1993-95 LCMR RESEARCH PROJECT - ABSTRACT

Project Title: Developing Soil Specific Nitrogen Management As A BMP
This project was funded by Oil Overcharge Fund

Program Manager: Bruce R. Montgomery
Agency Affiliation: Minnesota Department of Agriculture
Legal Citation: M.L. 93 Chptr. 172, Sect. 14, Subd. 3(l).
Total Biennial LCMR Budget: $294,000

Statement of Objectives:

A Develop technology that would create a soil condition map (organic matter, residual nutrient, etc.) to allow variable N inputs.

B. Determine the appropriate N rate and other BMPs in a soil specific manner using a soil condition map.

C. Conduct demonstrations and evaluate the economic and environmental impact of existing variable rate technology.

D. Integrate results into a user friendly decision aid for local use that can also be used as an educational tool that would promote site specific BMPs.

Overall Project Results:

The project was successful in demonstrating that variable rate fertilizer N application technology can both reduce the amount of fertilizer N needed to produce maximum economic yield, and maintain or increase profitability to the producer. Extreme variability was noted with soil characteristics, grain yields, and the optimum rate of fertilizer required to attain maximum economic yield. The variability present in Minnesota fields, when managed properly, should reduce fertilizer N inputs (energy), reducing the potential of nitrate contamination of groundwater and surface water, and at the same time increase profitability to the producer. Field-scale research data from three of the four 1994 sites showed that between 35 to 95% of the acreage was over-fertilized by rates ranging from 20 to 60 LB/N/A using conventional fertilizer recommendations.

Results suggest that modifications will be needed in the traditional approach with which fertilizer recommendations are currently provided to producers. Some benefits associated with the technology can be achieved immediately, but additional research information which incorporates temporal climatic variability will be required before the technology will achieve its full potential in reducing energy consumption, increasing profitability and minimizing environmental contamination.

A *Nitrogen Expert System,* a user friendly computer decision aid, was developed as an educational tool to promote site specific BMPs. A number of difficulties were encountered while developing with the Exsys RuleBook. This system is currently being imported into the Windows Environment. Despite the delays, the primary objectives have been met. A no-cost extension has been requested to finish minor software development.

Project Results Use and Dissemination:

Results and activities associated with this project have been distributed in many different ways. Producer educational programs have been presented via field days, Farmfest activities, field tours, extension meetings, and fertilizer dealer meetings. Results to researchers have been presented at symposiums on precision farming, seminars, and four papers were presented at the American Society of Agronomy meeting in St. Louis, Missouri. Interest from producers and scientists have grown rapidly during the two years of this project. Many additional questions have been forth coming from producers that are eager to use the technology.

Three tile-drained "mini-watershed" demonstration sites were developed across southern MN. The purpose of the sites is to make the agricultural community aware of the relationship between water quality and improved fertilizer management. Two sites are fully automated with continuous flow meters and water sampling systems. Support from local organizations has been very positive and it appears that alternative sources of funding may continue the water quality monitoring. It may take years to effectively show impacts on water quality. However future monitoring of the sites will continue because of the cooperation established with organizations such as the Clean Water Partnership of Nicollet-Brown-Cottonwood Counties, University of Minnesota, and "River-Friendly Farmer Program". Also, a NRI (National Research Initiative) grant has been granted to University of Minnesota--Department of Soil, Water, and Climate to further evaluate the impact variable rate technology application of pesticides on the environment and water quality using the mini-watershed design. The research and demonstrations proved to be a very promising educational activity with more educational activities and field days planned for the future.

Date of Report: July 1, 1995

LCMR Final Report - SUMMARY - Research

I. Project Title: Developing Soil Specific Nitrogen Management As A BMP

Program Manager: Bruce R. Montgomery
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A. Legal Citation: M.L. 93 Chpt. 172, Sect. 14, Subd. 3(l).

Total Biennial LCMR Budget: $294,000

Balance: $0000

This appropriation is from the oil overcharge money to the commissioner of administration for transfer to the commissioner of agriculture for development of new soil specific, variable rate nitrogen applications that will increase operating efficiency and reduce applied nitrogen without reducing yield.

B. LMIC Compatible Data Language: Not applicable.

C. Status of Match Requirement: Not applicable.

II. Project Summary:

Technology is now available to apply different rates of fertilizers and pesticides across variable soil conditions in any given field. Variable rate technology (VRT) can potentially result in immediate energy, fertilizer, and economic savings as well as reduced environmental risk. Currently, this technology has been dominantly used for phosphorus and potassium applications. Existing methods for nitrogen management are inadequate for maximizing the potential benefits that VRT can provide.

The overall goal of this project is to enhance existing VRT for improved nitrogen fertilizer use efficiency. This will be accomplished by better defining factors which influence field-scale nitrogen availability and fine tuning the resulting fertilizer rates. A significant educational effort will be initiated to educate farmers, dealers, industry related personnel, and others to promote the potential benefits of VRT. Educational programs will be developed through the use of "expert systems" computer software and field-scale demonstration sites. Where feasible, demonstration sites will be established over tile-drained "mini watersheds" to observe water quality trends.

III. Statement of Objectives:

A. Develop technology that would create a soil condition map (organic matter, residual nutrient, etc.) to allow variable N inputs.

B. Determine the appropriate N rate and other BMPs in a soil specific manner using a soil condition map.

C. Conduct demonstrations and evaluate the economic and environmental impact of existing variable rate technology.

D. Integrate results into a user friendly decision aid for local use that can also be used as an educational tool that would promote site specific BMPs.

IV. Research Objectives:

A. Title of Objective: Develop technology that would create a soil condition map (organic matter, residual nutrient, etc.) to allow variable N inputs.

A.1 Activity: The proper utilization of variable N rate technology requires the development of a soil condition map which describes what rates of fertilizer N should be added in different portions of a field. This soil condition map must integrate many different factors including: soil productivity, residual nutrient supply, potential nutrient availability, and past and present crop management practices.

A.1.a Context within the project: Focus of this objective will be to construct individual soil condition maps which relate to the above factors and then in conjunction with Objective B, determine what factor(s) would result in the best overall soil condition map for making variable rate applications. Development of a high quality soil condition map is essential if the technology is to improve the efficiency of fertilizer N application and reduce excess fertilizer application and energy use.

A.1.b Methods: Three to five production fields per year, 10 - 20 acres in size, will be selected for experimentation in Southern Minnesota. In cooperation with the USDA-SCS, each field site will have an intensive soil survey conducted at a 1 to 6000 scale to delineate the different soil types present in each field and to assist with soil productivity estimation. Aerial photographs will be obtained for each field and will be soil sampled on a grid basis (i.e., 100 X 100') to determine residual and potential nutrient availability. Samples at each grid point will be taken to a depth of two or four feet and separated into one foot increments. Each individual sample will be analyzed for nitrate and ammonium N to determine residual available N supply. Potential N supplying power of the field sites will be determined by analyzing the above samples for total N, organic C (organic matter), and potentially mineralizable N by the hot KCL extractable ammonium and phosphate borate distillable ammonium.

Each field site will generate 8 to 16 samples per acre. Each of the above parameters or a combination of the above can be used to develop a soil condition map which represents the variability present in the fields selected. After the completion of Objective B it will be possible to determine which soil condition map or combination of soil condition maps would be best suited for use in the construction of the overall soil condition map.

A.1.c Materials: Supplies and equipment necessary to conduct this objective will include expendable supplies needed for soil sample collection and laboratory analysis. The University of Minnesota currently has adequate capital equipment available for collection and analysis. Equipment to allow adequate geographic positioning within the field will be required. Computer software and hardware will be required to facilitate extensive data bases and condition map development.

A.1.d Budget: $119,650 **Balance:** $ 000

A.1.e Timeline:

	7/93	1/94	6/94	1/95	6/95
Locate cooperator/sites	*****			*****	
Detailed soil survey		***		***	***
Aerial photography			*****	***	***
Soil samples	***	**	***	**	
Sample analysis	*******	**		*******	**
Condition maps		*********			***********

A.1.f Status:

Field sites were selected in the fall of 1993 and 1994 according to the protocol outlined in "Methods". Field sites were selected to represent normal field variations that might be encountered by producers in southern Minnesota. Site characterization was conducted via several different methods to construct soil condition maps that would represent the variability present within each field. Variability was tested to determine what parameters could potentially be used in making site specific N recommendations. Site characterization included soil sample analysis, soil survey analysis, topographic analysis, and aerial photographs.

Variability encountered at each of the 1994 cropping season sites were much more extreme than previously anticipated. Many of the quantifiable characteristics had variability of 300-500% within the same field. Much of the variability associated with soil analysis was correlated with topographic position and, in turn, could be related to the photo-tones from aerial photographs. Residual soil nitrate, which is currently used for making fertilizer recommendations in western Minnesota, were relatively low at all locations. The low residual soil nitrate found in the fall of 1993 were probably a direct result of the excessively wet growing season encountered that year. Low nitrate concentrations would suggest that its use as a single diagnostic tool in allowing variable rate N applications during the time span of this research would be limited.

The variability quantified under this objective reinforces the need to increase the development of site-specific N rate management. When variability can be quantified, it can then be managed. Unfortunately, most of the variability that was determined in soil and landscape features at these selected locations are not currently considered when making fertilizer N recommendations to farmers. Residual soil nitrate, which is currently recommended to adjust fertilizer recommendation on a field scale basis, would be considered low by current soil testing standards and would not allow much flexibility in site-specific N management. Development of soil testing techniques which incorporate other parameters measured will require modification in the current methods utilized in making fertilizer recommendations. Changes are made to fertilizer recommendations on a periodic basis, but usually only after research has been conducted over many locations and environmental conditions. The limited data (one year) obtained from this project will be used to determine what additional factors should be considered into the integration (objective B) of new soil testing programs.

B. Title of Objective: Determine the appropriate N rate and other BMPs in a soil specific manner using a soil condition map.

B.1 Activity: Use of variable N rate technology can increase fertilizer N efficiency. The key to this occurring lies in the accuracy in which the soil condition map can predict the appropriate N application rate in regard to soil spatial variability in the field. The increased fertilizer N efficiency will come from applying less N where the crop has a lower requirement and more N in areas where the plants can utilize the additional N. Measuring crop grain yield as affected by different N rates and over many varying soilscapes will determine what the optimum N rate was in different areas of the field.

B.1.a Context within the project: Comparing these yields with the soil condition maps developed in Objective A will reveal the factor(s) which affect N fertilizer response in corn grain over many different soilscapes.

B.1.b Methods: Production fields characterized in Objective A will be utilized to determine the appropriate N rate for optimum corn grain yield. The study will be conducted at these locations on corn in the summer of 1994 and 1995. The treatments, applied across the field in replicated strips, will be composed of a zero check and up to five incremental N rates (i.e., 60, 90, 120, 150 and 180 pounds per acre) using anhydrous ammonia. The highest rate will satisfy maximum crop needs.

Crop management will be done by the cooperator. Grain yield and moisture will be determined on up to 75 subplots per acre (each subplot will be approximately 200 feet^2). This information will be

geo-referenced with the soil condition maps developed in Objective A. This data will then be analyzed using geostatistical and regression techniques to identify what N rate was the best for each area of the field and also to identify the best factor(s) to use in creating the soil condition map. From this information an economic analysis for comparative systems and variable rate technology can be calculated on a field basis to evaluate the systems.

B.1.c Materials: Inputs (seed, land, and pesticides) except N fertilizer will be provided by the cooperator; the project will purchase N fertilizer. The fertilizer will be applied by a VRT applicator furnished by the University of Minnesota. A tractor will be rented for the fertilization operation. The cooperator will be reimbursed for yield losses by the project. The size of the experimental area will require the use of global positioning system (GPS) to geo-reference N application and harvest data. Yield determination will require the rental or modification of an existing combine with a weighing system. Analysis and geo-referencing will require computer equipment which will be provided by the University of Minnesota.

B.1.d Budget: $119,650 **Balance:** $ 000

B.1.e Timeline:

	7/93	1/94	6/94	1/95	6/95
Establish treatments			***	***	
Plant response/yield			**********		*******

B.1.f Status:

Different N rate treatments were applied at each location to determine: the extent of yield variability; and the rates of fertilizer N that would be necessary to provide site specific optimum recommendations. Information from Objective A was used to determine the most important quantifiable parameters that would explain the measured crop response variability.

A wide range in corn grain yields (1994) was obtained at each site on fertilized and non-fertilized plots. Corn grain yields between different management zones within non-fertilized areas reflect the inherent nitrogen supplying power of the soil; yield differences within a given field ranging from 20 bu/acre to 90 bu/acre. Yield levels increased when fertilized, but the range in yield variability was similar to non-fertilized areas. Current fertilizer N recommendations use yield expectation or yield goal to adjust the rate of fertilizer application. Yield variability encountered within these experiments lend credibility to the fact that variable rate N applications may be utilized to improve fertilizer use efficiency.

Using georeferenced yield response information from small cells within each field, areas of similar response were grouped together. Regression analysis was then used within each grouped area to determine the rate of N required to provide the economic optimum N rate in different portions of each field. Within a given location, the amount of N required to attain maximum economic yield (1994) ranged from 0-150 lbs/acre at Hanska to 87-139 lbs/acre at Lake Crystal. At the Hanska and Lake Crystal, locations current U of Mn recommendations would suggest uniform application rate of 130 and 110 lbs/acre, respectively. This management treatment would have both under-fertilized and over-fertilized different portions of those fields. This trend was found on all fields tested in 1994. The amount of N required to achieve economic optimum yields levels with site specific management could have been reduced by an average of 30% on two of the four fields tested.

Site specific management may decrease fertilizer application rates in one portion of the field and increase rates in other portions. Conventional recommendations were given a 30 lb/acre margin of error to determine how much of a field would have been over or under fertilized when applying a uniform application rate. During 1994, three fields were over-fertilized. Portions of each field that were over-fertilized were 95, 72 and 34 %, at Hanska, Hector, and Lake Crystal, by an average rate of 45, 62 and 21 lbs N/acre, respectively. Likewise, all fields had some portion of the field that were under-fertilized when current uniform application rates were applied. Portions of the field that were under-fertilized were 5, 28, 11, and 7 % of the field by average rates of 20, 30, 29, and 63 lbs N/acre, respectively. Site-specific N rate management has the potential to reduce N rates in certain portions of a field and increase profitability in other portions of the field. Across all fields tested in this study, the rate of fertilizer N application could have been reduced by approximately 20% if site specific variable rate applications would have been used effectively.

One major obstacle in the implementation of site specific nitrogen management is the ability to predict what management practice(s) should be utilized in a specific portion of the field. Condition maps were developed utilizing many different soil and landscape parameters. Many of the soil parameters were correlated with landscape position. Many of these parameters were correlated with the grain yield that was obtained when no fertilizer N was applied. This is good evidence to support the ability to develop soil testing and/or landscape features to predict the nitrogen supplying power of the soil. These features, however, appeared to have limited application in determining which areas of the field were going to be most responsive and what rate of fertilizer N would be required to achieve the economic optimum yield. No single parameter was correlated with yield response at all locations. Much of the variability in N requirement at each location appeared to related to landscape position and soil water/drainage. This is not unrealistic since soil water controls many of the nitrogen transformation processes, losses from soil, and supply mechanisms to the plant. Refinement and development in the technology may require the integration of soil water along with soil and landscape features to determine the economic optimum N rates for a given field. Since soil water may change drastically with time a dynamic range in soil condition maps may be required to reflect that variability. Additional research in this area would be warranted.

C. Title of Objective: Conduct demonstrations and evaluate the economic and environmental impact of existing variable rate technology.

C.1 Activity: Development of educational and ground water monitoring demonstrations.

C.1.a Context within the project: Concurrent with the research sites described in Objectives A and B, demonstration sites will be developed to evaluate the effectiveness of existing variable-rate technology for nitrogen management. Profitability, nitrogen fertilizer inputs, yields, and water quality will be monitored under field-scale production. Demonstrations will provide educational opportunities to promote the "farming by the foot" concept as a tool for higher nitrogen use efficiency, potential fertilizer savings, and minimizing the impacts of N fertilization on water resources. Technology advances from the research component can be transferred directly to growers and dealers at the demonstration related activities.

C.1.b Methods:

Soil survey and tile-drain location maps will be used to identify 3 of 6 non-replicated micro-watersheds within south central and southwest Minnesota. Watersheds will be selected on the following criteria: corn-soybean rotation; sites not to exceed 100 acres in size; and soils/yield potentials must be highly variable within each field. Where feasible, the sites will be tile drained; the drains will serve as a tool to monitor the nitrate leaching component. Additional criteria for these sites are headwater locations on the drain fields will be selected to avoid complications from mixing of drainage waters upstream; uniform cropping practices over the individual mini-watershed that the drain services; an access point must be available for collecting water samples and flow measurements; and a minimum of one year's baseline water quality nitrate information before variable N rate technology is applied. Whenever feasible, sites will be established over tile drains which are currently being monitored through Soil and Water Conservation District efforts or LCMR funded projects such as the Brown-Nicollet Clean Water Partnership Program.

Sites selected for the 1994 cropping season will be planted into corn or other high nitrogen demanding crop. Past cropping practices, fertilizer rates and yield will be collected from the cooperator. Methods currently used by the variable rate industry to produce and respond to the yield potential map will be utilized. Nitrogen rates, timing of application, and other management strategies will follow the guidelines of the statewide and regional Best Management Practices as designated by the MDA's Nitrogen Fertilizer Management Plan.

Tile drains will be monitored for NO_3-N and flow volumes on two week intervals during drainage events. Soil and Water Conservation District personnel or other local water authorities will assist in the monitoring program. Sites established in 1994 will be monitored via the drains through the end of the study period to observe the full treatment effect of the variable rate technology.

Demonstration activities will be coordinated in cooperation with the Minnesota Department of Agriculture, Minnesota Extension Service, University of Minnesota - Soil Science, SWCD's and other affiliated agencies. Programs for both field and winter workshops will be developed.

C.1.c Materials: Materials for monitoring flow volumes will be required: staff gauges, stop watch and buckets will be purchased. Sampling bottles, sampling equipment, coolers and ice for sample preservation will also be required.

C.1.d Budget: $ 30,000 **Balance:** $ 000

C.1.e Timeline:	7/93	1/94	6/94	1/95	6/95
Identify sites/cooperators		******		***	
Develop condition maps			***		***
Establish treatments			*****		*****
Monitor tile drains	**				
Demonstrations			***		***
Final report					**

C.1.f Status:

Two tile-drained demonstration sites, meeting the criteria of described in "Methods", were established and monitored during the 1994 and 1995 growing season. The sites were located in Lac Qui Parle (near Bellingham) and Watonwan counties (near St. James) and specifics from each site were previously reported.

An additional site was selected in 1994, which also met the criteria described in "Methods". The site is located in Nicollet Co. (near St. Peter), and was established with cooperation from the Nicollet-Cottonwood-Brown Clean Water Partnership. The site is approximately 60 acres in size. The site was grid soil sampled, using a 2.6 acre grid, in the fall of 1994 and "soil condition" maps were developed for N (2 ft depth), P, K, Zn, pH, and organic matter. McPherson Crop Management, Inc. was contracted to do the grid soil sampling and create soil condition maps. A constant rate of anhydrous ammonia nitrogen was fall-applied to each "mini-watershed". Nitrogen treatments will be imposed in the next corn year (1997). The rationale to delay variable N rates to this site were provided in the previous report. Water quality chemistry and flows have been monitored since the spring of 1995. Automated water samplers and flow meters were installed to provide continuos water quality data from the two mini-watersheds. This information will establish the baseline data required prior imposing nitrogen fertilizer differences through variable rate technology.

Besides these types of demonstrations, a number of educational events have been held, during the time frame of this project. The focus has been directed toward increasing the farmers awareness of variable rate technology and educating them on the general concepts and benefits of variable rate fertilization. This has been a joint effort between all cooperators associated with Objectives A, B, C, and D. Agricultural dealers and the associated private industry have been extremely helpful in assisting in these events.

In summary, there are existing sites and systems conducive to this type of demonstration, but are difficult to locate. Previous research indicates it takes a number of years (5 to 10 years) to impact the water quality from sub-surface drainage. The support from local organizations was very positive and it appears that alternative sources of funding may continue the water quality monitoring. Future monitoring of the sites will continue because of the cooperation established with organizations such as the Clean Water Partnership of Nicollet-Brown-Cottonwood Counties, University of Minnesota, and "River-Friendly Farmer Program". Also, a NRI (National Research Initiative) grant has been granted to University of Minnesota--Department of Soil, Water, and Climate to further evaluate the impact variable rate technology application of pesticides on the environment and water quality using the mini-watershed design. The research and demonstrations proved to be a very promising educational activity with more educational activities and field days planned for the future. The demonstrations also encouraged cooperation among the University of Minnesota, Clean Water Partnerships, Crop Consultants, Cooperatives and the Minnesota Department of Agriculture.

D. Title of Objective: Integrate results into a user friendly decision aid for local use that can also be used as an educational tool that would promote site specific BMPs.

D.1 Activity: Variable rate N applications is a high technology management concept. It requires new or enhanced management skills. Historically, this kind of management has shown a slower rate or a resistance to adoption. However, today we have new tools to overcome the technology transfer barrier. A user-friendly management decision aid system integrating results from this project and from other sources will be developed to facilitate the adoption of this revolutionary management concept. Also, variable rate N management is a new concept that needs to be promoted by documenting its benefits as a BMP and increased productivity and profitability. The decision aid system will be used to demonstrate advantages of soil specific management over conventional management.

D.1.a Context within the project: Results from Objectives A and B, as well as BMPs for N management developed by MDA in collaboration with the University of Minnesota and other interested groups will be translated into decision rules utilized by the expert system for making management recommendations.

D.1.b Methods: An expert system "shell" will be used to develop the decision aid system. A shell based system will be developed more rapidly, will be updated more easily, and will take care of interfacing with a variety of continuously changing hardware. The expert system correctness will be verified by N management specialists using present N recommendations and field data and its ease-of-use by an advisory group made of Minnesota extension agents, ag-consultants, agri-business persons, and producers. An educational version will be developed using several management scenarios based on farm data.

D.1.c Materials: Expert system shell.

D.1.d Budget: $ 24,700 **Balance:** $ 000

D.1.e Timeline:

	7/93	1/94	6/94	1/95	6/95
Shell selection		*****			
E.S. flow and rules development			****	***	
System development		*******		***************	

D.1.f Status:

There have been two primary objectives pursued in the project to upgrade the Nitrogen Expert System: (1) Adding rules to arrive at a recommended nitrogen fertilization program, and (2) To import the Expert System into the Windows environment. Other minor objectives have also been pursued.

Complete Nitrogen Fertilization Program:

The original Nitrogen Expert System was designed to produce a Nitrogen fertilization rate recommendation based on a realistic yield goal, soil data, and management practices. It is intended that the upgraded Expert System be able, with the use of some additional variables, to arrive at a complete program of Nitrogen fertilization including timing and method of application, in addition to rate.

As detailed in a previous progress report, use of the Exsys RuleBook for system development was explored for this expansion of the Expert System's scope and some problems were encountered. These difficulties were overcome through the use of the Exsys system's ability to output the rules files in manually editable form. By outputting the rules file of the original Nitrogen Expert System and the one developed with the Exsys RuleBook, editing them by hand, and using the Exsys Rule Compiler to reassemble them, a single, combined Nitrogen Expert System was created. This Expert System has been completed and meets the first of the project's primary objectives.

Unfortunately, this experience has proven that, while the Exsys RuleBook may, in some instances, be used for expert system expansion on systems originally created using the standard Exsys Professional Editor, the process is no less difficult and time-consuming than using the Exsys Professional Editor for such additional development.

The other difficulty that was encountered in this phase of the upgrade was that the Exsys Runtime program failed to properly run the resulting combined Nitrogen Expert System. Only after a lengthy search for errors in the Expert System and repeated contacts with the Technical Support staff at Exsys, Inc. was it determined that the problem was not with the Nitrogen Expert System, but with the Exsys Runtime program. A new, revised version of the Exsys Runtime has been acquired from Exsys that allows the Nitrogen Expert System to run properly. While this difficulty has been fully overcome, it nonetheless significantly delayed the upgrade project.

Importation into the Windows Environment:

The importation of the existing DOS Nitrogen Expert System into the Windows environment has been undertaken using Exsys Professional for Windowed Environments. The Windowed version of the Nitrogen Expert system now uses the expanded Nitrogen Expert System which gives rate, timing, and method recommendations for application.

Importing the Nitrogen Expert System into Windows is intended to allow users of Windows to use the expert system directly without resorting to access through DOS and improve both the input and output interface for end users of the expert system. Users will be provided with simple point-and-click and scroll-bar screens for data input, hypertext screens for help and advice, and clear and complete instructions for Nitrogen application recommendations.

While completion of this objective of the upgrade has been delayed due to the difficulty encountered with the previous version of the Exsys Runtime program (as detailed above) the importation of the Nitrogen Expert System into the Windows Environment is proceeding without difficulty. As of this writing, over 100 custom screens have been designed and this phase of the project is nearing completion.

Minor Objectives:

Minor objectives of the Nitrogen Expert System upgrade project have included adding the ability for the user to save and retrieve data entered into the system for year-to-year use, allowing the user to enter data for multiple regions in a single field, reworking of the system's questioning order so that management practice questions are only asked once per field, adding warnings for extreme values entered for user data, and minor cosmetic alterations.

These minor objects have been met or are being developed without difficulty, although completion of all minor objects has also been delayed by the difficulty encountered with the Exsys Runtime program (see above). As of this writing, a command file has been created that allows for multiple field regions without unnecessary repetitions of questions, and the ability to save, retrieve, and modify data already entered is being added. This places us near the completion of the projects minor objectives as well.

V. Evaluation:

The overall goal of this entire project is to reduce nitrogen fertilizer usage while maintaining or improving yield production. Techniques for nitrogen management have not been developed to fully utilize the high precision accuracy of variable rate technology. This project will be successful if the following items are accomplished: (1) Develop technology to better predict soil nitrogen availability across a soilscape; (2) Successfully determine appropriate N fertilizer rates and other additional BMPs across the soilscape; (3) Successfully transfer the findings to farmers and industry through the development of decision aid computer system and field demonstrations; and lastly, (4) Demonstrate the influences of variable rate technology on fertilizer efficiencies, energy savings, and yields and establish long-term monitoring sites to observe effects on water quality.

VI. Context Within Field:

Current fertilizer recommendations and BMPs for nitrogen fertilizer management are a combination of statewide and/or regional suggestions. Research information has been combined over large geographic areas to provide these recommendations. Variable rate on-the-go nitrogen application depends on the premise that soils within a field vary, and because of that variability they should be managed differently. The scale at which recommendations need to made are on a much smaller basis. Individuals within industry and the University of Minnesota have placed Minnesota as one of the national leaders in the development of variable rate technology. The development of the technology, however, has been much more rapid than the ability to learn how to use it properly. Relatively little research information has been generated within the State of Minnesota to assist in the development of appropriate soil condition maps. This information is essential if the technology is to be developed into a BMP. Past experiences of the principal investigators in the areas of nitrogen management, soil survey, BMP development and crop production will be invaluable to this project.

VII. Benefits:

Variable rate technology has been traditionally used for the application of phosphorus, potassium, and pesticides. The fate of nitrogen across a soilscape is a very dynamic and complex system. Consequently, the tools to maximize VRT for nitrogen fertilizer applications have lagged in the development process. The ultimate benefit is to place the correct N rate where it is needed for crop uptake, therefore optimizing N fertilizer use efficiency, potentially saving on fertilizer costs, and minimize ground water and surface water degradation. This project will aid in the development of the essential tools as well as serve in the educational advancement of farmers, government and industry-related personnel. Lastly, this project will aid in the establishment of monitoring sites for studying the long-term effects of variable rate technology on water quality.

VIII. Dissemination:

Results from this project will be presented to a variety of audiences through three different, but interrelated methods. The methods are: the expert system; field demonstrations; and via professional avenues. The expert system approach will allow training industry personnel, educators and other associated professionals in responding to a variety of "What if ..." field scenarios. Yields, economics, fertilizer savings and environmental conditions will be simulated as a direct response to management practices selected by the user. The user will have a much better appreciation for the value of the BMPs and can transfer this knowledge directly to their clientele or own farming conditions.

Farmers and dealers will be the primary audience at the demonstration sites. These sites will serve as a center to transfer information from numerous sources. Site specific data such as yields, potential fertilizer savings, soil sampling and grid costs, and water quality information will be distributed. Farmers and dealers will be encouraged to be an active component of all educational activities. Advancements in nitrogen management technology from Objectives A and B will be shared at the demonstrations. Dealers and others associated with variable rate technology will be informed on technology advancements such as appropriate soil sampling grid sizes and desired method(s) for predicting N availability as well as interpreting and responding to soil condition maps. Existing research from other studies, including potential savings on phosphorus, potassium, and pesticides, can also be distributed at the demonstrations.

Results will also be presented at national and regional meetings, as well as published in peer-reviewed literature in the national journals. The University of Minnesota, as well as the private enterprise in the state, have been strong national leaders in technological advancements in variable rate technology. The international workshop titled, "Soil Specific Crop Management - A Workshop on Research and Development Issues", held in Bloomington in April, 1992 is a good example of Minnesota leadership.

IX. Time:

Due to the nature of biological studies and climatic conditions, additional funding requests from LCMR (for biennium 1995-1997), as well as alternative sources will be necessary.

X. Cooperation:

1. Mr. Bruce R. Montgomery, Soil Scientist
   Agronomy Services Division
   Minnesota Department of Agriculture

   Mr. Montgomery will serve as the Program Manager and will direct the activities outlined in Objective C.

2. Dr. Gary L. Malzer, Professor
   Department of Soil Science
   University of Minnesota.

   Dr. Malzer's research program is actively involved in developing methods that can be used to improve fertilizer use efficiency in crop production. His expertise in soil fertility, nitrogen chemistry, and nitrogen management practices for crop production have a strong field basis and will be active in Objectives A and B.

   He has been actively involved with the Center for Agricultural Impacts on Water Quality. Past research activities related to nitrogen management have evaluated time, placement, form, rate, and use of nitrification inhibitors in different regions of Minnesota. Activities have been important in N best management practice development, N loss potential estimates, and soil test development. Dr. Malzer's primary role will be in the coordination of the field, laboratory, and interpretation of results that are directly related to soil fertility aspects of N fertilization, site characterization and evaluation of soil condition maps.

3. Dr. John A. Lamb, Associate Professor
   Department of Soil Science
   University of Minnesota.

   Dr. Lamb's research involves field application of crop management systems and their effect on soil chemical properties and the quantification of soil variability and its effects on production inputs use efficiency. Primary duties will be to adapt field experimental procedures in Objective B to large scale research utilizing global positioning system, yield monitoring equipment, and electronic equipment to monitor soil physical parameters.

4. Dr. Pierre C. Robert, Associate Professor and Extension Soil Specialist
   Department of Soil Science
   University of Minnesota.

   Current research includes: Study, inventory, and management of the soilscape. Recent principal areas of research are: soil information systems, soil specific management, soil spatial variability, land evaluation, and simulation models and expert systems for Best Management Practices and environmental protection. Dr. Robert will develop the expert system discussed in Objective D.

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 Review:

See attachment within June 30, 1993 work plan.

Developing Soil Specific Nitrogen Management As a Best Management Practice

M.L. Chapter 172, Section 14, Subdivision (L)

Final Detailed Report Submitted to the Legislative Commission on Minnesota Resources

Minnesota Department of Agriculture

and

Department of Soil, Water, and Climate
University of Minnesota

Due: July 1, 1995

TABLE OF CONTENTS

Page

1993-95 LCMR RESEARCH PROJECT - ABSTRACT

Project Title: Developing Soil Specific Nitrogen Management As A BMP
This project was funded by Oil Overcharge Fund

Program Manager: Bruce R. Montgomery
Agency Affiliation: Minnesota Department of Agriculture
Legal Citation: M.L. 93 Chptr. 172, Sect. 14, Subd. 3(l).
Total Biennial LCMR Budget: $294,000

Statement of Objectives:

A Develop technology that would create a soil condition map (organic matter, residual nutrient, etc.) to allow variable N inputs.

B. Determine the appropriate N rate and other BMPs in a soil specific manner using a soil condition map.

C. Conduct demonstrations and evaluate the economic and environmental impact of existing variable rate technology.

D. Integrate results into a user friendly decision aid for local use that can also be used as an educational tool that would promote site specific BMPs.

Overall Project Results:

The project was successful in demonstrating that variable rate fertilizer N application technology can both reduce the amount of fertilizer N needed to produce maximum economic yield, and maintain or increase profitability to the producer. Extreme variability was noted with soil characteristics, grain yields, and the optimum rate of fertilizer required to attain maximum economic yield. The variability present in Minnesota fields, when managed properly, should reduce fertilizer N inputs (energy), reducing the potential of nitrate contamination of groundwater and surface water, and at the same time increase profitability to the producer. Field-scale research data from three of the four 1994 sites showed that between 35 to 95% of the acreage was over-fertilized by rates ranging from 20 to 60 LB/N/A using conventional fertilizer recommendations.

Results suggest that modifications will be needed in the traditional approach with which fertilizer recommendations are currently provided to producers. Some benefits associated with the technology can be achieved immediately, but additional research information which incorporates temporal climatic variability will be required before the technology will achieve its full potential in reducing energy consumption, increasing profitability and minimizing environmental contamination.

A *Nitrogen Expert System,* a user friendly computer decision aid, was developed as an educational tool to promote site specific BMPs. A number of difficulties were encountered while developing with the Exsys RuleBook. This system is currently being imported into the Windows Environment. Despite the delays, the primary objectives have been met. A no-cost extension has been requested to finish minor software development.

Project Results Use and Dissemination:

Results and activities associated with this project have been distributed in many different ways. Producer educational programs have been presented via field days, Farmfest activities, field tours, extension meetings, and fertilizer dealer meetings. Results to researchers have been presented at symposiums on precision farming, seminars, and four papers were presented at the American Society of Agronomy meeting in St. Louis, Missouri. Interest from producers and scientists have grown rapidly during the two years of this project. Many additional questions have been forth coming from producers that are eager to use the technology.

Three tile-drained "mini-watershed" demonstration sites were developed across southern MN. The purpose of the sites is to make the agricultural community aware of the relationship between water quality and improved fertilizer management. Two sites are fully automated with continuous flow meters and water sampling systems. Support from local organizations has been very positive and it appears that alternative sources of funding may continue the water quality monitoring. It may take years to effectively show impacts on water quality. However future monitoring of the sites will continue because of the cooperation established with organizations such as the Clean Water Partnership of Nicollet-Brown-Cottonwood Counties, University of Minnesota, and "River-Friendly Farmer Program". Also, a NRI (National Research Initiative) grant has been granted to University of Minnesota--Department of Soil, Water, and Climate to further evaluate the impact variable rate technology application of pesticides on the environment and water quality using the mini-watershed design. The research and demonstrations proved to be a very promising educational activity with more educational activities and field days planned for the future.

Date of Report: July 1, 1995

LCMR FINAL REPORT - DETAILED FOR PEER REVIEW - RESEARCH

I. Project Title: Developing Soil Specific Nitrogen Management As A BMP

Program Manager: Bruce R. Montgomery
Agency Affiliation: Minnesota Department of Agriculture
Address: 90 West Plato Blvd.
St. Paul, Minnesota 55107
Telephone: (612) 297-7178 FAX: (612) 297-2271

A. Legal Citation: M.L. 93 Chpt. 172, Sect. 14, Subd. 3(l).

Total Biennial LCMR Budget: $294,000

Balance: $0000

This appropriation is from the oil overcharge money to the commissioner of administration for transfer to the commissioner of agriculture for development of new soil specific, variable rate nitrogen applications that will increase operating efficiency and reduce applied nitrogen without reducing yield.

B. LMIC Compatible Data Language: Not applicable.

C. Status of Match Requirement: Not applicable.

II. Project Summary:

Technology is now available to apply different rates of fertilizers and pesticides across variable soil conditions in any given field. Variable rate technology (VRT) can potentially result in immediate energy, fertilizer, and economic savings as well as reduced environmental risk. Currently, this technology has been dominantly used for phosphorus and potassium applications. Existing methods for nitrogen management are inadequate for maximizing the potential benefits that VRT can provide.

The overall goal of this project is to enhance existing VRT for improved nitrogen fertilizer use efficiency. This will be accomplished by better defining factors which influence field-scale nitrogen availability and fine tuning the resulting fertilizer rates. A significant educational effort will be initiated to educate farmers, dealers, industry related personnel, and others to promote the potential benefits of VRT. Educational programs will be developed through the use of "expert systems" computer software and field-scale demonstration sites. Where feasible, demonstration sites will be established over tile-drained "mini watersheds" to observe water quality trends.

III. Statement of Objectives:

A. Develop technology that would create a soil condition map (organic matter, residual nutrient, etc.) to allow variable N inputs.

B. Determine the appropriate N rate and other BMPs in a soil specific manner using a soil condition map.

C. Conduct demonstrations and evaluate the economic and environmental impact of existing variable rate technology.

D. Integrate results into a user friendly decision aid for local use that can also be used as an educational tool that would promote site specific BMPs.

IV. Research Objectives:

A. Title of Objective: Develop technology that would create a soil condition map (organic matter, residual nutrient, etc.) to allow variable N inputs.

A.1 Activity: The proper utilization of variable N rate technology requires the development of a soil condition map which describes what rates of fertilizer N should be added in different portions of a field. This soil condition map must integrate many different factors including: soil productivity, residual nutrient supply, potential nutrient availability, and past and present crop management practices.

A.1.a Context within the project: Focus of this objective will be to construct individual soil condition maps which relate to the above factors and then in conjunction with Objective B, determine what factor(s) would result in the best overall soil condition map for making variable rate applications. Development of a high quality soil condition map is essential if the technology is to improve the efficiency of fertilizer N application and reduce excess fertilizer application and energy use.

A.1.b Methods: Three to five production fields per year, 10 - 20 acres in size, will be selected for experimentation in Southern Minnesota. In cooperation with the USDA-NRCS, each field site will have an intensive soil survey conducted at a 1 to 6000 scale to delineate the different soil types present in each field and to assist with soil productivity estimation. Aerial photographs will be obtained for each field and will be soil sampled on a grid basis (i.e., 100 X 100') to determine residual and potential nutrient availability. Samples at each grid point will be taken to a depth of two or four feet and separated into one foot increments. Each individual sample will be analyzed for nitrate and ammonium N to determine residual available N supply. Potential N supplying power of the field sites will be determined by analyzing the above samples for total N, organic C (organic matter), and potentially mineralizable N by the hot KCL extractable ammonium and phosphate borate distillable ammonium.

Each field site will generate 8 to 16 samples per acre. Each of the above parameters or a combination of the above can be used to develop a soil condition map which represents the variability present in the fields selected. After the completion of Objective B it will be possible to determine which soil condition map or combination of soil condition maps would be best suited for use in the construction of the overall soil condition map.

A.1.c Materials: Supplies and equipment necessary to conduct this objective will include expendable supplies needed for soil sample collection and laboratory analysis. The University of Minnesota currently has adequate capital equipment available for collection and analysis. Equipment to allow adequate geographic positioning within the field will be required. Computer software and hardware will be required to facilitate extensive data bases and condition map development.

A.1.d Budget: $119,650 Balance: $ 000

A.1.e Timeline:

	7/93	1/94	6/94	1/95	6/95
Locate cooperator/sites	******			*****	
Detailed soil survey		***		***	***
Aerial photography			*****	***	***

	7/93	1/94	6/94	1/95	6/95
Soil samples	***	**	***	**	
Sample analysis		******* **		*******	**
Condition maps		**********			***********

A.1.f Status: Objective A.

The main purpose of this objective was to characterize four field sites (1994) and to create soil condition maps that represent the spatial variability in soil chemical and morphological characteristics. Sites were characterized according to six different chemical analysis, landscape features (elevation, slope, etc.), phototones of aerial photography, and soil mapping units. Information from this objective was used to assist in the evaluation of yield variability measured in Objective B.

Four experimental sites were established on farmer-cooperator fields during the fall of 1993. Each site was planted to corn and managed by the producer except for fertilizer N application (see Table A-1 for soil parameter concentration ranges and Appendix A: Figures 1-2, 7-8, 15-16, and 23-24 for field information and experimental design.) Four new field experiments were established in the fall of 1994 for the 1995 growing season. These fields were also producer-managed.

Soil samples were collected in the fall preceding treatment application according to the protocol stated in the "methods" section. Every site exhibited substantial variability with all parameters measured. Table A-1 presents the ranges in soil analytical results for six different procedures at two soil depths from the four locations sampled in the fall of 1993. The range in soil analytical results, frequently represent variability of 300-500% within the same field, and with certain analysis more than 500%.

Table A-1. Soil parameter concentration ranges (Fall 1993) in top two feet at four 1994 locations.

	Hanska	Hector	Lake Crystal	Revere
	ppm			
NH4-N, 0-12 in.	5.6 - 20	4.6 - 15	5.1 - 12	3.8 - 16
NH4-N, 12-24 in	3.9 - 12	3.4 - 9.2	3.9 - 6.9	2.6 - 10.2
NO3-N, 0-12 in.	0.27 - 14	0.98 - 10.0	1.4 - 15	0.40 - 5.5
NO3-N, 12-24 in.	0.98 - 4.8	0.25 - 6.9	0.20 - 24	0.53 - 4.4
Hot KCl-N, 0-12 in.	8.0 - 33	6.8 - 29	6.4 - 25	4.9 - 17
Hot KCl-N, 12-24 in.	3.1 - 14	3.1 - 10.1	3.8 - 19	3.2 - 7.7
Phosphate borate N, 0-12 in.	34 - 78	34 - 87	15 - 101	20.2 - 77
Phosphate borate N, 12-24 in.	6.8 - 49	5.6 - 50.0	5.0 - 89	5.9 - 30.0
	%			
Total N, 0-12 in.	0.14 - 0.36	0.16 - 0.54	0.07 - 0.39	0.10 - 0.32
Total N, 12-24 in.	0.06 - 0.19	0.054 - 0.20	0.0 - 0.42	0.052 - 0.15
Total C, 0-12 in.	1.5 - 4.4	1.7 - 5.8	0.62 - 4.9	1.0 - 3.9
Total C, 12-24 in.	0.43 - 2.7	0.47 - 2.5	0.2 - 5.1	0.43 - 1.6

Of the soil analysis presented in Table A-1, only soil nitrate N is used by the University of Minnesota in adjusting fertilizer N application rates. Current recommendations would require an average of 6 ppm in the top two feet of soil before any adjustments would be made in fertilizer recommendations. Nitrate-N concentration were relatively low in most portions of the field, so only minimal adjustments would be made in fertilizer N rates based on current recommendations.

Hot KCl extractable N and phosphate borate N were determined to provide an indication of potentially mineralizeable N from organic matter. These values are frequently higher than the inorganic soil N, and represent that portion of the soil N that might be easily released from soil organic matter during the next growing season. The total N and total C are good indicators of soil organic matter. One percent organic carbon is approximately 1.7% organic matter. Soil organic matter in the surface 12 inches, averaged across locations, varied from 2.0-8.0 % within each field. Soil condition maps, which represent the spatial variability for each analysis, and site are presented in Appendix A (Figures 3-6, 11-14, 19-22, and 27-30).

For the implementation of VRT, it was not economically feasible to measure all the parameters presented in Table A-1. A cross-correlation analysis was conducted, therefore, to determine what factors are interrelated. The cross-correlation for the Hanska location is presented in Table A-2, and the remaining locations are presented in Appendix A (Tables 1, 4 and 7). At Hanska, inorganic ammonium-N and nitrate-N were highly correlated (positively) with total N and C but were negatively correlated with mineralizable N estimates of hot KCl and phosphate borate. The higher concentrations of inorganic N may have reduced the potential for mineralizable N in the surface 12 inches. At the 12-24 inch depth the mineralization indexes were positively correlated with total N and C.

Table A-2. Simple correlation coefficients for soil parameters with soil parameters in check plots at Hanska site, 1994. Correlations are significant at the 5% level ($P<0.05$).

	Total C 0-12 in.	Total C 12-24 in.	Total N 0-12 in.	Total N 12-24 in.	P-B N 0-12 in.	P-B N 12-24 in.	Hot KCl-N 0-12 in.	Hot KCl-N 12-24 in.	NO3 0-12 in.	NO3 12-24 in.	NH4 0-12 in.	NH4 12-24 in.
NH4 0-12 in.	0.50	0.19	0.44	NS	-0.25	-0.28	-0.23	NS	0.63	0.31	-	NS
NH4 12-24 in.	0.36	0.30	0.38	0.28	NS	NS	0.33	NS	NS	0.49	NS	
NO3 0-12 in.	0.57	0.33	0.55	NS	-0.33	-0.28	-0.21	-0.21	-	0.37		
NO3 12-24 in.	0.62	0.60	0.56	0.50	-0.19	NS	NS	NS	0.37			
Hot KCl-N 0-12 in.	NS	0.21	NS	0.50	0.49	0.52	-	0.76				
Hot KCl-N 12-24 in.	-0.31	0.21	-0.21	0.56	0.62	0.71	0.76					
P-B N 0-12 in.	-0.44	NS	-0.43	0.36	-	0.74						
P-B N 12-24 in.	-0.48	0.27	-0.50	0.53	0.74							
Total N 0-12 in.	0.90	0.42	-	0.23								
Total N 12-24 in.	0.24	0.81	0.23									
Total C 0-12 in.	-	0.57										
Total C 12-24 in.	0.57											

Digital elevation maps were produced from geodimetered surveys to determine relative elevation, slope, and aspect. Topographic and landform features may impact water infiltration, drainage, N availability to a crop, and overall production potential. Landform features may also be related to soil chemical and physical properties. The topography at each experimental site in 1994 was unique, but had similar landform features. A topographic map for the Hanska location is present in Figure A-1, with similar maps for the other locations presented in Appendix A (Figures 9, 17, and 25). All locations had landscape features that included eroded knolls, side slopes, valley or depressional areas, and low drainage areas.

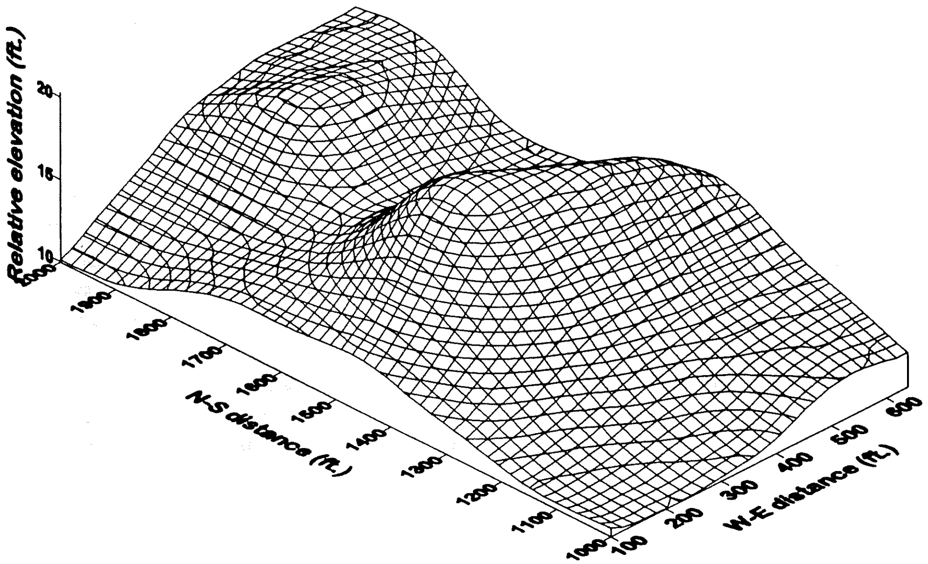


Figure A-1. Relative elevation at Hanska.

Aerial photographs of bare soil were taken in April and May of 1994. These photographs were obtained to determine if soil chemical or physical characteristics could be predicted. Color photographs of each site were digitized and scanned for red, blue, and green spectral bands. The digitized aerial photo for the Hanska location is presented in Figure A-2 and the images for the other locations are presented in Appendix A (Figures 10, 18 and 26). The lighter tones were typically associated with eroded knolls or hills and the darker tones were associated with accumulated organic matter at the lower elevations.

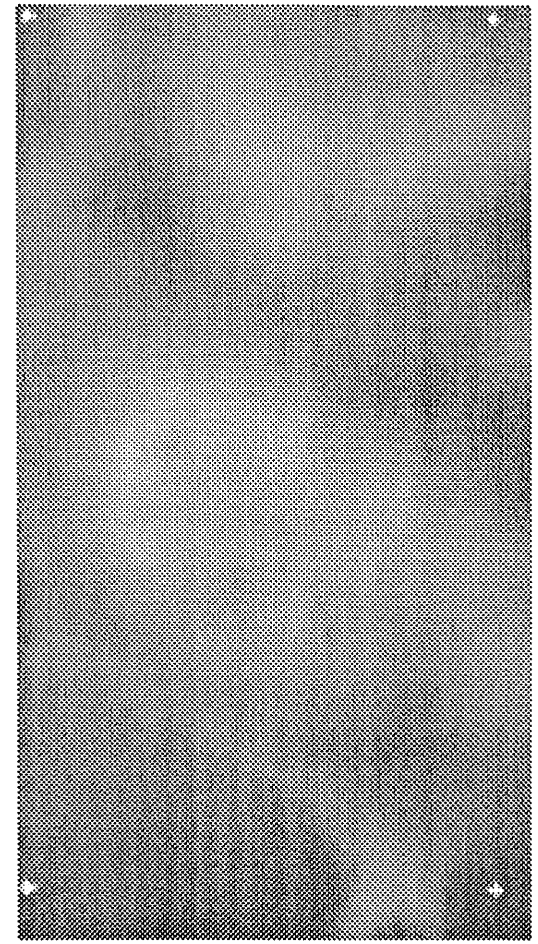


Figure A-2. Aerial photograph of baresoil at Hanska site, May 1994.

The correlation of topographic features and aerial photo images for the Hanska location is presented in Table A-3, with results from the other locations presented in Appendix A (Tables 2, 5 and 8). The red, blue and green spectral bands were correlated with each other suggesting that the separation into different color tones for bare soil photos was not necessary. All color band values were positively correlated with slope and elevation except at Hector where the correlation was negative.

Table A-3. Simple correlation coefficients for whole-field variables at **Hanska** site, 1994. Correlations are significant at the 5% level (P<0.05).

	Aspect	Slope	Elevation	Red	Green	Blue
Blue	-0.22	0.53	0.83	0.97	0.98	-
Green	-0.	0.55	0.82	0.98	-	
Red	-0.18	0.54	0.83	-		
Elevation	-0.16	0.37	-			
Slope	NS	-				
Aspect	-					

NS: not significant at 5% level

The correlation of soil chemical analysis with topographic features and phototone at Hanska are presented in Table A-4 with correlations for the other locations presented in Appendix A (Tables 3, 6 and 9). Nitrate-N and ammonium-N was negatively correlated with elevation indicating that the lower portions of the landscape had the highest concentration of inorganic N. This portion of the landscape also had the highest organic C content so similar correlations were found with phototone. Potentially mineralizable N (hot KCl and phosphate borate) was positively correlated with elevation, slope, and phototone suggesting that the mineralization potential may be higher, relative to the amount of organic matter, on the elevated portions of the landscape. Total C and N decreased as elevation increased. This relationship was highly correlated with the phototone. These strong relationships between phototone and chemical attributes may be very useful in reducing the number of soil samples that may be required to implement effective VRT. Phototone, however, provides only a relative indicator of field variability. Field analytical results will be needed to calibrate phototone images.

Table A-4. Simple correlation coefficients for soil parameters with landform and response variables in check plots at Hanska site, 1994. Correlations are significant at the 5% level (P<0.05).

	Elevation	Slope	Blue	Green	Red
NH4 0-12 in.	-0.36	-0.24	-0.37	-0.34	-0.39
NH4 12-24 in.	NS	NS	-0.37	-0.34	NS
NO3 0-12 in.	-0.48	-0.30	-0.45	-0.46	-0.47
NO3 12-24 in.	-0.53	-0.31	-0.58	-0.55	-0.52
Hot KCl-N 0-12 in.	NS	0.42	0.20	0.26	0.25
Hot KCl-N 12-24 in.	0.33	0.44	0.35	0.41	0.39
P-B N 0-12 in.	0.70	0.25	0.49	0.50	0.52
P-B N 12-24 in.	0.54	0.41	0.45	0.46	0.46
Total N 0-12 in.	-0.80	-0.49	-0.72	-0.70	-0.71
Total N 12-24 in.	NS	NS	-0.20	-0.16	NS
Total C 0-12 in.	-0.81	-0.55	-0.82	-0.82	-0.83
Total C 12-24 in.	-0.39	NS	-0.51	-0.51	-0.51

Soil surveys were developed for each site at an approximate scale of 1:3500. A summary of the survey from Hanska is provided in Figure A-3, and other survey results are in Appendix A (Figures 10, 18 and 26). The soils at Hanska are predominantly clay loams but have interspersed loams and silty clay loams. Sites typically had from 7 to 10 different mapping units per field and slopes ranged from 0 to at least 5 or 6% at each site. Texture classes were associated with elevation in the landscape.

Legend:

86	Canisteo clay loam, 0-2% slope
102B	Clarion loam, 2-5% slope
110	Marna clay loam, 0-2% slope
112	Harps clay loam, 0-2% slope
113	Webster clay loam, 0-2% slope
114	Glencoe silty clay loam, 0-1% slope
130	Nicollet loam, 1-3% slope
595B	Swanlake loam, 3-6% slope

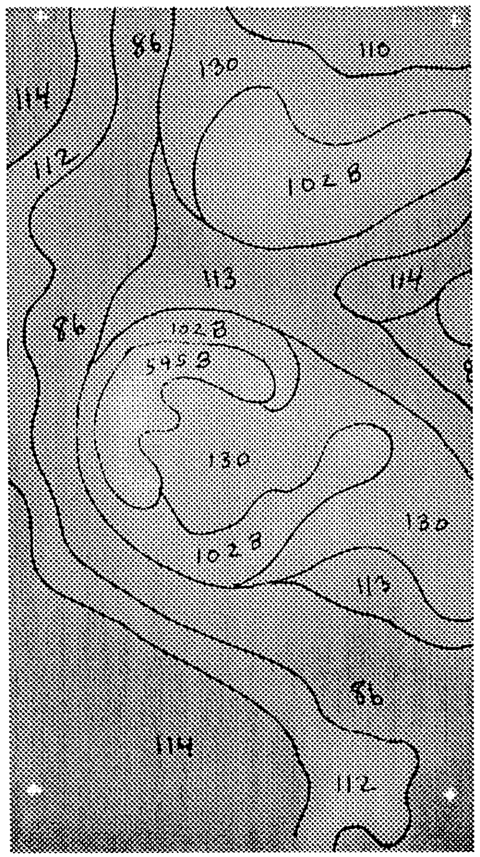


Figure A-3. Soil survey mapping units for Hanska site

Variability encountered at each site was much more extreme than was previously anticipated. Many of the quantifiable characteristics had variability of 300-500% within the same field. Much of the variability associated with soil analysis was correlated with topographic position and, in turn, could be related to the photo-tones from aerial photographs. Residual soil nitrate, which is currently used for making fertilizer recommendations in western Minnesota, were relatively low at all locations. The low residual soil nitrate found in the fall of 1993 probably reflects the excessively wet growing season encountered that year. The low nitrate concentrations would suggest that its use as a single diagnostic tool in allowing variable rate N applications during the time span of this research would be limited.

The variability quantified under this objective reinforces the need to increase the development of site-specific N rate management. When variability can be quantified, it can then be managed. Unfortunately, most of the variability that was determined in soil and landscape features at these selected locations are not currently considered when making fertilizer N recommendations to farmers. Residual soil nitrate, which is currently recommended to adjust fertilizer recommendation on a field scale basis, would be considered low by current soil testing standards and would not allow much flexibility in site-specific N management. Development of soil testing techniques which incorporate other parameters measured will require modification in the current methods utilized in making fertilizer recommendations. Changes are made to fertilizer recommendations on a periodic basis, but usually only after research has been conducted over many locations and environmental conditions. The limited data (one year) obtained from this project will be used to determine what additional factors should be considered into the integration (Objective B) of new soil testing programs.

Appendix A: Objective A

Hanska site:

Appendix A, Figure 1-2. Field layout and experimental design.
Appendix A, Figure 3-6. Soil parameters condition maps.

Hector site:

Appendix A, Figure 7-8. Field layout and experimental design.
Appendix A, Figure 9-10. Relative elevation and soil survey map.
Appendix A, Figure 11-14. Soil parameters condition maps.
Appendix A, Table 1-3 Correlation coefficients for selected variables.

Lake Crystal site:

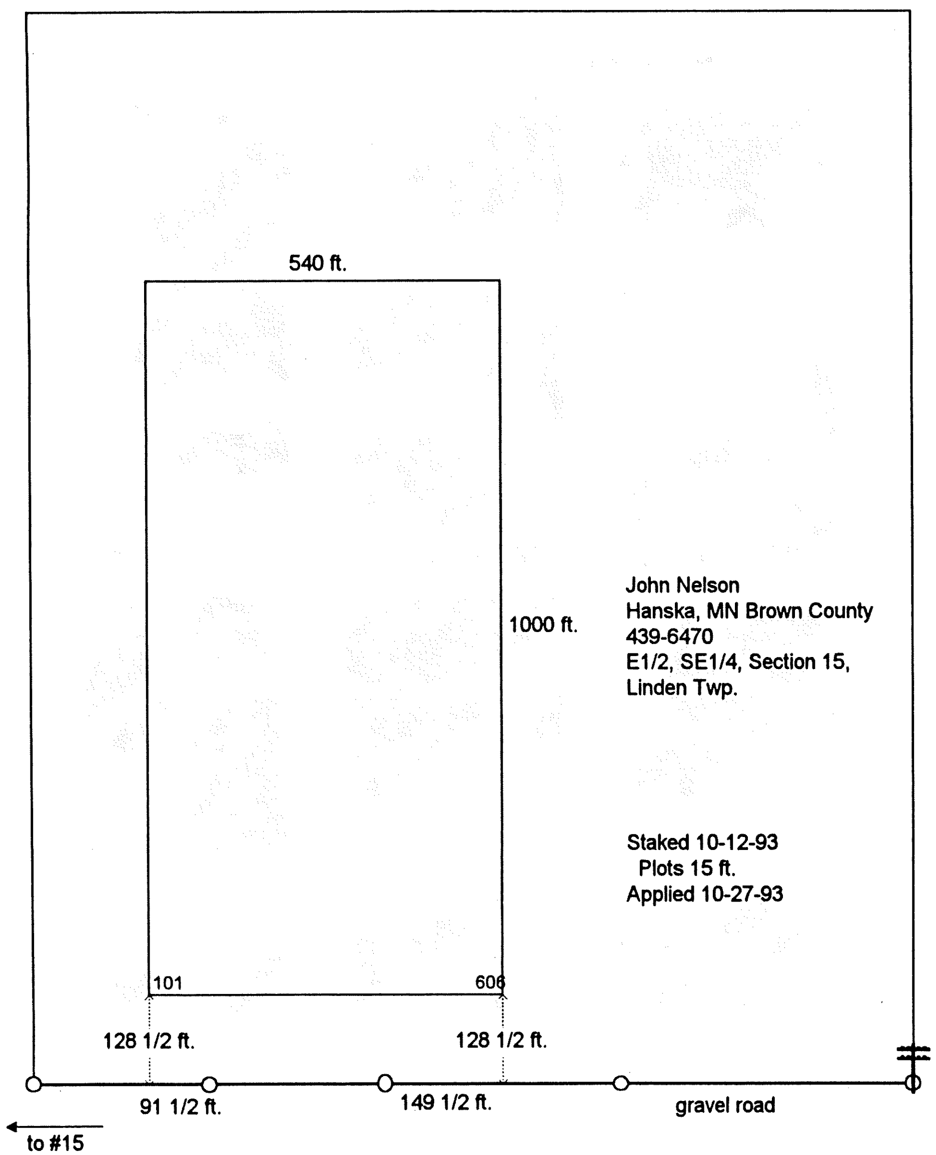
Appendix A, Figure 15-16. Field layout and experimental design.
Appendix A, Figure 17-18. Relative elevation and soil survey map.
Appendix A, Figure 19-22. Soil parameters condition maps.
Appendix A, Table 4-6. Correlation coefficients for selected variables.

Revere site:

Appendix A, Figure 23-24. Field layout and experimental design.
Appendix A, Figure 25-26. Relative elevation and soil survey map.
Appendix A, Figure 27-30. Soil parameters condition maps.
Appendix A, Table 7-9. Correlation coefficients for selected variables.

Hanska 1994

N-rate High intensity
Six reps of six treatments

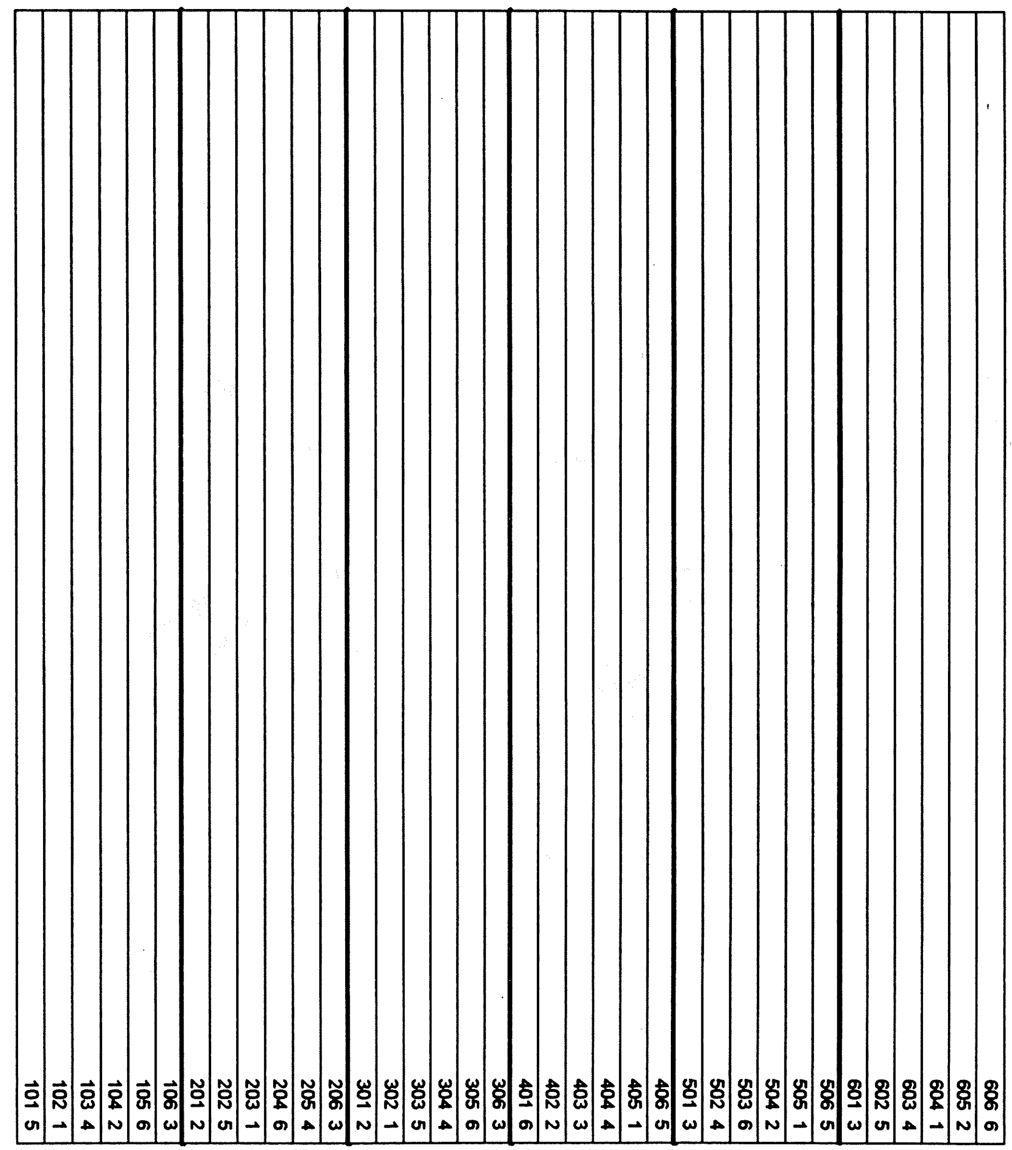


Appendix A, Figure 1. Field layout.

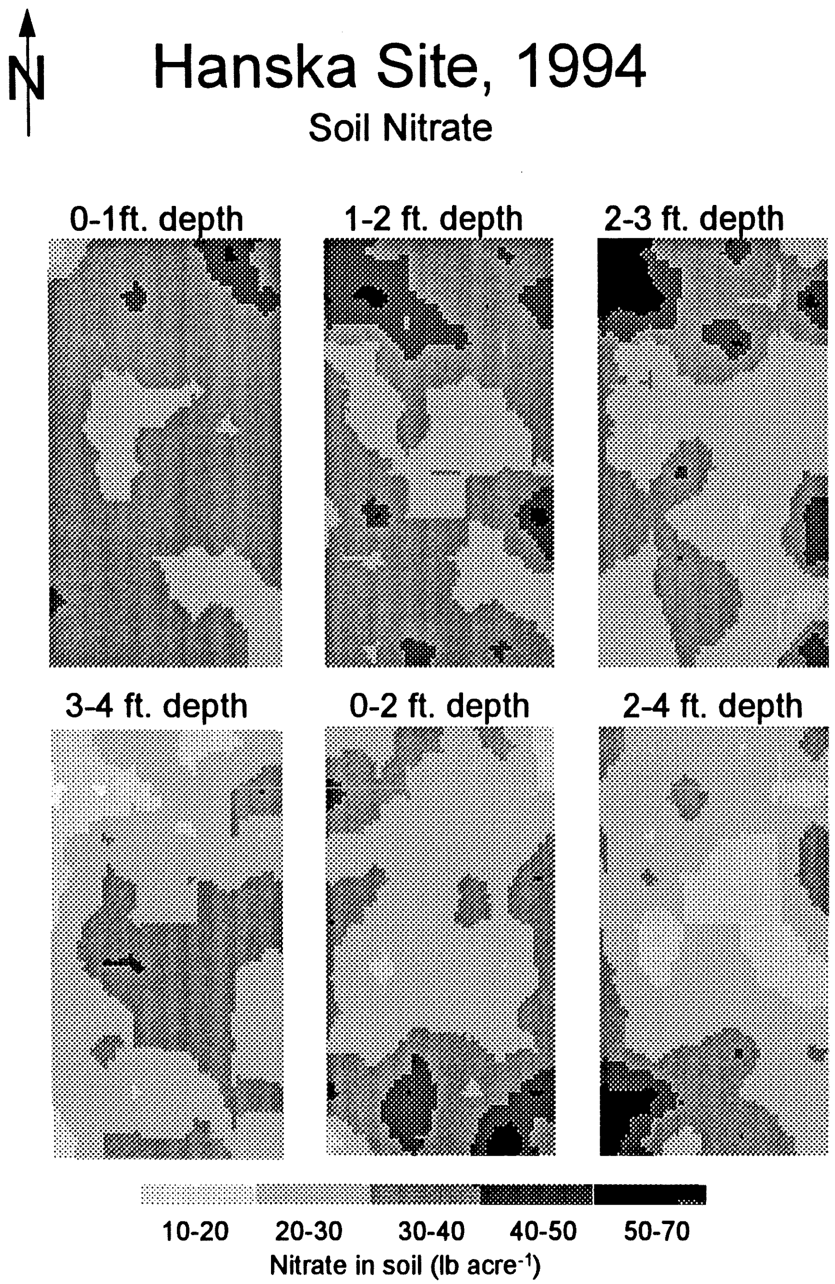
Hanska 1994

N-rate High intensity
6 reps of 6 treatments
Plots: 15 ft.

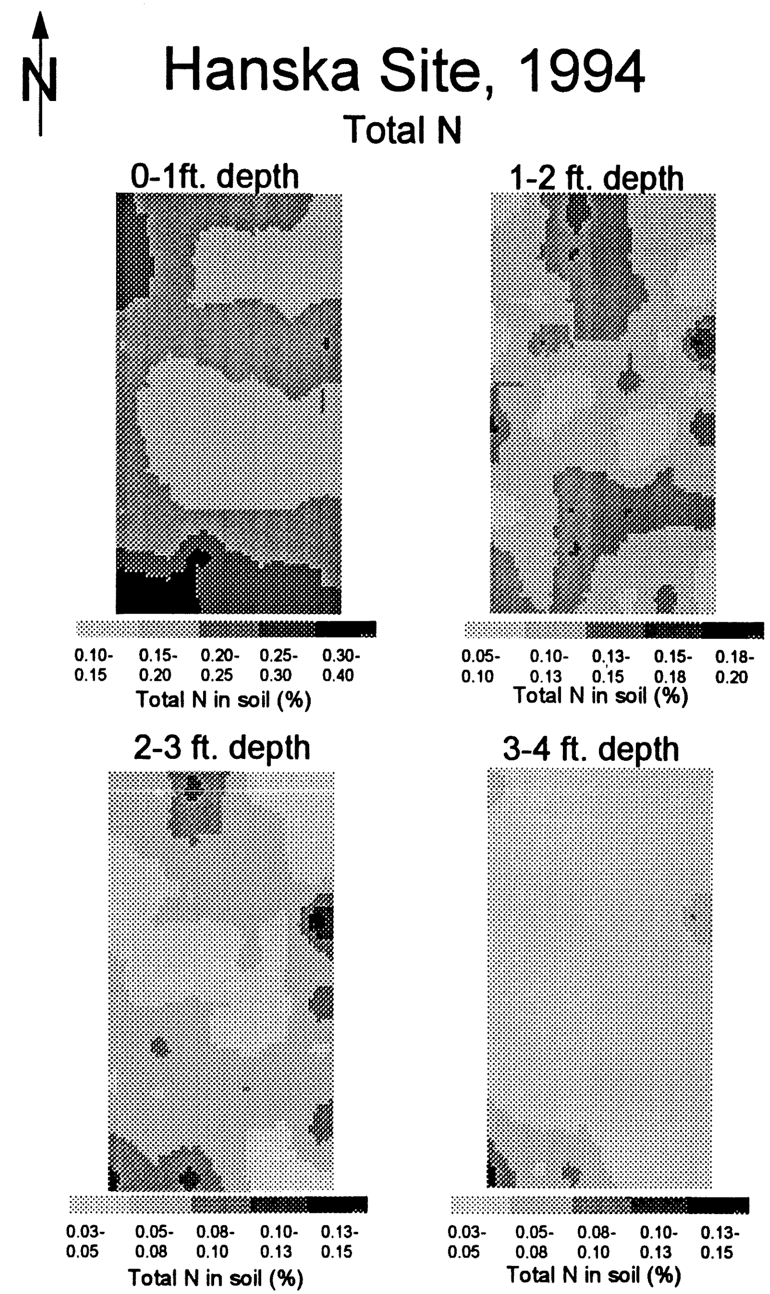
Trt	N rate (#/ac)
1	0
2	60
3	90
4	120
5	150
6	180



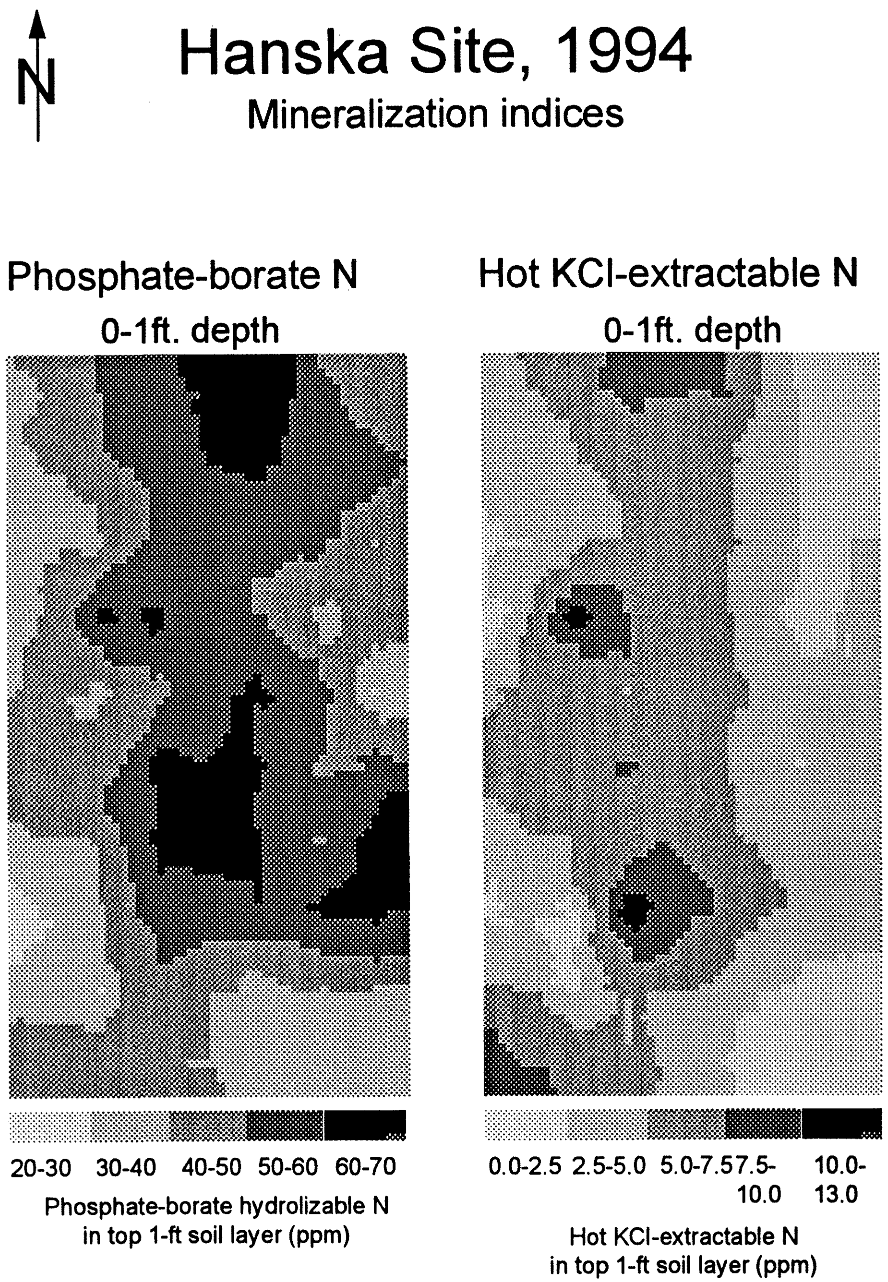
Appendix A, Figure 2. Experimental design.



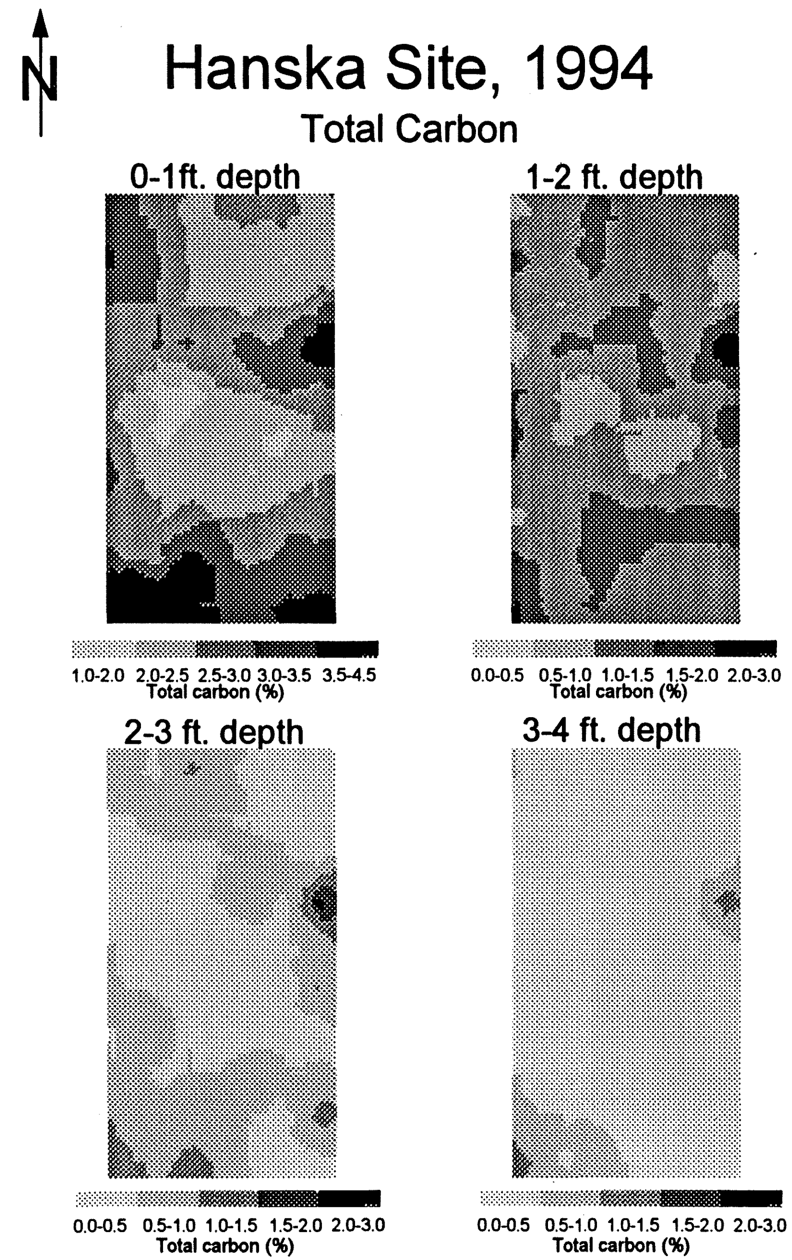
Appendix A, Figure 3. Soil nitrate by depth condition map.



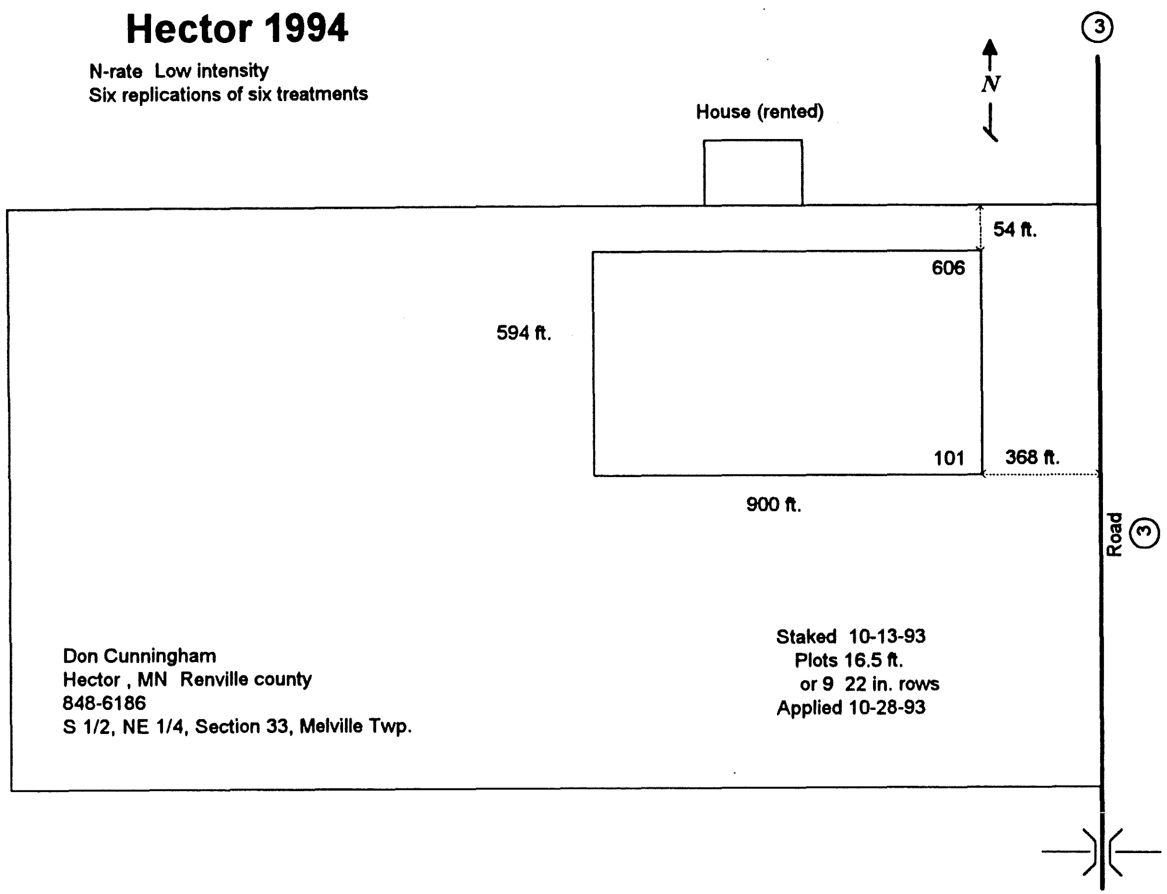
Appendix A, Figure 4. Total soil nitrogen by depth condition map.



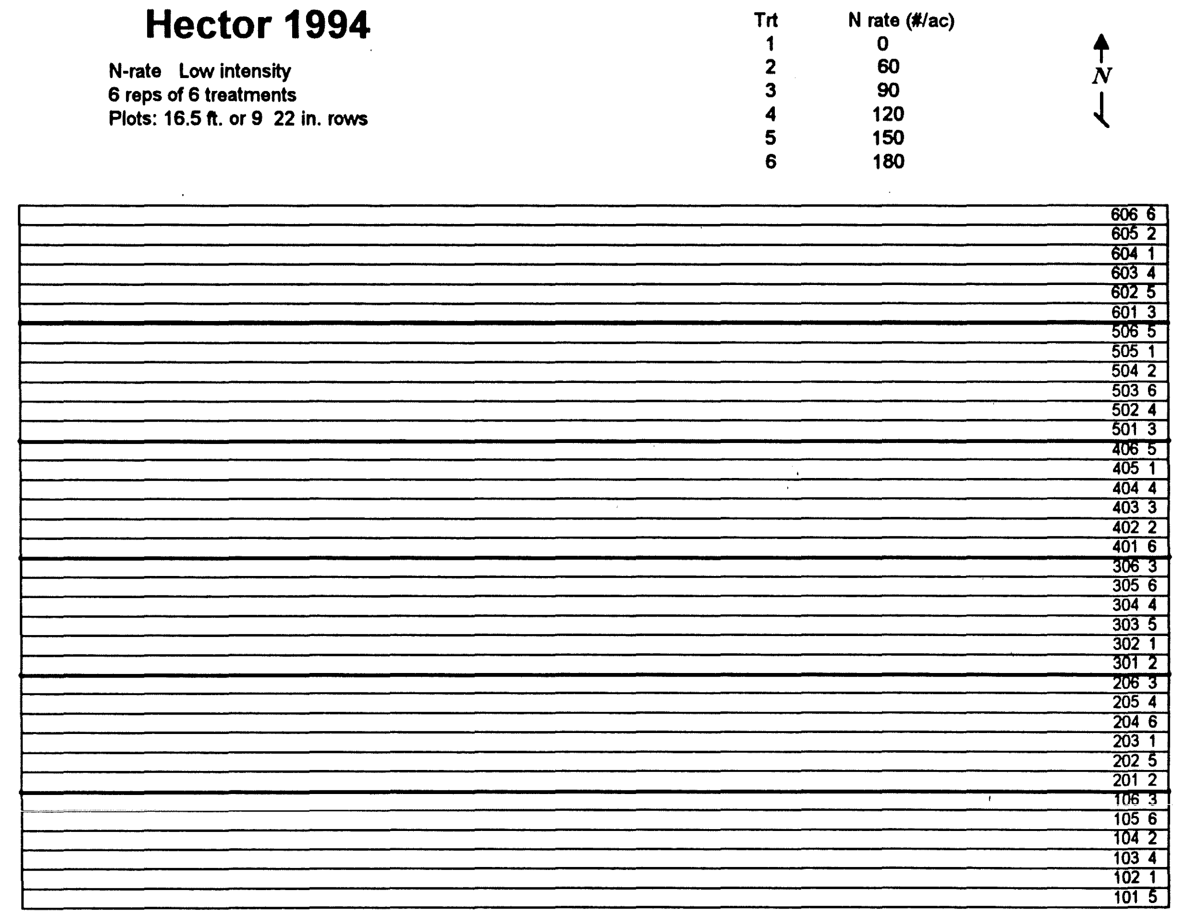
Appendix A, Figure 5. Soil mineralization indices condition map.



Appendix A, Figure 6. Total soil carbon by depth condition map.

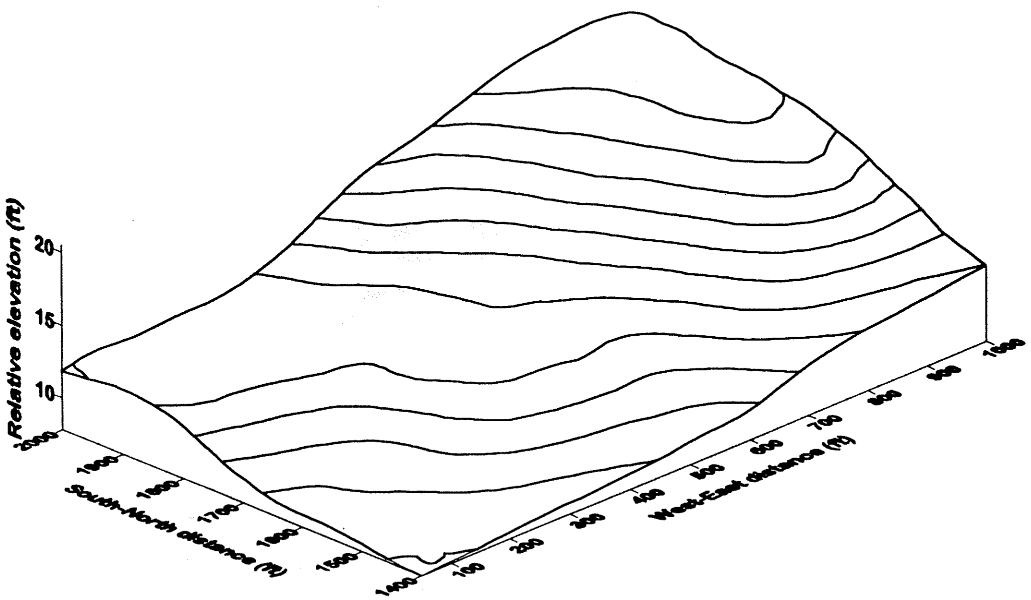


Appendix A, Figure 7. Field layout.



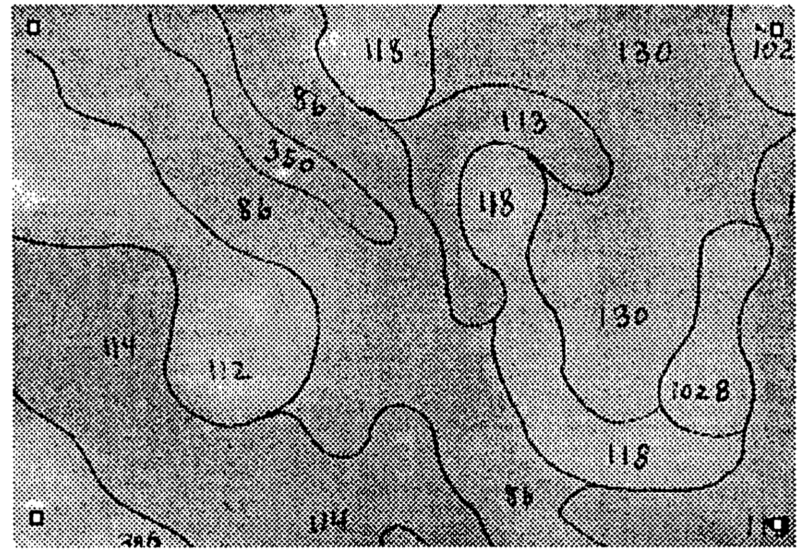
Appendix A, Figure 8. Experimental design.

Relative Elevation at Hector Site, 1994



Appendix A, Figure 9. Relative elevation of field.

Soil Survey Mapping Units for Hector Site, 1994 (approx. 1:3500)

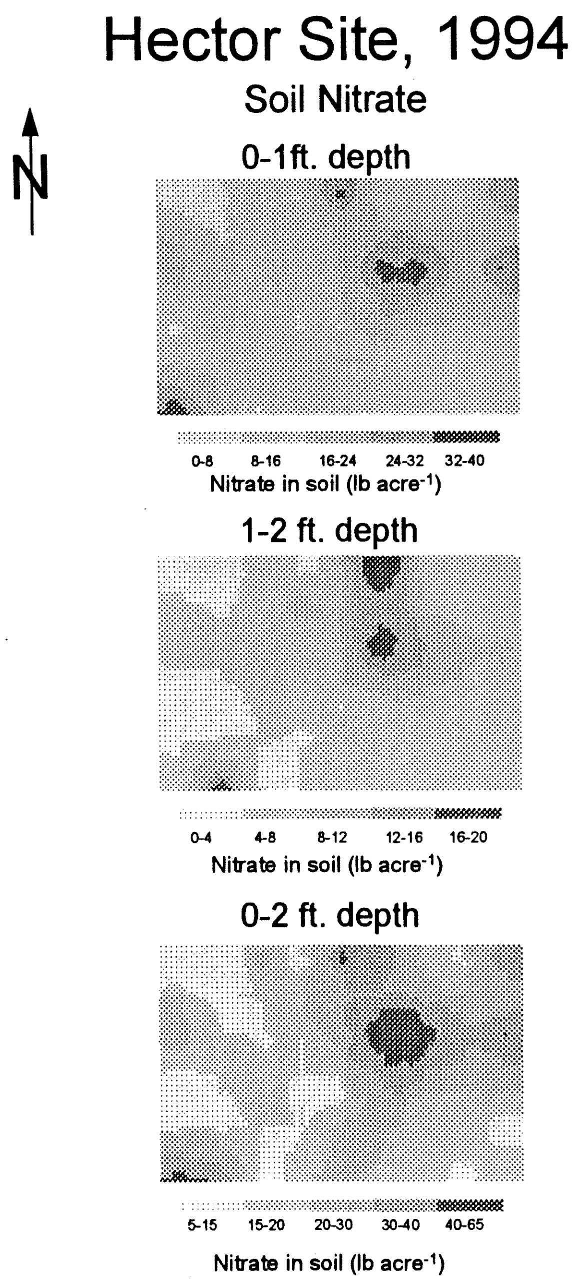


Legend:

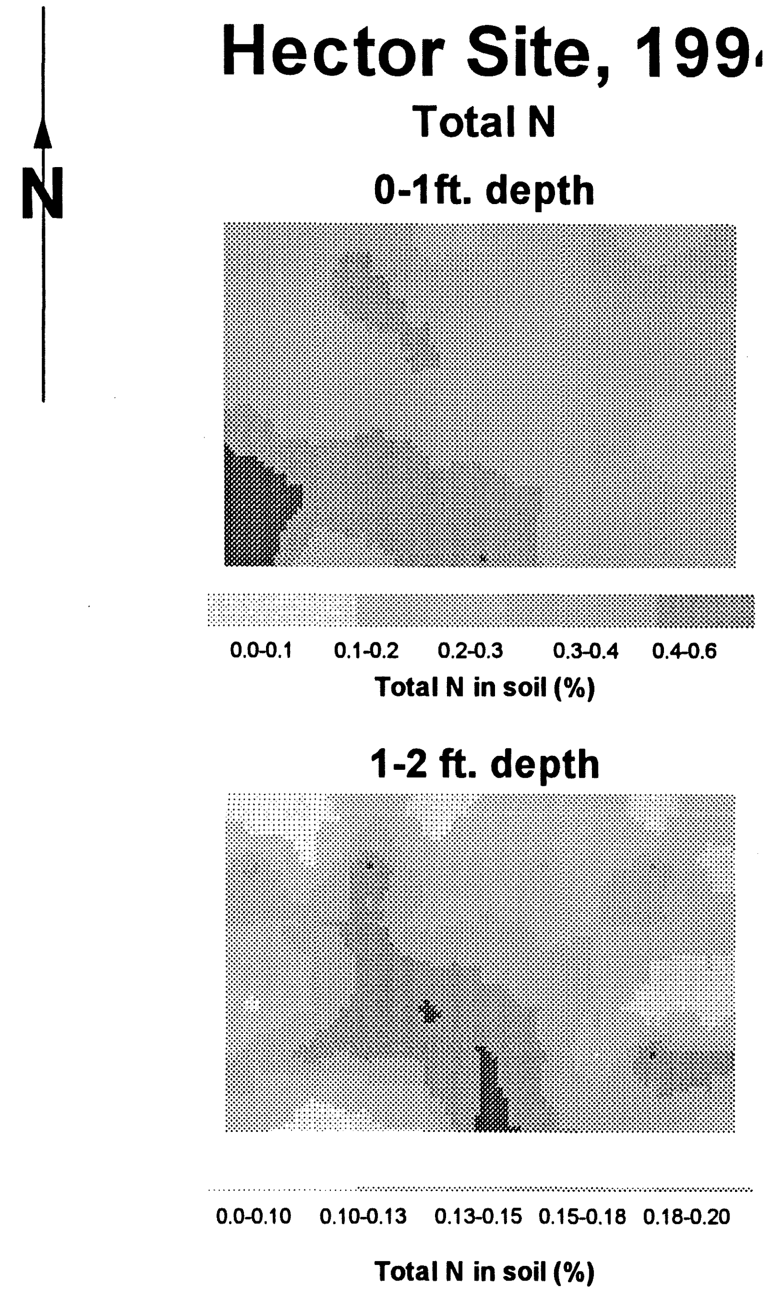
86	Canisteo cl, 0-2 %
102B	Clarion l, 2-5%
112	Harps cl, 0-2%
113	Webster cl, 0-2%
114	Glencoe sicl, 0-1%
118	Crippen l, 1-3%
130	Nicollet cl, 1-3%
350	Canisteo sicl, depressional, 0-1%
386	Okoboji mucky sicl, 0-1%

N

Appendix A, Figure 10. Soil survey map of field.



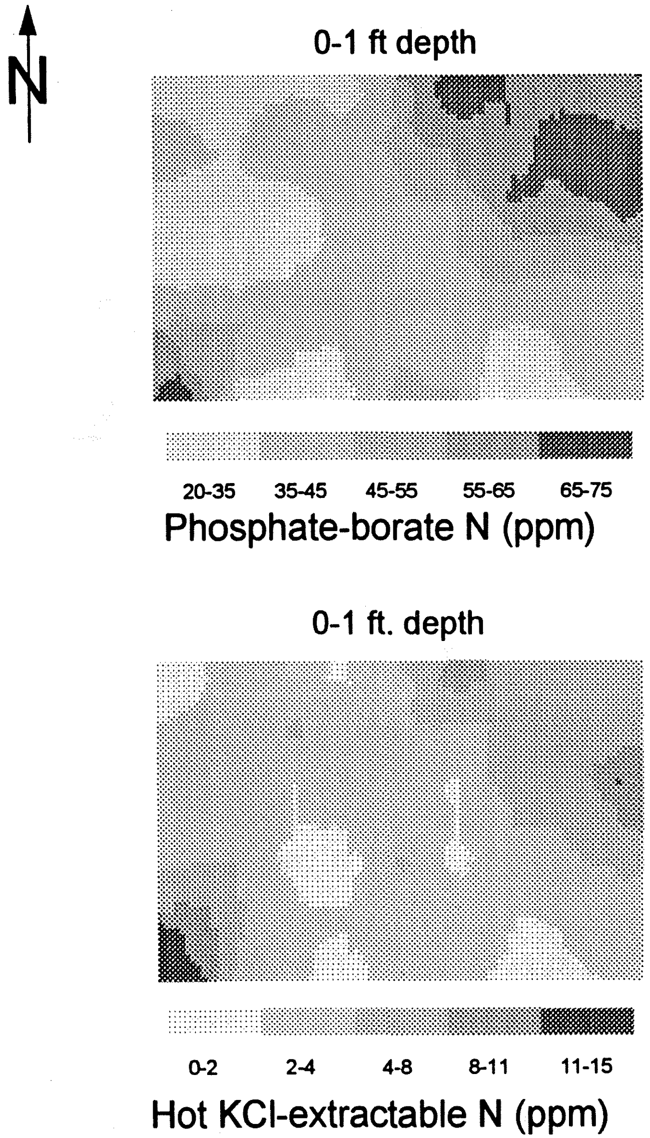
Appendix A, Figure 11. Soil nitrate by depth condition map.



Appendix A, Figure 12. Total soil nitrogen by depth condition map.

Hector Site, 1994

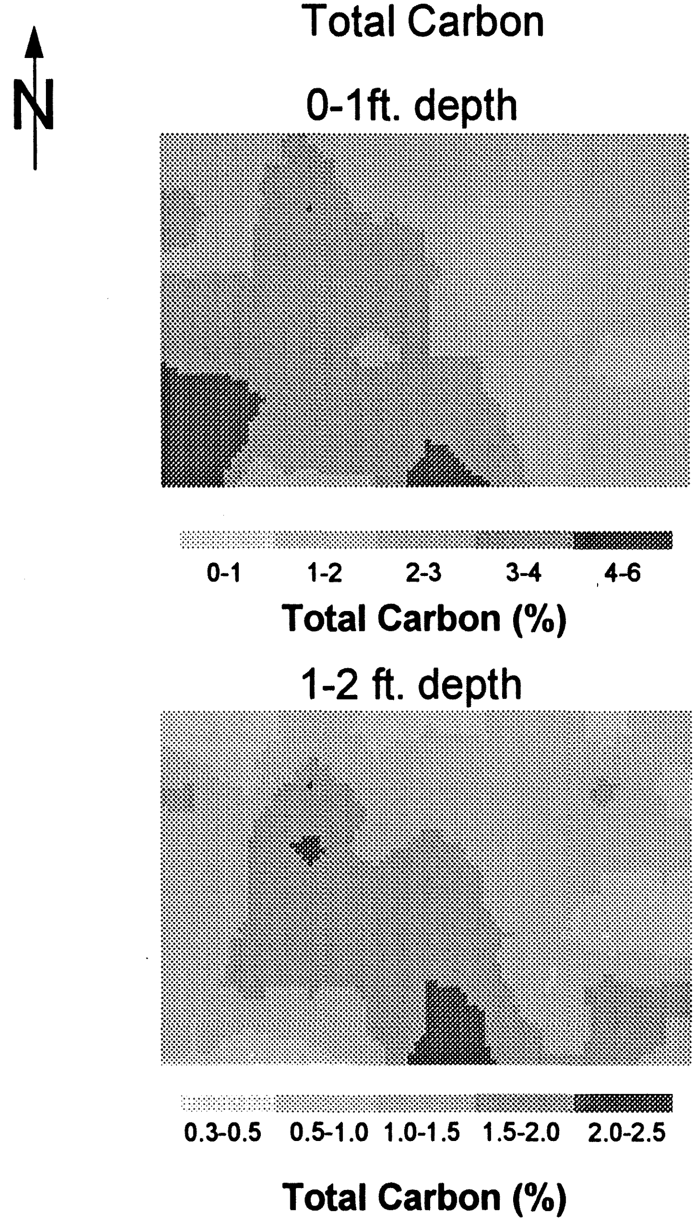
Mineralization indices



Appendix A, Figure 13. Soil mineralization indices condition map.

Hector Site, 1994

Total Carbon



Appendix A, Figure 14. Total soil carbon by depth condition map.

Appendix A, Table 1. Simple correlation coefficients for selected check plot variables at **Hector** site, 1994. Correlations are significant at the 5% level (P<0.05).

	Tot C 12-24 in.	Tot C 0-12 in.	Tot N 12-24 in.	Tot N 0-12 in.	P-B N 12-24 in.	P-B N 0-12 in.	Hot KCl-N 12-24 in.	Hot KCl-N 0-12 in.	NO3 0-24 in.	NO3 12-24 in.	NO3 0-12 in.	NH4 12-24 in.	NH4 0-12 in.
NH4 0-12 in.	0.24	0.33	0.24	0.29	0.28	NS	NS	NS	0.26	0.21	0.26	NS	-
NH4 12-24 in.	NS	0.27	NS	0.35	-0.35	NS	NS	NS	NS	NS	NS	-	
NO3 0-12 in.	NS	NS	NS	-0.21	0.33	**0.65**	0.35	**0.40**	**0.89**	**0.61**	-		
NO3 12-24 in.	NS	NS	NS	-0.30	**0.51**	**0.63**	0.36	**0.42**	**0.83**	-			
NO3 0-24 in.	NS	NS	-0.15	-0.29	**0.40**	**0.71**	**0.41**	**0.43**	-				
Hot KCl-N 0-12 in.	-0.21	NS	NS	-0.19	0.37	**0.72**	**0.50**	-					
Hot KCl-N 12-24 in.	**-0.48**	**-0.54**	**-- 0.43**	**-0.63**	**0.47**	**0.57**	-						
P-B N 0-12 in.	NS	NS	NS	-0.34	**0.61**	-							
P-B N 12-24 in.	0.24	-0.30	0.25	**-0.43**	-								
Total N 0-12 in.	**0.44**	**0.93**	**0.47**	-									
Total N 12-24 in.	**0.95**	**0.54**	-										
Total C 0-12 in.	**0.49**	-											
Total C 12-24 in.	-												

NS: not significant at 5% level

Appendix A, Table 2. Simple correlation coefficients for selected whole-field variables at **Hector** site, 1994. Correlations are significant at the 5% level (P<0.05).

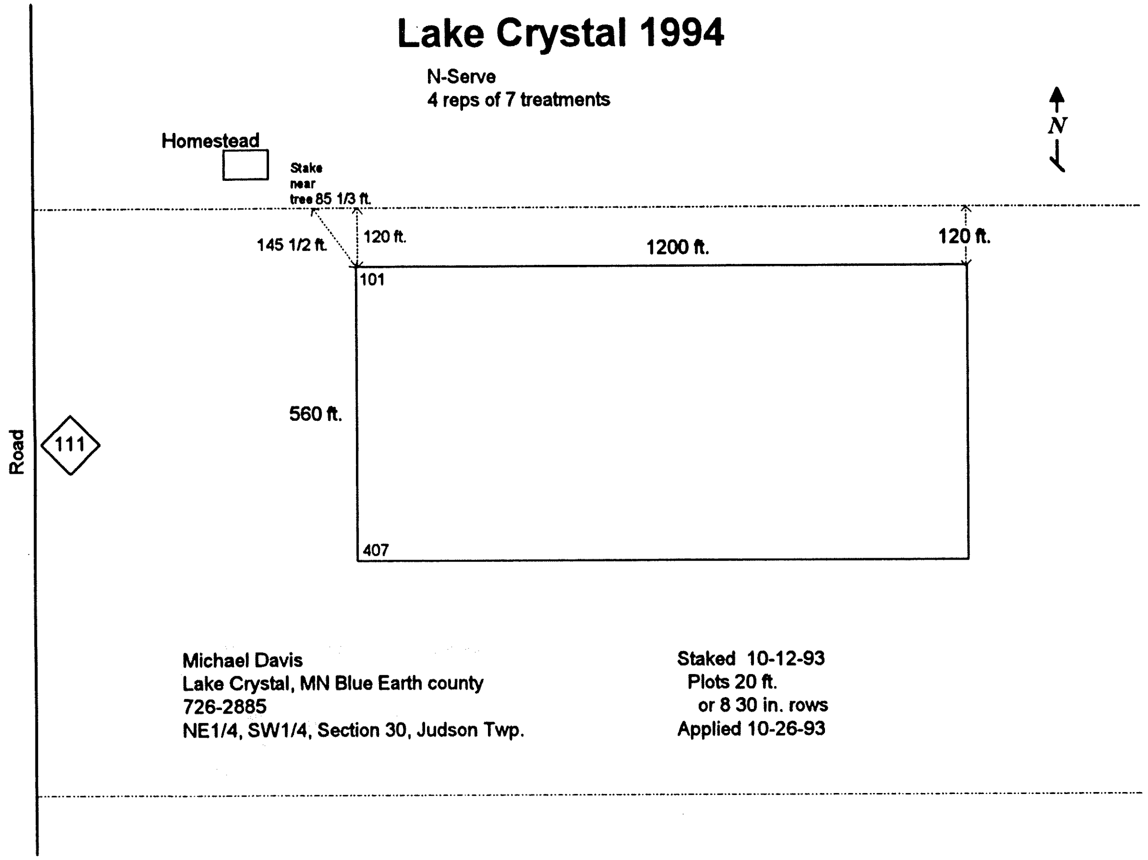
	Aspect	Slope	Elevation	Red	Green	Blue
Blue	NS	-0.11	**-0.41**	**0.90**	**0.95**	-
Green	NS	NS	-0.29	**0.96**	-	
Red	NS	NS	-0.16	-		
Elevation	0.093	0.26	-			
Slope	0.34	-				
Aspect	-					

NS: not significant at 5% level

Appendix A, Table 3. Simple correlation coefficients for selected check plot variables at **Hector** site, 1994. Correlations are significant at the 5% level (P<0.05).

	Aspect	Slope	Elevation	Red	Green	Blue
NH4 0-12 in.	-0.25	NS	NS	NS	NS	NS
NH4 12-24 in.	NS	NS	-0.43	NS	NS	NS
NO3 0-12 in.	NS	0.25	0.34	-0.23	-0.29	-0.37
NO3 12-24 in.	NS	NS	0.42	-0.39	-0.45	-0.48
NO3 0-24 in.	NS	0.26	0.43	-0.33	-0.39	-0.46
Hot KCl-N 0-12 in.	NS	NS	0.38	-0.32	-0.36	-0.42
Hot KCl-N 12-24 in.	NS	NS	0.72	NS	-0.20	-0.36
P-B N 0-12 in.	NS	NS	0.61	-0.40	-0.48	-0.57
P-B N 12-24 in.	NS	0.21	0.66	-0.36	-0.42	-0.46
Total N 0-12 in.	NS	-0.45	-0.85	NS	0.23	0.40
Total N 12-24 in.	NS	NS	-0.37	NS	NS	NS
Total C 0-12 in	NS	-0.43	-0.76	NS	NS	0.28
Total C 12-24	NS	NS	-0.37	NS	NS	NS

NS: not significant at 5% level



Appendix A, Figure 15. Field layout.

Lake Crystal 1994

N-Serve
4 reps of 7 treatments
Plots: 20 ft. (8 30 in. rows

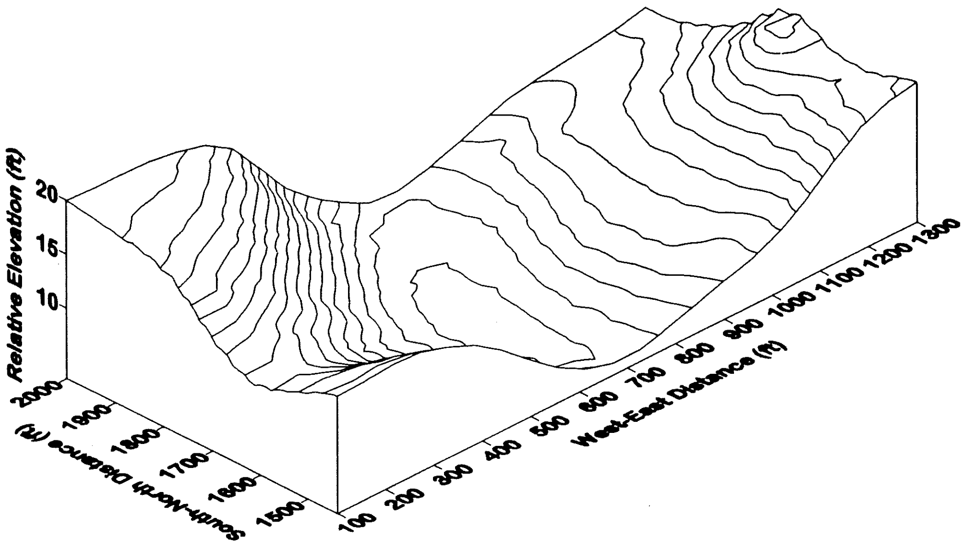
Trt	N rate (#/ac)	Inhibitor
1	0	---
2	60	---
3	60	N-serve
4	120	---
5	120	N-serve
6	180	---
7	180	N-serve

N

101	2
102	3
103	1
104	6
105	7
106	4
107	5
201	6
202	7
203	3
204	2
205	1
206	5
207	4
301	7
302	6
303	1
304	4
305	5
306	2
307	3
401	4
402	5
403	6
404	7
405	1
406	3
407	2

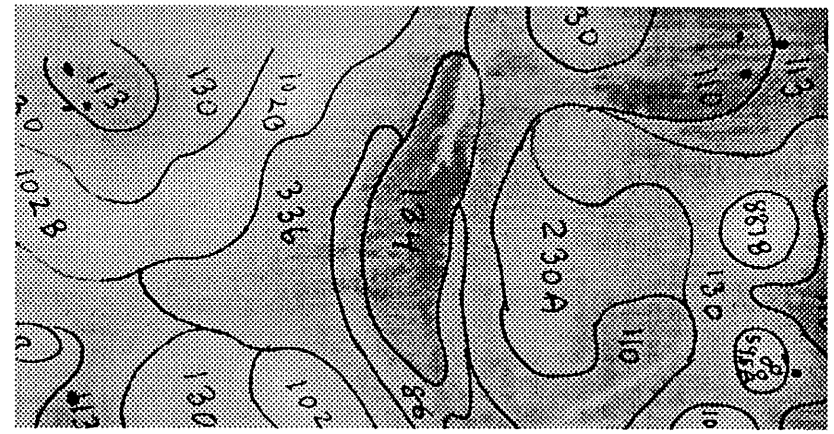
Appendix A, Figure 16. Experimental design

Relative Elevation at Lake Crystal Site, 1994



Appendix A, Figure 17. Relative elevation of field.

Soil Survey Mapping Units for Lake Crystal Site, 1994 (approx. 1:3500)



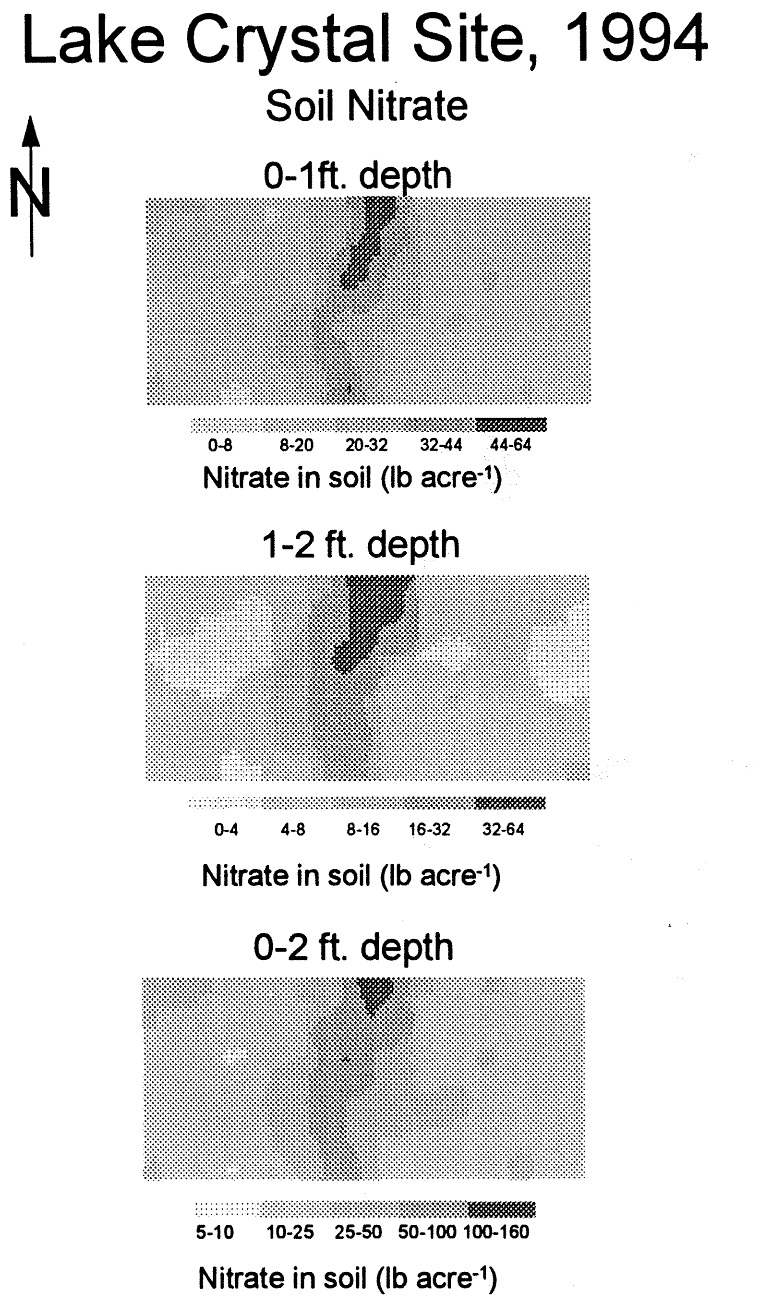
Legend:

86	Canisteo cl, 0-2 %
102B	Clarion l, 2-6%
110	Marna sicl, 0-2%
130	Nicollet cl, 1-3%
134	Okoboji sicl, 0-1%
230A	Guckeen sicl, 0-2%
595B	Swanlake l, 3-6%
887B	Clarion-Swanlake Complex l,2-6%
o o o	Gravel spot

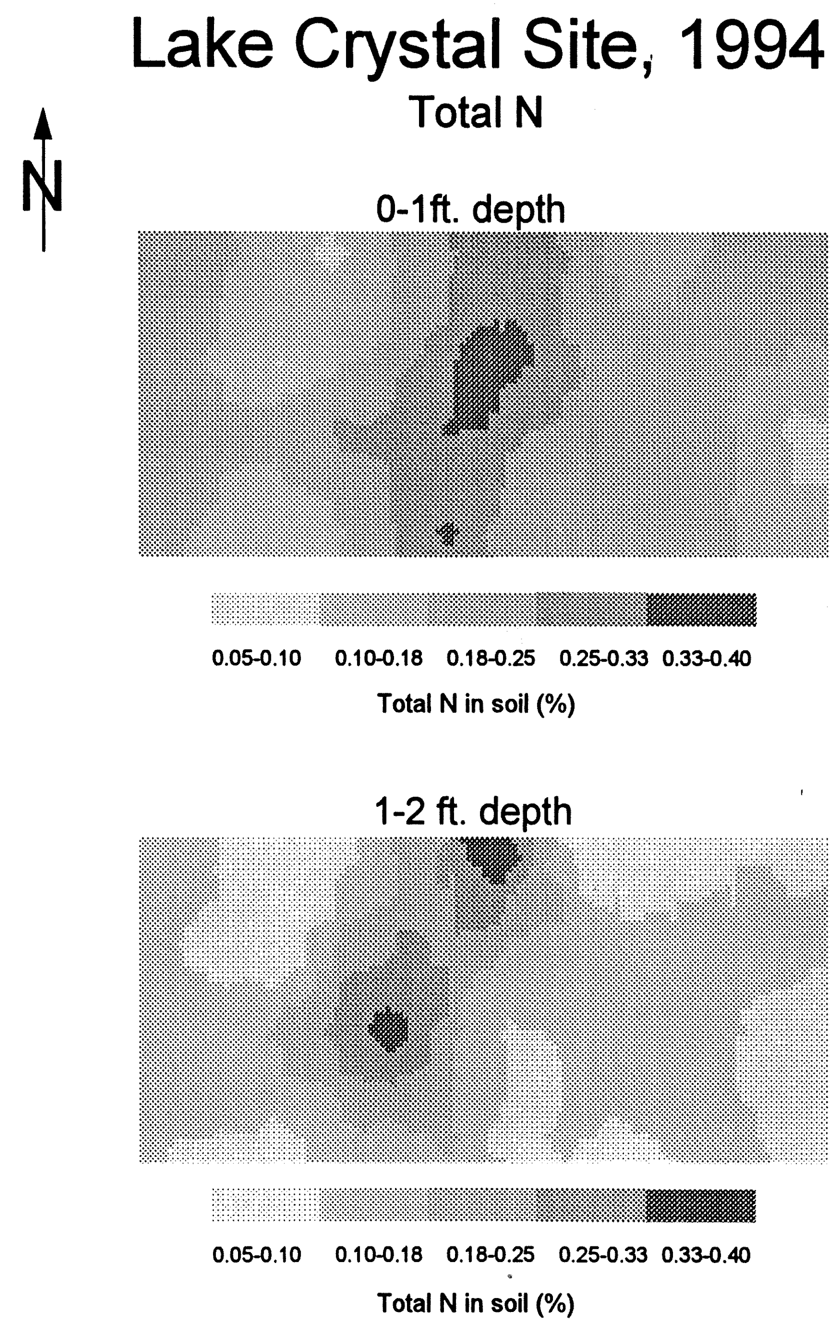
N

Note: small pockets of silt (< ¼ acre) found in 130 and 102B map units

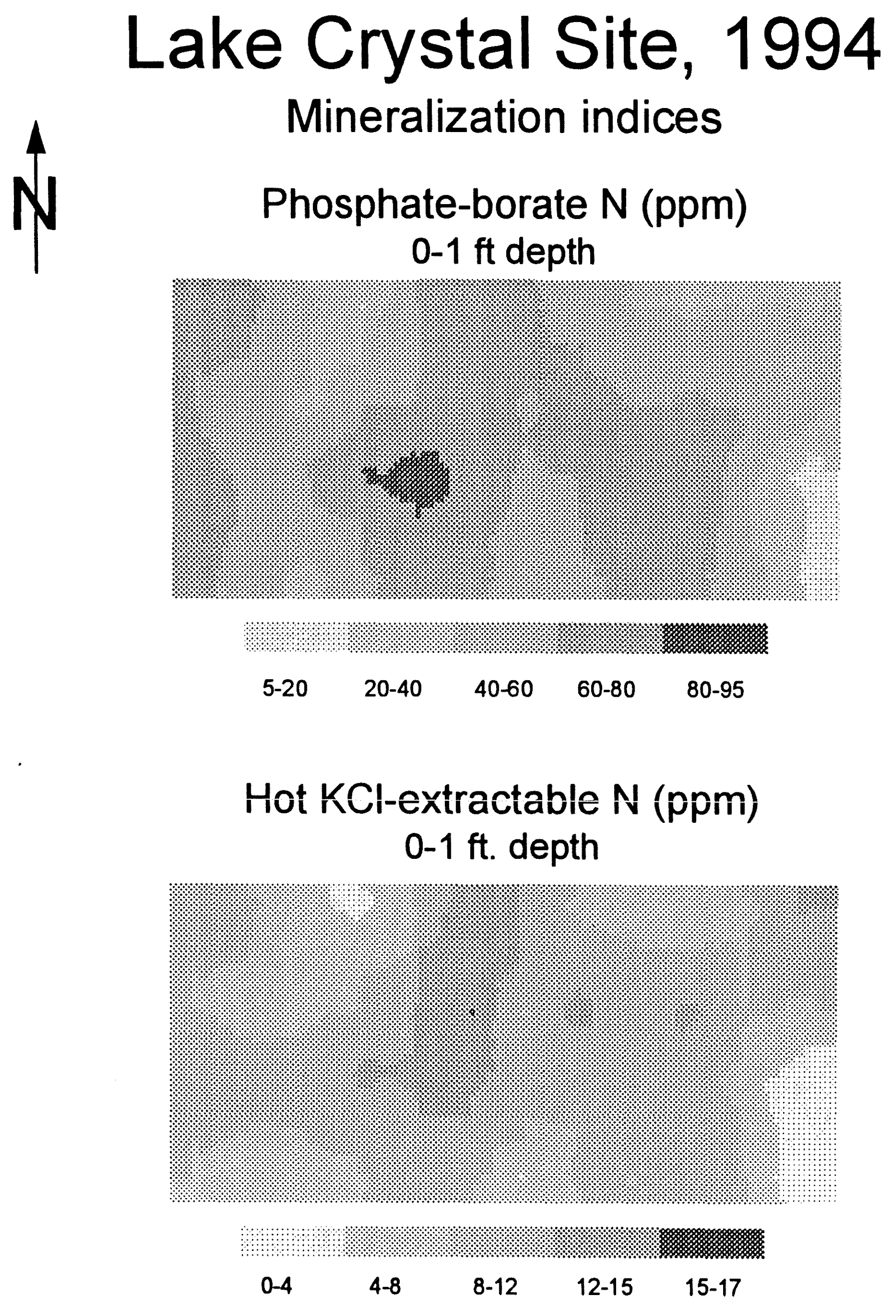
Appendix A, Figure 18. Soil survey map of field.



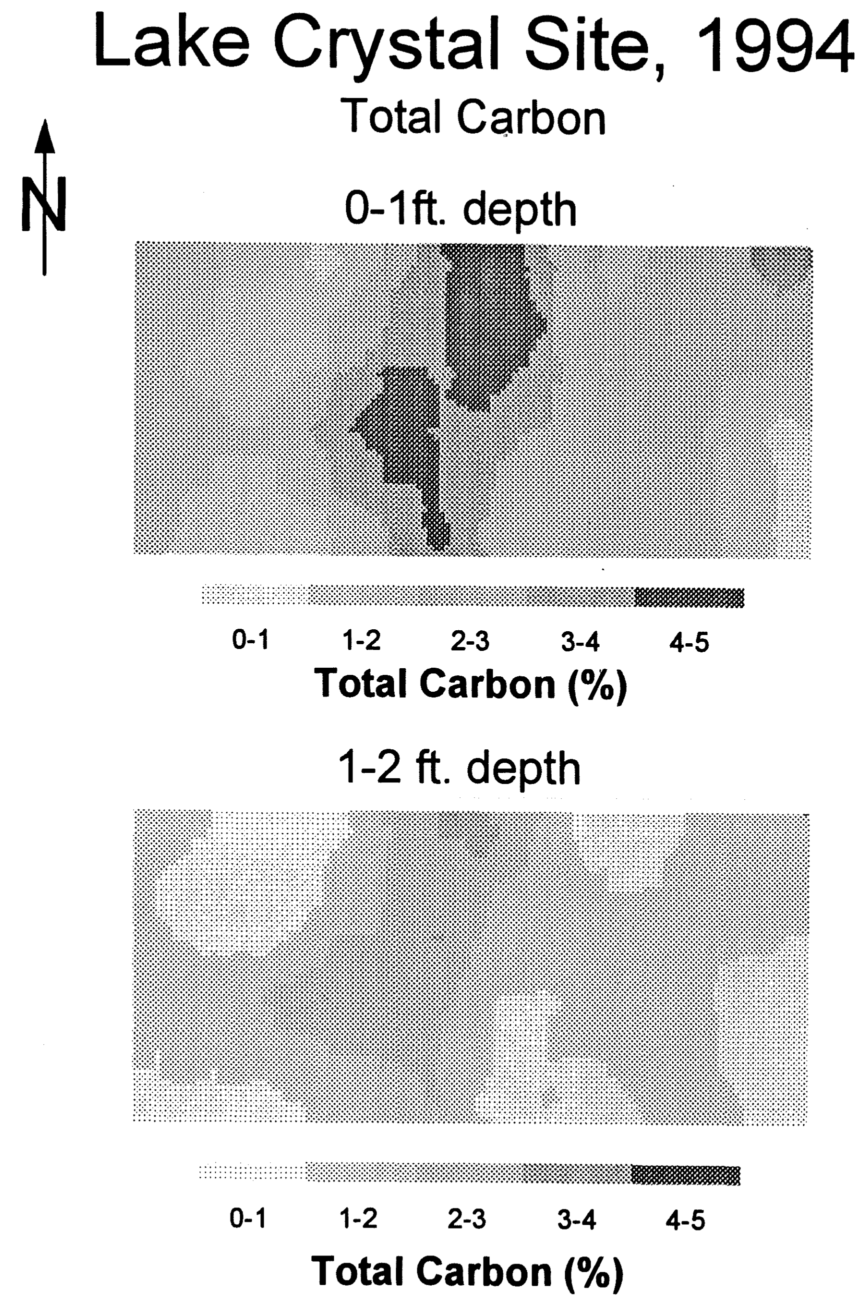
Appendix A, Figure 19. Soil nitrate by depth condition map.



Appendix A, Figure 20. Total soil nitrogen by depth condition map.



Appendix A, Figure 21. Soil mineralization indices condition map.



Appendix A, Figure 22. Total soil carbon by depth condition map.

Appendix A, Table 4. Simple correlation coefficients for selected check plot variables at **Lake Crystal** site, 1994. Correlations are significant at the 5% level (P<0.05).

	Tot C 12-24 in.	Tot C 0-12 in.	Tot N 12-24 in.	Tot N 0-12 in.	P-B N 12-24 in.	P-B N 0-12 in.	Hot KCl-N 12-24 in.	Hot KCl-N 0-12 in.	NO3 0-24 in.	NO3 12-24 in.	NO3 0-12 in.	NH4 12-24 in.	NH4 0-12 in.
NH4 0-12 in.	**0.58**	**0.72**	**0.49**	**0.66**	0.25	**0.51**	0.25	**0.58**	**0.69**	**0.58**	**0.68**	**0.44**	-
NH4 12-24 in.	0.23	NS	0.22	NS	NS	NS	NS	NS	**0.49**	**0.48**	**0.43**	-	
NO3 0-12 in.	**0.71**	**0.80**	**0.61**	**0.77**	0.28	**0.56**	0.27	**0.60**	**0.93**	**0.79**	-		
NO3 12-24 in.	**0.69**	**0.66**	**0.63**	**0.54**	0.32	0.33	0.39	**0.40**	**0.92**	-			
NO3 0-24 in.	**0.74**	**0.79**	**0.67**	**0.68**	0.33	**0.46**	0.38	**0.51**	-				
Hot KCl-N 0-12 in.	**0.76**	**0.77**	**0.72**	**0.76**	**0.62**	**0.86**	**0.49**	-					
Hot KCl-N 12-24 in.	**0.71**	**0.44**	**0.83**	NS	**0.86**	**0.41**	-						
P-B N 0-12 in.	**0.64**	**0.70**	**0.68**	**0.74**	**0.63**	-							
P-B N 12-24 in.	**0.74**	**0.43**	**0.85**	0.27	-								
Total N 0-12 in.	**0.66**	**0.90**	**0.56**	-									
Total N 12-24 in.	**0.93**	**0.74**	-										
Total C 0-12 in.	**0.80**	-											
Total C 12-24 in.	-												

NS: not significant

Appendix A, Table 5. Simple correlation coefficients for selected whole-field variables at **Lake Crystal** site, 1994. Correlations are significant at the 5% level (P<0.05).

	Aspect	Slope	Elevation	Red	Green	Blue
Blue	0.17	**0.66**	**0.44**	**0.97**	**0.97**	-
Green	0.17	**0.72**	**0.49**	**0.98**	-	
Red	0.17	**0.72**	**0.48**	-		
Elevation	0.14	**0.47**	-			
Slope	0.19	-				
Aspect	-					

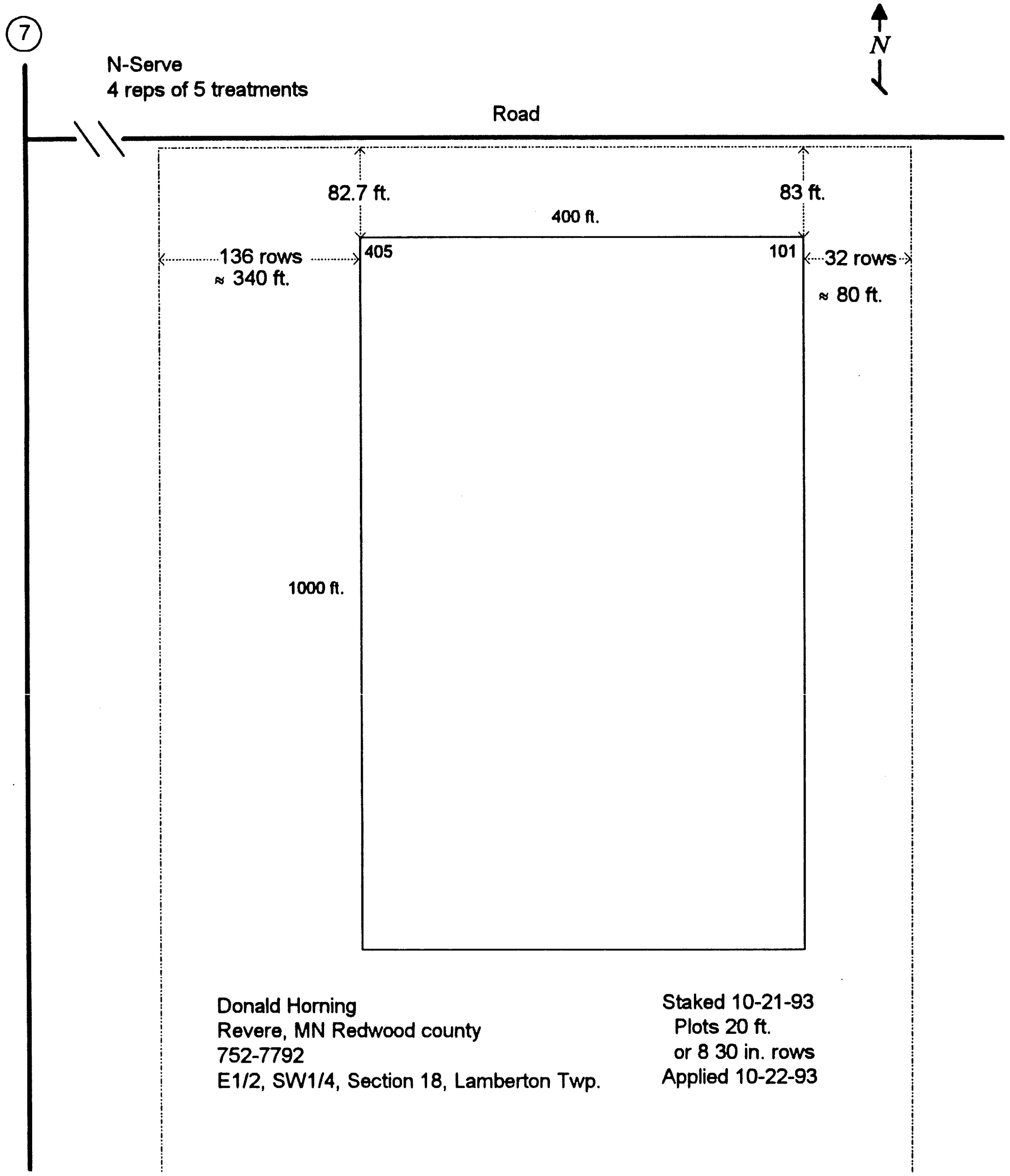
NS: not significant

Appendix A, Table 6. Simple correlation coefficients for selected check plot variables at **Lake Crystal** site, 1994. Correlations are significant at the 5% level (P<0.05).

	Aspect	Slope	Elevation	Red	Green	Blue
NH4 0-12 in.	NS	-0.47	-0.51	-0.33	-0.37	-0.28
NH4 12-24 in.	NS	-0.29	NS	NS	NS	NS
NO3 0-12 in.	NS	-0.48	-0.55	-0.20	-0.23	NS
NO3 12-24 in.	NS	-0.34	-0.45	NS	NS	NS
NO3 0-24 in.	NS	-0.44	-0.56	NS	NS	NS
Hot KCl-N 0-12 in.	0.25	-0.30	-0.57	NS	-0.30	NS
Hot KCl-N 12-24 in.	0.30	NS	-0.25	-0.27	-0.21	-0.27
P-B N 0-12 in.	NS	-0.25	-0.45	NS	-0.21	NS
P-B N 12-24 in.	NS	NS	-0.26	0.32	0.21	0.29
Total N 0-12 in.	NS	-0.53	-0.71	-0.41	-0.47	-0.36
Total N 12-24 in.	NS	NS	-0.54	NS	NS	NS
Total C 0-12 in	NS	-0.53	-0.77	-0.39	-0.44	-0.34
Total C 12-24	NS	-0.24	-0.59	NS	NS	NS

NS: not significant

Revere 1994

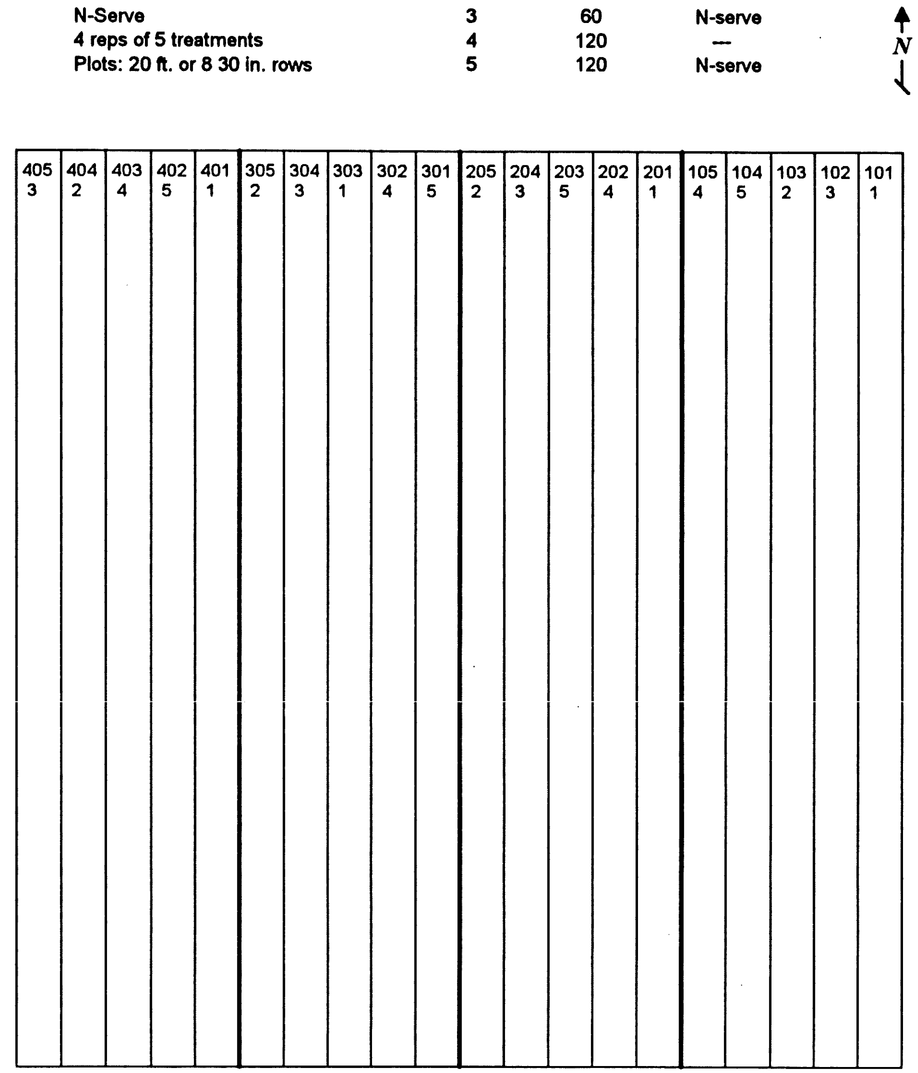


Appendix A, Figure 23. Field layout.

Revere 1994

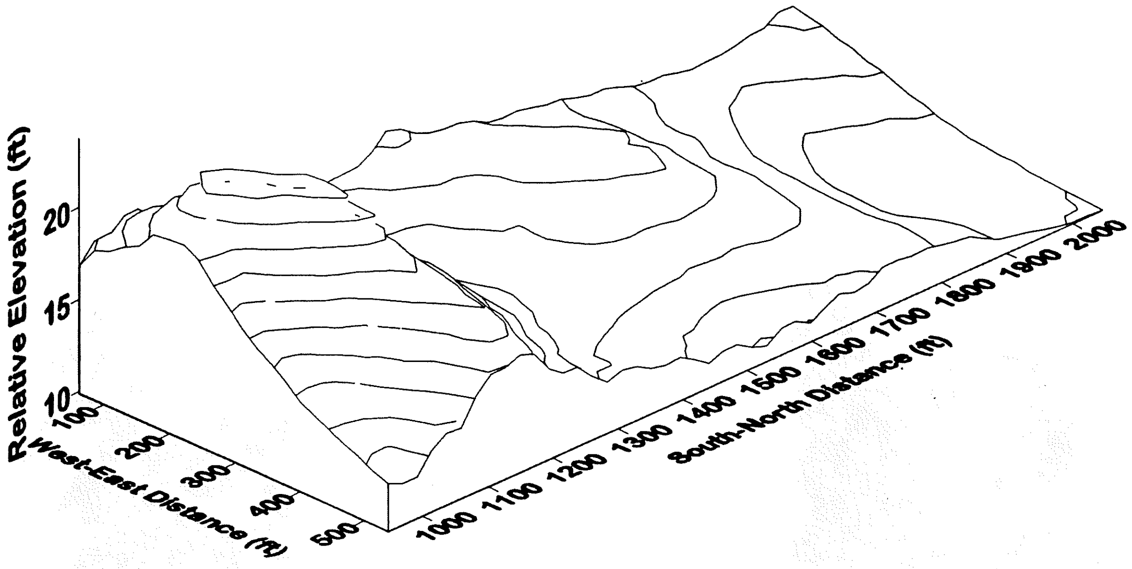
N-Serve
4 reps of 5 treatments
Plots: 20 ft. or 8 30 in. rows

Trt	N rate (#/ac)	Inhibitor
1	0	—
2	60	—
3	60	N-serve
4	120	—
5	120	N-serve



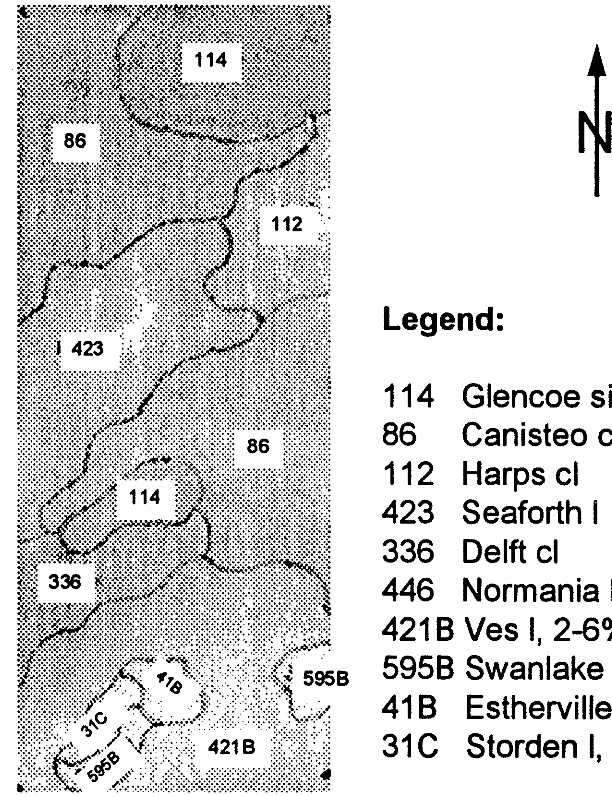
Appendix A, Figure 24. Experimental design.

Relative Elevation at Revere Site, 1994



Appendix A, Figure 25. Relative elevation of field.

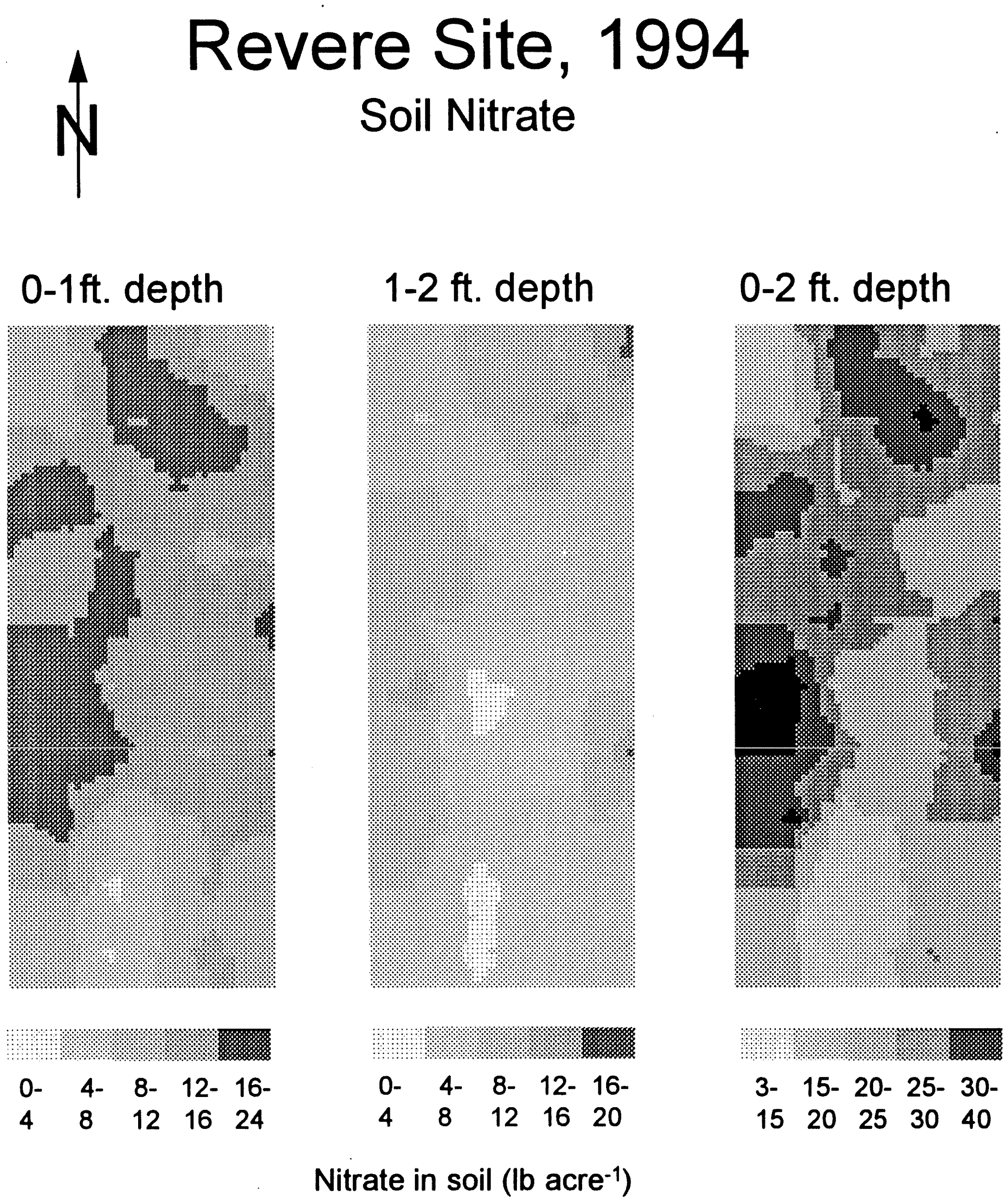
Soil Survey Mapping Units
for Revere Site, 1994
(approx. 1:3500)



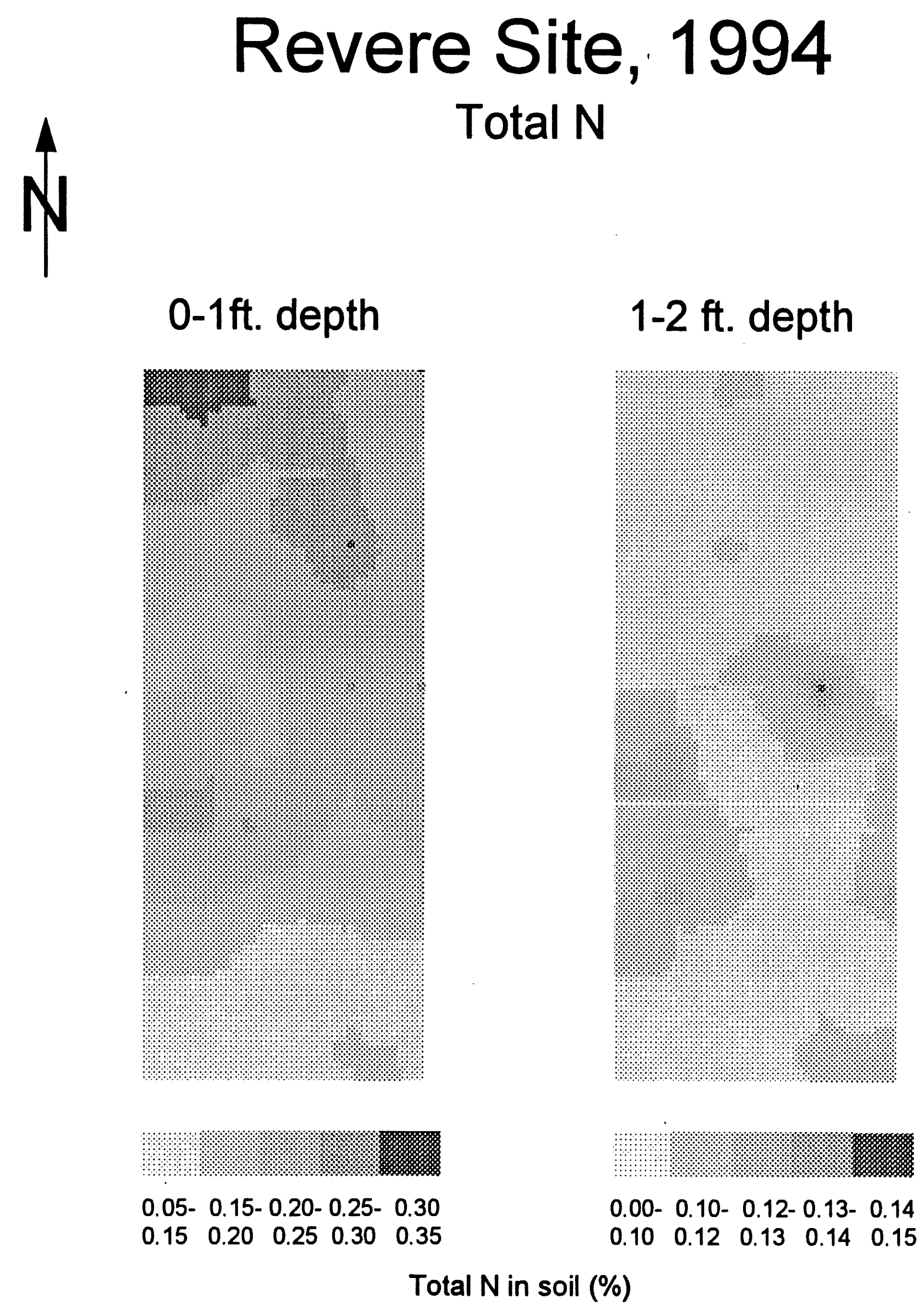
Legend:

114 Glencoe sicl
86 Canisteo cl
112 Harps cl
423 Seaforth l
336 Delft cl
446 Normania l
421B Ves l, 2-6%
595B Swanlake l, 2-6%
41B Estherville sl, 2-6%
31C Storden l, 6-12 %

Appendix A, Figure 26. Soil survey map of field.



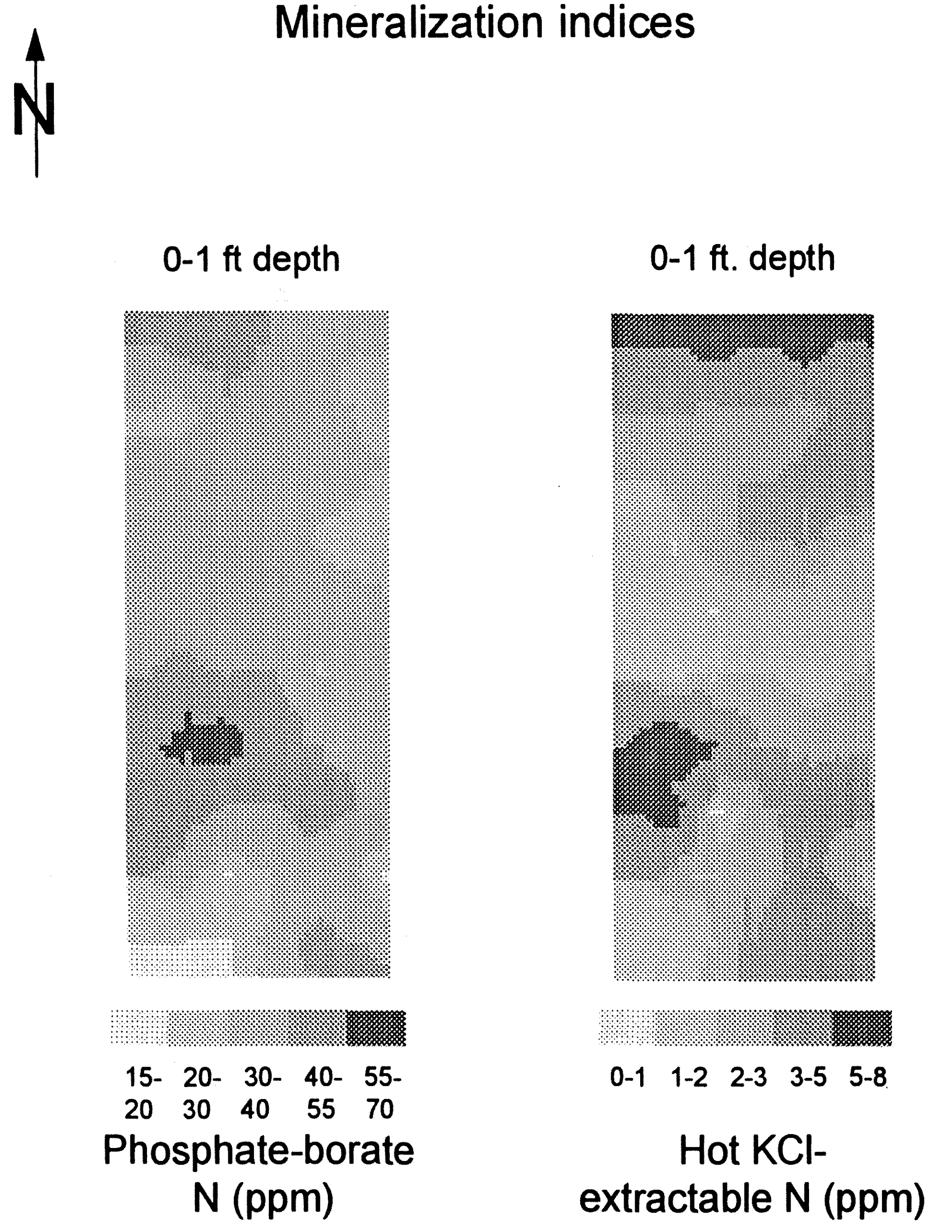
Appendix A, Figure 27. Soil nitrate by depth condition map.



Appendix A, Figure 28. Total soil nitrogen by depth condition map.

Revere Site, 1994

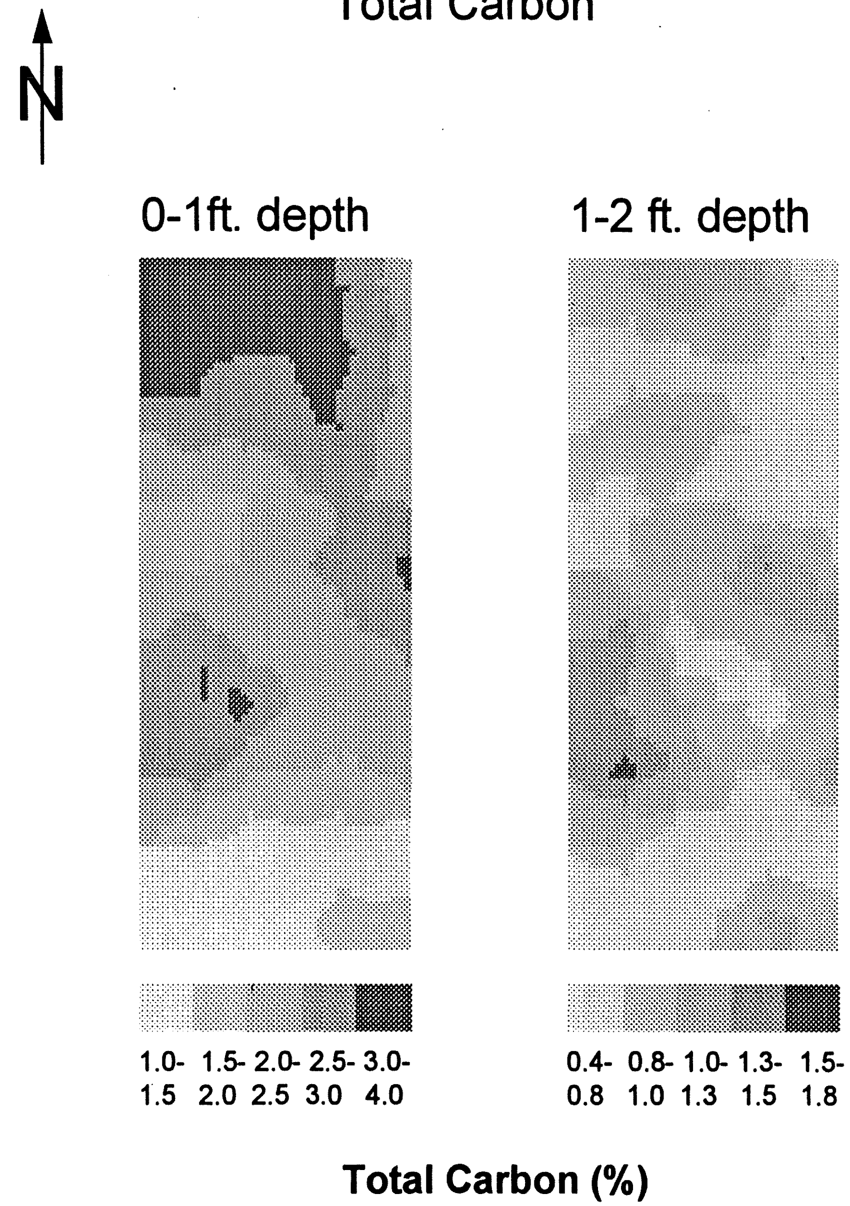
Mineralization indices



Appendix A, Figure 29. Soil mineralization indices condition map.

Revere Site, 1994

Total Carbon



Appendix A, Figure 30. Total soil carbon by depth condition map.

Appendix A, Table 7. Simple correlation coefficients for selected check plot variables at **Revere** site, 1994. Correlations are significant at the 5% level (P<0.05).

	Tot C 12-24 in.	Tot C 0-12 in.	Tot N 12-24 in.	Tot N 0-12 in.	P-B N 12-24 in.	P-B N 0-12 in.	Hot KCl-N 12-24 in.	Hot KCl-N 0-12 in.	NO3 0-24 in.	NO3 12-24 in.	NO3 0-12 in.	NH4 12-24 in.	NH4 0-12 in.
NH4 0-12 in.	NS	**0.62**	NS	**0.57**	-0.25	NS	NS	NS	NS	-0.30	NS	**0.75**	-
NH4 12-24 in.	NS	**0.60**	NS	**0.54**	-0.38	NS	0.23	0.38	NS	NS	NS	-	
NO3 0-12 in.	**0.45**	**0.57**	**0.46**	**0.59**	NS	**0.48**	NS	NS	**0.87**	0.35	-		
NO3 12-24 in.	0.28	NS	0.23	NS	NS	NS	NS	NS	**0.68**	-			
NO3 0-24 in.	**0.52**	**0.50**	**0.49**	**0.52**	NS	**0.48**	NS	NS	-				
Hot KCl-N 0-12 in.	0.23	0.36	NS	0.31	NS	**0.48**	**0.44**	-					
Hot KCl-N 12-24 in.	0.34	NS	0.27	NS	**0.52**	**0.45**	-						
P-B N 0-12 in.	**0.70**	**0.43**	**0.62**	0.38	**0.59**	-							
P-B N 12-24 in.	**0.62**	-0.32	**0.69**	-0.36	-								
Total N 0-12 in.	0.29	**0.97**	0.22	-									
Total N 12-24 in.	**0.87**	0.22	-										
Total C 0-12 in.	0.36	-											
Total C 12-24 in.	-												

NS: not significant

Appendix A, Table 8. Simple correlation coefficients for selected whole-field variables at **Revere** site, 1994. Correlations are significant at the 5% level (P<0.05).

	Aspect	Slope	Elevation	Red	Green	Blue
Blue	NS	NS	0.27	**0.90**	**0.88**	-
Green	0.11	**0.40**	**0.54**	**0.96**	-	
Red	NS	0.36	**0.52**	-		
Elevation	0.19	**0.72**	-			
Slope	0.14	-				
Aspect	-					

NS: not significant at 5% level

Appendix A, Table 9. Simple correlation coefficients for selected check plot variables at **Revere** site, 1994. Correlations are significant at the 5% level (P<0.05).

	Aspect	Slope	Elevation	Red	Green	Blue
NH4 0-12 in.	NS	NS	-0.27	-0.44	-0.44	-0.30
NH4 12-24 in.	NS	NS	NS	-0.55	-0.52	-0.43
NO3 0-12 in.	NS	-0.62	-0.47	-0.28	-0.34	NS
NO3 12-24 in.	NS	-0.32	-0.29	-0.28	-0.30	NS
NO3 0-24 in.	NS	-0.60	-0.46	-0.35	-0.40	NS
Hot KCl-N 0-12 in.	NS	NS	-0.29	-0.50	-0.45	-0.50
Hot KCl-N 12-24 in.	NS	0.29	NS	-0.24	NS	-0.34
P-B N 0-12 in.	NS	-0.29	NS	-0.46	-0.49	-0.47
P-B N 12-24 in.	NS	0.32	0.39	NS	NS	NS
Total N 0-12 in.	NS	-0.73	-0.76	-0.58	-0.60	-0.28
Total N 12-24 in.	NS	NS	NS	-0.24	-0.26	-0.27
Total C 0-12 in	NS	-0.69	-0.75	-0.68	-0.69	-0.41
Total C 12-24	NS	NS	NS	-0.44	-0.44	-0.46

NS: not significant

B. Title of Objective: Determine the appropriate N rate and other BMPs in a soil specific manner using a soil condition map.

B.1 Activity: Use of variable N rate technology can increase fertilizer N efficiency. The key to this occurring lies in the accuracy in which the soil condition map can predict the appropriate N application rate in regard to soil spatial variability in the field. The increased fertilizer N efficiency will come from applying less N where the crop has a lower requirement and more N in areas where the plants can utilize the additional N. Measuring crop grain yield as affected by different N rates and over many varying soilscapes will determine what the optimum N rate was in different areas of the field.

B.1.a Context within the project: Comparing these yields with the soil condition maps developed in Objective A will reveal the factor(s) which affect N fertilizer response in corn grain over many different soilscapes.

B.1.b Methods: Production fields characterized in Objective A will be utilized to determine the appropriate N rate for optimum corn grain yield. The study will be conducted at these locations on corn in the summer of 1994 and 1995. The treatments, applied across the field in replicated strips, will be composed of a zero check and up to five incremental N rates (i.e., 60, 90, 120, 150 and 180 pounds per acre) using anhydrous ammonia. The highest rate will satisfy maximum crop needs.

Crop management will be done by the cooperator. Grain yield and moisture will be determined on up to 75 subplots per acre (each subplot will be approximately 200 feet^2). This information will be geo-referenced with the soil condition maps developed in Objective A. This data will then be analyzed using geostatistical and regression techniques to identify what N rate was the best for each area of the field and also to identify the best factor(s) to use in creating the soil condition map. From this information an economic analysis for comparative systems and variable rate technology can be calculated on a field basis to evaluate the systems.

B.1.c Materials: Inputs (seed, land, and pesticides) except N fertilizer will be provided by the cooperator; the project will purchase N fertilizer. The fertilizer will be applied by a VRT applicator furnished by the University of Minnesota. A tractor will be rented for the fertilization operation. The cooperator will be reimbursed for yield losses by the project. The size of the experimental area will require the use of global positioning system (GPS) to geo-reference N application and harvest data. Yield determination will require the rental or modification of an existing combine with a weighing system. Analysis and geo-referencing will require computer equipment which will be provided by the University of Minnesota.

B.1.d Budget: $119,650 **Balance:** $ 000

B.1.e Timeline:	7/93	1/94	6/94	1/95	6/95
Establish treatments		***		***	
Plant response/yield			**********		*******

B.1.f Status: Objective B.

Different N rate treatments were applied at each of the locations described in Objective A (four in 1994 and four in 1995) to determine the extent of grain yield variability and the fertilizer N rates that would be necessary to provide site specific optimum recommendations. For the 1994 locations, response information was used to determine what soil condition map information from Objective A was needed to define management areas which would economically optimize the use of fertilizer N.

In 1994 grain yields from the area where no N was applied varied considerably at all locations (Table B-1). The spatial representation of check (no fertilizer N) grain yields for each locations can be found in Appendix B (Figures 1, 2, 5 and 8).

Table B-1. Corn grain yield range, mean, median from check areas (no N fertilizer applied) at four locations in 1994.

	Minimum	Maximum	Mean	Median
Location	-------------- Corn grain yield bu/A -----------			
Hanska	121	200	173	176
Hector	47	209	136	139
Lake Crystal	59	200	149	151
Revere	46	137	107	113

The range between the maximum and minimum check grain yields in 1994 was: Hanska 79 bu/A; Hector 162 bu/A; Lake Crystal 141 bu/A; and Revere 91 bu/A. The check grain yield data gives an indication of the variability of the soils' natural ability to supply nitrogen to the corn crop. The arithmetic mean is similar to the median at all four locations which indicates that the grain yield data is normally distributed.

To develop management areas within a field, the soil properties measured in Objective A were correlated with check grain yield (Table B-2). Of the 18 different properties measured, total soil N and total soil C in the 0 to 12 inch depth were correlated to grain yield at all locations. Check grain yield increased as total C and total N increased at Hanska, Lake Crystal, and Revere. Check grain yield decreased, however, at Hector with increased total C and total N. This was consistent with grain responses and other measured properties at this site but did not conform to results from the other locations. Nitrate-N in the 0 to 12 inch depth was positively correlated at all locations. The correlation is not strong, but the residual soil nitrate-N was low due to a wet 1993 season.

Table B-2. Simple correlation coefficients for check treatments at four locations in 1994. Correlations are significant at the 5% level ($P<0.05$).

	Check grain yield			
Property	Hanska	Hector	Lake Crystal	Revere
NH4N 0-12 in.	NS	NS	0.23	0.30
NH4N 12-24 in.	NS	NS	NS	0.36
NO3N 0-12 in.	0.24	0.51	0.34	0.37
NO3N 12-24 in.	0.23	0.33	0.31	0.28
Hot KCl 0-12 in.	NS	0.51	0.52	0.23
Hot KCl 12-24 in.	0.23	0.54	0.45	0.28
P Borate 0-12 in.	NS	0.60	0.53	0.41
P Borate 12-24 in.	-0.23	0.40	0.51	NS
Total N 0-12 in.	0.42	-0.25	0.43	0.52
Total N 12-24 in.	NS	NS	0.52	0.30
Total C 0-12 in.	0.45	-0.21	0.38	0.52
Total C 12-24 in.	0.29	NS	0.52	0.29
Elevation	-0.43	0.38	NS	-0.35
Slope	-0.42	NS	NS	-0.28
Aspect	NS	NS	NS	NS
Red	-0.57	NS	0.22	-0.51
Green	-0.57	NS	NS	-0.52
Blue	-0.55	NS	0.25	-0.43

Correlations of elevation, slope, and color tones of bare soil (red, green, and blue) with check grain yield were not consistent. Check grain yield at Hector, Lake Crystal, and Revere were positively correlated with potentially mineralizable soil N tests (hot KCl and phosphate borate--0-12 inches), but were not correlated at Hanska. The positive correlations indicate that these soil tests do reflect differential mineralization potential from organic matter and the resulting increased N availability and grain yields in the control areas.

Soil and landscape information from Objective A was combined with yield response information to delineate different management areas within each field site. The management zones for the Hanska location are presented in Figure B-1 and the other locations in Appendix B (Figures 3, 6 and 9). At Hanska, nine zones were delineated. The number of management zones at Hector, Lake Crystal, and Revere were 8, 7, and 5, respectively. After the management zones were identified, the grain yield response to applied fertilizer N was modeled to determine the economic optimum nitrogen fertilizer rate (EONR) in each zone. The fertilizer N response for each management zone for the Hanska location is present in Figure B-2 and for the other locations in Appendix B (Figures 4, 7 and 10). The optimum N rate at Hanska ranged from 0 to 150 lb N/A.

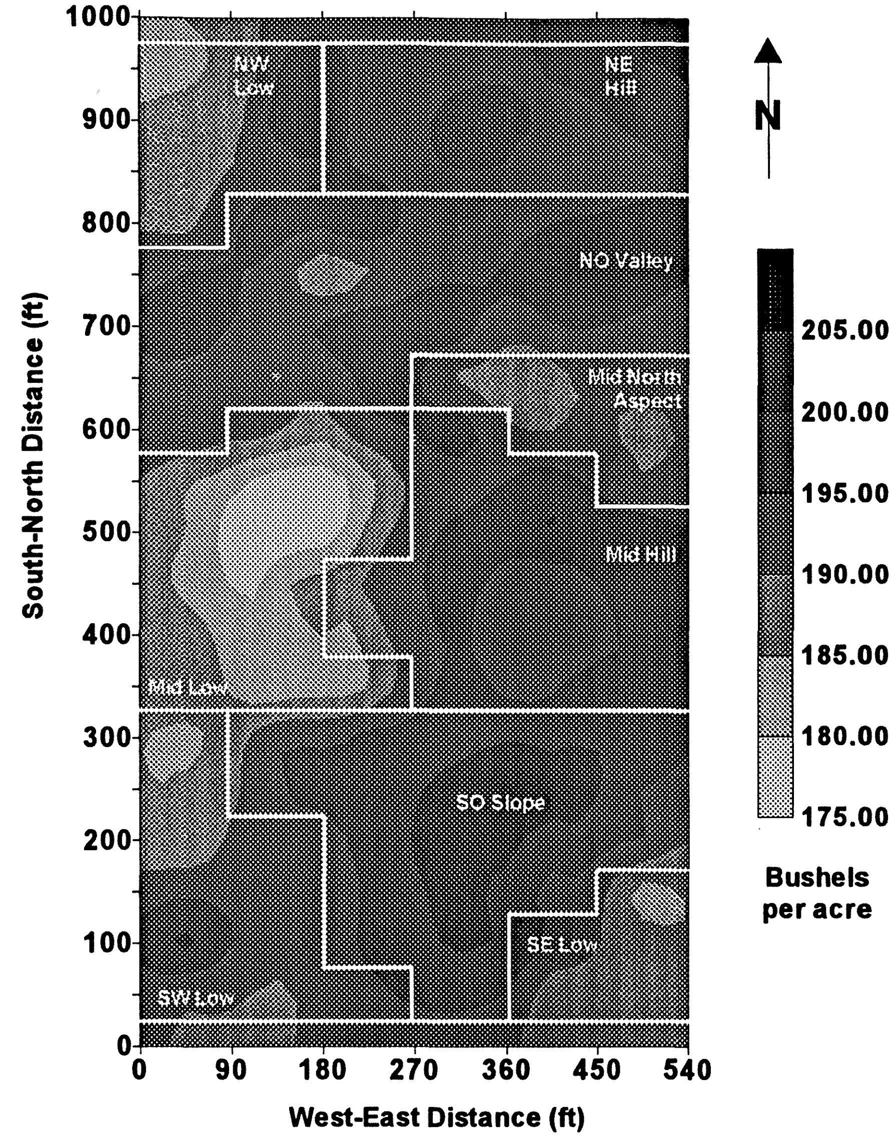
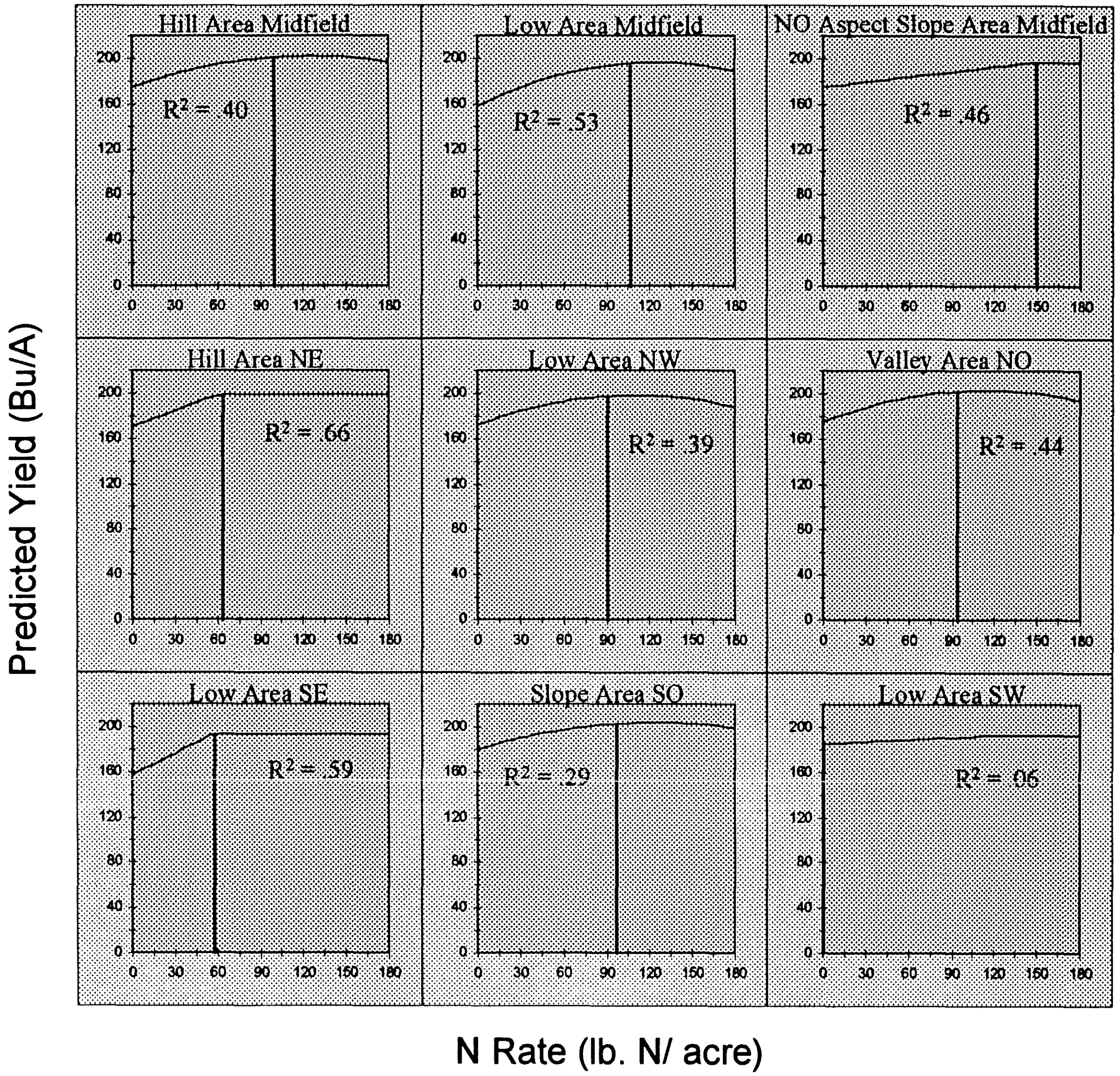


Figure B-1. Management areas and mean yield response to fertilizer treatments at Hanska.



Note: The vertical black line shows the economic optimum nitrogen rate according to the quadratic or linear-plateau models.

Figure B-2. Regressions for yield by response groups at the Hanska site.

Savings in energy, (EONR), production, and fertilizer use economics were evaluated by using four fertilization application strategies for the 1994 locations. The strategies include:
A. The use of site-specific management (VRT) at the EONR within each management zone.
B. A uniform rate over the entire field based on University of Minnesota (UM) N recommendations based on an average yield goal.
C. The use of VRT using UM N recommendations for average yield goal for each management zone.
D. A uniform high N rate application. This was 180 lb N/A at Hanska, Hector, and Lake Crystal and 140 lb N/A at Revere.

Energy conservation was estimated by comparing the economic optimum rate of fertilizer N (weighted average) needed for the entire field using VRT with the current UM uniform rate of application recommendations. At Hanska, Hector, and Lake Crystal, the site-specific rate based on EONR (A), required 44, 36, and 5 lb N/A less than the current method of N application (B), (see Table B-3).

Table B-3. Nitrogen fertilizer application rates and predicted yield for four nitrogen fertilizer application strategies at all locations in 1994.

	Nitrogen rate				Predicted grain yields			
	Hanska	Hector	Lake Crystal	Revere	Hanska	Hector	Lake Crystal	Revere
Situation	----- lb N/A -----				----- bu/A -----			
VRT EONR (A)	86	114	105	116	198	185	182	141
Uniform (B)	130	150	110	110	199	183	182	140
VRT yield goal (C)	133	149	113	108	199	182	180	139
Uniform high N rate (D)	180	180	180	140	195	185	173	143

The Revere location required slightly more N than current UM recommendations. The substantially reduced N rates that were possible with VRT at Hanska and Hector were possible with no reduction of yield. Overall, the use of site-specific management allowed substantial reductions in N use at two locations and had no influence at the other locations. The grain yield predicted and the amount of N recommended with a uniform application (B) compared to a VRT method based on yield goals assigned by management zone (C), resulted in similar results at all locations. Grain yields were similar at Hector and Revere when a high rate of fertilizer N was applied (D) but were reduced at Hanska and Lake Crystal. Applying "extra" N as insurance, even in a very optimum production year such as 1994, was not beneficial to grain yield.

Research results have shown that over-application of N is the single most important factor influencing ground water contamination. Site specific management (VRT) offers an improved management practice for farmers to protect their environment. Site-specific management N rate management should also have the potential to increase profitability to the producer. The increased economic return at Hanska and Hector, due to site-specific management (A) above a uniform rate (B) of application was $6 and $10 /A, respectively (Table B-4). Most of this increased return, in 1994, was due to a savings in fertilizer costs. The cost associated with site-specific management may vary considerably depending on what components of VRT are utilized. The cost of the technology have not be included in the potential return. The profit associated with the proper rate of fertilizer N ranged from $36 to $80 /A, highlighting the importance of fertilizer N in the production system.

Table B-4. Nitrogen fertilizer costs and dollars net returned due to fertilizer N application at Hanska, Hector, Lake Crystal, and Revere in 1994

	Fertilizer cost				Net return from fertilizer			
	Hanska	Hector	Lake Crystal	Revere	Hanska	Hector	Lake Crystal	Revere
Situation	---------- $/A ----------							
VRT EONR (A)	15	19	18	20	36	80	57	49
Uniform (B)	22	26	19	19	30	70	56	48
VRT yield goal (C)	23	25	19	18	29	69	54	46
Uniform high N rate (D)	31	31	31	24	13	68	28	47

At Lake Crystal and Revere, fertilizer cost and net return from fertilizer were similar for Strategies A, B, and C. The cost of fertilizer application, soil sampling, or creation of the proper soil condition map should be considered in a total economic evaluation. These costs will vary considerably from site to site.

Site specific management using VRT should minimize both over- and under-fertilization of a field. The conventional uniform rate application (B) was compared to the EONR from VRT (A) for each management zone to determine how much of a field would have been over- or under-fertilized. If the difference in N rate between these two strategies exceeded plus or minus 15 lb N/A, then the zone was classified as either over- or under- fertilized. During 1994, the over fertilized areas at Hanska, Hector, and Lake Crystal represented 95, 72, and 34%, of the field, respectively (Table B-5.)

Table B-5. Potential impact of VRT on N fertilization of four fields in 1994.

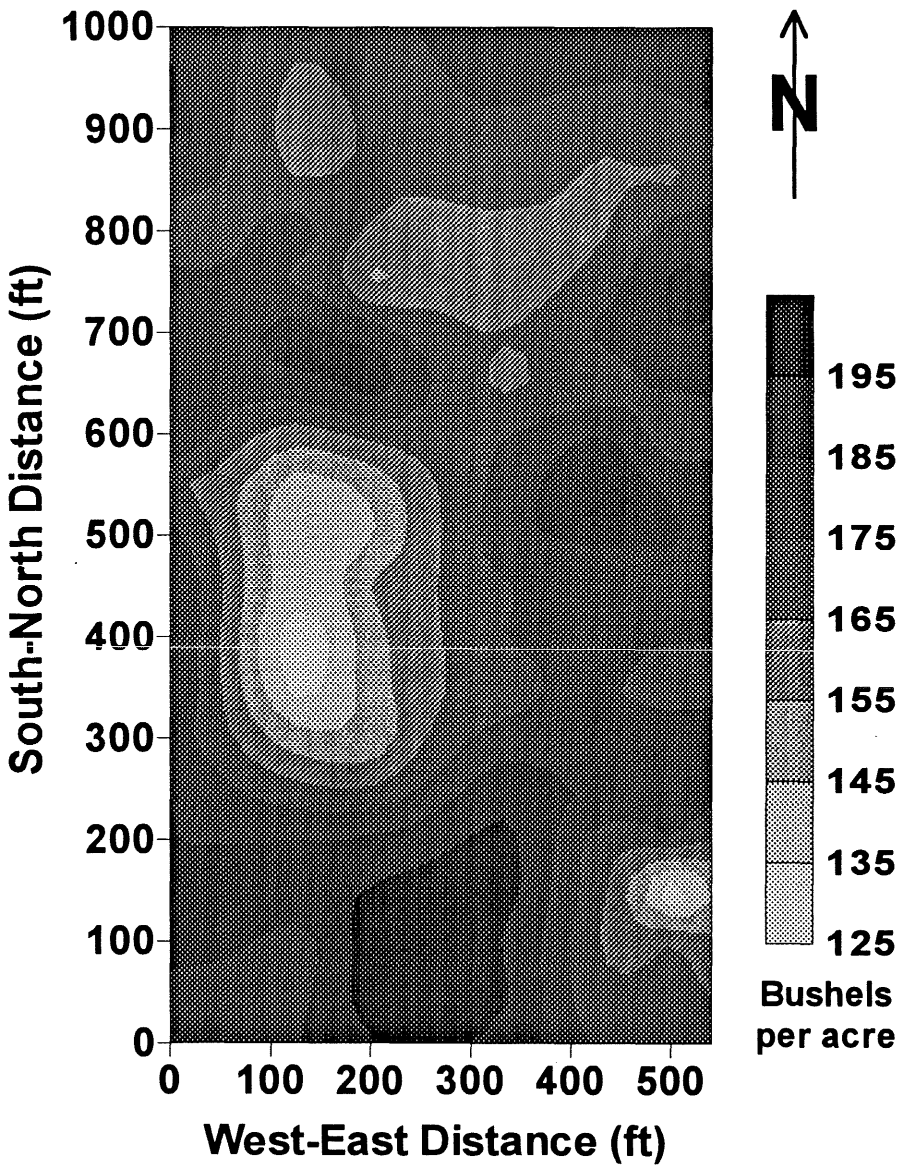
	Nitrogen application method						
	Variable rate (A)		Uniform rate (B)				
Location	Range	Field average	Over fertilized		Under fertilized		Adequate
	---- lb N/A ----		%	lb N/A	%	lb N/A	%
Hanska	0-150	86	95	45	5	20	0
Hector	64-180	114	72	62	28	30	0
Lake Crystal	87-139	105	34	21	11	29	55
Revere	108-173	116	0	0	7	63	93

These areas were over-fertilized by an average rate of 45, 62, and 21 lb N/A, respectively. Portions of the field that were under-fertilized were 5, 28, 11, and 7% and the deficits were 20, 30, 29, and 63 lb N/A at Hanska, Hector, Lake Crystal, and Revere, respectively. Site specific N rate management has the potential to reduce N rates in certain portions of a field while maintaining productivity and increase profitability with increased N application rates elsewhere.

One major obstacle in the implementation of site specific management is the ability to predict what management practice should be utilized in a specific field location. Conditions maps were developed utilizing many different soil and landscape parameters. Many of the soil parameters were correlated with landscape position. Many of these parameters were correlated with grain yields from the check areas. This is good evidence to support the need to develop soil testing and landscape features to predict the N supplying capability of the soil. These features appear to have limited application in determining which field areas were going to be most responsive. No single parameter was similarly correlated with yield response at all locations. Much of the variability in N requirement at each location appeared to be related to landscape position and soil water content and drainage. This is not unrealistic since soil water controls many of the N transformation processes, losses from soil, and supply mechanisms to the plant. Refinement and development in VRT may require the integration of soil water along with soil and landscape features to determine the economic optimum N rates.

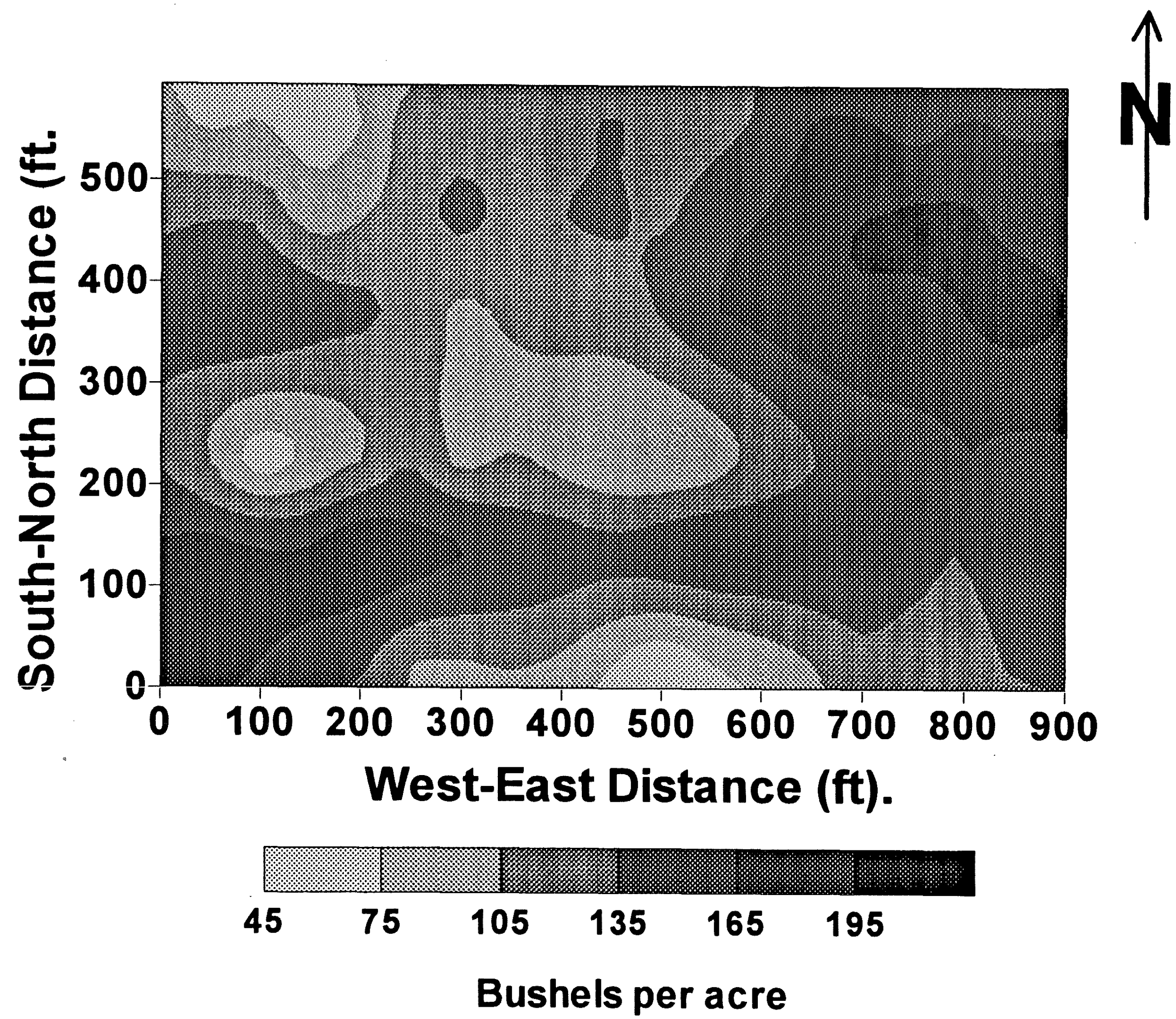
Appendix B: Objective B

Grain Yield in check plots
at Hanska Site



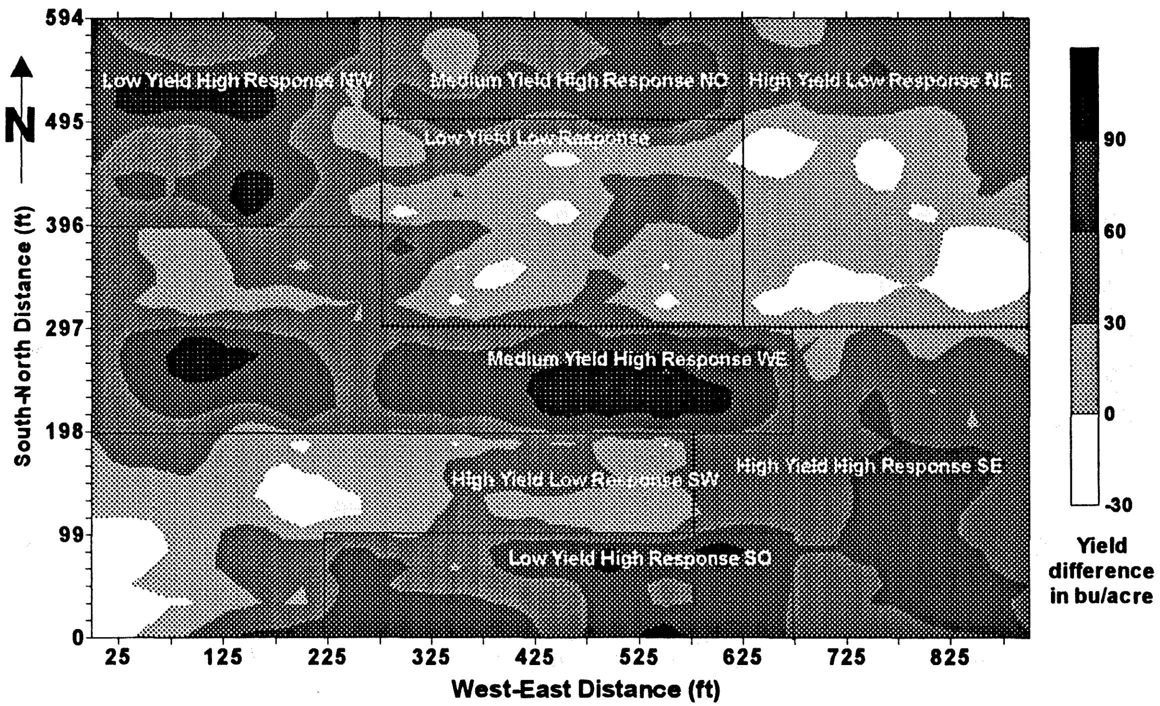
Appendix B, Figure 1. Corn check yields.

Grain Yield in check plots at Hector Site



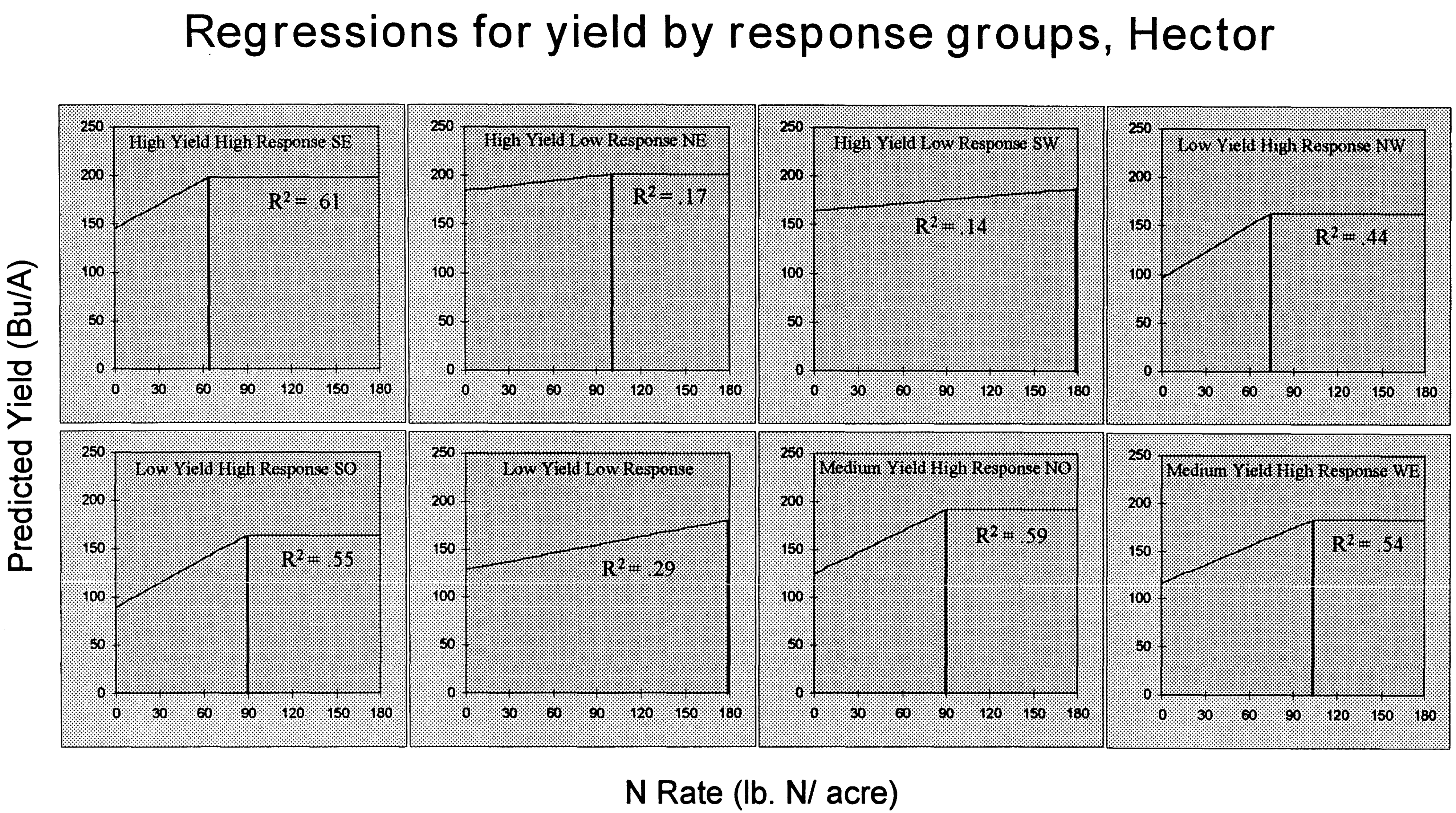
Appendix B, Figure 2. Corn check yields.

Management areas at Hector displayed over N response map



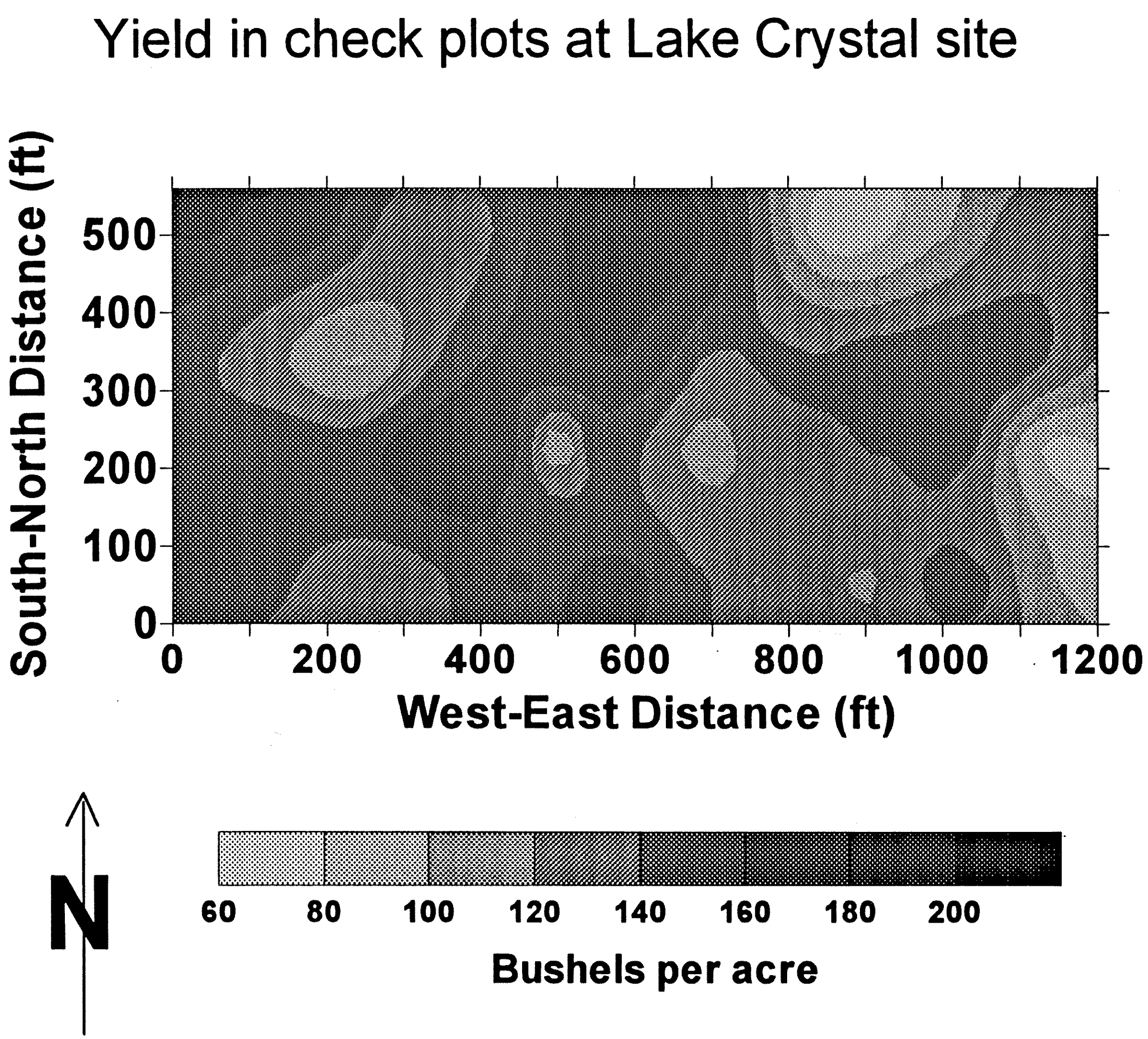
Note: N response calculated as yield of each N rate plot in sub-block minus yield of check plot in that sub-block.

Appendix B, Figure 3. Management zones.

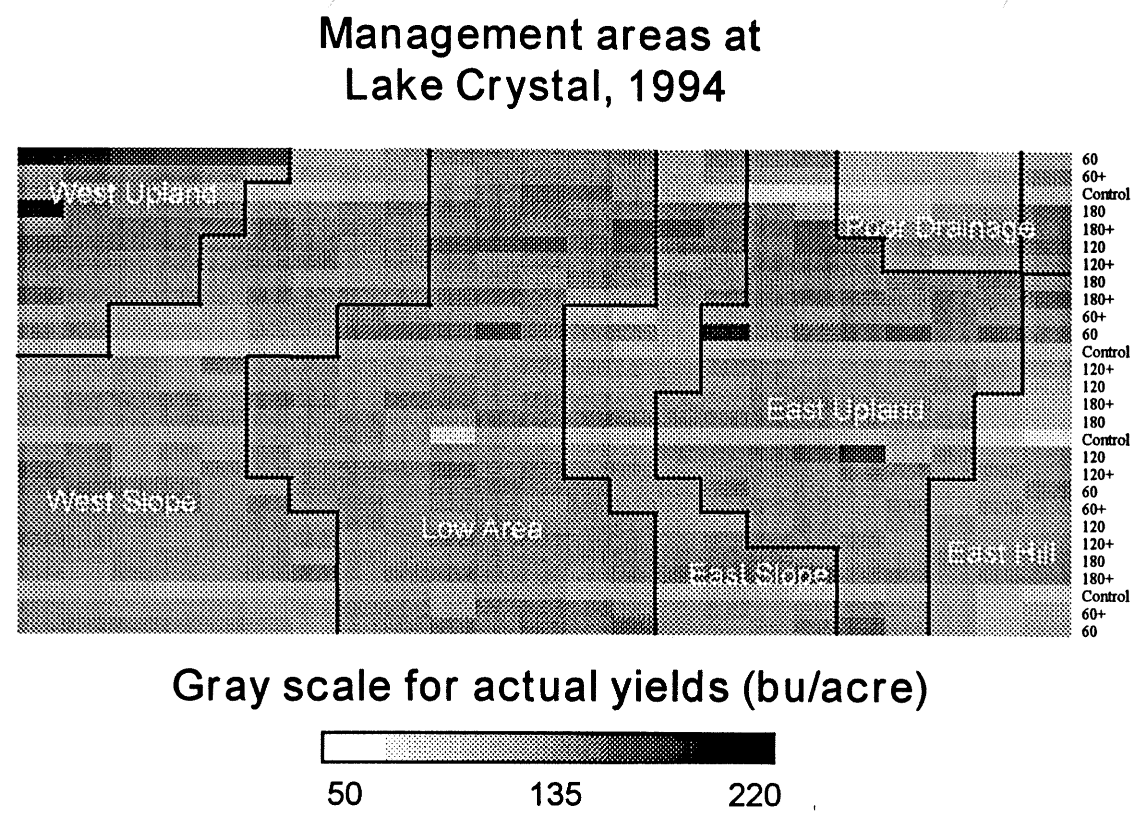


Note: The vertical black line shows the economic optimum nitrogen rate according to the linear-plateau model. The third and sixth graphs show a linear function, in which case the economic optimum N rate is determined as the highest N rate applied.. The lower R^2 values for some show a lower correlation of N rate with final yield.

Appendix B, Figure 4. Yield response functions.

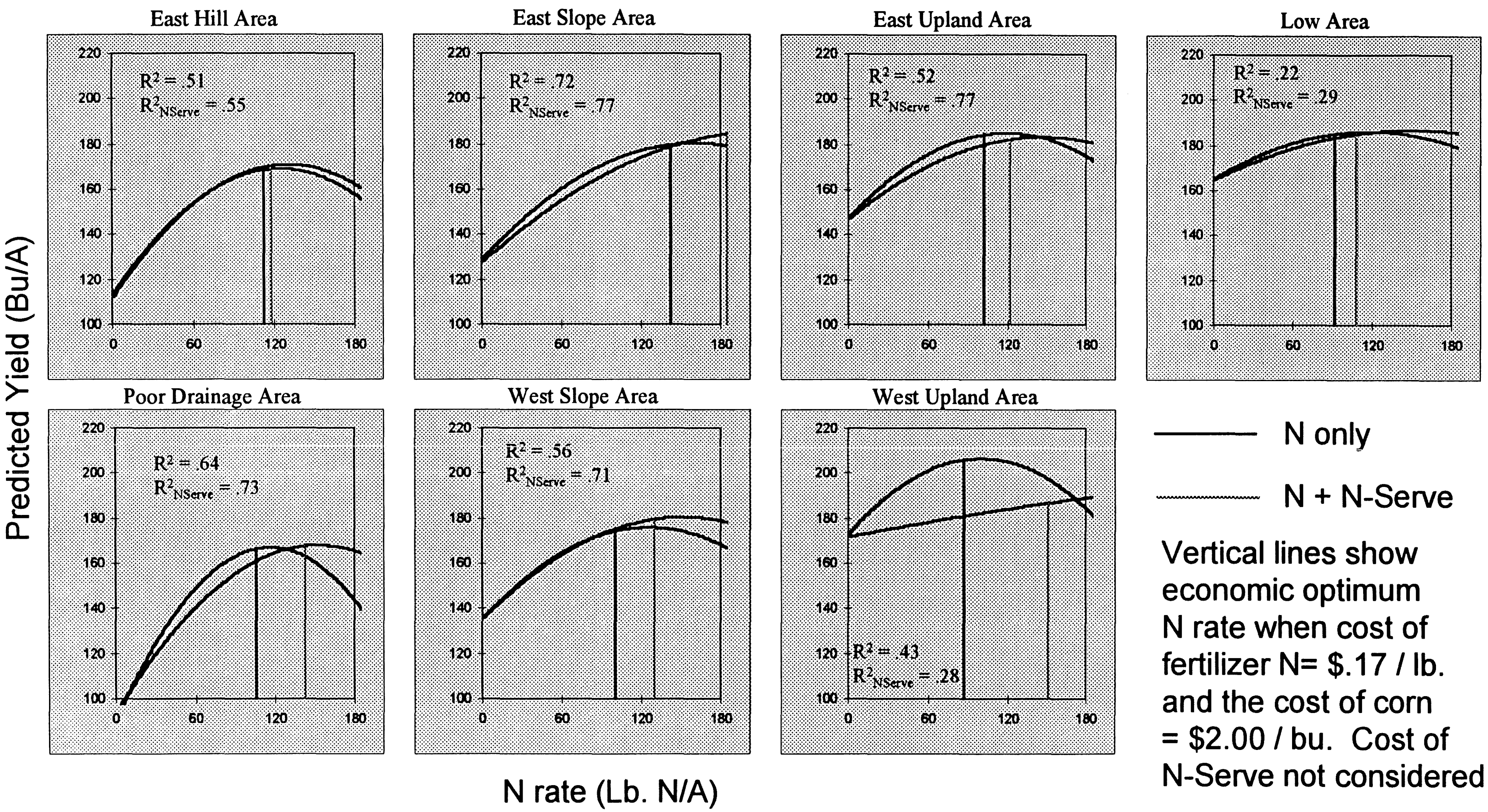


Appendix B, Figure 5. Corn check yields.

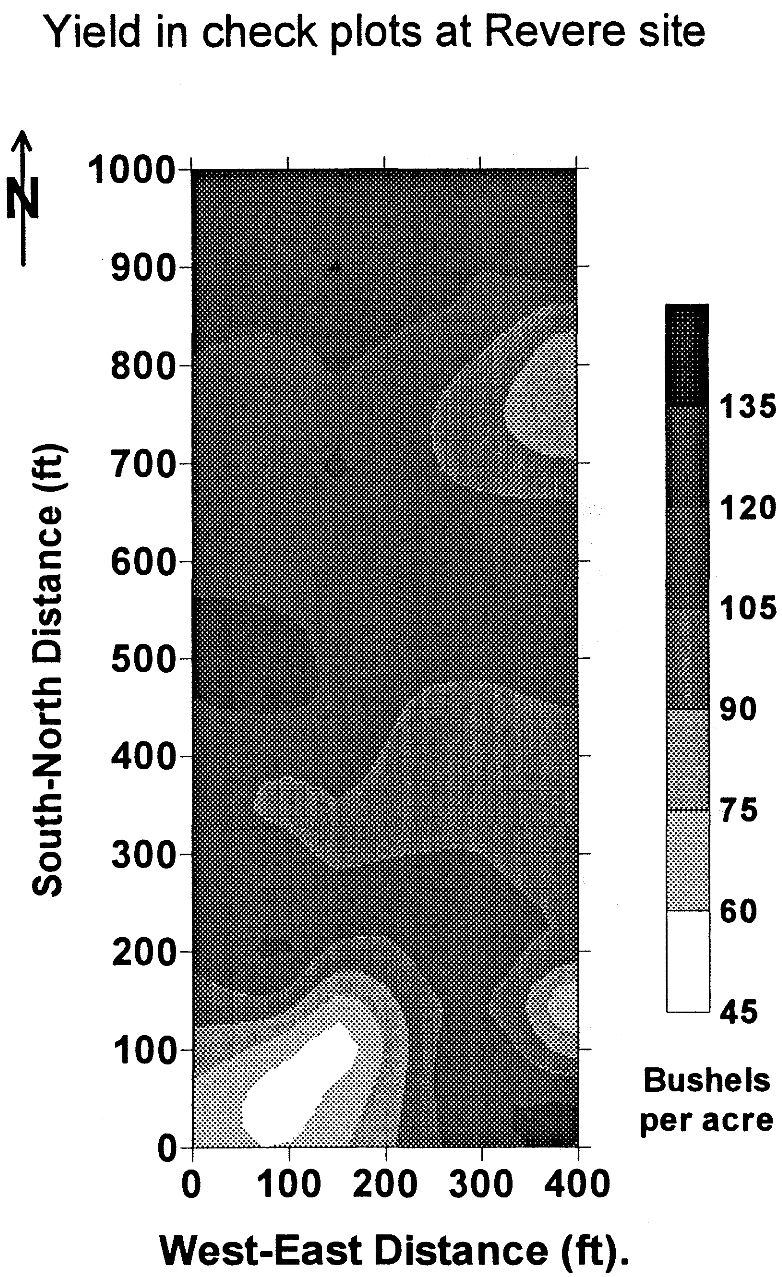


Appendix B, Figure 6. Management zones.

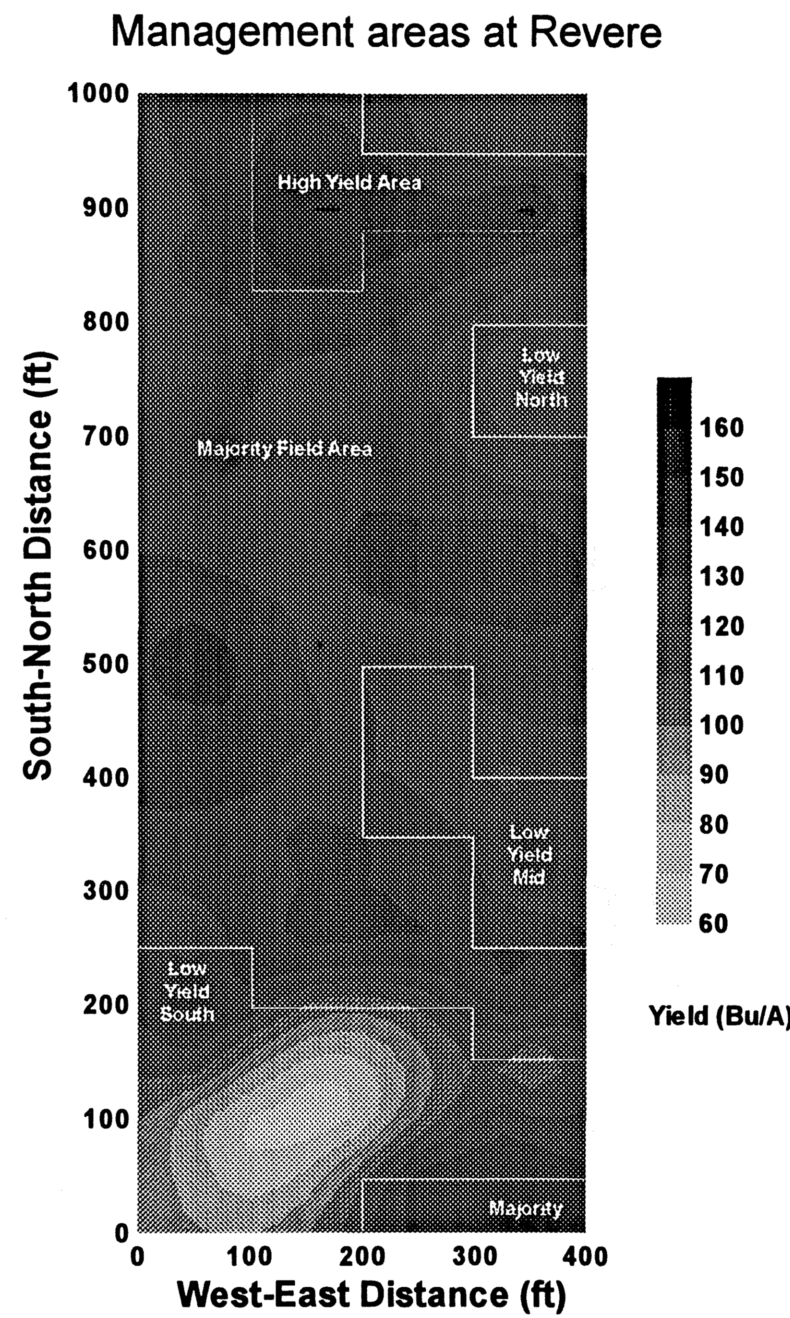
Quadratic regressions for yield response groups at Lake Crystal



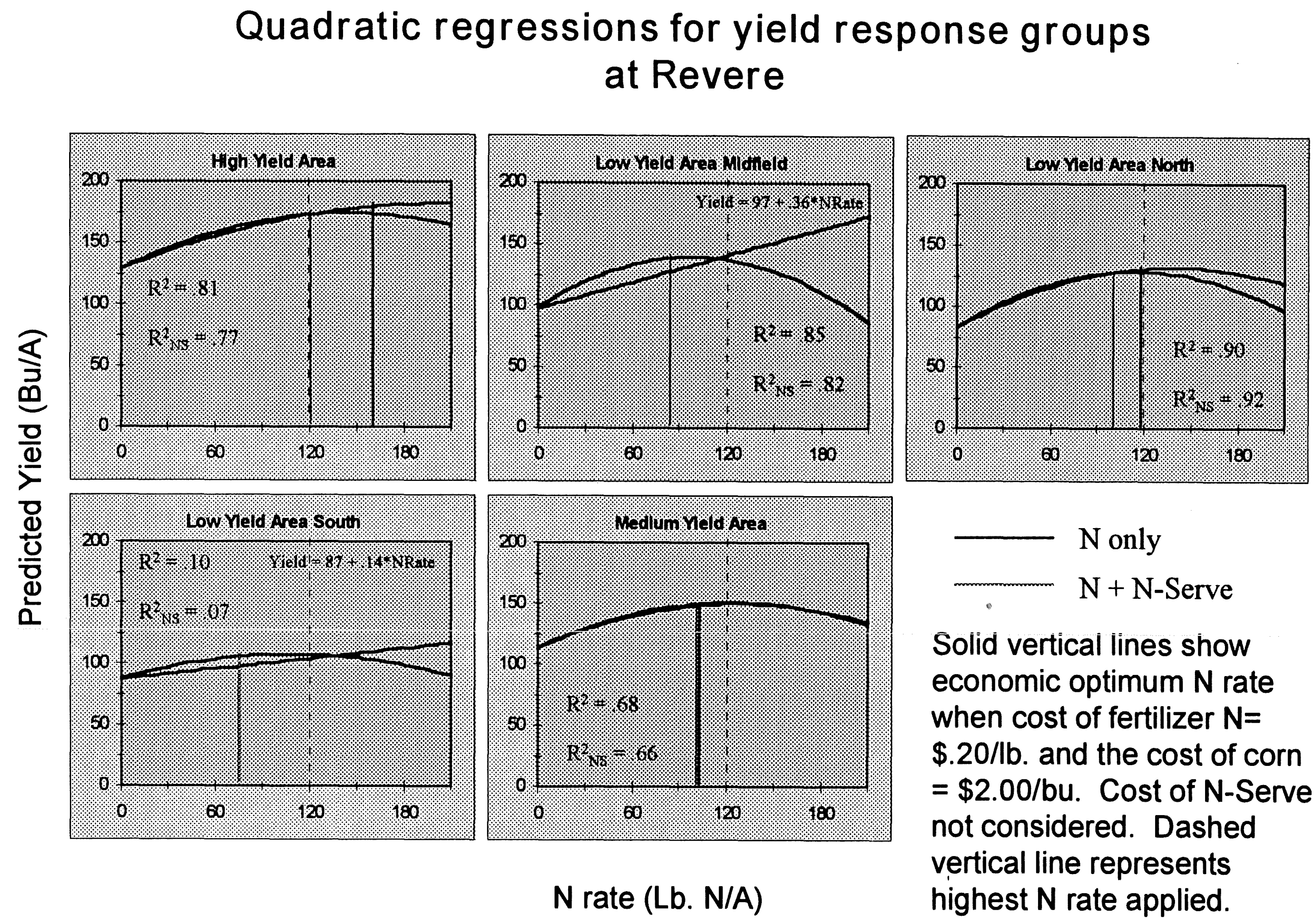
Appendix B, Figure 7. Corn yield response functions.



Appendix B, Figure 8. Corn check yields.



Appendix B, Figure 9. Management zones.



Appendix B, Figure 10. Corn yield response functions.

C. **Title of Objective:** Conduct demonstrations and evaluate the economic and environmental impact of existing variable rate technology.

C.1 Activity: Development of educational and ground water monitoring demonstrations.

C.1.a Context within the project: Concurrent with the research sites described in Objectives A and B, demonstration sites will be developed to evaluate the effectiveness of existing variable-rate technology for nitrogen management. Profitability, nitrogen fertilizer inputs, yields, and water quality will be monitored under field-scale production. Demonstrations will provide educational opportunities to promote the "farming by the foot" concept as a tool for higher nitrogen use efficiency, potential fertilizer savings, and minimizing
the impacts of N fertilization on water resources. Technology advances from the research component can be transferred directly to growers and dealers at the demonstration related activities.

C.1.b Methods:

Soil survey and tile-drain location maps will be used to identify 3 of 6 non-replicated micro-watersheds within south central and southwest Minnesota. Watersheds will be selected on the following criteria: corn-soybean rotation; sites not to exceed 100 acres in size; and soils/yield potentials must be highly variable within each field. Where feasible, the sites will be tile drained; the drains will serve as a tool to monitor the nitrate leaching component. Additional criteria for these sites are headwater locations on the drain fields will be selected to avoid complications from mixing of drainage waters upstream; uniform cropping practices over the individual mini-watershed that the drain services; an access point must be available for collecting water samples and flow measurements; and a minimum of one year's baseline water quality nitrate information before variable N rate technology is applied. Whenever feasible, sites will be established over tile drains which are currently being monitored through Soil and Water Conservation District efforts or LCMR funded projects such as the Brown-Nicollet Clean Water Partnership Program.

Sites selected for the 1994 cropping season will be planted into corn or other high nitrogen demanding crop. Past cropping practices, fertilizer rates and yield will be collected from the cooperator. Methods currently used by the variable rate industry to produce and respond to the yield potential map will be utilized. Nitrogen rates, timing of application, and other management strategies will follow the guidelines of the statewide and regional Best Management Practices as designated by the MDA's Nitrogen Fertilizer Management Plan.

Tile drains will be monitored for NO_3-N and flow volumes on two week intervals during drainage events. Soil and Water Conservation District personnel or other local water authorities will assist in the monitoring program. Sites established in 1994 will be monitored via the drains through the end of the study period to observe the full treatment effect of the variable rate technology.

Demonstration activities will be coordinated in cooperation with the Minnesota Department of Agriculture, Minnesota Extension Service, University of Minnesota - Soil Science, SWCD's and other affiliated agencies. Programs for both field and winter workshops will be developed.

C.1.c Materials: Materials for monitoring flow volumes will be required: staff gauges, stop watch and buckets will be purchased. Sampling bottles, sampling equipment, coolers and ice for sample preservation will also be required.

C.1.d Budget: $ 30,000 **Balance:** $ 000

C.1.e Timeline:	7/93	1/94	6/94	1/95	6/95
Identify sites/cooperators		******		***	
Develop condition maps			***		***
Establish treatments			*****		*****
Monitor tile drains	***				
Demonstrations			***		***
Final report					**

C.1.f Status: Objective C

Two tile-drained demonstration sites, meeting the criteria of described in "Methods", were established and monitored during the 1994 and 1995 growing season. The sites were located in Lac Qui Parle (near Bellingham) and Watonwan counties (near St. James) (Appendix C, Figure 1). The site in Lac Qui Parle Co. was approximately 100 acres in size and the site in Watonwan Co. was approximately 35 acres (Appendix C: Figures 2 and 4, respectively). Sites were grid soil sampled, using a 2.5 acre grid, in the spring of 1994 and "soil condition" maps were developed for N (2 ft depth), P, K, Zn, pH, and organic matter (Appendix C: Figures 3, 5, 6, and Tables 1 and 4). The grid sampling for the Lac Qui Parle County site was done by the Bellingham Farmer's Cooperative and Centrol, Inc.. Grid sampling for the Watonwan County site was done by Farmer's Coop of Hanska and Minnesota Crop Monitors. Soil condition maps for the Lac Qui Parle county site were created by Soil Tec, Inc. A "soil management" map was created by the Farmer's Coop of Hanska. Variable urea fertilizer rates were applied at the Lac Qui Parle site prior to planting (Appendix C: Table 2). Rates were based on residual soil nitrate test results. At the Watonwan site, grid soil sample information was used to partition the field into three different management zones based on 1993 crop history and manure application. Resultant nitrogen rates were 0, 80, and 120 pounds N per acre on manured soybeans, non-manured soybeans, and non-manured corn, respectively (Appendix C: Figure 6, Table 4). VRT application equipment was not necessary to apply the different fertilizer rates. Corn grain yield was collected for several "soil conditions" at the Lac Qui Parle site. Additional agronomic management information is provided in Appendix C (Tables 2 and 5).

An additional site was selected in 1994, which also met the criteria described in "Methods". The site is located in Nicollet Co. (near St. Peter, see Appendix C: Figure 1), and was established with cooperation from the Nicollet-Cottonwood-Brown Clean Water Partnership. The site is approximately 60 acres in size (Appendix C: Figure 9). The site was grid soil sampled, using a 2.6 acre grid, in the fall of 1994 and "soil condition" maps were developed for N (2 ft depth), P, K, Zn, pH, and organic matter (Appendix C: Figure 10 and Table 6). McPherson Crop Management, Inc. was contracted to do the grid soil sampling and create soil condition maps. A constant rate of anhydrous ammonia nitrogen was Fall applied to each "mini-watershed". Nitrogen treatments will be imposed in the next corn year (1997). The decision to delay variable N rates to this site were based on the following facts: 1) Residual soil N was rather uniform in the fall of 1994 (Appendix C: Table 6). 2) Yield potential maps have not been developed. 3) A commercial variable rate anhydrous applicator is not currently available in this region and the Minnesota Department of Agriculture does not endorse fall application of urea in south central Minnesota; and 4) Researchers felt that a thorough understanding of the hydrologic characteristics need to be developed prior to treatments. Imposing a uniform application of nitrogen will provide approximately two years of water quality information inherent to each "mini-watershed". This baseline water quality information is critical in order to differentiate the future differences between conventional and VRT fertilizer application methods. A variable rate of phosphorous was applied to the variable rate technology designated watershed, and a uniform rate of phosphorous was applied to the conventional technology designated watershed (Appendix C: Table 6 and Figure 10). Additional agronomic management information for the Nicollet Co. site is provided in Appendix C (Table 7).

Fertilizer inputs for each management strategy at the sites varied considerably. At the Lac Qui Parle Co. site there was little difference in nitrogen fertilizer between conventional and VRT treatments; both averaging approximately 110 lb. nitrogen per acre (Appendix C: Tables 1 and 2). This was primarily because soil nitrate sampling indicated little field variability. At the Watonwan Co. site, the VRT management strategy resulted in 44 percent reduction in nitrogen fertilizer input, assuming that a constant rate of 120 lb/N/ac would have been applied over both fields. (Appendix C: Figure 6 and Table 4). At the Nicollet Co. site, phosphorus and potassium fertilizers were varied according to grid soil sampling. The VRT field resulted in a 21 percent increase in application rates of phosphate fertilizer versus the conventional treatment. According to soil grid sampling results and University of Minnesota recommendations for potassium fertilizer, only one grid in the VRT field required any additional potassium fertilizer. The conventional system required no potassium fertilizer on a field average basis, even though, several soil sampling grids within the conventional treatment indicated a need for additional potassium, according to the University of Minnesota recommendations (Appendix C: Table 6).

Water quality monitoring was conducted throughout the 1994 growing season and into the beginning of the 1995 season for the Lac Qui Parle and Watonwan sites. Water monitoring at the Watonwan Co. site was done in cooperation with the University of Minnesota-Geology Department. The Nicollet Co. site, which is currently being monitored to establish "background" water quality, had a manhole installed in October, 1994 with cooperation from the Brown-Nicollet-Cottonwood Clean Water Partnership and the University of Minnesota-Geology Department. The Watonwan Co. site also has a manhole installed to facilitate water quality monitoring. The manholes have two tile (sub-surface) drainage inlets which allows the drainage to be partitioned into small "mini-watersheds" to determine the effects of VRT on water quality (Appendix C: Figures 3, 4 and 13). Automated water samplers and flow meters were installed (Appendix C: Figure 9). The automated samplers were configured to provide continuous monitoring of the watershed drainage after a sufficient amount of rain occurred to "trigger" the automated samplers. Water quality information, collected by the University of Minnesota-Geology Department, for the Watonwan site included: flow, nitrite and nitrate concentrations. Water quality information, collected by the Brown-Nicollet-Cottonwood Clean Water Partnership, for the Nicollet site included: flow, nitrite, nitrate, phosphorus and sediment.

At the Lac Qui Parle Co. site water sample collection was done manually, approximately every week, until no flow occurred (Appendix C: Table 3). Because both tile lines were partially submerged, water samples were collected by using a hand pump with a plastic tube extending from the unit. Water samples were collected by inserting the plastic tube several feet into the tile before operating the hand pump. This insured a "fresh" water sample.

Water quality data for the Lac Qui Parle site included: nitrite and nitrate concentrations.

As expected, due to the anticipated time lag of the leachate, no differences in nitrate concentration were observed, even with the substantial reductions in nitrogen fertilizer inputs at the Watonwan Co. site. At the Lac Qui Parle site nitrate concentrations were similar early in the growing season(Appendix C: Table 3). Later in the growing season it appeared that the VRT treatment may have had higher concentrations of nitrate-nitrogen than the conventional treatment. This was probably not caused by the N fertilizer treatments, but probably from differences in previous cropping history with the conventional treatment area producing soybeans in 1993 and the VRT treatment area producing wheat (Appendix C: Table 2). The soybean crop probably were more efficient in scavenging deep soil nitrate than the wheat. Also, the inherent soil differences and size in the mini-watersheds may have impacted tile flow nitrate concentrations(Appendix C: Figure 2, Table 1). It may have may take several years or more to realize the full water quality impact of VRT (Appendix C: Table 3, Figures 8 and 12). For the Watonwan and Nicollet Co. sites, where water flow data was collected, some differences between the watershed seemed apparent, which were probably not due to the treatments (Appendix C: Figures 7 and 11). One problem with using the "mass" values is that the portion of the watershed that is contributing to each tile drain has not been delineated. Also past history for each one of the paired watershed was different, which may contribute to the water quality differences. Background differences, prior to treatment application, for the Watonwan Co. indicates elevated nitrate concentrations from the VRT designated watershed (Appendix C: Figure 7). The value of the project will increase with time and ongoing related research.

Besides these types of demonstrations, a number of educational events were held, during the time frame of this project (Appendix C: Table 8). The focus has been directed toward increasing the farmers awareness of variable rate technology and educating them on the general concepts and benefits of variable rate fertilization. This has been a joint effort between all cooperators associated with Objectives A, B, C, and D. Agricultural dealers and the associated private industry have been extremely helpful in assisting in these events.

In summary, there are existing sites and systems conducive to this type of demonstration, but are difficult to locate. Previous research indicates it takes a number of years (5 to 10 years) to impact the water quality from sub-surface drainage. The support from local organizations was very positive and it appears that alternative sources of funding may continue the water quality monitoring. Future monitoring of the sites will continue because of the cooperation established with organizations such as the Clean Water Partnership of Nicollet-Brown-Cottonwood Counties, University of Minnesota, and "River-Friendly Farmer Program". Also, a NRI (National Research Initiative) grant has been granted to University of Minnesota--Department of Soil, Water, and Climate to further evaluate the impact variable rate technology application of pesticides on the environment and water quality using the established mini-watersheds. The research and demonstrations proved to be a very promising educational activity with more educational activities and field days planned for the future. The demonstrations also encouraged cooperation among the University of Minnesota, Clean Water Partnerships, Crop Consultants, Cooperatives and the Minnesota Department of Agriculture.

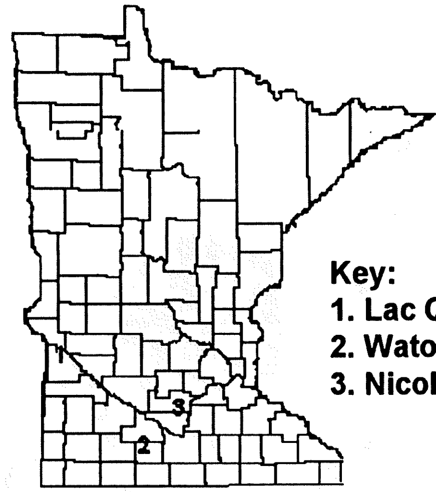
Appendix C: Objective C

Lac Qui Parle County site:

Watonwan County site:

Nicollet County site:

Location of Demonstration Sites



Key:
1. Lac Qui Parle County, Bellingham
2. Watonwan County, St.. James
3. Nicollet County, St.. Peter

Figure 1. Location of demonstration sites.

Lac Qui Parle County Site: Field Layout

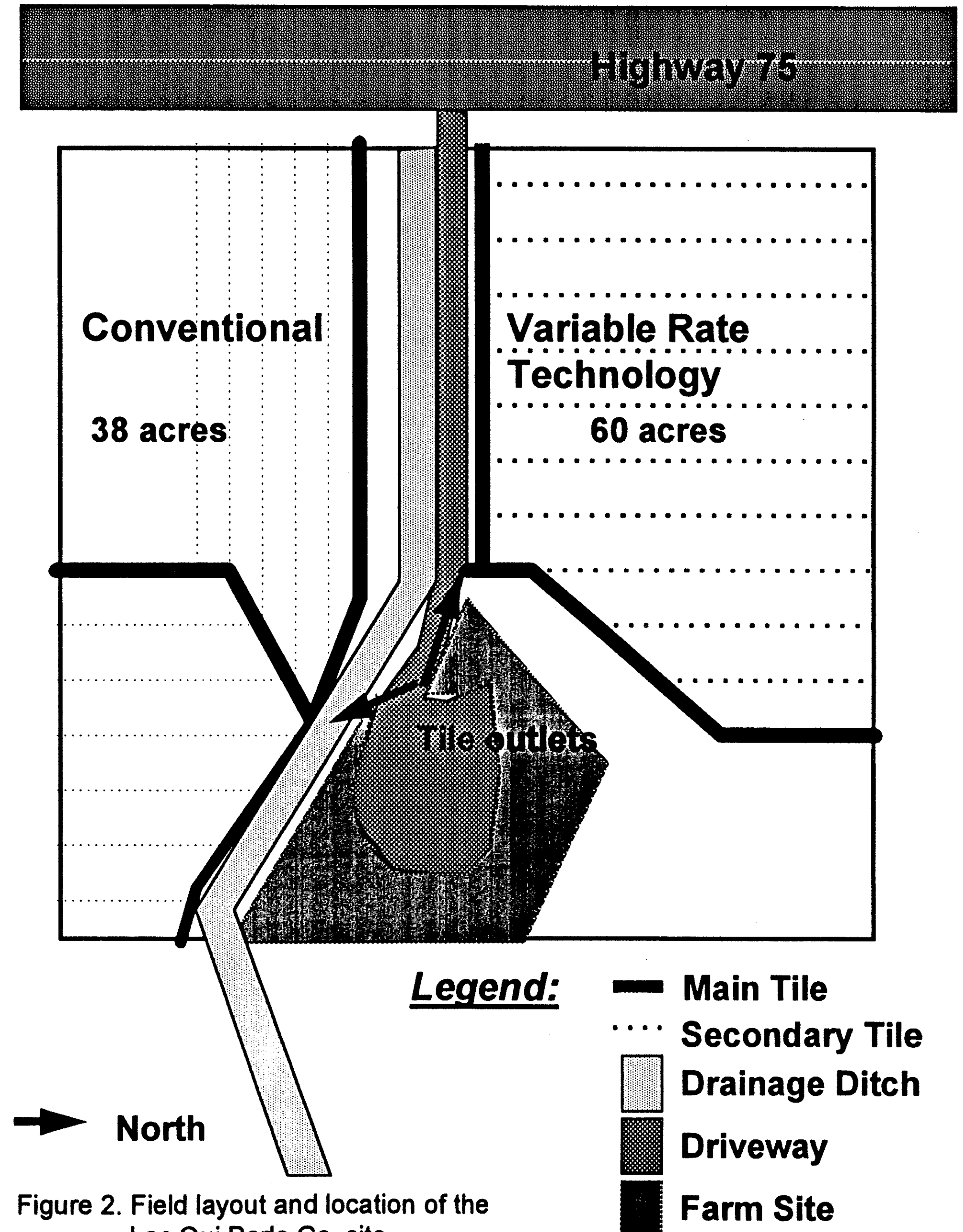


Figure 2. Field layout and location of the Lac Qui Parle Co. site.

Lac Qui Parle County Site: Grid Soil Sampling Layout, Spring 1994

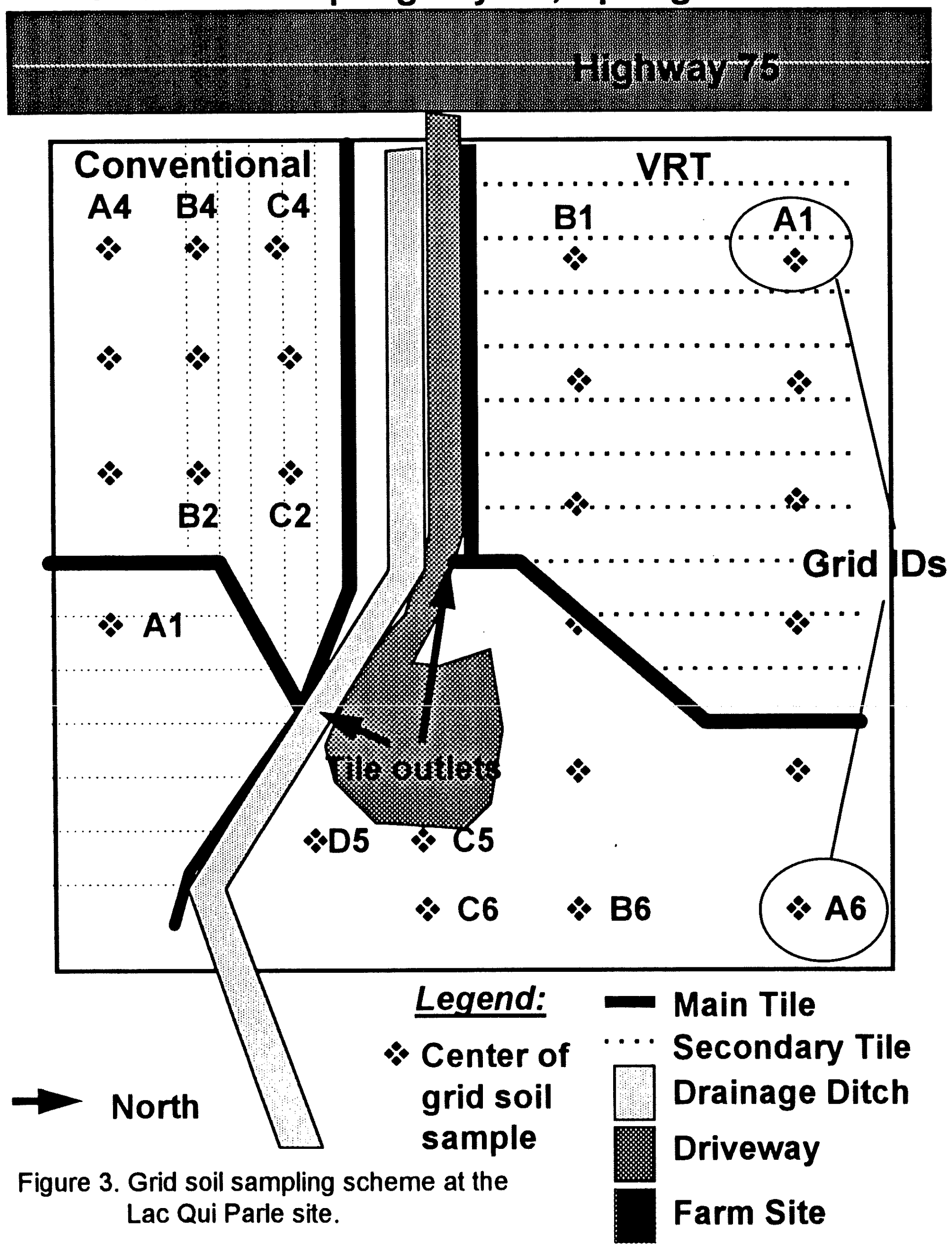


Figure 3. Grid soil sampling scheme at the Lac Qui Parle site.

MDA, Dennis Fuchs, 612-297-4400					Sample Depth:		N=0-24 in	
Cooperator:		Robert Heipler, Bellingham Coop					P,K,etc=0-6 in	
Location:		Lac Qui Parle Co., Bellingham			Yield Goal:		150	(bu/ac)
Study:		VRT Demo						
Sample Type:		Soil						
Sample Date:		4/1/94						
Area:		4 ac grid						
Grid (Letter)	VRT/Conv	Grid (#)	Soil pH	Nitrate-N (# N/ac)	OM (%)	Olson (ppm)	K (ppm)	Zn (ppm)
A	VRT	1	7.5	47	5	3	241	1.2
A	VRT	2	7.2	18	4	3	297	1
A	VRT	3	7.7	36	4.6	3	269	1.5
A	VRT	4	7.5	26	3.6	17	295	0.7
A	VRT	5	6.7	43	4.4	6	298	0.5
A	VRT	6	6.9	27	4.2	10	250	0.9
B	VRT	1	7.6	26	4.2	4	333	1
B	VRT	2	7.8	23	4	3	288	0.9
B	VRT	3	8.0	31	3.9	4	166	0.3
B	VRT	4	7.5	37	2.6	5	278	0.5
B	VRT	5	7.9	42	4.5	3	266	0.3
B	VRT	6	7.8	42	5.2	4	316	0.6
C	VRT	5	8.0	21	4.3	3	255	0.4
C	VRT	6	7.7	23	4.2	4	337	0.4
D	VRT	5	7.5	31	4.3	4	343	0.8
A	Conv	1	7.6	36	4.3	3	255	0.7
A	Conv	2	7.7	55	5.6	4	310	0.6
A	Conv	3	7.8	53	5.4	4	262	0.7
A	Conv	4	7.9	55	4.8	3	248	0.3
B	Conv	2	7.6	47	5.2	6	285	1.4
B	Conv	3	7.6	36	5.5	4	310	0.9
B	Conv	4	7.7	55	4.8	4	264	0.6
C	Conv	2	7.8	33	4.3	7	310	1.1
C	Conv	3	7.5	29	4.4	9	362	0.9
C	Conv	4	7.7	33	4	6	386	0.6
VRT Stats								
MIN:			6.7	18.0	2.6	166.0	166.0	0.3
MAX:			8.0	47.0	5.2	343.0	343.0	1.5
AVG:			7.6	31.5	4.2	282.1	282.1	0.7
Conventional Stats								
MIN:			7.5	29.0	4.0	248.0	248.0	0.3
MAX:			8	55	6	386	386	1
AVG:			7.7	43.2	4.8	299.2	299.2	0.8
Whole Field (A,B,C & D) stats:								
MIN:			6.7	18	2.6	166	166	0.3
MAX:			8.0	55	5.6	386	386	1.5
AVG:			7.6	36	4.5	289	289	0.8

Table 1. Grid soil sampling analysis information by grid at the Lac Qui Parle site for 1994.

Lac Qui Parle County: Management Infromation					
Year	Item	Type		Rate	Date
		VRT	Conv.		
1993	Previous crop	wheat	soybeans	---	---
1994	Seed (corn)	Pioneer 3733	Pioneer 3733	NA[1]	5/11/94
	Fertilizer	Starter	Starter	15-38-10 lbs/ac (N-P2O5-K2O)	5/11/94
	Nitrogen	Soil A-urea		102 lbs N/ac	5/10/94
		Soil B-urea		107 lbs N/ac	5/10/94
		Soil C-urea		112 lbs N/ac	5/10/94
		Soil D-urea		117 lbs N/ac	5/10/94
		Soil E-urea		122 lbs N/ac	5/10/94
			urea	109 lbs N/ac	5/10/94
	Herbicide	Banvel	Banvel	1/2 pint/ac	NA[1]
		Atrazine	Atrazine	1/4 pint/ac	NA
		Ramrod	Ramrod	NA	NA
	Row cultivation			twice	NA
1995	Primary tillage	Chisel plow			Fall 1994
	Secondary tillage	Field Cultivate		twice	5/25/95
	Seed	Soybean		150,000 seeds/ac	5/30/95
	Fertilizer			none	
	Herbicide	Treflan		1.5 pints/ac	5/25/95

[1] NA = No Information was available.

Table 2. Agronomic management information for the Lac Qui Parle Co. site.

Nitrate-N Concentrations in Tile Drainage Outflow Bellingham, MN

Sample Date	VRT Field	Conv. Field
	-------- ppm	-------
5/4/94	11.3	12.3
5/16/94	12.3	14.3
5/23/94	12.3	13.7
5/31/94	11.9	12.2
6/11/94	NF[1]	8.6
6/26/94	NF	NF
7/10/94	14.5	5.5
7/20/94	13.8	NF
7/28/94	NF	NF
8/10/94	20.6	6.0
Average conc.	***13.8***	***10.4***

[1] NF indicates no flow from tile drains.

Table 3. Comparison of tile drainage outflow nitrate-N concentrations for the Lac Qui Parle Co. site.

Watonwan County Site: Field Layout

Legal description: T-105-N R-32-W, Long Lake Township, SW1/4 Sec.

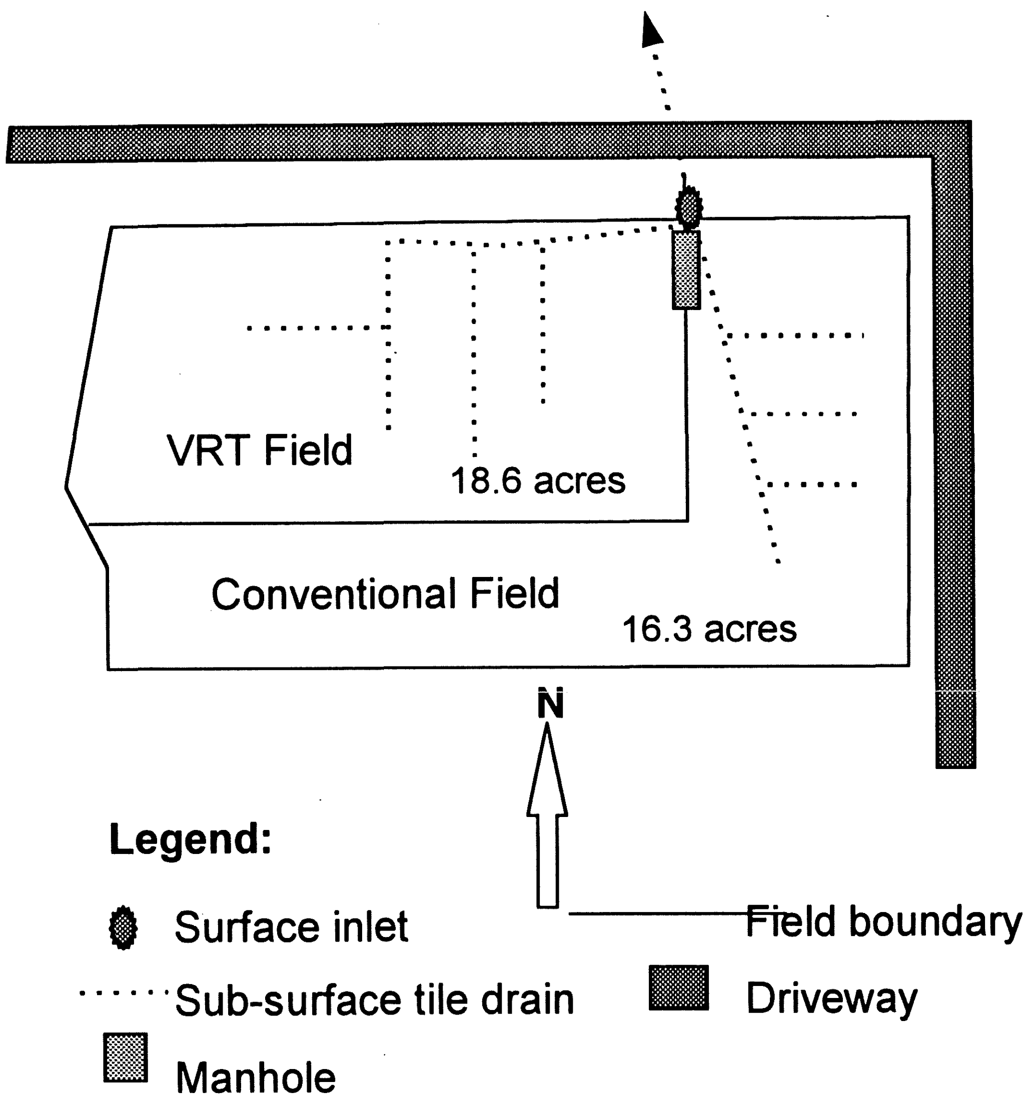


Figure 4. Field layout and location of the Watonwan Co.

Watonwan County Site: Grid Soil Sampling - P and K, Spring 1994

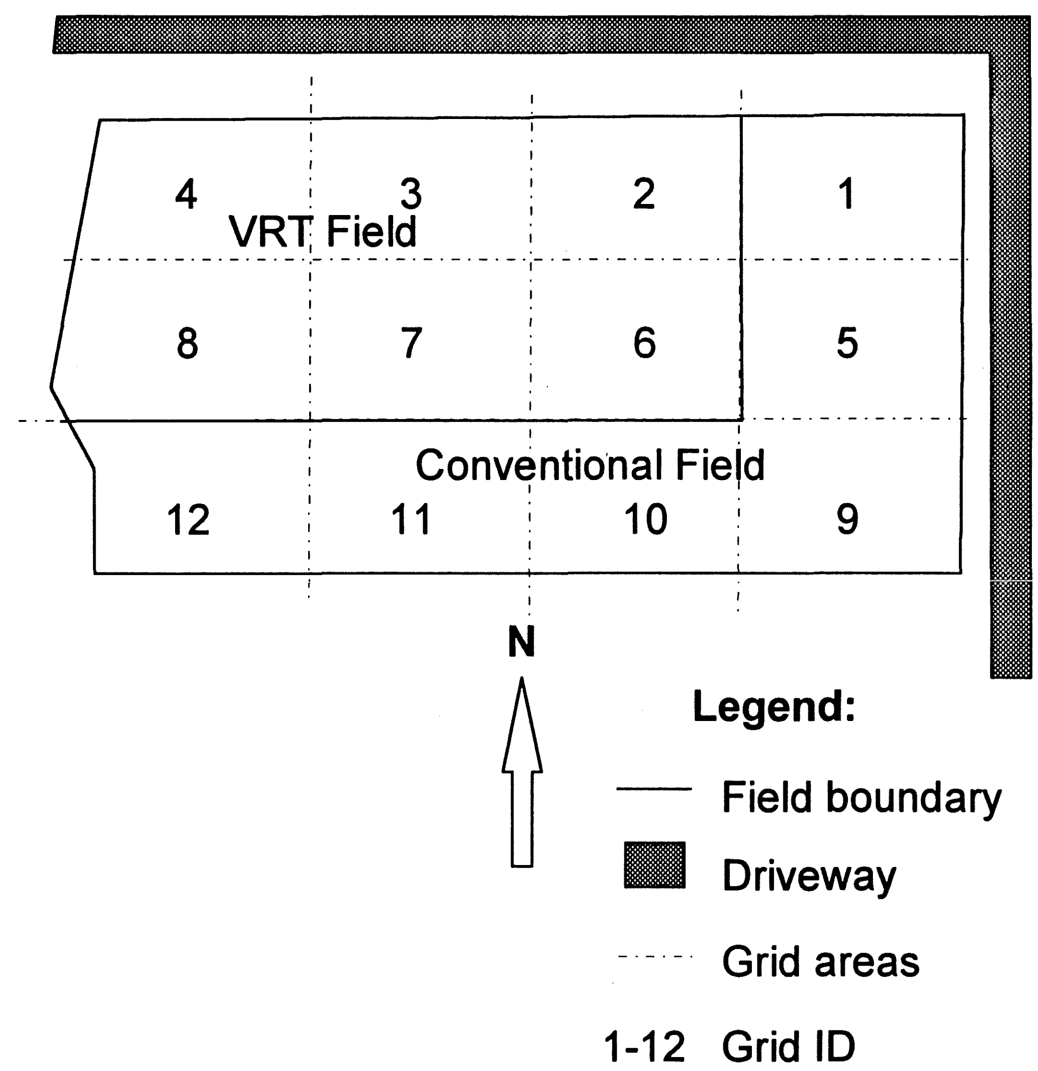


Figure 5. Grid soil sampling scheme for P & K at the Watonwan Co. site.

Watonwan County Site:
Grid Soil Sampling - Nitrate, Spring 1994

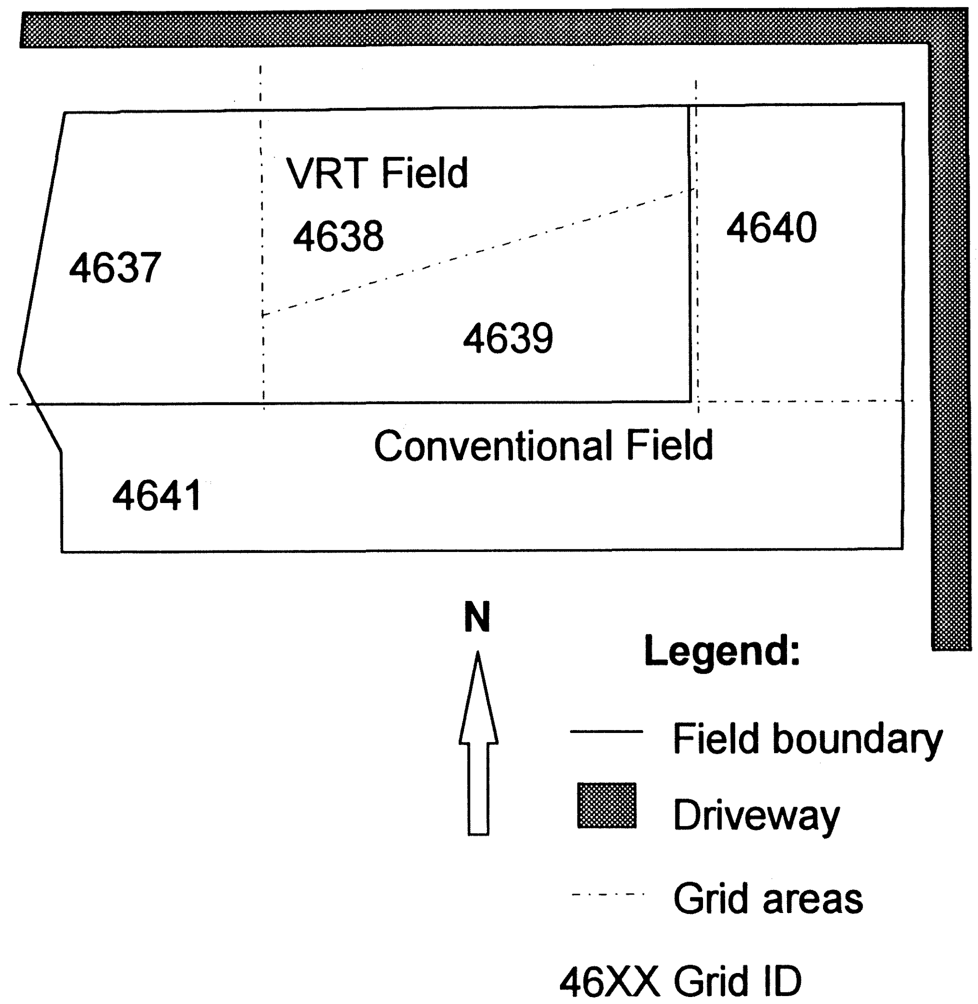


Figure 6. Grid soil sampling scheme for nitrate at the Watonwan Co. site. 4637-4641 are grid ID numbers for soil sample.

MDA, Dennis Fuchs, 612-297-4400								
Cooperator:		Merle Anderson, Hanska Coop, MN Crop Mon.						
Location:		Watonwan Co.						
Study:		VRT Demo		Sample Depth:		N=0-24 in		
Sample Type:		Soil				P,K,etc=0-6 in		
Sample Date:		4/19/94		Yield Goal:		130		
Area:		2.75 ac grid for P and K,				(bu/ac)		
		(N sampled by soil type)						N
Grid	Grid	Soil pH	Nitrate-N	OM	B-1 P	K	Zn	Amt to Apl
(type)	(#)		(# N/ac)	(%)	(ppm)	(ppm)	(ppm)	(#N/ac)
VRT	2	5.7		4.9	82	210	3.4	
VRT	3	6.5		6.4	82	130	5.4	
VRT	4	6.1		5	88	350	5.3	
VRT	6	5.8		4.7	32	150	1.5	
VRT	7	6.6		4.2	52	150	1.2	
VRT	8	5.7		5	66	320	2.1	
VRT	4637		196	(previous crop: soybean with manure)				0
VRT	4638		53	(previous crop: soybean without manure)				80
VRT	4639		45	(previous crop: corn without manure)				120
Conv	1	6.0		4.5	60	150	2.3	
Conv	5	6.6		6.1	31	160	2	
Conv	9	5.8		4.3	56	150	3.6	
Conv	10	5.9		5.6	56	180	3.8	
Conv	11	5.5		4.7	32	120	2.1	
Conv	12	5.4		5.1	31	240	2.7	
Conv	4640		61					120
Conv	4641		62					120
VRT Stats								
MIN:		5.7	45.0	4.2	32.0	130.0	1.2	
MAX:		6.6	196.0	6.4	88.0	350.0	5.4	
AVG:		6.1	98.0	5.0	67.0	218.3	3.2	
Conventional Stats								
MIN:		5.4	61.0	4.3	31.0	120.0	2.0	
MAX:		7	62	6	60	240	4	
AVG:		5.9	61.5	5.1	44.3	166.7	2.8	
Whole Field (A,B,C & D) stats:								
MIN:		5.4	45	4.2	31	120	1.2	
MAX:		6.6	196	6.4	88	350	5.4	
AVG:		6.0	83	5.0	56	193	3.0	

Table 4. Grid soil sampling analysis information by grid and recommended nitrogen rates at the Watonwan Co. site for 1994.

Watonwan County: Management Infromation					
Year	Item	Type		Rate	Date
		VRT	Conv.		
1992	Seed	Corn		NA[1]	5/7/92
			Soybean	NA	5/18/92
	Fertilizer	Starter-liquid	none	5-17-0 lbs/ac (N-P2O5-K2O)	5/7/92
		A. Ammonia	none	90 lbs N/ac	5/5/92
		18-46-0	none	8-20-0 lbs/ac (N-P2O5-K2O)	5/5/92
		0-0-62	none	0-0-80 lbs/ac (N-P2O5-K2O)	5/5/92
	Insecticide	Counter 15-G		7 lbs/ac	5/7/92
	Herbicide	Lasso II		10 lbs/ac	5/7/92
			Ranger	12 oz/ac	5/13/92
			2,4-D ester	8 oz/ac	5/13/92
			Fusilade 2000	10 oz/ac	6/12/92
			Pursuit	4oz/ac	6/12/92
1993	Seed	Soybean		NA	5/26/93
			Corn	NA	5/18/94
	Fertilizer	none	Dry	12-30-90 lbs/ac (N-P2O5-K2O)	5/16/93
			Zinc	4 lbs/ac	5/16/93
	Herbicide	NA	NA		
1994	Seed	Corn	Corn	NA	NA
	Fertilizer	VRT		0 lbs N/ac	5/20/94
		VRT		80 lbs N/ac	5/20/94
		VRT		120 lbs N/ac	5/20/94
			Conv	120 lbs N/ac	5/20/94
	Herbicide	Lasso	Lasso	10 lbs/ac	5/20/94
1995	Seed	Soybean	Soybean	NA	5/23/95
	Fertilizer	none	none		
	Herbicide	Treflan	Treflan	1.25 pt/ac	5/23/95

[1] NA = No Information was available.

Table 5. Agronomic management information for the Watonwan Co. site.

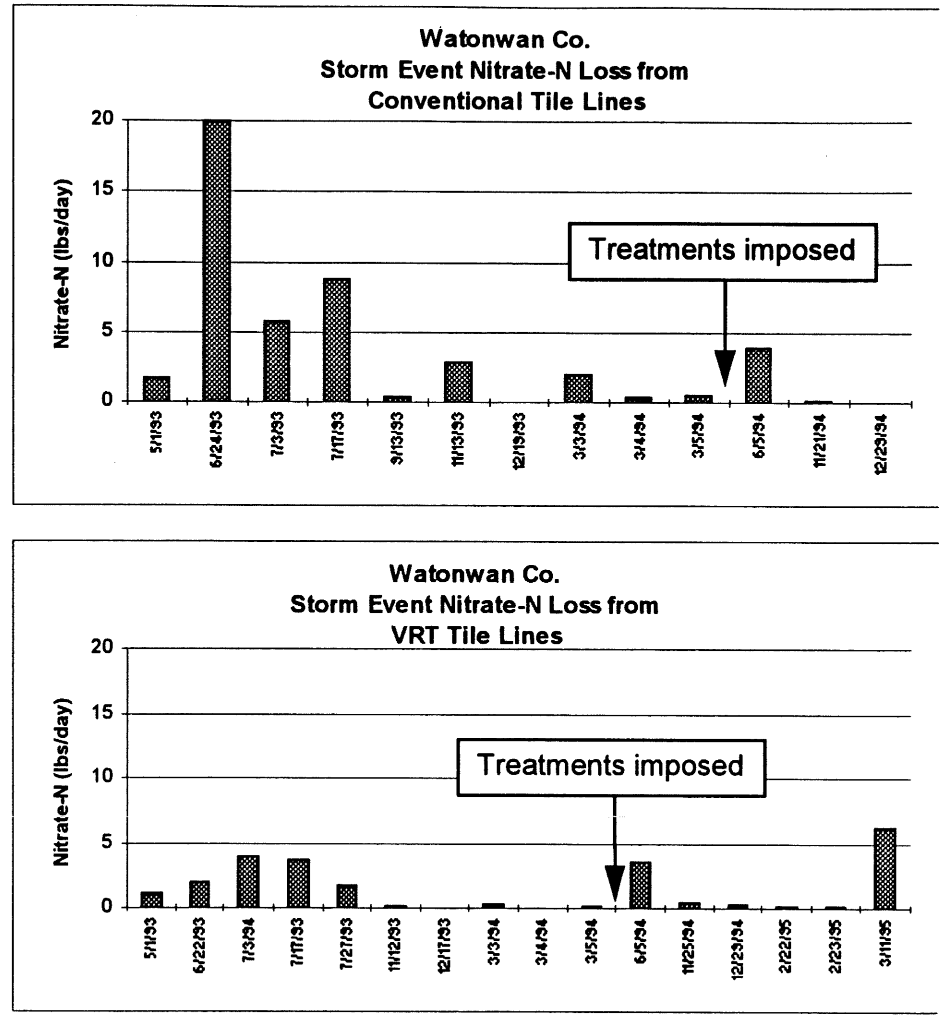


Figure 7. Comparison of tile drainage outflow nitrate-N mass for selected storm events at the Watonwan Co. site.

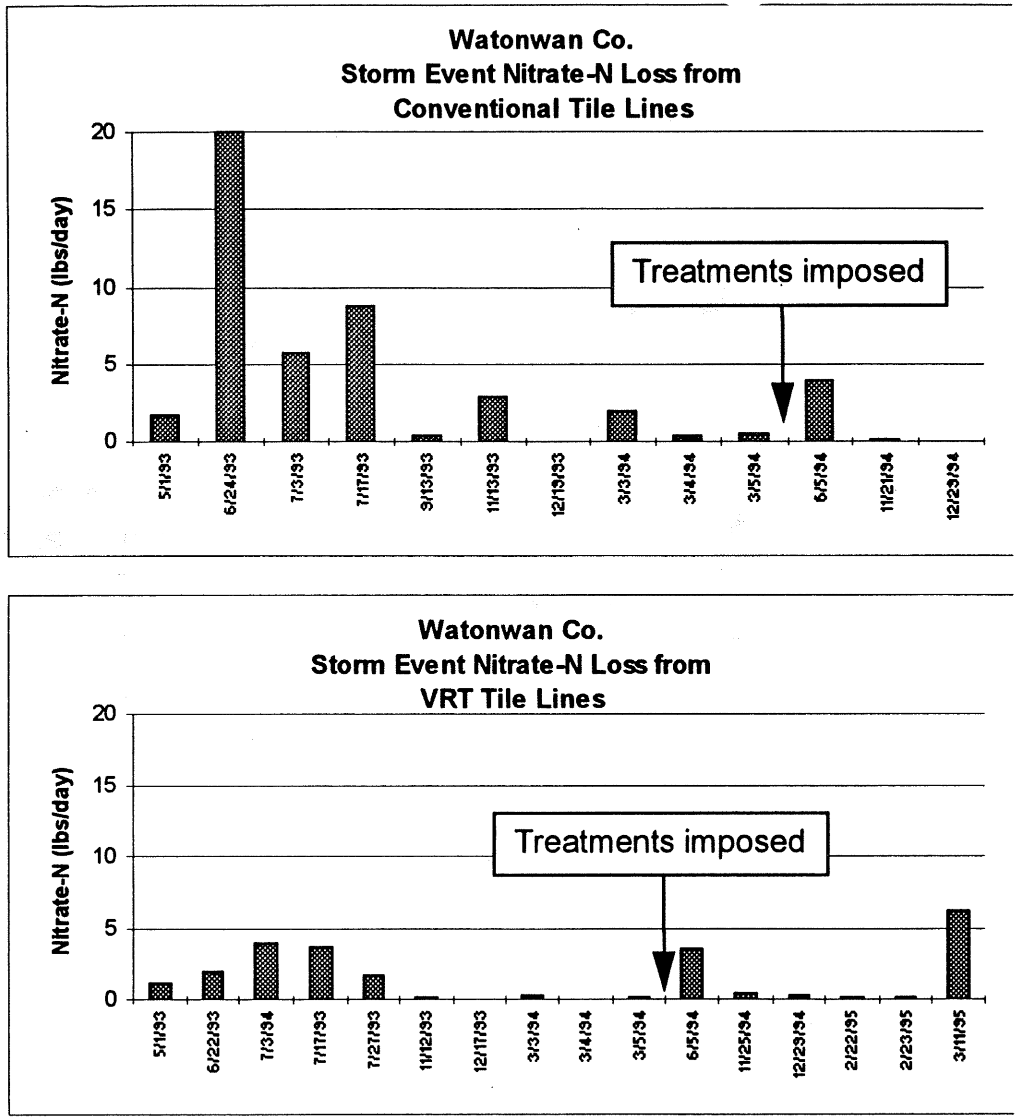


Figure 7. Comparison of tile drainage outflow nitrate-N mass for selected storm events at the Watonwan Co. site.

Nicollet County Site: Field Layout

Legal description: T-110-N R-26-27-W, Traverse Township, Sec. 16

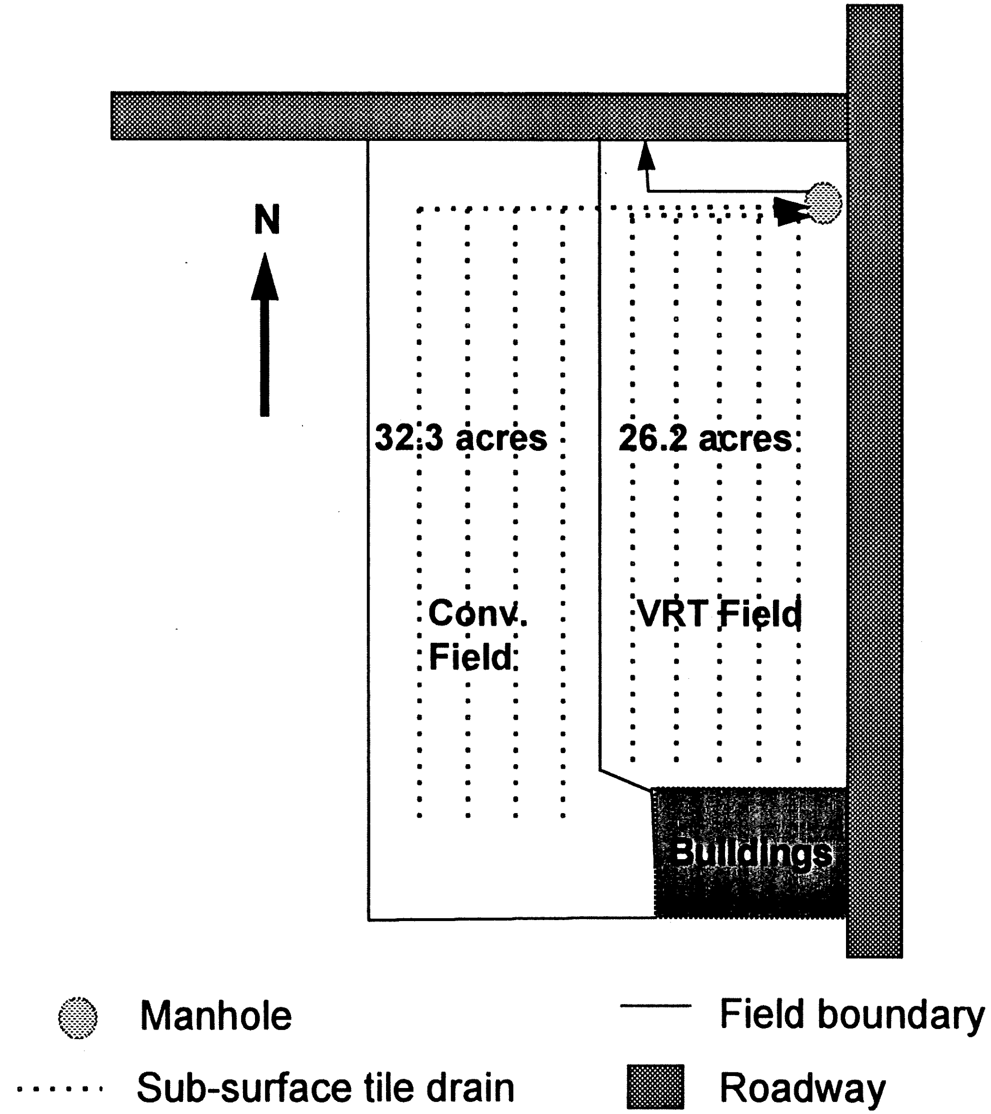


Figure 9. Field layout and location of the Nicollet Co. site.

Nicollet County:
Grid Soil Sampling, Fall 1994

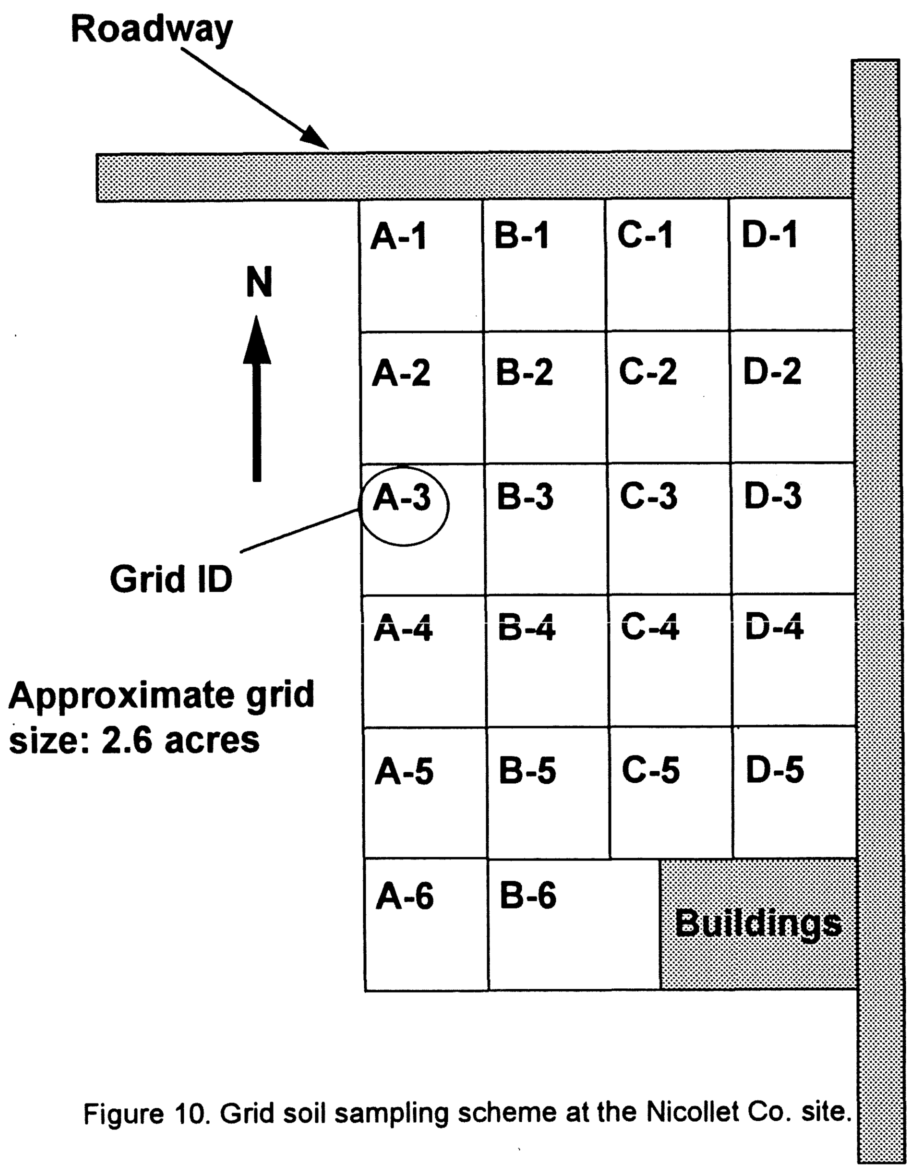


Figure 10. Grid soil sampling scheme at the Nicollet Co. site.

MDA, Dennis Fuchs, 612-297-4400				Sample Depth:		N=0-24 in				
Cooperator:		CWP, Rob Meyer				P,K,etc=0-6 in				
Location:		Nicollet Co.		Yield Goal:		150	(bu/ac)			
Study:		VRT Demo		Notes: Rob Meyer will apply a uniform application						
Sample Type:		Soil		of 100 lbs N/ac across the whole field using					Crystal Coop	
Sample Date:		10/29/94		Anhydrous Ammonia. Crystal Coop will apply the					Application Rates:	
Area:		2.65 ac grid		P & K at the rates listed, all material applied					P	K
				in the Fall of 1994					Amount	Amount
Grid	Grid	Soil pH	Nitrate-N	OM	B-1 P	Olson	K	Zn	to Apply	to Apply
(Letter)	(#)		(# N/ac)	(%)	(ppm)	(ppm)	(ppm)	(ppm)	(#18-46-0/a)	(#0-0-62/a)
A	1	7.1	55	4.1	17	14	170	1.9	60	0
A	2	6.4	41	4.5	19	15	150	2.3	60	0
A	3	7.0	62	5.8	14	12	140	3	60	0
A	4	6.8	38	4.3	14	12	130	1.9	60	0
A	5	6.4	34	5	14	11	150	2.2	60	0
A	6	6.0	31	5.7	9	11	260	2.7	60	0
B	1	6.3	39	5.2	10	9	160	1.7	60	0
B	2	6.0	36	5.3	13	9	130	2.2	60	0
B	3	6.5	44	5.9	18	14	160	3	60	0
B	4	6.5	42	5.2	34	24	240	2.9	60	0
B	5	6.3	30	4	28	20	160	2.4	60	0
B	6	6.5	38	6.1	7	7	200	2.5	60	0
C	1	7.4	47	5	4	6	180	1.9	140	0
C	2	7.6	34	6.2	1	7	130	2.1	130	100
C	3	7.7	no sample	7.5	4	7	170	2.2	130	0
C	4	7.2	no sample	9.2	52	54	490	4.8	0	0
C	5	7.4	no sample	6.9	42	31	280	5.3	0	0
D	1	7.7	no sample	6.8	2	9	190	2	100	0
D	2	7.4	no sample	7.1	12	10	270	2.8	90	0
D	3	7.4	no sample	6.8	14	11	270	2.4	70	0
D	4	7.6	no sample	6	11	10	230	2.3	90	0
D	5	7.2	no sample	5	19	12	190	2,1	10	0
Conventional (West side A & B) stats:										
MIN:		6.0	30	4.0	7	7	130	1.7	60	0
MAX:		7.1	62	6.1	34	24	260	3.0	60	0
AVG:		6.5	41	5.1	16	13	171	2.4	60	0
VRT (East side C & D) stats:										
MIN:		7.2	34	5.0	1	6	130	1.9	0	0
MAX:		7.7	47	9.2	52	54	490	5.3	140	100
AVG:		7.5	41	6.7	16	16	240	2.8	76	10
Whole Field (A,B,C & D) stats:										
MIN:		6.0	30	4.0	1	6	130	1.7	0	0
MAX:		7.7	62	9.2	52	54	490	5.3	140	100
AVG:		6.9	41	5.8	16	14	202	2.6	67	5

Table 6. Grid soil sampling analysis information by grid and recommended fertilizer rates at the Nicollet Co. site for 1995.

Nicollet County: Management Infromation				
Growing Year	Item	Type	Rate	Date
1993	Previous crop	corn		
1994	Seed (soybean)	Sturdy & Iowa 2008	150,000 seed/ac	May
			30 inch rows	
	Herbicide	Treflan (PPI)	Rec. rate	NA[1]
		Galaxy (Post-emerg)	Rec. rate	NA[1]
	Row cultivation			
1995	Seed	Anderson 4000	30,000 seed/ac	5/2/95
			30 inch rows	
	Fertilizer	Anhydrous Ammonia	100 lbs N/ac	Fall 1994
	Herbicide	Dual (PPI)	rec. rate	5/1/95
		Banvel (Post)	rec. rate	6/12/95
	Row cultivation		NA[1]	

[1] NA = No Information was available.

Table 7. Agronomic management information for the Nicollet Co. site.

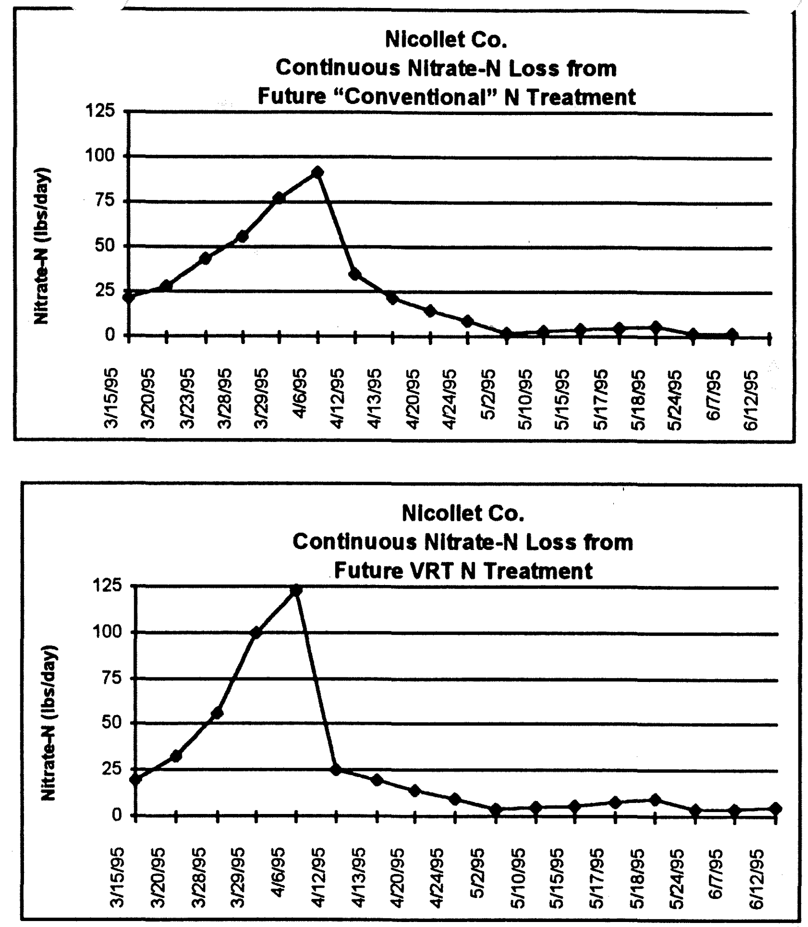


Figure 11. Comparison of tile drainage outflow nitrate-N mass from weekly sample collection at the Nicollet Co. site. Note that this is "background information". N treatments will not be imposed until the 1997 corn growing season.

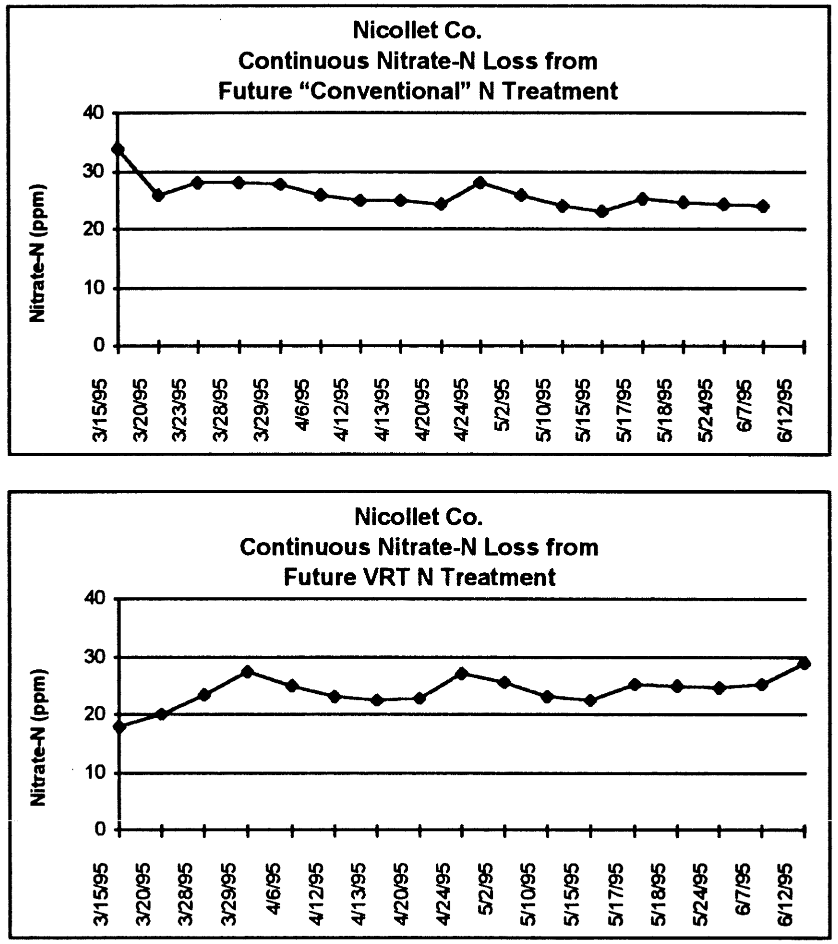


Figure 12. Comparison of tile drainage outflow nitrate-N concentrations from weekly sample collection at the Nicollet Co. site. Note that this is "background information". N treatments will not be imposed until the 1997 corn growing season.

Cross Sectional View of a Tile Drain Monitoring System

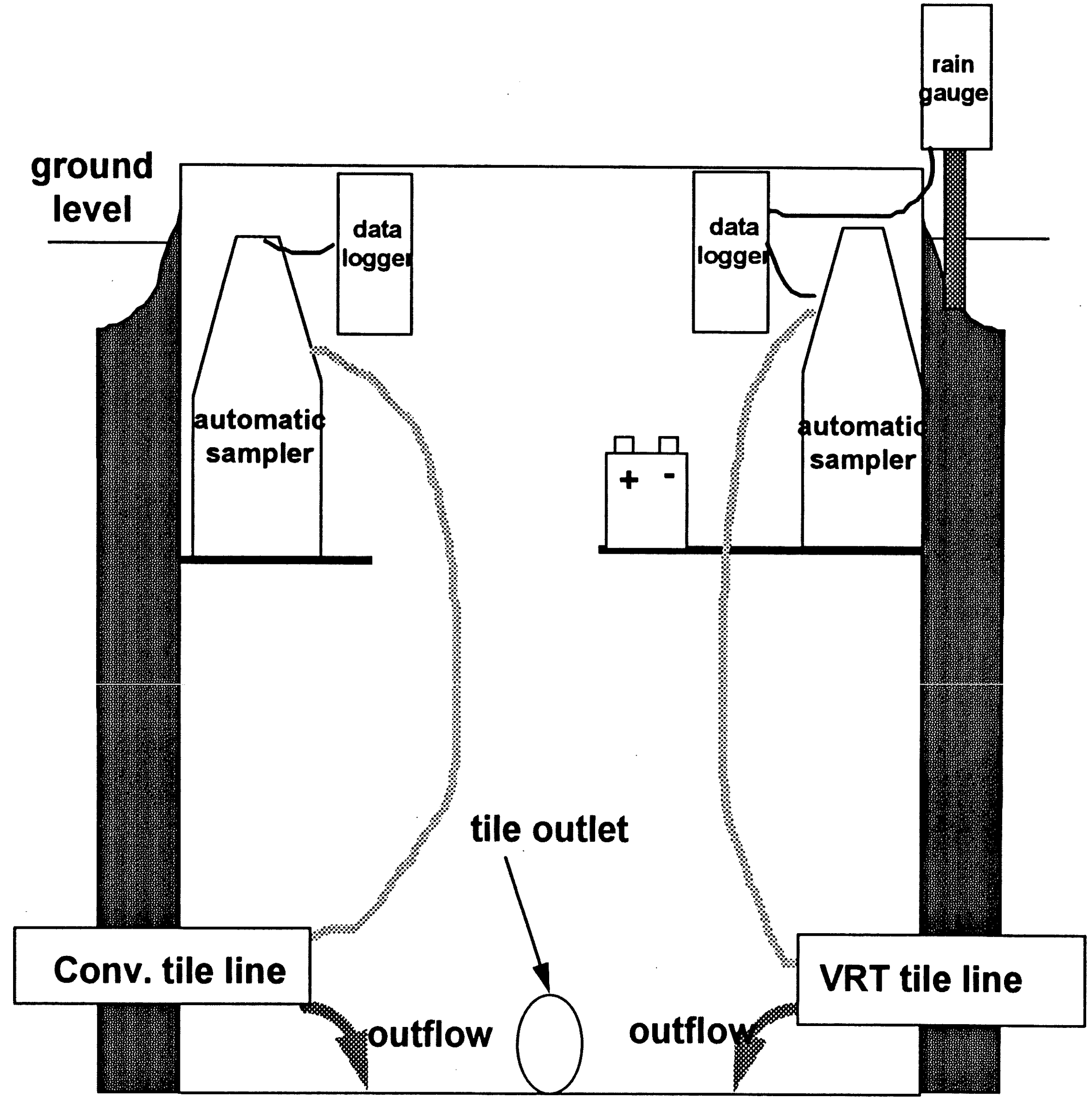


Figure 13. Cross sectional view of a tile drain monitoring system for Watonwan Co. and Nicollet Co. sites.

Activity	Location	Date
Summer Twilight Research Tour	Renville County	July 5, 1994
Farmfest	Redwood Falls	August 2-4, 1994
Bellingham Coop. Crop Tour	Bellingham	September 13, 1994
General Agriculture Training Program	Alexandria	Jan 27, Feb 3, 10, 17, 1995
Hanska growers meeting	Brown Co.	March 16, 1995
Brown-Nicollet-Cottonwood CWP Mtg.	St. Peter	March 20, 1995
Cenex agronomists	St. Paul	May 12, 1995
Precision Agriculture Conference	St. Paul	June 9, 1995
GPS User's Conference	Minneapolis	June 15, 1995
University of Minnesota - SW Experiment Station, Field Day	Lamberton	June 21, 1995
Brown-Nicollet-Cottonwood CWP Field Day	St. Peter area	August 24, 1995
Southern Corn Economics Group	Blue Earth Co.	Sept. 5, 1995
Waseca Field day	Waseca	September 14, 1995
Hanska corn growers tour	Hanska	September 19, 1995
ASA meetings (4 papers)	St. Louis	November 1, 1995
Extension crop update	St. Paul	December 7, 1995

Appendix C, Table 8. Educational activities.

D. Title of Objective: Integrate results into a user friendly decision aid for local use that can also be used as an educational tool that would promote site specific BMPs.

D.1 Activity: Variable rate N applications is a high technology management concept. It requires new or enhanced management skills. Historically, this kind of management has shown a slower rate or a resistance to adoption. However, today we have new tools to overcome the technology transfer barrier. A user-friendly management decision aid system integrating results from this project and from other sources will be developed to facilitate the adoption of this revolutionary management concept. Also, variable rate N management is a new concept that needs to be promoted by documenting its benefits as a BMP and increased productivity and profitability. The decision aid system will be used to demonstrate advantages of soil specific management over conventional management.

D.1.a Context within the project: Results from Objectives A and B, as well as BMPs for N management developed by MDA in collaboration with the University of Minnesota and other interested groups will be translated into decision rules utilized by the expert system for making management recommendations.

D.1.b Methods: An expert system "shell" will be used to develop the decision aid system. A shell based system will be developed more rapidly, will be updated more easily, and will take care of interfacing with a variety of continuously changing hardware. The expert system correctness will be verified by N management specialists using present N recommendations and field data and its ease-of-use by an advisory group made of Minnesota extension agents, ag-consultants, agri-business persons, and producers. An educational version will be developed using several management scenarios based on farm data.

D.1.c Materials: Expert system shell.

D.1.d Budget: $ 24,700 **Balance:** $ 000

D.1.e Timeline:

	7/93	1/94	6/94	1/95	6/95
Shell selection		*****			
E.S. flow and rules development			****	***	
System development		********		******************	

D.1.f Status:

There have been two primary objectives pursued in the project to upgrade the Nitrogen Expert System: (1) Adding rules to arrive at a recommended nitrogen fertilization program, and (2) To import the Expert System into the Windows environment. Other minor objectives have also been pursued.

Complete Nitrogen Fertilization Program

The original Nitrogen Expert System was designed to produce a Nitrogen fertilization rate recommendation based on a realistic yield goal, soil data, and management practices. It is intended that the upgraded Expert System be able, with the use of some additional variables, to arrive at a complete program of Nitrogen fertilization including timing and method of application, in addition to rate.

As detailed in the progress report of 12/16/94, use of the Exsys RuleBook for system development was explored for this expansion of the Expert System's scope and some problems were encountered. (See previous report.) These difficulties were overcome through the use of the Exsys system's ability to output the rules files in manually editable form. By outputting the rules file of the original Nitrogen Expert System and the one developed with the Exsys RuleBook, editing them by hand, and using the Exsys Rule Compiler to reassemble them, a single, combined Nitrogen Expert System was created. This Expert System has been completed and meets the first of the project's primary objectives.

Unfortunately, this experience has proven that, while the Exsys RuleBook may, in some instances, be used for expert system expansion on systems originally created using the standard Exsys Professional Editor, the process is no less difficult and time-consuming than using the Exsys Professional Editor for such additional development.

The other difficulty that was encountered in this phase of the upgrade was that the Exsys Runtime program failed to properly run the resulting combined Nitrogen Expert System. Only after a lengthy search for errors in the Expert System and repeated contacts with the Technical Support staff at Exsys, Inc. was it determined that the problem was not with the Nitrogen Expert System, but with the Exsys Runtime program. A new, revised version of the Exsys Runtime has been acquired from Exsys that allows the Nitrogen Expert System to run properly. While this difficulty has been fully overcome, it nonetheless significantly delayed the upgrade project.

Importation into the Windows Environment

The importation of the existing DOS Nitrogen Expert System into the Windows environment has been undertaken using Exsys Professional for Windowed Environments. The Windowed version of the Nitrogen Expert system now uses the expanded Nitrogen Expert System which gives rate, timing, and method recommendations for application.

Importing the Nitrogen Expert System into Windows is intended to allow users of Windows to use the expert system directly without resorting to access through DOS and improve both the input and output interface for end users of the expert system. Users will be provided with simple point-and-click and scroll-bar screens for data input, hypertext screens for help and advice, and clear and complete instructions for Nitrogen application recommendations.

While completion of this objective of the upgrade has been delayed due to the difficulty encountered with the previous version of the Exsys Runtime program (as detailed above) the importation of the Nitrogen Expert System into the Windows Environment is proceeding without difficulty. As of this writing, over 100 custom screens have been designed and this phase of the project is nearing completion.

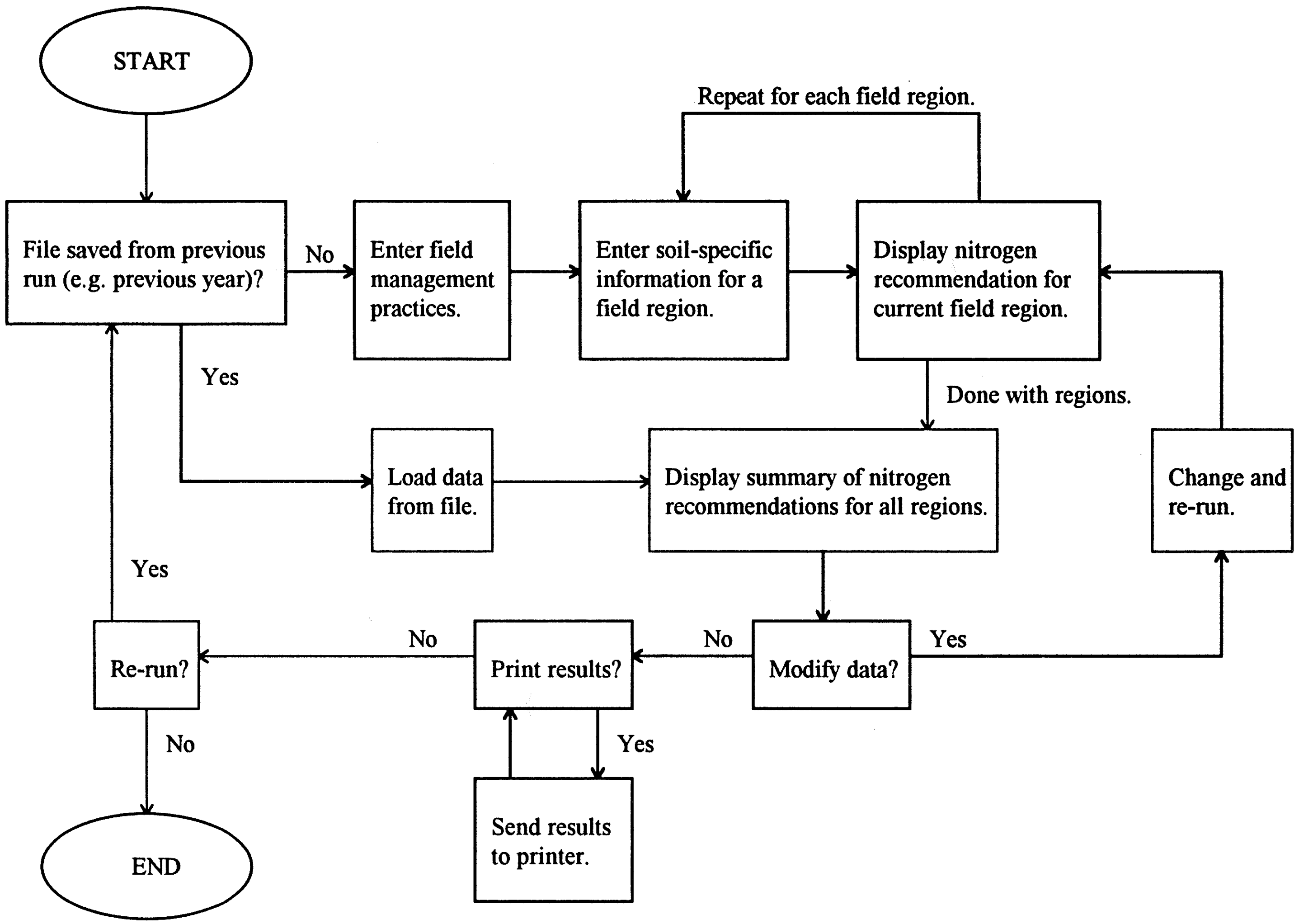
Minor Objectives

Minor objectives of the Nitrogen Expert System upgrade project have included adding the ability for the user to save and retrieve data entered into the system for year-to-year use, allowing the user to enter data for multiple regions in a single field, reworking of the system's questioning order so that management practice questions are only asked once per field, adding warnings for extreme values entered for user data, and minor cosmetic alterations.

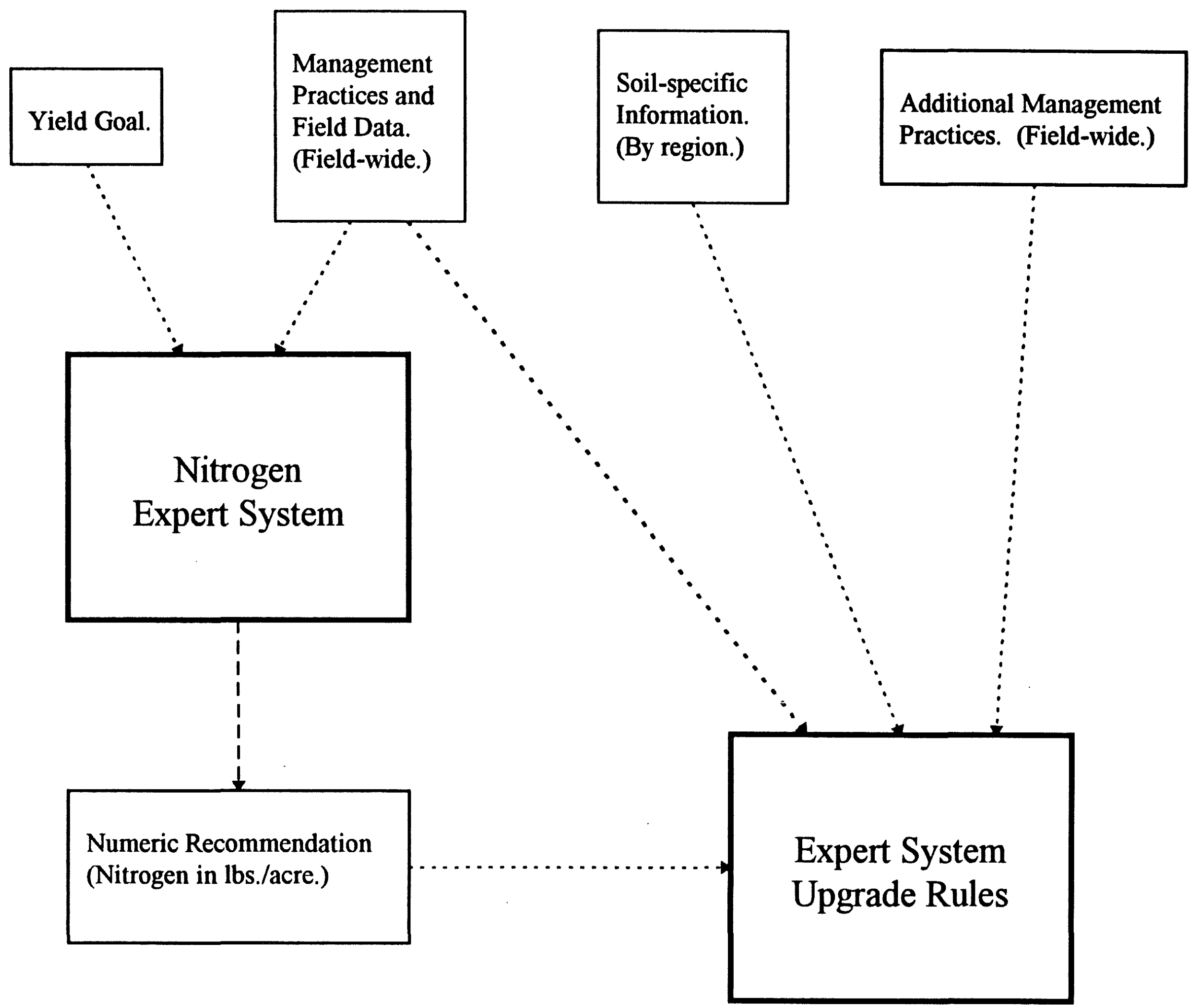
These minor objects have been met or are being developed without difficulty, although completion of all minor objects has also been delayed by the difficulty encountered with the Exsys Runtime program (see above). As of this writing, a command file has been created that allows for multiple field regions without unnecessary repetitions of questions, and the ability to save, retrieve, and modify data already entered is being added. This places us near the completion of the projects minor objectives as well.

Appendix D: Objective D

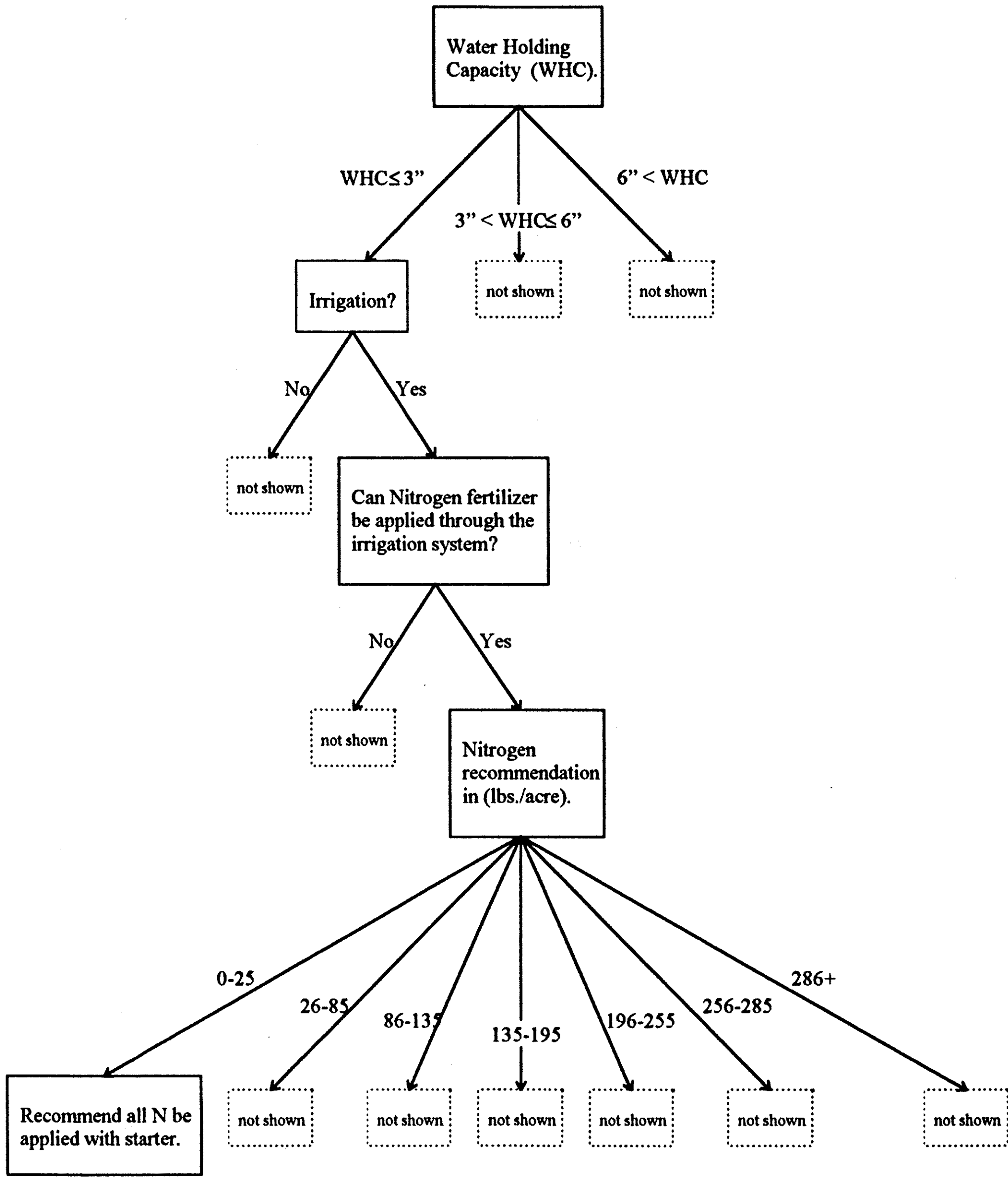
Appendix D, Figure 1. General Flow of Program



Appendix D, Figure 2. Data Flow and Results



Appendix D, Figure 3. N Application Timing and Method Flow Chart



V. Evaluation:

The overall goal of this entire project is to reduce nitrogen fertilizer usage while maintaining or improving yield production. Techniques for nitrogen management have not been developed to fully utilize the high precision accuracy of variable rate technology. This project will be successful if the following items are accomplished: (1) Develop technology to better predict soil nitrogen availability across a soilscape; (2) Successfully determine appropriate N fertilizer rates and other additional BMPs across the soilscape; (3) Successfully transfer the findings to farmers and industry through the development of decision aid computer system and field demonstrations; and lastly, (4) Demonstrate the influences of variable rate technology on fertilizer efficiencies, energy savings, and yields and establish long-term monitoring sites to observe effects on water quality.

VI. Context Within Field:

Current fertilizer recommendations and BMPs for nitrogen fertilizer management are a combination of statewide and/or regional suggestions. Research information has been combined over large geographic areas to provide these recommendations. Variable rate on-the-go nitrogen application depends on the premise that soils within a field vary, and because of that variability they should be managed differently. The scale at which recommendations need to made are on a much smaller basis. Individuals within industry and the University of Minnesota have placed Minnesota as one of the national leaders in the development of variable rate technology. The development of the technology, however, has been much more rapid than the ability to learn how to use it properly. Relatively little research information has been generated within the State of Minnesota to assist in the development of appropriate soil condition maps. This information is essential if the technology is to be developed into a BMP. Past experiences of the principal investigators in the areas of nitrogen management, soil survey, BMP development and crop production will be invaluable to this project.

VII. Benefits:

Variable rate technology has been traditionally used for the application of phosphorus, potassium, and pesticides. The fate of nitrogen across a soilscape is a very dynamic and complex system. Consequently, the tools to maximize VRT for nitrogen fertilizer applications have lagged in the development process. The ultimate benefit is to place the correct N rate where it is needed for crop uptake, therefore optimizing N fertilizer use efficiency, potentially saving on fertilizer costs, and minimize ground water and surface water degradation. This project will aid in the development of the essential tools as well as serve in the educational advancement of farmers, government and industry-related personnel. Lastly, this project will aid in the establishment of monitoring sites for studying the long-term effects of variable rate technology on water quality.

VIII. Dissemination:

Results from this project will be presented to a variety of audiences through three different, but interrelated methods. The methods are: the expert system; field demonstrations; and via professional avenues. The expert system approach will allow training industry personnel, educators and other associated professionals in responding to a variety of "What if ..." field scenarios. Yields, economics, fertilizer savings and environmental conditions will be simulated as a direct response to management practices selected by the user. The user will have a much better appreciation for the value of the BMPs and can transfer this knowledge directly to their clientele or own farming conditions.

Farmers and dealers will be the primary audience at the demonstration sites. These sites will serve as a center to transfer information from numerous sources. Site specific data such as yields, potential fertilizer savings, soil sampling and grid costs, and water quality information will be distributed. Farmers and dealers will be encouraged to be an active component of all educational activities. Advancements in nitrogen management technology from Objectives A and B will be shared at the demonstrations. Dealers and others associated with variable rate technology will be informed on technology advancements such as appropriate soil sampling grid sizes and desired method(s) for predicting N availability as well as interpreting and responding to soil condition maps. Existing research from other studies, including potential savings on phosphorus, potassium, and pesticides, can also be distributed at the demonstrations.

Results will also be presented at national and regional meetings, as well as published in peer-reviewed literature in the national journals. The University of Minnesota, as well as the private enterprise in the state, have been strong national leaders in technological advancements in variable rate technology. The international workshop titled, "Soil Specific Crop Management - A Workshop on Research and Development Issues", held in Bloomington in April, 1992 is a good example of Minnesota leadership.

IX. Time:

Due to the nature of biological studies and climatic conditions, additional funding requests from LCMR (for biennium 1995-1997), as well as alternative sources will be necessary.

X. Cooperation:

1. Mr. Bruce R. Montgomery, Soil Scientist
   Agronomy Services Division
   Minnesota Department of Agriculture

   Mr. Montgomery will serve as the Program Manager and will direct the activities outlined in Objective C.

2. Dr. Gary L. Malzer, Professor
Department of Soil Science
University of Minnesota.

Dr. Malzer's research program is actively involved in developing methods that can be used to improve fertilizer use efficiency in crop production. His expertise in soil fertility, nitrogen chemistry, and nitrogen management practices for crop production have a strong field basis and will be active in Objectives A and B.

He has been actively involved with the Center for Agricultural Impacts on Water Quality. Past research activities related to nitrogen management have evaluated time, placement, form, rate, and use of nitrification inhibitors in different regions of Minnesota. Activities have been important in N best management practice development, N loss potential estimates, and soil test development. Dr. Malzer's primary role will be in the coordination of the field, laboratory, and interpretation of results that are directly related to soil fertility aspects of N fertilization, site characterization and evaluation of soil condition maps.

3. Dr. John A. Lamb, Associate Professor
Department of Soil Science
University of Minnesota.

Dr. Lamb's research involves field application of crop management systems and their effect on soil chemical properties and the quantification of soil variability and its effects on production inputs use efficiency. Primary duties will be to adapt field experimental procedures in Objective B to large scale research utilizing global positioning system, yield monitoring equipment, and electronic equipment to monitor soil physical parameters.

4. Dr. Pierre C. Robert, Associate Professor and Extension Soil Specialist
Department of Soil Science
University of Minnesota.

Current research includes: Study, inventory, and management of the soilscape. Recent principal areas of research are: soil information systems, soil specific management, soil spatial variability, land evaluation, and simulation models and expert systems for Best Management Practices and environmental protection. Dr. Robert will develop the expert system discussed in Objective D.

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 Review:

See attachment within June 30, 1993 work plan.