Nitrogen Use in Iowa Corn Production

Introduction

Nitrogen (N) is an essential element for plant growth and reproduction, and management is critical for optimal yield in Iowa corn production systems. It is involved in many important plant biochemical processes, such as photosynthesis, and plant components such as amino acids, proteins, and chlorophyll. Plants require N to produce the chlorophyll used in photosynthesis; and it's chlorophyll that gives plants their green color. Plants growing with an adequate supply of N have a dark green color; if N is deficient plants are less green, and yellow in color, lack vigorous growth, and have reduced yield. Legumes like alfalfa and soybean host specific rhizobia bacteria common in Iowa soils which capture atmospheric N gas and convert it into plant available N. Legume crops very rarely require N fertilization; however, cereal crops–like corn–do not have symbiotic fixation. They rely on N from the soil, or N applied in manure or as commercial fertilizer for optimal growth and production. With corn being an important and widely grown crop in Iowa, adequate N supply is critical to achieve high yield and economic profitability.

N-deficient corn adjacent to N-sufficient corn

Yield potential of corn that is not fertilized with N will be very limited as the soil supply of plant-available N becomes depleted. Long-term research in Iowa shows corn yields will average only about 60 bushels/acre for continuous corn and 115 bushels/acre for corn following soybean when corn is not fertilized with N (Figure 1). Optimally fertilized corn will easily yield more than 200 bushels/acre, indicating the large yield increase possible with N application to corn fields. Rotation makes a difference, as previously noted for corn following soybean

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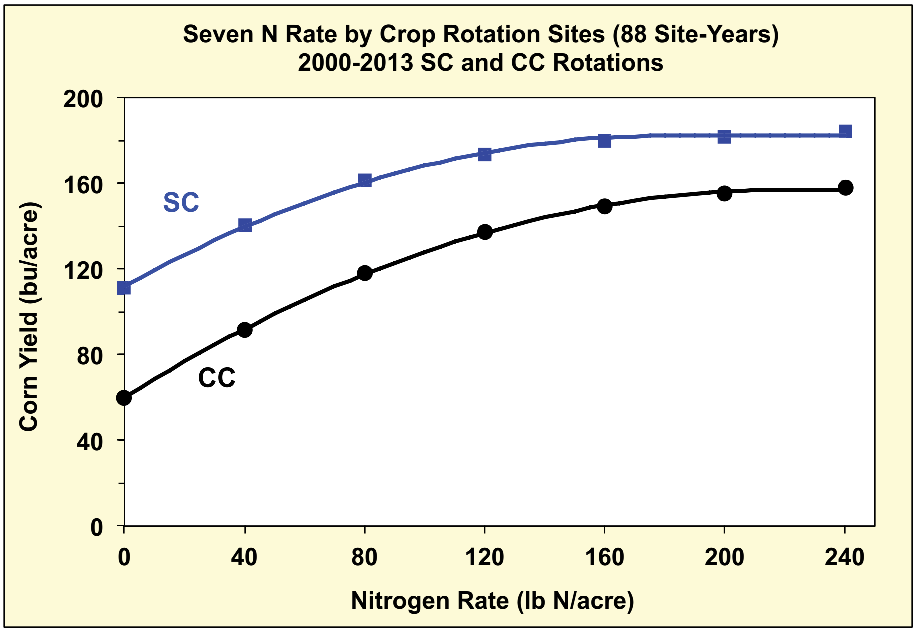

Figure 1. Yield of corn in continuous corn (CC) and corn following soybean (SC) across time with multiple rates of actual N fertilizer applied (Sawyer and Barker, 2013, Iowa State University).

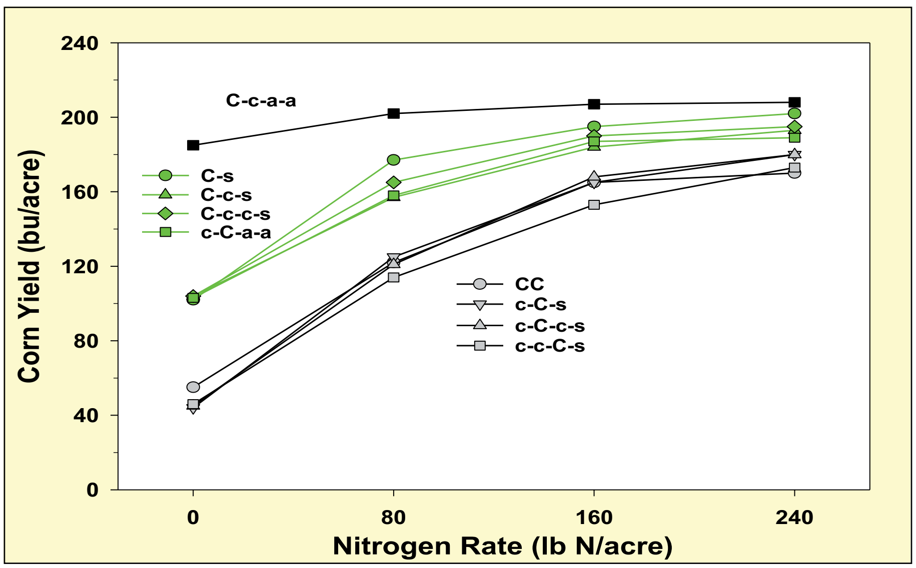

Figure 2. Corn yield with different crop rotations. Rotation abbreviations: C-c-a-a, first-year corn following alfalfa; c-C-a-a, second-year corn following alfalfa; C-c-c-s, C-c-s, and C-s first-year corn after soybean; CC, continuous corn; c-C-s and c-C-c-s, second-year corn; and c-c-C-s, third-year corn. First-year alfalfa is oat under-sown with alfalfa, with alfalfa harvested the second year. (Mallarino, Ortiz-Torres, and Pecinovsky, 2005-2008, Iowa State University Northeast Research and Demonstration Farm, Nashua, Iowa).

compared to continuous corn, and when corn immediately follows an established forage legume like alfalfa, yield will be 90% to 100% of optimally fertilized corn without N application (Figure 2).

Where does plant-available N come from if there is no N fertilization? Some originates from precipitation and ammonium can be released from clay minerals. However, the majority comes from microbial processing (net mineralization) of crop residues and soil organic matter. The amount of N release from organic matter breakdown varies significantly between previous crop, previous N management and application, soils, and years (largely due to weather conditions). The soil supply of N can be a large part of the total N taken up by corn, and typically is more than N taken up from applied fertilizer.

Nitrogen Cycling in Soils

Nitrogen cycling in soils is a complex mix of chemical and biological processes. Add interactions from weather, fertilizer, manure, cropping system, and soil properties, and it is apparent why management effects on soil N and availability for crop production are difficult to predict.

The majority (> 95%) of N in soils is contained in organic matter, with smaller inorganic proportions as ammonium fixed in clay mineral layers, exchangeable ammonium, and nitrate. Soil organic N includes a wide range of complex compounds: humified (stable) soil organic matter (the largest part), fresh crop residue, manure, partially degraded crop residue and manure, and microbial biomass. There is a constant microbial processing of soil organic matter and freshly added organic materials, and over time a stabilization of N into organic compounds that are difficult to degrade. The N content of soils varies greatly as the organic matter varies, but is within a range of approximately 0.06% to 0.30% (1,200 to 6,000 pounds N/acre in the top 6 ⅔ inches) for different cultivated soils.

Plants take up simple inorganic N compounds from soil as either ammonium or nitrate. Utilization of organic N by crops requires prior transformation by soil microbes to these inorganic forms. Microbial processing of organic compounds with release of inorganic ammonium is called mineralization. If this processing results in a gain of inorganic N in soil, then mineralization is considered a net positive, with an increase in plant-available N. If the microbial processing of organic compounds results in a reduction of inorganic N in soil, then mineralization is considered a net negative, and plant-available N decreases and is "tied-up" or immobilized by microbes. This "tie-up" can occur when organic materials are added to soils with high carbon (C) and low N content (examples are small grain crop straw and corn stalks). Microbial activity is not instantaneous, and occurs at various rates depending on many conditions, especially temperature and moisture. The continual microbial processing of added organic materials with concurrent gain or loss of C, N, and other elements results in a trend toward a relatively constant 10:1 C:N ratio for soil organic matter. Microbial N processing can have dramatic influence on needed N fertilization, as conditions more or less favorable for microbial activity (mineralization), and/or type and amount of crop residue with different rotations, change the net release of N available for plant use. An example is the difference in N fertilizer rate requirement with continuous corn (higher) compared to corn following soybean (lower). Differences in seasonal weather influences can easily change net mineralization by ±30 pounds N/acre—a wide range which has a large influence on optimal N application rate.

Nitrogen Fertilization of Corn

A portion of any applied fertilizer N is processed by soil microbes and incorporated into soil organic matter (perhaps 25% on average, which helps maintain soil organic matter); another portion is lost to denitrification, leaching, and ammonia volatilization (perhaps 20% on average). Therefore, crop fertilizer N use efficiency is always less than 100%. In the above example of ±30 pounds N/acre difference due to mineralization, and using a 50% fertilizer N use efficiency, the effect on needed fertilizer N rate would be ±60 pounds N/acre. Since the supply and loss of plant available N from the soil varies, as does N use efficiency, the corn yield response to applied N and point of economic optimum nitrogen rate (EONR) vary between years and fields. Figure 3 illustrates this for corn grain yield response to fertilizer N rate during five consecutive years at the same site with corn following corn. This uncontrolled variation in net N mineralization and N use efficiency is the major reason why it is difficult to predict optimal fertilization rates. This variability in N response, and EONR, makes rate guidelines challenging, but also provides an opportunity for more specific guidelines if the underlying differences can be accounted for (predicted).

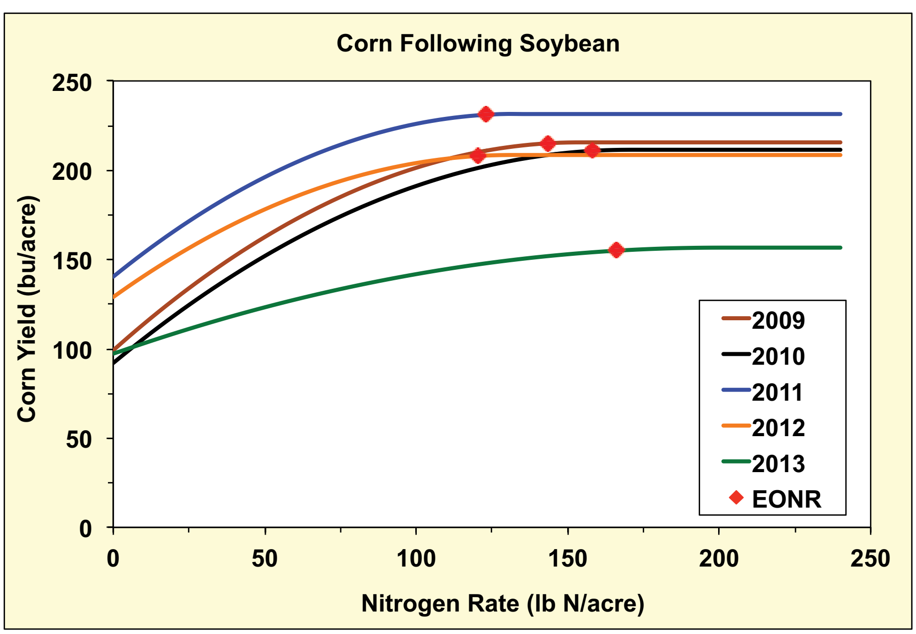

Figure 3. Variation in corn grain yield response to fertilizer N and economic optimum nitrogen rate (EONR) in five consecutive years at the same field site near Ames, Iowa (Sawyer and Barker, 2013, Iowa State University).

Nitrogen Application Rates for Corn

Current N application rate guidelines from Iowa State University Extension and Outreach are based on an extensive N response trial dataset with determination of economic return to N application. This approach was implemented in 2005 in Iowa and across the Midwest Corn Belt. The underlying principle is that suggested application rates should be determined from many research trials where multiple N rates provide grain yield response to applied N, and then economic return calculated from the response determining the most profitable application rate (in Iowa, there are currently 246 response trials for corn following soybean and 133 for continuous corn). This approach is called the maximum return to nitrogen (MRTN) and is fully explained in the Iowa State University Extension and Outreach publication "Concepts and Rationale for Regional Nitrogen Rate Guidelines for Corn" (PM 2015) https://store.extension.iastate.edu/Product/pm2015-pdf.

The MRTN is implemented through the online tool called the Corn Nitrogen Rate Calculator (CNRC) http://cnrc.agron.iastate.edu/. Specific input criteria, such as state or sub-state area, rotation, fertilizer product, fertilizer N price, and corn price are chosen by the user and used to determine the suggested N rate—called the MRTN rate. A most profitable N rate range is also provided, which provides N rates within $1.00/acre of the maximum return. This profitable N rate range provides flexibility in choice of rate to apply; with selection based on production risk tolerance, water quality concerns, maintaining soil N, and availability of other N response information or N diagnostic test results. Table 1 gives output from the online CNRC for continuous corn and corn following soybean and for four N:corn price ratios ($/pound N:$/bushel corn). For the most up-to-date guidelines, use the online CNRC. The CNRC allows input of any chosen set of prices, and is recommended over use of the table values as the database changes over time and users can input specific prices. Generally, there has been an approximate 50 pounds N/acre rate difference between the two rotations. The MRTN rates are derived from rate trials with good N management practices; for instance, trials with spring or sidedress N application.

While the MRTN approach provides guidance for N application rate, site- or seasonal-specific adjustments can be made with various tools such as the late spring soil nitrate test (LSNT) or corn plant N stress sensing. Explanations for use of these and other tools are provided in other Iowa State University Extension and Outreach publications and are not covered here, but located at https://store.extension.iastate.edu.

Table 1. Nitrogen rate guidelines for Iowa continuous corn and corn following soybean based on output of the Corn Nitrogen Rate Calculator (CNRC). See Figure 4 for map of Iowa soil regions.

Price Ratio[1]	Corn following Soybean		Corn following Corn	
	Rate[2]	Range[3]	Rate[2]	Range[3]
$/pound N:$/bushel	(------------pounds N/acre------------)			
Main Iowa Region				
0.05	159	142 - 178	210	194 - 229
0.10	140	126 - 153	188	174 - 204
0.15	124	112 - 137	171	156 - 185
0.20	113	102 - 124	154	142 - 167
Southeast Iowa (Soil Regions 17, 21, 22)				
0.05	179	160 - 201	239	217 - 240
0.10	153	138 - 168	201	185 - 220
0.15	136	126 - 148	182	175 - 195
0.20	127	115 - 137	178	164 - 186

[1] Price per pound N divided by the expected corn price. For example, N at $0.35/pound N and corn at $3.50/bushel is a 0.10 price ratio. Corn held at $3.50/bushel for all price ratios.

[2] Rate is the pounds N/acre that provides the **M**aximum **R**eturn **T**o **N** (MRTN). All rates are based on results from the Corn Nitrogen Rate Calculator as of March, 2018 (http://cnrc.agron.iastate.edu).

[3] Range is the range of most profitable N rates that provides a similar economic return to N (within $1.00/acre of the MRTN).

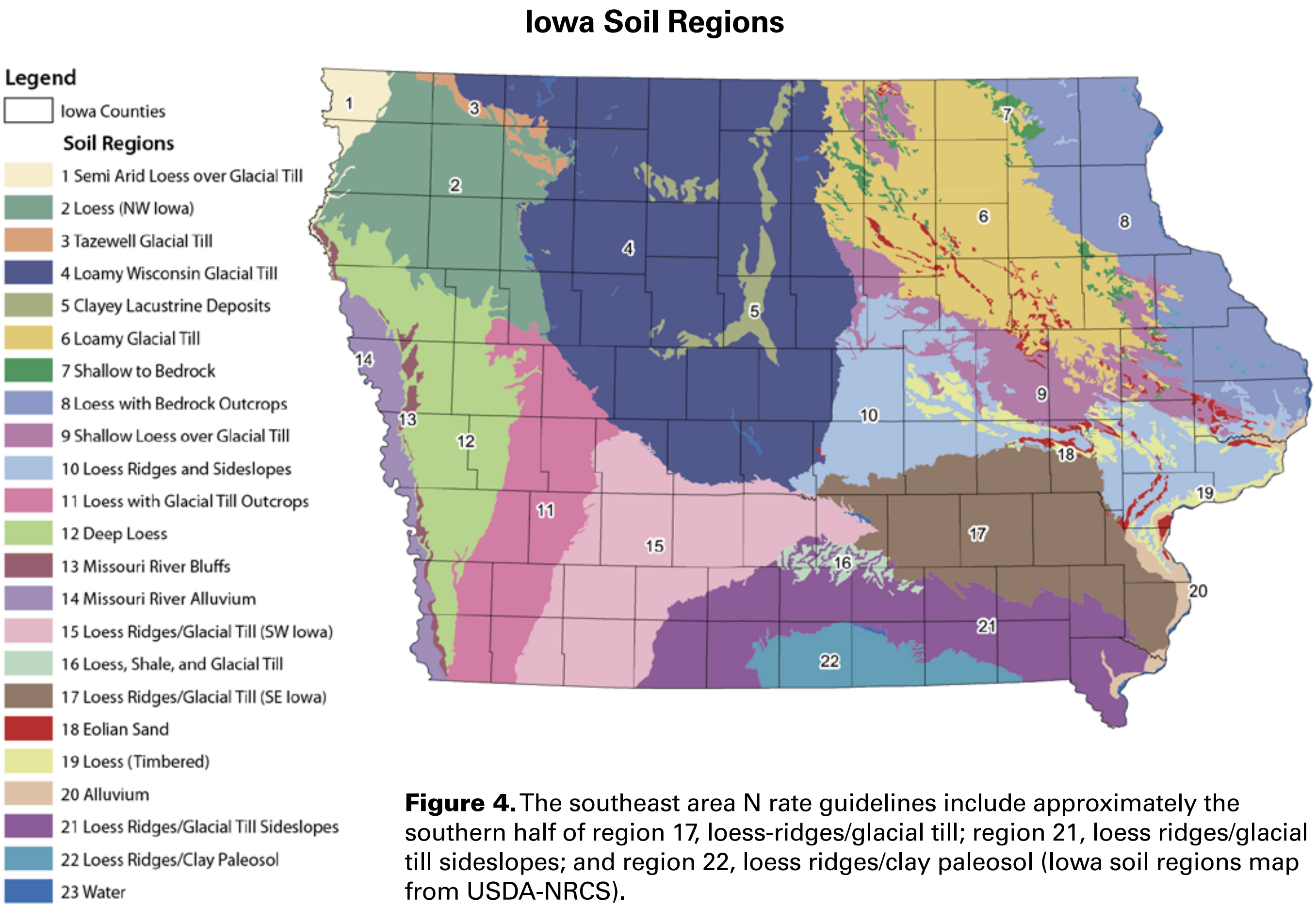

Figure 4. The southeast area N rate guidelines include approximately the southern half of region 17, loess-ridges/glacial till; region 21, loess ridges/glacial till sideslopes; and region 22, loess ridges/clay paleosol (Iowa soil regions map from USDA-NRCS).

A major shift in how N rate guidelines are determined, initially implemented in 1997, was discontinuing use of corn grain yield goal as a determinant for rate (also,earlier publications used N rate ranges for various rotations instead of yield goal) as many datasets have shown that yield is not related to EONR (Figure 5). This method of not directly using yield continued with the MRTN approach. Instead of yield goal, the MRTN uses grain yield

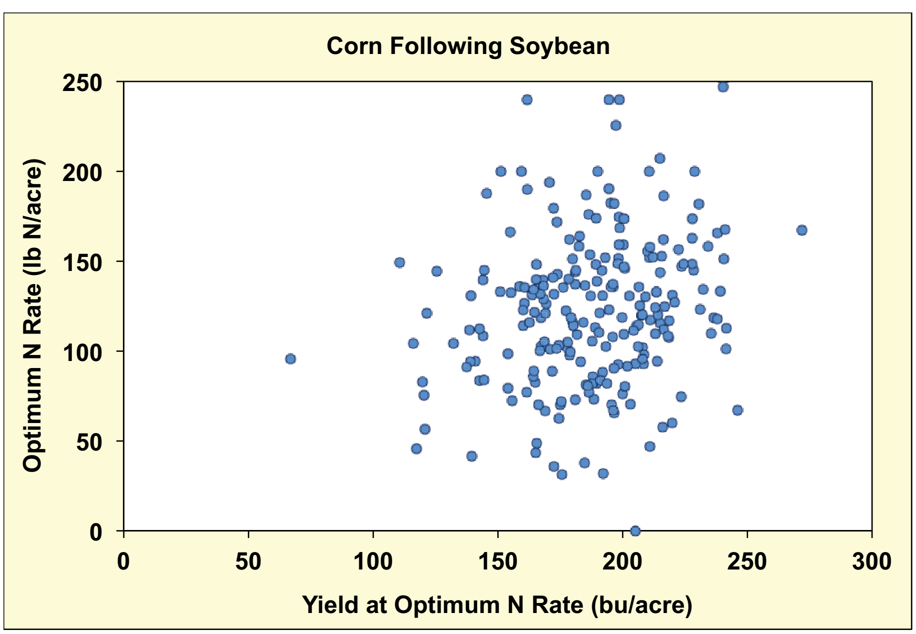

Figure 5. The lack of relationship between corn grain yield and the optimum N rate, corn following soybean in Iowa (data from the CNRC).

response from applied N to determine economic optimal rates. It is the yield increase with N application that pays for the applied N, not yield level. It is a well-known principle, with an example in Figure 6, that as N rate increases, the incremental yield increase gets smaller and eventually there is no further yield increase at higher and higher N rates (also seen in figures 1 and 3).

The important point of the N rate response is the point of maximum economic return, which is always slightly below the maximum yield response because it takes some incremental yield increase to pay for the last amount of applied N (the point of no net economic gain to more applied N). This concept is used in the MRTN calculation, whereby all N response trials are used to determine that point of maximum net return (the MRTN rate). The net return (yield return minus fertilizer cost) and MRTN rate point is illustrated in Figure 7. The economic maximum

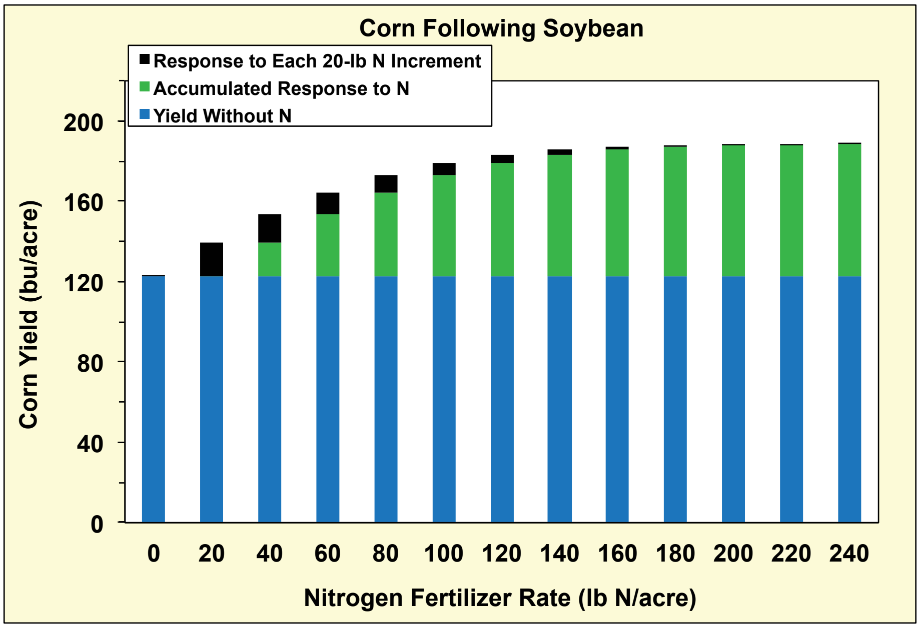

Figure 6. Diminishing returns in yield response to fertilizer N as rate increases. The MRTN rate for this CNRC dataset was 137 pounds N/acre (at 0.10 price ratio).

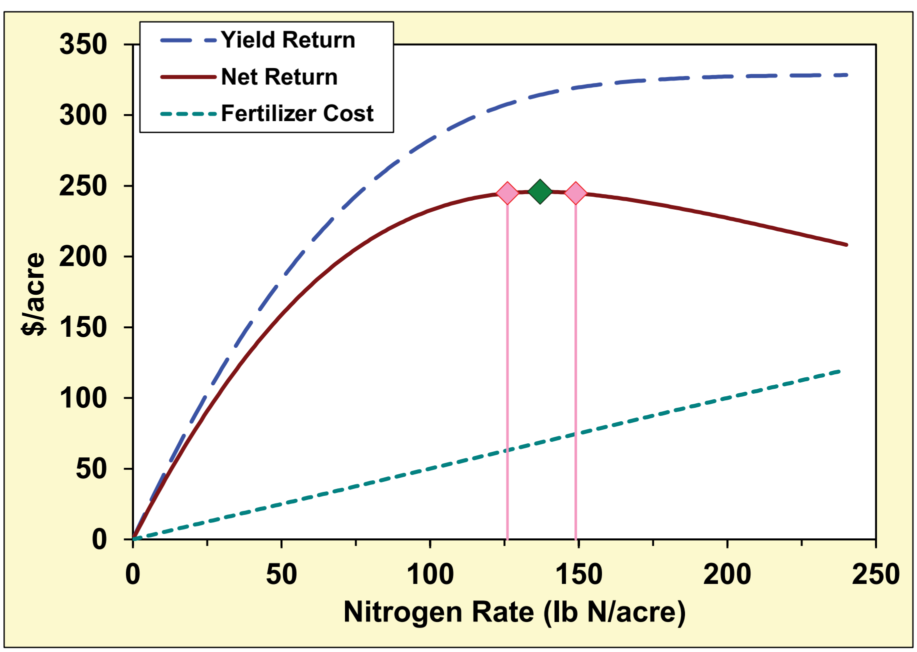

Figure 7. Net economic response to N fertilizer rate for corn following soybean, data from the CNRC dataset (at 0.10 price ratio). The MRTN rate, and most profitable range are indicated on the net return line.

depends on the cost of N and the price of corn (the N:corn price ratio, $/pound N:$/bushel corn). Table 1 gives four price ratio examples, and the impact on N rate as the price of N becomes larger relative to the price of corn (going from a 0.05 to 0.20 ratio).

For rotations other than continuous corn and corn following soybean, there is not an extensive dataset of recent N response trials with an adequate number of sites and N rates to utilize the MRTN approach for rate guidelines. Therefore, table ranges of suggested rates are provided for corn following alfalfa (Table 2). The general concept of rate guidelines for corn following alfalfa follow from the response presented in Figure 2, where corn N rate requirements can be significantly lower; and, in some situations, with very low frequency of yield increase from applied N. Therefore, N application and rate guidelines for corn following alfalfa should be carefully considered, as described in the footnote of Table 2.

Interest has increased in regard to corn stover harvest and use of winter cereal rye as a cover crop. Recent research in Iowa at two sites across three years in continuous corn, with either chisel plow or no-tillage, indicates that with approximately 30% corn stover harvest, the N application rate can be reduced 20 pounds N/acre, and with approximately 80% stover harvest the N rate can be reduced 40 pounds N/acre. For corn following a rye cover crop, recent research in Iowa at five sites across five years with no-tillage corn following soybean indicates no difference in needed N application rate. These research results can be considered for potential adjustments to suggested MRTN rates.

Table 2. Nitrogen rate guidelines for corn following alfalfa.

First-year Corn after Alfalfa[1]	Alfalfa Stand	Nitrogen Rate Range (pounds N/acre)
Coarse-textured soils		Use corn following soybean[3]
Fine-textured soils		0-30 pounds N/acre
Medium-textured soils	One-year stand age	Use corn following soybean
	Two-year stand age or second-year alfalfa established underseeded with oat	Use corn following soybean
	Three-year or older stand age	0-30 pounds N/acre
Second-year Corn after Alfalfa[2]	**Alfalfa Stand**	**Nitrogen Rate Range (pounds N/acre)**
	Two-year stand age or second-year alfalfa established underseeded with oat	Use corn following soybean
	Three-year or older stand age	Use corn following soybean

[1] First-year corn after alfalfa. The corn yield response to N is very frequent on coarse textured soils, about half of the time on fine-textured soils, about half of the time on medium-textured soils with two-year-old alfalfa that had been underseeded with oat, and rarely on medium-textured soils following an established alfalfa stand three or more years old. Coarse textured soils are sandy soils; fine-textured soils generally have clay in the textural class, like clay loam, silty clay loam; and medium-textured soils generally have loam in the textural class, like loam, sandy loam, silt loam, fine sandy loam.

[2] Second-year corn after alfalfa. The corn yield response to N is about half of the time with three-year or older established alfalfa and very frequent following two-year old alfalfa that had been underseeded with oat.

[3] See the CNRC online site or Table 1 for N rate guidelines for corn following soybean.

Note: The N rate requirement can vary considerably for first- or second-year corn after alfalfa due to many factors, such as alfalfa stand age, stand persistence, fall regrowth, frequency of corn in the rotation, and late fall or early spring temperatures.

Water Quality

Nitrogen application is one of the main determinants of nitrate-N loss to surface and groundwater from corn production. Figure 8 shows that as N rate increases, nitrate-N concentration in tile flow water increases, with the concentration increasing more rapidly above suggested MRTN rates. This means managing N inputs carefully, and using optimal N rates, are important components of minimizing impacts of N application to corn on water quality. The higher needed N rate for continuous corn does result in higher nitrate-N concentration in tile flow. Therefore, corn in rotation with other crops can lessen the water quality impact from N fertilization of corn.

The Challenge

Many soil chemical and physical properties benefit from having organic matter in soils, with resultant benefits for soil sustainability and crop productivity. To maintain (or increase) soil organic matter requires a concurrent maintenance (or increase) of soil N. Because of the complex and open soil system, it is challenging to produce high-yielding row crops in Iowa agricultural systems without impacting soil N and nitrate loss to the environment. Proven soil management and N fertilization practices, such as using economical optimum N rates, should be used to help optimize crop yields, N use efficiency, and water quality.

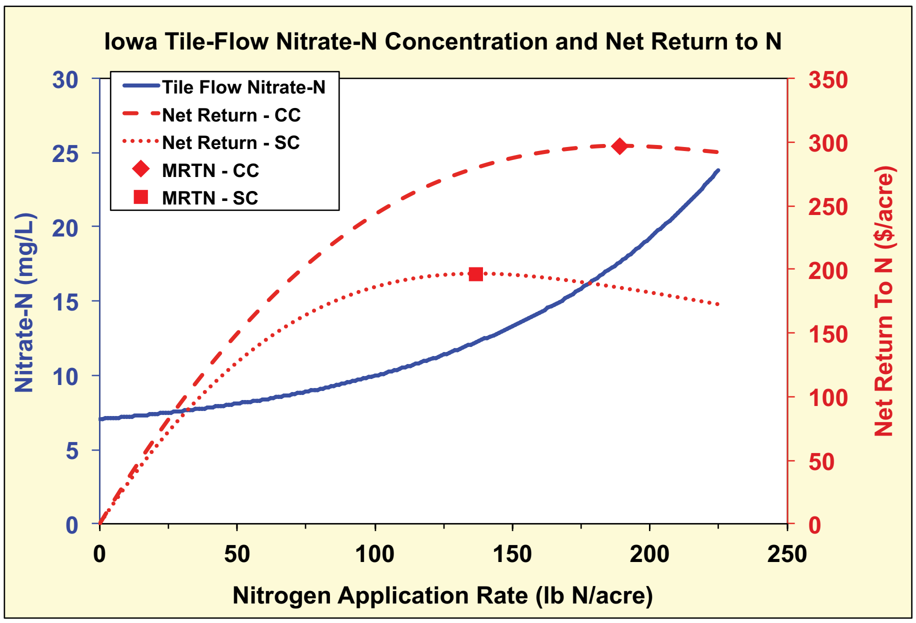

Figure 8. Tile-flow annual average flow-weighted nitrate-N concentration for continuous corn (CC) and the soybean-corn (SC) rotation, and net economic return across N rates for CC and SC in Iowa. The MRTN for each rotation is indicated by the symbol (adapted from Sawyer and Randall, 2008 and Lawlor et al., 2008).

N-deficient corn adjacent to N-sufficient corn

Maintaining Soil Nitrogen

There is an ongoing debate about N fertilizer rate needed to maintain total soil N (and soil C), and long-term sustainability of crop production for cropping systems that do not include forage legumes or mixtures of grasses and forage legumes. For corn and soybean, several principles are clear.

- Maintaining total soil N means maintaining soil organic matter.
- Without N fertilization soil N will deplete, and small changes in total soil N can influence plant-available N supply.
- Without N fertilization soil organic matter will decline and supply of plant-available N will decrease—stabilizing at a low net plant-available N level with resultant low corn yield.
- High (and acceptable) corn yields require N application to supplement the soil N supply.
- Applied N furnishes required plant N and aids in maintenance of soil N.
- A goal for N applications is to approximately balance the input and output of N from soil (maintain soil N) in corn production systems. In continuous corn this is possible, but in rotation with soybean, N application in the corn phase cannot overcome the soil N depleting effect of the soybean crop.
- Nitrogen mineralization from soil organic matter and crop residues supplies inorganic plant-available N; however, nitrate formed from soil organic matter mineralization can also leach from soils as evidenced by tile flow nitrate-N when no N is applied.
- Nitrogen fertilization supplies needed plant-available N, but increases nitrate that can leach from soils.
- Nitrate-N concentration loss in tile flow is greater with continuous corn compared to the corn-soybean rotation due to the higher required N application rate, not solely the annual application with continuous corn.
- Reducing N fertilization to below economic optimum rates reduces nitrate loss, but will not eliminate it.
- Growing forage legumes in rotation with grain crops reduces–but does not stop–nitrate loss, because of N mineralization during and after the forage crop.
- Because the soil is an open system (top and bottom), N losses will occur. This makes maintenance of soil N (and organic matter) and optimal crop yields with fertilization difficult while attempting to eliminate negative environmental impacts.

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