Corn nitrogen fertilization: production and environment aspects

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Introduction

Nitrogen (N) fertilization continues to be a dynamic and evolving practice for optimal corn production. Iowa soils supply considerable crop-available N, but supplemental fertilizer or manure application is needed on the majority of fields. The challenge is optimizing crop productivity within the many constraints of weather, economics, and input capacity (time, equipment, products, etc.).

Production aspects

Corn yield response to applied N is well-known. Figure 1 shows the mean yield response from fertilizer N application across time and space in Iowa. It is clear that N application allows for high corn yields, and that over-application does not further increase yield. Also, at the same sites included in Figure 1, when no N was applied in the year after the many years of application, there was little to no residual effect on corn yield from the prior N rate history. This effect highlights the continual need for N application in corn production and the difference in soil nutrient supply compared to "immobile" nutrients like P and K that can be "stored" crop available in the soil. The Corn Nitrogen Rate Calculator (CNRC, http://cnrc.agron.iastate.edu) provides rate guidance (Maximum Return to N, MRTN, and most profitable N rate range), with adjustment for corn and N price for continuous corn (CC) and corn following soybean (SC).

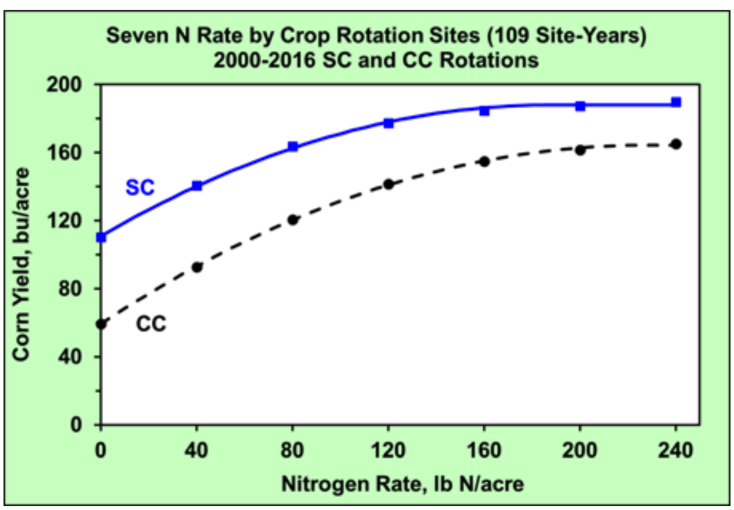

Figure 1. Mean corn yield response to applied fertilizer N rate in Iowa for continuous corn (CC) and corn following soybean (SC), J.E. Sawyer and D.W. Barker.

Due to the rate estimation approach used in the CNRC (no yield goal for example), and uniform rate for a wide geographic area, there are frequent questions about suggested MRTN rates versus expectation of needed N application: do high yields require a high N rate, do modern hybrids require more N, should N rates be based on corn grain N removal, do high N rates reduce yield variability, would knowing the exact yearly EONR increase profitability, and should prior-year crop yield or N response relate to the next year optimal N rate?

High corn yields need more applied N?

Research the last two plus decades in Iowa have shown that optimal N rate is not related to the yield level that year (Figure 2). Another way to look at the question; what are the recommended or optimal rates if one breaks out yield categories from N response databases. Following the first sentence in this paragraph (i.e. no relationship) and the graphic in Figure 2, such analysis has potential issues (also can be confounded with number of site-years and seasonal weather), but results are interesting. For the CNRC database in the Main area of Iowa, the equivalent MRTN rates for several CC yield ranges are: 101-150 bu/acre, 177 lb N/acre; 151-175 bu/acre, 184 lb N/acre; 176-200 bu/acre, 199 lb N/acre; 201-225 bu/acre, 211 lb N/acre; and 226+ bu/acre, 182 lb N/acre. For SC yield ranges: 101-150 bu/acre, 105 lb N/acre; 151-175 bu/acre, 125 lb N/acre; 176-200 bu/acre, 135 lb N/acre; 201-225 bu/acre, 143 lb N/acre; and 226+ bu/acre, 167 lb N/acre. Yes, there is variation across yield ranges, but not consistent, and a trend with lowest rates at very low yields – but does anyone plan for low yields? At respectable to high yield levels, those MRTN equivalent rates are quite similar, and similar to those produced from the CNRC (and the most profitable rate ranges). These results highlight the variation in yield response to applied N, and thus not a reasonable to attempt varying N rate by yield category.

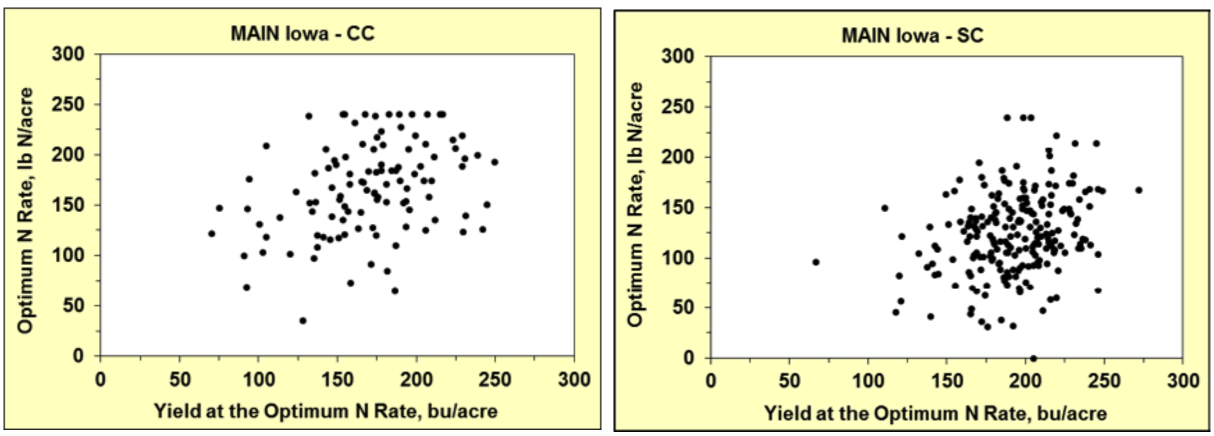

Figure 2. Corn yield versus optimal N rate for continuous corn (CC) and corn following soybean (SC), Iowa Main region of the CNRC database (linear regression R^2 for CC 0.12 and SC 0.07).

A way to look at the high yield question is to investigate N rate response in site-specific research trials where corn yields are 220 bu/acre or greater. Based on multiple years of rate responses, the mean EONR is quite similar to the CNRC MRTN suggested rates or within the most profitable ranges for each rotation (Table 1). It is clear that corn N use efficiency plus environment impact on soil N supply allow for varying yield level within similar rotation N rate.

Table 1. Mean economic optimum N rate (EONR) in high corn yield environments (corn yield ≥ 220 bu/acre), across 2000-2016. Data from seven long-term N rate by rotation sites in Iowa, J.E. Sawyer and D.W. Barker.

Rotation	No. site-years *(n)*	Mean EONR *(lb N/acre)*	Mean yield at EONR (range) *(bu/acre)*
SC	40	150	233 (220-272)
CC	13	183	232 (220-250)

EONR at 0.10 Nitrogen:Corn price ratio.

Corn hybrid N use changed across time?

It is well known that corn yields have increased across time. From 1940 to 2016 the Iowa statewide yield has increased at 1.9 bu/acre per year. That is a large yield increase. However, comparing yield and N use of two 1960 era hybrids and two 2000 era hybrids (all planted near Ames in 2007 and 2008) the grain yield increase with the 2000 era hybrids was 90 bu/acre (67% increase), but the total plant N and grain N increased only 19 and 22% (Table 2). The main reason for the smaller plant N increase was lower plant component N concentrations and 24% lower grain N concentration. There was a clear change in N use for modern hybrids along with higher productivity, and despite similar grain N harvest index (fraction of total plant N in grain) and similar harvest index (fraction of total plant biomass in grain). The lower grain N concentration, and smaller increase in plant N (compared to yield increase), moderated the need for more applied N with the improved corn yield.

Table 2. Comparison of 1960 and 2000 era hybrids, planted near Ames in 2007-2008, following soybean at 150 lb N/acre.

Plant Measurement	1960 era	2000 era
Grain Yield (bu/acre)	134b	224a
Total N uptake at maturity (lb/acre)	159b	190a
Grain N (lb/acre)	113b	138a
Grain N Harvest Index	0.71a	0.73a
Grain Harvest Index (%)	49a	53a
Internal N Efficiency (bu/lb of total plant N)	0.84b	1.18a
Grain N Concentration (% DM basis)	1.61a	1.23b
Grain N (lb N/bu at 15.5%)	0.76a	0.58b

Letters indicate statistical difference between eras ($P \leq 0.10$).
K.P. Woli, M.J. Boyer, Roger W. Elmore, J.E. Sawyer, L.J. Abendroth, and D.W. Barker. 2016. Iowa State University.

Base N rate guidance on grain N removal?

From an environmental perspective, applying a nutrient like N at the rate removed in harvested grain has perceived merit. However, with an open soil system and a nutrient subject to losses, management (replacing nutrient removed) that can be done with “immobile” nutrients (ex. P and K) at optimal soil test levels does not hold for N. There is also the need to maintain soil carbon and N resources (organic matter), which is important for many nutrient cycles and water holding capacity. Therefore, the expectation should be that optimal N application rates need be greater than that removed in grain harvest. For SC, depending on the database and analysis method, the EONR rate varies between 32 to 58 lb N/acre more than the grain N removed in harvest. Therefore, basing a recommended N rate on grain removal would underestimate actual needed N application. Not an economic optimal outcome.

High N rates reduce corn yield variability?

Applying N increases yield, but does not dictate yield level as many factors make up the final yield in a given year – hybrid, environment, precipitation, etc. all interacting. As N rate and concurrent yield increases to a plateau (Figure 1), the variability (as measured by standard deviation) also increases. At research sites from 2000-2016, the mean yield standard deviation was 22 bu/acre with no N applied and 44 bu/acre at 240 lb N/acre for CC, and 29 and 37 bu/acre for SC for the same N rates. Therefore, farmers should not expect high N rates, including those above optimal rates, to even out yield (reduce variability) across time.

Fertilizing N at the exact yearly EONR increases profitability?

While being able to know and apply the perfect field-specific N rate each year is a lofty goal, would that capability provide significant economic return compared to a consistent MRTN rate? Using the CNRC response trial database for the main area of Iowa, such a perfect application would theoretically increase net return by $11.19/acre with SC and $14.73/acre with CC (using $0.35/lb N and $3.50/bu). There would be a concurrent theoretical overall decrease in N rate of 16 lb N/acre for SC and 22 lb N/acre for CC. The calculation does not include cost for yearly site-specific rate prediction or implementation of the applications, which would reduce or eliminate the positive return, as would less than perfect rate predictions. In comparison, if high N rates were considered essential for high yield goals, say 220 or 250 bu/acre (yield-based calculation at 264 and 300 lb N/acre for CC and 216 and 252 lb N/acre for SC), the net loss compared to yearly EONR would be in the range of $30 to $45/acre for both rotations. Much more "loss" than using MRTN rates or most profitable rate ranges from the CNRC, and does not include increased environmental impacts.

Prior-year crop yield or N response relate to next year optimal N rate?

The short answer is no. Research at seven long-term crop rotation by N rate sites in Iowa show no strong relationship for: the prior year soybean yield and the next year difference between optimal N rate in CC and SC (i.e. soybean "credit" amount); prior year corn yield and next year CC optimal N rate; prior year corn optimal N rate and the next year CC optimal N rate; prior year corn response (yield increase) to N, or no-N (control) corn yield, and the next year CC optimal N rate. As one would suspect, the many factors that influence corn productivity, N use efficiency, and N supply cause these types of relationships to be weak or non-existent.

Environment aspects

Another challenging year for N management in 2018 for many areas of Iowa. Except for a couple of years with statewide below normal precipitation, there have been several years recently where precipitation has been above normal. In addition, average precipitation has been increasing – including during the spring and early summer periods most prone to N loss either through denitrification or leaching. In 2018, in some areas the frequency and amount of precipitation across the growing season meant no real solution for optimizing N supply to corn. One saving aspect is the continual (season-long) soil N mineralization in warm/moist soils (especially soils with high organic matter) – which can offset loss of fertilizer or manure N. However, in years with little carryover of profile nitrate from previous crops, and years with wet conditions like in 2018, N rate requirement typically is greater than normal with resultant higher than normal optimal rates. As discussed at previous ICM conferences and in ICM newsletter articles, when the Main area of Iowa (CNRC area) has April 1 to June 30 precipitation greater than 15.5 inches, or March 1 to June 30 precipitation greater than 17.8 inches in the Southeast area of Iowa, then an N rate greater than the MRTN rate, or use of the upper end of the most profitable range (CNRC web site, http://cnrc.agron.iastate.edu/) would be suggested. This was the case for much of Iowa in 2018, especially the northern portion (Figure 3). It's these high (extreme) N fertilization rate need years that have the greatest impact on potential economic loss due to insufficient N; but are hard to predict and why the suggestion is to follow the total springtime precipitation guidance as to when additional N would be needed.

Even if N is sidedressed after wet springtime conditions, the springtime wetness impact on soil-derived nitrate-N (residual nitrate and mineralized organic matter) influences needed fertilization rates. That is, excessively wet conditions before sidedress N is applied can result in increased needed rate. Similarly, if conditions are more or less conducive to nitrate retention after sidedressed fertilizer, then required N fertilization will be greater or smaller. In 2018, precipitation totals after June to season end were greater than from April to June and much above average (Figures 3 and 4); making fertilizer N management to maintain crop available N difficult to impossible for many reasons, and reducing potential differences from application timing. Nitrogen processing in soil is dynamic, as is crop N use efficiency, which further affects variation in N fertilization needs. It has been difficult in recent years to find a consistent/best N timing management, that is, most times there is no difference between all spring preplant and split application, or if a difference measured about equal times one is better than the other. This has been a similar pattern in other states for many soils (does not apply to sandy soils).

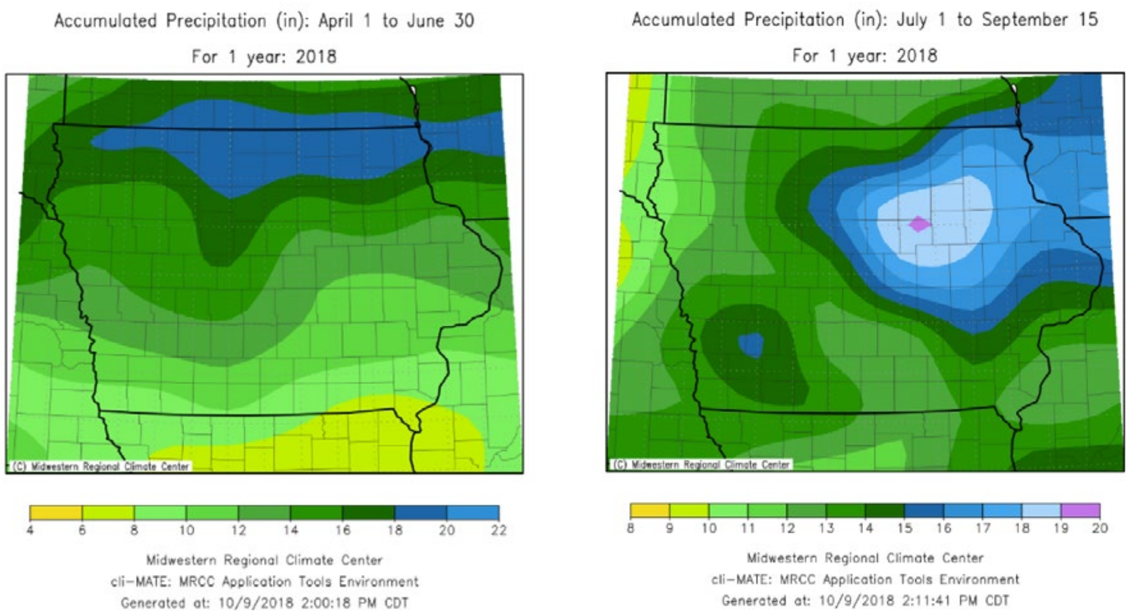

Figure 3. Precipitation in 2018 for two time periods in Iowa.

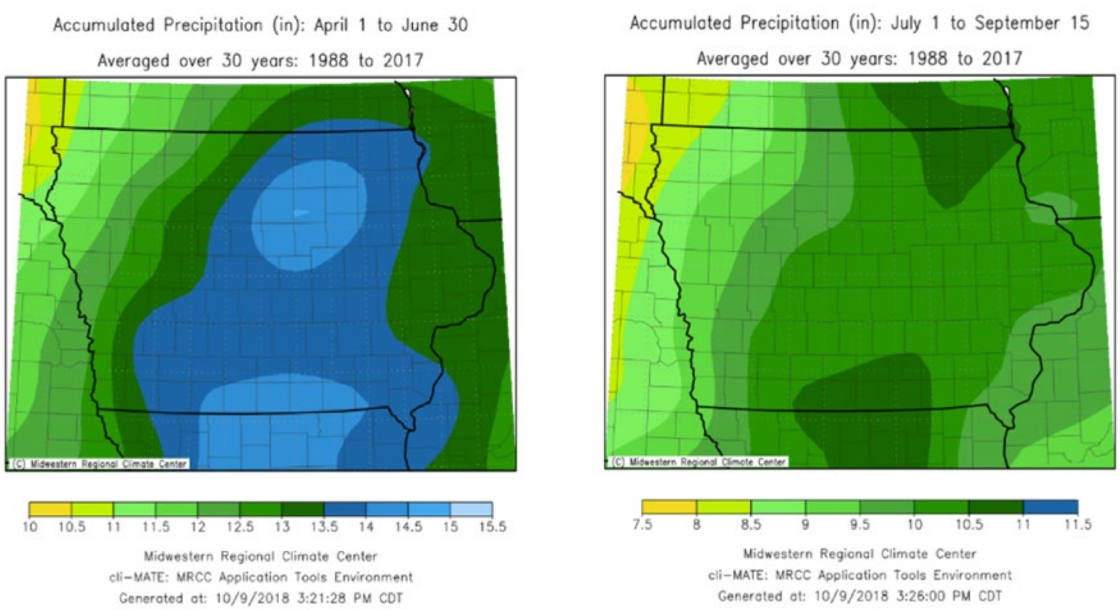

Figure 4. Average 30-year precipitation for two time periods in Iowa.

Mid- to late- corn vegetative growth stage N application has gained interest in recent years as an approach to lessen the impact of early season wet conditions on fertilizer N loss. Corn accumulates approximately 70% of total plant N by the silking stage (sometimes up to 80%), the percent of plant total N in grain N at maturity is approximately 70%, and the grain harvest (biomass) index is approximately 50% of plant total. There is opportunity to help supply late season N needs of corn with late sidedress N application; however, there is also the risk of lost yield potential if N supply limits early vegetative growth and N uptake. Corn response to late vegetative N application can be quite positive if soil moisture or precipitation is adequate after application, the N is needed, and corn can respond. An example of a large positive response to late N was a field-length trial (2005) where split N (UAN surface-dribbled) was applied at the V13 corn growth stage (60 lb N/acre was applied early sidedress), rained 2+ inches after the V13 application – a 32 bu/acre yield increase. An example of a large negative response to late N was a trial at the Northwest Research Farm water quality site in 2017 where split N (urea surface-dribbled) was applied at the V10 stage (40 lb N/acre was applied as starter N), a "dry" summer and with no or small rain events for a considerable time after the V10 application – a 22 bu/acre lower yield compared to anhydrous ammonia applied in late fall (with nitrapyrin) or spring preplant. These are examples of how precipitation variation affects response to "late" applied N, and enhances or detracts from attempted improved management in rainfed corn production.

Environmental N loss continues to be an issue in Iowa crop production, especially nitrate loss to surface water systems. A large influence on nitrate loss relates to application rate (Figure 5 with tile drainage), with loss accelerating as application rate increases above recommended rates. With ever increasing precipitation, and increased acreage of tile drainage, managing loss from drainage systems will continue to be an important area of environmental N management. Unfortunately there is a baseline nitrate-N concentration (Figure 5, approximately 7 ppm nitrate-N in tile drainage), so even with the best in-field management that baseline will be the best possible to achieve. In a new water quality site at the Northwest Research Farm, the nitrate-N concentration in tile drainage (in corn or soybean crops across 2015-2017) with no N applied has ranged from 6 to 13 ppm. Unfortunately, the practice of applying N for corn production, no matter when or how managed, results in similar drainage loss of nitrate. According to the practice list for the Iowa nutrient reduction strategy, traditional N management practices (rate, timing, inhibitors) are helpful but will not achieve the desired concentration reduction goal. Instead other practices, such as a rye cover crop or out-of-field practices, will be needed.

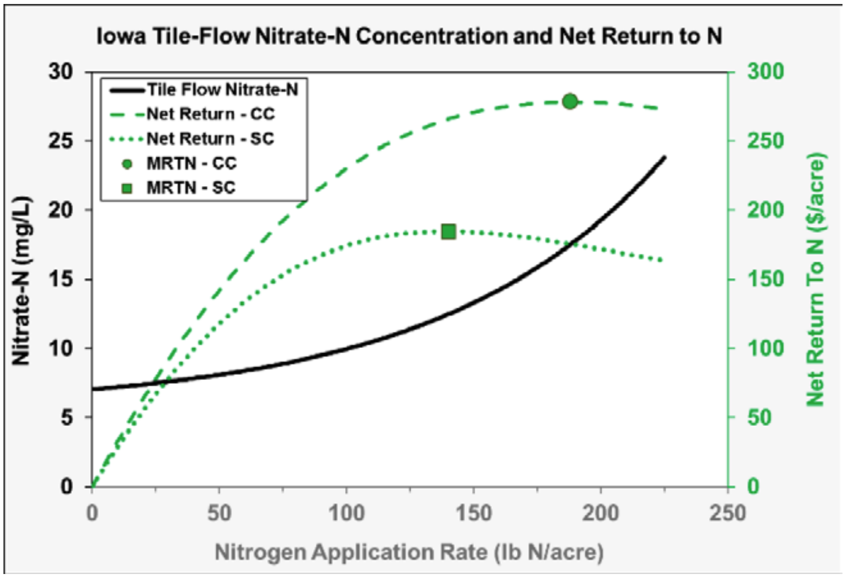

Figure 5. Tile-flow annual mean flow-weighted nitrate-N concentration (Lawlor et al., 2008), which is the same for continuous corn (CC) and corn following soybean (SC), and net economic return to N across rates for CC and SC in Iowa. The maximum return to N rate (MRTN) for each rotation is indicated by the symbol (adapted from Sawyer and Randall, 2008).

Summary

It's not always a gloomy picture for N management. Corn productivity in Iowa is high and ever increasing. Corn hybrids are now more efficient in N use than previous decades, and needed fertilization rates have not kept pace with increasing yields due to increased efficiency and lower plant and grain N concentrations. Those are good outcomes in regard to economics of corn production and nitrate movement to water systems. Adequate soil moisture is helpful for high yields and N mineralization. However, if the frequency of high precipitation increases, then N management will become more challenging from the production and environment aspects. Research will need to continue in order to provide enhanced management options that allow successful N use and crop productivity.

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