Site-Specific Management Guidelines

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SSMG-36

Variable-Rate Nitrogen Management for Corn Production – Success Proves Elusive

Summary

- Adoption of variable-rate nitrogen (N) management by North American corn producers is low, despite the potential economic and environmental benefits of this practice.
- A major obstacle is that **recommended** N fertilizer rates based on yield goal are often poorly correlated with **actual** economically optimum N rates.
- Nitrogen response patterns are often field- and season-specific and can vary widely within the same field, further complicating adoption.
- Side-by-side comparisons of uniform and variable-rate N management have revealed no consistent advantages for either strategy in yields achieved, profitability, whole-field N usage, or N-use efficiency by plants.
- In the future, a better understanding of temporal variation in N soil test levels, better crop simulation models, and improved N sensing and application equipment may assist growers in capturing the benefits of site-specific N management.

Variable Rate Phosphorus (P) and Potassium (K) Management…Will It Work for N?

Every season, corn producers must decide on the correct amount of N fertilizer to apply to their fields. Today's global positioning system (GPS)-enabled application equipment and related precision farming tools have created another decision for growers – whether to apply N at a uniform rate or at variable rates within fields.

Early variable-rate management successes with N in sugarbeet (Cattanach et al., 1996) have prompted some growers to consider site-specific N management for corn production. Tailoring N application rates to more exactly meet crop needs should increase profitability, reduce environmental risk, and may result in higher and more consistent grain quality.

Adoption of variable-rate N management is also favored by the widespread availability of application equipment and related precision farming services in nearly all corn-growing regions. However, adoption of variable N application has lagged behind those of other precision farming practices. Recent university research has revealed why. Managing N in sub-regions of fields or even in whole fields is a complex process and challenges some long-held nutrient management beliefs.

The key to success and eventual adoption of variable-rate N management will be the development of decision-making criteria that can **accurately** predict N rates for sub-regions of corn fields that are economically optimum and environmentally sustainable.

This *Guideline* discusses the difficulties in predicting crop N needs, challenges for variable-rate N adopters, and future improvements in site-specific N management for corn production in North America.

Can We Predict N Rates for Corn Accurately ?

The Nitrogen Cycle in Soils

The availability of N to crop plants is affected by a complex set of interacting soil, biological, climatic and management factors (**Figure 1**). These factors have been studied extensively over the last century, and this understanding has been used to develop and refine methods for determining fertilizer N requirements of many crops. In principle, the predicted N requirement is the difference between N needed to produce the biomass of the crop and the net supply of N to plants from all other sources.

Using 'Yield Goal' to Determine N Fertilizer Rates

Agronomists have long sought a simple, easy-to-use algorithm or formula to calculate economically optimum N fertilizer rates (EONR). The typical practice in many states is to use the common-sense relationship between the expected crop yield and the amount of N the crop will

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need. This relationship implies that high yielding locations will respond to higher rates of N while low-yielding locations should require less N.

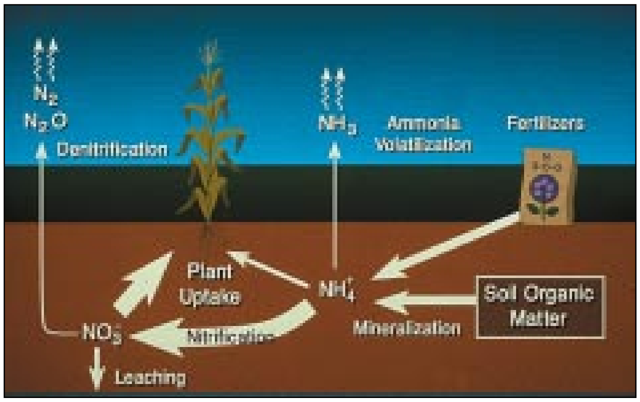

Figure 1. The nitrogen cycle in soils.

Most recommendation strategies include some adjustment for the amount of N needed per bushel of yield, plant uptake efficiency, and any applicable N credits. A typical example is the formula used in many areas of the midwest:

N recommendation = target yield x 1.2 – N credits

In this example, the ***target yield*** is the average yield achieved in the field over the past five years plus 5 percent. Each bushel of grain yield is assumed to require 1.2 lb of N, and ***N credits*** include additions of N in legume residues, starter and other fertilizers, manures, herbicide carrier N solutions, and irrigation water. For a 150 bu/A corn crop following soybeans (***N credit*** of 40 lb/A) the calculated N recommendation would be 140 lb/A.

Each state has a somewhat different approach to calculating N credits and estimating the N contribution from soil nitrate (NO_3) and the mineralization of soil organic matter.

Yield Goals Are Poorly Related to Optimum N Rates

Without question, the total amount of N utilized by a corn crop will increase with yield level. However, extensive research has shown that expected, potential, average, or even actual yields are often poorly correlated with the **economically optimum N rate** for a site. Across more than 460 field studies in Ontario, Colorado, Illinois, Iowa, Michigan, Minnesota, and Wisconsin, variation in the recommended N rate explained less than 10 percent of the variation in the actual economically optimum N rate (Kachanowski et al., 1996; Fleming et al., 2000; Harrington et al., 1998; Blackmer et al., 1992; Everett and Pierce, 1996; Davis et al., 1996; Vanotti and Bundy, 1994).

Other important findings have emerged from these studies:

- The EONR's in sub-regions of a single field varied widely, ranging from <30 to > 200 lb N/A.
- High-yielding sites with low N requirements and low-yielding sites that responded to unexpectedly high rates of N were common.
- The best predictor of EONR was the yield of control plots that received no N fertilizer. Unfortunately, this information is not available to guide pre- or in-season N management.
- Soil type, landscape position and soil drainage class showed no consistent relationship with N response.
- N response patterns in fields with similar cropping history, yield levels and soil characteristics can be very dissimilar.
- N response patterns in the same field varied dramatically in different seasons even if the overall yield patterns were similar across years.

In summary, there are temporal factors affecting N levels in soils that are independent of soil type and landscape position that are not well understood and complicate variable-rate N management.

Current Variable-Rate N Strategies

In the mid-1990s, many researchers expected that developing accurate N recommendations for sub-regions of fields would be a certainty. Part of this optimism stemmed from the development of many new tools such as soil and stalk NO_3 tests, remote sensing, yield monitors, and soil electrical conductivity maps that measure site characteristics directly related to crop N status, soil N supply, or crop productivity. However, for these new spatial tools to be effective, the variable N application maps they helped produce had to be accurate and applicable from year to year.

Proactive Strategies

The first variable-rate N strategies took a proactive, prescriptive approach. Fields were divided into smaller sub-regions, and methods developed for whole field N management were applied to these individual "management zones". The variable N rate prescription map was developed prior to the growing season, and fertilizer was applied at the usual time(s). These approaches included the use of **grid soil sampling** and **crop productivity zones**. In general, many studies found:

- There is no consistent income advantage for either variable- or uniform-rate N strategies.
- Yields were not impacted by N strategy.
- Whole field N rates were similar for either strategy.
- Post-season soil NO_3 levels were not appreciably reduced when using variable-rate N.
- Either strategy could out-perform the other in a particular growing season, depending on crop related conditions.

Other difficulties were revealed through detailed on-farm research over the past 10 years in Minnesota. This research found that N response patterns within a field often do not mimic yield patterns. This could invalidate yield level indicators such as yield maps, corn suitability ratings, etc. for use as sources of information on which to base site-specific N recommendations. This research also discovered that N response patterns within the same field can be dissimilar in different seasons (**Figure 2**). Clearly, much additional research is needed to be able to predict N response patterns on a field scale.

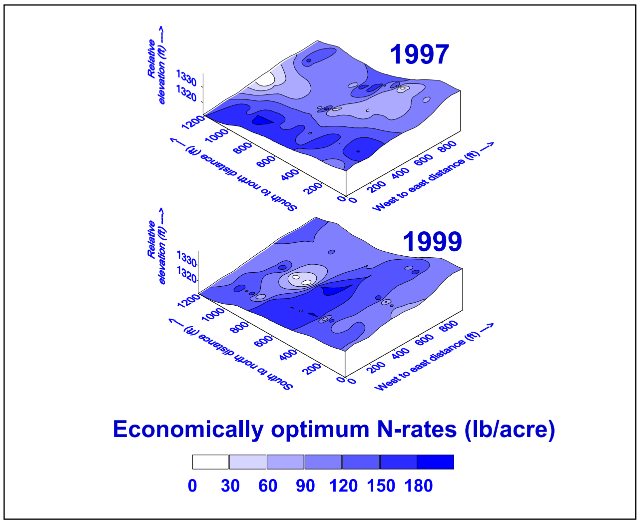

Figure 2. Maps of the EONR for a 30-acre corn field near Windom, Minnesota in 1997 and 1999. The N rates are overlain on a block diagram to show the topographic relief in the field. (Courtesy of Gary Malzer, University of Minnesota).

Reactive Strategies

A second approach to site-specific N management involves reacting to actual N levels in corn fields during the growing season. Crop N status is monitored in near-real time, and N is applied only when and where it is needed. With this method, plant or canopy reflectance of light or chlorophyll content is used to indicate plant N stress. This approach can utilize remotely-sensed crop canopy imagery and typically requires the presence of an adequately N fertilized reference strip within each field (Schepers et al., 1992). Interestingly, these optical methods create in-season N prescription maps that are based on crop N stress rather than yield level.

A variation of this method is to equip field applicators with remote sensing devices similar to those contained in satellites or aircraft. Then, the applicator moves through the field, sensing the N status of the crop and directing N application on-the-go (**Figure 3**). For example, Scharf and Lory (2000) developed a system that uses a tractor mounted radiometer to take green:near infrared canopy reflectance readings beginning at the 6-leaf stage. These readings are compared to similar readings from a well fertilized reference strip to determine the presence and severity of N stress. From that estimation, it may be possible to predict optimum sidedress N rates.

Challenges for Variable-Rate N Adopters

Although technology is available to deliver different rates of N across variable fields, this practice is not yet economically beneficial in most cases. Growers who wish to implement variable-rate N management strategies should be aware of these challenges:

- **Potential cost savings can be minimal.** The maximum potential benefit of a variable-rate N strategy vs. a conventional uniform-rate is typically between $5 and $15/A. When all the costs of developing and executing the variable-rate strategy are considered, the net return may be insufficient to cover the added expenses.
- **Prescriptive N strategies involve risk.** Prescriptive strategies are not yet reliable and cannot respond to unexpected in-season crop conditions. These could include unusually favorable growing conditions or yield-limiting events such as frost, hail, stalk lodging, pest infestation, drought, or N losses resulting from excessive rainfall and denitrification.
- **Reactive N strategies can limit yield potential.** Nitrogen deficiencies prior to the 8-leaf stage can result in non-recoverable yield loss. In addition, adverse weather conditions after emergence could restrict field entry and further delay the correction of an early season N deficiency.
- **Check strips should be included.** If a variable-rate N strategy is used, growers should be sure to include several uniform rate check strips per field. These strips can be conveniently harvested as separate loads on a yield monitor or as side-by-side comparisons with a weigh wagon. A uniform N rate should be used in these check strips based on current university or local recommendations. Additional uniform N strips with rates 50 lb/A above and below the recommended rate may also be helpful.

Figure 3. High-clearance applicator equipped for on-the-go sensing of crop N status and variable-rate N application (Photo provided by USDA-ARS, Lincoln, Nebraska).

Future Improvements for Variable-Rate N

New N management strategies will be adopted by producers if they reduce risk and are affordable, accurate, easy to use, and environmentally sustainable. For corn production, this probably precludes the use of grid soil sampling for N content, due to the cost of sampling and analysis and the limited life of sample results.

Future use of any N recommendation formula based on yield goal, productivity index, or soil type should be carefully evaluated for accuracy and reliability under field conditions.

Clearly there is a need for new diagnostic tools that provide a better prediction of the EONR in sub-regions of fields. These tools must consider temporal variability in the environmental factors that affect crop responsiveness to N.

Researchers at Oklahoma State University have reported very promising results with in-season correction of N deficiency in winter wheat. They use two post-dormancy crop canopy reflectance readings plus the number of growing degree days between the two readings to estimate topdress N requirements on-the-go. In two field tests, this procedure increased wheat yields by an average of 15 percent and decreased the whole field N rates by 44 percent when compared to a uniform N rate strategy (Solie et al., 2000). The researchers are currently modifying this system for use in corn, with a prototype expected in several years.

Crop simulation models may provide an economical way to estimate economic and environmental outcomes of different N management strategies in the future. These models intensively characterize a site and then evaluate crop growth and nutrient utilization using multiple years of historical weather data. Initial model simulations have shown only small benefits for variable-rate N management strategies (Paz et al., 1999). One excellent contribution of these types of models is the identification of site characteristics that do and do not have significant effects on crop response to N fertilizer in different cropping regions. However, these models will only add value at the farm level if they are carefully validated under multiple environments and lead to a better understanding of the way corn crops respond to N fertilizer.

In many ways, adoption of variable-rate N and variable-rate seeding in corn has been similar in that the technology available to vary these inputs likely exceeds the knowledge of how to best use it. When finally successful, variable-rate N strategies will need to be carefully customized to fit local soil, climatic, and agronomic conditions. ■

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