

Concepts and Rationale for Regional Nitrogen Rate Guidelines for Corn



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Introduction

Nitrogen (N) is typically one of the largest corn fertilization expenses. Nitrogen application is critical because it significantly improves corn yield in many crop rotations. When choosing N rates, producers need to carefully consider both achieving most profitable economic return and advancing environmental stewardship.

In 2004, university agronomists from the Corn Belt states began discussions regarding N rate use for corn production. The reasons for the discussions centered on apparent differences in methods for determining N rates across states, misperceptions regarding N rate guidelines, and concerns about application rates as corn yields have climbed to historic

levels. An outcome of those discussions was an effort with the objectives to:

- develop N rate guidelines that could be applicable on a regional basis and
- identify the most profitable fertilizer N rates for corn production across the Corn Belt.

This publication provides an overview of corn N fertilization in regard to rate of application, investigates concepts for determining economic application rates, and describes a suggested regional approach for developing corn N rate guidelines directly from recent research data.



Definitions

CC—Corn following corn.

EONR—Economic optimum N rate; the point where the last increment of N returns a grain yield increase large enough to pay for that N.

MRTN—Maximum return to N; N rate where the economic net return to N application is greatest.

Maximum Yield—The yield where application of more N does not result in yield increase.

Net Return—The value of corn grain produced minus the N fertilization cost.

N Factor—The lb N per bu of corn; derived by dividing the optimum N rate by grain yield.

Price Ratio—The ratio of N fertilizer price to corn grain price (\$/lb:\$/bu).

SC—Corn following soybean.

Site—The land area occupied by an N rate trial; either replicated small plots in a specific field area or replicated field-length strips.

Site N Responsiveness—The corn grain yield increase with N application; nonresponsive indicates no yield increase with N application while high response indicates large yield increase from N application.

Yield Return—The value of corn grain produced due to N application.

Nitrogen and Corn Use

Brad Joern, Purdue University, and John Sawyer, Iowa State University

Corn is truly an amazing plant. Only 15 to 20 lb dry matter/acre is planted in the spring as seed, and in only four months, these seeds build an energy-capturing factory that produces nearly 20,000 pounds of dry matter/acre and generates 500 to 1,000 new seeds for each seed that was planted. While approximately 95 percent of this dry weight is in the form of carbon, hydrogen, and oxygen that come from air and water, 14 other essential mineral elements are needed in adequate supply to keep the corn factory up and running throughout the life cycle of the plant. Among these 14 mineral elements, N is generally the most limiting nutrient for corn production in the Corn Belt. This section describes how N accumulates during the growth and development of the corn plant and examines sources of N available for corn uptake.



Corn Growth, Development, and Nitrogen Accumulation

From emergence, it takes until about the four-leaf stage of growth for a corn plant to double its dry weight. During the next five to six weeks of growth prior to tasseling, 9,000 to 10,000 lb/acre of aboveground dry matter can be generated by a high-yielding corn crop. Between tasseling and physiological maturity, aboveground dry weight will double again (to a total of about 20,000 lb/acre), with roughly half of this aboveground weight in harvested grain (Figure 1).

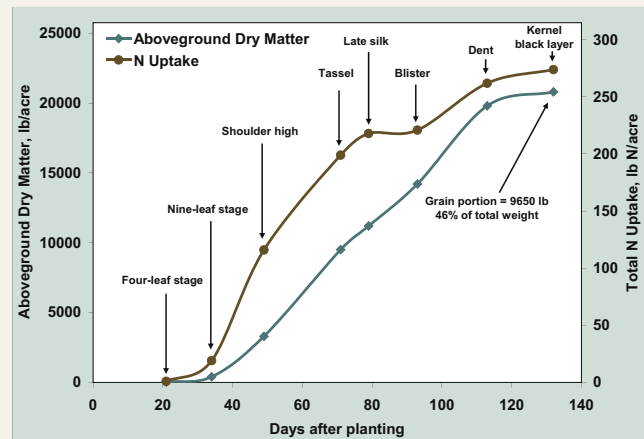


Figure 1. Corn aboveground dry matter accumulation and N uptake for a 204 bu/acre corn crop (Mengel, 1995).

While the growth and development of the aboveground portion of a corn plant is easily observed, it is the fibrous root system that transports from soil the water and the vast majority of mineral nutrients needed to complete the plant life cycle. The total length of the corn root system can reach 30,000–40,000 miles/acre. From planting through the blister kernel stage, root growth roughly parallels the growth of the aboveground portion. From that point on, roots begin to die off as the plant redirects nutrients and carbohydrates to developing kernels.

Corn accumulates only about 1 lb N/acre by the four-leaf growth stage. During the next six weeks of growth prior to tasseling, N accumulation approaches 60 to 70 percent of total N uptake (approximately 200 lb N/acre for a high-yielding corn crop). Nitrogen accumulation slows dramatically between silking and kernel blister and then increases again until the dent stage, as nutrients and carbohydrates are translocated from other parts of the plant to developing kernels during the final stages of grain fill. A maximum accumulation of approximately 275 lb N/acre is reached by physiological maturity for high-yielding corn. About half or more of this N will be in grain (Figures 1 and 2).

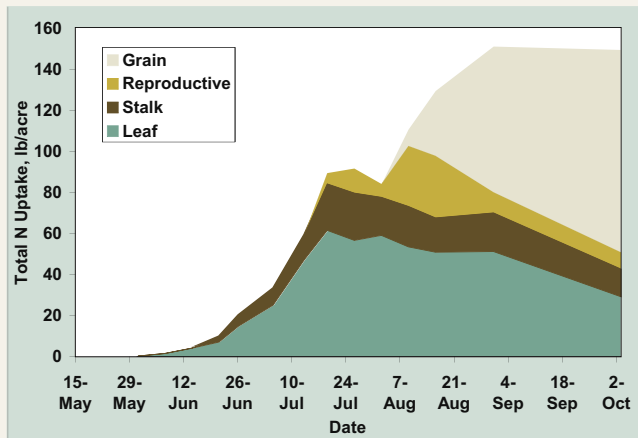


Figure 2. Corn aboveground N uptake and partitioning between plant components. (Data from Jim Schepers, USDA-ARS, Lincoln, Nebraska [personal communication]).

Nonfertilizer Sources of Nitrogen

If no N fertilizer or manure is applied to corn, yields will be low unless the soil already contains a high level of plant-available N. Without fertilizer N, corn yields in productive soils average about 55 percent of optimum yield in continuous corn (CC) and about 70 percent of optimum yield in a soybean-corn (SC) rotation (Table 1). If no fertilizer or manure is applied for several years and plant-available N becomes depleted, corn yield will average only 50 to 60 bu/acre in CC and 100 to 110 bu/acre in SC. So where does N that the plant takes up come from if we are not providing any fertilizer?

Table 1. Corn grain yield at the zero N rate as a fraction of yield at the EONR (0.10 price ratio).

State	CC	SC
	-----%-----	
Illinois	54	64
Iowa	45	75
Minnesota	60	76
Wisconsin	71	77
Mean*	56	70

*Total of 271 CC and 427 SC sites

Although precipitation may supply 5 to 20 lb N/acre annually and small amounts of N can be released from clay minerals, crop residues and soil organic matter are the major contributors of nonfertilizer N (Figure 3). Recently applied organic materials, including previous crop residues, make up the pool of organic N most available to microorganisms. Microbial conversion of this organic N to plant-available N, a process called N mineralization, can supply substantial amounts of N to a growing corn crop. In high-yielding corn, approximately 125 lb N/acre may remain in the 10,000 lb plant residue (including roots) that is not removed during harvest. This material has a high carbon to N ratio, and until the carbon is processed by microorganisms, N in plant residue will not be released in mineral forms (ammonium and nitrate) that plants can use. The length of time required for crop residue N to become available to corn depends on how fast microorganisms can break the residue down. Warm, moist, aerated, near-neutral pH soil conditions favor breakdown. When the previous crop is soybean, less crop residue remains after harvest, and because it has a lower carbon to N ratio, it is more easily degraded by microorganisms than corn residue. These are major reasons why Corn Belt states have lower corn N rate recommendations when soybean is the previous crop. Soil organic matter is more difficult for microorganisms to degrade than crop residue, with approximately 2 to 4 percent of soil organic matter broken down by microorganisms each year compared to 50 percent or more for recently added organic materials.

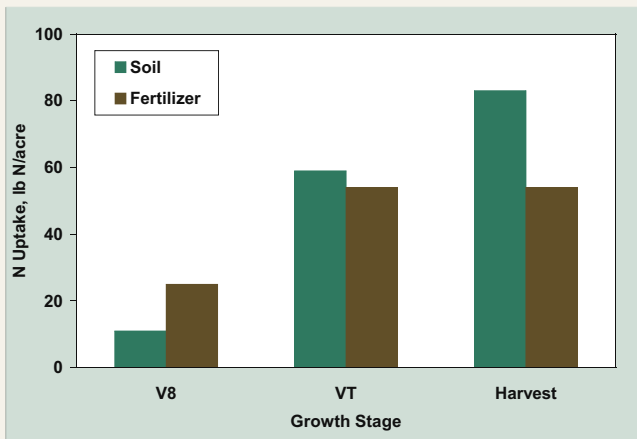


Figure 3. Aboveground plant N uptake from soil and applied fertilizer N (100 lb N/acre) at three corn growth stages in a SC rotation on a silt loam soil in south-central Illinois. Fertilizer depleted in ¹⁵N was applied in order to track N in the plant derived from the soil or fertilizer.

Role of Organic Matter and Crop Residues

The important role of organic matter breakdown to plant N availability can be illustrated with an example. Assume that a soil has 3.5 percent organic matter (3,500 lb N/acre) and that 100 lb N/acre is left in the field as crop residue. If 50 percent of the crop residue N is released as crop-available N (50 lb N/acre), 3 percent of the soil organic matter N is released (105 lb N/acre), and 10 lb N/acre is deposited via precipitation, then a total of 165 lb N/acre may be available to the crop from sources other than fertilizer. If grain yield is about 200 bu/acre, with total crop N uptake of 275 lb N/acre, then the crop will need 110 lb N/acre of supplemental N to obtain that yield. However, only about 55 to 65 percent of applied fertilizer N is taken up by a corn crop. Approximately 20 to 25 percent of applied fertilizer N will be incorporated into soil organic matter, with the other 15 to 20 percent lost via denitrification, nitrate leaching, ammonia volatilization, or uptake by weeds. If 60 percent of applied N is taken up by the crop, then an application of about 180 lb fertilizer

N per acre is required to supply the additional 110 lb supplemental N/acre needed by the crop. This example represents what may happen under good growing conditions on some soils.

If there are adverse conditions that negatively affect organic matter breakdown, then soil N supply is likely to be reduced. If organic matter mineralization in the above example is reduced by just 25 percent, 30 lb/acre less N will be available from the soil and an additional 50 lb of N (230 lb total) would need to be supplied as fertilizer. Excess moisture also can increase soil nitrate losses, which will further increase fertilizer N needs. Under more ideal conditions, increased organic matter breakdown can increase soil N supply. If organic matter mineralization in the example is increased by 25 percent, then more N becomes plant available (200 lb N/acre including precipitation) and less fertilizer N will need to be applied (125 lb N/acre) to grow the 200 bu/acre corn crop.

Organic matter mineralization varies across the Corn Belt. Moreover, within each state, there are differences among soils and within soils across years; the differences may vary due to current and previous crop and nutrient management practices and local environmental conditions during a growing season. This makes prediction of soil N contributions difficult. For these reasons, organic matter content of mineral soils is often not incorporated into fertilizer N recommendation systems. Rather, soil organic N contributions are accounted for through such factors as crop rotation and soil N testing. The uncertainty of N availability from nonfertilizer N, coupled with the high cost of N fertilizers and the need for increased environmental stewardship, necessitates evaluation of N fertilizer recommendation strategies.

Why Evaluate Corn Nitrogen Recommendation Systems?

Larry Bundy, University of Wisconsin–Madison



Nitrogen recommendations provided by land grant universities and extension services are receiving increasing scrutiny due to continuing concerns about the effects of agricultural N use on water quality. Specifically, N losses from agricultural systems have been identified as likely contributors to elevated groundwater nitrate concentrations and to Gulf of Mexico hypoxia. In addition, university N recommendations are being widely used as the technical criteria for nutrient management regulatory policy. These policies often view university recommendations as a vehicle for achieving environmental objectives, while the basis for developing the recommendations is usually economic. These issues, along with the need to provide producers with reasonable economic returns from N use in crop production, emphasize the importance for reliable, science-based N recommendations. This section will explore several concepts regarding N recommendation systems.

Historically, corn N recommendations were based on soil-specific criteria and/or on crop management variables such as rotation and manure application. For example, N recommendations for CC in Iowa (Voss, 1969) varied depending on

soil productivity and the geographic location of the soil. In Wisconsin, recommendations were based on relative soil yield potential determined from soil type information and producer management level (Walsh and Schulte, 1970). These recommendations were also adjusted for manure and previous crop N contributions.

Currently, yield-based N recommendations are used in most Corn Belt states. The widespread interest in and adoption of yield goal-based N recommendations in much of the United States was stimulated by Stanford's classic paper (Stanford, 1973). That work described a mass balance approach for assessing corn N fertilizer needs by considering N uptake at a specific dry matter yield level and N contributions from nonfertilizer sources. Stanford's approach was probably intended to provide an assessment of total crop N requirement rather than a process for making N recommendations. However, it identified corn N requirements on a per-unit-of-yield basis, and it was widely adopted for making yield-based N recommendations. The typical yield-based approach is to multiply a yield goal value by a lb N/bu factor (often 1.2 lb N/bu) to obtain a fertilizer N recommendation that can be adjusted for N contributions from other sources, such as manure, previous legume crops, soil nitrate, and soil organic N mineralization.

Recently, the yield-based approach to N recommendations has been questioned for the following reasons:

- poor relationship between recommendations and the *economic optimum N rate* (EONR) observed in N rate response trials (Figure 4),

- uncertainty about how yield goals should be determined,
- the assumption that N use efficiency is constant across sites and years, and
- use of inadequate or inappropriate adjustments for nonfertilizer N sources.

While there should not necessarily be an expectation for a yield-based rate recommendation to precisely match each site EONR, lack of such a relationship does raise questions about the approach. Poor performance of yield-based recommendations becomes particularly apparent when observed crop N fertilization needs at current high corn yield levels are substantially less than the yield-based N recommendations (Figure 4). That is, high corn yields are not indicative of high N fertilization need.

The lack of relationship between EONR and yield occurs for both CC and SC, and is found in states across the Corn Belt. While plant N requirement does increase with greater plant biomass production (and higher grain yield), variation in soil N supply disrupts the direct relationship between yield and fertilization need. The soil N supply (as measured by the fraction of yield when no N is applied) varies among sites and can be quite large (Table 1). These variations have an important influence on the magnitude of yield increase from N application (N response), shape of the response curve, and EONR (Figure 5). Another issue with the yield-based approach is use of a lb N/bu factor derived from CC for calculating N fertilization rates for SC. Instead of using an N factor derived from CC, a direct determination of optimal N rate should be made for corn in each rotation. This approach eliminates the need to estimate N factors and rotation credits and removes the confounding of yields with different rotations.

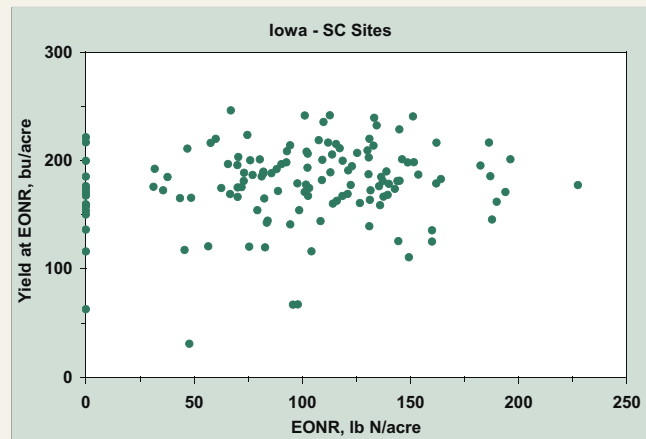


Figure 4. Example of the relationship between corn grain yield and EONR found in states across the Corn Belt. The graph is for SC sites in Iowa (0.10 price ratio). Points on the left axis represent sites where there was no response to N fertilizer rate.

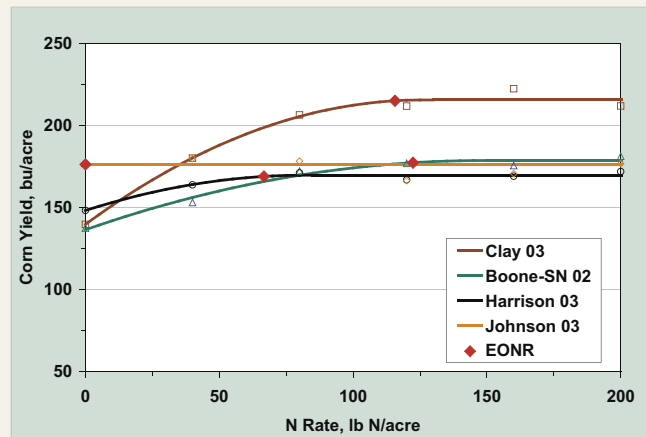


Figure 5. Types of responses found in N rate trials, with site examples showing corn yield increase with N application (EONR indicated at 0.10 price ratio).

Alternatives to yield-based N recommendations are in use in several states, and additional alternatives are explored in this publication. Nitrogen recommendations in Iowa are based on cropping system and results of a soil nitrate test (Blackmer et al., 1997). In Wisconsin, N recommendations were revised in 1990 using a soil-specific approach based on the results of numerous N response trials conducted on the major soils used for corn production. These recommendations recognize that corn yields can vary substantially from year to year on a given soil, and are consistent with results of N rate response trials that showed that EONR does vary,

but not with the yield attained. Both the rationale and approach used in developing the recommendations are described by Vanotti and Bundy (1994a; 1994b).

Obviously, average corn yields and yield potential of today's corn hybrids are greater than those seen in previous decades. It is not clear, however, that these higher yields translate into higher rates of N needed to optimize yields. Corn yield response data were examined from about 20 site-years in Wisconsin that were separated by 10 to 12 years in time. The results showed no clear indication that current optimum N rates are higher than those of 10 years ago. Further

investigation of this question using long-term data from two Iowa cropping systems studies allowed comparison of optimum N rates observed in a recent 10- to 12-year period with those from the preceding 10 to 12 years. These data showed that optimum N rates increased over time at one site and decreased at the other site. Again, the results provide no clear indication of a change in N rates over time. Potential reasons for similar or decreasing optimum N rates where yields have increased substantially include more efficient utilization of available N by the crop and increased soil N supplying capability.



Factors That Affect Suggested Fertilizer Nitrogen Rates

George Rehm, University of Minnesota

It would be highly desirable to have one N fertilizer rate to fit all production situations throughout the Corn Belt; however, the ability to change suggested rates to fit various production environments is well justified. Timing of application, climate, crop rotation, tillage system, and soil productivity are among major factors that can change rate suggestions. This section will explore factors that may affect N rates.

While N is mobile in soils and can be lost, there still can be flexibility in management practices for fertilizer N. With appropriate consideration for soil texture and potential for losses, N can be applied either before planting, sidedress, or as a split preplant-sidedress treatment. Nitrogen is used more efficiently if applied during the growing season prior to the time of maximum uptake rate, as compared to application before the crop is planted. There have been numerous studies to evaluate the effect of application timing on grain yield and N uptake. The results frequently lead to the conclusion that the rate suggested for optimum yield should not be adjusted for time of application. This could change as future N rate suggestions become more precise.

The influence of legumes in rotation on N fertilization requirements is widely recognized; the reduction in N fertilization rate when corn follows annual legumes (soybean) is less than when following perennials (alfalfa, clovers). Although rotation differences can also vary depending on local situations, it is important that legume effects be considered.

Because soil temperature has a substantial effect on N transformations in soils, the influence of tillage system is important as well. Reduced early-season soil temperatures frequently observed in no-till, strip-



till, and reduced-tillage management can delay or reduce residue breakdown, or mineralization, thereby reducing the N supplied from crop residue. A reduction in N supply from the soil system translates to the need for a higher rate of fertilizer N. In general, different N rate suggestions may be expected when no-till or limited tillage planting systems are used.

Finally, the productive potential of soils across a landscape is not uniform. Soils where productivity is limited frequently require higher rates of fertilizer N to reach optimum yield. These limits to productivity could be due to differences in soil texture, drainage, subsoil restrictions to root growth, or other factors. Conversely, lower rates of fertilizer N may be needed to reach optimum yield on highly productive soils. The N that is not supplied by fertilizer mostly originates from the mineralization of soil organic matter, which tends to be high in productive soils. The environmental conditions that contribute to high yields also help release N from soil organic matter. There might be other specific factors that can affect rate suggestions for fertilizer N use on corn in particular locations. These factors should be included in N rate guidelines when indicated by results from N response trials.

Risks Associated with Nitrogen Rate Decisions

Gyles Randall, University of Minnesota

Applying the proper rate of N for a crop is a major management decision corn producers make. Using too little N for a highly responsive crop such as corn results in lower yields, poorer grain quality, and reduced profits. When too much N is applied, corn yield and quality are generally not decreased, but profit is reduced and negative environmental consequences are likely to occur. This section will assess the risks associated with over- or underapplying N. Besides economic and environmental consequences described above, other psychological and social factors including perceptions by landlords and neighbors, tradition, and comfort level of the producer and fertilizer supplier also may play a role in determining the rate of N used by an individual producer.

The green coloration, light or dark, of a corn field throughout the growing season may affect neighbors' and landlords' perception of a corn producer's production ability. Thus, dark green corn is usually associated with excellent management and serves as a visual illustration of success and pride for the producer. Corn that shows light green to yellow colors early in the season may suggest improper N timing or placement. However, corn that begins to show a general light green color or N deficiency symptoms on the lower leaves late in the growing season suggests to most observers that an inadequate rate of N was used. In these cases, grain yields and profitability are assumed to have been limited. For landlords, less than uniformly dark green corn may suggest considering a different renter for next year. Overapplying N to keep the plant dark green until maturity is the simplest way to prevent this risk. However, research shows that some yellowing of corn late in the season usually results in greatest economic return and minimal nitrate carryover for potential loss to ground and surface water resources.



Tradition is another factor affecting a producer's N rate decision. If a producer has been applying a specific N rate for the last several years and has become satisfied with this rate, it is likely they will continue applying that same rate unless results from comparison trials on their farm suggest adjusting the N rate, or they are convinced by other research that their N rate may be too high. That is, the producer has developed a high comfort level with his/her traditional N rate even though it may be too high for maximum profit. In addition, the fertilizer supplier, who strives for season-long dark green corn and is dedicated to protecting producers from yield loss, also has a greater comfort level with applying traditional N rates.

However, many studies have shown that the amount of nitrate leached toward groundwater or subsurface drainage water increases as the rate of applied N increases. The research has also shown that profitability decreases once the EONR has been exceeded. A five-year CC study conducted on a silt loam soil in southeastern Minnesota provides a vivid example of how profitability and protecting the environment can be balanced by using the proper N rate (Table 2). In this study, economic return to fertilizer N was greatest at the 150-lb N rate. Exceeding this N rate by 75 pounds reduced profitability by \$27/acre and almost doubled the nitrate-N concentration in water percolating through the soil below the root zone at the end of five years. The EONR at this site was determined to be 140 lb N/acre. The nitrate-N concentration in the leachate would likely have been about 15 mg/L with a 140 lb N/acre rate.

A three-year SC rotation study on a glacial till soil in south-central Minnesota, clearly demonstrates the influence of N rate as anhydrous ammonia on corn yield, profitability, and nitrate loss to subsurface

drainage (Table 3). Economic return to the fertilizer was optimized at the 160-lb N rate (\$74/acre) when applied in the fall, and at the 120-lb N rate (\$100/acre) when preplant applied in the spring. Moreover, nitrate-N concentrations in the tile drainage were 28 percent greater for the 160 than for the 120-lb N rate. These data suggest the importance of selecting both the proper N rate and time of N application when maximizing profitability and minimizing nitrate loss to the environment, thus reducing risk for both the producer and society.

Table 2. Five-year average corn yield with CC, economic return to fertilizer N, and nitrate-N concentration in soil water at 7.5 ft in November at the end of the study on a silt loam soil in southeastern Minnesota.

Annual N Rate	Grain Yield	Economic* Return to Fertilizer N	Nitrate-N in Soil Water at 7.5 ft
lb/acre	bu/acre	\$/acre	mg/L
0	82	—	2
75	141	95	4
150	168	130	17
225	164	103	32

*Corn = \$2.00/bu; N = \$0.25/lb; application = \$4.00/acre

Table 3. Three-year average corn yield, economic return to fertilizer N, and nitrate-N concentration in subsurface tile drainage water for a SC rotation in Minnesota.

Annual N Treatment			Grain Yield	Economic* Return to Fertilizer N	Nitrate-N Concentration in Tile Water
Rate	Time	N-Serve			
lb/acre			bu/acre	\$/acre	mg/L
0	—	—	106	—	ND**
80	Fall	Yes	135	26	16
120	Fall	Yes	160	66	18
160	Fall	Yes	169	74	23
120	Spring	No	175	100	ND

*Corn = \$2.00/bu; fall N = \$0.25/lb; spring N = \$0.28/lb; N-serve = \$8.00/A; application = \$4.00/acre

**ND = not determined

Regional Approach to Corn Nitrogen Rate Guidelines

John Sawyer, Iowa State University, and Emerson Nafziger, University of Illinois



Measurement of grain yield response in N rate trials has been the historical basis for determination of corn N fertilization requirements. Analysis and economic interpretation of response trial data provide the foundation for guidance on profitable N application rates. This general approach continues today. Research trials provide information about past and current responses, while guidelines developed from such responses direct action into the future. The value of N rate trials is to provide the information required for assisting rate decisions at some level of future response expectation. One example is different N rate recommendations with various previous crops. For instance, corn N fertilization need is smaller when corn follows forage legumes or soybean than when corn follows corn. Guidance for N rates has previously been developed through research and scientific judgment within state boundaries, with land grant universities or extension services publishing suggestions for corn N fertilization.

This section will analyze recent N response trials from several states, with the goal of developing a regional approach to N rate guidelines. The goal is

not necessarily to develop the same suggested N rates across states or regions. Since corn production crosses state lines, regional guidelines could be more meaningful. However, similar guidelines will result only if data from response trials are in sufficient agreement and indicate that similar approaches are appropriate.

Analysis of Data from Nitrogen Response Trials

The overall goal of conducting N rate trials is to find the point where the value from grain yield increase by adding more N just matches the cost of that added N. This is the EONR. For a typical corn yield response curve to different N rates, the curve rises slower and slower as N rate increases until it reaches a plateau with no more yield response to increasing N. Typically, the EONR is less than the N rate at which yield levels off or reaches a maximum. How far less than the maximum depends on the cost of N and the price of corn grain; the more expensive N is, the more yield it takes to pay for the last pound of N, and so the lower the EONR. When the corn price increases, the EONR increases because the value of the corn pays for a higher rate of N.

Nitrogen responses vary widely across fields and years, and are affected by factors such as soil type and weather. How can a set of varying responses be turned into N rate recommendations? Several methods can be used to evaluate N response data, and many will provide similar results. The method selected, along with the associated N rate guidance, should be one that utilizes economic analysis, results in reasonable N rates, provides high net return, and is understandable by producers and crop advisers. Additionally, the method should have straightforward calculations, be easy to implement, and be capable of analysis across a database of N response trials. It is important to have a large number of sites so there is adequate representation across a range of possible corn N responses.

Of the various methods available for evaluating N response data, the *maximum return to N* (MRTN) approach outlined by Nafziger et al. (2004) is attractive for the following reasons:

1. Data can be utilized from a large number and variety of N response trials, and new trials can be easily added to the analysis.
2. Specific responses of each site are considered in the determination of optimum N and net return rather than average response.
3. A representative number of nonresponsive sites does not excessively influence optimum N rate and net return.
4. Site data can be grouped according to criteria that indicate differing N response.
5. Risk assessment can be included.

6. Calculations are straightforward and likely economic outcomes at different N rates can be easily determined with different N and corn prices.

These advantages help bridge the gap between research and practical N rate guidelines.

Regional Guideline Approach

Having a common approach to corn N rate guidelines across the Corn Belt has several benefits. Similarity across states will increase as differences in philosophy, data analysis technique, or method of guideline presentation are eliminated. This will reduce skepticism about guidelines. Government programs that cross state boundaries may become easier to implement. Nitrogen rate guidance can be more uniform within geographically similar soil and climatic conditions. Nitrogen response data can be shared and compared more easily when a common approach is used. Finally, as new N rate response data are accumulated, they can easily be integrated into databases and analyses, and thus more quickly and uniformly influence rate guidelines.

It must be recognized that rate guidelines developed from analysis of trials conducted across a wide geography will be general in nature. Those guidelines reflect the research data and provide insight into general fertilizer N needs. However, they cannot predict site-specific N requirements, and they are unlikely to provide an accurate estimate of the optimum N rate needed in each specific environment. It is well documented that optimum N rate varies among sites and years within sites (Figure 5, 6, and 7). *Nevertheless, guidelines should provide an N rate that reflects economic value and probability of achieving expected economic return across a range of locations and period of time.* The MRTN approach provides both the above-mentioned benefits and allows analysis across a range of N response trials.

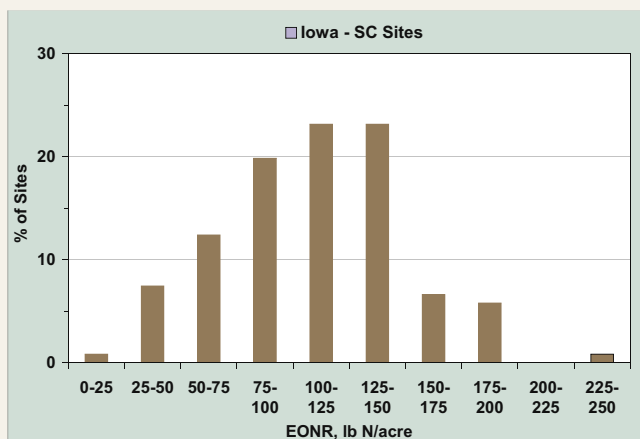


Figure 6. Frequency distribution of EONR (0.10 price ratio) for SC sites in Iowa.

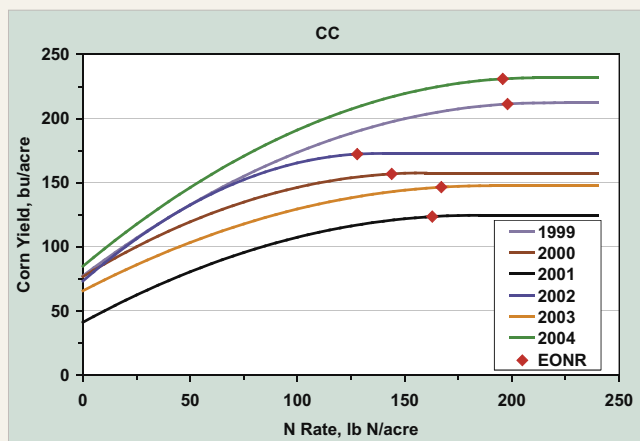
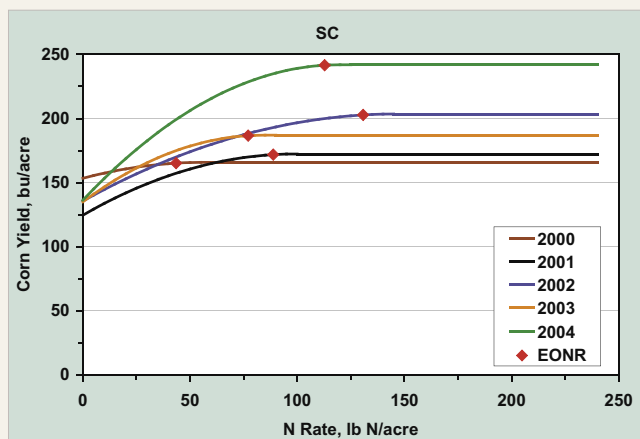


Figure 7. Variation in EONR (0.10 price ratio) and corn yield in different years for SC (top) and CC (bottom) at the same site location, Ames, Iowa.

Steps in Calculation of MRTN

Step 1. Yield data are collected at replicated N rates from many N rate trials.

Step 2. The shape of the N response is observed for each trial to find out if the response is flat (no response), the yield at zero N, how fast yield increased as N rate increased, and the point at which yield leveled off where additional N provided no further yield increase (Figure 5).

Step 3. A computer program is used to fit a line to the yield points for each site to show the shape of the response as well as to provide a mathematical equation of that line (“curve-fitting”).

Step 4. The set of site response curves is accumulated for corn in different rotations. This set of curves represents a population of N rate responses, and with an appropriate number of sites, represents the potential responses that might occur in fields in the future.

Step 5. For each site, several values are calculated from the response curve equation at 1-lb N rate increments from zero to 240 lb N/acre: yield increase (above the yield at zero N), gross dollar return at that yield increase (corn grain price times yield), fertilizer cost (N price times rate), and net return to N (gross return minus N cost) (Figure 8). Economic values are calculated from specified N fertilizer and corn prices.

Step 6. For each N rate, net return is averaged across all sites in the dataset for each specific rotation.

Step 7. The N rate with the largest average net return to N is the MRTN rate (Figure 8). Nitrogen rates with net return within \$1.00/acre of the MRTN provide a range of N rates with similar profitability. Net return will vary depending upon specific N and corn prices, but the MRTN rate remains constant when the ratio of these prices (\$/lb:\$/bu) stays the same.

The MRTN approach uses economic return to N application found in research trials as the basis for suggested N rate. The average of N responses accumulated from a population of N rate trial sites is used to estimate the point of MRTN. The net return is the increase in yield times the grain price at a particular N rate, minus the cost of that amount of N fertilizer (Figure 8). The maximum return is the N rate, where net return is greatest. Both corn price and N cost affect the return to N, and it is their ratio that directly influences the net return and point of maximum return.

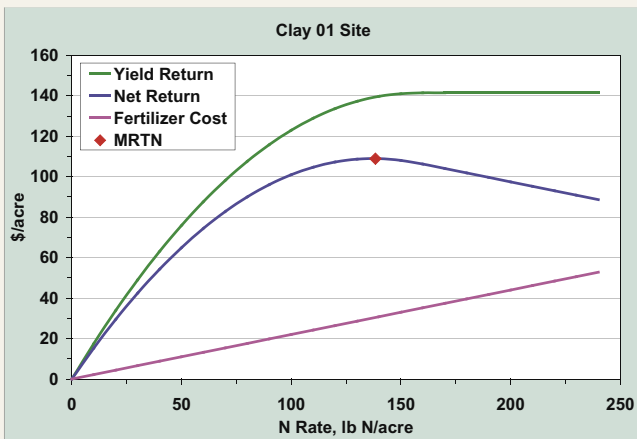


Figure 8. Corn grain yield and fertilizer economic components of calculated net return across N rates; example SC site with MRTN indicated at 0.10 price ratio (N price \$0.22/lb N and corn price \$2.20/bu).



The MRTN was evaluated as a potential regional approach to N rate guidelines. Nitrogen response data were assembled from 698 trials conducted from 1983 to 2004 (with most after the mid-1990s) in Illinois, Iowa, Michigan, Minnesota, Ohio, and Wisconsin (Figure 9). All sites in the database were nonirrigated and had either spring preplant or sidedress fertilizer N application. Data were accumulated for CC and SC. There were 93 CC and 185 SC trial sites in Illinois, 60 CC and 136 SC sites in Iowa, 73 CC and 55 SC sites in Minnesota, and 39 CC and 34 SC sites in Wisconsin. These sites represent a sampling or population of corn N responses. The number of sites from Michigan and Ohio was too small for analysis by state, and therefore results are not presented. Grain yield response to N rate was analyzed for each site and then accumulated into a database.

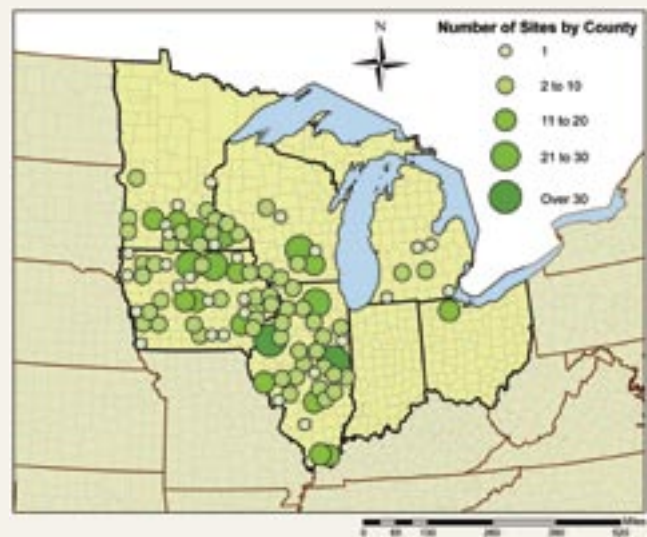


Figure 9. Regional N rate database map indicating the geographic distribution of N response trial sites.

Datasets for SC and CC from Illinois, Iowa, Minnesota, and Wisconsin were analyzed using four N:corn grain price ratios (\$/lb:\$/bu). The price of corn was held constant at \$2.20/bu and the N price was varied from \$0.11, \$0.22, \$0.33, to \$0.44/lb N to give ratios of 0.05, 0.10, 0.15, and 0.20, respectively. Analysis included only responsive sites. Inclusion of nonresponsive sites had little influence on the

MRTN rate (average of 4 lb N/acre lower for SC and 5 lb N/acre lower for CC at a 0.10 price ratio for the multi-state database). If desired, nonresponsive sites can be included in the analysis. However, many nonresponsive sites are fields that have characteristics that result in quite different response to N.

Increasing the N price relative to corn price decreases both net return and the N rate at the point of maximum return (Tables 4 and 5, and Figures 10 and 11). Large yield responses to N often occur when yields without N fertilizer are low, which produces large net returns (that is, there is larger net return with CC compared to SC due to greater yield increase from added N for CC). Differences in N rate at MRTN

vary among states. For example, the N rate at MRTN is quite similar for the Minnesota and Wisconsin SC and CC databases, and for the Iowa and Illinois CC databases. For the SC database, N rate at MRTN is greatest for Illinois, intermediate for Iowa, and lowest for Minnesota and Wisconsin.

An interesting result of the MRTN analysis is that the net return to N is fairly flat at rates that surround the point of maximum net return. Thus, a range of N rates above and below the MRTN rate that produces a return to N within \$1.00/acre of the MRTN can be used to provide guidance for selecting a profitable N rate (LOW to HIGH rates in Tables 4 and 5). This range of similar profitability along with the effect

Table 4. For SC, the MRTN and profitable N rate range within \$1.00/acre of the maximum return for several N:corn grain price ratios (nonresponsive sites not included).

Price Ratio*	MRTN			LOW**		HIGH**	
	N Rate	Net	Yield	N Rate	Yield	N Rate	Yield
\$/lb:\$/bu	lb N/acre	\$/acre	bu/acre	lb N/acre	bu/acre	lb N/acre	bu/acre
Illinois							
0.05	197	130.62	177	170	175	221	178
0.10	163	110.98	174	143	172	186	176
0.15	141	94.30	172	122	168	161	174
0.20	122	79.86	168	106	165	140	172
Iowa							
0.05	145	96.65	180	126	179	170	181
0.10	123	81.78	179	107	176	144	180
0.15	109	69.05	177	93	174	125	179
0.20	95	57.80	174	82	171	111	177
Minnesota							
0.05	120	77.96	161	101	159	142	161
0.10	101	65.86	159	86	157	119	161
0.15	90	55.46	158	76	155	103	160
0.20	80	46.20	156	68	153	93	158
Wisconsin							
0.05	138	80.51	171	117	170	168	172
0.10	107	66.87	169	98	167	133	171
0.15	101	55.22	168	91	166	114	169
0.20	95	44.28	167	79	163	107	169

*Corn grain price held constant at \$2.20/bu; N prices at \$0.11, \$0.22, \$0.33, and \$0.44/lb N.

**LOW and HIGH approximates the range within \$1.00/acre of the MRTN for each price ratio.

of N:corn price ratio can be used to define a range of suggested N rates. *The flat net return surrounding the N rate at MRTN reflects the small yield change near optimum N (Tables 4 and 5, and Figures 5 and 8) and indicates that choice of a specific rate within this general range is not critical.*

The fact that the data used to develop these guidelines are from a wide variety of trials should give producers confidence that N applications based on MRTN will provide adequate yield across variable production conditions. Also, because of the small yield change, rates at the lower end of the N rate ranges will produce greater N use efficiency (more bushels per lb N) than will rates at the high

end of the range. Rates at the low end of the MRTN range may be more appropriate for soils with lower productivity potential, while rates at the high end of the range may be more appropriate for soils without yield-limiting factors and where greater production and external risks exist for producers.

For the Iowa SC and CC databases, the calculated ranges around the MRTN at the 0.10 price ratio are quite similar to previously suggested N rate ranges for Iowa SC (100–150 lb N/acre) and CC (150–200 lb N/acre) rotations (Voss and Shrader, 1979). Table 6 gives an example of how N rate guidelines might look for SC and CC in Iowa based on MRTN, and ranges for different price ratios.

Table 5. For CC, the MRTN and profitable N rate range within \$1.00/acre of the maximum return for several N:corn grain price ratios (nonresponsive sites not included).

Price Ratio*	MRTN			LOW**		HIGH**	
	N Rate	Net	Yield	N Rate	Yield	N Rate	Yield
\$/lb:\$/bu	lb N/acre	\$/acre	bu/acre	lb N/acre	bu/acre	lb N/acre	bu/acre
Illinois							
0.05	213	156.32	154	184	152	239	155
0.10	176	135.19	152	156	149	199	154
0.15	154	117.08	149	136	146	174	151
0.20	137	101.09	146	122	142	154	149
Iowa							
0.05	200	158.98	144	179	142	234	145
0.10	174	138.36	142	153	139	196	143
0.15	152	120.53	139	138	136	171	141
0.20	140	104.34	137	125	133	156	139
Minnesota							
0.05	148	129.66	153	133	151	168	153
0.10	136	114.09	152	123	150	150	153
0.15	126	99.69	151	114	148	139	152
0.20	118	86.23	149	103	146	131	151
Wisconsin							
0.05	165	105.61	165	140	164	197	166
0.10	139	89.21	164	124	162	157	165
0.15	127	74.62	162	111	159	141	164
0.20	112	61.38	159	97	156	129	162

*Corn grain price held constant at \$2.20/bu; N prices at \$0.11, \$0.22, \$0.33, and \$0.44/lb N.

**LOW and HIGH approximates the range within \$1.00/acre of the MRTN for each price ratio.

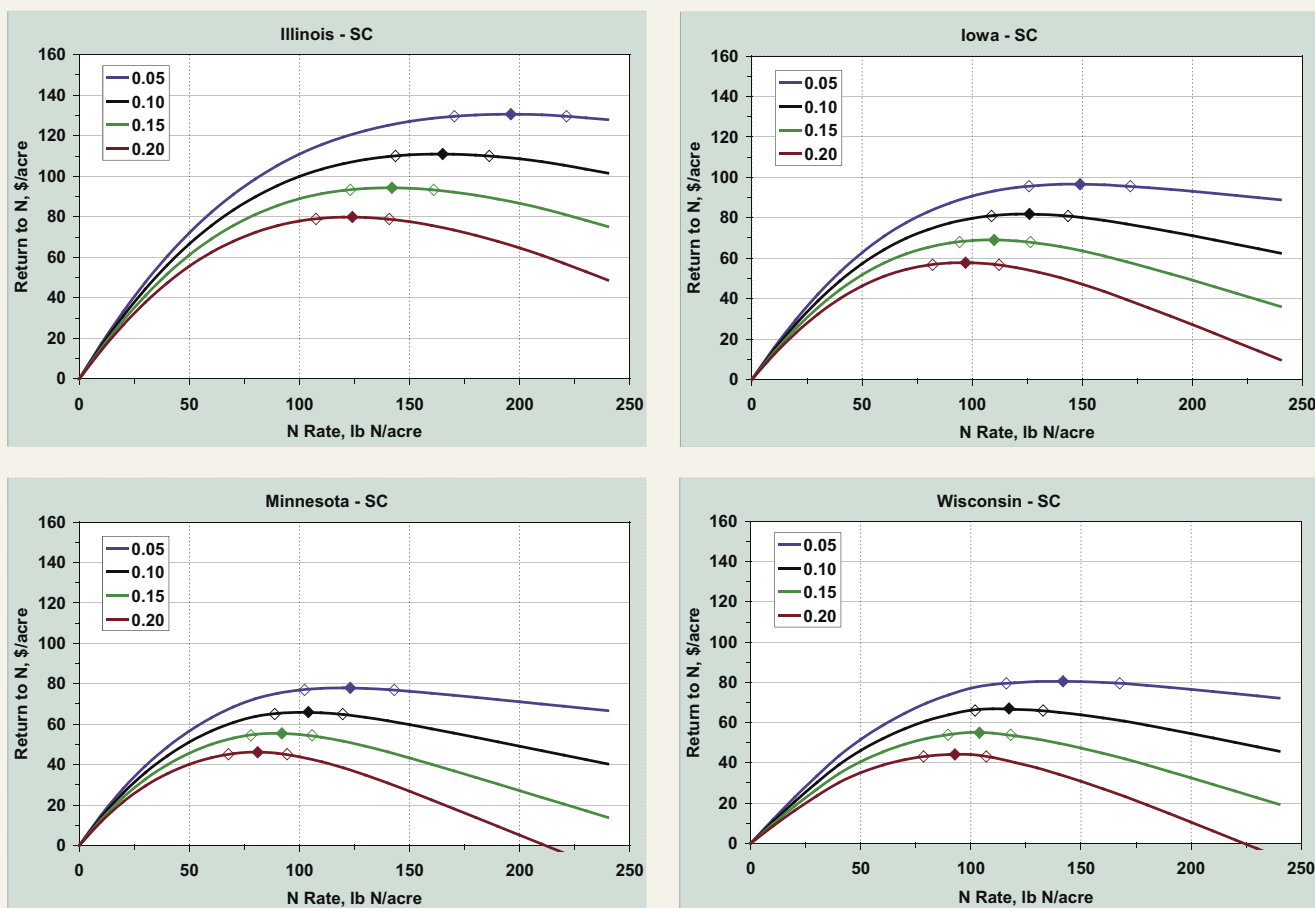


Figure 10. For SC, net return to N and effect of fertilizer N:corn grain price ratio. The symbols correspond to the MRTN and profitable LOW to HIGH N rate range given in Table 4.

Table 6. Example N rate fertilization guidelines for SC and CC in Iowa based on N:corn grain price ratios and economic return calculated by the MRTN approach.

Price Ratio	SC			CC		
	LOW*	MRTN	HIGH*	LOW*	MRTN	HIGH*
\$/lb:\$/bu	----- lb N/acre -----					
0.05	125	145	170	180	200	230
0.10	105	125	145	155	175	195
0.15	90	110	125	140	155	170
0.20	80	95	110	125	140	155

*LOW and HIGH approximates the profitable N rate range providing net return within \$1.00/acre of the MRTN for each price ratio.

While the analysis used each state's entire database, subsets can be created to determine if site-conditions, management history, or regions within or across states should have the same or different rate guidelines. For example, the MRTN is slightly lower for SC in northern Illinois (163 lb N/acre) than in southern Illinois (179 lb N/acre). Rate guidelines thus might be adjusted for different regions within a state. In another example, data for Iowa SC sites show similar MRTN rate when grouped into various yield ranges (128 lb N/acre for 0–150 bu/acre, 126 lb N/acre for 150–200 bu/acre, and 127 lb N/acre for 200+ bu/acre). In this case, since the MRTN rate is similar across the wide range in yield, N rate adjustment is not needed based on yield level. Similar analyses can be applied to other rotations such as first- or second-year corn following forage legume, if an adequate number of trials is available.

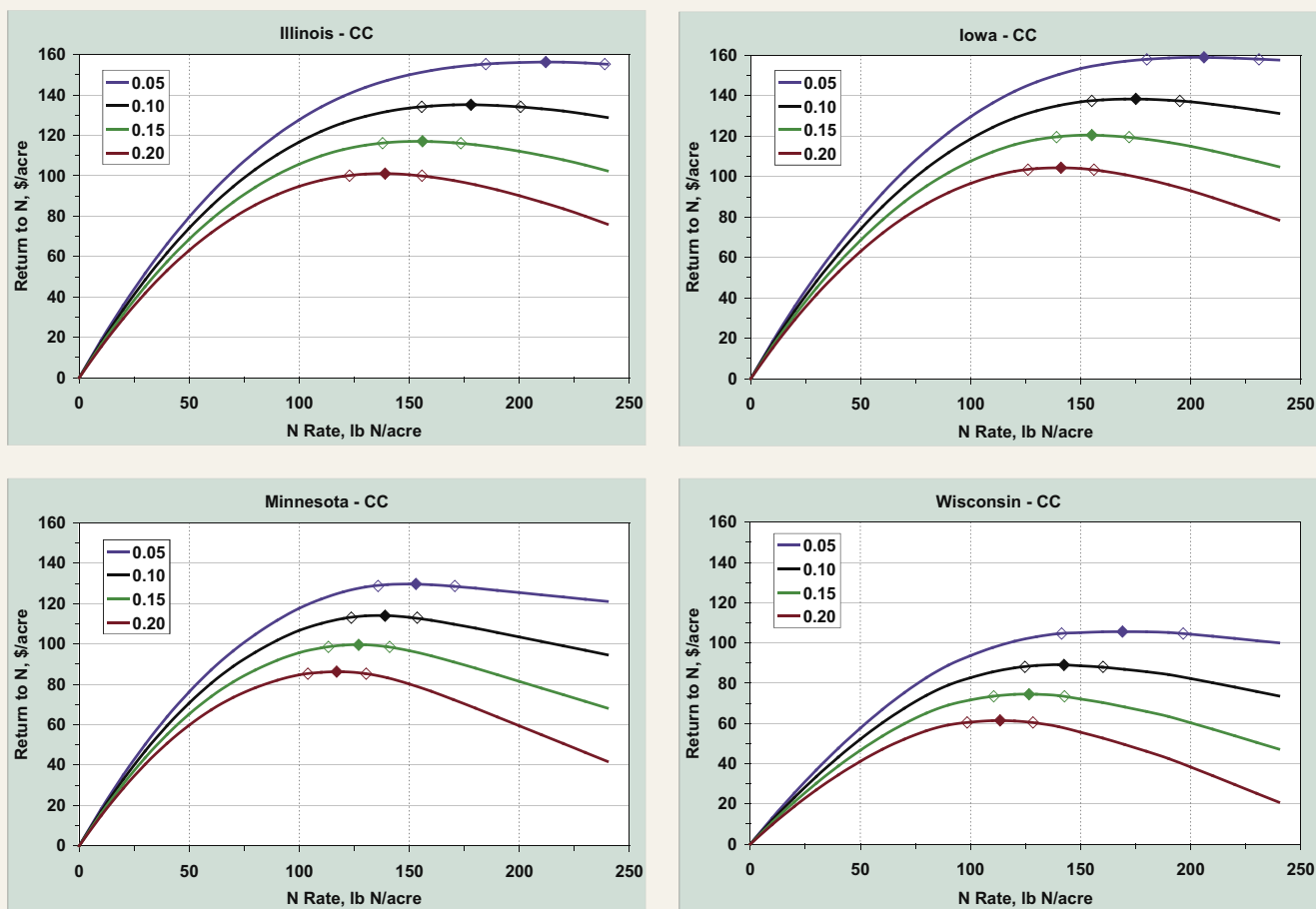


Figure 11. For CC, net return to N and effect of fertilizer N:corn grain price ratio. The symbols correspond to the MRTN and profitable LOW to HIGH N rate range given in Table 5.

Uncertainty does exist in regard to expectation of having sufficient N to meet crop N needs in any given year. Producer concerns have centered on the potential for severe yield and economic losses associated with deficient N, as shown in Figures 10 and 11 at low N rates. In the past, and with inexpensive N relative to corn, this uncertainty sometimes led to high N application rates. When N is relatively inexpensive, rates well above the MRTN result in a minor decline in net return (Tables 4 and 5, and Figures 10 and 11). However, as N becomes more expensive relative to corn, N application rates much higher than the MRTN result in significant economic losses. Therefore, the use of high N rates to ensure high yield should be reconsidered as this strategy will not provide the greatest economic return

to N application. Additionally, application above economic rates leads to increased nitrate reaching water systems, which carries an environmental cost.

To help understand the uncertainty associated with choice of a particular N rate, percent of maximum grain yield can be calculated for each rate guideline and price ratio (Figures 12 and 13). These values are based on the yield response among all N rate trials in the database and provide an expectation that a given N rate will provide a certain level of potential productivity. Individuals can use risk tolerance in regard to corn production and decisions about enterprise capital allocation to either refine chosen rates, or increase confidence that chosen rates will provide the level of N supply desired.

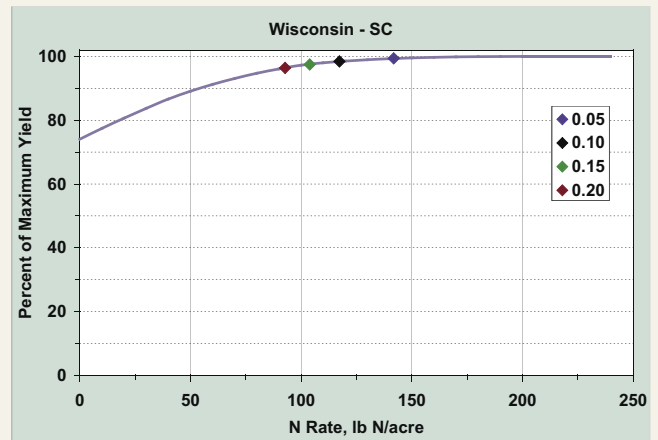
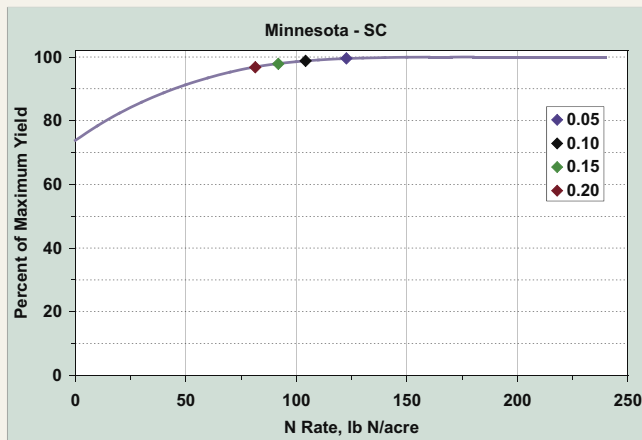
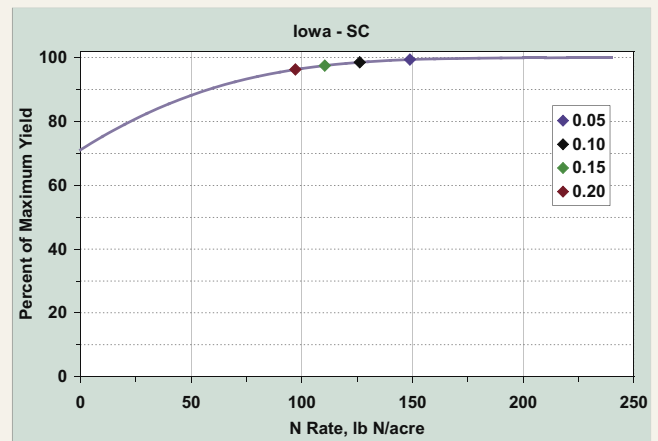
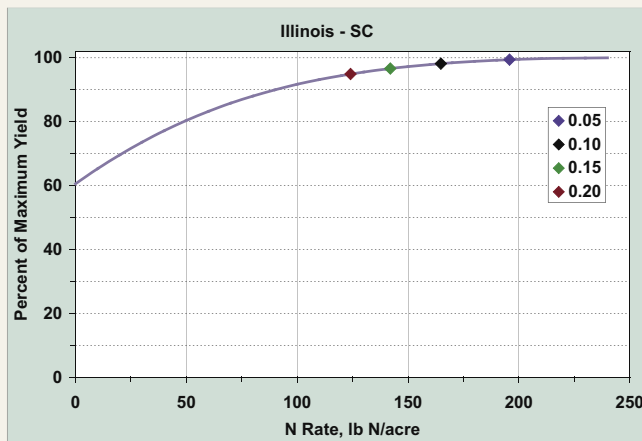


Figure 12. For SC, the percent of maximum yield across N rates. The symbols correspond to the MRTN rate for the fertilizer N:corn grain price ratios given in Table 4.

Producers are often concerned that a suggested N rate will not produce an adequate crop if that rate is determined from an “average response,” or is based on economic rather than on “maximum-yield” goals. However, choice of a rate within the profitable range surrounding the MRTN minimizes the net loss for over- and underapplication, both in regard to frequency of occurrence and magnitude of economic loss. While it may seem logical or desirable to have N sufficiency near 100 percent, with little to no risk of N deficiency, producers cannot afford to apply N at rates providing that level of sufficiency (Figures 10 and 11). An attempt to meet the N requirement of the few most responsive sites by using a high rate across all sites does not result in enough potential yield gain to pay for that N rate. In addition,

yield in exceptionally good corn production years is not compromised with N applied at economically optimum rates (Figure 4). Therefore, high N rates are not needed to ensure high yield.



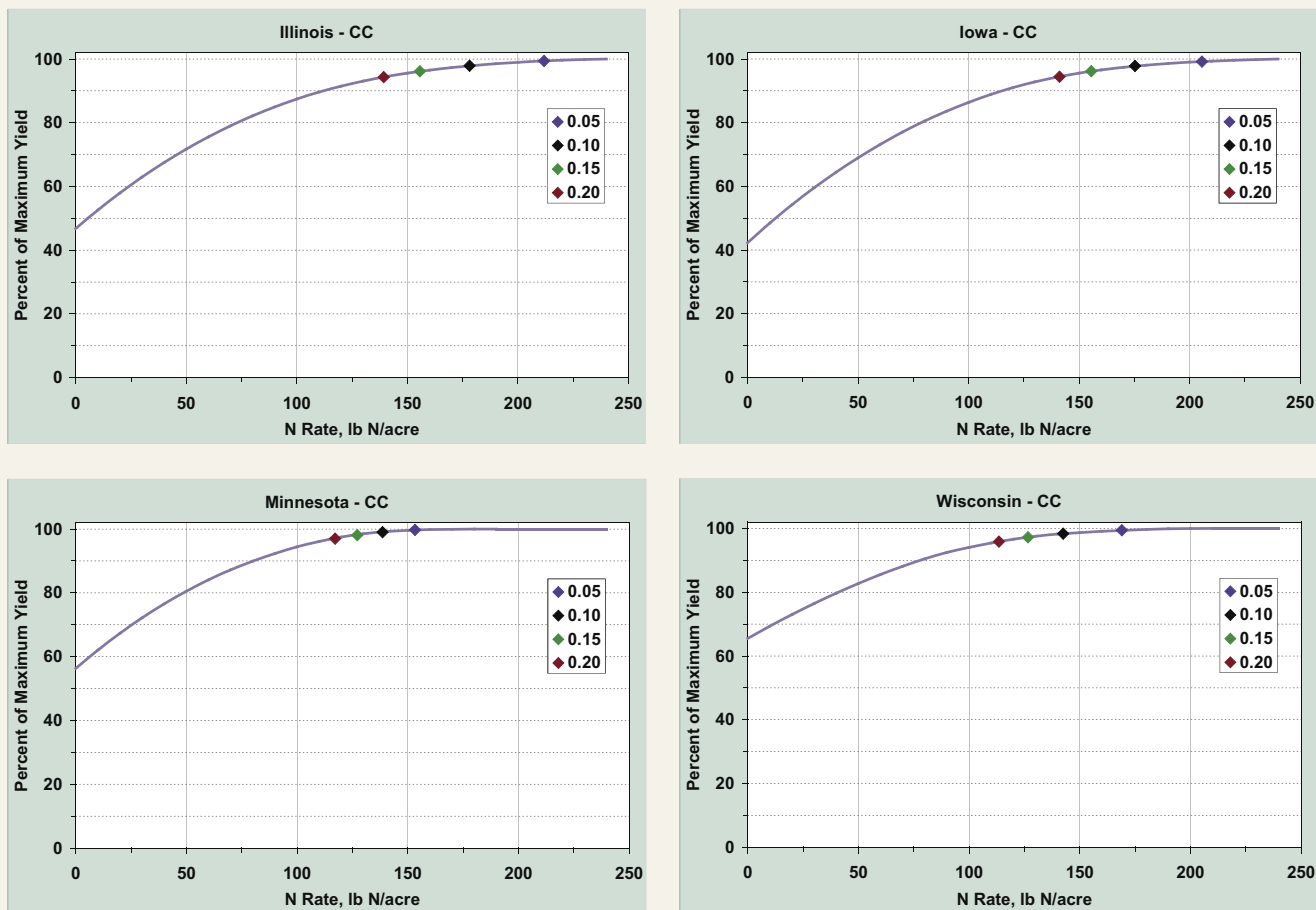


Figure 13. For CC, the percent of maximum yield across N rates. The symbols correspond to the MRTN rate for the fertilizer N:corn grain price ratios given in Table 5.

In general, N rates at the MRTN tend to be at or above the EONR for individual sites in some 60 to 80 percent of trials. While 20 to 40 percent chance of “insufficiency” may seem high, the nature of the response curves is such that the economic penalties for overapplication and underapplication are at a minimum at the MRTN. Therefore, while producers bear some level of risk in order to maximize economic return from N fertilization, the MRTN provides the best estimate of the N rate that minimizes this risk. At low N rates, chance of N sufficiency is low, risk of N shortage is high, and

economic return is severely reduced (Figures 10 and 11). At higher N rates, the slow increase in the yield response curves illustrates that it takes relatively large increases in N rate to move yield higher; with the average return from such high amounts of N expected to be negative. Finally, when N increases in price relative to corn (larger price ratio), the chance of having high percent of maximum yield becomes lower (Figures 12 and 13) and risk increases. Risks and rewards from N application are therefore balanced by choice of rates from a range that produces maximum profitability.

Summary

Application of the MRTN approach to the four-state N response databases indicates the following:

- The flat net return surrounding the N rate at MRTN reflects small yield change near optimum N and indicates that choosing an exact N rate is not critical to maximize profit.
- The MRTN rate and range of N rates surrounding the MRTN that results in similar profitability provide guidelines for rate selection and flexibility for producers in addressing production risk and price fluctuations.
- Nitrogen rates at the MRTN are different for SC and CC rotations, but are not consistent among all state databases. Northern regions have lower N fertilizer application rate requirement, likely due to a greater amount of N supplied by soil organic matter and different climate and crop conditions.
- For SC, at a 0.10 price ratio (\$0.22/lb N:\$2.20/bu corn), the MRTN rate is 163, 123, 101, and 107 lb N/acre for Illinois, Iowa, Minnesota, and Wisconsin datasets respectively.

- For CC, at a 0.10 price ratio (\$0.22/lb N:\$2.20/bu corn), the MRTN rate is 176, 174, 136, and 139 lb N/acre for Illinois, Iowa, Minnesota, and Wisconsin datasets respectively.
- Higher N prices relative to corn prices (larger price ratio, \$/lb:\$/bu) result in reduced net return, lower MRTN rate, reduced width of the profitable N rate range around the MRTN, lower chance of N sufficiency, lower percent of maximum yield, and greater economic penalty with N rates above MRTN.
- Nitrogen rates well below MRTN result in severe reduction in net return, especially with the more N-responsive CC crop sequence.
- If adequate data exist, subsets can be created to determine if site-conditions, management history, prior crop, or regions within or across states could have different rate guidelines.



Because N fertilizer is one of the most expensive inputs for producing corn, N rate guidelines should provide producers the opportunity to maximize return from applied N. Due to a poor relationship between yield and economic optimum N, the regional N rate guideline approach does not incorporate yield level. Instead, yield responses measured in N rate trials conducted across many sites provide the database required for economic analysis and determination of most profitable rates. The MRTN approach provides a flexible method to develop N rate guidelines directly from response databases on a local or regional basis. It has intuitive appeal because it focuses on maximum economic return and incorporates likelihood of expected outcome. Moreover, guidelines can become interactive rather than static due to the ease of calculation and potential for adjustments based on site history, N price, and grain price. This approach should appeal to producers and crop advisers since adjustments in rate can be made for varying production situations.



Corn Nitrogen Rate Calculator

For Illinois, Iowa, Minnesota, and Wisconsin, the MRTN rate can be calculated using a Web-based tool called the Corn Nitrogen Rate Calculator. This calculator is located at <http://extension.agron.iastate.edu/soilfertility/nrate.aspx>. The MRTN, profitable N rate range, net return, percentage of maximum yield, and other information can be calculated directly from N response trial databases for each state. Calculations can be computed for CC or SC, and can be compared with up to four sets of N fertilizer and corn prices. While results are given across the entire state databases at present, zones or regions within some states may be further defined as more N response data are generated, or when such regionalization is shown to be useful.

References

- Blackmer, A. M., R. D. Voss, and A. P. Mallarino. *Nitrogen fertilizer recommendations for corn in Iowa*. PM 1714. Ames: Iowa State University Extension, 1997.
- Mengel, D. B. *Roots, growth and nutrient uptake*. Dept. of Agronomy Pub. AGRY-95-08. 8 pp. West Lafayette, IN: Purdue University Coop. Extension Services, 1995.
- Nafziger, E. D., J. E. Sawyer, and R. G. Hoelt. Formulating N recommendations for corn in the Corn Belt using recent data. *In Proc. N.C. Ext.-Ind. Soil Fertility Conf.*, Des Moines, IA. 17–18 Nov. 2004. Potash and Phosphate Inst., Brookings, SD, 2004.
- Stanford, G. Rationale for optimum nitrogen fertilization in corn production. *J. Environ. Qual.* 2 (1973):159–166.
- Vanotti, M. B., and L. G. Bundy. An alternative rationale for corn nitrogen fertilizer recommendations. *J. Prod. Agric.* 7 (1994a):243–249.
- Vanotti, M. B., and L. G. Bundy. Corn nitrogen recommendations based on yield response data. *J. Prod. Agric.* 7 (1994b):249–256.
- Voss, R. D. ISU soil testing and fertilizer recommendation revisions. p. 7.1–7.8. *In Proc. 21st Annual Fertilizer and Ag Chemical Dealers Conf.*, Des Moines, IA. 14–15 Jan. 1969.
- Voss, R. D., and W. D. Shrader. *Crop rotations—effect on yields and response to nitrogen*. PM 905 (out of print). Ames: Iowa State University Extension, 1979.
- Walsh, L. M., and E. E. Schulte. *Soil test recommendations for field and vegetable crops*. No. 5, Soil Fertility Series. Madison: University of Wisconsin, Department of Soil Science, 1970.





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