.1	2.51	818	789	29.1
Manure	21.8	1.24	564	538	25.8
Average	25.6	1.76	679	652	27.4
Average					
No Manure	16.0	0.517	285	252	32.7
Manure	12.8	0.334	257	220	36.5
P > F Values					
Tillage (T)	0.007	0.002	0.016	0.008	0.286
Manure (M)	0.060	0.095	0.709	0.537	0.647
T by M	0.294	0.256	0.355	0.472	0.359

Table 1-12. Effects of tillage and manure on annual runoff and associated, sediment, total P (TP), particulate P (PP) and dissolved molybdate reactive P (DMRP) losses from 22 February through 26 August 1994, from Barnes loam at the West Central Exp. Stn., Morris, MN.

	Runoff	Sediment	TP	PP	DMRP
	mm	Mg ha^{-1}	kg ha^{-1}	kg ha^{-1}	kg ha^{-1}
Ridge till					
No Manure	39.4	0.161	0.307	0.165	0.141
Manure	42.2	0.142	0.458	0.168	0.289
Average	40.8	0.152	0.375	0.172	0.202
Moldboard					
No Manure	41.2	2.54	0.850	0.803	0.047
Manure	39.9	1.28	0.626	0.561	0.065
Average	40.7	1.80	0.730	0.674	0.055
Average					
No Manure	40.30	640.5	0.510	0.429	0.082
Manure	41.05	425.7	0.535	0.398	0.138
P > F Values					
Tillage (T)	0.988	0.003	0.104	0.018	0.064
Manure (M)	0.970	0.232	0.914	0.415	0.344
T by M	0.919	0.391	0.449	0.685	0.714

Table 1-13. Effects of tillage and manure on soil bulk density† (0-7.5 cm depth), 10-(C10), 30-(C30), 60-(C60) minute cumulative infiltration and Ksat‡ on Barnes loam at The West Central Exp. Stn., Morris, MN.

Treatment	BD	C10	C30	C60	Ksat
	Mg m^{-3}	--------------- cm	---------------		cm/hr
Ridge till					
No Manure	1.34	10.9	27.2	46.1	39.0
Manure	1.31	13.4	30.7	51.3	39.6
Average	1.32	12.2	28.9	48.7	39.3
Moldboard					
No Manure	1.28	4.23	12.2	22.8	20.7
Manure	1.34	8.92	22.9	39.3	32.7
Average	1.31	6.58	17.5	31.0	26.7
Average					
No Manure	1.31	7.58	19.7	34.4	29.9
Manure	1.32	11.2	26.8	45.3	36.2
P > F Values					
Tillage (T)	0.830	0.071	0.102	0.138	0.204
Manure (M)	0.845	0.174	0.274	0.303	0.422
T by M	0.518	0.639	0.558	0.573	0.463

†=measured on 5 May 1994, a week after planting
‡=measured on 28 October 1994, after harvest but before primary tillage

Table 1-14. The dissolved molybdate reactive P (DMRP) leached (presented in percent TP) from corn leaves and stover in the laboratory experiment.

Leaching cycles	Leaf pretreatments[†]				Stover pretreatments			
	A	B	C	D	A	B	C	D
	%				%			
1	39.2	34.3	20.3	22.0	43.6	57.5	30.0	33.6
2	10.6	15.6	9.9	22.0	14.7	10.8	15.3	20.3
3	6.7	5.6	7.8	10.8	2.2	0.6	9.7	10.3
Total	56.6	55.5	38.1	50.2	60.6	68.9	55.0	63.9

[†]A= Freezing 20 hour, add water, freeze 20 hour, thaw and decantation; B=Cooling (2 °C) 20 Hr, add water, soak 20 hour and decantation; C=Freezing 20 hour, add water, decantation; D= Cooling (2 °C), add water, decantation.

CHAPTER 2: Tillage and Manure Interactions on Soil Phosphorus Dynamics, Yield and Phosphorus Uptake of Corn

Tillage and Manure Interactions on Soil Phosphorus Dynamics, Yield and Phosphorus Uptake of Corn

ABSTRACT

Manure incorporation into soil is necessary in order to maximize the nutrient availability for crop production. The specific objective of this study was to evaluate the effects of ridge till and moldboard plowing tillage treatments with and without beef cattle (*Bos taurus* L.) manure application on the soil-P dynamics, corn (*Zea mays* L.) yield, and corn P-uptake. Beef manure was applied one time at the rate of 56 Mg ha^{-1}. Dynamics of $NaHCO_3$ extractable-P (Olson-P) in soil at 0-5, 5-10 and 10-15 cm depths, corn yield, and corn P-uptake were evaluated on Barnes loam (fine-loamy mixed Udic Haploboroll) with 12 % slope from 1992-1994. Corn was planted up and down the slope. Manure application in the RT system resulted in Olson-P stratification with soil depth. At 0-15 cm depth between the plant rows, manure application increased Olson P by 4.5 and 12.5 mg kg^{-1} in RT treatments and by 6.5 and 9.5 mg kg^{-1} in PL plots one and two years after its application, respectively. Incubation studies of soil and manure in the laboratory showed that Olson-P decreased exponentially with time. In 1993 grain yield was significantly greater in the PL treatment (7.42 Mg ha^{-1}) than in RT plots (6.19 Mg ha^{-1}). In 1994 tillage effects were not significant. In 1993, manure had no significant effect on grain yield whereas in 1994 manure increased grain yield by 500 kg ha^{-1}. Tillage had no significant influence on P uptake in 1993 and 1994, but in each year manure significantly increased corn P-uptake by 4.7 kg ha^{-1}. Grain yield in the PL plots was either greater or similar to the RT plots, depending on the year. Tillage had no significant effect on corn P-Uptake. Manure influence on grain yield was not consistent.

INTRODUCTION

Tillage

Tillage and Erosion

Tillage influences soil surface hydrology and consequently the transport of sediment and nutrients in surface runoff. Conservation tillage systems are less intensive in soil cultivation than the moldboard plowing tillage and leave some residue at or near the surface that reduces soil erosion and non-point source pollution (Moncrief, et al. 1989; Unger and McCalla, 1980). Several studies have shown that transport of particulate N and P in surface runoff is less from conservation compared to conventionally tilled corn (Barisas et al., 1978; McDowell and McGregor, 1984).

It is well established that erosion has a direct impact on soil chemical and physical properties and in turn on soil productivity and crop yield. Rhoton and Tyler (1990) showed that degradation of soil chemical and physical properties due to erosion reduced seedling emergence and plant vigor. The influence of erosion on soil chemical properties is mostly through its influence on accelerated loss of organic matter and associated plant available macro and micro-nutrients in surface runoff (Barrow and Kilmer, 1964; Burwell, et al., 1977). As erosion decreases soil organic matter, it also reduces the soil cation exchange capacity (Nizeyimana and Olson, 1988). An effect of erosion on soil physical properties is through its influence on reducing soil depth, and water holding capacity (Frye et al., 1982).

Tillage Effects on Nutrient Stratification

Since depth of soil inversion varies among tillage systems, different tillage systems create different types of nutrient stratification in the soil profile. The two extremes tillage systems are the no-till where there is negligible soil inversion and maximum residue cover vs. a moldboard tillage system where there is maximum soil inversion and minimum residue cover. Several studies have shown that compared to a tillage system that periodically inverts the soil, no-till leads to an accumulation of P at the soil surface and a decrease in P at deeper depths (Cruse et al., 1983; Fink and Wesley, 1974;Pierce et al., 1994). Eckert and Johnson (1985) indicated that P accumulation occurred in the 0-5 cm depth regardless of method of P application in the no-tillage system. Even when no P fertilizer was applied in the no-till system, water soluble P was significantly greater in the upper 5 cm. This was due to the accumulation of organic matter (Weil et al., 1988).

Incorporation of plant residue with tillage systems is important in order to maximize the nutrient cycling in soil. Mineralized labelled N recovered from sorghum residue after 110 and 1097 d after incorporation ranged from 4.5 to 24.8 and 6.6 to 36.5 percent, respectively (Vigil et al., 1991). Ladd and Amato (1986) indicated that up to 17% of N in legume was recovered by a subsequent wheat crop. Since there is a lack of incorporation of crop residues with no-tillage, an accumulation of nutrient occurs at the soil surface. According to Hargrove (1985), accumulation of nutrients at the soil surface is not a disadvantage to crops in terms of nutrient uptake, plant growth, and yield. However, the accumulation of P at the soil surface in no-till could lead to increased soluble-P in surface runoff (Baker and Laflen, 1983).

Tillage Effects on Crop Yield

Crop yields, with conservation tillage systems are greater, less, or about the same as the conventional tillage system depending upon the particular circumstances. Some of the factors affecting differences in crop yield between tillage systems are soil type, drainage, climate, insect infestation, and weed management practices (Christensen and Nortis, 1983; Moncrief et al., 1987). A large variation in crop yields in both conventional and conservation tillage practices make generalizations about yield difficult. However there have been efforts to generalize tillage effects on yield potentials for different crop rotations and soil types for the eastern corn belt. The yield potentials are not based on yield comparisons in any one experiment but collectively reflect the experience of the researchers in the area (Griffith and Mannering, 1985).

Tillage and Manure Interactions on Soil Conditions

Application of manure increases organic matter content which in turn reduces soil bulk density and evaporative water loss, and improves soil porosity, water retention, and water stable aggregates (Unger and Stewart, 1974; Guttay et al., 1956; Weil and Kroonje, 1979; Sommerfeld and Chang, 1985; Sweeten and Mathers, 1985).

The influence of manure on nutrient availability and soil conditions depends on the depth of tillage. In general, manure effects on penetration resistance, bulk density, water retention, and pH decrease with an increase in the depth of manure incorporation. Manure incorporated to 10-cm depth resulted in greater change in soil conditions compared to incorporation to 20- or 30-cm depth (Tester, 1990). In the same study, Tester (1990) also showed that there was more decomposition of organic matter in the surface 4.5 cm than at deeper depths. For example, 37 % of the organic matter from beef manure decomposed in the 1st year, and about 37% of the remaining organic matter decomposed over the next 3 years. Weil and Kroontje (1979) showed that incorporation of poultry manure by moldboard plowing created a plowsole manure layer which reduced the water infiltration. However, Sommerfeldt and Chang (1985) showed that tillage (plow, rototiller, or cultivator) and manure, independently affected most soil properties (organic matter, bulk density, soil tilth, and aggregate size distribution); and tillage by manure interactions were only observed in soil tilth.

Manure

The value of farmyard manure to increase crop yield on a wide range of soils have been reported in the literature (Tiarks et al., 1974; Guttay et al., 1956). It is difficult to single out one factor that clearly explains how manure increases yield; i.e. whether the yield increase on manure application is due to improved soil chemical or soil physical properties.

Hensler et al. (1970) showed that the application of manure significantly increased average corn grain and dry-matter yield on a silt loam soil. The range of recovery of N, P, and K by corn over three years were 7 to 15, 4 to 9, 17 to 31 percent, respectively. Hedlin and Ridley (1964) indicated that manure increased the $NaHCO_3$ extractable P and it was only the manure treatment that resulted in a residual effect on crop yield. Olsen et al. (1970) showed that the addition of dairy beef manure at higher rates tend to increase soil organic N. Under aerobic conditions, available P and K increased by 0.3 and 1 mg kg^{-1} soil, respectively, per metric ton of applied manure. Significant increases in the exchangeable Ca and Mg were also observed on manure addition (Olson et al., 1970).

Incorporation of manure with tillage is an effective method of land-disposing of animal waste as well maximizing its nutrient value to crops (Mueller et al., 1984). In a study by Young and Mutchler (1976), corn yield from non-manured check plots did not differ significantly from that of surface applied manured plots; however, there was an increase in corn yield when manure was plowed under .

Some manure incorporation in soil is necessary in order to maximize its nutrient availability to crops and in order to avoid nuisance odor. However, excessive soil cultivation leads to a decrease in surface residue cover that thus increase the susceptibility of soil to erosion. The premise of this research was to evaluate a conservation tillage management system in terms of providing sufficient degree of cultivation to incorporate surface applied manure and its impact on the availability to the crop. At the same time enough crop residue should be left at the soil surface to prevent excessive erosion. In this research, we are interested in evaluating the interactions of tillage and manure on sediment and P losses as well as availability of P to crops. This study is specifically evaluating soil-P dynamics, corn yield, and phosphorus uptake from manured and non manured plots under ridge tillage and moldboard tillage systems.

MATERIALS AND METHODS

Field Experiment

Tillage and manure interaction study was conducted at the West Central Experiment Station, Morris, MN during 1992-1994. The land had been previously cropped with alfalfa and the land slope was 0.12 m m⁻

[1] with south-eastern aspect. The soil type is Barnes loam (fine-loamy mixed Udic Haploborolls). Initial soil tests in 1992 for pH (1:1), Olson-P, and K were 8.0, 17, and 155 mg kg^{-1} (Table 1 in Appendix A1)

In 1992 twelve erosion plots 22 m by 3 m (to accommodate four rows of corn) were isolated using corrugated steel plates. The tillage treatments were ridge till (RT) and moldboard plowing (PL). Tillage was up and down the slope. Manure treatments were a one time application of solid beef manure at the rate of 56 Mg ha^{-1} (M) and no-manure (NM) application. Manure application provided approximately 161 kg total-P ha^{-1}. Solid N, P, and K contents of manure are given in Table 2 of Appendix 1. The detailed methods of manure analysis is given in Appendix A2 and A3.

The combinations of tillage and manure treatments were Ridge till system with manure (RTM), Ridge till system without manure (RTNM), Moldboard plow system with manure (PLM), and Moldboard plow system without manure (PLNM). The treatments were replicated three times in a randomized complete block (tillage) with split (manure) plots.

In the spring of 1992 beef manure was spread over the assigned plots for manure treatments. The moldboard plots were then tilled with a moldboard plow, followed by disking. In the ridge till plots, the ridges were formed with a row cultivator on 21 July 1992. Thus, prior to 21 July 1992 the manure was not incorporated in the RTM plots. Since the previous year crop was alfalfa, no nitrogen fertilizer was applied in the year of the establishment to any treatment.

In 1993 and 1994, moldboard plots were tilled with a moldboard plow in the fall followed by a spring field cultivation and then planted. For the ridge tillage, seeds were planted directly in the spring in the previous year's ridges and a row cultivation in the summer to rebuild the ridges.

In 1993 and 1994 N fertilizer was added such that there was similar soil-N among all treatments. In 1993 45 kg ha^{-1} N as NH_4NO_3 was broadcast-applied to no manure plots (RTNM and PLNM). This amount was equal to the estimated mineralizeable N from the organic N of manure in the manure plots (RTM and PLM). In 1994 NH_4NO_3 was broadcast applied at the rate of 111 and 134 kg N ha^{-1}, to the PLM and PLNM plots, respectively whereas for the RTM and RTNM plots, NH_4NO_3 was broadcast applied at a rate of 134 and 157 kg N ha^{-1}, respectively. Greater amounts of N were applied in RT treatments considering the greater residue cover and reduced mineralization of soil organic matter, which determined the availability of N to plants. In both tillage systems, N fertilizer was hand broadcasted and then incorporated with cultivation (6 June 1994).

Corn (Pioneer-3751) was planted up and down the slope at a rate of 79,000 seeds ha^{-1} with a Hiniker 4-row planter equipped with a 5-cm fluted coulter set at 76-cm row spacing. In 1992, due to gophers eating the germinating seeds, corn (Pioneer-3617) was reseeded again at a rate of 99,000 seeds ha^{-1} on 26 May, 1992. Due to continuous gopher damage, corn (Pioneer-3921) was reseeded again at a rate of 148,000 seeds ha^{-1} on 15 June 1992. Both replantings were done using Almaco planter equipped with a 2.5-cm fluted coulter set at the same row spacing. In 1992, no corn grain or stover was harvested from the plots. Corn plants in moldboard plots were chopped and plowed into the soil during moldboard plowing in the fall. Due to poor corn stands, baled dry corn stalks were spread on the RT plots at a rate of 5.6 Mg ha^{-1}. These corn stalks were added to simulate residue cover that generally exists in ridge tillage after fall harvest. The detailed field activities and pesticides used during 1992-1994 are given in Appendix A1.

In 1993 and 1994, grain and stover yields were measured by hand harvesting the plants. Grain yield (after drying at 60 °C), number of ears, and corn population at harvest were estimated from 21 percent (14 m^2) of a plot area (67 m^2). Stover yield was measured by weighing ten randomly selected plants after grain harvest. Plants were cut above ground, shredded and subsampled for total P (TP) determination. The TP-uptake was also determined on corn grain and stover. In 1994, ear leaves at tasseling were also sampled for TP analysis. This was done because there were significant visual differences in plant height between the manured and the non-manured plots.

Determination of TP in plant involved digesting sample with perchloric acid (Olsen and Sommers, 1982), neutralizing with NaOH, and then measuring the intensity of blue molybdate as a coloring agent at 882 ηm wave length after ascorbic acid addition (Murphy and Riley, 1962). Details of the procedure are described in Appendix A9.

In 1993 soil samples were taken after planting from depths of 0-5, 5-10 and 10-15 cm, both row as well as the interrow areas. The 'row area' was defined as a 10-cm wide strip centered over the row and the 'interrow' area was the remainder. In 1994 soil samples were taken before spring field cultivation from depths of 0-5, 5-10, and 10-15 cm between plant rows. Soil samples were taken at up hill, center and down hill positions in each plot. Soil was air dried, extracted with 0.5M $NaHCO_3$ and then filtered (Olsen and Sommers, 1982) before Olson-P determination. The detailed method of analysis of Olson-P in this study is given in Appendix A7. Phosphorus in the neutralized filtrate was determined using ascorbic acid method of Murphy and Riley (1962).

Laboratory Incubation Study

An incubation experiment in the laboratory was conducted to study the dynamics of P in a calcareous soil (Udic Haploboroll) mixed with beef manure. Decomposing organic material such as manure and crop residues generally release P increase soil-P. Evaluations on P release from plant material (without mixing with soil) in incubation studies have been reported by Sharpley et al. (1979) and Timmons et al. (1970). However, incubation studies on solely plant material without mixing it soil, will not explain the fate of phosphorus in the cultivated soils since the P released also interacts with soil. In addition, there is also a lack of data on the release of P from manure and its subsequent fate in a calcareous soil. Therefore an incubation study was undertaken to evaluate temporal changes in Olson-P in manured-soils.

For the incubation study, soil was taken from 0-15 cm depth from the untreated area in the experimental field and air dried. Fresh beef manure taken from the Morris Experimental Station was oven dried at 60 °C. Soil and manure moisture contents were determined by oven drying a portion of air-dried soil and oven-dried manure at 105 °C. Air dried soil and oven dried manure were ground to pass through a 2-mm sieve and then mixed with the soil. The treatments for the incubation study were: 0 g of manure per kg soil (control), 8.7 g of manure per kg soil (equivalent to the manure-soil mixing ratio of the moldboard plow treatment) and 26.1 g of manure per kg soil (equivalent to manure-soil mixing ratio of the ridge till treatment). This equivalence of soil and manure was based on the assumption that manure is mixed to a depth of 15-cm in the moldboard tillage and to a 5-cm of depth in the ridge till system. Soil-manure mixing for each treatment was done in a rolling drum mixer.

Incubation of the soil-manure mixture was done in polypropylene bottles. The procedure involved weighing a 5.1 g of air dried soil-manure mixture in each 250 mL polypropylene bottle, and evenly distributing 1.34 g deionized distilled water with a syringe. The amount of water was equivalent to the water content of the soil at -33 kPa matric potential (field capacity). The experiment was arranged in a completely randomized design with three replications. Other details of the procedure are given in Appendix A8.

The soil-manure mixture was incubated for 0, 1, 3, 5, 10, 30 days in an incubator at a constant temperature of 30 °C. At the end of each incubation time, Olson-P was analyzed as described in Appendix A7. Briefly, the procedure involved adding 100 mL 0.5 M $NaHCO_3$ to each incubation bottle, shaking for 30 minutes, filtering, neutralizing the filtrate, and then measuring phosphorus using ascorbic acid method of Murphy and Riley (1962).

RESULTS AND DISCUSSION

Dynamics of Soil Olson-P

In the Field

After planting (29 April 1993), soil samples were taken at 0-5, 5-10 and 10-15 cm depths from the row area and the interrow area. Soil tests showed that manure application resulted in a significantly greater soil Olson-P. In the RT treatment, manure application resulted in greater Olson-P in the row area than interrow areas. In the manured RT plots, Olson-P at 0-5 cm depth in row area was significantly higher than Olson-P at 5-10 and 10-15 cm depths (Fig. 2-1 B). This was because manure and surface soil were moved from furrow to the row area during ridging (21 July and 26 October 1992) which caused the concentration of Olson-P to increase in the row area but not in the interrow area (Fig. 2-1 A and B). In the non-manured RT treatment, there was a slight but not significantly greater Olson-P at 0-5 cm interrow area than the in row area, which presumably was due to P released from residues (Fig. 2-1 A).

In the PL plots, incorporation of manure resulted in a significantly greater soil P test at the 5-10 cm depth in (Fig. 2-1 D). In non-manured in PL plots, Olson-P was nearly same with depth both in row and interrow area (Fig. 2-1 C).

For temporal dynamic of Olson P during 1993 and 1994, only Olson P in the interrow area was described because in 1994 soil samples were taken only between the plant rows after planting. Soil samples in the row area were not taken because P containing starter fertilizer (7-21-7) was banded in the row at planting.

There was a significant interaction of time (year) and tillage (Table 2-1), on Olson-P at 0-15 cm depth in the interrow area. In other words, the dynamics of Olson-P varies with tillage and time; i.e. one (1993) and two years (1994) after manure application. In the RT plots, Olson-P increased by 9.2 mg P kg^{-1} soil whereas in PL treatment Olson-P decreased by 3.1 mg $kg^{-1}$from planting 1993 to planting 1994.

Manure had no significant interaction with time or tillage systems on Olson-P (Table 2-1). This suggests that manure application significantly increased Olson-P independent of time and tillage treatment. Manure application resulted in a significantly greater Olson-P both in RT and PL plots. Total P in applied manure was 161 kg ha^{-1} containing 64 kg ha^{-1} of inorganic P. As a result, Olson-P increased by 4.5 and 12.5 mg P kg^{-1} soil in RT treatments, one and two year after its application, respectively. Also, manure increased Olson-P by 6.5 and 9.5 mg P kg^{-1} soil in PL treatments, one and two years after its application, respectively.

The dynamics of Olson-P also varied with soil depth, tillage and manure application. The dynamics of Olson-P varied with depth in the RT treatment. In manured RT plots, the increase on Olson-P occurred at 0-5, 5-10 and 10-15 cm depths (Fig. 2-2 A, and B). This may have been due to the redistribution of phosphorus from ridges to the furrow. On 6 July 1993, ridges was formed by moving the manured soil from furrow to the row area. It is likely that the manured soil from ridges backfilled the furrow. Some soil also moved from the row to interrow area at planting on 5 May 1994 before soil samples were taken. This resulted in greater Olson-P in all depths in the manured RT plots. In the non-manured RT plots, a comparison between the 1993 and 1994 Olson-P showed that there was an increase in Olson-P in the 0-5 cm depth (Fig. 2-2 A and B), which was presumably due to P released from plant residue and a slight redistribution of P from ridge area during 1993 to 1994.

In the PL treatment there was no stratification of Olson-P with depth. In the manured PL treatment, Olson-P in 1993 was similar to the Olson-P in 1994. This was most likely due to the incorporation of manure and residue with fall moldboard plowing. However, in the non-manure manured PL plots, Olson-P decreased in all depths (Fig. 2-2 C and D). **In Laboratory Incubation Study**

Incubation data showed that Olson-P decreased exponentially with time. The greater the manure rate (less mixing equivalence), the greater was the decrease in the slope of the log P vs. time curve (Fig. 2-3). In other words, the rate of decrease of Olson-P was greater the higher the rate of manure applied. The log Olson-P vs. time curves from manure and non manure treated soil converged after 30 days of incubation. This suggests that the calcareous soil was a sink for mineralized P from manure probably precipitated as calcium phosphate. Griffin and Jurinak (1973) showed that the exposure of calcite to phosphate ions resulted in development of calcium phosphate mineral crystals on the surface of the calcite.

The dynamics of Olson-P study in the laboratory were different from the dynamics of Olson P in the field for manured soil. In the field, manure application increased the Olson-P test with time whereas in the laboratory, Olson-P decreased with time. In the field, manure was not mixed with soil as completely as in the laboratory for extensive precipitation to occur. Also, the redistribution of P occurs with time in the field with tillage operations, especially in the RT system. However, although at different rate, both the non-manured soil in the laboratory study and the non-manured PL system in the field indicated a decrease in Olson-P with time.

Crop Yield and Phosphorus Uptake

The Crop Year 1993

Grain and Stover Yield: Grain yield differed significantly with tillage system. In 1993, the PL system resulted in 1.2 Mg ha^{-1} greater grain yield compared to RT system (Table 2-2). This greater yield was associated with significantly greater number of corn ears in the PL plots (72,200) compared to the RT plots (66,980). We presumed that moldboard tillage was better in alleviating the excess wetness from the landscape and thus higher soil temperature which also contributed to a greater yield. The 1993 growing season was a wet and cold year compared to the 1994 growing season. The total rainfall during the 1993 and 1994 growing season was 73 and 57 cm, respectively. The Corn growing degree day (10 and 30 °C base) at Morris, MN during May to September in 1993 and 1994 was 2025 and 2404, respectively. The long term average of growing degree day in the area was 2300. According to Swan et al. (1987), low spring soil temperature, associated with residue cover at planting, commonly restrict the early growth of corn in the northern corn belt. Tillage had no significant influence on plant population and grain moisture at harvest (Table 2-2).

Manure application resulted in similar grain yield, numbers of corn ears, number of plants, and stover yield. Stover moisture was significantly higher in manure applied plots than non-manured plots. Presumably improved soil conditions and nutrient availability in manure applied plots enhanced water and nutrient uptake. Jamison (1956) indicated that the improved soil structure and nutrient availability were among factors that governed the availability of soil moisture to plants. There was no significant tillage by manure interaction on grain yield, grain moisture, stover yield, stover moisture, population and number of ears (Table 2-2).

Grain and Stover P-Uptake: Although tillage significantly increased grain yield (Table 2-2), there was no significant influence of tillage on the grain P-uptake (Table 2-3). Although grain yield was higher in the PL plots, TP concentration was lower. Conversely, grain yield was lower but TP concentration higher in RT treatment. The antagonistic relationship between yield and P concentration was due to nutrient dilution effects. Fribourg (1976) exemplify that P uptake did not increase with increased corn silage due to dilution of nutrients. Although not significant, TP concentration was greater (300 mg P kg^{-1} grain) inthe RT plots compared to the PL plots (Table 2-3). This may have been partially due to higher Olson-P in the RT plots (Fig 2-1). Olson-P at 0-15 cm was 23.4 mg P kg^{-1} soil in the RT plots, whereas in the P L plots Olson-P was 14.2 mg P kg^{-1} soil. Since tillage had no significant influence on stover yield (Table 2-2) and stover TP concentration, the TP uptake in corn stover was not influenced by tillage.

Although manure application resulted in no significant difference in grain and stover yield, the increase in grain-P and stover-P concentration with manure application resulted in significant TP uptake in grain and stover. Grain-P and stover-P concentrations from manured plots were 500 and 200 mg P kg^{-1} of tissue, respectively, higher compared to the non-manured plots. Significantly higher TP concentration in grain and stover from manured plots may have been due to greater Olson-P content in the soil due to manure application. Olson-P in the manured and non-manured plots was 26.3 and 13.3 mg P kg^{-1} soil, respectively. There was no tillage by manure interaction on TP uptake or TP concentration in grain and stover.

The Crop Year 1994

Grain and Stover yield: In 1994, tillage had no significant influence on grain yield, number of ears, population at harvest, or grain moisture (Table 2-4). Manure had a significant influence on grain yield but not on grain moisture, number of ears or number of plants at harvest. Greater yield with manure application presumably was due to improved nutrient availability to corn plants. Sutton et al. (1986) reasoned that accumulation of nutrients in the soil from manure increased corn yields during residual cropping year. During the growing season, it was qualitatively observed that plants in the manured plots were taller than non-manured plots. As a result, we also sampled the earleaf for TP determination. Data on earleaf TP concentration (Table 2-4) showedthat there was no significant effect of tillage or manure on earleaf TP concentration. Differences in corn yield between manure and no manure plots was in part due to soil Olson-P. Soil Olson-P test in manured plots (23.7 mg kg^{-1} soil) was significantly higher than the no manure plots (12.7 mg kg^{-1} soil) in the interrow area.

There was also a significant influence of tillage by manure interaction on grain yield (Table 2-4). In the RT plots, manure application resulted in 1.1 Mg ha^{-1} of yield increase, whereas in the PL system there was no difference between manure and non-manured plots. Although significant, tillage by manure interaction on stover yield was opposite to that of grain yield. In RT plots, manure application reduced stover yield by 0.7 Mg ha^{-1} where as in the PL plots, manure application increased stover yield by 0.5 Mg ha^{-1}.

Grain and Stover P-Uptake: Tillage system significantly influenced soil Olson-P test in the interrow area. The Olson-P concentration in the RT plots was 24.5 mg P kg^{-1} of soil compared to 12.7 mg P kg^{-1} of soil in the PL plots. However, tillage system had no significant effect on grain TP uptake and grain TP concentration (Table 2-5). Lack of significant differences in grain yield and grain TP concentration from the type of tillage resulted in non-significant differences in grain P uptake. Stover TP uptake and stover TP concentration, however, were significantly higher in the RT treatment.

Manure application resulted in higher grain yield (Table 2-4), grain TP concentration and thus TP uptake (Table 2-5). These were in part due to greater soil test in manured than non-manured plots. Olson-P concentrations in manured and non-manured plots were 23.7 and 12.7 mg kg^{-1} soil, respectively. Manure addition had no significant effects on stover yield (Table 2-4), TP concentration and thus TP uptake by stover (Table 2-5). Tillage by manure interaction on TP uptake in grain and stover were also non-significant (Table 2-5).

SUMMARY AND CONCLUSIONS

In 1993, a year after tillage and manure application, Olson-P varied both with soil depth and soil sampling position. In RT plots, manure application resulted in accumulation of P in 0-5 cm depth and a sharp decrease with depth both in row and interrow area. Olson-P in row area was greater than interrow area because ridging in July 1992 moved the manure and soil to row area. In the PL plots, tillage incorporated manure into the soil thus Olson-P concentration increased with soil depth. In non-manured plots, Olson-P was similar at 0-15 cm depth between the RT and PL plots, although in the RT plots, there was a weak accumulation of P in row area mainly from residue.

Changes in Olson-P concentration in the interrow area from spring 1993 to spring 1994 showed that a P dynamic varied with tillage systems, manure application and soil depths. In non-manured RT plots, Olson-P concentration at 0-5 cm depth was greater in 1994 compared to the 1993, mainly due to P from residue and slight redistribution of P. In manured RT plots, however, Olson-P concentration at all depths was greater in 1994 compared to 1993. This greater Olson-P showed a redistribution of P due to soil movement and deposition from the row to the interrow area after ridging in July, 1993. In both years, Olson-P was stratified, decreasing steeply with depth in RT plots.

Except for a slight increase with soil depth in manured plots, distribution of Olson-P concentration with depth in non-manured PL plots were similar to the manured PL plots during both 1993 and 1994. In the PL plots, Olson-P concentration at 0-15 cm depth decreased 3.1 mg kg^{-1} soil from 1993 to 1994. The decrease of Olson-P with time in PL system was also shown in the laboratory experiment although the rate of decrease of Olson-P concentration was faster in the laboratory than in the field. The exponential decrease in Olson-P concentration with time in the laboratory failed to reflect the RT system in field conditions. In the RT plots Olson-P increased significantly 9.2 mg kg^{-1} soil from 1993 to 1994. Shallow mixing of manure and residue with soil in the RT system resulted in less volume of soil for precipitation of P. On the contrary in the PL plots, incorporation of manure or residue to greater depth resulted in greater soil volume for P interactions and thus greater precipitation of P.

Tillage influence on grain yield was greatly dependent on weather conditions, especially precipitation. For example, in 1993-a wet and cold year, PL plots resulted in greater number of ears thus grain yield compared to the RT treatment. In the wet year, greater wetness induced lower soil temperature (especially in the presence of surface residue as in RT plots) thus slowed corn growth and thus productive ears. Tillage had no significant effect on grain moisture, stover yield, or stover moisture. Also, tillage effects on grain-P uptake were not significant in spite of the fact grain-TP concentration was significantly greater due to greater soil Olson-P in the RT plots. Stover TP uptake or TP concentration was not influenced by tillage. In 1993, manure had no significant influence on grain or stover yield. However, greater TP concentration in grain and stover due to greater soil Olson-P in manured plots resulted in greater P-uptake in grain and stover, respectively. There was no significant tillage by manure interaction on yield or P uptake.

In 1994, when rainfall was well distributed in the growing season, tillage system had no significant effect on grain yield, grain moisture, stover yield, number of corn ears or corn population. There was also no significant influence of tillage on grain-P concentration or grain P-uptake. However, stover-P concentration and stover P-uptake was higher in the RT system. Manure application resulted in significantly greater grain yield, grain-TP concentration and thus TP uptake in grain partly due to greater soil P in manured plots. Interaction of tillage by manure suggested that manure application significantly increased grain yield in RT plots. The tillage by manure interaction in stover yield was opposite to that of grain yield. Manure application had no significant influence on stover-P uptake since manure had no effects on stover yield and stover TP concentration.

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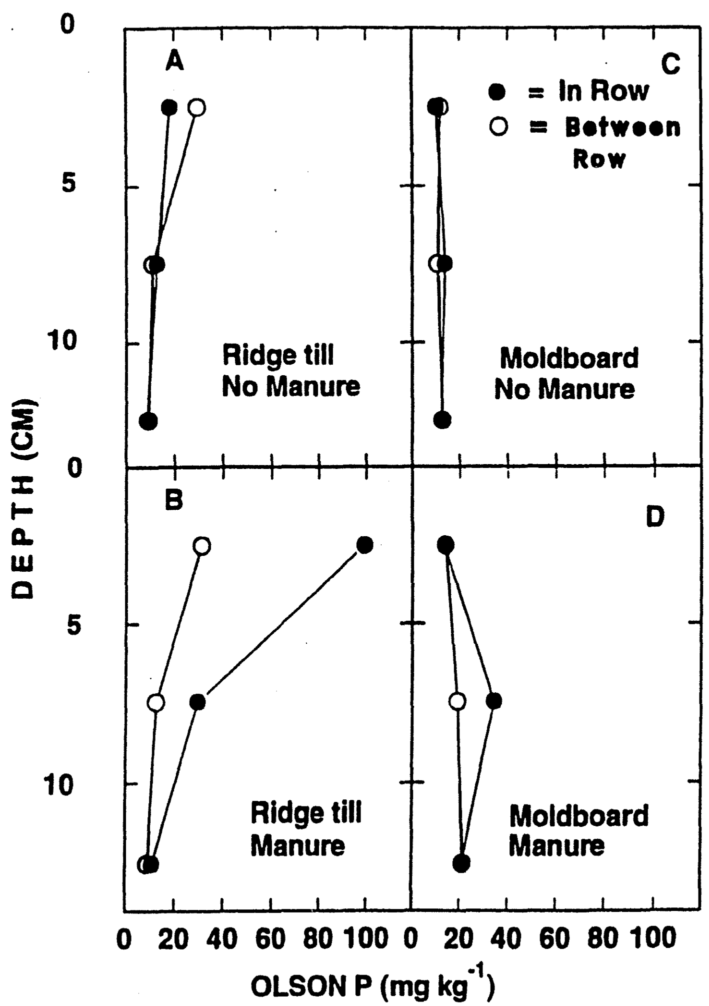

Fig. 2-1. Tillage and manure interactions on Olson-P concentration on 29 April 1993 in row and interrow areas at 3 depths for ridge tillage and moldboard plow treatment with and without manure.

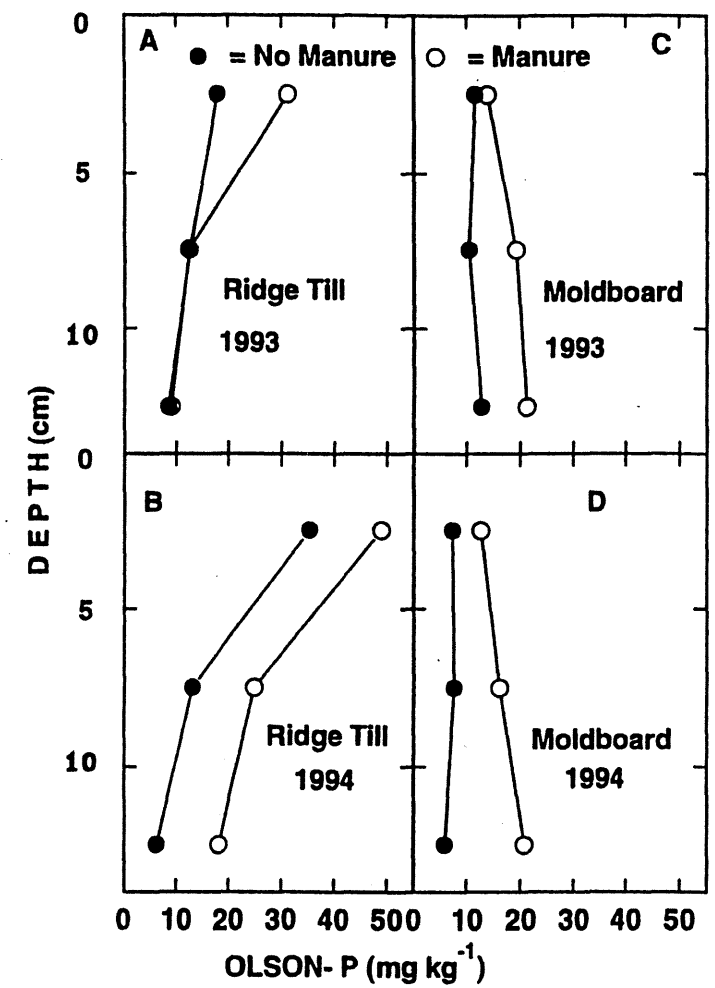

Fig. 2-2. A comparison of Olson-P concentration after planting at 3 soil depths between ridge tillage and moldboard plow systems with and without manure in 1993 and 1994.

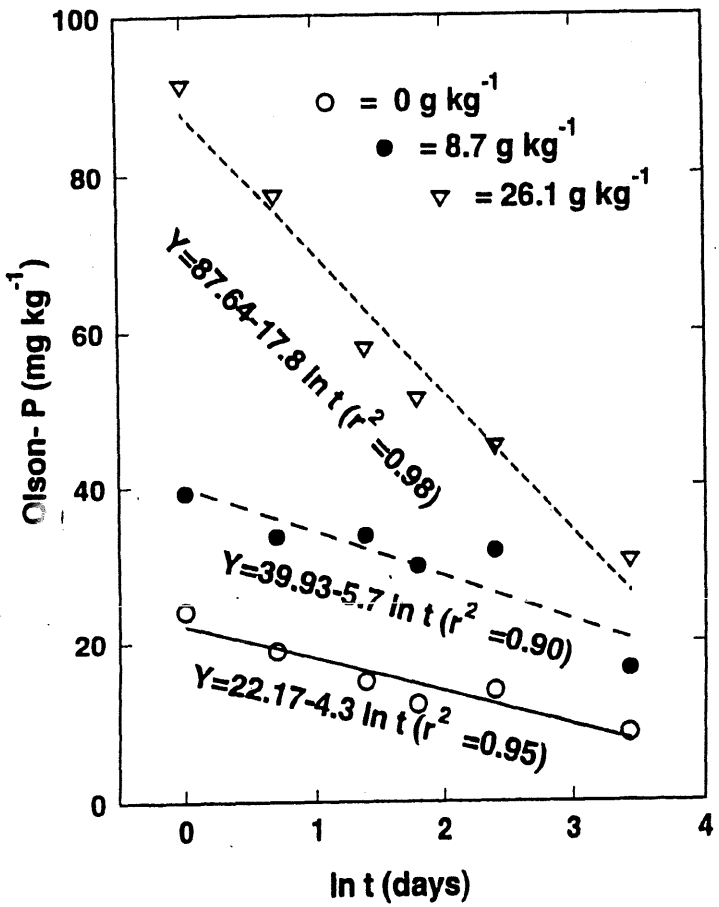

Fig. 2-3. Sodium bicarbonate extractable-P (Olson-P) vs. time during incubation of Barnes loam mixed with various rates of manure.

Table 2-1. The effects of tillage and manure application on soil Olson-P test at 0-15 cm depth in interrow area one (1993) and two years (1994) after manure application on Barnes loam at the West Central. Exp. Stn. Morris, MN.

Year	Tillage	No Manure $mg\ kg^{-1}$	Manure $mg\ kg^{-1}$	Avg. $mg\ kg^{-1}$
1993	RT	13.1	17.6	15.4
	PL	11.6	18.1	14.9
1994	RT	18.3	30.8	24.6
	PL	7.0	16.5	11.8
P>F value				
Year (Y)	0.046			
Tillage (T)	0.017			
Manure (M)	0.003			
Y by T	0.022			
Y by M	0.116			
T by M	0.950			
Y by T by M	0.552			

Table 2-2. The effects of tillage and manure on grain yield, grain moisture, stover yield, stover moisture, number of ears, and corn population in the 1993 crop year at the West Central Exp. Stn., Morris. MN.

Treatment	Grain Yield	Grain Moisture	Stover Yield	Stover Moisture	Ears	Plants
	Mg ha-1	% wt	Mg ha^{-1}	% wt	-- 1000 ha^{-1} ---	
Ridge Till						
No Manure	6.11	27.8	4.92	48.1	70.1	74.9
Manure	6.26	26.3	5.14	51.3	63.8	63.2
Average	6.19	27.0	5.03	49.7	66.9	69.
Moldboard						
No Manure	7.12	25.9	5.47	47.5	73.7	73.9
Manure	7.72	26.0	5.64	53.0	72.7	75.4
Average	7.42	26.0	5.56	50.2	73.2	74.6
Average						
No Manure	6.61	26.8	5.19	47.8	71.9	74.4
Manure	6.99	26.2	5.38	52.2	68.3	69.3
P>F Value						
Tillage (T)	0.060	0.258	0.237	0.549	0.095	0.271
Manure (M)	0.277	0.442	0.655	0.018	0.281	0.432
T by M	0.496	0.392	0.959	0.356	0.413	0.385

Table 2-3. The effects of tillage and manure on total P (TP) uptake and TP concentration in corn grain and stover in the 1993 crop year at the West Central Exp. Stn., Morris. MN.

Treatment	Grain-P Uptake	Grain TP-Conc.	Stover-P Uptake	Stover TP-Conc.
	kg ha^{-1}	g kg^{-1}	kg ha^{-1}	g kg^{-1}
Ridge till				
No Manure	20.1	3.3	2.9	0.57
Manure	22.0	3.5	4.4	0.85
Average	21.0	3.4	3.6	0.72
Moldboard				
No Manure	19.5	2.7	3.2	0.58
Manure	27.0	3.5	4.4	0.76
Average	23.2	3.1	3.8	0.67
Average				
No Manure	19.8	3.0	3.0	0.58
Manure	24.5	3.5	4.4	0.81
P > F Values				
Tillage (T)	0.294	0.265	0.791	0.638
Manure (M)	0.082	0.055	0.067	0.020
T by M	0.241	0.214	0.755	0.443

Table 2-4. The effects of tillage and manure on grain yield, grain moisture, stover yield, earleaf TP concentration, number of ears and corn population in the 1994 crop year at the West Central Exp. Stn., Morris, MN.

Treatment	Grain Yield	Grain Moisture	Stover yield	Earleaf TP-Conc.	Ear	Plant
	Mg ha-1	% wt	Mg ha^{-1}	g kg^{-1}	--- 1000 ha^{-1} ---	
Ridge Till						
No Manure	9.2	33.2	7.0	0.88	68.0	67.2
Manure	10.2	32.0	6.3	1.00	72.3	70.9
Average	9.7	32.6	6.7	0.94	70.2	69.0
Moldboard						
No Manure	9.5	26.9	6.5	0.99	74.6	72.3
Manure	9.3	24.5	7.0	1.10	70.6	70.6
Average	9.4	25.7	6.7	1.04	72.6	71.5
Average						
No Manure	9.3	30.1	6.7	0.93	71.3	69.8
Manure	9.8	28.2	6.6	1.05	71.5	70.8
P>F Value						
Tillage (T)	0.217	0.308	0.481	0.610	0.270	0.432
Manure (M)	0.065	0.158	0.605	0.356	0.955	0.802
T by M	0.016	0.600	0.019	0.937	0.163	0.508

Table 2-5. The effects of tillage and manure on total P (TP) uptake and concentration in grain and stover in the 1994 crop year at the West Central Exp. Stn., Morris. MN.

Treatment	Grain-P Uptake	Grain TP-Conc.	Stover TP Uptake	Stover TP-Conc.
	kg ha^{-1}	mg ha^{-1}	kg ha^{-1}	mg kg^{-1}
Ridge till				
No Manure	18.6	2.02	2.98	0.42
Manure	24.7	2.42	2.28	0.37
Average	21.7	2.22	2.63	0.39
Moldboard				
No Manure	19.0	1.98	2.02	0.31
Manure	22.3	2.39	2.38	0.34
Average	20.6	2.19	2.17	0.32
Average				
No Manure	18.8	2.00	2.50	0.36
Manure	23.5	2.44	2.30	0.35
P > F Values				
Tillage (T)	0.395	0.737	0.040	0.0452
Manure (M)	0.018	0.017	0.816	0.9505
T by M	0.307	0.939	0.565	0.7415

Validation of GLEAMS Model to Predict, Runoff, Sediment and P transport

INTRODUCTION

Livestock operations are an important part of the economy in West Central Minnesota. Environmentally sound manure utilization practices from these farming enterprises is imperative. Some soils are steeply sloping, having moderate permeability, and can subsequently pose a hazard to surface water contamination with N and P in water runoff.

The experimental part of this study quantified the effects of tillage and manure on sediment and P transport in surface runoff. Since it is expensive andtime consuming to gather such a data base for a whole series of treatments, computer models that integrate soil, climate, and management information to predict surface runoff and associated nutrients offer an opportunity to generatethis information inexpensively. Though these models are based on physical principles of water and nutrient transport, they still use site specific information and thus require field testing and validation before they can be extensively used for developing guidelines on best management practices. The objective of this study was to test the GLEAMS (Ground Water Loading Effects of Agricultural Management Systems) model against the measured data from our field experiment at Morris, MN. The GLEAMS model simulated surface runoff and the associated sediment and total P, particulate P (PP) and dissolved molybdate reactive P (DMRP) from the erosion plots in 1993 and 1994.

PROCEDURE

Briefly, the field study was undertaken from 1992 through 1994 at the West Central Experiment Station Morris, MN. The soil at the experimental site is a Barnes loam (fine-loamy mixed Udic Haploboroll) on a 12 % slope with a south-eastern aspect. The soil had been previously cropped with alfalfa. The initial (1992) soil test for pH water (1:1), Olson-P, Bray-P and ammonium acetate extractable K were 8.0, 17 mg kg-1, 23 mg kg-1, and 155 mg kg-1, respectively.

Erosion plots, each sized 22 m by 3 m (to accommodate four rows of corn) were marked and isolated using corrugated steel plates. At the end of each plot the runoff was directed to a collecting system. Each year, corn was planted up and down the slope at recommended seeding rate in each plot.

Tillage treatments were ridge till (RT) and moldboard plowing (PL). Tillage was up and down the slope. Each tillage block was split into with and without manure treatment. The manure treatment is defined as a one time application of solid beef manure at the rate of 56 Mg ha-1 in 1992. The application provided approximately 161 kg total-P ha-1 containing 64 kg ha-1 of inorganic P. Treatments considered for the GLEAMS' were: Ridge till system with manure (RTM), and Moldboard plow system with manure (PLM). Detailed treatments and field operations are described in Ginting (1995).

Climatic inputs to the models are daily precipitation, daily mean temperature, monthly maximum and minimum temperature, monthly wind speed and monthly solar radiation. Daily precipitation and daily air temperature is given in Figs. 3-1 and 3-2. The monthly temperature, wind and solar radiation is given in Table 3-1.

RESULTS AND DISCUSSION

RTM Treatment

Figures 3-3 and 3-4 show comparison between the measured and predicted runoff volume and associated sediment, TP, PP, and DMRP in 1993. In general, the model prediction were higher than the measured values. The overestimation of runoff was mainly during the snowmelt period (Fig. 3-3). This is partially because the model does not consider snow loss from the plots because of snow drift. In otherwords, the model assumes that all snowfall is present at the surface of the erosion plots. Since, the corn residue were laying flat and not standing uprightin winter 1993, it resulted in some loss of snow due to snowdrift. The overestimation of snow melt runoff in turn resulted in an overestimation of sediment loss in the snow melt. In addition, the model also overestimated runoffand sediment loss (Fig.3-3) from the largest rainfall (2-hour 10-cm rain) event that occurred on 4 July 1993 (Julian day 185). This may be partially that the model uses 24-hour rainfall for calculating runoff whereas in reality the largest rainfall occurred in 2 hours which will lead to significantly underprediction of runoff and sediment yield by the model. As the loss of DMRP heavily depends upon runoff and the loss of PP depends upon amount of sediment, the overestimation of runoff and sediment also resulted in the overestimation of DMRP, PP, and consequently TP during 1993.

In 1994 the model predictions of the runoff from both the snow melt and the rainfall were close to the measured values (Fig. 3-5). Since in 1994, the residue were standing in the RTM plots after the fall harvest, they were able to keep the snow in place and thus the input for the snowfall precipitation was well represented. Although the model predictions of runoff are close to the measuredvalues, the model overestimated the sediment loss during the snow melt period (Fig. 3-5). This is because the model was not able to represent the influence of residue in the interrow area. Residue cover in the interrow area of RTM treatment during winter is as high as 80 percent which helps increase infiltration and thus reduce surface runoff. Also, the application of manure improved soil structure and thus helped increase infiltration and reduce soil detachment and transport.

The model predictions of the sediment loss due to rainfall runoff in 1994 were close to the measured values because of the absence of any high intensity storms. However due to an overestimation of sediment loss in snow melt, the predictions of TP and PP in snow melt were also higher than the measured values.On the other hand, a good prediction of sediment loss during rainfall runoff ledto much closer prediction of TP and PP loss to the measured values during rainfall runoff.

Annual prediction of both TP and PP in 1994 were higher than the measured values because of an overestimation of sediment loss during snow melt. Since themodel predictions of runoff both from snow and rainfall were good, the DMRP predictions by the model for 1994 were close to the measured values (Fig. 3-6)

PLM Treatment

For the 1993 simulations, the model overestimated runoff values (Fig. 3-7). This overestimation was solely during the snow melt period and was mainly a result ofthe deficiency that the model can not account for a loss of snow due to snow drift. The absence of residues in the moldboard treatment resulted in a lack of snow trapping and therefore higher input value of snowfall compared what to probably happened in the field. The additional reasons may be that the presence of surface roughness in the moldboard system that reduces snow melt runoff is not well represented in the model. The runoff from the rainfall was underestimated, especially from the largest rain that occurred on 4 July 1993 (Julian day 185). This again indicates that daily representation of rainfall in the model is not appropriate for a high intensity rainfall. The overestimation of snow melt runoff resulted in an overestimation of annual runoff.

For the 1993 simulation, estimated sediment loss in snow melt runoff was close to the measured value. The model estimate of sediment loss in the rainfall runoff except from the largest rainfall were also close to the measured values, however, the model prediction of sediment loss for the high rainfall event werelower than the measured values (Fig. 3-7). Also, the estimates of PP and TP loss were higher than the measured values even though the model underestimated the sediment loss for the largest rainfall event. This is because the model predictsan overestimation of the concentration of PP in the runoff. Overestimation of snow melt runoff resulted in an overestimation of DMRP loss. Also, the model underestimated the runoff for the largest rainfall event (Julian day 185), but overestimated the DMRP in rainfall runoff because of an overestimation of DMRP
concentration for this particular event (Fig. 3-8).

For the 1994 simulation, the model overestimated the snow melt runoff. This wasagain due to a loss of snow by snowdrift. Since the rainfall was not of high intensity, the model gave a good prediction of the rainfall runoff. Predicted annual runoff was close to the measured values (Fig. 3-9). The overestimation of snow melt runoff resulted in an overestimation of sediment loss in the snow melthowever, the model estimates of sediment loss due to rainfall were close to themeasured values. On an annual basis, overestimation of the snow melt runoff resulted in an overestimation of the annual sediment loss (Fig. 3-9). This overestimation of sediment also resulted in an overestimation of PP and TP loss in the snow melt and annual runoff (Fig. 3-10). The model prediction of DMRP in both snow melt and rainfall runoff were close to the measured values (Fig. 3-10).

SUMMARY AND CONCLUSION

Since the standing residue trapped and kept the snow in place in the ridge tillage system, the model predictions of snow melt runoff from ridge till systemwere good. The model predictions of the snow melt runoff in the absence of residue (moldboard) were not close to the measured values. It is hypothesized that since the model did not consider snowdrift, there may have been some loss of snow due to snow drift thus resulting in an overestimation of snow melt runoff in bare soils. In general, the model predictions of rainfall runoff was good for both the moldboard and ridge tillage systems when the rainfall intensity was not high. For the high intensity rainfall, the model overestimatedand underestimated the surface runoff for the ridge tillage and the moldboard plow systems, respectively.

The model overestimated sediment loss in snow melt runoff for both the ridge tillage and the moldboard systems. In general, the model predictions of the sediment loss from rainfall were close to the measured values for both the ridgetill and moldboard plow systems. Only for a high intensity rainfall, the model predictions of sediment loss were higher and lower for the ridge till and the moldboard system, respectively.

Since the PP and TP greatly depends upon the sediment loss, the overprediction of sediment loss in the snow melt runoff resulted in an overestimation of TP andPP losses. Similarly, the model prediction of DMRP were good as long as the prediction of runoff were also reasonable. Field representation of snow melt is not very well represented in the model especially where snowdrifts may occur extensively. The model needs to be improved in sediment loss for both snow melt and high intensity rainfall conditions.

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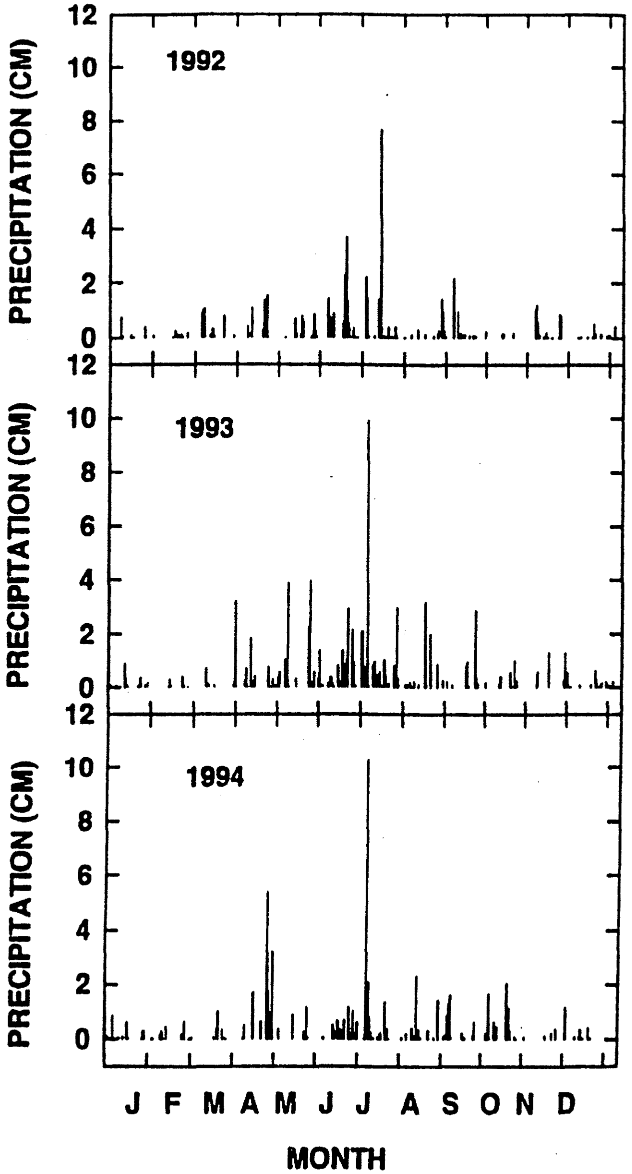

Fig. 3-1. Daily precipitation recorded at the West Central Exp. Stn., Morris, MN 1 km from the study site (1992-1994).

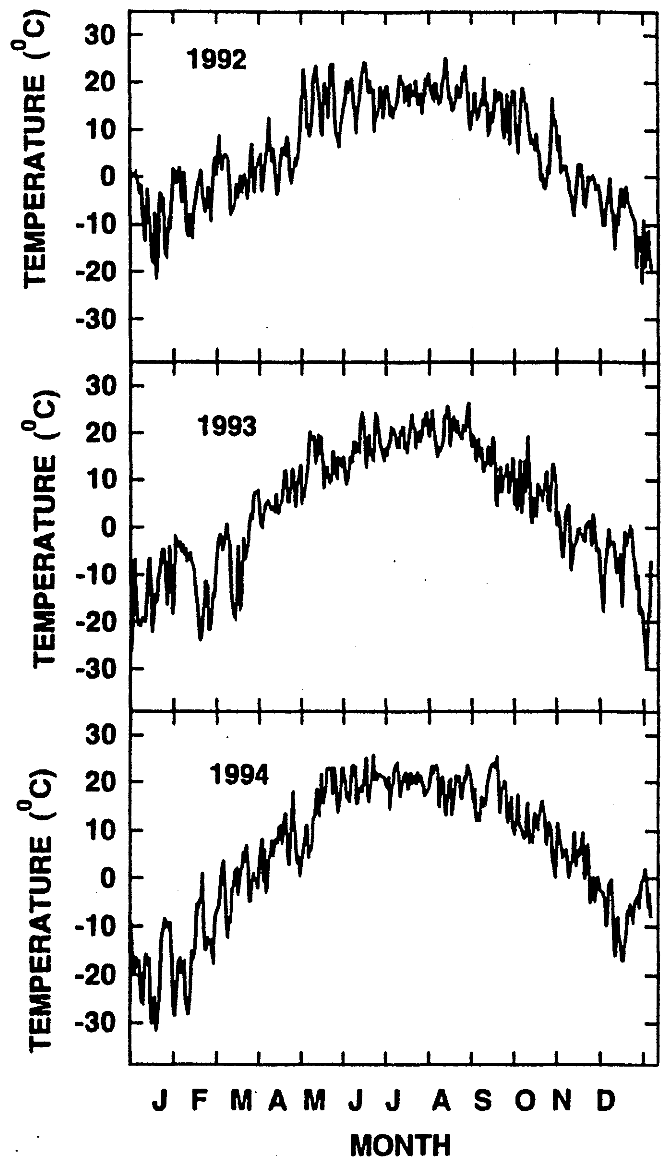

Fig. 3-2. Daily mean temperature recorded at the West Central Exp. Stn., Morris, MN 1 km from the study site (1992-1994).

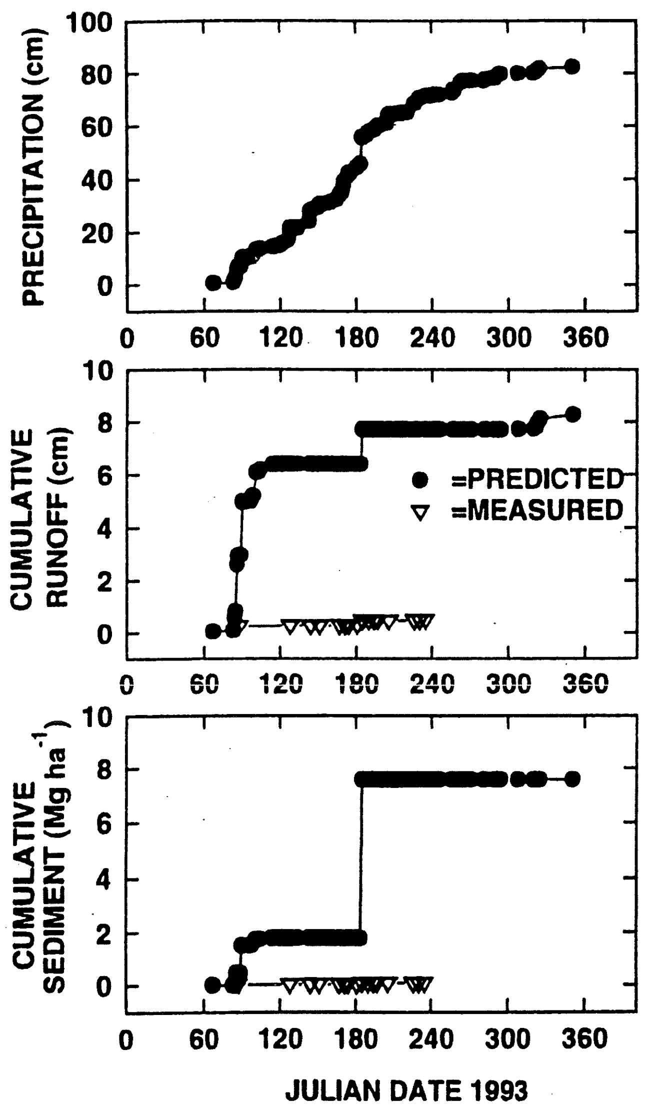

Fig. 3-3. Simulated and observed runoff volume and associated sediment loss from ridge tilled manure applied plots in Morris, MN (1993).

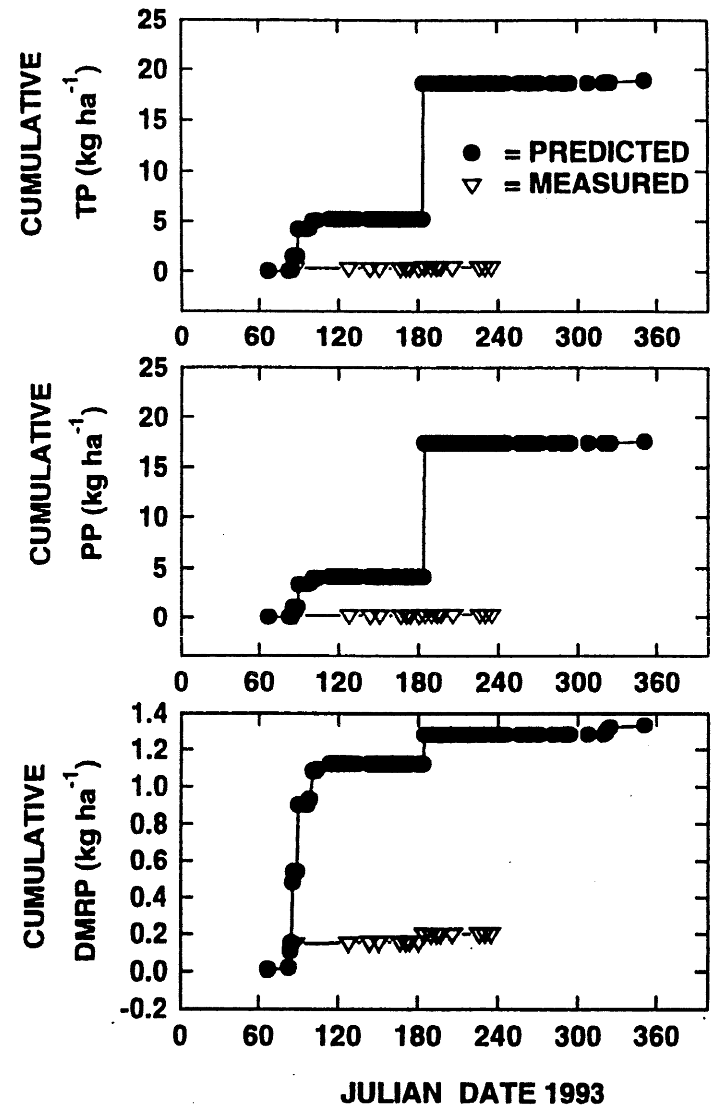

Fig. 3-4. Simulated and observed total P (TP), particulate P (PP), and dissolved molybdate reactive P (DMRP) from ridge tilled manure applied plots in Morris, MN (1993).

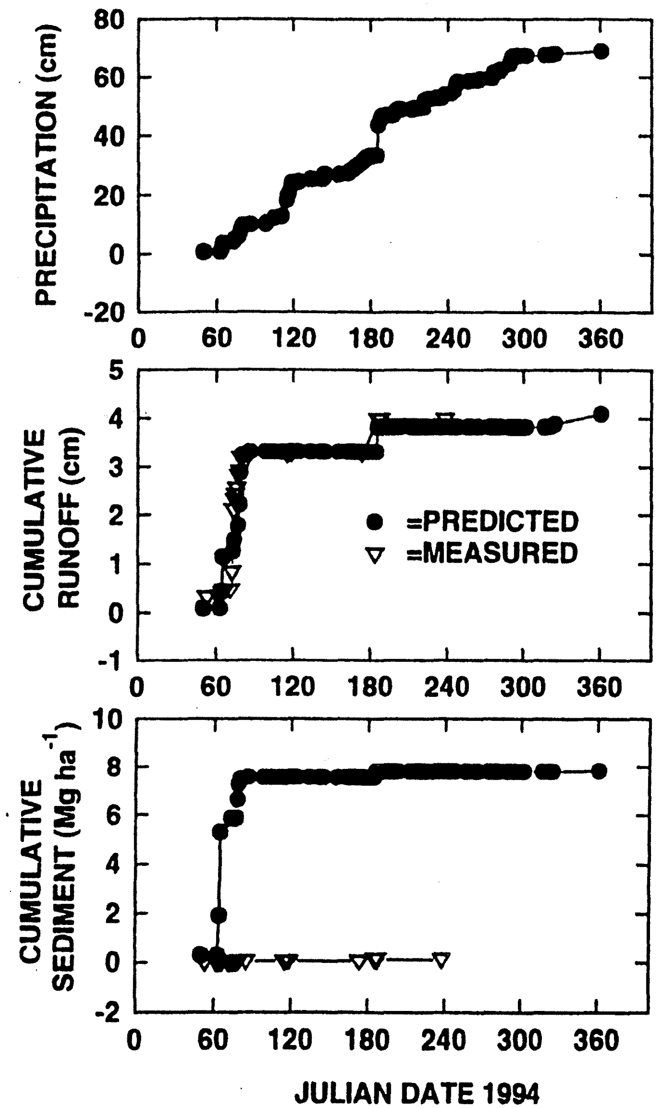

Fig. 3-5. Simulated and observed runoff volume and associated sediment loss from ridge tilled manure applied plots in Morris, MN (1994).

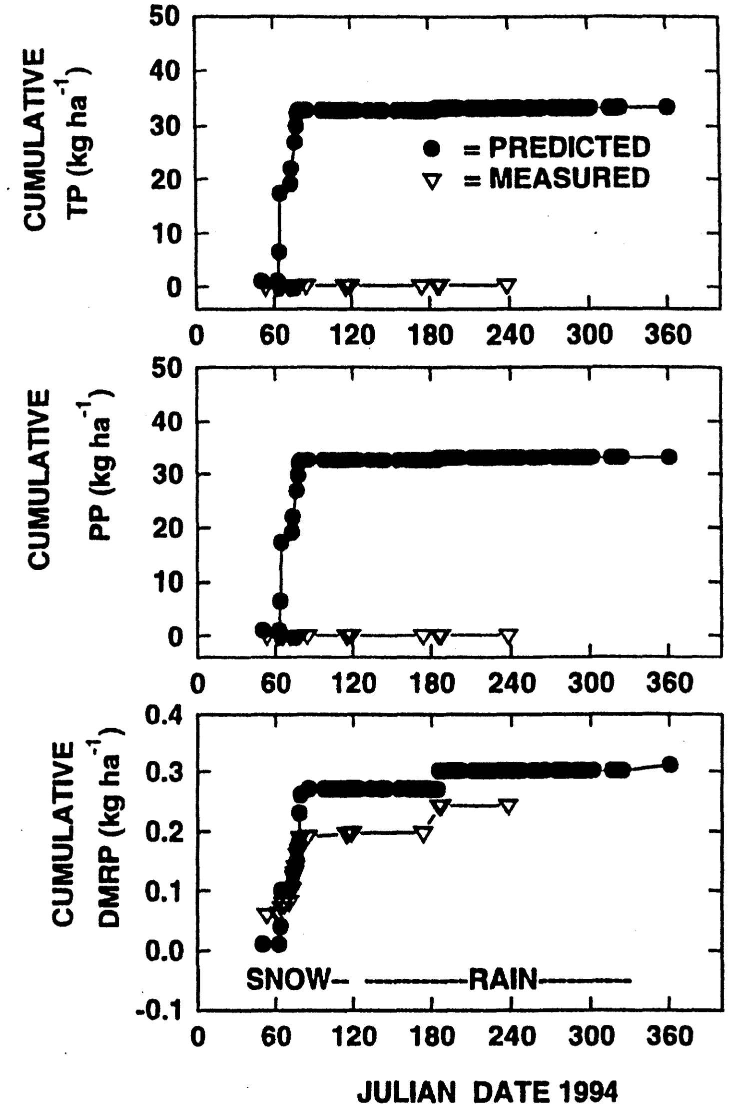

Fig. 3-6. Simulated and observed total P (TP), particulate P (PP), and dissolved molybdate reactive P (DMRP) from ridge tilled manure applied plots in Morris, MN (1994).

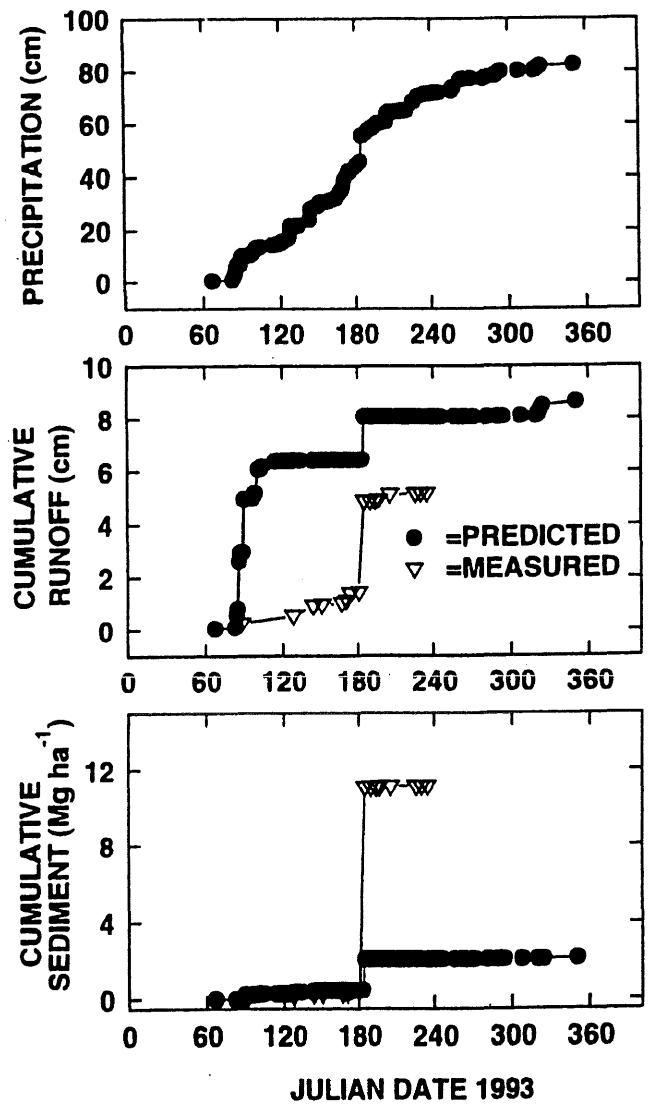

Fig. 3-7. Simulated and observed runoff volume and associated sediment loss from moldboard plowed manure applied plots in Morris, MN (1993).

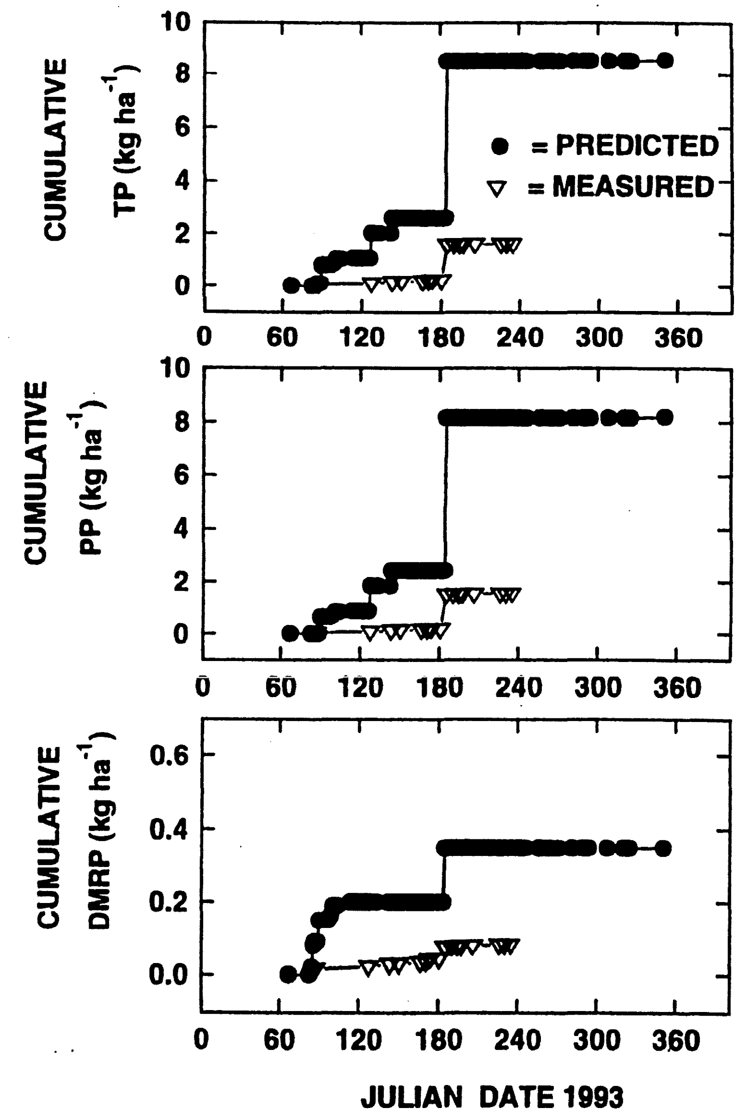

Fig. 3-8. Simulated and observed total P (TP), particulate P (PP), and dissolved molybdate reactive P (DMRP) from moldboard plowed manure applied plots in Morris, MN (1993).

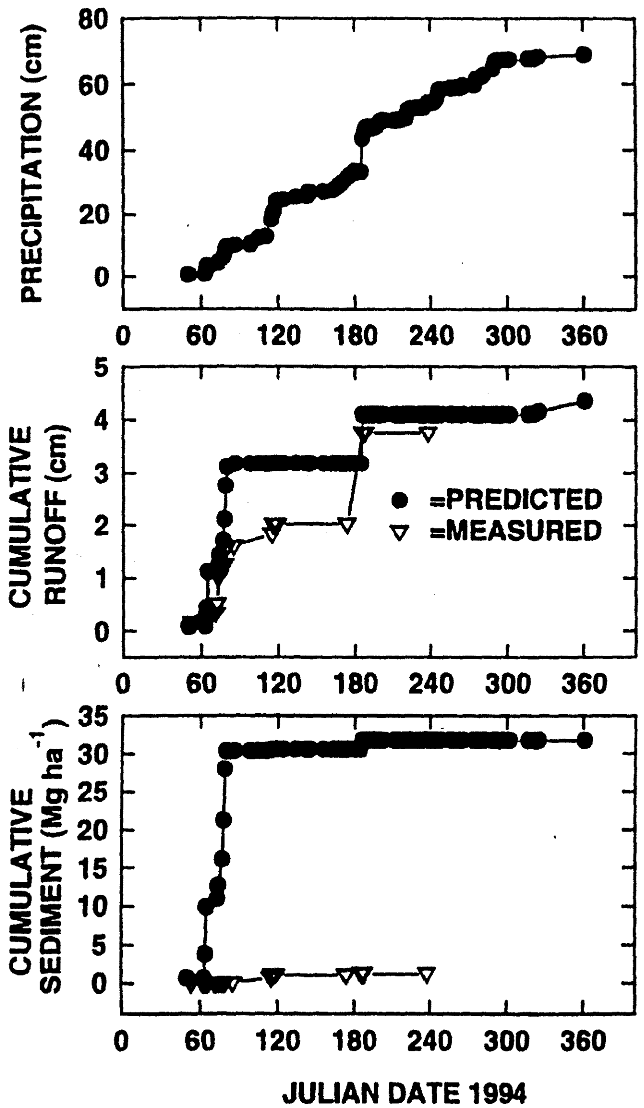

Fig. 3-9. Simulated and observed runoff volume and associated sediment loss from moldboard plowed manure applied plots in Morris, MN (1994).

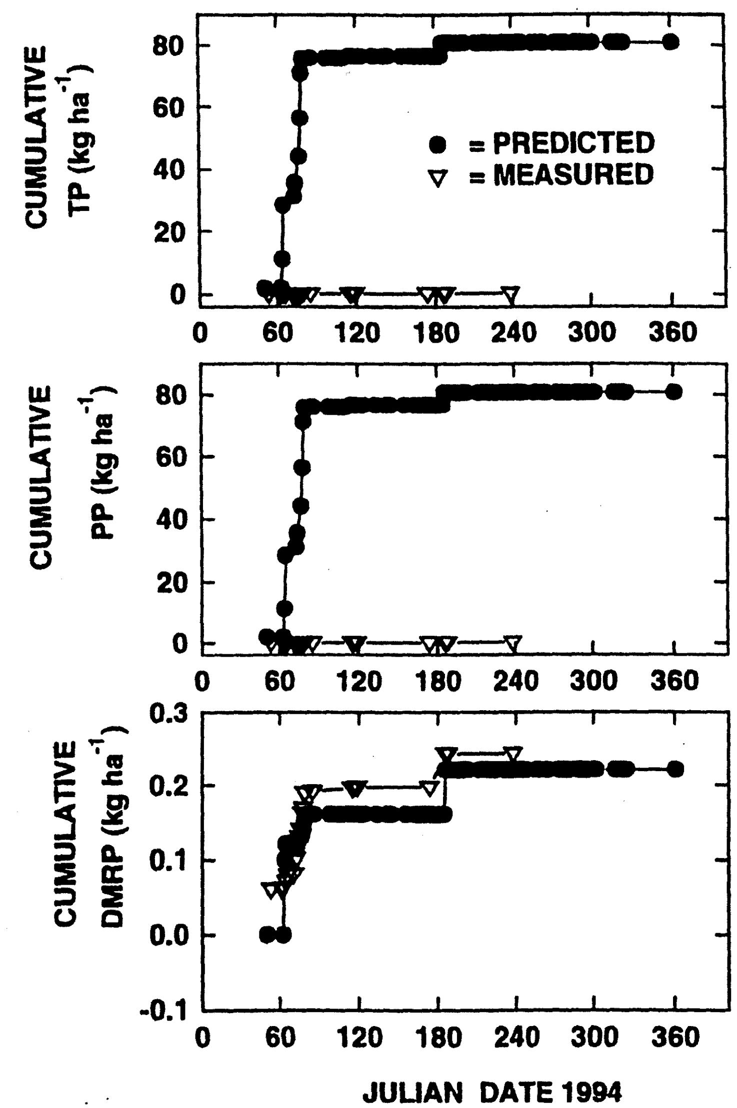

Fig. 3-10. Simulated and observed total P (TP), particulate P (PP) and dissolved molybdate reactive P (DMRP) from moldboard plowed manure applied plots in Morris, MN (1994).

Table 1. Monthly mean maximum (Max†) and minimum (Min†) temperature, solar radiation (Solar‡), and wind speed (Wind¶) from 1992 through 1994 at The West Central Exp. Stn., Morris, MN.

					MONTH							
	J	F	M	A	M	J	J	A	S	O	N	D
1992												
Max	-2.01	3.78	5.41	11.48	22.98	23.40	27.66	26.75	24.47	14.22	0.47	-5.44
Min	-11.82	-6.84	-3.96	0.28	7.61	11.58	12.38	11.68	7.14	1.31	-4.7	-14.83
Solar	36.7	48.28	83.96	92.04	148.1	138.8	130.2	123.6	103.7	69.7	31.7	30.7
Wind§	758.0	754.8	825.6	870.6	798.2	749.9	651.8	627.6	709.7	761.2	820.7	743.5
1993												
Max	-6.77	-5.44	3.35	12.14	19.28	22.14	24.66	25.23	17.8	12.45	0.27	-4.60
Min	-18.62	-15.4	-8.49	0.61	7.81	12.6	15.54	14.51	4.79	0.20	-7.22	-15.06
Solar	46.23	71.23	95.85	0.18	130.9	129.1	134.6	124.1	98.87	0.08	37.68	44.43
Wind	154.72	104.30	159.6	108.4	163.5	150.6	124.1	103.9	126.4	67.15	155.0	188.6
1994												
Max	14.48	-8.8	3.48	14.51	22.7	25.84	25.2	24.43	22.9	15.06	6.42	-2.64
Min	-23.99	-19.58	-5.23	1.02	9.08	13.93	14.46	12.87	10.68	5.04	-3.53	-11.52
Solar	178.05	273.13	371.4	449.8	553.3	484.1	499.1	432.5	322.3	200.5	151.84	139.7
Wind	374.21	358.1	352.1	379.6	376.5	306.2	241.7	224.0	258.8	378.4	05.6	325.8

† = temperature in °C
‡ = solar radiation in Langley
¶ = wind speed in km day^{-1}
§ = long term average of wind speed km day^{-1}

Appendices

APPENDIX A1.

Initial soil tests

Table 1. Initial soil tests of Barnes loam at the West Central Exp. Stn., Morris, MN.

Characteristics	Units	Value
Olson-P	mg kg^{-1}	17
Bray-P	mg kg^{-1}	23
NH_4OAC extractable K	mg kg^{-1}	155
pH 1:1	-	8.0

Beef Manure Analysis and application rate.

Manure application rate was estimated from a calibration using nine plastic trays. Each tray measured 66 cm by 45 cm. With the trays on the ground, the manure was spread with a box type manure spreader. The manure from the trays was collected and weighed in the field. A composite manure sample was taken for solid, N, P, and K analysis (Table 2). Based on the calibration data, it is estimated that manure application rate was 56 Mg ha^{-1}.

Mineral N (NH_4-N and NO_3-N) was determined using the procedure described in Appendix 3. Total N was determined with Kjeldahl method. Organic N was determined from the difference of total N and mineral N. Plant available N from the manure in the year of application was calculated assuming that all mineral N and 25 percent of the organic N was available in the year of application. Manure solids, total phosphorus (TP), and total potassium (K) were determined using the procedure described in Appendix A2. The analysis is reported on both wet and dry weight basis (Table 2).

Table 2. Beef manure analysis on both wet or dry weight basis.

Characteristic		Content (g kg^{-1}) wet	dry
Nitrogen	Mineral	2.20	7.61
	NH4	2.15	7.43
	NO3	0.05	0.17
	Organic	6.40	22.1
	Available	3.80	13.1
	Total	8.60	29.8
Phosphorus	Total	2.89	10.0
	DMRP	1.14	3.94
Potassium	Total	6.7	23.2
Solids	Total	290	1000
	fixed	50	160
	volatile	240	840

Field Operations and the Pesticide Used

Field activities during 1992, 1993 and 1994 are listed in Tables 3, 4 and 5. In 1992 Lorsban 15G at 11.2 kg ha^{-1} was applied at planting (7 May 1992). On 8 May 1992 a tank mix of glyphosate (Ranger® at 1.1 kg ha^{-1}), 2,4-D ester (0.6 kg ha^{-1}), dicamba (Banvel® at 0.3 kg ha^{-1}), alachlor (Lasso® EC at 4.5 kg ha^{-1}), cyanazine (Bladex® 90 DF at 2.5 kg ha^{-1}) was applied as pre-emergent herbicide. To kill regrown of alfalfa and grasses, glyphosate (at 1.1 kg ha^{-1}) was reapplied in the RT plots on both 22 May and 19 June, 1992.

In 1993 prior to seeding, glyphosate (Roundup® at 2.3 L ha^{-1}) was sprayed to the RT plots for volunteer alfalfa control on 21 April 1993. At seeding on 29 April 1993 Counter 15 G at 11.1 kg ha^{-1} was applied over the furrow for insect control on 29 April 1993. Alachlor at 4.4 kg ha^{-1} and cyanazine at 2.5 kg ha^{-1} were mixed in a tank and applied as a pre-emergent herbicide. Subsequently, Roundup at 2.3 L ha^{-1} was reapplied on 30 April 1993 to control volunteer alfalfa. Atrazine at 0.8 kg ha^{-1} was used for post emergence quack grass control on 20 May 1993.

In 1994, prior to seeding, glyphosate at 3.5 L ha^{-1} was sprayed on the RT plots for quackgrass control on 22 April, 1994. At seeding, Force 15 G at 11 kg ha^{-1} was applied through the planter for insect control on 5 May 1994. Alachlor at 3.4 kg ha^{-1}, cyanazine at 2.5 kg ha^{-1} and Roundup at 2.3 L ha^{-1} were applied as pre-emergent herbicides. A tank mix of Atrazine at 2.2 kg ha^{-1}, bromoxynil (Buctril® 1.2 L ha^{-1}), and vegetable oil concentrate was applied for post-emergent weed control on 1 June 1994.

Table 3. The 1992 Field Season Activities

Event	Date
Soil sample for initial analysis of pH, P, K, OC	14 Apr
Application of beef manure to designated plots followed by plowing and disking of moldboard plowed plots	6 May
Corn planted, Row application of Lorsban 15G	7 May
Applied herbicides as tank mix of Ranger, 2,4-D ester,Banvel, Lasso 4 EC, Bladex DF	8 May
Installed plastic border	9 May
Herbicide, Ranger application	22 May
Replant corn due to gopher damage	29 May
Sample runoff	4 Jun
Sample runoff	8 Jun
Replant corn due to gopher damage	15 Jun
Sample runoff	17 Jun
Applied Ranger	19 Jun
Ridge tilled plots	21 Jul
Chopped corn stalk in moldboard plots, rototilled area between plots	23 Oct
Ridging the ridge till plots	26 Oct
Remove steel borders from moldboard plowed plots; moldboard plowed	27 Oct
Rototilled strips between moldboard plots; Spread baled corn stalks and install steel border for ridge-tilled plots	30 Oct
Installed steel borders on moldboard plow plots	31 Oct

Table 4. The 1993 Field Season Activities

Event	Date
Sample snowmelt Runoff	29 Mar
Roundup application for volunteer alfalfa control	21 Apr
Steel borders removed; Cultivated PL plots	28 Apr
Measured surface residue before and after planting; Soil sampling for soil-P test; Corn planting; Application of Counter 15 G at seeding; Replaced steel border	29 Apr
Lasso and Bladex for pre-emergence; Roundup for volunteer alfalfa	30 Apr
Rain runoff sample; Measured soil residue cover	10 May
Atrazine application for quackgrass control	20 may
Rain runoff sample	25 May
Rain runoff sample	1 Jun
Rain runoff sample	18 Jun
Rain runoff sample	21 Jun
Rain runoff sample	25 Jun
Rain runoff sample	1 Jul
Row cultivation in the RT plots	6 Jul
Rain runoff sample	7 Jul
Rain runoff sample	9 Jul
Rain runoff sample	14 Jul
Rain runoff sample;Broadcast application of 45 kg ha^{-1} N (NH_4NO_3) on non-manured plots	16 Jul
Rain runoff sample	26 Jul
Rain runoff sample	16 Aug
Rain runoff sample	19 Aug
Rain runoff sample	24 Aug
Grain and plant harvest	13 Oct
Removed steel border; fall plowing; soil sample before/after plowing; residue cover measurement; replace steel border	27 Oct
Placing leaf-bags for leaching study	28 Oct

Table 5. The 1994 Field Season Activities

Event	Date
Sample snowmelt runoff	22 Feb
Snow depth and density measurement	1 Mar
Air, soil temperature measurement	2 Mar
Air, soil temperature measurement; Snow runoff sample	3 Mar
Air, soil temperature measurement; Snow runoff sample	4 Mar
Snow runoff sample	6 Mar
Snow depth and density measurement; Snow runoff sample	7 Mar
Snow runoff sample	13 Mar
Snow runoff sample	14 Mar
Air, soil temperature measurement; Snow runoff sample	15 Mar
Snow runoff sample	16 Mar
Snow runoff sample	17 Mar
Snow runoff sample	18 Mar
Snow runoff sample	19 Mar
Snow runoff sample	20 Mar
Snow runoff sample	26 Mar
Snow runoff sample	26 Mar
Pressure transducer for water depth measurement	31 mar
Rain shelter construction	19 Apr
Round up for quackgrass control on ridge-till plots	22 Apr
Rain runoff sample	25 Apr
Rain runoff sample	26 Apr
Rain runoff sample	29 Mar
Soil sample	3 May
Steel border removal; Moldboard plowed plots were field cultivated; soil sampling; Border area rototilled; Corn planting; At seeding fertilizer (7-21-7) and Force 15G	5 May
Mix of Lasso, Bladex, Roundup for pre-emergence; replaced steel border	6 May
Mix of Atrazine, Buctril, Oil concentrate for post emergence	1 Jun
Broadcast followed by incorporation by of N (NH_4NO_3)	6 Jun

Table 5....Continued

Event	Date
Reside cover measurement	14 Jun
Rain runoff sample; Ridging the ridge till system	24 Jun
Residue cover measurement	25 Jun
Rain runoff sample	5 Jul
Rain runoff sample	7 Jul
Replace pressure transducer	11 Jul
Field day	14 Jul
Rain gage installation	28 Jul
Earleaf sample	29 Jul
Rain runoff sample	26 Aug
Harvest for grain and plant material;steel border removed	11 Oct
Steel border on ridge till system replaced; hydraulic conductivity measurement	19 Oct
Continued saturated hydraulic conductivity measurement	20 Oct
Continued Saturated Hydraulic Conductivity Measurement; Corn stalks chopped in the moldboard plowed plots	21 Oct
Moldboard plowing; replacing steel border	27 Oct
Continue replacing steel border	28 Oct
Cleaning piping and collection system	3 Nov

APPENDIX A2

Determination of solid component, Total Phosphorus and Total Potassium of Beef manure

Percent solids

1. Weigh about 25 g of field-moisture manure (WM) in a pre weighed pyrex beaker and dry at 105 °C for about two days. Run samples in triplicate.
2. Weigh the dried manure (DM) and determine the total solid portion in wet weight basis.

   Percent Total solid (TS)= DM/WM × 100
3. Return the manure to the oven and ash the manure at 405 °C. Weigh the ashed manure (AM); save the ashed manure for total phosphorus and total potassium determination. Calculate the portion of fixed solid in wet weight basis.

   Percent fixed solid (FS)=AM/WM ×100
4. Calculate percent of volatile solid:

   Volatile Solid (VS)= TS-FS
5. Report the mean value of percent total solid, fixed solid, and volatile solid in wet and dry weight basis.

Manure Total Phosphorus and Total Potassium

Extraction with 1N HCl:

1. Pour carefully 85 mL of concentrated HCl to a 500 mL deionized water in a 1000 mL volumetric flask. Cool down and bring to volume with deionized water to make 1N HCl.
2. Add 25 mL of 1N HCl to the ashed manure previously described in the manure solid determination. Shake with reciprocal shaker for 15 minutes. Let stand at least 1 hour to settle out the particulate matter. Transfer 2 mL of aliquot to a 100 mL volumetric flask. Bring to volume with 1N HCL. The diluted aliquot was then used for TP and TK determination.

Total phosphorus

Coloring reagent (HNO_3-Vanadomolybdate):

1. Dissolve 1.25 g of NH_4VO_3 in 300 mL of hot deionized water in a clean beaker. Cool and add 250 mL of concentrated HNO_3. Transfer to 1000 mL volumetric flask. Flush the beaker with 50 mL deionized water and pour to the flask.
2. Dissolve 25 g of ammonium molybdate $(NH_4)_6MO_7O_{24}.4H_2O$ to 400 mL deionized water and add to the vanadate solution. Bring to volume with deionized water.

Total P determination.

1. Transfer 1 mL aliquot of sample to colorimeter tube. Add 3 mL of HNO_3 vanadomolybdate reagent.
2. Add 10 mL of deionized water and vortex.
3. Allow to stand for at least 10 minutes (the color stable for 2 to 3 days)
4. Determine P at 430 nm.

Standard curve:

1. Make a stock solution (1000 mg L^{-1}). Dissolve 4.3935 g of dried (105 °C) KH_2PO_4 in a deionized water and dilute to 1000 mL. Store in a refrigerator.
2. Make standard concentration P solution. Dilute 0, 5, 10, 20, 30, and 40 mL of stock solution to 100 mL with 1N HCl. The resulting standard

concentration will be 0, 50, 100, 200, 300, and 400 mg L^{-1} P, respectively.

3. Transfer 1 mL of each standard P concentrations to colorimeter tubes. Add 3 mL of HNO_3-vanadomolybdate reagent.
4. Add 10 mL of deionized water and vortex.
5. Allow to stand for at least 10 minutes. Measure absorbance at 430 nm.

Calculation

From the standard curve, obtained the equation y=a + bX where Y=P (mg L^{-1}) and X=absorbance. From the equation determined phosphorus of manure:

Manure TP (mg kg^{-1})={a + b × (absorbance)} × 50 × 25/manure weight

Total K Determination

1. Transfer 5 mL aliquot of sample to a 50 mL volumetric flask and bring to volume with deionized water.
2. Read absorbance with the Atomic Adsorption Unit for K

Standard Curve.

1. Stock K solution (1000 mg L^{-1}). Standard solution should be prepared in a 0.1N HCl matrix prepared by dilution of 200 mL of 1N HCL to 2 L with deionized water.
2. Add 1.907 g of dried KCl (105 °C) to a 1000 mL volumetric flask and bring to volume with 0.1N HCL.
3. Take 0, 15, 30, 45 and 60 mL of stock solution and dilute to 1 L with 0.1N HCl. This will result in 0, 15, 30, 45, and 60 ppm K standard concentration.
4. Read absorbance with the Atomic Adsorption Unit for K

Calculation.

From the standard curve, obtained the equation y=a + bX where Y=P (mg L^{-1}) and X=absorbance. From the equation determine K of manure.

Manure K (mg kg^{-1})={a + b × (absorbance)} × 10 × 50 × 25/manure weight

APPENDIX A3

Nitrate, Ammonium, and Total Nitrogen Determination

Manure Sample Preparation

1. Weigh about 100 g manure and dilute it with about 130 mL deionized water. Record the weights. Run samples in triplicate.
2. Blend the samples for 5 minutes or until homogenous thick slurry is formed. Keep the sample frozen in storage.

Total Nitrogen

1. Weigh about 2 g of slurry in a boat shaped cigarette paper. Carefully deliver the manure to the bottom of the tube. Run a standard sample and blank every 10 samples.
2. Add 2 glass beads.
3. Add 3.5 mL of concentrated H_2SO_4
4. Add one Kjeldahl tablet (1.5 g K_2SO_4 + Selenium)
5. Arrange the tube in the a rack and place on the block digester. Place reflux glass funnel on the mouth of the tubes to reduce rapid loss acid vapor .
6. Heat at 150 °C for one hour and then increase to 350 °C for another hour until dark color of organic material vanishes.
7. Remove rack and cool the solution. Bring to 50 mL with deionized water followed by vortexing.
8. Read total NH_4-N on a semi-permeable membrane-electrical conductivity apparatus.

Standard Curve

1. Make 1M NH_4-N Stock solution. Dissolve 6.607 g ammonium sulfate $(NH_4)_2SO_4$ and bring to 100 mL in a volumetric flask. Agitate thoroughly.
2. Pipet 0, 2, 5, 10, 15, 20 and 30 mL of stock solution in 2 L volumetric flask.
3. Add deionized water to about 1.5 L. Transfer to each flask 30 mL of concentrated H_2SO_4 , dissolve 60 g K_2SO_4 and mix thoroughly. Cool down and bring to volume. This will make 0, 1, 2.5, 5, 7.5, 10 and 15 mM of NH_4-N standard concentrations.
4. Read total NH_4-N on a semi-permeable membrane-electrical conductivity apparatus which give the relationship of known NH_4-N concentration and peak numbers derived from chart recorder.

Calculation.

From the relationship, obtain the equation $Y=a + bX + cX^2 + dX^3$ where Y = NH4-N (mM) and X = chart numbers. From the equation, determine N for the manure samples:
Total-N (mg kg^{-1})= $(a + bX + cX^2 + dX^3) \times 14 \times 50$/manure weight where X is corrected against blank peak number from the chart.

Mineral Nitrogen (Nitrate and Ammonium)

1. Weigh between 1 to 2 g of manure slurry in a 50 mL Erlenmeyer flask.
2. Add 25 mL of 2N KCL. Shake for 30 minutes and filter with Whatman no. 2 filter paper. Run samples in duplicate. Run a standard sample, and a blank for every ten samples.
3. Take.5 mL aliquot and add 25 mL 2N KCL.
4. Read NH_4-N of aliquot flow through zinc reduction column. Similarly, read also NH_4-N of aliquot without reduction. Both readings use a semi-permeable membrane-electrical conductivity apparatus.

Standard curve:

1. Make a 2N KCl. Dissolve 149.12 g dried KCL in a 1 L volumetric flask. Bring to volume with deionized-distilled water.
2. Stock 0.1M NH_4-N solution. Dissolve 6.607 g ammonium sulfate $(NH_4)_2SO_4$ in a 1L volumetric flask and bring to volume with 2N KCL.
3. Dispense 0, 1, 2, 4, 5, 7.5, and 10 mL stock solution to 500 mL volumetric flask and bring to volume with 2N KCL. This will prepare standard solutions of 0, 0.2, 0.4, 1, 1.5 and 2 mM NH_4-N working standards.
4. Read total NH_4-N on a semi-permeable membrane-electrical conductivity apparatus which give the relationship of known concentration and peak numbers derived from chart recorder.

Calculation.

From the relationship, obtain the equation $Y=a + bX + cX^2 + dX^3$ where Y = NH4-N (mM) and X = chart numbers. From the equation, determine N for the manure aliquot that was treated with and without zinc reduction:

Total NH_4-N (mg kg-1)= $(a + bX + cX^2 + dX^3) \times 14 \times 5 \times 25$/manure weight

The NO_3-N is derived by the difference of NH_4-N of the Zn-reduced aliquot and NH_4-N of non reduced aliquot.

APPENDIX A4

RUNOFF TOTAL-P

I. Reagents

A. Digestion

$HCLO_4$, HNO_3, 6N NaOH, phenolphthalein

B. Coloring Agents

Ammonium Paramolybdate $(NH_4)_6Mo_7O_{24}.4H_20)$, Potassium Antimony Tartrate $K(SbO)C_4H_4O.1/2H_2O$, 5N H_2SO_4, and Ascorbic Acid.

II. Equipment and Instruments:

Spectrophotometer, hot plate, 125 mL Erlenmeyer flask, glass balls, glass funnels, safety goggles, acid proof gloves.

DIGESTION

1. Agitate thoroughly and pour runoff sample to a glass beaker and mix thoroughly with magnetic stirrer. While stirring, measure 20 mL sample (unfiltered) into a 125 mL Erlenmeyer flask. Add 5 mL concentrated HNO_3. Evaporate on a hot plate to about 15 mL. Add 10 mL concentrated HNO_3. Let it cool down overnight, and then add 10 mL $HClO_4$. For every ten samples, make a blank and a standard solution (1 mg L^{-1} standard solution made from stock P solution described below).
2. Add a few glass balls, place funnels at the top of the Erlenmeyer flask. Heat on a hot plate. Evaporate gently under 203 °C until the dark color due to organic material disappears (solution turns color to a yellowish milk like suspension). Then continue heating until dense white fume of $HClO_4$ just appears and continue heating for about 10 minutes. If the dark color persists, cool the solution and add 5 mL HNO_3 and 5 mL of $HCLO_4$. Repeat heating as mention above.

Important hint: Temperature can be estimated by inserting thermometer to a sand-filled beaker on the hot plate. The range of 160-180 °C is enough. HNO_3 boils at 150-160 °C whereas $HClO_4$ boils at 195-205 °C.

3 Cool digested solution, dilute with about 50 mL deionized distilled water and add 1 drop aqueous phenolphthalein solution. Add 6N NaOH a drop at a time until the solution just turns pink. Bring up to 100 mL with deionized-distilled water and let the precipitates settle.

II. Determination

A. To make 1000 mL fresh reagents.

1. H_2SO_4: dilute 70 mL concentrated H_2SO_4 to 500 mL with distilled water and cool down. Transfer to 1000 mL glass beaker and agitate with magnetic stirrer.
2. Weigh 0.1375 g of Potassium Antimony Tartrate $K(SbO)C_4H_4O.1/2H_2O$ crystals and dissolve to the H_2SO_4 in the beaker.
3. Weigh 6.000 g of Ammonium molybdate $(NH_4)_6Mo_7O_{24}.4H_20$ and dissolve in the H_2SO_4 in the beaker.
4. Weigh 5.2800 g of ascorbic acid $C_6H_8O_6$ and dissolve in the H_2SO_4 in the beaker.
5. Transfer the solution to a 1000 mL volumetric flask. Flush the beaker two or three times with deionized distilled water. Each time, pour it to the flask. Bring to volume with deionized distilled water and agitate the solution thoroughly. Shake and let it stand a few minutes.

B. Total-P determination.

1. Pipet 10 mL from the clear part of digested solution to a 50 mL dry volumetric flask (Folin Wu tube is more practical). Add deionized-distilled water to bring the solution to 35 mL. Add 1 drop phenolphthalein. While vortexing, add 5N H_2SO_4 a drop at a time to dissolve color. To develop color, add 8 mL combined reagents and bring it to 50 mL. Mix thoroughly. After 10-20 minutes measure absorbance of each sample at 882 nm.

2. Standard Curve

1. Standard concentration of P Solution: Dilute the stock solution to make 0, 0.1, 0.2, 0.5, 1, 2.5, and 5 mg P L^{-1} for calibration curve.

0.0	deionized distilled water
0.1	2 mL stock P diluted to 1000 mL in volumetric flask
0.2	4 mL stock P diluted to 1000 mL in volumetric flask
0.5	10 mL stock P diluted to 1000 mL in volumetric flask
1.0	20 mL stock P diluted to 1000 mL in volumetric flask
2.5	50 mL stock P diluted to 1000 mL in volumetric flask
5.0	100 mL stock P diluted to 1000 mL in volumetric flask

2. Pipet 10 mL of the diluted Stock-P solution for calibration curve to a 50 mL a dry volumetric flask (Folin Wu tube is more practical). Add distilled water to make about 40 mL. To develop color, add 8 mL reagents and bring to 50 mL with deionized-distilled water and then mix thoroughly. Measure absorbance of each sample at 882 nm.

3. Calculation

From calibration curve, obtained the equation Y= a + bX where Y=P mg L^{-1} and X=absorbance. From the equation determined P of runoff samples.

Total-P (mg L^{-1}) = {a + b × (sample absorbance-blank)} × 100/20

APPENDIX A5

BIOAVAILABLE-P

Extracting solution.

To make 10 L of 0.111 N NaOH, add 44.44 g NaOH crystal to a 2 L glass beaker. Add distilled water to about 1.5 L in the glass beaker. Stir carefully, since heat will be produced. Stir until all the crystal dissolved. Let it cool. After cooling, pour the solution to a 2 L volumetric flask. Dilute residual NaOH left in the beaker with 100 mL distilled water 3 times and pour the solution into the volumetric flask. This is intended to reduce error from excessive residual NaOH in the beaker. Bring the solution to 2 L with deionized-distilled water. Transfer the solution to a 10 L container. Using the same volumetric flask, pour 8 L of distilled water to the container to bring the solution to 10 L.

Sample extraction.

Agitate thoroughly and pour a runoff sample into a glass beaker and mixed thoroughly with a magnetic stirrer. While stirring, measure 20 mL sample (unfiltered) into a 250 mL plastic bottle. Add 180 mL NaOH to make a 0.1 M NaOH (200 mL final volume). Shake for 17 hour on a reciprocal shaker. For every ten samples, make a standard solution (1 ppm standard solution made from stock P solution described below) and a blank.

Phase separation.

Agitate runoff sample thoroughly and pour sample into a centrifuge tube. Centrifuge the solution at 15,000 rpm for 5 minutes (10 minutes total time) at 25 °C and then filter the aliquot to pass 0.45 μm filter membrane on a suction manifold. For each 10 samples make one standard and one blank (deionized-distilled water). This phase separation technique was used for the 1992 runoff samples.

This phase separation was cumbersome, time consuming and expensive. The result of an experiment (to see if centrifugation only is sufficient) showed that phase separation with only centrifugation at 15,000 rpm for 5 minutes (10 minutes total time) at 25 °C is adequate. Thus for the 1993 and 1994 runoff samples, only centrifugation at 15,000 rpm for 5 minutes at 25 °C is the method used for phase separation.

Hint:

A small experiment was conducted to evaluate the influence of sample yellowish color on absorbance reading. Yellowish runoff samples was selected. A portion of the samples was treated with active carbon to eliminate the yellowish color followed by filtration as mentioned above. Another portion was only filtrated without active carbon treatment. Without addition of coloring reagent (the ascorbic method), the absorbance of the aliquot was determined. The absorbance of both the active carbon treated and not treated were measured at the wavelength of 882 ηm. The measurement was repeated in triplicate. The results indicated that yellowish color in the runoff solution did not influence absorbance reading. Thus no active carbon was used to eliminate the yellowish color prior to filtering/centrifugation.

II. Determination

A. To make 1000 mL fresh reagents (same as Appendix A4)

B. Bioavailable-P determination

1. Carefully (avoid any floating plant material) pipet 10 mL of aliquot from centrifuge tube to 50 mL dry clean volumetric flask. Add deionized-

distilled water to bring the volume to about 35 mL and add a drop of phenolphthalein. If red color develops add 5N H_2SO_4 to dissolve the color. Add 8 mL combined reagents and bring to 50 mL with distilled water. Mix thoroughly. After 10-20 minutes measure absorbance of each sample at 882 nm. Experience indicates that color is stable for about 5-6 hours.

2. Standard Curve (same as Appendix A4).

3. Calculation

From calibration curve, obtained the equation Y= a + bX where Y=P (mg L^{-1}) and X=absorbance. From the equation obtain the determined P-ppm of runoff samples.

Bioavailable-P (mg L^{-1}) ={a + b × (sample absorbance-blank)} × 100/20

APPENDIX A6

Dissolved Molybdate Reactive Phosphorus (DMRP)

I. Phase separation (same as Appendix A5)

II. Determination

A. To make 1000 mL fresh reagents (same as in Appendix A4).

DMRP determination.

1. Carefully (avoid any floating plant material) pipet 10 mL of aliquot from centrifuge tube to 50 mL dry clean volumetric flask. Add deionized-distilled water to bring it to a volume of about 35 mL. Since runoff pH is close to normality, neutralization is not needed. Add 8 mL combined reagents and bring it to volume with distilled water. Mix thoroughly. After 10-20 minutes measure absorbance of each sample at 882 nm. Experience indicates that color is stable for about 5-6 hours.

2. Standard Curve (Same as Appendix A4)

3. Calculation

From calibration curve, obtained the equation Y= a + bX where Y=P (mg L^{-1}) and X=absorbance. From the equation obtain the determined P-ppm of runoff samples.

DMRP (mg L-1) = {a + b × (sample absorbance-blank)}

APPENDIX A7.

Sodium bicarbonate extractable P (Olson-P)

Chemicals preparations:

1. $NaHCO_3$, 0.5 M, adjusted to pH 8.5 using 1M NaOH. Dissolve 420 g $NaHCO_3$ in a 2 L volumetric flask with distilled water. Bring to volume and transfer to a 10 L plastic container. Using the same flask (4 times), bring to 10 L with distilled water.
2. Sulfuric acid 5N. In a 500 mL volumetric flask add 70 mL concentrated H_2SO_4 to 400 mL with distilled water. Wait to cool and bring it to volume with distilled water.
3. Stock P Solution: Dissolve in the deionized-distilled water 219.5 mg anhydrous KH_2PO_4 and dilute it to 1000 mL to make a 50 mg L^{-1} P solution.
4. Standard Curve (same as Appendix A4)

Extraction.

To each extraction bottle add about 5 g of dry soil. Add 100 mL of extracting solution ($NaHCO_3$, pH 8.5). Agitate 30 minutes using reciprocal shaker and filter with Whatman #42 filter paper. Shake flask before pouring the suspension. A blank and a standard was treated the same for every 10 samples.

Determination.

A. To make 1000 mL fresh reagents (similar to Appendix A4).

B. Olson-P determination

1. Acidify a 10 mL aliquot of the extract in a 50 mL volumetric flask (folin wu tube is more practical). From a buret slowly drip 5N H_2SO_4 to reach pH 5 and determine the volume of acid needed. Use the same amount of acid for other 10 mL aliquot of samples, blank or standard.
2. Add distilled water to make 40 mL. To develop color, add 8 mL prepared reagents and bring to volume with distilled water. Mix thoroughly to develop a color. After 10-20 minutes, measure absorbance of each sample, blank or standard at 882 nm.

Standard Curve

Pipet 10 mL of the P solution for standard curve to a 50 mL dry clean volumetric flask (Folin Wu tube is more practical) and add 10 mL extracting solution. Acidify with 5N H_2SO_4 as described above. Add distilled water to make about 40 mL. Add 8 mL reagents and bring the volume to 50 mL with distilled water. Vortex thoroughly. Measure absorbance at 882 nm.

Calculation

From the standard curve, obtained the equation Y= a + bX where Y=P (mg L^{-1}) and X=absorbance. From the equation determined phosphorus of samples.

Olson-P (mg kg^{-1})={a + b × (absorbance-blank)} × 100/Soil dry weight

APPENDIX A8.

Release of Phosphorus from Beef Manure (An Incubation Study)

Objective.

Due to a lack of data on the release of P from the manure and also its interaction with a calcareous soil, an evaluation on the rate of release of inorganic-P to soil is important.

Materials and Methods

Methods:

Soil-Manure Mix Preparation

The rate of 46.7 Mg ha^{-1} dry manure ha^{-1} of soil at a bulk density of 1.19 Mg m^{-3} is equivalent to 26.1 g dry manure for each kg dry soil. Weigh 203.9 g air dry soil (200 g oven dry soil) in a mixing bottle. In another weighing container, weigh 5.4 g air dry manure (5.2 g oven dry manure). Pour the manure into the mixing bottle and mix it for 30 minutes on a ball mill apparatus.

The rate of 15.6 Mg dry manure ha^{-1} of soil at a bulk density of 1.19 Mg m^{-3} is equivalent to 8.7 g dry manure for each kg soil. Weigh 203.9 g air dry (200 g oven dry) soil in a mixing bottle provided. In another weighing container, weigh 1.8 g air dry (1.7 g oven dry) manure. Pour the manure into the mixing bottle and mix it for 30 minutes on a ball mill apparatus as above.

To imitate no manure application, a 203.9 g of air dry soil in the mixing bottle and mix it for 30 minutes in a ball mill apparatus as above.

Incubation Procedure.

1. Weigh 250 mL polypropylene bottle.
2. Weigh 5.1 g soil-manure mix (weighted mean of moisture is 0.02 % wt) or 5.0980 gram of soil mix (moisture=0.0196) in the bottle.
3. To the soil in the bottle distribute evenly 1.3 g of water with a syringe. This water addition brought the soil water content to field capacity water content.
4. Incubate the soil-manure mixture at 30 °C for 0, 1, 3, 5, 10, and 30 days. Zero incubation time measurement are used for the initial value for all treatments.

Three replicates for rate/time incubation were used. The manure and time treatments are arranged in a completely randomized design. Phosphorus from the incubated soil was extracted using $NaHCO_3$ solution (Olson P, Appendix A7). To each incubation bottle 100 ML of extracting solution was added followed by 30 minutes shaking and filtration with Whatman # 42 filter paper. Phosphorus was determined with ascorbic acid procedure (Murphy and Riley, 1962).

APPENDIX A9

Plant Material Total-P

Plant Material Preparation

Grind plant material to pass through 1 mm diameter sieve. Weigh about 1 g of the plant material to a 125 mL Erlenmeyer flask. Add 5mL concentrated HNO_3. Evaporate on a hot plate to about 15mL. Add 10 mL concentrated HNO_3. Let it cool down overnight, and then add 10 mL $HClO_4$. For every ten samples, make a blank and a standard solution (20 mL 1 mg P L^{-1} standard solution made from stock P solution).

I. Reagents

A. Digestion (same as Appendix A4)

B. Coloring Agents (same as Appendix A4)

II. Instruments (same as Appendix A4)

III. Perchloric Digestion (Similar to Appendix 4)

IV. Determination

A. To make 1000 mL fresh reagents (same as Appendix A4).

B. Procedure for total-P determination (same as Appendix A4)

2. Standard Curve (same as Appendix A4)

3. Calculation

From standard curve, obtained the equation Y= a + bX where Y=P (mg L^{-1} and X=absorbance. From the equation determined P of samples.

Total-P (mg kg-1)=(a + b × (sample absorbance-blank)) × 100/plant dry weight

APPENDIX A10

The effects of tillage and manure on daily (10 May-24 August 1993) rainfall runoff and associated sediment, total P (TP), particulate P (PP), and dissolved molybdate reactive P (DMRP) losses from Barnes loam at the West Central Exp. Stn., Morris, MN.

Event 8 May 1993	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	0.29	2.69	20.9	14.95	6.02
Manure	0.20	1.98	12.2	7.04	5.25
Average	0.24	2.32	16.0	10.47	5.62
Moldboard					
No Manure	3.74	172	120	115.09	5.17
Manure	2.94	121	41.9	34.30	7.61
Average	3.32	144	71.1	64.84	6.29
Average					
No Manure	1.47	24.3	50.6	45.03	5.58
Manure	1.17	18.1	22.8	16.53	6.34
P > F Values					
Tillage (T)	.003	<.001	0.002	0.0200	.718
Manure (M)	.096	.417	0.243	0.2144	.378
T by M	.387	.841	0.659	0.7497	.110

Event 24 May 1993	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	0.14	2.61	5.31	0.42	4.89
Manure	0.07	1.53	4.34	0.13	4.21
Average	0.11	2.02	4.80	0.34	4.54
Moldboard					
No Manure	5.46	209	46.2	40.9	5.30
Manure	3.80	99.2	42.1	36.5	5.64
Average	4.57	144	44.1	38.6	5.47
Average					
No Manure	1.72	26.5	16.2	11.1	5.09
Manure	1.27	14.9	14.1	9.30	4.88
P > F Values					
Tillage (T)	0.006	.007	.007	0.003	0.625
Manure (M)	0.026	.007	.547	0.110	0.875
T by M	0.088	.154	.859	0.885	0.700

APPENDIX A10. (Continued).

Event 31 May 1993	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	0.01	0.26	0.53	0.27	0.26
Manure	0.02	0.21	0.88	0.35	0.53
Average	0.01	0.23	0.70	0.31	0.39
Moldboard					
No Manure	0.50	7.59	29.6	24.66	1.96
Manure	0.32	12.8	30.0	28.50	1.59
Average	0.41	9.88	29.8	28.02	1.77
Average					
No Manure	0.23	2.28	5.85	4.91	0.94
Manure	0.16	3.08	6.65	5.66	0.99
P > F Values					
Tillage (T)	0.135	0.031	0.002	0.0065	0.098
Manure (M)	0.743	0.746	0.854	0.8295	0.795
T by M	0.704	0.705	0.874	0.9871	0.169

Event 16 June 1993	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	0.00	0.00	0.00	0.00	0.00
Manure	0.01	0.09	0.41	0.31	0.10
Average	0.00	0.05	0.19	0.14	0.05
Moldboard					
No Manure	1.58	62.52	64.27	59.5	4.69
Manure	0.56	17.91	7.53	3.68	3.85
Average	1.01	33.66	22.60	18.3	4.25
Average					
No Manure	0.91	6.97	7.08	5.69	1.39
Manure	0.35	3.55	2.46	1.16	1.30
P > F Values					
Tillage (T)	0.104	0.023	0.020	0.025	0.028
Manure (M)	0.124	0.035	0.120	0.131	0.850
T by M	0.113	0.022	0.050	0.072	0.504

APPENDIX A10. (Continued).

Event 20 June 1993	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	0.01	1.25	0.17	0	0.17
Manure	0.01	0.32	0.46	0.24	0.22
Average	0.01	0.72	0.31	0.11	0.20
Moldboard					
No Manure	3.15	80.1	7.99	5.51	2.48
Manure	0.92	13.7	10.8	9.51	1.43
Average	1.83	33.6	9.32	7.40	1.92
Average					
No Manure	1.05	12.5	2.50	1.48	1.02
Manure	0.39	3.42	3.16	2.43	0.73
P > F Values					
Tillage (T)	0.087	0.037	0.087	0.0903	0.084
Manure (M)	0.033	0.048	0.486	0.4152	0.005
T by M	0.035	0.214	0.938	0.8604	0.002

Event 23 June 1993	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	0.06	3.67	6.04	4.05	1.99
Manure	0.05	2.51	4.93	3.27	1.66
Average	0.06	3.05	5.46	3.64	1.82
Moldboard					
No Manure	3.95	284	59.2	52.75	6.46
Manure	2.94	176	22.2	14.67	7.53
Average	3.42	225	36.3	29.39	6.98
Average					
No Manure	1.29	35.5	19.5	15.87	3.72
Manure	1.04	24.1	10.7	6.96	3.77
P > F Values					
Tillage (T)	0.009	0.005	0.258	0.6310	0.078
Manure (M)	0.054	0.065	0.313	0.4213	0.980
T by M	0.060	0.589	0.468	0.5025	0.935

APPENDIX A10. (Continued).

Event 30 June 1993	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	0.01	0.67	0.34	0.24	0.12
Manure	0.02	0.61	0.56	0.0	0.56
Average	0.01	0.64	0.45	0.13	0.32
Moldboard					
No Manure	0.77	44.9	5.34	4.79	0.55
Manure	0.27	11.6	2.93	2.31	0.68
Average	0.50	23.0	3.99	3.38	0.61
Average					
No Manure	0.34	7.76	1.92	1.61	0.31
Manure	0.14	3.50	1.48	0.86	0.62
P > F Values					
Tillage (T)	0.081	0.010	0.031	0.0237	0.545
Manure (M)	0.084	0.002	0.261	0.0543	0.298
T by M	0.072	0.002	0.064	0.3229	0.500

Event 4 July 1993	Runoff (mm)	Sediment (Mg ha^{-1})	TP kg ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	5.61	0.527	0.555	538.58	17.4
Manure	1.73	0.043	0.112	71.68	41.2
Average	3.25	0.152	0.250	224.02	26.8
Moldboard					
No Manure	34.4	21.4	1.59	1564.09	35.1
Manure	34.4	10.6	1.36	1330.69	33.2
Average	34.4	15.1	1.47	1442.81	34.1
Average					
No Manure	14.3	3.36	0.943	918.29	24.8
Manure	8.84	0.688	0.393	356.32	37.0
P > F Values					
Tillage (T)	0.019	0.055	0.007	0.0056	0.368
Manure (M)	0.096	0.080	0.233	0.1866	0.062
T by M	0.096	0.263	0.315	0.2352	0.043

APPENDIX A10. (Continued).

Event 9 July 1993	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	0.00	0.00	0.00	0.0	0.00
Manure	0.00	0.00	0.00	0.0	0.00
Average	0.00	0.00	0.00	0.0	0.00
Moldboard					
No Manure	0.11	0.96	0.54	0.39	0.15
Manure	0.03	3.26	0.30	0.22	0.08
Average	0.07	1.89	0.42	0.30	0.12
Average					
No Manure	0.05	0.40	0.24	0.17	0.07
Manure	0.01	1.06	0.14	0.10	0.04
P > F Values					
Tillage (T)	0.301	0.145	0.245	0.2849	0.194
Manure (M)	0.416	0.119	0.600	0.6247	0.432
T by M	0.416	0.119	0.600	0.6247	0.432

Event 13 July 1993	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	0.00	0.00	0.00	0.0	0.00
Manure	0.00	0.00	0.00	0.0	0.00
Average	0.00	0.00	0.00	0.0	0.00
Moldboard					
No Manure	0.16	9.32	1.09	0.82	0.27
Manure	0.08	3.74	0.43	0.25	0.18
Average	0.12	5.99	0.73	0.50	0.23
Average					
No Manure	0.08	2.21	0.49	0.32	0.13
Manure	0.04	1.18	0.20	0.11	0.09
P > F Values					
Tillage (T)	0.101	0.051	0.050	0.0700	0.039
Manure (M)	0.243	0.178	0.110	0.2102	0.157
T by M	0.243	0.178	0.110	0.2102	0.157

APPENDIX A10. (Continued).

Event 16 July 1993	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	0.00	0.00	0.00	0.0	0.00
Manure	0.00	0.00	0.00	0.0	0.00
Average	0.00	0.00	0.00	0.0	0.00
Moldboard					
No Manure	0.90	20.7	5.35	0.85	0.85
Manure	0.53	13.5	5.07	0.79	0.79
Average	0.71	16.8	5.21	0.82	0.82
Average					
No Manure	0.38	3.67	1.52	0.36	0.36
Manure	0.24	2.82	1.46	0.34	0.34
P > F Values					
Tillage (T)	0.013	0.012	0.004	0.0145	0.014
Manure (M)	0.090	0.351	0.667	0.7226	0.722
T by M	0.090	0.351	0.667	0.7226	0.722

Event 25 July 1993	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	0.20	1.78	3.18	0.97	2.21
Manure	0.04	0.36	0.75	0.14	0.61
Average	0.12	0.94	1.70	0.42	1.28
Moldboard					
No Manure	4.51	94.1	33.8	30.74	3.07
Manure	1.97	27.9	17.2	15.19	2.05
Average	3.04	51.4	24.2	21.68	2.52
Average					
No Manure	1.57	15.2	11.0	8.45	2.62
Manure	0.76	5.27	4.64	3.42	1.22
P > F Values					
Tillage (T)	0.008	0.000	0.011	0.0035	0.169
Manure (M)	0.003	0.002	0.083	0.1222	0.120
T by M	0.016	0.174	0.749	0.5835	0.466

APPENDIX A10. (Continued).

Event 14 August 1993	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	0.13	2.28	5.99	1.48	4.51
Manure	0.03	0.29	0.51	0.05	0.46
Average	0.08	1.05	2.24	0.41	1.83
Moldboard					
No Manure	0.30	8.98	3.92	1.54	2.38
Manure	0.23	6.39	3.74	2.12	1.62
Average	0.26	7.59	3.83	1.86	1.97
Average					
No Manure	0.21	4.72	4.86	1.55	3.31
Manure	0.12	2.08	1.67	0.71	0.96
P > F Values					
Tillage (T)	0.045	0.016	0.480	0.1512	0.923
Manure (M)	0.171	0.114	0.048	0.5402	0.051
T by M	0.679	0.359	0.055	0.2356	0.135

Event 18 August 1993	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	0.03	0.091	0.73	0.21	0.52
Manure	0.01	0.12	0.17	0.0	0.17
Average	0.02	0.46	0.43	0.10	0.33
Moldboard					
No Manure	0.15	1.85	3.09	2.56	0.53
Manure	0.10	1.26	1.48	0.95	0.53
Average	0.12	1.54	2.19	1.66	0.53
Average					
No Manure	0.09	1.34	1.66	1.14	0.52
Manure	0.06	0.59	0.71	0.37	0.34
P > F Values					
Tillage (T)	0.115	0.003	0.086	0.0417	0.403
Manure (M)	0.268	0.214	0.110	0.1638	0.248
T by M	0.626	0.596	0.816	0.4535	0.259

APPENDIX A10. (Continued).

Event 23 August 1993	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	0.00	0.00	0.00	0.0	0.00
Manure	0.09	1.17	0.30	0.0	0.30
Average	0.04	0.47	0.14	0.0	0.14
Moldboard					
No Manure	0.05	1.31	1.29	0.27	1.02
Manure	0.04	1.42	0.96	0.49	0.47
Average	0.04	1.37	1.21	0.49	0.72
Average					
No Manure	0.02	0.52	0.51	0.09	0.42
Manure	0.07	1.29	0.60	0.22	0.38
P > F Values					
Tillage (T)	0.966	0.398	0.093	0.0798	0.145
Manure (M)	0.406	0.385	0.712	0.0009	0.853
T by M	0.359	0.436	0.197	0.0009	0.100

APPENDIX A11

Significant levels of the effects (EFF) of tillage (T), manure (M), and tillage by manure (TM) interactions on the 1993 daily rainfall runoff volume (RV) and associated sediment (SED), sediment concentration (CSED), total P (TP) amount, TP concentration (CTP), dissolved reactive molybdate P (DMRP) amount, DMRP concentration (CDMRP), particulate P (PP) amount, and PP concentration (CPP).

	month/day														
	EFF	5/8	5/24	5/31	6/16	6/20	6/23	6/30	7/4	7/9	7/13	7/16	7/25	8/14	8/18	8/23
RV	T	***	***	-	-	*	***	***	*	-	*	**	***	**	-	-
	M	*	**	-	-	**	*	***	*	-	-	*	***	-	-	-
	TM	-	*	-	-	**	*	***	*	-	-	*	*	-	-	-
SED	T	***	***	**	**	**	***	***	*	-	*	**	***	**	***	-
	M	-	***	-	**	**	*	***	*	-	-	-	***	-	-	-
	TM	-	-	-	**	-	-	***	*	-	-	-		-	-	-
CSED	T	**	**	-	**	-	-	-	*	**	***	**	-	**	-	**
	M	-	-	-	-	-	-	-	*	-	-	-	-	-	-	-
	TM	-	**	-	-	-	-	-	-	-	-	-	-	-	-	-

*** = P>F value 0.00-0.010; ** = P>F value 0.011-0.050; * = P>F value 0.051-0.100; - = P>F value greater than 0.100

APPENDIX A11. (Continued)

	EFF	5/8	5/24	5/31	6/16	6/20	6/23	6/30	7/4	7/9	7/13	7/16	7/25	8/14	8/18	8/23
		month/day														
TP	T	***	***	***	**	*	-	**	***	-	*	***	**	-	*	*
	M	-	-	-	-	-	-	-	-	-	-	-	**	**	-	-
	TM	-	-	-	*	-	-	*	-	-	-	-	-	*	-	-
CTP	T	*	**	-	-	-	-	-	-	*	***	**	-	-	-	*
	M	-	***	-	-	*	-	-	-	**	*	-	-	*	-	-
	TM	-	***	-	-	-	-	-	-	**	*	-	-	*	-	-
DMRP	T	-	-	*	**+	*	*	-	-	-	**	**	-	-	-	-
	M	-	-	-	-	***	-	-	*	-	-	-	-	*	-	-
	TM	-	-	-	-	***	-	-	**	-	-	-	-	-	-	-
CDMRP	T	**	**	-	-	-	*	-	**	***	**	***	-	-	-	*
	M	**	***	*	*	-	-	-	**	-	-	***	-	-	-	-
	TM	-	***	-	-	-	-	-	***	-	-	***	-	*	-	-
PP	T	**	***	***	**	*	-	**	***	-	-*	***	***	-	**	*
	M	-	-	-	-	-	-	*	-	-	-	-	-	-	-	***
	TM	-	-	-	*	-	-	-	-	-	-	-	-	-	-	***
CPP	T	-	-	-	-	-	-	-	-	-	*	**	-	-	*	***
	M	-	-	-	-	-	-	-	-	-	-		-	-	*	-
	TM	-	**	-	-	-	-	-	-	-	-		-	*	-	-

*** = P>F value 0.00-0.010; ** = P>F value 0.011-0.050; * = P>F value 0.051-0.100; - = P>F value greater than 0.100

APPENDIX A12

The effects of tillage and manure on daily (22 February-26 March 1994) snowmelt runoff and associated sediment, total P (TP), particulate P (PP), and dissolved molybdate reactive P (DMRP) losses from Barnes loam at the West Central Exp. Stn., Morris, MN.

Event 22 February 1993	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	3.59	6.26	23.1	1.73	21.4
Manure	3.28	3.64	74.2	13.7	60.5
Average	3.43	4.80	41.6	5.5	36.1
Moldboard					
No Manure	1.40	1.24	6.12	0.01	6.11
Manure	1.62	1.57	13.8	1.25	12.6
Average	1.51	1.40	9.29	0.45	8.84
Average					
No Manure	2.32	3.03	12.1	0.48	11.6
Manure	2.35	2.45	32.4	4.48	27.9
P > F Values					
Tillage (T)	0.102	0.128	0.115	0.075	0.165
Manure (M)	0.977	0.782	0.116	0.004	0.173
T by M	0.832	0.608	0.691	0.193	0.737

Event 3 March 1994	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	0.14	0.32	0.16	0.14	0.02
Manure	0.07	0.06	0.10	0.08	0.02
Average	0.10	0.18	0.13	0.11	0.02
Moldboard					
No Manure	0.13	0.13	0.20	0.17	0.03
Manure	0.12	0.12	0.19	0.16	0.03
Average	0.12	0.13	0.19	0.16	0.03
Average					
No Manure	0.14	0.22	0.18	0.15	0.03
Manure	0.09	0.09	0.14	0.12	0.02
P > F Values					
Tillage (T)	0.659	0.095	0.365	0.4472	0.210
Manure (M)	0.080	0.076	0.556	0.5747	0.522
T by M	0.161	0.099	0.694	0.6829	0.911

APPENDIX A12. (Continued)

Event 4 March 1993	Runoff (mm)	Sediment (kg ha⁻¹)	TP g ha⁻¹	PP g ha⁻¹	DMRP g ha⁻¹
Ridge till					
No Manure	0.31	0.61	2.65	0.01	2.58
Manure	0.12	0.13	1.94	0.0	1.94
Average	0.21	0.35	2.27	0.03	2.24
Moldboard					
No Manure	0.21	0.19	0.92	0.06	0.86
Manure	0.23	0.31	0.76	0.03	0.73
Average	0.22	0.25	0.83	0.04	0.79
Average					
No Manure	0.26	0.39	1.65	0.07	1.58
Manure	0.18	0.22	1.27	0.02	1.25
P > F Values					
Tillage (T)	0.861	0.454	0.092	0.5319	0.085
Manure (M)	0.520	0.401	0.654	0.3514	0.693
T by M	0.422	0.180	0.850	0.4277	0.8514

Event 6 March 1994	Runoff (mm)	Sediment (kg ha⁻¹)	TP g ha⁻¹	PP g ha⁻¹	DMRP g ha⁻¹
Ridge till					
No Manure	1.60	2.84	10.1	3.64	6.47
Manure	0.72	0.87	10.7	1.66	9.11
Average	1.12	1.68	10.4	2.75	7.69
Moldboard					
No Manure	0.84	0.61	2.08	0.16	1.92
Manure	0.59	0.68	2.05	0.21	1.84
Average	0.71	0.64	2.05	0.17	1.88
Average					
No Manure	1.19	1.48	4.85	1.18	3.67
Manure	0.65	0.77	4.97	0.61	4.36
P > F Values					
Tillage (T)	0.077	0.143	0.002	0.0395	0.012
Manure (M)	0.404	0.410	0.972	0.5774	0.770
T by M	0.680	0.359	0.945	0.6069	0.728

APPENDIX A12. (Continued)

Event 7 March 1994	Runoff (mm)	Sediment (kg ha⁻¹)	TP g ha⁻¹	PP g ha⁻¹	DMRP g ha⁻¹
Ridge till					
No Manure	0.71	0.33	4.86	0.78	3.08
Manure	0.35	0.34	9.94	1.53	8.41
Average	0.52	0.77	7.01	1.82	5.19
Moldboard					
No Manure	0.42	1.09	1.15	0.10	1.05
Manure	0.21	0.29	0.70	0.06	0.64
Average	0.31	0.64	0.91	0.06	0.84
Average					
No Manure	0.56	1.21	2.54	0.65	1.89
Manure	0.28	0.32	3.31	1.42	2.94
P > F Values					
Tillage (T)	0.514	0.865	0.039	0.0823	0.050
Manure (M)	0.376	0.277	0.689	0.8497	0.431
T by M	0.853	0.937	0.398	0.9280	0.208

Event 12 March 1994	Runoff (mm)	Sediment (kg ha⁻¹)	TP g ha⁻¹	PP g ha⁻¹	DMRP g ha⁻¹
Ridge till					
No Manure	0.74	0.90	3.01	0.74	2.27
Manure	0.18	0.61	1.39	0.08	1.31
Average	0.43	0.75	2.10	0.35	1.75
Moldboard					
No Manure	0.62	2.10	1.57	0.48	1.09
Manure	0.57	0.93	2.09	0.21	1.80
Average	0.60	1.44	1.82	0.37	1.45
Average					
No Manure	0.68	1.43	2.21	0.60	1.61
Manure	0.36	0.76	1.72	0.14	1.58
P > F Values					
Tillage (T)	0.524	0.544	0.823	0.8094	0.728
Manure (M)	0.448	0.544	0.982	0.3754	0.982
T by M	0.517	0.762	0.612	0.3763	0.612

APPENDIX A12. (Continued)

Event 13 March 1994	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	2.84	3.75	9.45	2.72	6.73
Manure	3.58	3.02	21.5	3.58	17.9
Average	3.19	3.37	12.4	1.33	11.1
Moldboard					
No Manure	2.61	6.17	11.0	7.31	3.72
Manure	1.77	4.88	8.22	3.03	5.19
Average	2.16	5.49	9.53	5.13	4.40
Average					
No Manure	2.72	4.84	10.2	5.17	5.04
Manure	2.56	3.86	11.6	1.79	9.84
P > F Values					
Tillage (T)	0.296	0.432	0.652	0.9368	0.006
Manure (M)	0.946	0.824	0.920	0.6485	0.554
T by M	0.742	0.984	0.748	0.9045	0.747

Event 14 March 1994	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	7.33	13.6	5.13	3.85	1.28
Manure	12.7	14.4	11.4	8.24	3.16
Average	9.70	14.0	7.72	5.64	2.08
Moldboard					
No Manure	1.88	2.02	0.46	0.32	0.14
Manure	4.91	11.9	1.60	1.17	0.43
Average	3.12	5.25	0.94	0.67	0.27
Average					
No Manure	3.89	5.64	1.99	1.38	0.61
Manure	8.02	13.1	4.66	3.23	1.43
P > F Values					
Tillage (T)	0.280	0.284	0.046	0.0430	0.028
Manure (M)	0.328	0.237	0.267	0.3149	0.284
T by M	0.851	0.268	0.901	0.9028	0.605

APPENDIX A12. (Continued)

Event 15 March 1994	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	2.73	3.39	17.9	9.97	7.99
Manure	2.18	2.04	35.2	13.52	21.7
Average	2.44	2.65	25.2	11.92	13.3
Moldboard					
No Manure	0.12	0.12	0.30	0.12	0.18
Manure	0.65	1.25	2.23	0.81	1.42
Average	0.36	0.59	1.05	0.36	0.69
Average					
No Manure	1.04	1.22	4.00	1.74	2.26
Manure	1.29	1.62	9.82	3.41	6.41
P > F Values					
Tillage (T)	0.108	0.195	0.062	0.0485	0.041
Manure (M)	0.835	0.798	0.518	0.7979	0.428
T by M	0.618	0.434	0.911	0.8296	0.915

Event 16 March 1994	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	1.84	2.18	8.29	4.02	4.27
Manure	1.10	2.64	8.47	2.44	6.03
Average	1.44	2.41	8.38	3.29	5.09
Moldboard					
No Manure	0.08	0.15	0.19	0.04	0.15
Manure	0.22	0.28	0.70	0.18	0.52
Average	0.15	0.21	0.42	0.10	0.32
Average					
No Manure	0.75	0.91	2.33	0.87	1.46
Manure	0.60	1.16	3.01	0.74	2.27
P > F Values					
Tillage (T)	0.087	<0.001	0.056	0.0610	0.037
Manure (M)	0.827	0.867	0.867	0.9343	0.758
T by M	0.619	0.986	0.880	0.8127	0.997

APPENDIX A12. (Continued)

Event 17 March 1994	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	3.74	4.38	15.7	6.63	9.08
Manure	1.28	3.24	12.5	2.60	9.99
Average	2.28	3.77	14.0	4.55	9.52
Moldboard					
No Manure	0.19	0.33	0.34	0.13	0.21
Manure	0.78	1.13	2.20	0.94	1.26
Average	0.46	0.69	1.07	0.41	0.66
Average					
No Manure	1.37	1.68	3.72	1.23	2.49
Manure	1.01	2.00	5.59	1.61	3.98
P > F Values					
Tillage (T)	0.211	0.045	0.101	0.100	0.070
Manure (M)	0.766	0.893	0.770	0.839	0.713
T by M	0.336	0.684	0.639	0.493	0.780

Event 18 March 1994	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	2.96	2.75	17.8	9.48	8.41
Manure	2.66	3.99	27.8	6.66	21.2
Average	2.81	3.32	22.3	8.90	13.4
Moldboard					
No Manure	0.16	0.34	0.32	0.15	0.17
Manure	0.64	1.27	2.05	0.85	1.20
Average	0.34	0.75	1.01	0.41	0.60
Average					
No Manure	1.14	1.24	3.99	1.67	2.32
Manure	1.45	2.37	8.38	2.40	5.98
P > F Values					
Tillage (T)	0.153	0.266	0.056	0.1358	0.022
Manure (M)	0.698	0.371	0.320	0.9569	0.174
T by M	0.545	0.780	0.730	0.6976	0.809

APPENDIX A12. (Continued)

Event 19 March 1994	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	1.53	1.39	9.70	3.66	6.04
Manure	0.94	1.36	8.83	1.69	7.14
Average	1.22	1.37	9.26	2.69	6.57
Moldboard					
No Manure	0.00	0.00	0.00	0.0	0.00
Manure	0.14	0.34	0.33	0.22	0.11
Average	0.07	0.16	0.15	0.10	0.05
Average					
No Manure	0.59	0.55	2.27	0.62	1.65
Manure	0.49	0.78	2.62	0.62	2.00
P > F Values					
Tillage (T)	0.032	0.046	0.011	0.0774	0.003
Manure (M)	0.863	0.767	0.897	0.7658	0.858
T by M	0.622	0.748	0.812	0.5274	0.977

Event 20 March 1994	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	3.03	2.61	24.6	13.15	11.5
Manure	2.82	4.14	21.6	0.60	21.0
Average	2.92	3.33	23.1	7.50	15.6
Moldboard					
No Manure	0.34	0.66	1.02	0.64	0.38
Manure	3.17	5.59	13.1	7.48	5.71
Average	1.37	2.31	4.35	2.30	2.05
Average					
No Manure	1.33	1.45	6.20	3.04	3.16
Manure	2.99	4.85	16.9	5.77	11.1
P > F Values					
Tillage (T)	0.338	0.713	0.185	0.7106	0.118
Manure (M)	0.251	0.132	0.104	0.7389	0.033
T by M	0.251	0.332	0.076	0.0280	0.207

APPENDIX A12. (Continued)

Event 26 March 1994	Runoff (mm)	Sediment (kg ha⁻¹)	TP g ha⁻¹	PP g ha⁻¹	DMRP g ha⁻¹
Ridge till					
No Manure	0.10	0.05	0.46	0.10	0.36
Manure	0.31	0.43	1.81	0.05	1.76
Average	0.20	0.22	1.02	0.09	0.93
Moldboard					
No Manure	0.00	0.00	0.00	0.0	0.00
Manure	0.32	0.52	0.92	0.46	0.46
Average	0.15	0.23	0.38	0.17	0.21
Average					
No Manure	0.05	0.03	0.21	0.05	0.16
Manure	0.32	0.47	1.32	0.31	1.01
P > F Values					
Tillage (T)	0.765	0.973	0.579	0.9508	0.502
Manure (M)	0.122	0.126	0.153	0.1051	0.214
T by M	0.694	0.771	0.996	0.3076	0.680

APPENDIX A13

Significant levels of the effects (EFF) of tillage (T), manure (M), and tillage by manure (TM) interactions on the 1994 daily snowmelt runoff volume (RV) and associated sediment (SED), sediment concentration (CSED), total P (TP) amount, TP concentration (CTP), dissolved reactive molybdate P (DMRP) amount, DMRP concentration (CDMRP), particulate P (PP) amount, and PP concentration (CPP).

	month/day														
	EFF	2/22	3/3	3/4	3/6	3/7	3/12	3/13	3/14	3/15	3/16	3/17	3/18	3/19	3/20	3/26
RV	T	-	-	-	*	-	-	-	-	-	*	-	-	**	-	-
	M	-	*	-	-	-	-	-	-	-	-	-	-	-	-	-
	TM	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SED	T	-	*	-	-	-	-	-	-	-	***	**	-	**	-	-
	M	-	*	-	-	-	-	-	-	-	-	-	-	-	-	-
	TM	-	*	-	-	-	-	-	-	-	-	-	-	-	-	-
	T	-	-	-	-	-	-	-	-	-	-	-	*	-	-	-
	M	-	-	-	-	-	-	-	-	-	-	-	-	*	*	-
CSED	TM	-	-	-	-	-	**	-	-	-	-	-	-	-	-	-

*** = P>F value 0.00-0.010; ** = P>F value 0.011-0.050; * = P>F value 0.051-0.100; - = P>F value greater than 0.100

APPENDIX A13. (Continued)

	month/day															
	EFF	2/22	3/3	3/4	3/6	3/7	3/12	3/13	3/14	3/15	3/16	3/17	3/18	3/19	3/20	3/26
TP	T	-	-	*	***	*	-	-	**	*	*	-	*	**	-	-
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	*	-
	TM	-	-	-	-	-	-	-	-	-	-	-	-	-	*	-
CTP	T	*	-	***	**	**	*	-	***	*	*	**	**	**	*	-
	M	**	-	**	***	***	-	-	*	-	-	*	-	-	-	-
	TM	-	-	**	**	**	-	-	-	-	-	-	-	-	-	-
DMRP	T	-	-	*	***	*	-	***	**	*	*	*	*	***	-	-
	M	-	-	-	-	-	-	-	-	-	-	-	-	-	*	-
	TM	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CDMRP	T	-	-	***	*	*	*	-	**	**	*	**	-	*	*	-
	M	**	-	**	***	***	-	-	*	**	-	***	-	-	-	-
	TM	-	-	**	**	**	-	-	-	*	-	**	-	-	-	-
PP	T	*	-	-	**	*	-	-	**	**	*	*	-	*	-	-
	M	***	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TM	**	-	-	-	-	-	-	-	-	-	-	-	-	**	-
CPP	T	-	-	-	***	***	*	-	***	*	*	*	-	-	-	-
	M	**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TM	*	-	-	-	-	-	-	-	-	-	-	-	-	*	-

*** = P>F value 0.00-0.010; ** = P>F value 0.011-0.050; * = P>F value 0.051-0.100; - = P>F value greater than 0.100

APPENDIX A14.

The concentration of total-P (TP) and DMRP of snowmelt runoff taken in 13 and 15 March 1994.

---- March 13 ----				---- March 15 ----			
Plot	Time	TP	DMRP	Plot	Time	TP	DMRP
1	11.0	1.14	0.50	1	9.0	2.20	1.28
	16.1	0.38	0.38		12.8	2.30	1.37
	18.5	0.53	0.47		14.8	1.74	1.30
	22.8	0.53	0.47		17.5	2.39	1.68
2	11.0	0.70	0.22	2	9.0	1.17	0.06
	16.0	0.23	0.17		13.0	0.93	0.37
	22.8	0.23	0.17		15.0	0.89	0.31
					17.6	1.51	0.26
3	11.0	0.48	0.17	3	9.0	0.69	0.41
	15.8	0.24	0.19				
	22.7	0.24	0.19				
4	11.0	0.79	0.24	4	9.0	0.49	0.28
	16.2	0.34	0.34		13.1	0.48	0.31
	22.6	0.34	0.34		15.7	0.53	0.34
5	11.0	0.51	0.18	5	9.0	0.32	0.14
	15.7	0.18	0.14		13.1	0.23	0.15
	22.6	0.18	0.14		15.8	0.38	0.19
6	11.0	0.70	0.32	6	9.0	0.48	0.25
	16.4	0.28	0.28		13.2	0.20	0.13
	22.5	0.28	0.26		15.2	0.21	0.15
					17.2	0.30	0.19
7	11.0	1.38	0.60	7	9.0	2.68	0.88
	15.6	0.48	0.57		13.3	2.04	1.32
	18.6	0.63	0.63		17.0	2.69	2.10
	22.3	0.63	0.63				
8	11.0	1.31	1.16	8	0	0	0
	16.5	1.10	1.10				
	22.3	1.10	1.10				
9	11.0	3.03	1.27	9	9.0	4.55	3.43
	16.5	2.08	2.08		13.4	1.41	0.51
	22.2	2.08	2.08		15.3	1.79	1.17
					16.9	2.55	1.86
10	11.0	0.95	0.29	10	9.0	1.64	0.56
	15.5	0.50	0.48		13.5	1.99	0.70
	18.7	0.86	0.45		15.3	1.66	0.54
	22.1	0.86	0.45		16.8	1.56	0.41
11	11.0	1.24	0.36	11	9.0	0.77	0.44
	15.4	0.60	0.37		13.6	0.61	0.36
	22.0	0.60	0.37		15.5	0.63	0.32
12	11.0	0.187	0.11	12	9.0	0	0
	15.3	0.205	0.11				
	21.9	0.205	0.11				

APPENDIX A15

The effects of tillage and manure on daily (25 April-24 August 1994) rainfall runoff and associated sediment, total P (TP), particulate P (PP), and dissolved molybdate reactive P (DMRP) losses from Barnes loam at the West Central Exp. Stn., Morris, MN.

Event 25 April 1994	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	0.88	33.3	33.8	28.49	5.33
Manure	0.36	14.7	21.0	16.59	4.33
Average	0.60	22.2	26.6	21.88	4.81
Moldboard					
No Manure	3.66	1201	623	619.14	4.15
Manure	2.24	590	382	377.75	4.65
Average	2.89	842	488	483.84	4.40
Average					
No Manure	1.96	202	146	141.72	4.71
Manure	1.10	95.4	90.8	86.39	4.49
P > F Values					
Tillage (T)	0.003	0.004	0.002	0.0027	0.694
Manure (M)	0.055	0.053	0.226	0.2137	0.866
T by M	0.879	0.903	0.966	0.9854	0.581

Event 26 April 1994 11 - 12 a.m.	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	0.08	1.87	2.34	1.46	0.88
Manure	0.03	0.75	0.73	0.37	0.36
Average	0.05	1.24	1.41	0.81	0.60
Moldboard					1.45
No Manure	2.66	945	24.1	22.68	2.01
Manure	1.71	388	23.4	21.46	1.72
Average	2.14	606	23.8	22.08	
Average					
No Manure	0.99	51.2	8.16	7.02	1.14
Manure	0.66	25.0	5.52	4.49	1.03
P > F Values					
Tillage (T)	<0.001	0.001	0.041	0.0368	0.028
Manure (M)	0.1250	0.096	0.587	0.6129	0.595
T by M	0.2466	0.577	0.616	0.7076	0.053

APPENDIX A15. (Continued)

Event 26 April 1994 12:30-13.23 p.m.	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	0.00	0.00	0.02	0.01	0.01
Manure	0.00	0.01	0.04	0.01	0.03
Average	0.00	0.01	0.03	0.01	0.02
Moldboard					
No Manure	0.54	38.7	3.32	3.08	0.24
Manure	0.15	5.05	1.63	1.43	0.20
Average	0.33	14.5	2.37	2.15	0.22
Average					
No Manure	0.24	5.30	1.10	0.98	0.12
Manure	0.07	1.48	0.65	0.54	0.11
P > F Values					
Tillage (T)	0.059	0.045	0.060	0.0518	0.215
Manure (M)	0.001	<0.001	0.080	0.0638	0.728
T by M	0.001	0.000	0.069	0.0633	0.378

Event 29 April 1994	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	0.14	0.46	2.00	1.14	0.86
Manure	0.05	0.32	1.42	0.53	0.89
Average	0.09	0.39	1.69	0.81	0.88
Moldboard					
No Manure	0.12	0.32	0.30	0.27	0.10
Manure	0.04	0.20	0.29	0.17	0.12
Average	0.08	0.26	0.33	0.22	0.11
Average					
No Manure	0.13	0.39	1.03	0.06	0.43
Manure	0.05	0.26	0.76	0.30	0.46
P > F Values					
Tillage (T)	0.549	0.083	0.027	0.0272	0.050
Manure (M)	0.047	0.023	0.304	0.1466	0.764
T by M	0.844	0.926	0.559	0.3382	0.972

APPENDIX A15. (Continued)

Event 23 June 1994	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	0.10	4.21	1.62	0.06	1.56
Manure	0.02	0.76	0.38	0.03	0.35
Average	0.06	2.03	0.90	0.04	0.86
Moldboard					
No Manure	0.20	18.2	8.37	6.66	1.71
Manure	0.07	1.36	0.40	0.00	0.40
Average	0.13	5.74	2.62	1.67	0.95
Average					
No Manure	0.15	9.02	3.96	2.33	1.63
Manure	0.04	1.04	0.39	0.02	0.37
P > F Values					
Tillage (T)	0.413	0.425	0.274	0.1742	0.078
Manure (M)	0.056	0.046	0.103	0.0988	<0.001
T by M	0.572	0.415	0.356	0.0987	0.014

Event 5 July 1994	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	7.34	57.6	55.5	28.27	27.2
Manure	7.11	68.9	92.2	46.61	45.5
Average	7.22	63.0	71.6	36.29	35.3
Moldboard					
No Manure	22.6	287	128.5	110.04	18.5
Manure	17.4	150	99.9	81.95	17.9
Average	19.8	208	113.3	95.10	18.2
Average					22.5
No Manure	13.0	129	84.6	62.09	28.7
Manure	11.2	102	95.9	67026	
P > F Values					
Tillage (T)	0.009	0.044	0.311	0.1031	0.209
Manure (M)	0.095	0.342	0.403	0.8069	0.402
T by M	0.157	0.131	0.048	0.3302	0.349

APPENDIX A15. (Continued)

Event 7 July 1994	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					
No Manure	0.00	0.00	0.00	0.0	0.00
Manure	0.00	0.00	0.00	0.0	0.00
Average	0.00	0.00	0.00	0.0	0.00
Moldboard					
No Manure	0.13	2.69	0.74	0.48	0.26
Manure	0.02	0.33	0.25	0.21	0.04
Average	0.08	1.21	0.47	0.32	0.15
Average					
No Manure	0.06	0.92	0.32	0.20	0.12
Manure	0.01	0.15	0.12	0.10	0.02
P > F Values					
Tillage (T)	0.187	0.188	0.235	0.2880	0.021
Manure (M)	0.202	0.173	0.188	0.1398	0.060
T by M	0.202	0.173	0.188	0.1398	0.067

Event 26 August 1994	Runoff (mm)	Sediment (kg ha^{-1})	TP g ha^{-1}	PP g ha^{-1}	DMRP g ha^{-1}
Ridge till					0.00
No Manure	0.00	0.00	0.00	0.0	0.00
Manure	0.00	0.00	0.00	0.0	0.00
Average	0.00	0.00	0.00	0.0	
Moldboard					
No Manure	0.01	0.16	0.79	0.48	0.66
Manure	0.00	0.17	0.34	0.21	0.09
Average	0.01	0.16	0.55	0.32	0.34
Average					
No Manure	0.01	0.08	0.34	0.20	0.29
Manure	0.00	0.08	0.16	0.10	0.04
P > F Values					
Tillage (T)	0.268	0.183	0.225	0.2880	0.337
Manure (M)	0.612	0.983	0.723	0.1398	0.485
T by M	0.612	0.983	0.723	0.1398	0.485

APPENDIX A16

Significant levels of the effects (EFF) of tillage (T), manure (M), and tillage by manure (TM) interactions on the 1994 daily rainfall runoff volume (RV) and associated sediment (SED), sediment concentration (CSED), total P (TP) amount, TP concentration (CTP), dissolved reactive molybdate P (DMRP) amount, DMRP concentration (CDMRP), particulate P (PP) amount, and PP concentration (CPP).

		month/day							
	EFF	4/25	4/26 11 am	4/26 13:30 am	4/29	6/23	7/5	7/7	8/24
RV	T	***	***	*	-	-	***	-	-
	M	*	-	***	**	*	*	-	-
	TM	-	-	***	-	-	-	-	-
SED	T	***	***	**	*	-	**	-	-
	M	*	*	***	**	*	-	-	-
	TM	-	-	***	-	-	-	-	-
CSED	T	***	***	**	-	-	-	-	-
	M	-	-	-	*	*	-	-	-
	TM	-	-	-	-	-	-	-	-

*** = P>F value 0.00-0.010; ** = P>F value 0.011-0.050; * = P>F value 0.051-0.100; - = P>F value greater than 0.100

APPENDIX A16. (Continued)

		month/day							
	EFF	4/25	4/26 11 am	4/26 13:30 am	4/29	6/24	7/5	7/7	8/24
TP	T	***	**	*	**	-	-	-	-
	M	-	-	*	-	*	-	-	-
	TM	-	-	*	-	-	**	-	-
CTP	T	**	**	-	*	-	-	-	-
	M	-	-	-	**	-	-	-	-
	TM	-	-	*	-	-	-	-	-
DMRP	T	-	**	-	*	-	**	**	-
	M	-	-	-	-	-	*	*	-
	TM	-	*	-	-	-	*	*	-
CDMRP	T	*	**	-	*	-	**	-	-
	M	-	-	-	***	-	*	-	-
	TM	-	-	*	**	-	*	-	-
PP	T	***	**	*	**	-	*	-	-
	M	-	-	*	-	*	-	-	-
	TM	-	-	*	-	*	-	-	-
CPP	T	***	-	-	-	-	-	-	-
	M	-	-	-	-	-	-	-	-
	TM	-	-	*	-	-	-	-	-

*** = P>F value 0.00-0.010; ** = P>F value 0.011-0.050; * = P>F value 0.051-0.100; - = P>F value greater than 0.100

IV. Research Objectives (continued)

D. Title of Objective: Identify economic risk of using plant available N estimation.

D.1. Activity: Measure economic and risk related impacts of using PAN estimates. This activity will use the demonstration farms in activity E.2 as part of the database in order to reduce expenses. Coordination will also be carried out between this activity and that in E.1. R.D. Alderfer will spend 3% of his time over the next two years on this activity.

D.1.a. Context within the project: This phase of the project draws on all other parts of the project to measure economic and risk related financial impacts of N management in the farm environment.

D.1.b. Methods: Costs of commercial inorganic N fertilizers and their application, will be compared to costs and production results using organic N sources on surveyed farms. Emphasis will be on measuring the costs and benefits of N management when yields and prices are uncertain. The climatic model in activity B.2 will be used to compute historical yields and estimated income over variable costs, using the long-term weather data from the West Central Experiment Station. Final results must be expressed in a form that most producers would be able to understand. Through the work in activities A and B, it will also be possible to estimate a value for swine and dairy manure.

D.1.c. Materials: Part-time clerical help will be hired to gather, and format electronic data during the last two months of the first year of the project. A masters student research assistant will be hired in the second year of the project to assist with analysis of economic and risk-related data.

D.1.d. Budget: $375.23 remaining on 6/26/95

D.1.e. Timeline:

	7/93	1/94	6/94	1/95	6/95
Gather first year results in electronic form			*****		
Analyze research and economic results			****	****	****
Write up final report					****
Prepare extension-type publication					****

Status:

The following section details the overall progress, alterations to the original methods, and related justifications. Keep in mind that the original Project Summary states:

"The ultimate goal of this project is to develop improved techniques to use animal manure in West Central Minnesota so that manure use efficiency is increased and the probability of N and P losses to the environment is decreased."

Uhn-Soon Gim (Ag. Econ. Ph.D. student) was hired on a one-quarter time graduate research assistantship, but had to be discontinued, because she was finishing her studies and leaving the country. Uhn-Soon was unable to make much progress with the concepts and methods outlined in the original plan.

The Plant Available Nutrient portion of this study, generated promising results, but at the culmination of the first year of the project, it was not evident where the crop income risks were involved, that were a part of section D. As a result, in the 3rd quarter of the project, methods were revised and the focus turned to the value of managing all manure nutrients rather than just PAN. Two reasons for focusing on N, P and K, were (1) that all nutrients are joint products in manure and jointly needed in crop production and (2) that a common failure in manure management is sampling and testing manure, when nutrient content can be incredibly variable (30 to 300 percent of the average nutrient levels).

A preliminary draft of the extension-type publication was completed. The title of that paper was "The value of Manure Sampling and Testing for Central Minnesota Dairy and Swine farms.

In the final quarter of the project, substantial revisions were performed and recalculations made. It was hoped that data from section E could could be analyzed, but most of the farms were too complex to include in the final draft of the paper. They did not fit well into the MAP software input forms. This is also explained in the paper.

Attached is the final draft of the paper, which outlines the methods used and calculations. Results outlined in the paper indicate that dairy and swine producers who are similar to the farms described in the paper will save $50 to $1000 annually. Larger farms would logically save more total dollars. Consult the paper and its findings for further detail and an estimated state-wide impact statement in the last section of the paper.

The Value of Manure Sampling and Testing for Central Minnesota Dairy and Swine Farms

R. Alderfer, M. Schmitt and R. Levins

The nutrient content of dairy and swine manure can vary greatly, depending upon handling, storage and a number of factors already outlined in Schmitt and Rehm (1992a and 1992b). Livestock producers are strongly encourage to take manure samples in order to measure actual manure nutrient content prior to application to crop land. The number of producers who have their manure tested is generally agreed to be low. In a survey of more than 400 hog producers, roughly 80 percent had not done a manure analysis in the last 5 years, and most of those who had sampled, indicated they sampled only one time (Schmitt, unpublished data). From 1991 data Montgomery indicated that the number of Minnesota livestock producers testing manure varied from 4 to 8.5 percent depending on the area of the state.

Reasonable average nutrient content for swine and dairy manure can be found in the Midwest Planning Service (WPS-18, 1995), software by Goodrich, Doanes and other sources. Schmitt and Rehm (1992a) state that, "Research results for manure analyses in Minnesota range from 25-300 percent of the average values." See Table D.1.1 for more precise representation.

The cost of manure sampling and testing are in the neighborhood of 20 to 40 dollars per sample, depending on the distance to the lab, the costs of stirring and sampling and the tests to be performed by the lab. The cost of **not** sampling are the errors of under or over applying manure and the related errors in purchases of commercial fertilizer to meet the crop fertility needs. This paper explores the costs of not sampling (benefits of sampling and testing) for swine and dairy producers.

Nutrient Content of Manures (all units are lbs. per 1000 gallons)				
	DAIRY LIQUID		SWINE LIQUID	
	MWPS	U of MN (range)	MWPS	Uof MN (range)
Nitrogen	24	29 (10-47)	36	48 (7-107)
P_2O_5	18	15 (6-28)	27	28 (3-64)
K_2O	29	24 (11-38)	22	22 (7-51)

Table D.1.1. Manure Nutrient Variability in Minnesota. (Wagner, Schmitt, Clanton and Bergsrud and MWPS).

The Farms

A farm management record supervisor for the Central Minnesota Farm Business Management Cooperative, laid out the following two farms as reasonable representatives of swine and dairy farms for its more than 700 member farms. The record supervisor was asked to make sure that both farms had adequate crop acres to feed the animals and manage the manure in a sustainable manner. Both are single operator, with some family labor input and seasonal part-time labor.

The swine farm is a 100 sow farrow-to-finish totally confined facility, with 900 tillable acres. The swine farm has 400 acres of corn, 400 of soybeans, and 100 of spring wheat. The Dairy farm has 80 cows, also in confinement, with 230 acres of corn, 50 of silage, 130 of soybeans 40 of alfalfa and 50 acres of oats.

Both farms created for this study have added acreage of buildings, open lots, homesite and non-tillable areas. Both farms store manure in pits and co-mingle manures from all stock. Problems with manure scheduling and application timing are not problems for either farm and are not part of the analysis of this study. Both knife their manure into the soil to take increased advantage of nutrients. This same equipment can be used to broadcast, rather than inject the manure, giving maximum flexibility for manure utilization. Both farms have inventories of growing stock and breeding animals throughout the year, according to their herd sizes and neither are in an expansion or contraction period, with regard to herd size.

These two farms have been created to make it easier for producers to compare to their own farms. Using these simple, but reasonable cases will also make analysis clearer and easier to follow. There are many complicating factors on real farms, such as multiple species, multiple pits with varying animals above each pit, as well as systems that separate solid and liquid components.

Each of the two farms will be examined at two different soil fertility levels, for a total four situations: (1) a swine farm with medium soil fertility for N, P and K, (2) the same swine farm, but with higher levels of each of the primary soil nutrients, (3) a dairy farm with medium soil fertility and (4) the same dairy farm, but with higher soil fertility. Analysis of the four base cases will be performed with University of Minnesota data in Table D.1.1 and per animal manure production, from MWPS. Twelve sets of inputs will produce the economic outputs that will be compared (2 species, 2 soils, 3 manure content levels).

Manure Quantity

The MWPS indicates that dairy cows produce 3,787 gallons of manure for each 1000 lbs of body weight. If cows averaged 1300 lbs. of body weight, total production would be 4,900 gallons of liquid manure per cow and 392,000 gal. per year, for the 80 cow herd. Using the same table and methods for the 100 sow swine farm, the average 400 lb. sow produces 581 gallons of waste per year. Annual sow manure would be 58,100 gallons. By finishing the pigs, the producer has 8 finishing pigs per litter on hand at any period of the year. The 8 pigs would average 125 lbs.of body weight each during their stay (weaning to finish) and would annually produce 3700 gallons of manure per pig, per sow. Together the farrow to finish operation would produce 428,100 (58,100 + 370,000) gallons of manure.

Current Crop Fertility

Both farm fertility situations are based off of the medium and high relative fertility levels for phosphorus and potassium (Table D.1.2). These levels were chosen as representative of the area by a University of Minnesota Soil Science professor.

Each farm has a constant history of livestock and therefore manure has been applied and organic N from previous years of manure is available to the crop. Manure broadcast in year one gives 30 percent available N the first year, 15 percent for year 2, 15 percent in year 3 and the remainder is lost (MWPS). There are similar second and third year results for injection or incorporation, but first year credits are higher and resulting losses are much lower.

Nutrient	Test Name	Relative Level - lbs./acre	
		Medium*	High*
Phosphorus (P)	Bray-P	26	36
Phosphorus (P)	Olsen-P	18	27
Potassium (K)	NH_4-Acetate	200	280

Table D.1.2. Soil P and K fertility *(from Rehm, Schmitt and Munter)

If the dairy producer spreads 392,000 gals. per year on 460 (500 - alfalfa) acres, the second and third year credit from previous years would be (392,000 gals./460acres x 0.3 organic x 29 lbs. N/1000 gals.) for a minimum of 7 lbs. organic N/acre. For the swine producers (428,000/900 x 0.3 x 48) a minimum of 7 lbs. organic N/acre.

Most producers would not cover all their acres with a uniform amount of manure every year. This would mean that some fields would have higher organic N credit and others lower. Allocating the N to all of the acres will result in the same total N needed (for the farm) in the current year, but the allocation of the N will differ across fields when organic N differs from field to field.

Yield Goals

The farm manager from the Central Minnesota Farm Business Management Cooperative set the acreage and yield goals for each crop, for the two farms. Tables D.1.3 and D.1.4 describe the two swine farm cases and the two dairy cases respectively. Fertilizer in the "To Apply" category was computed from tables in Rehm, Schmitt and Munter, and from the values of the "In Soil" column.

Swine Crop Plan with Med. Fertility Land			
New/Old Crop, Acres	Current Yield Goal	In Soil N - Bray P- K lbs./acre	To Apply* N - P_2O_5 - K_2O lbs./acre
Corn/SB, 300	120	47-26-200	97-30-50
Corn/Wht, 100	120	7-26-200	137-30-50
SB/C or W, 400	38	7-26-200	0-10-15
SpWht/SB, 100	50	27-26-200	58-20-55
Swine Crop Plan with High Fertility Land			
Corn/SB, 300	120	47-36-280	97-10-20
Corn/Wht, 100	120	7-36-280	137-10-20
Soybeans, 400	38	7-36-280	0-0-0
SpWht/SB,100	50	27-36-280	58-0-0
*Based on Rehm, Schmitt and Munter tables.			

Table D.1.3. Soil Nutrient Needs for the Swine Farm

Dairy Crop Plan with Med. Fertility Land			
New/Old Crop, Acres	Current Yield Goal	In Soil N - Bray P- K lbs./acre	To Apply* N - P_2O_5 - K_2O lbs./acre
Corn/SB, 130	120 bu/a	47-26-200	97-30-50
Corn/Corn, 100	120 bu/a	7-26-200	137-30-50
CornSil/Oats.50	18 T/a	7-26-200	137-30-50
Alfalfa, 40	4 T/a	50-26-200	0-25-70
Oats/Corn, 50	60bu/ac	7-26-200	33-10-25
SB/C or Oat,130	32 bu/ac	7-26-200	0-0-0
Dairy Crop Plan with High Fertility Land			
Corn/SB,130	120 bu/a	47-36-280	97-10-20
Corn/Corn, 100	120 bu/a	7-36-280	137-10-20
CornSil/Oats,50	18 T/a	7-36-280	137-10-20
Alfalfa, 40	4 T/a	50-36-280	0-10-10
Oats/Corn, 50	60 bu/a	7-36-280	33-0-0
SB/C or W,130	32 bu/a	7-36-280	0-0-0
*Based on Rehm, Schmitt and Munter tables.			

Table D.1.4. Soil Nutrient Needs for the Dairy Farm

Manure Nutrient Content Variability

If a producer does not sample and test manure, the actual content could be higher or lower than the average table values (Table D.1.1). Table D.1.5 values were established from the values in Table D.1.1, using Uof MN data. Base values are the average (and logical) values a producer would choose in absence of a manure test. **Low** and **High** levels of nutrients in the manure were established carefully, based on the University of Minnesota Columns in Table D.1.1. Since the range and expected value define a triangular distribution of potential test results (low, mode, high) the mode and high were averaged to get an approximation of the first standard deviation above the mean and the mode and low were averaged to approximate the first standard deviation below the mean.

With these computed values, there is still a 1/6 chance that actual manure N for swine could exceed the 78 lbs. per 1000 gallons, and a 1/6 chance that an untested sample could be less than 28 lbs. per 1000 gallons. Using an approximation of the first standard deviation, is a conservative approach. Using the ends of the distribution (range), overstates the probability of the event, and would inflate the values that result.

Liquid Manure Nutrient Content (in lbs per 1000 gallons)			
Stock, Manure Nutrients	N	P_2O_5	K_2O
Swine, High	78	46	36
Swine, Base	48	28	22
Swine, Low	28	16	14
Dairy, High	38	22	36
Dairy, Base	24	18	29
Dairy, Low	20	10	18

Table D.1.5. Liquid Manure Nutrient Variability.

Dollars spent on Commercial Fertilizer		
Stock, Nutrients	Low Soil Fertility	High Soil Fertility
Swine, High	$5,689	$4,645 - 3,340*
Swine, Base	8,025	4,630 - 822**
Swine, Low	10,079	5,030
Dairy, High	$4,276	3,579
Dairy, Base	5,038	3,786
Dairy, Low	6235	3,840
* Extra manure = 107,000 gal. (48-28-22) value net hauling.		
** Extra manure = 107,000 gal.(48-28-22) value net hauling		

Table D.1.6. Commercial Fertilizer Purchased.

Table D.1.6 was produced from the data in tables D.1.1 through D.1.5, using the Manure Application Software (MAP). The dollar values in Table D.1.6 are part of the MAP output and show the cost of commercial fertilizer needed to supplement the applied manure and meet the crop needs. Two cases resulted in leftover manure. Knowing how to value this leftover manure is difficult since the "manure market" is a thin one. There are buyers and sellers, but increasingly crop producers will buy excess manure, especially if they know its nutrient content. Local hauling rates are from $5 to $10 per 1000 gal., depending on distance and method of movement (trucking or portable irrigation).

Excess manure was priced as the value of the primary nutrients minus the cost of hauling (all on a per 1000 gal. basis). N, P_2O_5 and K_2O were valued at 12, 19, and 12 cents per pound, respectively, as inputs into MAP. The sale of the high analysis swine manure grosses (12cents x 78lbs + 19cents x 46lbs + 12cents x 36lbs) per 1000 gal. or $21.04 per 1000 gal. With a $7.00 per 1000 gal. hauling charge, a buyer should pay $14.04 net per 1000 gal. The revenue of $14.04 x 232 1000 gal. or $3340 should be subtracted from the amount of $4645 in Table D.1.6, to compute purchased fertilizer minus sales of extra manure. Medium or "base" level of swine manure resulted 107,000 gal. of slightly less nutrient content for a gross value of $14.68 minus hauling cost of $7.00 times the volume gives $822 of potential manure sales.

Manure Testing Benefit Calculations

With manure testing each of the 12 situations represents a mix of injection and surface application, as well as rates, that minimize purchased fertilizer inputs. Without manure testing a producer could naively choose the base (average) nutrient content for liquid manure, while the actual tested results of the manure content (if they had been performed) could easily be low or high. Taking simple difference from base to low and base to high results in Table D.1.7. These values are only the economics of the nutrients as represented in MAP. Not included are the potential of crop and environmental damage when too much manure was unknowingly applied. Further, it is possible that crop losses when unknowingly underapplying manure, could be greater than just the value of the under applied nutrients.

Assumed Content	Actual Content	Under or Over Applied	Costs Changes on Low Fertility Land	Costs Changes on High Fertility Land
Swine - Base	Low	Under	$2054	$1222
Swine - Base	High	Over	$2336	$2503
Dairy - Base	Low	Under	$1197	$54
Dairy - Base	High	Over	$762	$207

Table D.1.7. Economic Errors from Assuming Average Manure Nutrient Content.

Results

When farmers under applied nutrients it was assumed that crop losses were equal to the value of the nutrients <u>not</u> applied. This is a very conservative estimate, when one considers most crop yield response functions to N, P, and K. The economic losses from over application of manure nutrients do not include potential crop damage loss nor any environmental benefits which farm families and society would jointly benefit.

When a swine producer, like the one described, assumes an average table value for nutrient content in their manure, this study shows that reasonable economic errors are $1200 to $2500 on an annual basis, not including potential environmental impacts and their costs. Similarly, dairy farms, like the one described, could save $54 to $1197 annually, by testing their manures. Errors much larger are likely to occur (but with less frequency), since the values for high and low manure nutrient analysis were very conservative compared to the possible range of error that could potentially occur. With 15,000 hog farms and 13,500 dairy farms, the Minnesota pork industry could conservatively save $1000 per farm or $15 million dollars on an annual basis, and the dairy industry with 13,500 farms could annually save $500 per farm or $6.75 million dollars.

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IV. Research Objectives (continued)

E. Title of Objective: Conduct farm nutrient and cost inventory and disseminate information to producers.

E.1. Activity: Conduct farm nutrient and cost inventory of fertilizer and manure use patterns on selected farms in west central Minnesota. The scope of this activity has been reduced (fewer number of farmers to be contacted) and coordinated with activity D.1. Bruce Montgomery will spend 4% of his time over the next two years on this activity. R.D. Alderfer will spend 1% of his time on this activity over the next two years.

E.1.a. Context within the project: Data from participating demonstration farms and other similar livestock/crop farms in West Central Minnesota will be will be gathered for analysis in activity D.1.

E.1.b. Methods: On-farm nutrient inventories coordinated through the Minnesota Department of Agriculture will be conducted by their designee, with assistance from R.D. Alderfer at the West Central Experiment Station. Some station support for travel and miscellaneous expenses will be paid with station funds. Data includes soil and manure analysis, crop acreage, crop yield and farm plans. This will form the basis for farm-level simulation and analysis for measuring economic and risk related impacts.

E.1.c. Materials: Soil and manure tests on surveyed farms as needed. Soil maps and recorded farm-level data. Hired or contracted person will assist in on-farm data collection, and Richard Alderfer will assist when possible.

E.1.d. Budget: $0.00

E.1.e. Timeline:

	7/93	1/94	6/94	1/95	6/95
Identify potential farms for survey effort	***				
Contact farms and make final selection		****			
Collect on-farm data		****		****	
Summarize data					**
Prepare final report					**

Status:

The final report for this objective starts on the next page.

General Information

County educators (MN Extension Service) from Douglas, Grant, Stevens, and Swift counties were contacted and individually interviewed in the fall of 1994. Purpose of the interviews was to: inform them of the specifics of the project and overall goals; obtain pertinent county information (i.e. dominant farm types); 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 MDA researchers. Educators commonly made personal telephone contacts to the potential participants after the introduction letter was mailed (Appendix E-1). Approximately eight farmers were contacted in each of the four counties. Producers were selected on perceived management skills and farm types. Introduction letters, signed by the Commissioner of Agriculture, were mailed out in September, 1994. The letter's intent was to identify to the farmers: the overall LCMR project and purpose; the specific purpose of the nutrient management assessment; why they were specifically 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 database design were patterned after a previous successful project[1]. A copy of the inventory form is included in Appendix E-1. Timing, 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**. Soil and manure testing results were also collected if available. Specific field information focused on the 1994 cropping season. Crop types and manure applications[2] were also collected from the 1993 season for purposes of 1994 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.

[1] Effective Nitrogen and \ lanagement for Water Quality Sensitive Regions of Minnesota, L(91-93

[2] Manure applications st. .vith fall, 1993.

Farm Size and Crop Characteristics of the Selected Farms

Twenty three farms (Douglas-7, Grant-4, Stevens-3, Swift-6, and 3 Misc. farms connected with MDA Sustainable Agriculture demonstrations[3]) went through the inventory process. Fourteen (14) farms were dominantly dairy, eight (8) pork, and one (1) turkey (Table E.1.1). Total 1994 area covered was 13,649 acres of which 11,525 was cropland[4]. Average farm size was 593 acres ranging from 369 (Douglas) to 1,056 (Stevens) acres. Approximately 85% (501 acres) of the total acreage was classified as cropland.

Table E.1.1. General description of all farms participating in the nutrient management survey, 1994

		Total Acreage Inventoried			Average Acreage by Farm			
County	Farm	Total(1)	Crop(2)	Non-Crop	Total(1)	Crop(2)	Non-Crop	Average Herd Size
		.... Number of Acres	....	....	....	....	....	(Cows)
Douglas	7	2584	1691	893	369	241	128	58.6
Grant	4	1830	1547	283	458	387	71	60.0
Stevens	3	3168	2684	484	1056	895	161	0.0
Swift	6	2738	2336	402	456	389	67	61.5
Other(3)	3	3329	3269	60	1110	1090	20	67.0
Mean		**2730**	**2305**	**425**	**593**	**501**	**92**	**61.8**
Total	**23**	**13,650**	**11,525**	**2125**				
Percent Total	**100**	**84.4**	**15.6**					

(1) Includes owned, rented and rented out acres; (2) Includes pasture and set-aside acres; and (3) Includes farms in Montevideo, Sauk Centre and Fergus Falls.

Corn (43%), soybeans (31%), small grains (13%) and alfalfa (11%) accounted for over 99% of the cropland acres (Figure E.1.1 and Table E.1.2). In contrast, the cropland distribution across <u>all farms in the four county area</u>[5] was comprised of corn (32%), soybeans (36%), small grains (24%), hay (7%), and miscellaneous crops (7%) (Figure E.1.2). The selected farms were skewed towards higher corn and alfalfa acres and less small grains than the overall four county distribution. County-specific data are presented in Table E.1.2.

[3] Includes farms in Montevide Sauk Centre, and Fergus Falls. These farms were involved in der ·ations within different objectives of this project.

[4] Defined here as includin ops, forages, grains, fertilized pasture, set-aside and CRP acre

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

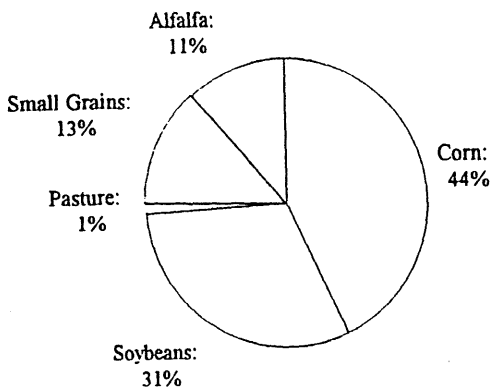

Figure E.1.1. Crop type distribution across all cropland acres of the 23 farms.

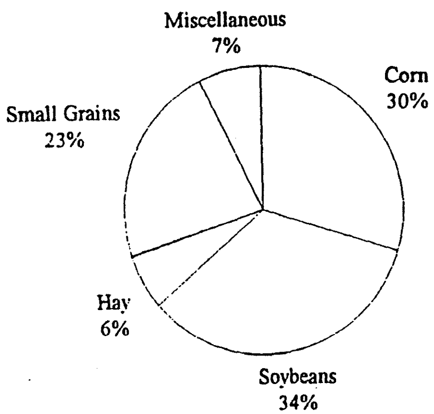

Figure E.1.2. Crop type distribution across all cropland acres in Douglas, Grant, Stevens and Swift Counties. Acreage based on 1993 statistics (MN Agricultural Statistics, 1994).

Table E.1.2. Average Distribution of Cropland Acres Per Farm By County - 1994

County	Corn	Soybeans	Alfalfa	Small Grains	Edible Beans	Other	Pasture	TOTAL
	In Acres							
Douglas	116	16	72	35	0	0	2	241
Grant	122	95	37	114	9	10	0	387
Stevens	365	416	0	101	0	13	0	895
Swift	139	106	80	42	0	2	20	389
Other	564	386	49	91	0	0	0	1090
Mean	**261**	**204**	**48**	**77**	**2**	**5**	**4**	
Total	**4924**	**3533**	**1273**	**1527**	**37**	**95**	**138**	
Total By Percent	**42.7**	**30.6**	**11.0**	**13.2**	**0.3**	**0.8**	**1.2**	

Commercial Fertilizer Use Characteristics on Selected Farms

Corn (84%) and small grains (14%) accounted for 98% of the total N commercial fertilizer use (Figure E.1.3). Mean N use was approximately 27,000 lb/farm. Average fertilizer N rate on corn acres was 116 lb/A (Figure E.1.4); 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. Soybeans and alfalfa received 12 and 13 lb/A, respectively, however the total acreage of either of these crops receiving commercial N is very limited (Table E.1.3).

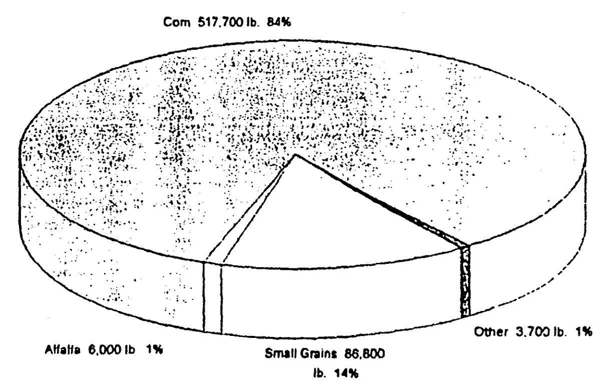

Figure E.1.3. Distribution of commercial nitrogen fertilizer by crop type. Total nitrogen supplied by fertilizer was 614,000 pounds across all 23 farms.

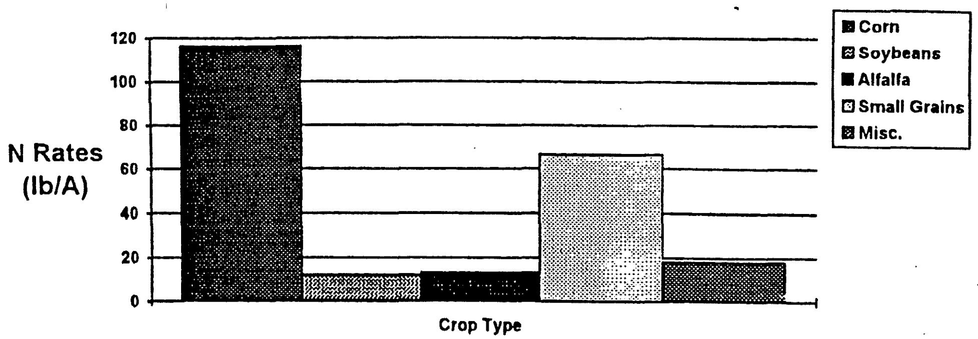

Figure E.1.4. Average N fertilizer rates across fertilized acres by crop type.

Crop	Acres Receiving N Fertilizer	Total N Applied (LBS X 1000)	Acres Receiving Phosphate Fertilizers	Total Applied Phosphate (LBS X 1000)
Corn	4447	517.7	4063	91.5
Soybeans	57	0.7	387	56.0
Alfalfa	456	6.0	604	41.4
Small Grains	1305	86.8	1165	22.9
Other	165	3.0	248	9.4
TOTALS	**6430**	**614**	**6467**	**221**

Table E.1.3. Distribution of Fertilizer Nitrogen and Phosphate On Cropland - 1994

Ninety (90%) and 83% of the corn acres received N and P_2O_5 fertilizer applications. Forty two (42) percent of the P_2O_5 tonnage was applied to the 1994 corn acres at an average P_2O_5 rate of 23 lb/A. Rates to other crops were considerably higher. One possible explanation is that producers may be building up fertility levels prior to bringing corn back into the rotation. Also it is a common practice to apply P_2O_5 and potassium fertilizers at sufficient inputs in a single application to maintain optimum production for 3-4 years.

Timing of N fertilizer applications is an important consideration in maximizing fertilizer use efficiency and minimizing environmental effects. Fall application of N is considered a BMP[6] in West-Central and Southwestern Minnesota if the proper source (anhydrous ammonia or urea) are selected and proper soil temperatures are reached. Fall applications should be delayed until the soil temperature is below 50 F at the 6-inch depth. Long-term climatic data from the West Central Experiment Station (Morris) indicate that soil temperatures will generally remain below 50 F after October 15. The average fall fertilization date from the selected farms was October 15± 2 days. The total time range for all fall N applications was October 14 through 21. Producers seem to be very consistent with the recommended practice.

Seventy-six (76%) of all N fertilizer to corn was either applied in the fall (45%), spring preplant (26%) or starter (5%) (Table E.1.4). Early sidedress[7] (2%) and late sidedress[8] (22%) made up the balance of the applications. Distribution of remaining N to non-corn acres focused on spring application (77%). As previously mentioned, a high percentage of "non-corn" N was applied to small grains.

Table E.1.4. Timing of N Fertilizer Applications On Corn and Non-Corn Acres - 1994

	Corn				Non-Corn			
Timing of Fertilizer N Applications	Total Acre	Total N (LBS X 1000)	% Total		Total Acre	Total N (LBS X 1000)	% Total	
Fall	1116	236	45.3		343	14.0	15.0	
Spring Preplant	1054	135	25.9		991	71.3	76.5	
Starter	1512	26	5.0		398	5.5	5.9	
Early SD	178	10	1.9		21	0.5	0.5	
Late SD	587	114	21.9		230	1.9	2.0	
TOTALS	**4447**	**521**	**100**		**1983**	**93**	**100**	

Nitrogen sources were dominated by anhydrous (59%), granulars (34%) which represented a large array of various formulas which were dominantly ammonium based, UAN[9] (5%) and urea (2%) (Figure E.1.7). UAN should not be fall-applied and is also not an ideal source for spring preplant applications. Timing of UAN has not yet been examined in this data set. However the total tonnage is low and the overall impacts from improper timing would probably be minimal.

The soil nitrate test is a recommended BMP[10] in West-Central and Southwestern Minnesota on medium-to-fine soil textures. Samples should be collected in either early spring (preferred time) or in the fall after soil temperatures drop below 50 F at the 6-inch depth. This test was used for

[6]Best Management Practices for Nitrogen Use in Southwestern and West-Central MN. 1993. G.W. Randall and M.A. Schmitt. AG-FO-6128-C.
[7]Defined as N applications while the corn height was between 2 to 8" tall.
[8]Defined as N applications on corn after height development of 8".
[9]Urea Ammonium N[illegible] (28% N by weight)
[10]Best Managemer[illegible] ces for Nitrogen Use in Southwestern and West-Central MN. 1[illegible] N. Randall and M.A. Schmitt. AG-F[illegible] 3-C.

only 16% of the co. es (Figure E.1.6). Considerably more cropland acres soil sampled for phosphorus and potassium (data not available at this time).

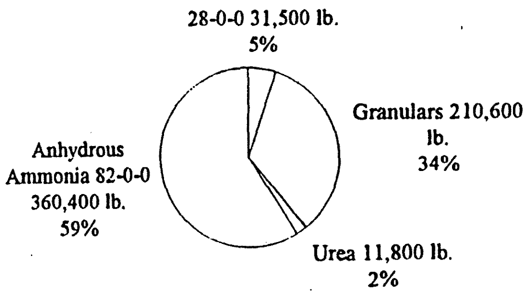

Figure E.1.5. Contributions of N from various fertilizer sources on selected farms.

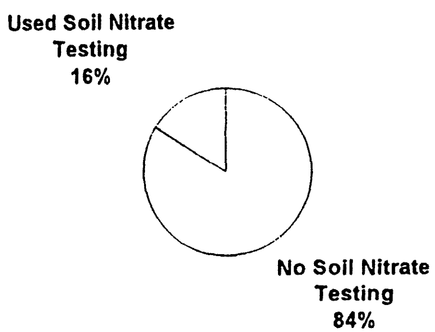

Figure E.1.6. Percentage of corn acreage which used the soil nitrate test.

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. Over 2,400 dairy animals (cows, calves, heifers, and steers) and a significant number of hogs were inventoried. A complete animal inventory, including nitrogen and phosphate produced and collected, are summarized in Table E.1.5[11].

Table E.1.5. Total Livestock Numbers: Manure Nitrogen and P_2O_5 Produced and Collected By Livestock Type In Sample Population - 1994

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	908	177.1	160.9	71.7	65.2
Calves & Heifers	1076	98.6	74.2	39.5	29.6
Dairy Steers	119	17.8	15.6	7.3	6.3
Boars	19	0.5	0.5	0.4	0.4
Sows & Litters	300	9.6	9.6	7.5	7.5
Feeders (20 - 50 pounds)	7885	0.9	0.9	0.7	0.7
Finishers (50 -240 pounds)	6955	31.5	31.5	23.9	23.9
Bulls	3	0.5	0.1	0.3	0.1
Beef Cows & Calves *	111	17.0	4.9	12.9	3.7
Beef Feeders	150	12.4	5.7	9.0	4.1
Sheep Ewes	80	1.3	0.8	0.4	0.3
Feeder Lambs	130	1.0	0.7	0.4	0.2
TOTAL	**17,736**	**368**	**305**	**174**	**142**

* Includes 106 calves

Estimated amounts of N and P_2O_5 produced from all livestock were 368,000 and 174, 000 pounds, respectively. Dairy and beef (cows, steers, calves and heifers) generated approximately 80% of the associated N and P_2O_5 produced from manure.

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Figure E.1.7. Amounts of nitrogen (total) generated by animal types across all selected farms. Total N produced was 368,000 pounds.

[11] Overall feeder and finisher inventory numbers reflect some "double counting" due to growth stage advancements.

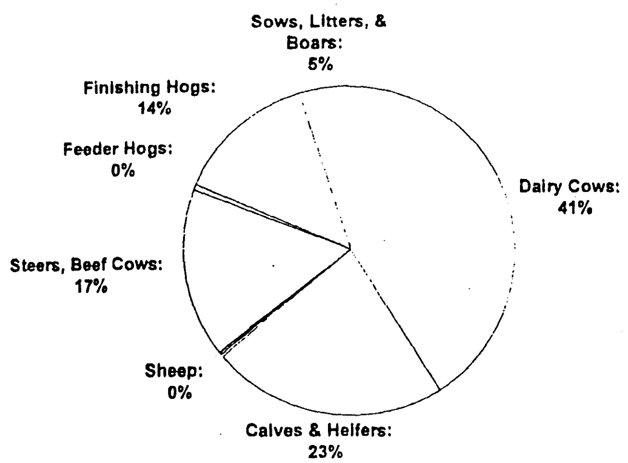

Figure E.1.8. Amounts of P_2O_5 generated by animal types across all selected farms. Total P_2O_5 produced was 174,000 pounds.

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.Table E.1.6 contains information on amounts of N and P_2O_5 collected and lost due to the various storage system. Figure E.1.9 illustrates the relative importance, ranked by the amount of total N retained after storage, of the various collection systems. 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.

Table E.1.6. Manure Nitrogen and Phosphate Collected And Storage Losses by All Livestock On All Farms - 1994

	Nitrogen Pounds X 1000			Phosphate Pounds X 1000		
Livestock Type	Collected	Lost	Retained	Collected	Lost	Retained
Daily Scrape/Haul	68.5	17.2	51.3	27.7	0	27.7
Unpaved Lot	16.1	8.1	8	6.6	1.96	4.64
Paved Lot	15.1	7.6	7.5	8.1	2.4	5.7
Animal Barn	52.1	15.6	36.5	22.1	0	22.1
Paved Pad	2.9	0.6	2.3	1.2	0	1.2
Slurry Store	17.9	3.9	14	9	0	9
Unpaved Pad	4.1	1.2	2.9	1.6	0	1.6
Earthen Pit	125.2	37.6	87.6	63.2	0	63.2
SUBTOTAL	**301.9**	**91.8**	**210.1**	**139.5**	**4.4**	**135.1**

Most of the dominant storage systems (earthen pits, slurry store, and barn storage) on these selected farms allowed produces some flexibility in the timing of manure application. Daily scrape and haul systems accounted for 24% of the total N retained (Figure E.1.9) and poses the one of the largest environmental potential threats due to winter application.

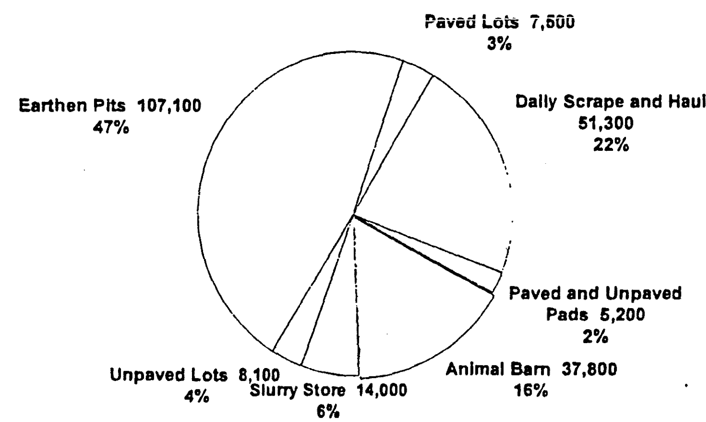

Figure E.1.9. Contributions of total **nitrogen retained after storage** by manure collection systems.

Nutrient losses fro ,ection and storage were estimated from accepted gu ies[12] for each individual storage system. Losses as a function of application methods and timing factors were calculated on a field-by-field basis (Table E.1.7). Participants were offered manure testing services as part of the program. Only four producers requested to have the manure tested even at no cost to them. None of the farms had manure testing data from samplings prior to the study.

Approximately 65,000 pounds of N was brought onto the farms from other sources[13]. The overall fate of manure-N, from excretion to "first year plant available", is summarized in Figure E.1.10. Accounting for all the various losses mechanisms by the time the manure-N is plant available, there were 146,000 pounds of N produced in 1994 across all farms.

Table E.1.7. Distribution of Applied Manure to Cropland, Application and Timing Loses, and Manure Nitrogen Plant Available - 1994*

Crop	Manure Nitrogen Applied Pounds X 1,000			Nitrogen Losses Pounds X 1,000			
	Total N	NH_4^+ (Inorganic)	Organic N	Mineralized Organic N 1st Yr. Avail	Application Losses	Timing Losses	Manure-N First Yr. Available
	Pounds Manure Nitrogen X 1000						
Corn	201.2	107.1	94.2	28.8	24.2	8.5	103.2
Soybeans	26.7	14.6	12.1	3.9	2.4	1.0	15.1
Alfalfa	8.5	4.3	4.2	1.3	1.5	0.3	3.8
Small Grains	22.5	11.3	11.2	3.3	2.9	0.8	11.0
Other	16.2	10.2	6.0	2.4	1.8	0.8	8.6
TOTAL	275	148	128	39.7	32.8	11.4	142

* Includes imported manure.

Fate and Amounts of Manure N Across the 23 Farms

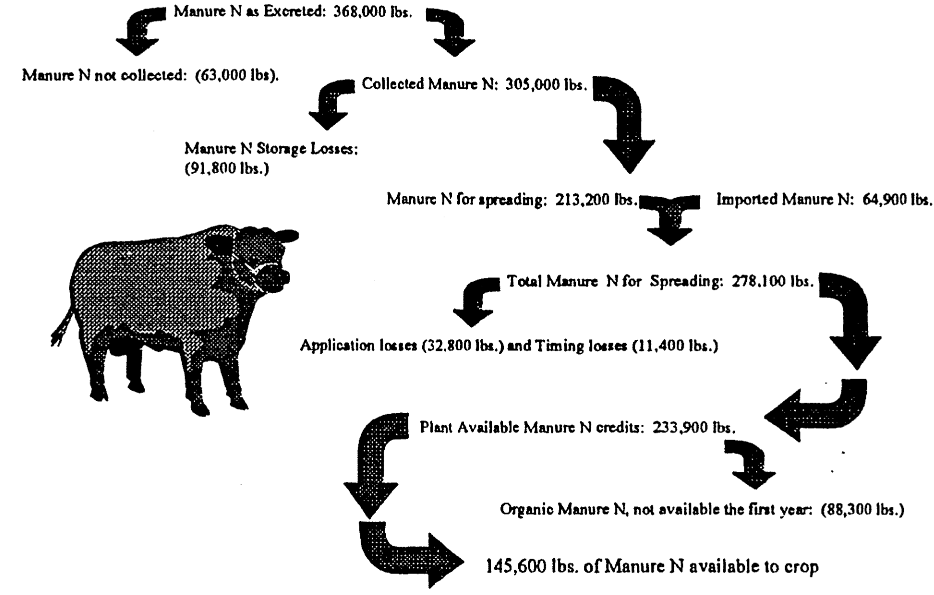

Figure E.1.10. Fate of manure-N across all storage and management factors.

In this study of West Central Minnesota farmers, a high percentage (72%) of the "first year available" N was applied to fields planted to corn in 1994 (Figure E.1.11 and Table E.1.7).

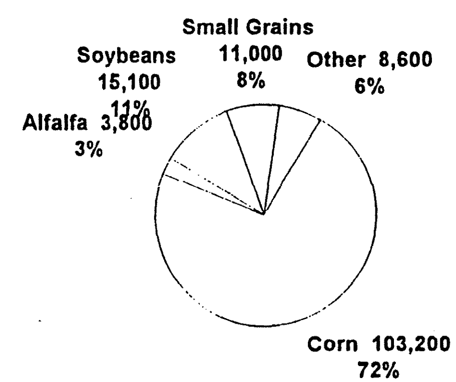

Figure E.1.11. Distribution of "first year available" nitrogen by crop type calculated on a tonnage basis.

[12]Livestock Waste Facilities Handbook, Midwest Plan Services, Iowa State University, Ames, Iowa. 1985.
[13]Therein referred to as "imported manure".

Relative Importance of N and P Sources on the Selected Farms

Commercial fertilizer (73%), manure (17%), and legume[14] (10%) contributed a total of 835,400 pounds of "first year available" N across all acreage. Commercial fertilizer (62%) and manure (38%) contributed a total of 356,100 pounds of phosphate.

Commercial fertilizer (74%), manure (15%), and legume (11%) contributed a total of 703,581 pounds of first year available N to **corn acres**. This is an average N rate of 143 lb/A across all corn acres.

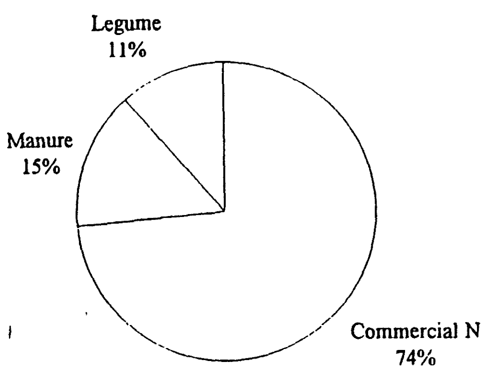

Figure E.1.12. Relative contributions from fertilizers, manures and legumes on first year available N across all corn acres. Total N inputs is 703,500 pounds.

[14]Approximated value; ' `gume credits have been calculated however the value across all ' has not yet been determined.

Nitrogen Balances and Economic Considerations

The corn yield goal across all participating counties was 116 bushels/A. Current University of Minnesota N recommendations to fulfill this goal is 112[15] lb/N/A. It is important to note that these recommendations[16] 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[17], N recommendations for 116-135 bushel corn following a Group 2 previous crop (crops with no residual N credit such as corn) would have been between 150 and 120 lb/A for soil organic matter groups of low-to-medium and high, respectively. In 1994, 100 lb/N/A would have been recommended for 111-130 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 45 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 (1993[18]) 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 credit which would have been correct several years ago. However, some producers in the western portion of Minnesota credit the soybeans similar to North and South Dakota by using a one pound credit for each bushel of beans produced. Due to the poor 1993 growing conditions and an average yield of 20 bu/A throughout most of west central MN, growers may have taken less than normal credits. Based only on the N fertilizer replacement value, proper crediting could save these producers approximately $9/A assuming no additional transportation and labor costs.

[15] Averaged across all fields classified as "Group 2" in the classification scheme of the UM recommendations.
[16] G.Rehm, M. Schmitt and R. Munter. 1994. Fertilizer recommendations for agronomic crops in Minnesota. BU-6240-E.
[17] G.Rehm and M. Sc' 1990. Fertilizer recommendations for agronomic crops in Minne' G-MI-3901.
[18] Referring to any ma... applications prior to those made in the fall of 1992.

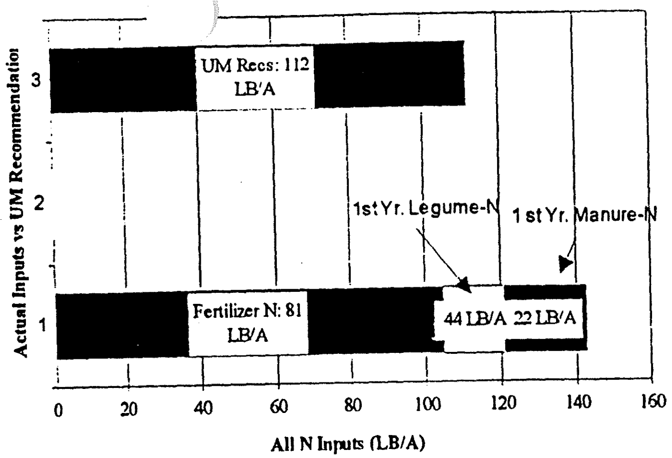

Figure E.1.13. Comparison of University of MN recommendations to N inputs (fertilizer, legumes and manure) across all corn acres. Total corn area in this analysis was 4,924 acres.

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

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

Nitrogen balances for all corn acres are broken down into these scenarios in Table E.1.8. Fertilizer N rates specific to each scenario is illustrated in Figure E.1.13. Rates in scenario 1 (no legumes, no manure) averaged 127 lb/A. Producers were clearly reducing N fertilizer by 20 lb/A for the soybean credit (N rate averaged 107 lb/A). 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 to 52 lb/A and 66 lb/A, respectively. These translate into reduction of 59 and 48%, respectively, in comparison to acres receiving commercial N rates.

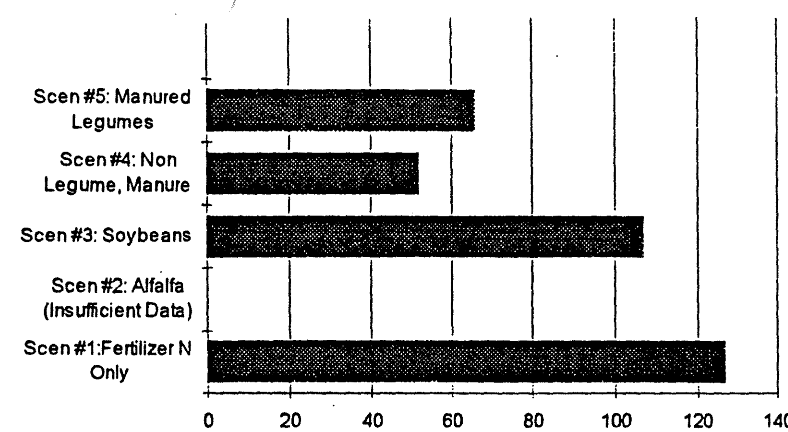

Figure E.1.14. Commercial fertilizer N rates on corn by management scenario.

Factoring in legume and manure credits into the process, the amounts in excess of University of MN recommendations are illustrated in Figure E.1.15. Excess amounts for scenarios 1, 3 and 4 are quite similar; the acres in scenario 4 are insufficient to make any conclusions. Clearly, producers are not taking sufficient credits in scenario 5 (manured legumes); over-application rates averaged 130 lb/A (Table E.1.9A).

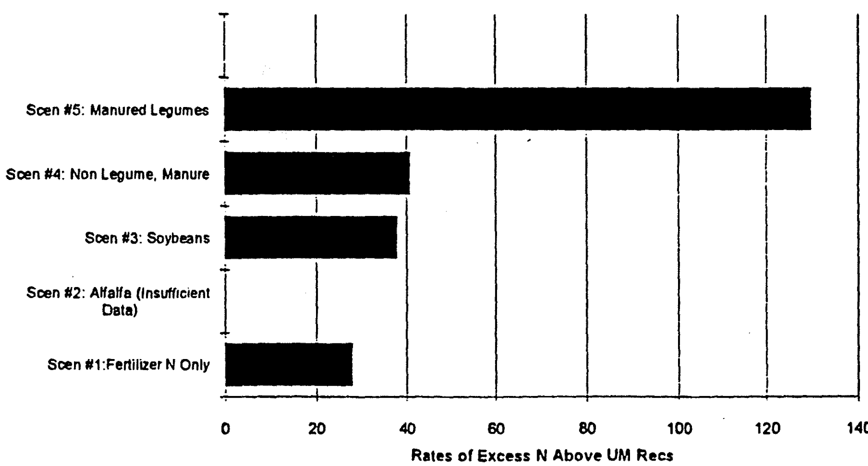

Figure E.1.15. Amounts of N in excess of University of Minnesota recommendations across the different management scenarios. Analysis includes all 4,924 acres.

Acreage distributions and N balances were then divided into two additional categories; ABOVE and BELOW UM recommendations. Data are given in Tables E.1.9B and E.1.9C respectively. Seventy-eight (78%) of the total corn acres were classified into the ABOVE category. Excess amounts of N average 55 lb/Acre. The remaining acres (22%) were classified as BELOW UM recommendations. Shortage amounts of N average 27 lb/A. Viewing the distribution of excess N from a water quality perspective, a helpful indicator is the cumulative excess N values found in Table E.1.8. These figures factor in both the total acres of any given scenario as well as the rate of excess (shortage) of N. Although the over-application rates (130 lb/A) of scenario 5 (manured legume crop) are much higher than the others, the total acres are relatively small. In contrast, the over-application rates on scenario 3 (previously soybeans, no manure) were relatively low (38 lb/A), however the acreage is high. Figure E.1.16 captures this concept by illustrating the relative excess N by the various management scenarios.

These results from the West Central producers is somewhat unique from the stand point that no one particular scenario dominates the direction where educational focus should be directed. Based on this graphic, educators will have to remain diverse in dealing with proper N fertilizer rates and proper crediting of both manures and legumes.

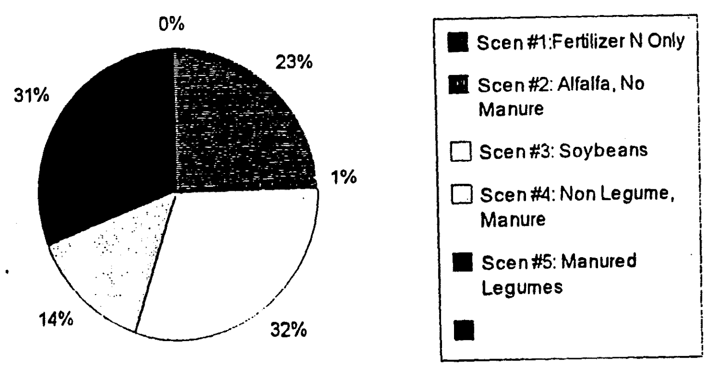

Figure E.1.16. Total excess N by the different management scenarios across all corn acres.

Table E.1.9A.
Nitrogen Inputs and Balances Across All Corn Acres

Scenario Number	Total Acres	PCN (LBS/A)	PCN Cumulative (LBS)	Manure N (LBS/A)	Manure Cumulative (LBS)	Fert N (LBS/A)	Fert N Cumulative (LBS)	N Rec. (LBS/A)	N Rec. Cumulative (LBS)	Excess or Shortage (LBS/A)	Excess or Shortage (LBS)
1	1,809	0	0	0	0	127	230,039	112	202,279	28	50,934
2	31	100	3,100	0	0	96	2,961	0	0	96	2,961
3	1,758	30	52,740	0	0	107	188,943	78	137,760	38	66,648
4	768	0	0	67	51,706	52	39,798	89	68,447	41	31,150
5	509	46	23,541	89	45,373	66	33,527	26	13,320	130	66,017
TOTALS FOR ALL SCENARIOS	4,875	16	79,381	20	97,080	102	495,267	87	421,806	45	217,709

Table E.1.9B.
Nitrogen Inputs and Balances Across Only Corn Acres
Above University of Minnesota Recommendations

Scenario Number	Total Acres	PCN (LBS/A)	PCN Cumulative (LBS)	Manure N (LBS/A)	Manure Cumulative (LBS)	Fert N (LBS/A)	Fert N Cumulative (LBS)	N Rec. (LBS/A)	N Rec. Cumulative (LBS)	Excess or Shortage (LBS/A)	Excess or Shortage (LBS)
1	1,607	0	0	0	0	144	231,991	111	179,150	33	52,806
2	31	100	3,100	0	0	96	2,961	0	0	96	2,961
3	1,327	30	39,810	0	0	117	154,910	70	92,486	47	62,476
4	357	0	0	75	26,678	90	31,956	91	32,536	73	26,205
5	486	46	22,391	89	43,187	69	33,680	22	10,904	136	65,963
TOTALS FOR ALL SCENARIOS	3,808	17	65,301	18	69,865	120	455,497	83	315,076	55	210,409

Table E.1.9C.
Nitrogen Inputs and Balances Across Only Corn Acres
Below University of Minnesota Recommendations

Scenario Number	Total Acres	PCN (LBS/A)	PCN[19] Cumulative (LBS)	Manure N (LBS/A)	Manure Cumulative (LBS)	Fert N (LBS/A)	Fert N Cumulative (LBS)	N Rec.[20] (LBS/A)	N Rec. Cumulative (LBS)	Excess or Shortage (LBS/A)	Excess or Shortage (LBS)
1	202	0	0	0	0	99	20,022	152	30,652	34	6,890
2	0	0	0	0	0	0	0	0	0	0	0
3	431	30	12,930	0	0	82	35,146	111	48,027	30	12,865
4	411	0	0	55	22,780	9	3,817	84	34,590	20	8,199
5	23	50	1,150	1	23	0	0	20	460	19	439
TOTALS FOR ALL SCENARIOS	1,067	13	14,080	21	22,803	55	58,985	107	113,729	27	28,383

Scenario Representative:

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.

Conclusions a[illegible] ummary of the Current Nutrient Manageme[illegible] ractices in West Central Minnesota

Twenty-three farms, covering over 13,000 acres, participated in the FArm Nutrient Management Assessment Program (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.

Producers in this study appeared to be using the correct timing of N fertilizer for fall and spring applications. Although just based on one year of information, fall-applied N was applied correctly based on long-term soil temperature data. Nitrogen sources were dominated by ammonium-based products which is particularly important in fall applications. Use of the soil nitrate test was limited only covering 16% of the corn acres, however, the previous wet season may have limited the usefulness of the test. Manure testing was very limited.

Manure accounts for approximately 15% of the 'first year available' N; legumes account for another 11%. Organic contributions are less than other regions of the state where FANMAP was used. Obviously proper crediting of both of these sources is needed to successfully manage N in any cropping system. On corn acres where no previous manure or legume credits existed to confound the rate selection process, producers appear to be in agreement with recommendations that were made by UM/MES **four to five years ago**. Recommended rates have been reduced a minimum of 20 lb/A. Consequently due to the development of more conservative recommendations. producers are over-applying fertilizer inputs by 28 lb/N/A. Roughly 89% of the acreage in this particular scenario were above UM recommendations.

Producers were reducing N fertilizer inputs following soybeans by 20 lb/A. Soybean crediting may have been less than normal due to the poor 1993 crop. Using the one pound N credit per bushel, which is typical in western Minnesota, producers were taking the appropriate credits. Statewide recommendations give soybeans a 40 lb/A credit.

Producers were basically reducing commercial N inputs by 75 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. A common practice is to apply manure to soybean acres which are followed by corn in the rotation. In this scenario, producers were found to reduce their commercial inputs by approximately 60 lb/A. However the combination of legume and manure credits, coupled with the fertilizer (average of 66 lb/A), creates a situation where over-applications in excess of 130 lb/A develops. In these situations, only a starter N application should be applied and would trim 40 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 over 70% of the "first year" available N was applied to corn in this study, only 25% of the corn acres received annual applications of manure. For a water quality perspective, the most significant impacts could be made by improving the N crediting process in this particular cropping scenario.

The process of manure crediting is greatly simplified with manure storage systems that allow for a minimal number of land application events. In general, most of the storage facilities of the selected farms in West Central Minnesota allowed some flexibility in storage capabilities and thus timing of application. Approximately 75% of the N retained after storage originated from a variety of systems that allowed for some storage benefits. Scrape and haul collection systems, a type of system which demands frequent applications, accounted for 25% of the N available for land application. In previously studies by the MN Extension Service, the nutrient value from manure has been found to be highly variable. Manure testing needs continual promotion as a fundamental part of a nutrient management plan. None 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. Producers can make significant reductions by using the most recent recommendations. Producers have made significant progress in the crediting of organic contributions although there are certain cropping sequences where large improvements need to be made.

Minnesota Department of Agriculture

Example of Introduction Letter to Potential Producers

DATE (612)297-3219

NAME
ADDRESS
CITY, STATE, ZIP

Dear :

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 pork and dairy industries are highly visible and are specialized segments 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.

Last summer, the University of Minnesota, the Minnesota Extensions Service and the Minnesota Department of Agriculture (MDA) received a research/educational grant from the Legislative Commission on Minnesota Resources. You may already be aware of some activities going on at the West Central Experiment Station and in west central Minnesota as a result of this grant.

One project is studying the influence of potassium on ridge-till crops compared to conventional methods of planting. Another project is the study of manure applied to corn at various times and with various methods such as sidedress compared to broadcasting and incorporation.

Another critical component of this project involves **you!** We simple do not have adequate information on how our pork producers and 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.

• 90 West Plato Boulevard • Saint Paul, Minnesota 55107-2094 • (612) 297-2200 • TDD (612) 297-5353/1-800-627-3529 •

I am asking you, along with 10 other dairy farmers and 11 pork producers to participate in a survey of nitrogen and phosphorus management practices. I have summarized a series of questions that you may already be asking yourself:

WHY WAS I SELECTED?

This project focuses on **pork producers and dairy farmers** from Douglas, Grant, Stevens and Swift 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 twenty-two (22) participants. It is critical that the farmers selected are representative of farming practices typical for the west central region of Minnesota.

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, soil test results, and factors motivating nitrogen decisions. Questions will be limited to the 1993 and 1994 cropping season.

HOW LONG WILL THE MEETING LAST?

The meeting time will depend 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 keep your information confidential. Only composite results will be published.

WHEN WILL THE MEETING TAKE PLACE AND WHERE?

We would like to visit with you, at your convenience, at your farm. Interviews would occur sometime late August or early September.

WHO WILL COME TO MY FARM?

Denton Bruening, a research assistant for the MDA, will be visiting with you and conducting the interviews. Denton is from a small farm in Lincoln county and is well acquainted with farm operations. He has conducted over 150 similar interviews with farms in central, south central, and southeastern Minnesota.

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 determine the effectiveness of future educational programs.

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 ______________________, your county extension educator within the next two weeks. 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 when Denton calls you for directions and to answer any additional questions you may have.

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

Sincerely,

Elton R. Redalen
Commissioner

ERR:DLB/clj

NITROGEN MANAGEMENT INTERVIEW CONTROL FORM-MORRIS

August 7, 1994

Farm Number____________________

NAME______________________________________ PHONE____________

ADDRESS____

____

DIRECTIONS____

____

DATE____________________________ TIME_________________________

c:\data\intervie.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:___________

Note:____

Farm Number____________________

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(cows)	_____	_____	_____

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. age at purchase	______	______	______
Avg. age at sale	______	______	______
Calf to finish:(birth to slaughter)			
35 - Feeders sold (total)	______	______	______
Feeders on hand	______	______	______
Avg. age at sale	______	______	______

Farm Number____________________

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___________

FARM NUMBER:______

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**________ **TIS**

Conveyed_____

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

20--Nursery (APPROX 20 LB)
21--GROWER(APPROX 50LB)
22--Feederpig days (APPROX 50LB)
23--Feeder to Slaughter(50LB TO 240)
24--Birth to Slaughter(0-240LB)
25--Mature Hogs
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

System 2: **Codes**________ **TIS**

Conveyed_____

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

20--Nursery (APPROX 20 LB)
21--GROWER(APPROX 50LB)
22--Feederpig days (APPROX 50LB)
23--Feeder to Slaughter(50LB TO 240)
24--Birth to Slaughter(0-240LB)
25--Mature Hogs
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

System 3: **Codes**________ **TIS**

Conveyed_____

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

20--Nursery (APPROX 20 LB)
21--GROWER(APPROX 50LB)
22--Feederpig days (APPROX 50LB)
23--Feeder to Slaughter(50LB TO 240)
24--Birth to Slaughter(0-240LB)
25--Mature Hogs
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

System 4: **Codes**________ **TIS**

Conveyed_____

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

20--Nursery (APPROX 20 LB)
21--GROWER(APPROX 50LB)
22--Feederpig days (APPROX 50LB)
23--Feeder to Slaughter(50LB TO 240)
24--Birth to Slaughter(0-240LB)
25--Mature Hogs
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

Farm Number______

System 5:_______________ Code________

	Animal Types	Animal numbers	Months Contributed
Months________ SYSTEM CAPACITY:			
MANURE TYPE:_____ (-LI1QUID 2-SOLID)			
Months________ SPREADING FREQUENCY:			
SPEADER CAP:________			
UNITS:________ (GAL, BUSH, TON)			

System 6:_______________ Code________

	Animal Types	Animal numbers	Months Contributed
Months________ SYSTEM CAPACITY:			
MANURE TYPE:_____ (-LI1QUID 2-SOLID)			
Months________ SPREADING FREQUENCY:			
SPEADER CAP:________			
UNITS:________ (GAL, BUSH, TON)			

Farm Number______

System 7:_______________ Code________

	Animal Types	Animal numbers	Months Contributed
Months________ SYSTEM CAPACITY:			
MANURE TYPE:_____ (-LI1QUID 2-SOLID)			
Months________ SPREADING FREQUENCY:			
SPEADER CAP:________			
UNITS:________ (GAL, BUSH, TON)			

System 8:_______________ Code________

	Animal Types	Animal numbers	Months Contributed
Months________ SYSTEM CAPACITY:			
MANURE TYPE:_____ (-LI1QUID 2-SOLID)			
Months________ SPREADING FREQUENCY:			
SPEADER CAP:________			
UNITS:________ (GAL, BUSH, TON)			

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________________________

____

PAGE

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________________________

____

Farm Number____________________

V. OFF FARM MANURE PURCHASE; GENERAL QUESTIONS

System number_______ (101 or more)

If you purchase, or receive free, manure:

What type of manure is it?______________________________

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

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

____

Last analysis____________________ per(vol.)____________________

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_________

Type of Animal_______ 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"
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 94 - 93 - 92	ACRES	TILL?	MAN?	*N*?	NOTES

Farm Number__________ CONTINUED

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

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). **A**mount **P**er **A**cre column is for manure applied where amount applied per acre is known. Measure column 1--gallon per acre 2--pounds per acre 3--bushel per acre

<---------------------These--------------------->**OR**<-----These------->

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:

____

____

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).______

IV. Research Objectives (continued)

E. Title of Objective: Conduct farm nutrient inventory and disseminate information to producers.

E.2 Activity: Develop a network of on-farm demonstrations, field days, winter meetings and publications to serve as the core of the educational effort. The scope of this activity has been cut in half because of the budget reduction. Data collected on the demonstration farms will also be used in activities D.1 and E.1. Doug Gunnink will spend 8% of his time on this activity over the next two years. R.D. Alderfer will spend 1% of this time on this activity over the next two years. P.R. Goodrich will assist in this activity. Mary Hanks will also allocate 2% of her time to this activity.

E.2.a. Context within the project: One of the most effective methods for disseminating management information to farmers is quality, local, on-farm demonstrations. Demonstrations offer the opportunity for farmers to see research results from numerous sources integrated into management and cropping systems designed for and utilized by farmers with similar enterprises and geographical/soil characteristics. The adoption of new guidelines presented in the on-farm demonstrations will decrease losses of NO_3-N while maintaining profitable farming. Information from the on-farm demonstrations and other project objectives will be summarized at field days, workshops, and through publications. The impact of this information will be increased because the data will come directly from local farmer's fields. Joint training of field staff of the Minnesota Extension Service, the Soil Conservation Service, and Soil and Water Conservation Districts will greatly multiply the information dissemination efforts by using "in-place" agency field staff as vehicles for information transfer.

E.2.b. Methods: The core of this education program is three strategically placed on-farm demonstrations of fertilizer and manure management strategies to reduce and/or make more efficient use of N for corn. Cooperators will be identified through County Extension Agents, Soil Conservation Service District staff, Soil and Water Conservation Service staff and non-profit advocacy groups. Cooperators and sites will be evaluated for demonstration suitability by on-site visits. Plots will be large to accommodate and simulate cooperators' operations and designed in a randomized complete block design with three replications. Treatments and crop responses will be characterized in enough detail to determine probable cause and effect on yield differences and inputs tallied to assess influences on profitability.

The on-farm demonstrations will focus on the more efficient use of manure N sources through examination of the use of split N applications based on the presidedress NO_3-N test. Using cooperator manure and soil testing records, manure will be applied at varying rates up to a maximum of approximately 168 to 180 kg N/ha available to the corn crop (may be modified to fit realistic yield goals). Treatments will vary the amount of additional inorganic N fertilizer to be applied as sidedress based on the presidedress NO_3-N test. Crop response will be used to evaluate the effectiveness of the NO_3-N test. Sites will be selected in silt loam or silty clay loam areas that are representative of typical soil types in the west central part of Minnesota. This basic protocol will vary based on the individual cooperator's operations and equipment available and will be reevaluated based on research from other project components as they become available.

Field days will be scheduled at each demonstration site. All cooperators, including farmers, will meet to evaluate the data collected and to determine the program for farmer and field staff workshops.. One workshop per year will be held at a location to be determined at that time. Presentations from both farmer cooperators and researchers will be included. Data from the demonstrations and other research components will be summarized into workshop presentation materials and fact sheets for general distribution in the west-central area of the state.

E.2.c. Materials: Materials necessary to accomplish this activity will consist of : 1) farm equipment, seed, fertilizer/manure supplied by farmer cooperators; 2) sample bottles and bags, use of existing assorted laboratory equipment for analyzing soil, water, plant tissue and manure samples; 3) scales for determining manure application rates, data forms, field markers, tape measure, other plot related miscellany, fact sheets, field maps and advertising flyers.

Data collected during the 2 years of the project as well as information obtained from previous projects and complementary projects will be integrated to produce the fact sheets and workshop presentation materials.

E.2.d. Budget: $0.00

E.2.e. Timeline:

	7/93	1/94	6/94	1/95	6/95
Identify cooperators	****				
Assess farming operation and design demonstration	****		****		****
Implement demonstrations and collect data	****		****		****
Field tours held in cooperation with local agency advisors	****	****		****	
Prepare data summaries and fact sheets	*****		*****		****
Field staff and farmer training workshop		****		****	

Status:

Three on-farm demonstrations of efficient nitrogen and manure management have been successfully completed. Two field tours were held in July, 1994 on the Steve Sunderland and Gordon Johnson Farms in cooperation with the University of Minnesota Extension Service at Montevideo and Fergus Falls. Manure management fact sheets were assembled from U of M and MDA sources, bound in easy to use three ring binders and passed out at the field days. Data summaries and an overall written review of the three projects have been completed and are included in Appendix E.2. Manure management information was presented by Sam Evans, U of M soil scientist at Morris at winter meetings at Staples Technical College on December 6, 1994, at Alexandria Technical College on February 10, 1995 and at the Morris West Central Experiment Station field tours on July 8, 1993 and July 14, 1994. Extension staff including agents and Manure Application Planner specialists are meeting in mid-June to review the demonstration summaries and schedule further farmer meetings. These summaries are a valuable addition to the existing manure management literature, providing a regional and farm-based experience.

Demonstration Design

Three on-farm manure management demonstrations were held in West-Central Minnesota in 1993-94 including the Steve Sunderland hog farm east of Montevideo, the Gene Fiedler cash grain farm north of Sauk Centre, and the Gordon Johnson dairy farm west of Fergus Falls. The purpose was to show the effectiveness of manure as a nitrogen source by promoting proper manure nutrient testing, estimation of nutrient availability, and spreader calibration. Yields in manured corn were compared to yields in corn fertilized with conventional rates of anhydrous ammonia.

The following demonstration design was used at all sites. Twelve adjacent field-size plots (300 ft. long strips), planted and harvested with standard farm equipment, were fertilized with four nitrogen treatments: a no nitrogen control, half rate manure, full rate manure (both according to manure lab analysis), and a conventional rate of anhydrous ammonia. The experimental design was a randomized, complete block with three replications and four treatments.

The sampling regime focused on the dynamics of the nitrogen status of the crop and soil through the season as well as corn grain yield and quality. The assessment of nitrogen dynamics included in-season measurement of leaf chlorophyll (using a chlorophyll meter) at corn V5 stage and at tassel, soil mineral nitrogen at V5 stage (to correlate soil mineral nitrogen to leaf chlorophyll readings), corn ear leaf nitrogen at silk, and basal stalk nitrogen (corn stalk from 6-14" above ground) at harvest.

As growers refine their nitrogen management, they continually need better diagnostic tools to assess the availability of both the nitrogen fertilizer applied and the nitrogen being mineralized from the organic pool. The chlorophyll reading at the V5 stage was used in hopes of assessing the corn nitrogen status quickly in the field and accurately enough to determine the need for a late nitrogen sidedress.

The ear leaf samples were taken as a standard assessment of the nitrogen status of the corn at the critical point of movement of nitrogen to the grain. Although this is a good diagnostic tool, it occurs too late for the grower to use as a quick test for a nitrogen sidedress. It is also cumbersome, requiring handling of samples and a turn-around time from the lab.

The basal stalk samples were taken to test for the amount of excess residual nitrogen not translocated to the grain. It is assumed that a high level of nitrogen in the stalk may reflect excess mineral nitrogen in the soil at the end of the season which would be susceptible to leaching.

Yields were taken by harvesting the entire 300 ft. strip with a combine and measuring with a weigh wagon. On the Sunderland farm we also hand subsampled 40 ft. of row per plot. Grain quality was assessed by measuring grain moisture, test weight, and protein.

Steve Sunderland Manure Rate Demonstration

Steve raises corn, beans and hogs on 760 acres located 8 miles east of Montevideo. His soil is a level, tile-drained lacustrine clay loam. Along with the corn and soybeans, Steve occasionally plants wheat to provide straw and to break weed cycles. He also has had alfalfa but only on his set-a-side acres.

Steve typically applies 120 lbs. N/acre as anhydrous ammonia to his corn in the corn-bean rotation and wanted to match this nitrogen rate with his liquid hog manure application. A laboratory analysis of a sample from the agitated pit revealed the following nutrient content:

Sunderland Hog Manure Nutrient Content

Nitrogen (total)	0.42 %
Phosphorous (P_2O_5)	0.20 %
Potassium (K_2O)	0.26 %
Moisture	96.4 %

We assumed that 65% of the total nitrogen would be available to the crop in the first year according to the U of M publication, "Fertilizing Cropland with Swine Manure"(1). Steve hired a professional custom applicator to knife in the manure in late fall (November 10) so we assumed minimal losses due to volatilization. We followed the sample calculation below.

To determine lbs. N/1000 gal. manure:

0.42 lb. N/100 lbs. water x 8.4 lb./gal. H_2O x 0.65 (first year avail.) = 2.29 lbs. N/100 gal. manure
or = 22.9 lbs. N/1000 gal. manure

To achieve 120 lbs. N/acre:

(120 lbs. N /acre)/(22.9 lbs. N/1000 gal. manure) = 5200 gal. manure/acre

The spreader was calibrated by measuring the acreage covered by one spreader load of known volume. 5200 gallons/acre were applied to the full rate manure treatment. A half rate was attempted but the spreader was limited to a minimum rate application of 3600 gallons/acre or 2/3 of the full rate.

Results

It appears that the process of testing the nutrients in the manure and calibrating the spreader allowed Steve to provide his corn with a similar amount of nitrogen from both the manure and the 120 lb. nitrogen as anhydrous ammonia (Table E.2.1). Steve harvested the entire 300 ft. strip by combine. A 40 ft. row subsample was also taken in each plot. The larger combine sample reduced much of the field variability compared to that found in the subsample yield. The nitrogen sufficiency of the full rate manure treatment was reflected not only in grain yield, but also in a trend across most variables measuring the corn nitrogen status through the season, including ear leaf nitrogen, chlorophyll reading at tassel, and grain protein. The exception to this trend was the chlorophyll reading at V5. Unfortunately, it appears that the chlorophyll readings do not detect nitrogen deficiency until it is too late to amend with a sidedress application.

The combined trends in basal stalk nitrogen (Table E.2.1) and soil nitrate on June 29 (Table E.2.2) suggest that the manure application achieved the desired crop yield without an increase in soil nitrate leaching potential. In fact the manured plots had a slightly lower level of nitrate in the 0-2 ft zone and a slightly lower total nitrogen in the basal stalk. The manured plots may have been less susceptible to leaching loss than the anhydrous ammonia treatment.

It is interesting to note that the no nitrogen control yielded 149 bushel/acre. This points out the great extent of the combined residual mineral nitrogen from the previous year and that mineralized in 1994. Growing conditions were very poor in 1993. It makes sense that extensive residual nitrogen remained in the soil in the spring of 1994. The 1994 growing season was excellent with a high potential for nitrogen release from the organic fraction of the soil.

At the outset of the project, Steve was leery of the economic competitiveness of manure as a fertilizer source so he did a rough cost:benefit estimate. Steve pays $47 to fertilize an acre with N-P_2O_5-K_2O at a rate of 120-60-20. He pays 1 penny/gallon to have his manure custom applied so the 5200 gallons/acre he used this year cost him $50/acre. So, he is roughly breaking even in the short-term while benefiting from long-term manure nutrient release and paying for the handling of the manure.

Overall, the project showed that manure is a dependable and economical source of fertility when managed properly.

Gordon Johnson Manure Rate Demonstration

Gordon's farm is a conventional dairy with corn, soybeans, wheat, and alfalfa hay. The farm is located 5 miles west of Fergus Falls on a loamy glacial till in a region of shallow lakes and potholes.

Gordon normally applies 100 lbs. N/acre to his corn after wheat. A lab analysis of the manure revealed 0.87% nitrogen or 17.4 lbs. N/ton of manure. Assuming that 60% of the nitrogen would be available to the crop in the first year (2), we calculated the spreading rate as follows.

To achieve 100 lbs. N/acre:

0.87% N x 2000 lbs./ ton = 17.4 lbs. N/ton manure
17.4 lb N/ton x 0.60(first year avail.) = 10.4 lbs. N/ton
(100 lbs. N/acre)/(10.4 lbs. N/ton) = 9 tons manure/acre

An attempt was made to calibrate the spreader by taking a subsample in the field using a plastic sheet of known surface area. A combination of high winds and the small size of the subsample yielded too much variability so the spreader was placed on load cells and the area covered by one spreader load was measured. The manure was applied at 10 and 5 tons/ acre for the full and half rate treatments, respectively.

Results

The manured corn yields were similar to the 100 lb N/acre anhydrous ammonia treatment. It is likely that the desired nitrogen nutrition was achieved as is reflected in the trends in ear leaf nitrogen and grain protein (Table E.2.3). The use of the chlorophyll meter did not prove to be an effective predictor of in-season crop nitrogen status.

Soil nitrogen levels in the manured plots were not greater than the conventionally fertilized corn (Table E.2.4). Basal stalk nitrogen was lower in the manured plots than in the anhydrous ammonia plots (Table E.2.3), suggesting that the manured plots may have been less susceptible to leaching of residual nitrate.

The control plots yielded well with no added nitrogen. The demonstration site was located relatively near the barn. Although it had no manure applied the previous year, it may have received extensive manure in the past.

The Johnson study, like the Sunderland study, again showed the dependability of manure as a primary source of nitrogen for corn.

Gene Fiedler Manure Rate Demonstration

The Fiedler farm is located between Sauk Centre and Westport in western Stearns County. Gene raises corn and soybeans on a loamy glacial till soil. He has been involved in a long-term soil building program that includes reduced but deep tillage and improved surface residue management. He became interested in using turkey manure as part of his soil building program.

The Fiedler demonstration was started in 1993. Gene has achieved 200 bushel/acre yields in recent years and wanted to supply 200 lbs. N/acre with the turkey manure. He has an existing manure nutrient data base that suggests an approximate nutrient value of 55, 73, and 72 lbs/ton of N, P_2O_5, and K_2O, respectively. Assuming that 75% of the manure nitrogen would become available in the first year (3), we applied 5 tons/acre to equal Gene's 200 lbs. N/acre as anhydrous ammonia. The manure was applied and incorporated on April 22, 1993.

The spreader was calibrated using Gene's farm scale. The spread was uneven due to uneven contact with the beaters. The spreader was a rear beater type. Slabs of manure would break away and deliver a heavy rate followed by a light rate of application.

Results

In 1993, all yields were low due to the cold, wet growing season (Table E.2.5). It was not a good test of manure nutrient availability. It is likely that soil nitrate levels were not as high during the growing season in the manured plots compared to the conventional treatment, judging from the nitrate levels on June 23 and the basal stalk nitrogen level at the end of the season (Tables E.2.5 and E.2.6). This trend was no long dent in the late fall (Table E.2.7). The organic nitrogen manure probably did not mineralize as much as would be expected in a more typical growing season.

In 1994, the farmer accidentally fertilized the plots with a uniform rate of 200 lbs. N/acre. The manured treatments yielded slightly higher than non-manured treatments (Table E.2.8), showing the residual mineralization from the manure applied the previous year. Soil nitrate was highest in the conventional plots (Table E.2.9). The same trend was present in the basal stalk nitrogen. The manure appears to have helped with nutrient availability even when nitrogen was expected to be sufficient. This occurred without an increase in nitrate leaching potential.

Summary

These demonstrations provided good local examples of refined manure management practices. There was strong interest in these farm communities to use this information to save money on fertilizer where manure is already being spread. The demonstrations showed that manure can be a dependable, environmentally sound sole source of nitrogen when combined with lab analysis and spreader calibration. The use of the basal stalk nitrogen test shows promise but needs to have threshold values developed for total nitrogen. The in-season chlorophyll meter test for crop nitrogen status did not predict nitrogen stress early enough for a late nitrogen sidedress but did detect nitrogen status at tassel.

References

1. Fertilizing Cropland with Swine Manure. Michael Schmidt and George Rehm. FO-5879-C. Minnesota Extension Service. University of Minnesota.
2. Fertilizing Cropland with Dairy Manure. Michael Schmidt and George Rehm. FO-5880-C. Minnesota Extension Service. University of Minnesota.
3. Fertilizing Cropland with Poultry Manure. Michael Schmidt and George Rehm. FO-5881-C. Minnesota Extension Service. University of Minnesota.

Table E.2.1. Sunderland Manure Rate Study Yield '94.

Treatment	yield by subsample (bu/a)	yield by combine (bu/a)	grain moisture (%)	test wt	grain protein (%)	ear leaf N(%)	- chlorophyll ratio* - at V5	at tassel	basal stalk N(%)
			--------------------	mean of three replications			--------------------		
No N (control)	135	149	21.0	55.3	7.9	2.3	1.07	0.86	0.24
2/3 rate manure	153	175	19.8	54.7	8.3	2.6	1.03	1.00	0.23
Full rate manure	177	186	19.7	55.4	9.0	2.5	1.01	1.02	0.30
Anhydrous	160	189	20.2	54.3	9.1	2.4	1.00	1.00	0.35
Pr>F	0.296	0.002	0.034	0.203	0.245	0.783	0.320	0.023	0.131

*Chlorophyll meter reading divided by that of the anhydrous treatment.

Table E.2.2. Sunderland Soil Mineral N (6-29-94).

Treatment	------- NO3 (ppm) 0-6"	6-12"	------ 12-24"	- NH4 (ppm) - 0-6"
	------- mean of three replications -------			
No N (control)	6.9	6.2	7.2	8.8
2/3 rate manure	6.6	6.2	6.5	8.0
Full rate manure	10.6	7.5	7.4	11.7
Anhydrous	18.2	23.0	14.5	13.4
Pr>F	0.059	0.340	0.160	0.063

Table E.2.3. Johnson Manure Rate Study Yield '94.

Treatment	yield (bu/a)	grain moisture (%)	test wt	grain protein (%)	ear leaf N(%)	- chlorophyll ratio* - at V5	at tassel	basal stalk N(%)
			-------------	mean of three replications	-------------			
No N (control)	135	24.5	54.6	8.0	2.30	0.99	0.97	0.25
1/2 rate manure	154	24.7	55.5	8.5	2.56	1.00	0.93	0.27
Full rate manure	160	24.3	54.5	8.9	2.43	0.98	0.98	0.31
Anhydrous	170	24.0	55.2	8.3	2.73	1.00	1.00	0.44
Pr>F	0.02	0.961	0.382	0.122	0.093	0.769	0.457	0.007

*Chlorophyll meter reading divided by that of the anhydrous treatment.

Table E.2.4. Johnson Soil Mineral N (6-20-94).

Treatment	------- NO3 (ppm) 0-6"	6-12"	------ 12-24"	- NH4 (ppm) - 0-6"
	------- mean of three replications -------			
No N (control)	5.8	3.5	2.3	5.5
1/2 rate manure	16.1	2.7	2.5	6.7
Full rate manure	16.3	4.2	2.2	5.8
Anhydrous	17.6	3.4	4.1	6.6
Pr>F	0.514	0.474	0.057	0.681

Table E.2.5. Fiedler Manure Rate Study Yield '93.

Treatment	yield (bu/a)	grain moisture (%)	test wt	basal stalk N(%)
	-------	mean of three replications	-------	
No N (control)	92	28.7	47.3	0.25
1/2 rate manure	97	28.3	48.0	0.27
Full rate manure	97	28.7	46.7	0.33
Anhydrous	99	29.0	47.7	0.39
Pr>F	0.617	0.487	0.201	0.095

Table E.2.6. Fiedler Soil Nitrate and Chlorophyll ratios,1993.

Treatment	-NO3 (ppm)- 0-2 ft. 23-Jun	-NH4- 23-Jun	-chlorophyll ratio*- at V5 23-Jun	at tassel 26-Jul
	---- mean of three replications ----			
No N (control)	5.2	3.9	0.99	0.85
1/2 rate manure	7.4	4.0	0.98	0.89
Full rate manure	6.5	3.7	1.01	0.91
Anhydrous	21.9	4.8	1.00	1.00
Pr>F	0.107	0.575	0.057	0.192

*Chlorophyll meter reading divided by that of the anhydrous treatment.

Table E.2.7. Fiedler Soil Mineral N (10-21-93).

Treatment	-NH4+NO3 (ppm)- 0-6"	6-24"
	-mean of three replications-	
No N (control)	12.9	6.1
1/2 rate manure	13.1	6.5
Full rate manure	16.1	6.7
Anhydrous	15.4	7.6
Pr>F	0.157	0.561

Table E.2.8. Fiedler Manure Rate Study Yield '94.

Treatment	yield (bu/a)	grain moisture (%)	test wt	grain protein (%)	ear leaf N(%)	- chlorophyll ratio* - at V5	at tassel	basal stalk N(%)
		--------------------		mean of three replications			--------------------	
No N (control)**	160	20.8	53.6	8.5	2.1	0.99	0.89	0.26
1/2 rate manure**	185	19.7	55.0	9.0	2.5	1.06	0.99	0.24
Full rate manure**	184	19.5	55.3	8.9	2.6	1.05	1.00	0.31
Anhydrous**	170	20.3	54.9	8.3	2.4	1.00	1.00	0.35
Pr>F	0.027	0.045	0.039	0.602	0.606	0.069	0.003	0.055

*Chlorophyll meter reading divided by that of the anhydrous treatment.
**Treatments listed are from previous year. All plots recieved 200 lb N as anhydrous in 1994.

Table E.2.9. Fielder Soil Mineral N (6-29-94).

Treatment	------- NO3 (ppm) 0-6"	6-12"	------ 12-24"	- NH4 (ppm) - 0-6"
	------- mean of three replications -------			
No N (control)	6.9	6.2	7.2	8.8
1/2 rate manure	6.6	6.2	6.5	8.0
Full rate manure	10.6	7.5	7.4	11.7
Anhydrous	18.2	23.0	14.5	13.4
Pr>F	0.059	0.340	0.160	0.063

V. Evaluation: This program will be evaluated by its ability to: 1) predict N availability from manure sources under varying climatic conditions by using the in-season soil and plant N status, 2) identify management practices to reduce sediment and nutrient runoff, 3) identify the risk on farm income of using manure as an N source, and 4) improve manure utilization on farms in West Central Minnesota.

VI. Context within field: Animal production is an important part of the agriculture in West Central Minnesota. Field studies started at Morris in the early 70's showed the benefit of manure on crop production (Evans et al., 1977; Evans, 1979). Manure applications were detectable for at least 15 years following treatment (unpublished data). Present University of Minnesota fertilizer recommendations contain provisions for manure credits, but these changes are based on 1) general manure analysis guidelines or 2) manure analyses from a specific manure source.

Farmers tend to give less credit to manure than suggested because 1) N fertilizer is cheap and 2) a little extra N gives them a cushion in case of N losses or less N available from manure than predicted. At the present time there are no in-season plant or soil tests to evaluate the N status. Activities A.1, A.2, C.1, and C.2 address this problem. The soil NO_3-N test has been useful for over 15 years in predicting N needs in western Minnesota. At the present time a large study is being completed assessing various soil tests in their ability to predict N availability in eastern Minnesota under higher rainfall conditions. Some of these tests involve early season soil tests. Fall NO_3-N tests on the long-term manure plots at Morris did not correlate with yields the following year. In this project, early season soil and plant tests will be used to evaluate the apparent N mineralization rate and N status of the corn crop. Climatic variables will also be measured so that apparent N mineralization can be modeled. This study will be the first in West Central Minnesota where detailed soil and climatic measurements will be made to explain variable apparent N mineralization rates.

The soil NO_3-N test in the top 30 cm of soil 4 to 5 weeks after emergence has been used (Fox et al., 1989) to separate N responsive from nonresponsive sites. Jokela (1992) found that the presidedress NO_3-N test reflected N availability with manure sources showing similar or slightly lower soil profile NO_3-N levels than agronomically equivalent rates of fertilizer N. Basal corn stalk samples collected after black layer and analyzed for NO_3-N have been used (Binford et al., 1990) to characterize degree of N excess during corn production.

In an effort to reduce wind and water erosion, farmers are turning to tillage practices which involve less soil tillage and which leave more crop residue on the soil surface. Activity C.1 addresses manure management under these reduced tillage conditions. It has been shown that surface runoff carries nutrients off the land which contributes to lake and stream degradation. The most critical element is phosphorus, but runoff of nitrogen can also cause problems. This phase of the project will assess tillage systems on their effect on nutrient runoff from manure and fertilizer sources.

VII. Benefits: If this effort is successful, the use efficiency of nutrients contained in manure will increase, producer costs for fertilizer will decrease, and the potential for movement of N and P into surface and sub-surface water will decrease.

VIII. Dissemination: The results obtained from this study will be presented to farmers in activity E.2, will be presented to peers at scientific meetings, and will be published in extension folders and scientific journals.

IX. Time: Due to the nature of the research in this project, additional funding might be needed in the future in assessing climatic variability effects and test validation of the computer models. The opportunity to measure the residual effect of manure is limited because of the 2-year length of this project.

X. Cooperation

A. Dr. Richard Alderfer, Production Economist. West Cent. Expt. Station, UM, will carry out the risk assessment phase (D.1), assist in the survey effort (E.1), and advise 1 graduate student.

B. Dr. Samuel D. Evans, Soil Scientist, West Cent. Expt. Station, UM, will act as project manager and direct the field experiment in activity A.1.

C. Dr. Philip R. Goodrich, Extension Agrcultural Engineer-Animal Waste, Agr. Eng. Dept, UM, will assist in the manure application studies (A.1 & A.2), adapt the model NCSWAP to run under the expert system (Smart Pitchfork) (Activity B.1), and will assist with informational meetings.

D. Dr. Satish Gupta, Soil Physicist, Soil Science Dept., UM, will act as a resource person on the N and P runoff phase of the study, activity C.1..

E. Dr. John Moncrief, Extension Soil Management Specialist, Soil Science Dept., UM, will assist in activities A.1 and C.1. He will act as primary advisor of 1 graduate student

F. Dr. J.A.E. Molina, Soil Microbiology-Soil Fertility, Soil Science Dept., UM, will incorporate the 1970-91 Manure Type Study data into the model NCSWAP, activity B.1. He will require the help of a post-doctorate fellow for a 6-month period.

G. Dr. Clive Reece, Soil Physics-Climatology, Soil Science Dept., UM will assist in characterizing the soil and climatic environment and make estimates of N plant available N, activity B.2. He will act as primary advisor of 1 graduate student.

H. Dr. Mark W. Seeley, Climatology, Soil Science Dept., UM, will assist in monitoring the soil and climatic parameters and developing weekly distributions of soil temperature and moisture conditions from long-term WCES weather data, activity B.2. He will act as primary advisor of 1 graduate student who will spend one-half time on this study.

I. Dr. Alan E. Olness, Soil Scientist, Soil Conservation Research Laboratory, USDA-ARS, will be responsible for monitoring NO3-N concentrations which develop as a function of soil water content and soil texture (Activity A.2). He will also assist in determining analysis procedures for Activity A.1.

J. Bruce Montgomery Special Projects Coordinator, Planning Division, Minnesota Department of Agriculture will collect information on manure and fertilizer use practices in West Central Minnesota (in coordination with Alderfer), activity E.1.

K. Doug Gunnink, On-Farm Demonstration Coordinator, Agronomy Services Division,Minnesota Department of Agriculture, will be in charge of developing on-farm demonstration plots and carrying out informational meetings in West Central Minnesota, activity E.2.

L. Dr. Mary Hanks, Director, Energy and Sustainable Agriculture Program, Agronomy Services Division, Minnesota Department of Agriculture, will review and supervise the demonstration activity

E.2. She will also participate in planning sessions with cooperators, prepare reports, and manage the budget for this project.

XI. Reporting Requirements

Semiannual status reports will be submitted not later than January 1, 1994, July 1, 1994, January 1, 1995 and a final status report by June 30, 1995.

XII. Literature Cited

Literature Review

Livestock production is a major component of agriculture in Minnesota. Minnesota had about 680,000 dairy cows and 4,750,000 hogs on Minnesota farms in 1991 (Minnesota Dept. of Agriculture, 1992). Using average manure production figures (Midwest Plan Service, 1975) these animals produce about 110,000 tons of N and 30,000 tons of P (70,000 tons of P_2O_5) per year. In 1991 fertilizer use in Minnesota amounted to 650,000 tons of N and 260,000 tons of P_2O_5. In west central Minnesota livestock production accounts for slightly over 40% of the total farm income. Therefore, livestock are an important part of the farm economy and manure has the potential to supply a large portion of the nutrient needs of Minnesota crops.

Field studies started at Morris in the early 70's showed the benefit of manure on crop production (Evans et al., 1977 and Evans, 1979). Benefits of manure application were detectable for at least 15 years following treatment (Evans et al., 1986). Present University of Minnesota fertilizer recommendations for corn (Rehm and Schmitt, 1989) contain provisions for manure credits, but these credits are based on 1) general manure analysis guidelines or 2) manure analyses from a specific manure source. Specific bulletins developed for fertilizing with dairy manure (Schmitt and Rehm, 1992) and swine manure (Schmitt and Rehm, 1992) use generalized guidelines, but do not address specific situations. Farmers tend to give less credit to manure than suggested because 1) N fertilizer is cheap and 2) a little extra N gives them a cushion in case of N losses or less N available from manure than predicted. There is no method available to directly measure the N contribution from previous manure applications.

Fall NO_3-N tests have been used for over 15 years for predicting N needs in western Minnesota. The present guidelines for corn (Rehm and Schmitt, 1989) adjust the N rate based primarily on the NO_3- N in the top 60 cm of soil either in the fall or spring. In recent years many workers (Fox et al., 1989; Jokela, 1992; Magdoff et al., 1984; Magdoff et al., 1990; and Magdoff, 1991) have been instrumental in developing a 30-cm depth pre-sidedress soil test to predict N availability. They found that a NO_3-N concentration of 20-25 ppm in the upper 30-cm soil zone is adequate for maximal grain yield. More recently Blackmer et al. (1989) in Iowa has found a similar model holds. Ongoing work in Minnesota (Randall and Schmitt, 1992) shows some sort of early spring or early season soil NO_3-N test holds promise for predicting N needs in eastern Minnesota where the 60-cm fall test does not work. Some of the studies mentioned above have sites with a manure history, but the bulk of the work was done on non-manured sites.

Other methods are being developed to assess N sufficiency. Recent work in Nebraska has shown that a chlorophyll meter can be used to monitor the N status of corn, but the meter needs to be calibrated against known reference strips in the same field. A final tool that has been used is a end-of-season NO_3-N concentration of basal stalk samples. This was used to measure degree of excess N at that time of year (Binford et al., 1990).

Doran et al. (1990) and Skopp et al. (1990) have advanced the concept of an optimum water content for maximal aerobic microbial activity. Depending on soil texture, readily available organic matter, and bulk density; they estimated that the optimum water filled pore space for nitrification in several soils is about 66%. Measures of NO_3-N and NH_4-N levels in the early season as influenced by soil moisture levels and texture would be useful in predicting apparent N mineralization. The inclusion of this type of data would improve the predictive model.

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 al., 1969; Römkens et al., 1973; Wendt and Corey, 1980; Mueller et al., 1984a,b;. Andraski et al., 1985a,b; 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. 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. This was due to manure acting as mulch and retarding the flow of water until the soil was able to absorb it.

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<u>Attachment A</u>

VITAE

PROGRAM MANAGER

Dr. Samuel D. Evans

Soil Scientist, West Central Expt., Station, UM
Ph.D. Soil Science, Purdue Univ., 1963.
M.S. Soil Science, Purdue Univ., 1960.
B.S. General Agriculture, Univ. of Illinois, 1955.

Dr. Evans' research interests are in soil fertility and soil management on soils in west central Minnesota. Research includes both long- and short-term studies on nitrogen requirements of crops commonly grown in the area; phosphorus and potassium studies on corn, soybean, and alfalfa; manure evaluation; and crop management studies involving such variables as tillage, nitrogen rates, crop rotation, and varieties.

<u>Recent Publications and Presentations</u>:

Rehm, G.W., S. D. Evans, W.W. Nelson, and G.W. Randall. 1988. Influence of placement of phosphorus and potassium on yield of corn and soybeans. Journal of Fertilizer Issues 5:6-13.

Olness, Alan, Jana Rinke, H-M Hung, and S.D. Evans. 1989. Effect of tillage on redox potential of a Tara silt loam. Soil Sci. 148:265-274.

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Lueschen, W.E., J.H. Ford, S.D. Evans, B.K. Kanne, T.R. Hoverstad, G.W. Randall, J.H. Orf, and D.R. Hicks. 1992. Tillage, row spacing and planting date effects on soybean following corn or wheat in rotation. J. Prod. Agric. 5:254-260.

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Evans, S.D., G.A. Peterson, D.G. Westfall, and E. McGee. 19912. Nitrate leaching in dryland agroecosystems as influenced by soil and climate gradients. Agronomy Abstracts, p. 330. (Poster Paper, Div. S-6, ASA Meeting, Denver, CO, Oct. 31, 1991.)

COOPERATORS

Dr. Richard D. Alderfer

Assistant Professor, Dept. of Ag. & Applied Economics, U of MN
Ph.D. Agricultural Economics, Michigan State Univ., 1991
M.S. Extension Education, Purdue Univ., 1985
B.S. General Agriculture, Purdue Univ., 1979

Dr. Alderfer's graduate program focus was on production economics and marketing, with a minor in System Science (School of Engineering). His research and extension teaching at the West Central Experiment Station have focused on farm enterprise income risks and their management. His practical background of six years as an Extension Agent have helped him focus on results that producers want and can understand.

Recently, Dr. Alderfer co-authored a Univ. of MN staff paper on the effects of taxing nitrogen fertilizer. He is also working on two other small projects related to nitrogen fertilizer on corn.

Dr. Philip R. Goodrich

Associate Professor, Agricultural Engineering Dept., U of MN
Ph.D. Agricultural Engineering, Purdue Univ., 1970
M.S. Agricultural Engineering, Purdue Univ., 1968
B.S. Agricultural Engineering, Cornell Univ., 1963

Dr. Goodrich's research interests are to determine the best method to manage animal waste and reduce the potential groundwater and surface water pollution hazard of these materials. Research includes using separtation and fermentaiton to produce marketable products with monetary value. The development of computer systems using artificial intelligence to assist the dairy ndustry to remain viable and contributng to the economy of our state include manure management modules.

Recent Publications:

Goodrich, P.R., B.J. Conlin, G.R. Steuernagle, and J.K. Reneau. 1990. The DAIRY MANAGER. *In*: Proceedings of The 3rd International Conference on Computers in Agricultural Extension Programs. Orlando, FL. February, 1990. Florida Extension Service, University of Florida, Gainesville, FL. pp 542-546.

Goodrich, P.R. 1991. Manure management in an urban environment. *In:* Environmental Challenges and Solutions in Agricultural Engineering. Agr. Univ. of Norway, As, Norway. pp 28-33.

Goodrich, P.R., and Z. Sun. 1991. A User Manual for Smart Pitchfork. MSDOS Version, Department of Agricultural Engineering, St. Paul, MN. 15 pp.

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Achkari-Begdouri, A., and P.R. Goodrich. 1992. Bulk density and thermal properties of dairy cattle manure. Biosource Technology 40:225-233.

Fox, E.J., C.J. Clanton, P.R. Goodrich, B.D. Backus, and H.A. Morris. 1992. Liming an anaerobic cheese whey digestger. Transactions of the ASAE 35(1):269-274.

Douglas Gunnink

On-Farm Research Coordinator, Ag Planning & Development Division, MN Dept. of Agr.
B.S. Agricultural Education, University of Minnesota, 1975

Mr Gunnink is on-farm research coordinator for the Energy and Sustainable Agriculture Program in the Minnesota Department of Agriculture. He has had experience as a county extension agent, adult farm management instructor, contractor for Farmers Home Administration, project manager for Rural Ventures, Inc., and vocational agriculture instructor.

Dr. Alan Olness

Soil Scientist, USDA-ARS N.Central Soil Conservation Res. Lab., Morris, MN
Ph.D. Soil Science, University of Minnesota, 1973.
M.S. Soil Science, University of Minnesota, 1967.
B.S. Soil Science, University of Minnesota, 1963.

Dr. Olness' research responsibilities are focused on conservation cropping and factors influencing nitrogen use efficiency. Time and rate of nutrient accumulation and form of nutrient accumulation have been an area of particular interest. Additional research has focused on chemical transformations and availability in soil as affected by aeration and tillage.

Recent Publications:

Olness, A., G.R. Benoit, K. Van Sickle, and J. Rinke. 1991. Effect of planting date and thermal energy intensity on rate of phosphorus and potassium accumulation by maize (Zea mays L.). J. Agron. and Crop Sci. 167:497-502.

Basta, N.T., and A. Olness. 1992. Determination of alachlor, atrazine, and metribuzin in soil by resin extraction. J. Environ. Qual. 21:497-502.

Olness, A., and G.R. Benoit. 1992. A closer look at corn nutrient demand. Potash and Phosphate Inst. Better Crops. 76:18-20.

Dr. Satish C. Gupta

Professor, Soil Science Department, Univ. of MN
Ph.D. Soil Science, Utah State Univ., 1972
M.S. Soil Science, Punjab Agric. Univ., 1968
B.S. Soil Science, Punjab Agric., Univ., 1966

Dr. Gupta's research involves modeling of soil physical properties and processes in crop production and environmental protection systems. Recent projects include macropore, tillage and surface seal effects on water entry into karst soils of southeast Minnesota, modeling of heat and water flow under various tillage systems, models of soil compaction from agricultural machinery, modeling the optimum use of crop residues for erosion control and bioenergy,and use of dredged and waste material for improving agricultural lands. Dr. Gupta's earlier work involved modeling simultaneous transport of water and salt through soils.

Selected Publications:

Ela, S.D., S.C. Gupta, and M.J. Rawls. 1992. Macropore and surface interactions affecting water infiltration into soil. Soil Sci. Soc. Am. J., 56: 714-721.

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.

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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).

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Dr. Molina'a focus of attention is on the living components of the soil. Research considers the soil biological activity from two points of view: the holistic approach, which uses computer modeling to study the relationship between the dynamics of soil-carbon-nitrogen transformations, microbial activity, and crop growth; and the ecology of selected soil organisms--for example, ammonium oxidizers, microorganisms associated with earthworms.

Recent Publications:

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.

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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.

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Dr. John F. Moncrief

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M.S. Soil Science, Montana State Univ., 1977
B.S. Soil Science and Natural Resource Management, Univ. of Wisconsin-Stevens Point, 1975

Dr. Moncrief's teaching and research responsibilities are focused in the area of tillage effects on soil physical and chemical properties. Of special interest is how tillage affects: water and contaminant transport through soil; and influences on soil biological effects on nitrogen and carbon transformations from organic sources.

Dr. Moncrief has extensive experience with technology transfer efforts to help farmers adopt systems that minimize environmental degradation. Program efforts include training agency field staff of the Minnesota Extension Service, the Soil Conservation Service, and Soil and Water Conservation Districts.

Recent Publications:

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

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

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

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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.

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Mr. Montgomery has 13 years experience at North Dakota State University working in the area of agriculture and environmental quality. He administered several research grants and has authored 10 publications dealing with nutrient and pesticide movement. His research interests were focused on quantifying environmental impacts of agricultural practices and the development of nitrogen best management practices.

Mr. Montgomery presently holds a Soil Scientist position with the Minnesota Department of Agriculture and his primary responsibility is the development and implementation of the Nitrogen Fertilizer Management Plan. The agency's role in the plan is to identify practices, and respond in areas of the state where ground water supplies are affected by agricultural activities. Mr. Montgomery recently researched and authored the MDA's portion of the legislatively mandated "Nitrogen in Minnesota Ground Water".

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.
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.
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Dr. Seeley is responsible for coordination and operation of the Minnesota Cooperative Agricultural Weather Advisory Program and the Minnesota Agricultural Weather Network (including the automated weather station network). He also provides educational programs in weather/climate and their application to management of agricultural enterprises and natural resources. He also conducts applied research in appropriate areas.

Recent Articles, Presentations and Publications:
Seeley, M.W., and J. Zandlo. 1992. Some applications of Minnesota's Centennial Climate Data Base. Presentation at Minnesota Water '92, Minneapolis Convention Center, Minneapolis, MN.
Seeley, M.W. Weather, climate and cereal growth. 1992. Presentation to the Minnesota Small Grains Institute, Crookston, MN.
Seeley, M.W. 1990. Climatic cycles: Uncertainties for 1991 and beyond. Presentation to the 1990 Soils and Fertilizer and Agricultural Pesticides Short Course. Minneapolis Convention Center, Minneapolis, MN.
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. 19:86-91.
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).

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Ph.D. Soil Science, Washington State Univ., 1991
M.S. Soil Science, Cornell Univ., 1988
B.S. Plant and Soil Biology, Univ. of California-Berkeley, 1983

Dr. Reece recently joined the faculty of the Soil Science Department and is developing a research program in the area of climate-soil physics and effects on plant growth.

Recent 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 13:229-234.
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.