Agricultural Nitrogen Management to Protect Water Quality

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Introduction

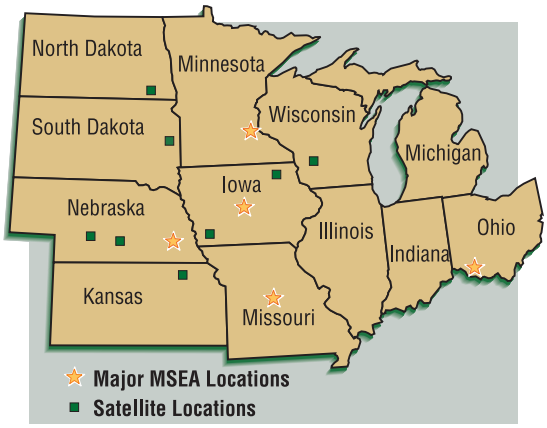


Figure 1. The five major centers for the MSEA project were located in Iowa, Minnesota, Missouri, Nebraska, and Ohio. Satellite field sites were also located in North Dakota, South Dakota, Wisconsin, and Kansas. Collectively, these sites represented most of the soil and hydrological conditions in the Midwest where significant nitrate leaching occurs.

A growing global population and improved world living standards will increase the demand for food and, consequently, the potential for degradation of surface and groundwater quality by agricultural activities. Greater crop yields will be required to meet this demand, requiring larger nutrient inputs, especially nitrogen. With present technology, adding increasing amounts of nitrogen to our production systems would greatly increase the quantity of nitrates entering our surface and groundwater resources. It is clear that new and improved technologies for nitrogen (N) management must be developed and implemented into agricultural production to protect our water resources.

To address the impact of agriculture on water quality, the Presidential Water Quality Initiative was announced in 1989. The United States Department of Agriculture (USDA) responded to this Presidential Initiative by funding and organizing the *Management Systems Evaluation Areas* (MSEA) project "... to evaluate the impact of farming systems and nitrogen inputs to crop production on groundwater quality beneath the crop ..." MSEA activities were designed to document the effectiveness of existing technologies and initiate the development of new technologies capable of increasing crop yields while improving surface and groundwater quality.

The global nitrate problem is most apparent in the North Central Region of the United States, where 83 percent of the nation's corn is produced and 53 percent of the commercial nitrogen fertilizer is used. As a consequence, principal MSEA research sites were established in several midwestern states, including:

- Iowa,
- Minnesota (Northern Cornbelt Sand Plain),
- Missouri,
- Nebraska, and
- Ohio.

Field research was conducted at multiple sites in most of these states as well as at sites in North Dakota, South Dakota, Wisconsin, and Kansas (Figure 1). The MSEA research and education program

Iowa MSEA

Deep, fine-textured soils with subsurface drainage

Northern Cornbelt Sand Plain MSEA

Sandy soils over shallow aquifers

Missouri MSEA

Claypan soils with large volumes of surface runoff

involved four USDA agencies, two other federal agencies, and additional state and local agencies from the respective states. The MSEA program is the largest interagency water quality study ever undertaken.[1]

Collectively, the MSEA research sites included a number of conditions and situations in the Midwest where nitrate pollution of water resources might occur. At these field sites, field-scale comparisons were made between conventional corn production practices and improved practices designed to reduce nitrate losses, improve water quality, and increase crop yields. Practices studied included improved manure and nitrogen fertilizer management, water management, and the use of different farming practices (such as tillage and cropping systems). Included in these studies were such factors and practices as:

- mineralization of nitrogen from soil organic matter and animal manures
- use of pre-plant and pre-sidedress soil nitrogen tests (PPNT and PSNT)
- stalk nitrate tests
- soil moisture effects
- use of chlorophyll meters and remote sensing to detect nitrogen deficiencies in the crop
- fertilizer placement, timing, and form
- watershed studies
- surge and sprinkler irrigation techniques
- subsurface drainage studies
- reduced and no-tillage practices
- ridge-tillage
- cropping systems and rotations
- soil variability

In most instances research was conducted for five years or more. Research activities at all sites were similar. Many of the same measurements were made at each site. Weather stations at each site collected climatic data on precipitation, temperature, wind speed, relative humidity, and other relevant parameters. Methods for sampling water and soil and for chemical analysis of these samples were standardized. Strict guidelines were followed for quality assurance and quality control in sampling and analysis. To the extent possible, common treatments and research methods were coordinated to enable pooling of results and a comprehensive evaluation of nitrogen management and its impacts on water quality across the North Central Region of the United States.

Nebraska MSEA

Sprinkler and furrow irrigated lands on medium-textured soils above a shallow, nitrate-contaminated aquifer

Ohio MSEA

Rainfed production on medium to fine-textured soils over a buried valley aquifer

[1] ***USDA Agencies*** included the Agricultural Research Service (ARS) and Cooperative Research, Extension, and Education Service (CSREES). Other participating Federal agencies were the Environmental Protection Agency (EPA), U.S. Geological Survey (USGS), USDA Natural Resources Conservation Service (NRCS), and Economic Research Service (ERS).

Lessons Learned

from MSEA

Leaching losses usually remain low as long as the nitrogen rate is at or below the amount required for optimum yield. The potential for nitrate leaching increases rapidly when available nitrogen exceeds the optimum rate. Available nitrogen can come from mineralization of nitrogen in soil organic matter, crop residues, and manures, as well as fertilizer.

Nitrate leaching

In numerous MSEA-project fields, nitrogen fertilizer rates for optimum yield in good growing years provided a crop that was uniformly green and produced high yields. Frequent groundwater sampling and subsurface drainage showed that significant nitrate leaching loss sometimes occurred when the field was fertilized at a rate only slightly greater than that required for optimum yield (Figure 2). Leaching occurs when nitrate, dissolved in soil water, is transported below the depth of the rooting system of the crop by excess rainfall or irrigation. High rates of previously applied manure often resulted in serious leaching, as did converting from rainfed to irrigated corn. Leaching losses increased greatly as the nitrogen application rate increased beyond the amount needed for optimum yield. Previous research has shown that leaching is most common in:

- shallow or highly permeable soils
- fields that had previously received animal manures or were in rotation with alfalfa
- fields the first few years after they were irrigated
- years when yields were substantially below normal due to poor growing conditions

Leaching may be much greater in some parts of a field than in others because of soil variability (Figure 3). Quantity of estimated leaching losses varied greatly between fields as well as within each field. This occurred because variability in soil properties affected nitrogen mineralization and water movement through the soil. Most of these situations reflected an inability to anticipate at planting time, the weather conditions that occurred during the growing season, and subsequently, the actual yield. In less favorable years, when fertilizer nitrogen was applied at planting to meet crop needs for near-optimum growing conditions, excess nitrates remained in the soil after harvest and were subject to leaching (Figure 4). The uncertainties of weather contributed greatly to nitrate leaching.

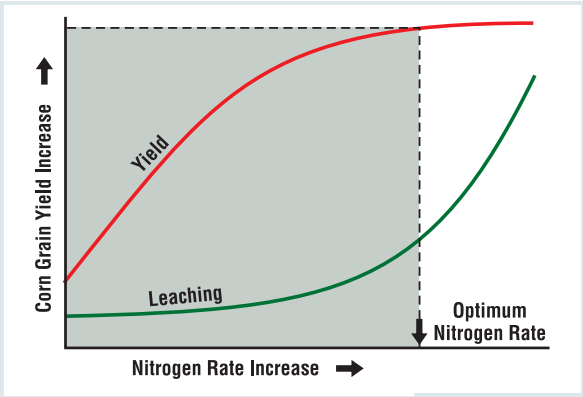


Figure 2. Conceptual impact of nitrogen supply from all sources on corn grain yield and the potential for nitrate leaching.

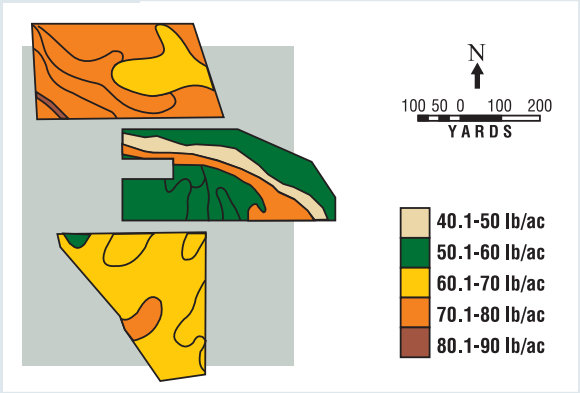


Figure 3. Estimated amount of nitrates lost by leaching for three adjacent fields in Ohio. Soil type boundaries are shown by the irregular lines within each field, indicating that leaching may or may not be closely tied to soil type.

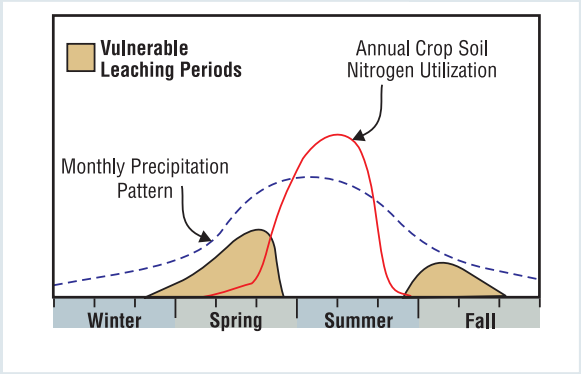


Figure 4. Typical seasonal patterns for precipitation, nitrogen uptake rates, and periods potentially favorable for nitrate leaching for corn production in the Midwest. Little nitrate leaching is likely to occur during the period of active crop growth, but significant leaching may occur after maturity in the fall, and in the spring. Leaching is more likely in years with above average rainfall during these periods.

Improved management of water and fertilizer reduces leaching

Nitrate leaching can be better controlled during the growing season with sprinkler irrigation than with furrow irrigation because of greatly improved water control.

For nitrate leaching to occur, two conditions are needed:

- the soil must contain soluble nitrates, and
- water must move through the soil.

Results of MSEA research have shown that the two keys to controlling nitrate leaching were better water management and improved nitrogen fertilizer management. Under irrigation, good water control was especially critical. The best control was achieved by changing from surface (furrow) to sprinkler irrigation, especially center pivot or linear move systems (Figure 5), so that water was applied more uniformly, and timely, and in the right amount.

Switching from conventional furrow irrigation to surge flow irrigation substantially reduced deep percolation and the resulting nitrate-leaching loss. Sprinkler irrigation also permitted fertigation, in which supplemental fertilizer nitrogen was added to the irrigation water to meet current crop nitrogen needs. This reduced the need to apply all the fertilizer before planting.

Where installed, subsurface drainage helped maintain groundwater quality, but diminished quality of surface water bodies into which the drains discharged. Subirrigation through subsurface drainage systems also effectively controlled nitrate leaching beneath the crop root zone. Adding a runoff recovery system to either conventional or surge systems in furrow-irrigated fields further increased irrigation efficiency and reduced water and nitrogen loss.

Discharge from the Walnut Creek watershed, a MSEA site in Iowa, was monitored for nitrates on a field, sub-basin, and watershed basis to quantify nitrate loads. In this intensively subsurface-drained region, patterns throughout the year were the same for a small field, a sub-basin, and the entire watershed (Figure 6). The only difference was the magnitude of the load at the different scales. It may be possible to evaluate changes at a field scale and then develop simple multiplier systems to estimate the effect of changing management practices for a watershed.

Reductions in nitrate losses were also achieved by:

- improving nitrogen fertilizer placement (banded rather than surface broadcast placement),
- applying part of the fertilizer nitrogen later in the growing season rather than all pre-plant,
- using slow-release fertilizers or nitrification inhibitors, and currently recommended soil-testing procedures for fertilizer management.

Nitrate losses were much higher when a standard rate of fertilizer nitrogen was applied each year than when the amount of nitrogen added was based on results of soil tests appropriate for the region of concern (Figure 7). In most soils, nitrogen fertilization according to modern soil nitrate testing procedures greatly reduced nitrate-leaching losses.

Routing subsurface drainage through well-designed wetlands removed most of the nitrates from the drainage water.

Basing nitrogen applications on soil testing is effective in reducing nitrate losses over a period of years. Post-harvest stalk nitrate analysis is also useful in determining if excess fertilizer nitrogen has been applied. Use of ridge-till systems and placement of fertilizer nitrogen in bands on ridge shoulders reduce nitrate leaching, especially when the soil is compacted over the fertilizer bands, which reduces infiltration into the bands. Regardless of field conditions and weather, nitrate leaching remains a problem in some parts of fields in certain years because of soil variability.

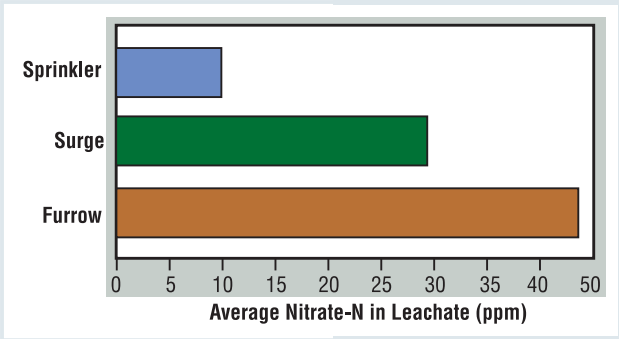


Figure 5. Nitrate nitrogen concentrations in soil water below the corn root zone for sprinkler, surge, and conventional furrow irrigation, averaged over two seasons.

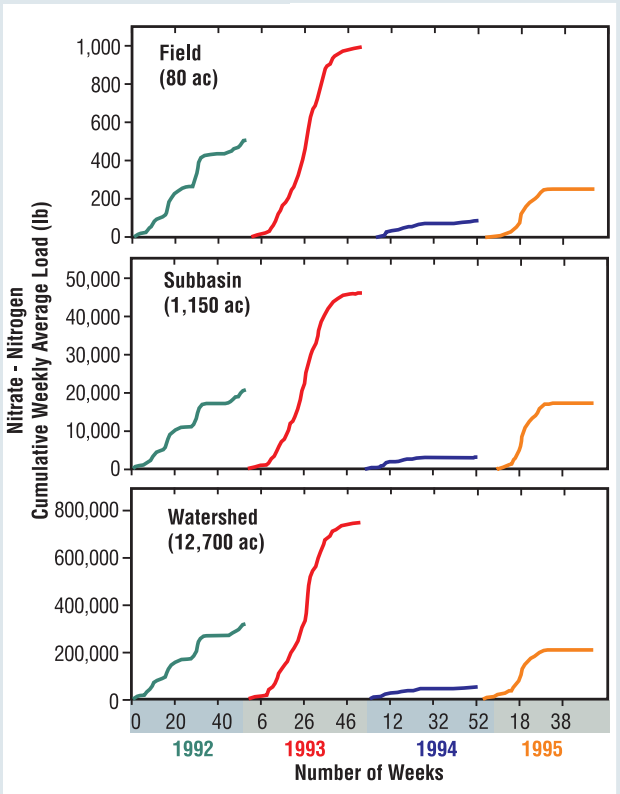


Figure 6. This figure illustrates how monitoring an individual field can reflect water quality on a sub-basin or entire watershed.

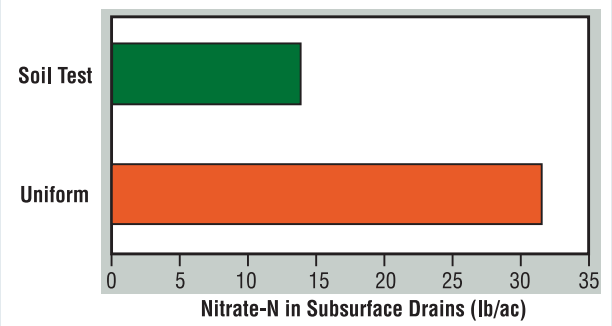


Figure 7. Nitrate nitrogen removed by subsurface drainage for three years of corn production in Iowa under two nitrogen management systems. "Soil test" refers to the amount of nitrogen that was applied based on late spring soil (nitrate) tests. "Uniform" refers to 100 lb nitrogen per acre applied to corn in all years at planting, regardless of soil test.

Nitrogen transformations in soils

Because of the variables that affect nitrogen mineralization, it is difficult to determine the exact amount of nitrogen fertilizer needed in the early season.

Although the concept of balancing the amount of nitrogen available to a crop with the amount of nitrogen needed by the crop is simple, achieving this goal is very complex (Figure 2). It is difficult to predict or control nitrogen mineralization. (Mineralization is the complex biological process by which crop residues such as straw and stalks, and organic matter are decomposed by soil microorganisms, resulting in natural production of nitrate.) Physical, chemical, and biological soil properties all affect nitrogen transformations in soil. In addition to soil properties, mineralization is affected by climate, which is impacted by temperature and moisture, and management (current and previous crops, tillage, residue management, and other practices). All of these factors vary which make it difficult to accurately predict, at planting, what their effects will be on mineralization several months later. Average amounts of nitrogen produced through mineralization are estimated in calculating fertilizer needs. Actual values in any given year, however, vary greatly.

Many interactions exist among factors influencing nitrogen transformation and movement in the soil, crop uptake of nitrogen, and potential leaching losses (Figure 8). These interactions are numerous, complex, and interrelated. Only through the use of computer simulation models has it been possible to quantify them. Existing simulation models, however, have major limitations. They are no better than the research data upon which they are based. The knowledge base must continue to be expanded if we are to develop reliable computer models that fit most cropping situations. At the MSEA sites, net results of interactions between soil properties, crop management practices, and weather varied greatly from year to year, or even month to month during the growing season. Because these interactions were site-specific, no single nitrogen management system worked for all situations. New knowledge from research data made it possible to mathematically model relationships between factors. MSEA results indicated that while existing models were useful in certain situations, they were inadequate in many respects. Suitable predictive models need to be perfected so that the numerous interactions that exist in a cropping system can be better quantified and understood. Some progress is being made toward this goal (Figure 9).

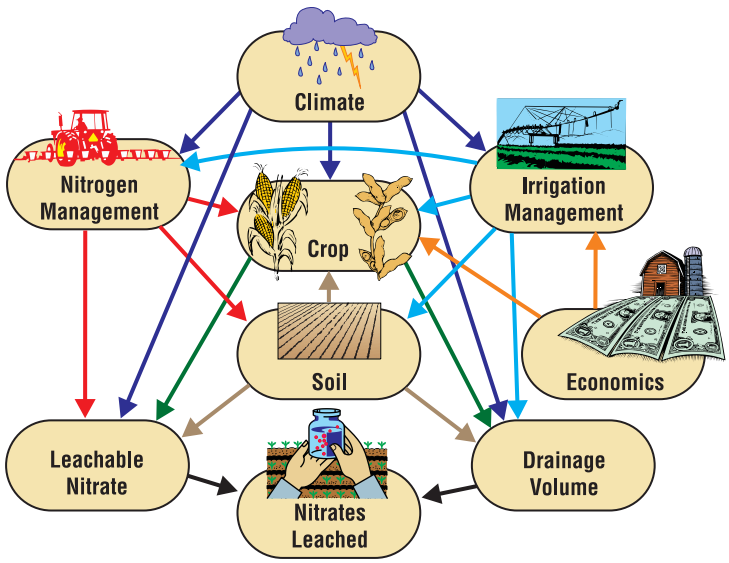


Figure 8. Factors that affect nitrate leaching in a cropped field. This diagram shows that few, if any, of these factors act independently. Numerous and complex interactions among the factors are common.

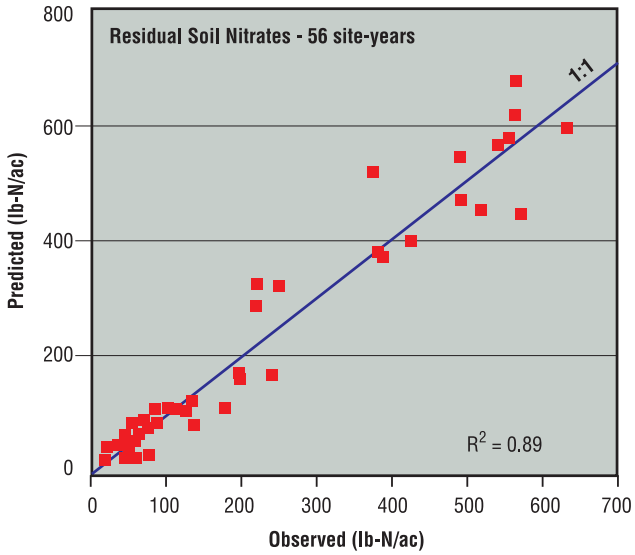


Figure 9. Measured residual soil nitrate nitrogen concentrations compared with those predicted by use of a computer simulation model.

Color of the growing crop

Results of MSEA research showed that plant greenness, as measured by a hand-held chlorophyll meter, can be used to determine whether the plant has sufficient available nitrogen to meet growth requirements for optimum yield. The greenness of a plant results, in part, from the amount of chlorophyll in its leaves. The chlorophyll molecule is where sunlight and carbon dioxide from the air are converted to plant material. Plant greenness indicates the general health of the plant and how rapidly it is growing. Research results also indicated that deficiencies in available nitrogen could be corrected in medium- and heavy-textured soils by adding nitrogen fertilizer before greenness declined below 95 percent of optimum. This finding implies that plant color can be used as a basis for supplemental nitrogen fertilization. The chlorophyll meter detects much smaller changes in plant greenness than can be seen by the human eye. A decrease in greenness of 5 percent, compared to that of a well-fertilized plant, results in decreased corn grain yields if not corrected. This can be done by applying 20 to 40 pounds of fertilizer nitrogen per acre, when the decrease is first detected.

Plant greenness can be used to determine whether the plant has sufficient available nitrogen. A hand-held chlorophyll meter is an effective tool to measure plant color.

These MSEA results show that by using plant color to integrate all factors that affect growth (soil properties, climate, management), the crop can serve as an integrator of the factors that affect crop nitrogen uptake. This can eliminate the need to predict the nitrogen requirement at planting time based on average growing conditions and final expected crop yield. Although other researchers have tried to use the crop as an integrator of growth factors, the MSEA approach was the first to develop a practical field technology for doing so. There are two limitations to the application of this technology: time requiements and field variablility may limit its widespread application in its present form, and use of the chlorophyll meter may be less reliable for very sandy soils. Perhaps the most important outcome of this research is that the results have led to the on-going development of technologies that are even more reliable and faster and easier to apply.

Crop nitrogen status and remote sensing

Although the hand-held chlorophyll meter adequately measured greenness of individual plants, it had problems in field-scale use. Because some areas of a field showed nitrogen deficiencies before others, it was difficult to know where to take chlorophyll meter readings without viewing the field from above. Once a deficiency was detected, prompt and adequate application of nitrogen fertilizer was needed before permanent yield reduction occurred. MSEA research developed inexpensive sensors that were mounted on a high-clearance sprayer with drop-nozzles to monitor crop greenness immediately ahead of the vehicle. The sensors could activate valves to turn fertilizer application on and off as needed while moving through a corn crop at any stage of growth (spoon-feeding or simulated fertigation). Liquid fertilizer could be side-dressed on ~160 acres per day, with sensors controlling the application so that only nitrogen deficient areas of the field were fertilized. On wet soils or in wet years, however, weather conditions sometimes restricted the number of days on which side-dressing was possible. The same sensors were used on a linear-drive sprinkler irrigation system to map crop nitrogen status. The sensor-based system would be expected to minimize nitrate leaching. This MSEA research provided new technology for use in precision (site-specific) farming.

Sensors mounted on sprinkler irrigation equipment or high clearance side dressing machines can monitor crop greenness, allowing for more precise nitrogen application, thereby minimizing leaching.

Techniques were also developed for using aerial photographs to assess crop greenness. Computer analysis of an aerial picture was used to generate a nitrogen stress map. Map data were coupled with global positioning system information on machine location within the field to automatically apply nitrogen fertilizer while driving through the field. The high-clearance sprayer with drop nozzles was able to sidedress nitrogen according to crop needs without the need for on-board greenness sensors.

Site-specific Farming

Each acre needs management based on the soil properties of that acre, rather than a field-average value. Precision (site-specific) farming allows each acre to be treated according to its needs.

Soil texture, thickness, nutrient status, and other properties often varied greatly within a field. Sandy soils were found within a few yards of clay soils; deep soils within a few yards of shallow soils. This variability affected soil fertility levels and final crop yields, as verified by intensive (grid) soil sampling and by crop yield maps. Basing fertilizer rates on average values for the field resulted in overfertilization of some areas and underfertilization of others. Likewise, the common practice of fertilizing at rates needed for the most infertile areas in the field resulted in excess fertilizer for other areas. This created potential for nitrate leaching (Figure 10). Each acre needs management based on the soil properties of that acre, not on a field-average value. The development of precision (site-specific) farming technology (variable rate application technology–VRAT) allowed each acre to be treated according to its needs. At several of the MSEA sites, scientists initiated VRAT research to develop the technologies needed for precision farming systems. An important part of VRAT research was the incorporation of remote sensing technologies into precision farming systems.

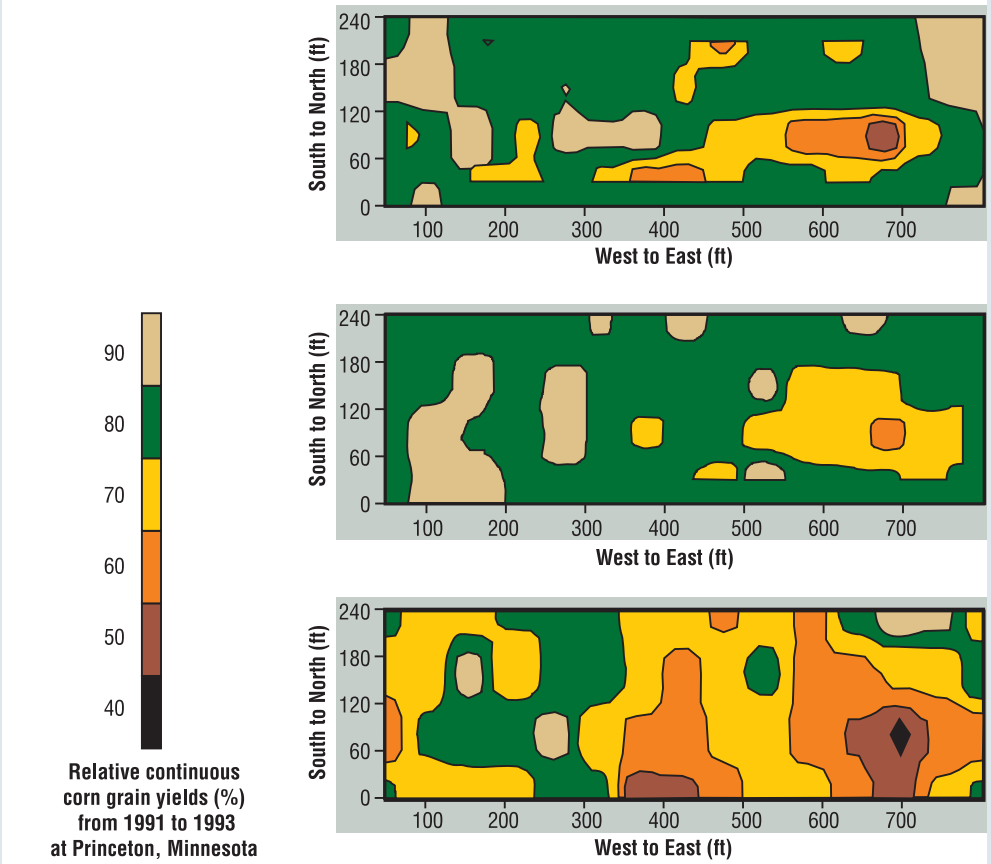
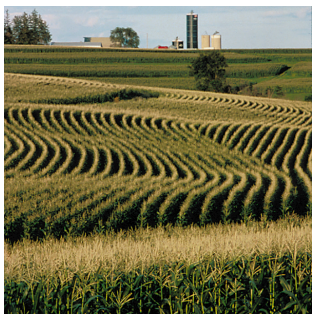


Figure 10. Contour maps of corn grain yield (percent of maximum) for three consecutive years in the same field. Each site in the field has inherent soil properties that interact with weather conditions in the crop year, creating unique growing environments for that site and year. Because crop yield is a major factor in regulating crop nitrogen uptake and quantity of nitrogen available for leaching, this changing yield pattern greatly complicates nitrogen management.

Cropping systems and tillage practices affected nitrogen availability and leaching

The art of good soil management lies in the ability to use cultural practices that maintain productivity and economic viability while protecting natural resources. Chief among these cultural practices are cropping systems (or rotations) and tillage practices. Results of MSEA research determined that, if properly managed, the corn–soybean cropping system, common in the Midwest, was an excellent system for environmental protection and maintenance of economic viability. Corn grain yields after soybean were usually greater than those under continuous corn. Also, only half as much nitrogen fertilizer was used because the soybean crop received no fertilizer nitrogen. The nitrogen fixed by the soybean crop and the rapid mineralization of nitrogen in soybean residues further reduced fertilizer nitrogen needed by the following corn crop. Soybean is an excellent scavenger for nitrogen compared with corn and can reduce the amount of nitrates in the soil after harvest. This reduces leaching potential (Figure 11). The corn-soybean rotation left the soil surface mellow and erodible after soybean harvest. This erosion potential was controlled by using reduced and no-tillage practices. These tillage systems left enough crop residue on the soil surface to control erosion, and often slowed down the rate of nitrification (but not the total quantity of nitrogen mineralized during the season), again reducing nitrate leaching potential.

Ridge-till was another reduced system used that was well suited to the corn–soybean rotation. The crops were grown on a ridge and crop residues were left on the soil surface for erosion control. At planting time, soil from the top of the ridge was moved into the furrow, leaving a clean but flattened ridge top suitable for planting and rapid crop emergence. Fertilizers were banded on the ridge to reduce potential for leaching.



The corn–soybean cropping system can be an excellent system for environmental protection and maintenance of economic viability. Nitrogen for the corn crop is supplied by the soybean crop and the residue.

Ridge-till is well suited to a corn-soybean rotation.

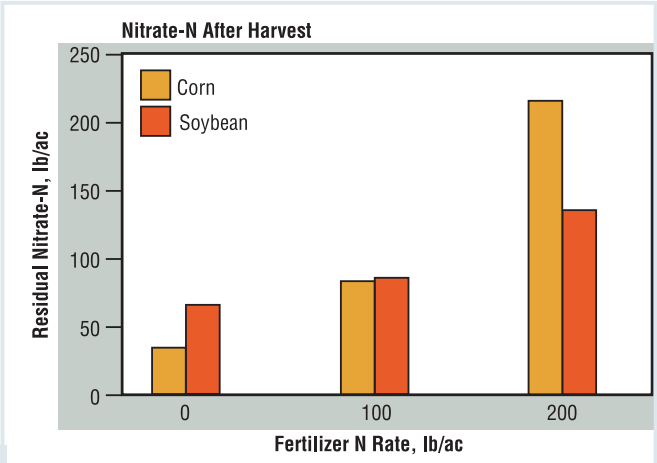


Figure 11. Residual nitrates remaining in the soil after harvest of a corn crop compared with those after harvest of a soybean crop in Nebraska. Soybean is very effective in scavenging the soil for nitrates, often reducing soil nitrates to low levels, thereby reducing leaching potential. Soybean is particularly effective in reducing the adverse effects of overfertilization of corn (200 lb/ac). Also, nitrogen fixation by the soybean and rapid mineralization of nitrogen in soybean residues reduce the amount of fertilizer nitrogen usually applied to the following corn crop.

Nitrogen management research needs to reach the right audience

Most producers are open to changes in their management systems as soon as they can overcome constraints of labor, capital, equipment, and management.

MSEA research programs have generated information with a practical bearing on nitrogen management technology. The ultimate success of any agricultural production research project is the incorporation of research results into crop production practices. Information targeted to a specific group (producer, supplier, advisor, regulator) is insufficient for a satisfactory adoption rate. Information must be simultaneously shared with a wide range of users. Experience has shown that management improvements are incremental and gradual. Most rural residents are sensitive to water quality concerns because they live on farms or in rural areas that are the first to be affected by water quality problems. Producers are willing to learn about useful, feasible technologies that can be adopted into their production systems. Most are open to changes in their management systems as soon as they can overcome constraints of labor, capital, equipment, and management. In the 1990s, the effectiveness of this approach was demonstrated in Nebraska when the Central Platte Valley, a multicounty area around the MSEA project, showed groundwater nitrate-nitrogen content decreasing by about 0.5 ppm each year, following an intensive educational program. In many MSEA areas, reduced tillage practices have increased rapidly in recent years due to ease of shifting to such practices and their positive effects on water quality.

Results obtained from MSEA research have pointed toward new technologies in nitrogen management for use by agricultural producers. MSEA results determined that fine-tuning current practices can help solve or reduce some present-day water quality problems. MSEA results also indicated that as the need for agricultural production increases, with a parallel requirement for more fertilizer nitrogen, the approaches used today will become inadequate. One of the major long-term benefits from the MSEA research projects was the realization that nitrogen fertilizer practices should be based on actual needs of the plant as it grows and matures. Nitrogen amounts should not be based only on the best estimate of crop needs at (or before) planting time. There is little probability of accurately predicting weather several months in advance to know how rapidly the crop will grow or how much soil nitrogen will mineralize. Additional development is needed of technologies that help the producer determine the nitrogen needs of the crop as it grows, and that facilitates fertilizer application on rainfed production during the period of rapid nitrogen uptake.

Nitrogen fertilizer practices should be based on actual needs of the plant as it grows and matures. They should not be based only on an estimate of crop needs at (or before) planting time.

Results of MSEA research showed that the greenness of the crop is a good indicator of the nitrogen status of the crop. Using this approach will require some changes in crop production practices and adoption of some precision farming techniques. A possible scenario may be that before planting, or when the crop is still small, producers would apply 50 to 75 percent of the anticipated nitrogen fertilizer required for optimum yield. As the season progresses, crop greenness would be monitored and, if growing conditions are relatively poor, additional fertilizer may not be added. If, however, there are good-to-exceptional growing conditions, whenever monitoring shows a significant decline in greenness, additional fertilizer nitrogen would be added at the time. By following this procedure, adequate but not excessive quantities of nitrogen would be applied, greatly reducing the likelihood of nitrate leaching while maintaining high yield potential.

A major impediment to this approach is that soils are seldom uniform across a field. Some areas in the field may show the need for additional nitrogen while others may not. In addition, sandy soils have less water-holding capacity (and nitrate-holding capacity), so this approach may not be as well adapted. Soil variability requires that we develop precision (site-specific) farming techniques to treat each area within a field more or less individually. MSEA results have led to research in this technology, but additional support is needed to make the technology a practical reality. For example, annual crop yield maps show that areas with relatively high yield one year may not be as productive the next year, while areas that are low-yielding one year can have much higher yields the next year. This phenomenon occurs because different and complex interactions exist between the weather and soil properties within a field at each stage of plant growth. Because some soil properties, as well as weather, vary from year to year, the impact of their interactions on soil nitrogen availability and crop growth also

Soil variability requires that we develop precision (site-specific) farming techniques to treat each area within a field more or less individually.

can vary from year to year. Knowledge of these interactions must be improved so that the combined effect of soils, weather, and farming practices can be predicted with greater accuracy. An additional problem with using crop appearance to monitor nitrogen needs is that in some years and on some soils, the soil is too wet when additional nitrogen is needed. This makes it difficult or impossible to move equipment through the field to apply the fertilizer.

Implementing change in the producer's mind is the first step in reducing the movement of nitrates into water resources. This can be achieved through renewed research and extension efforts to develop the needed technologies and show the producers why and how change can be achieved.

Future crop yields will need to increase greatly to provide the food and fiber needs of an expanding world population on shrinking agricultural production acreage. Fertilizer nitrogen application rates will also need to be increased. Adding more nitrogen to a biologically complex soil system requires new technologies to protect future water resources. Better integration is required of techniques and technologies for management of both nitrogen and water under the millions of combinations of soil, climate, and management systems that exist. Failure to do so means that nitrate leaching into water resources will continue to increase. MSEA results provided basic information with new concepts and advanced technologies. Precision or site-specific farming is one such technology that offers much promise (Figure 12). These technologies, however, are in their infancy and much more research and education is needed to develop them and make them useable by producers of food and fiber nationwide.

The real value of continued research using intense crop monitoring for improved nutrient use will be the adoption and implementation of these technologies which require a major educational effort. Through technology transfer, outreach, or extended education programs, the crop producer will understand the need for change in practices and know how new technologies can fit this need. Relevant, timely, applicable research must reach producers so they can begin to adjust crop inputs, plan for changes of field equipment, implement useful technologies, and realize the social and economic benefits of change. Implementing change in the grower's field is the ultimate solution to reducing the movement of nitrates through soil into water. Continued research and educational efforts will help develop the needed technologies and show producers why change is needed and how it can be reasonably achieved.

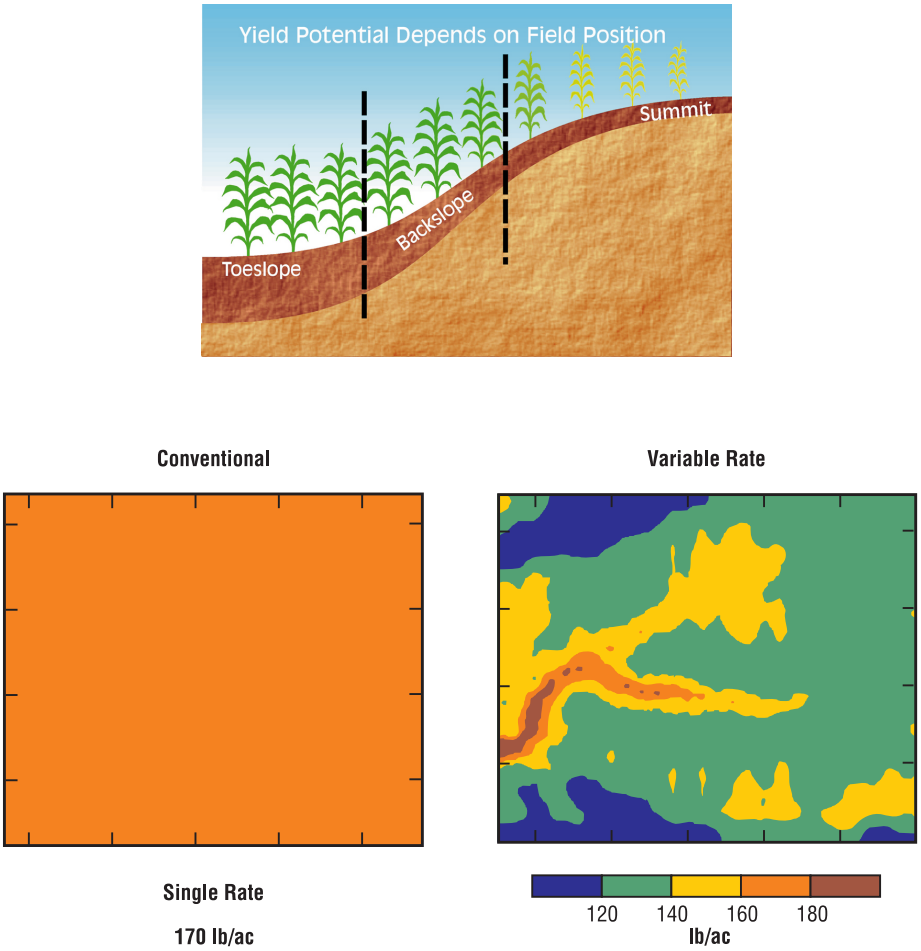


Figure 12. Nitrogen fertilization rates for corn are often determined using an expected yield value, adjusted for measured or expected inorganic nitrogen in the soil. MSEA research at the Missouri claypan soil site has shown that corn yield is closely related to depth of topsoil above the claypan soil horizon. An automated technique was developed for measuring topsoil depth using an electromagnetic induction sensor to measure soil electrical conductivity. Fields can be quickly surveyed using this method (15 to 20 ac/hr). Variable-rate N management is then used. The field on the left received a uniform 170 lb of N/ac. Using variable rate technology, nitrogen rates (right) vary from about 100 lb/ac where there is little or no topsoil up to about 200 lb/ac where topsoil is greater than 40 inches. Variable-rate N application reduced total nitrogen fertilizer use by 15 percent compared with the uniform rate. Results have found grain production to be similar between variable-rate and uniform-rate N management by using this technique on claypan soils.