Determining Optimum Nitrogen Rates for Corn
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Summary

• Nitrogen (N) is typically the most yield-limiting nutrient for corn production. How to meet N requirements without over-applying is a dilemma corn producers face each year.

• Low N use efficiencies are frequently due to N losses from the system but are also due to an inability to accurately estimate the economically optimum nitrogen rate (EONR).

• There are several methods of developing corn N recommendations, including the “yield goal” or “mass balance” approach and “maximum return to N” (MRTN) approach.

• Growers can adjust N-rate recommendations by in-season testing of N sufficiency, using soil tests or crop sensors.

• All N-management approaches have advantages and disadvantages. Growers should consider various strategies and choose those that maximize profit potential while minimizing risk of over-application and nitrogen loss.

Nitrogen (N) is typically the most yield-limiting nutrient for corn production, and represents one of the largest economic inputs associated with maximizing returns. High N fertilizer prices together with recent N losses from excessive rainfall have placed N management at the forefront of corn production issues in many states. Growers there are questioning previous N management practices and are keen to adopt new strategies for improving N use efficiency in their operations (Mathesius Luce, 2009; Shanahan et al., 2008).

This article reviews newly developed strategies for determining N rates and improving N use efficiency in corn production. This includes the latest procedures for estimating economically optimum nitrogen rates (EONR), known as the maximum return to nitrogen (MRTN) method, along with soil- and crop-based approaches for determining EONR. A second article in the series will discuss the use of “in-season” or “split-timed” N applications to better synchronize N fertilizer inputs with corn uptake. The final article in the sequence will discuss rescue nitrogen applications to corn for situations where significant N losses have occurred due to excessive precipitation.

Difficulties in Determining Optimum N Rates

There are several causes for the low N use efficiencies often experienced in corn production. These are frequently associated with N losses from the system, primarily resulting from excessive rainfall (Figure 1). However, another primary reason is the inability to accurately estimate EONR, the point where the last increment of N returns a grain yield increase large enough to pay for that N (Sawyer et al., 2006a). This uncertainty occurs because corn exhibits a highly variable yield response to fertilizer N application due to highly variable weather conditions.

Inaccurate EONR estimates result in over-fertilization in some years and fields and under-fertilization in others. The former scenario reduces grower profits through wasted fertilizer inputs and can also lead to environmental contamination (Shanahan et al., 2008). The latter situation reduces grower profits through unattained yield goals. Hence, there is an undeniable need to improve N fertilizer management, but the ability to accurately estimate EONR on a year-to-year and field-to-field basis remains elusive (van Es et al. 2007).

Yield-Goal Approach to N-Rate Decisions

Previous methods for developing N rate recommendations have often relied on the “yield goal” approach (Stanford, 1973, Stanford and Legg, 1984). This method begins by establishing a realistic yield goal based on field history and/or current capability. The amount of N required by the targeted yield is then determined from crop nutrient removal tables, (with a percentage added to account for losses). Finally, N “credits” from manure, preceding legume crops and soil
organic matter mineralization are subtracted from the requirement. The result is the amount of nitrogen fertilizer that must be added to supply crop needs.

Also referred to as the “mass balance” approach, this method is simple and holds considerable appeal, but it is not without its shortcomings (Shanahan et al. 2008). The major weakness inherent in this approach is that the relationship between yield and EONR determined by this method appears to be very poor for humid regions of the Corn Belt. This is a compelling limitation, considering that all Midwestern states east of the Great Plains are generally considered humid.

A summary of nearly 300 research studies revealed the limitations of the mass balance approach to N-rate determination. Researchers analyzed data from 298 previously reported experiments in five Corn Belt states in the U.S. where corn yield response to N was measured (Lory and Scharf, 2003). Their investigations showed that the recommended N rates determined by yield goal exceeded EONR by an average of 80 lb/acre. These results strongly support the notion that yield goal is a poor forecaster of corn N needs. Similarly, researchers in Iowa (Blackmer et al., 1997), Kentucky (Grove and Schwab, 2006), Pennsylvania (Fox and Piekielek, 1995), Ontario (Kachanoski et al., 1996) and Wisconsin (Bundy, 2000), also found that yield goal was a poor predictor for optimum N rate.

An explanation for these observations provided by Grove and Schwab (2006) is that years with very favorable growing conditions (adequate but not excessive precipitation) also have favorable conditions for N mineralization from soil organic matter. Conversely, years with poor growing conditions tend to have lower rates of mineralization. Because more N is supplied by the soil in productive years, the rate of N required per bushel of yield is less compared to the years with low mineralization. The net result is that corn requires about the same amount of fertilizer N regardless of the yield potential in a given year. (This does not apply to low organic soils (e.g., sandy soils) incapable of supplying significant N by mineralization).

### N-Rate Calculator Approach to N-Rate Decisions

Acknowledging the problems associated with the “mass-balance” method, extension and crop advisors in several top corn producing states have embraced a new process of N-rate determination for corn. These states: Iowa, Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin are now using the so-called maximum return to N (MRTN) approach for N-rate decisions (Sawyer et al., 2006a). This method provides generalized or regional N-rate recommendations using a database compiled from a network of multi-year and multi-location N-rate field trials conducted in these states. This database is used in fitting yield response curves to N and conducting economic analyses of the yield responses. The approach is embodied in the “Corn Nitrogen Rate Calculator” available from Iowa State University Agronomy Extension: [http://extension.agron.iastate.edu/soilfertility/nrate.aspx](http://extension.agron.iastate.edu/soilfertility/nrate.aspx).

The rate with the largest average net return represents the MRTN (or “EONR”), and recommendations vary with grain-to-fertilizer price ratio. To illustrate operation of the calculator two different N-corn price scenarios for a soybean-corn rotation in Iowa are presented (Figures 2 and 3).

The first example is for corn at $4.50/bu and N at $0.50/lb (Figure 2) and second is for corn at $6.50/bu and N at 0.50/lb (Figure 3). The calculator forecasts MRTN for the two different price scenarios would be 124 and 138 lbs of N/acre, respectively. For a continuous corn rotation, the calculator estimates that MRTN would increase to 176 and 187 lbs of N/acre,
respectively, for the same two price situations (data not shown), reflecting the overall greater N requirements for continuous corn compared to corn following soybean.

It is worth noting that the flat net return surrounding the N rate at MRTN reflects small yield changes near optimum N and indicates that choosing an exact N rate is not critical to maximizing profit. This range provides flexibility in rate selection for growers in addressing production risk and price fluctuations.

**Advantages of MRTN Approach**

The MRTN approach should represent progress over the mass balance method because it incorporates current fertilizer and grain price information and uses updated N-response datasets from an extensive network of ongoing field trials. It recognizes the role soil organic matter plays in supplying a portion of the crop’s N requirements by adjusting N recommendations. For example, recommended N rates are generally lower in northern states (e.g., Minnesota, Wisconsin), where soil organic matter values are typically higher compared to southern states with lower organic matter levels (Sawyer et al., 2006a).

However, because this approach provides generalized N-rate recommendations over large areas and years, it does not address the issue of year to year variability in temperature or rainfall (Grove and Schwab, 2006; van Es et al. 2007). This weather variability can cause considerable year-to-year variation in soil N supply as well as crop N requirements (Shanahan et al., 2008). Nonetheless, the MRTN approach can serve as a general guideline to growers, and be useful for estimating EONR values for their fields.

Another way for estimating EONR is the use of a variety of soil test procedures to approximate soil N supply for crop use (Figure 5). One of the first soil tests growers should consider for this goal is the Pre-Plant N Test (PPNT; Bundy et al., 1995). It measures soil nitrate or soil nitrate-plus-ammonium in the soil (typically from 0 to 24 inches) early in the season, and can be used to direct N-rate decisions prior to or at planting. This test can be used in situations with either high residual nitrate-N from the previous season or for manure applications, where it can provide some direction for adjusting early N application rates based on N inputs from organic matter. Use of the PPNT along with recognition of other nitrate-N credits (e.g., irrigation water) is especially useful for estimating EONR in the drier western Corn Belt (Shapiro et al., 2008). However, this procedure is less useful for estimating EONR in the more humid regions where nitrate-N losses can be high during the early season due to excess precipitation (van Es et al., 2007).

Another test which can be considered for use in approximating available N and/or EONR is the pre-sidedress nitrate test (PSNT) developed by Magdoff et al. (1984). Results from this test provide an opportunity to adjust sidedress N rates (Blackmer et al., 1989) based on residual soil N present at the time of application. Sogbedji et al. (2000) found, for example, that the use of this test resulted in reduced N rates and consequently reduced nitrate leaching, with similar yields compared to the traditional yield goal method for estimating N fertilizer rates. The main problems associated with this approach are the extensive requirements for soil sampling and sample analysis during a short time window in the spring (Ma and Dwyer, 1999).

Finally, the Illinois Soil Nitrogen Test (ISNT) has been offered as an alternative means for identifying fields that are not responsive to N fertilizer (Mulvaney et al., 2001). This simple test measures the level of amino sugars present in the soil, which is presumably related to organic matter contributions to soil N levels. Test values were found to be highly correlated with yield response to fertilizer N applications. The procedure was found to be generally successful at identifying non-responsive sites in Illinois (Mulvaney et al., 2005) and for some regions in the Southeast, when accounting for soil types (Williams et al., 2007). However, several researchers in the Corn Belt (Laboski, 2004; Osterhaus and Bundy, 2005; Barker et al., 2006) found no relationship between the test

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**Figure 4.** Evaluation of corn response to a range of N rates at a Pioneer research trial conducted in Johnston, IA in 2009. In the fourth year of the study, severe nitrogen deficiency was clearly visible in some low N-rate treatments for continuous corn. (Percentages are the % of Iowa State University recommended N-rate applied as a treatment.)

**Figure 5.** Soil sampling.
and EONR. Hence, the procedure appears to have limited utility for optimizing N application rates across the Corn Belt.

### Adjusting N Rates with Crop Monitoring

Recent developments in crop sensing allow for real-time estimation of crop N status during the growing season. Leaf chlorophyll meters (Figure 6, Sawyer et al., 2006b) or crop canopy sensors (Figure 7, Shanahan, 2010) have been proposed as a means for assessing leaf or canopy N status, typically for the purpose of in-season N application. This implies the use of high-clearance fertilizer application equipment.

This procedure generally requires the establishment of an \( N \)-sufficient reference, an area of corn plants that has been well-fertilized since planting. This approach offers particular advantages for large acreages where pre-plant or in-season soil tests are simply too labor intensive for estimating EONR.

Crop sensor technologies offer the opportunity to optimize tradeoffs among yield, profit, and environmental protection (Shanahan et al. 2008). Nevertheless, it should be recognized there are areas where the sensor-based approach may not be appropriate (Shanahan, 2010). One example is rainfed areas where precipitation from the proposed time of in-season N applications to the end of the growing season is low and/or erratic. Under these circumstances, in-season N applications made to the soil surface may be unavailable for crop uptake and thus likely to limit yields. In such cases, current pre-plant N applications would likely be more suitable.

### Conclusions

Current N management schemes for estimating EONR have been mainly designed to provide N-rate recommendations for applications made prior to or at planting. Though these methods have proven to vary in their ability to consistently predict seasonal corn N needs, they provide a starting point for answering the question of how much N to apply. The major limitation of these methods is that they provide static recommendations that cannot account for in-season weather changes that affect soil N availability and/or crop N uptake (van Es et al., 2007). For example, using the MRTN method, which is based on regionalized crop responses (Sawyer et al., 2006a), can result in excessive fertilization in years with dry springs, and inadequate fertilization in years with high early season N losses.

In practice, growers have often opted to use higher N rates in case losses occur due to excessively wet early season conditions (insurance fertilizer). This sometimes results in excessive fertilizer application, unnecessary expense, and increased N losses. Soil test methods like PPNT and PSNT provide opportunities to adjust N rates for variation in soil N supply. Similarly, crop sensing methods enable growers to better synchronize soil N supply with crop N needs, resulting in reduced N rates (Shanahan, 2010). However, these methods are not without their own shortcomings, including additional costs associated with acquiring and processing soil samples (van Es et al., 2007) as well as a narrower time window for in-season N applications. Hence, growers must carefully consider the pros and cons of each N management approach, using one or more strategies (or a combination) that maximize profit potential while minimizing risk.

### Figures

**Figure 6.** A chlorophyll meter is used to collect readings in corn. Source: John Sawyer, Iowa State University.

**Figure 7.** High-clearance applicator with a crop sensor directing in-season N application.

### References


