Site-Specific Nutrient Management

For Nutrient Management Planning To Improve Crop Production, Environmental Quality, and Economic Return

Nitrogen: Chapter 2 of 10

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Funding provided by the USDA-NRCS and TFI.

Chapter 2:

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Introduction

Nitrogen (N) is essential for plant growth and is part of every living cell. It plays many roles in plants and is a component of chlorophyll, which is necessary for photosynthesis. Symptoms of N deficiency in plants generally include chlorosis or yellowing. Nitrogen is typically taken up in larger amounts than other nutrients and is the most common, and most important, limiting nutrient for non-legume agricultural crops. Not only does N nutrition affect yield, but it also affects the quality (protein or sugar content) of crops such as grain and sugar beets, for example. In addition, N also has interaction implications with efficient use of other nutrients. To understand how N management (cropping systems, N fertilizer forms, application rates, and timing of N fertilization) affects crop yield and quality, it is important to first understand the various processes that N undergoes in the soil-plant system.

Basic nitrogen processes in the soil-plant system

Nitrogen, present or added to the soil, is subject to several changes (transformations) and gain/loss mechanisms that dictate the availability of N to plants and influence potential N-related environmental issues. These processes are listed and briefly described in Table 1. As is demonstrated by the extensive list, N cycling in the soil-plant system is complex, which increases the difficulty for N management.

Table 1. Processes that N undergoes in the soil-plant system, factors that influence these process, and consequences for N management.

Process	Definition	Enhanced by	Consequence for N management
Mineralization	Conversion of organic N forms to inorganic N (ammonium, NH_4^+) through microorganisms.	Warm, moist, well-aerated soils.	Increase N (NH_4^+) readily available for crop uptake or loss by leaching.
Nitrification	Conversion of NH_4^+ to nitrate (NO_3^-) through bacteria.	Warm, moist, well-aerated soils.	Increase N (NO_3^-) readily available for crop uptake.
Immobilization	Conversion of inorganic N forms (NH_4^+ and NO_3^-) to organic N through bacteria.	High carbon-low N residues. Warm, moist, well-aerated soils.	Reduction in the amount of plant-available N.
Leaching	Loss of NO_3^- as it moves with soil water below the root zone.	Coarse-textured soils, excess rainfall or irrigation.	Reduction in the amount of plant-available N and water contamination.
Denitrification	Process by which bacteria convert NO_3^- to N gases (N_2 and N_2O) that are lost to the atmosphere.	Waterlogged and warm soils with high soil organic matter (OM).	Reduction in the amount of plant-available N and air contamination.
Volatilization	Process by which N is lost as ammonia (NH_3) gas to the atmosphere. This mechanism is enhanced greatly by the enzyme urease, which is present in the soil and plant residues.	Application of manure and fertilizer products containing urea. Warm, low cation exchange capacity (CEC) soils, high pH soils, high surface residue.	Reduction in the amount of plant-available N and air contamination.
Crop uptake and removal	Amount of N that is lost from the soil system through crop harvest.	Good conditions for plant growth.	Reduction in the amount of plant-available N.
Erosion	Nitrogen loss from agricultural lands through soil erosion and runoff.	Highly erodible soils with excess tillage.	Reduction in the amount of OM and potential plant-available N and reduced water quality/contamination.
Symbiotic N fixation	Conversion of N gas (N_2) in the air to plant available N through microorganisms in association with legume plants.	Good conditions for plant growth and low levels of inorganic soil N.	Increase available N supply to legumes and decrease fertilization need of subsequent crops.

A good knowledge of these processes and their interactions helps with understanding the underlying principles for optimal N management practices, from both the production and environmental perspectives. Many years of research and experience by crop producers and advisers have resulted in valuable tools to aid in determining when, how, where, and how much N to apply to crops. For example, tools include fertilization rate guidelines, analysis of soils and plant tissues, chlorophyll meter (CM) and crop canopy sensing for plant N stress, site-specific technologies, and economic evaluation of N management practices and fertilization recommendations.

Rate determination and economic response

Nitrogen fertilization rate is the most important N management decision regarding potential to achieve optimum crop yield, influence nitrate loss to water systems, and return maximum economic profitability. Nitrogen fertilizer price volatility has increased in recent years, and continues to be one of the most expensive variable production costs. For cereal crops, N fertilization is required to achieve acceptable production levels. Several terms or acronyms are important to be understood in relation to yield response to N and economic returns. The term “Agronomic Optimum N Rate” or AONR defines the N rate that will produce maximum grain yield, regardless of cost. The term “Economic Optimum N Rate” or EONR defines the N rate that will result in the maximum economic return to N, the point where the last increment of N just pays for the applied N. The recently developed recommendation approach “Maximum Return to N” or MRTN is similar to EONR and defines the maximum response rate and an N rate range within a set economic return level from the maximum return (within $1/acre). The MRTN is derived directly from a population or database of N response research trials. The EONR, and MRTN rates are less than the AONR, will decrease as N prices increase relative to crop price, increase as grain prices increase relative to N price, and remain the same if the ratio between N and grain prices remains the same even though prices change. These economic rate determination approaches require yield response data from numerous field trials documenting yield responses to N fertilizer rates across different soil types, growing seasons, crop rotations, genotypes, tillage systems, etc.

Figure 1 depicts a low corn grain yield when no N is applied, and a large increase in yield with N application. The challenge is to identify application rates that allow for maximum economic net return without over- or under-fertilization for different conditions. In Figure 1, the blue points indicate the EONR. Due to the need to pay for the fertilizer input, recommended rates are less than the rate to produce maximum yield (indicated by the vertical lines). They are close to the rates that result in the maximum yield, however, and in the example the yield for the EONR is 98% of agronomic maximum yield. One can also see the influence of the prior crop on crop response to N and yield. For example, the EONR is

170 lb N/acre for corn following corn (CC) and 123 lb N/acre for corn following soybean (SC), with an approximate 15% higher yield for the rotated corn.

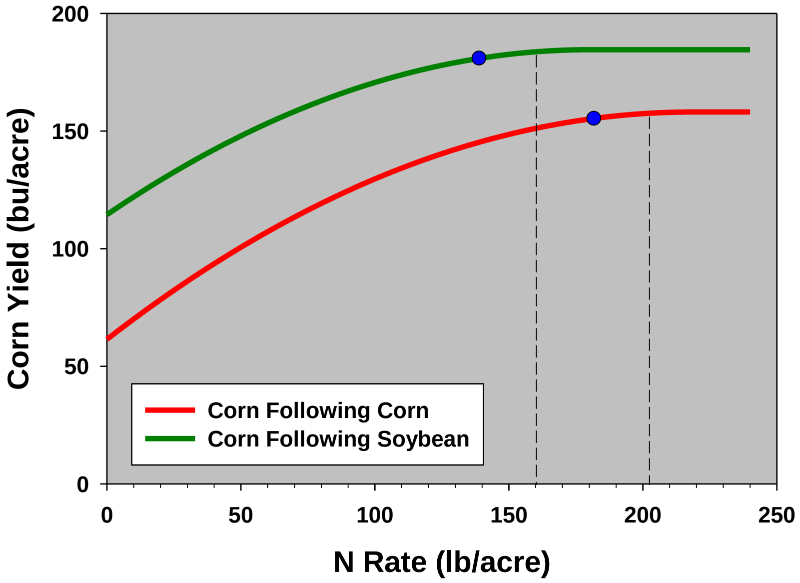

Figure 1. Nitrogen rate response of corn following corn and corn following soybean in Iowa. The vertical lines indicate the agronomic optimum N rate (AONR) and the blue points the economic optimum N rate (EONR). J.E. Sawyer, Iowa State University.

Applying "more than enough N" is no longer a safe and cheap "insurance"; certainly not as it once was due to the increased cost of N fertilizers. Also, applying "more than enough N" is not environmentally friendly and, therefore, must be avoided. High N fertilizer costs, uncertainty about crop process, and environmental impacts should encourage growers to critically determine N application rates. Figure 2 shows how nitrate-N loss increases as N rate increases beyond the optimum N. This concept applies for all crops fertilized with N and most production scenarios, which highlights the importance of accurately determining the optimum N rate to maximize profitability and minimize environmental impacts within specific crops and production systems. In spite of much research, this is much easier to say than actually achieved in production fields due to the numerous and unpredictable factors that affect the optimum N rate and the crop response to applied N.

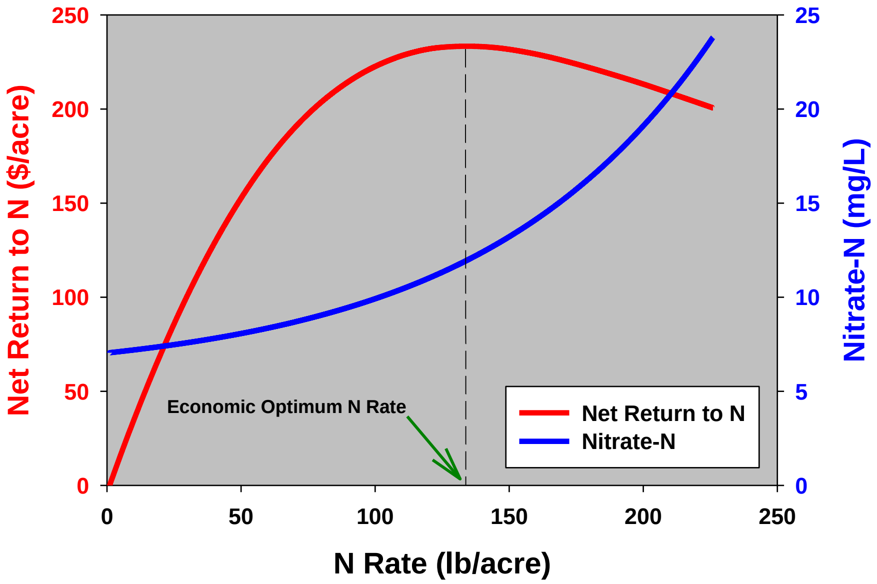

Figure 2. Importance of using optimum N rates for greatest profit and minimizing nitrate-N loss (via subsurface tile drainage).

The common N rate recommendation system used in cereal crops for many years in the Midwest USA and other regions was a yield-goal based factor. This approach uses expected crop yield as the criterion for determining N rates; the higher the expected crop yield the greater is the N requirement, and presumably the recommended N rate. For example, N recommendations for wheat in Ohio have been based on this rate equation: 40 + [1.75 x (yield potential - 50)] (mineral soils, with 1 to 5% organic matter and adequate drainage). The equation indicates that a realistic yield goal should be the first place in which to consider rate adjustment. For example, if the yield goal has been targeted at 100 bu/acre but yield has actually been 80 bu/acre, then the crop has received 35 lb/acre each year that were not needed for grain yield production and therefore prone to be lost.

This yield-goal recommendation approach is still the recommendation system in some regions and some crops (for example, irrigated corn in Nebraska). In the Midwest USA, however, research for corn and other grain crops has identified a poor correlation between individual site-year crop yield and EONR, and that the EONR for a specific soil do not necessarily change with yield level. Figure 3 shows an example of this issue for corn in Iowa, but similar results can be found for other regions and crops. At issue is the concern of too high or low calculated N recommendations when based on yield goals. Therefore, some university N recommendation systems have moved away from yield-based systems to N response data-driven recommendations that are sensitive to N and grain prices. In the Midwest USA this approach is called MRTN, Maximum Return To N. Economic-based approaches are not new; however, this particular approach links documented yield responses to N rate from recent research trials directly with the relative economics of grain price and N cost.

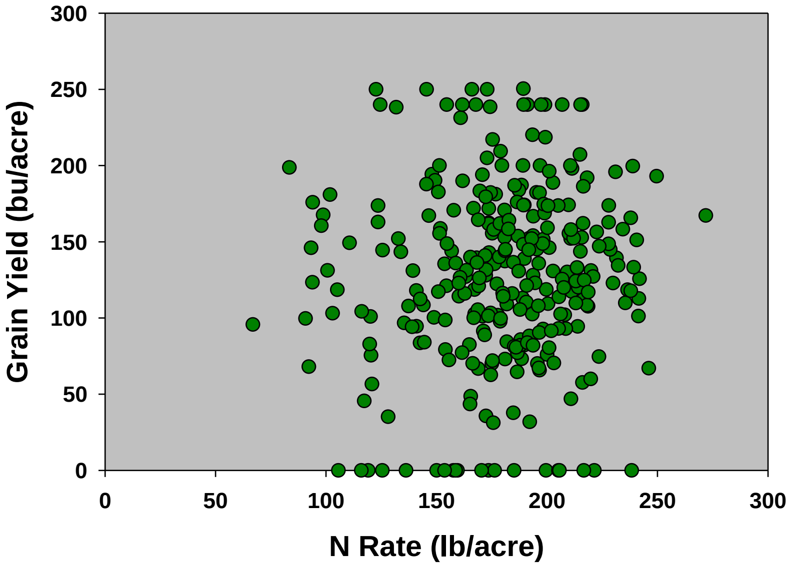

Figure 3. Relationship between net return to N and applied N rate for corn after soybean in Iowa. J.E. Sawyer, Iowa State University.

An important aspect of the data-driven approach is the need for current N response trials. This is an issue with all recommendation systems, that is, keeping current with changing cropping practices and environmental conditions. It is also important to utilize rate recommendations derived from research in representative geographic areas and cropping systems as needed fertilization rates vary based on soils, climatic conditions, and crops grown.

Soil testing and rate adjustment

Soil testing for relatively “immobile” nutrients, like phosphorus and potassium, is commonplace in most production systems. With the importance of N fertilization, and the difficulty in rate prediction, one would assume that soil testing would be as widely used for N management as is for other nutrients. However, soil sampling and testing for N is less used, and often works best only in certain geographic regions and crops. The reason for limited use is due to the many and rapid processes that influence N in soil, such as change in inorganic N forms and levels, especially in humid regions, variation in net N mineralization rate and prediction of that rate, and nitrate losses after measurement. The limited use of soil N testing is also related to the time required for sampling/analysis and the desire for rapid results, for example when adjusting sidedress N applications. There are two general soil N test sampling approaches used, with both based on soil nitrate. One is post-harvest/preplant sampling and the other is in-season sampling.

Preplant soil sampling

Post-harvest or preplant soil sampling is based on determination of the profile (rooting zone) soil nitrate-N amount. This is either determined directly by sampling the rooting depth or by sampling a shallower depth and then predicting the amount for a deeper profile. Usually only nitrate-N is measured, and not ammonium-N as ammonium is converted quickly to nitrate and the measurement is attempting to find residual inorganic N from mineralization or unused fertilizer which would be predominately nitrate. In humid regions (like the Midwest, Eastern, and Southern USA), leaching and denitrification typically cause soil profile nitrate levels to change rapidly and therefore be unreliable as an adjustment to application rates for subsequent crops. Profile nitrate sampling/testing is more reliable and useful in dry climates (for example the northern Great Plains area) and areas where soils remain frozen for much of the time between fall harvest and spring planting (for example the upper Midwest).

Preplant profile sampling systems account for the amount of nitrate-N. The amount of nitrate-N is subtracted from the general recommended rate to arrive at the amount of fertilizer N to apply. This is illustrated in Figure 4. In some systems a baseline amount of nitrate is assumed, so the amount measured is adjusted downward for that baseline before determining the fertilizer rate to apply.

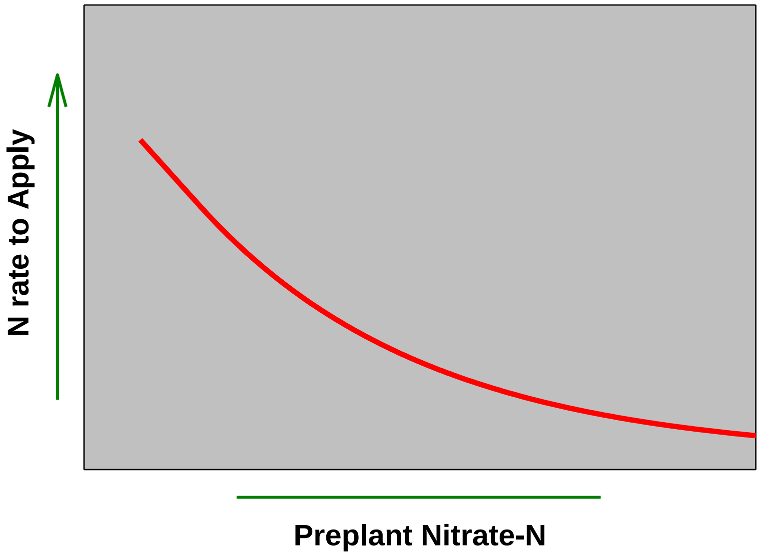

Figure 4. General relationship between N fertilization rate and preplant soil nitrate-N content.

The depth of soil sample and the depth increments separated for nitrate analysis are determined by local research and cropping system needs. Fall profile sampling may be to the rooting depth, up to four or five feet, or more shallow for spring preplant profile sampling (often 2- to 3-ft sample). In Montana, for example, fertilizer guidelines for spring wheat consider the total of amount of nitrate-N (2-ft soil depth) in the spring and a general estimate of fertilizer N needed. Then specific fertilizer rates for a field are calculated by subtracting the measured nitrate-N from the recommendation. For example, if the spring wheat yield potential is 50 bu/acre (the recommended total N is 165 lb N/acre for that yield), and if the preplant 2-ft depth soil nitrate-N measured is 40 lb N/acre, then the fertilizer rate to apply is 165 – 40 = 125 lb N/acre.

In-season soil sampling

The objective of in-season sampling is not to quantify the total inorganic N present in the soil rooting profile, but to develop an index of N availability that integrates residual inorganic-N and springtime mineralized N up to the sampling time. Soil samples are collected prior to the maximum crop N uptake period, and allowing for time to make needed N applications. For example, the nitrate-N concentration determined in soil samples collected in corn at V6 (when plants are 6 to 12 inches tall) or in winter cereals at tillering has been related through research with crop yields and EONR. This type of test goes by different names depending on the region and intent. A test for corn, for example, in some regions is known as the pre-sidedress nitrate test (PSNT) while in other states is referred to as the late-spring nitrate test (LSNT). For both, the soil is sampled to a one-foot depth and analyzed for nitrate-N concentration when corn is 6 to 12 inches tall. The test is calibrated for a specific sample time, crop, and region. That is, the nitrate concentration (index) is evaluated against relative yield and fertilization rate requirement for specific situations (general example in Figure 5).

Figure 5. Generic relationship between economic optimum N rate and in-season soil N, i.e. PSNT in corn or soil N at late tillering in small grain cereals.

Use of locally developed critical values is important as the soil, environment, and crop influence the relationship between soil nitrate concentration and crop response to N application. Also, states may have specific adjustments for test interpretation based on situations such as previous legume crop, manure application, and springtime rainfall amount. For the PSNT or LSNT in corn, for example, is approximately 20 to 25 ppm nitrate-N. There may be some states or regions that include ammonium-N in addition to nitrate-N in specific situations, such as soils amended with organic wastes (manure, sewage sludge, etc.), where ammonium plus nitrate analysis may improve prediction of in-season N responses compared to nitrate alone.

The N-fertilizer need is calculated by subtracting the measured concentration of soil-test nitrate-N from the previously determined critical concentration and then multiplying the result by a factor, or using a table where the N rate recommendation is reduced as the test concentration increases. In Iowa, for example, the difference between the test result and the critical value for the LSNT is multiplied by 8 because studies have shown that it generally takes 8 lb N/acre to increase the soil-test nitrate-N by 1 ppm. For example, if a soil tests 15 ppm and the critical concentration is 25 ppm, then the fertilizer recommendation would be 80 lb N/acre [(25 ppm – 15 ppm) x 8 = 80 lb N/acre.

Chlorophyll/Canopy Sensing and Plant Sampling

Plant N sufficiency/stress sensing offers a relative new approach to determine crop N status and manage in-season fertilizer applications. The concept is to have the plant assess the supply of plant-available soil N, and show potential deficiency through reduced plant growth and coloration. Instead of a soil test, the plant is the used as the integrator of soil N supply with plant need. Adequate crop growth is needed in order for the plant to have significant N uptake and have potential to show N deficiencies; and then time is needed to make N rate decisions, apply N, and have the crop respond to that N. Cereal crops take up N rapidly beginning at specific growth stages (V6-V8 in corn and late tillering in small grains for example). Since the objective is to detect and correct N deficiency in time for adequate yield recovery, N stress sensing may begin at those growth stages. If there is no expression of N deficiency, then the sensing either misses later season development of deficiency or none exists in the field.

Plant sampling with N analysis is infrequently used to derive rate recommendations in many crops. This has been due to difficulty in determining specific critical values and correlation to rate need, practicality for sampling, cost, and other issues similar to those with plant sensing. Plant sampling of specific plant parts has been useful in certain crops, especially for monitoring and to determine N adequacy/deficiency, for example, petiole nitrate analysis in potato and cotton, and total N in winter wheat at tillering. With corn, in-season plant tissue sampling/analysis has been difficult to find strong relationships with N fertilization need, and therefore research efforts have been directed to plant and canopy sensing to determine N need and rate determination. In corn the concentration of nitrate-N in the lower stalk near plant maturity has been useful to determine situations of excess N availability. It has not, however, been calibrated to specific rate adjustment, and of course is specific to adjusting N in future years, not the current year.

Chlorophyll meter (CM) and canopy sensor readings are unit-less values and by themself do not adequately determine N sufficiency/stress. When readings are compared (normalized) with readings from an adequately N fertilized reference area (non-N stressed), then the crop N status relative to the greenest and/or greatest vegetation crop area in the field is evaluated. It is critical that each field has reference strips or areas to reduce the confounding effects of other variables on growth and coloration such as hybrid/varieties, other nutrient deficiencies, soils, or environmental conditions. Reference strips or areas can be created by applying extra N (approximately 50 percent more than typically required for the rotation) at preplant or early sidedress growth stages. Other reference concepts include using a “virtual reference”, where the best (greenest and greatest growth) crop in the field is used as the reference and no pre-set references are created with extra applied N. Normalization is made by taking the average reading of the crop in the area of interest and dividing this number by the average reading of the closest reference area. Enough reference areas are needed to characterize differing field areas.

Figure 6 shows a conceptual relationship (calibration) between normalized CM or canopy sensor values and the differential (N rate difference) from the EONR. Information like this, or other calibrated algorithms, should be used to decide how much N (if any) is necessary to apply based on CM or canopy sensor determinations. This type of information is being developed by universities and the industry to help producers make in-season N decisions based on these sensing tools. Various sensing devices are available, including the Minolta SPAD 502® CM (Konica Minolta) and several canopy sensors like the GreenSeeker® (NTech/Trimble), Crop Circle®/OptRx® (Holland Scientific/AgLeader), and CropSpec® (TOPCON).

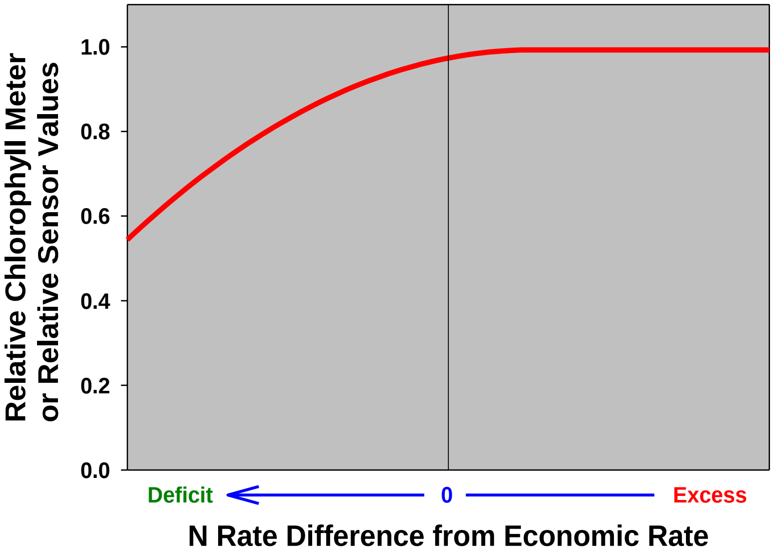

Figure 6. Relative chlorophyll meter or relative canopy sensor value as related to the differential from the economic optimum N rate in corn in Iowa. Rates to the left of zero are deficient N, and to the right excess N.

Chlorophyll Meter

The Minolta SPAD 502 CM is a handheld device that measures the greenness of crop leaves as reflected by the chlorophyll content and N status. The relationship between leaf greenness and N sufficiency is well documented for various crops. Plants will reach a maximum greenness with adequate N and when N stressed, the plants will be less green. The CM is highly portable and provides an instantaneous non-destructive reading of the crop N status. It is important to sample the plant part (same leaf at the same spot on the leaf) and growth stage that has been used for the CM sensing calibration. For corn, this is halfway down the leaf from the tip to the base and halfway from the leaf edge to the midrib, and the uppermost leaf that is fully collared (leaf collar fully visible around the stalk) at mid-vegetative growth stages. For cereal crops, sampling may be at or after late tillering. Readings should be collected from many plants to account for sampling errors and natural color variation across leaves and between plants.

The example for Iowa research of the CM method for corn in Figure 6 shows that relative CM values decline below optimal N, and as the relative values become smaller, the N deficiency and needed N application rate increases. However, relative CM values are similar with slight deficient N, adequate N, and excess N. This makes it difficult to determine in-season N need when N deficiency is slight. Research has shown that in-season N applications may be suggested by relative CM values when the N deficiency appears slight, but yield response indicates the in-season N is not always needed. At a given relative CM value, the N rate is derived from the calibration curve. For example, at a relative value of 0.93, the suggested N rate would be 60 lb N/acre. Either an equation can be used for determining application rates, or a table can be created that gives N rates for ranges in relative CM values.

In the same way, in-season N recommendations for wheat (Kentucky) are based on CM readings at Feekes 5 growth stage (late tillering): N rate (lb N/acre) = 6 + (7 x (CM reference area – CM field)). For example, if the CM value of the reference area at late tillering is 52 and the CM value of the rest of the field is 45 the recommendation would be 6 + (7 x 7) = 55 lb. N/acre. When using a CM to determine N stress and N application need, it is important to follow locally suggested sensing timing, crop stage, plant part, and calibrated application rates.

Active Canopy Sensors

Active canopy sensors, which are positioned above the crop canopy, have been developed as a tool to determine plant N stress deficiency and provide an on-the-go decision for implementing variable rate N application. This is a relatively new method of remote sensing. It is similar to that of natural light reflectance with passive (reflected sunlight) sensing technologies. However, active canopy sensors utilize their own light source and measure light reflectance in real-time at the canopy level. Initial research with the GreenSeeker active canopy sensor in Oklahoma documented that active sensors are a viable method to improve N use efficiency in winter wheat, and when compared to uniform N rate application based on traditional yield goal, N use efficiency was improved 15%. In corn, research with active sensors has investigated issues such as growth stage for sensing, need for normalization of sensor readings to non-limiting N field areas, and calibration of sensor indices to N fertilization requirements. Also, use of active sensors to direct variable rate N must include an understanding of situations where other factors are limiting growth, such as poor stand, excess water, or other nutrient deficiency.

Many canopy indices can be calculated from the visible (VIS) and near-infrared (NIR) light reflectance variables typically collected with active sensors. Examples being implemented are normalized difference vegetative index (NDVI) and chlorophyll index (Chl). Indices emphasize different plant characteristics important for determining N stress, such as plant canopy biomass or plant coloration. The various indices have different strengths and weaknesses. Most important is to know the sensor and especially the index being utilized, and the specific calibration of the index for the crop being sensed. As with the CM, there needs to be a calibration between the relative index, N stress level, and recommended N rate to apply. Nitrogen application rates based on canopy sensors should be calculated using locally developed algorithms and recommendation systems.

An important consideration for active canopy sensing is the crop stage to sense. For corn, this is still a subject of research. It appears that the early to mid-vegetative growth stage may allow for adequate expression of N stress, if it is to occur, and if N deficiency is found then time for corn to respond to applied N. Of issue, as with the CM, is the rate of N applied preplant, at planting, or early sidedress. The greater that N rate, the less chance for significant N stress to develop by the time of sensing, especially for early growth stages. The lower that rate (or no application), then the greater the chance for N stress development that can be measured, but also the greater chance for too much N stress and loss of crop yield potential. As with the CM, the difference between slight N deficiency and adequate to excess N is difficult to differentiate with active canopy sensors.

Two general approaches could be implemented with active sensors. One is to plan on conducting canopy sensing each year, with a reduced N rate applied preplant, at planting, or early sidedress and then sensing conducted at mid-vegetative growth to determine additional application need. A second approach is to conduct sensing only if conditions result in N loss from the primary N application, or other factors change expected crop requirements. Both approaches could address variable N fertilization and seasonal circumstances. The second approach allows producers to use normal preplant or early sidedress N management. However, there could be instances where less than normally recommended N rates would produce optimal yield, and those situations would be missed with that approach. Also, as with CM sensing, canopy sensing may miss season-long N deficiency if the preplant rate is adequate to meet plant needs through the time of sensing.

Variable Rate Technologies

Recognition of within-field variability in soil properties, crop yield, crop nutrient need, and nutrient supply by site-specific nutrient management is gaining popularity as technology advances. Applying different amounts of N fertilizer in different parts of the field according to soil conditions and crop need seems intuitively obvious. Crop producers are interested in variable rate N management due to the popularity of site-specific phosphorus, potassium, and lime application. Producers know soils differ within fields, and often those differences can result in significant yield variation. During the growing season, crops may express differences in leaf color if N or other nutrients are low in supply and deficiencies result. Crop and soil computer simulation models also suggest there can be substantial differences in soil N supply or crop N demand within a field.

Whole fields are divided into management units where the fertilizer application may differ using some form of field diagnostic, such as intensive soil sampling, soil and crop remote sensing, aerial images, yield mapping. Consistently poor crop performance in one part of the field may indicate (although not always) greater potential for N loss if N is applied uniformly across the field. Variation in soil organic matter and soil texture can be important influences on N management. Soil maps, bare soil images, grid soil sampling and/or mapping of electrical conductivity may indicate this type of variation. For example, a field divided into knolls, mid-slope and depressions areas may have a small N demand in the depressions, moderate on the mid-slope, and high on the knolls. However, producers know that while the fertility level may be low on the knoll, so can be water supply and yield potential. Field history can also be zoned to account for old barnyard sites, past manure management and sections of the field which may have been broken from natural grassland later than other areas. Together, this information can be used to develop zone specific nutrient application strategies. However, the magnitude of the variation or lack of predictability or repeatability in N rate need may not justify varying N rates. Aerial imagery is useful once the crop canopy is sufficiently developed and soil reflectance no longer dominates the image. These tools are particularly suited for surveying large areas, such as when wet weather creates potential for N loss. Aerial photos or calculated sufficiency indices potentially can be calibrated to predict likely yield gain from applying additional N.

A recent, and potentially the most promising approach for making variable rate N applications, is the use of the previously mentioned active canopy sensors. The sensor is mounted on a field applicator capable of varying the N rate on-the-go. In instances where field variability of N is large, this type of application prevents the over-application characteristic of fixed field rates in those areas where the soil N supply is sufficient. Potential drawbacks of chlorophyll or canopy sensors were discussed before and apply to their use for variable-rate application. For example, the leaf area needs to be sufficiently developed to reflect enough light to reliably indicate N fertilization need. This increases risk as wet weather may delay or prevent sidedress application. To approach in-season N management in tall crops, i.e. corn or sorghum, high clearance equipment is likely needed to apply sensor-based N. In-season variable rate N application may be useful and very practical for fertigation because of rapid advances in the technology to sense N deficiency and vary N application rates through center-pivot systems. The specific knowledge and recommendations for variable-rate N application at this time vary greatly across states due to the different set of issues across regions and different pace of research.

Application Timing, Product and Placement

Timing

The demand for N by a growing crop is not constant through the growing season, with the highest uptake associated with the period of most rapid growth. Timing N fertilizer applications so that they provide a plant-available supply of nutrients when the crop needs them is the desired goal. Plants subject to deficiency during a high demand period may not recover to achieve full yield potential even with high N rates applied too late. Because N fertilizers are subject to transformation in the soil, application timing can play a critical role in optimizing crop response and high use efficiency.

Producers in certain geographic areas, such as the upper Midwest (colder winter season) and Great Plains (drier winter season) prefer to apply N fertilizer for corn as anhydrous ammonia in the fall when there is more time for application, the N price may be lower, and the soil is more likely to be in good condition for application. The disadvantage of fall application is increased risk of loss before crop N uptake the next summer. Nitrification of ammonium N will be slow if the soil temperature is low after application, with a suggested practice to not apply ammonia in the fall until soils cool to 50°F and continue to get colder. Fall-applied N may be nitrified before the crop is planted due to application when soil temperatures are relatively high, unexpected warming of the soil after application, periodic warming during the winter, and early warming of the soil in spring. This nitrate will be subject to leaching and denitrification with spring rains and waterlogged soils that occur before and after the crop is established. Anhydrous ammonia is slower to convert to nitrate than ammonium from other fertilizers and is the only N source that should be considered for fall application in most areas. Use of a nitrification inhibitor (such as N-Serve®, Dow AgroSciences) with fall-applied ammonia can improve the effectiveness by slowing nitrification. Many studies show, however, that spring applied N is more effective than inhibitor-treated fall ammonia when conditions favoring N loss develop.

Despite the advantages of anhydrous ammonia and potential slowing of nitrification with an inhibitor, geographic areas with warm winters and high rainfall do not utilize fall applied ammonia due to the high risk of nitrate loss. Fall application is only suggested for regions where winters have frozen soils, rainfall is low, and soils have good but not excessive internal drainage – that is, are not coarse textured with excess leaching or poorly drained and subject to excessive wetness. Nitrogen use efficiency with fall application typically averages 10-15 percent lower than spring application, and reduced yield will cancel other benefits of fall application.

Benefits from delayed, sidedress, and split N applications are greatest where there is a high risk of N loss between planting and crop N use. These typically are with sandy soils that have high leaching, poorly drained soils that increase chance of saturated soils and denitrification, and regions with early high spring rainfall. In these cases, N use efficiency and crop yield can be increased and nitrate leaching reduced by applying a major part of the N in-season, at or near the time when crop N demand is high. Sidedress application also allows for use of in-season soil tests and plant N stress sensing to adjust N rates. Many producers are reluctant to apply N in-season as they may be busy with other operations, concerned about yield loss due to early N stress, or concerned that wet weather will prevent application. Delay in sidedress applications can reduce yield, but this can be avoided or minimized by applying a portion of the needed N before or at planting as a split application.

Applying N through irrigation systems (fertigation) is an important form of in-season N management in irrigated regions. Fertigation can be very efficient, especially in sandy soils with high leaching potential, but must be practiced with appropriate safeguards such as backflow contamination and avoiding over watering which can result in leaching. In most cases, N application through irrigation systems is completed by the end of vegetative growth.

Product

Several organic and inorganic N sources can supply N required for optimum crop growth. Efficient management of all N products requires an understanding of N cycling, soil transformations, and crop demand. Product management that minimizes losses and maximize the quantity of applied N recovered by the crop will increase production efficiency and reduce potential impacts on the environment.

Manure

Manure sources have characteristics that make nutrient management different and sometimes more complicated than fertilizer. These characteristics include a mix of organic and inorganic N forms, variation in N concentration and forms, handling as a liquid or solid, and relatively low nutrient concentration requiring large application volumes. Since manure N composition can vary significantly, sampling and laboratory analysis are always needed. As with fertilizers, significant amounts of plant usable manure nutrients can be lost and became unavailable to crops after application. For example, inorganic N in manure or derived from manure through mineralization can be lost through processes such as volatilization, leaching, or denitrification. Also, inorganic N can be converted for short or long periods of time into forms not usable by plants through processes such as immobilization to organic materials. Conversely, with high carbon containing manure sources, significant time may be needed to provide plant available inorganic N.

Anhydrous ammonia (NH_3) (82 percent N)

Anhydrous ammonia is widely used for direct application because of its relative low cost and high N concentration. Many safety features must be considered when transporting and applying anhydrous ammonia, and strict safety procedures must be followed during handling. It can be applied preplant or sidedressed in row crops. Soil moisture content should not be too dry or too wet when anhydrous ammonia is applied in order to avoid volatile losses due to poor soil sealing or coverage of the injection track. Shallow placement may result in early season crop seedling or root damage from free ammonia. Proper depth and injection in good soil conditions helps avoid such problems. Also, injection between future corn rows, using GPS and auto guidance, can avoid future corn rows. In corn, application can be made between every other row. For small grains, knife spacing needs to be close enough to avoid streaking of poor plant growth between injection tracks. Addition of a nitrification inhibitor with late fall application may be beneficial to slow nitrification in the fall and early spring.

Urea ($CO(NH_2)_2$) (46 percent N)

Dry urea is widely used as a broadcast N product for many crops. It converts quickly to ammonium (a process called hydrolysis), especially in warm-moist soils. That conversion is increased rapidly due to the urease enzyme, found in soil and plant residue. In no-till situations, ammonia volatilization from surface application is a concern, especially if there is high crop residue, soils are warm and moist, soil has high pH, and there is not a significant (> 0.25 inch) rainfall for many days after application. Incorporation soon after application (within 2 days), or injection, places urea into the soil and avoids loss of ammonia. If surface application with no incorporation is planned, then urea can be treated with a urease inhibitor (Agrotain®, Agrotain International) to slow urea conversion to ammonium and give more time for rain to move urea into the soil. The best management, however, is to incorporate broadcast urea. Because of urea hydrolysis and production of ammonia, urea should not be placed in furrow with seed placement.

Coated urea and slow release products

Coating urea with various impermeable substances (such as elemental sulfur, polyurethane, semi-permeable polymers, etc.) allows the urea to be protected from conversion to ammonium and subsequently to nitrate when applied to soils. This technology allows production of urea based fertilizers that have controlled release characteristics. That means the timing of urea conversion (release) to plant available inorganic ammonium and nitrate can be controlled to match the unique uptake pattern of specific crops. For crops like wheat, this would be an early spring release. For corn, it would be release in late spring before rapid vegetative growth. The reason for having such products is to have urea in a form that is not be affected by wet weather, and thus avoids times where excess rainfall and wet soils would cause nitrate loss. Many such products have been developed. Most are targeted and most useful in specialty crops and turf. More recently, products have been developed for agronomic crops, such as corn. An example is ESN® (Agrium, Inc.). That product, for example, controls release based on soil temperature. Product cost is higher due to the need for adding the coating. While a controlled release product has advantages to help control N loss, there is also the option for using traditional products and changing the timing to more closely match crop uptake. A similar strategy is used with products that have varying chemical structures that slow the conversion to plant available inorganic N. There are many of these products, with greatest use in specialty crops and turf. Timing of N release has been an issue with agronomic crops due to rapid crop N uptake patterns and too slow of release to plant available N. If the N remains in the original fertilizer form as when applied, then it will not be in a plant available form and not be taken up by the intended crop.

Urea-ammonium nitrate solution (UAN) (28-32 percent N)

Urea-ammonium nitrate solution is widely used as a broadcast and injected product for many crops. It is approximately one-half urea and one-half ammonium nitrate. Therefore, the product contains 50 percent of the N as urea, 25 percent as ammonium, and 25 percent as nitrate. UAN is popular because of the versatility as a liquid, as well as widespread availability and applicability. The nitrate portion is immediately subject to leaching and denitrification upon application. The urea portion is subject to ammonia formation, and therefore the same loss and plant injury mechanisms as dry urea. UAN can also be banded on the soil surface by dribbling, which reduces the interaction with crop residue and potential for volatile ammonia loss. As with dry urea, a urease inhibitor can be added to UAN for planned surface applications that will not be incorporated. Potential effectiveness of a urease inhibitor is similar to that with dry urea, but overall the potential gain is less with UAN as only half of the N is in the urea form.

Ammonium nitrate (NH_4-NO_3^-) (34 percent N)

In recent years, use of dry ammonium nitrate as a fertilizer has decreased due to regulations and safety issues. Both the ammonium and nitrate portions (50 percent each) are immediately available for plant uptake. The nitrate portion is immediately subject to leaching and denitrification upon application. There is no volatile loss potential from surface application on most soils, with some on calcareous (high pH) soils. This characteristic has made ammonium nitrate popular as a broadcast material in grass crops, small grains, and no-till production systems.

Placement

An important part of optimizing crop response to fertilization is ensuring that N is placed in a location where crop root interception or dissolved nutrient movement to roots is in time for optimum growth. Maximizing crop N uptake also reduces the potential for nutrient loss, and placement can be a powerful management tool to help minimize N losses. Under ideal conditions, the goal is to have applied N so that it is in a plant-available form and in close proximity to roots when plants require the N. Since nitrate is rapidly produced from all applied fertilizers, and it moves easily in soil with water, N placement is not as critical as for nutrients that have limited movement. Nitrogen fertilizers can be applied by several methods depending on the N source, equipment availability, and time of application. In some cases, the fertilizer product characteristic dictates the placement method, such as anhydrous ammonia.

Injected or banded

Injecting N fertilizers and manure may be required due to the product, to avoid volatile losses and odors, to match crop row spacing, to avoid crop injury that may occur with broadcast application, or may simply be of convenience. Anhydrous ammonia must be injected into the soil as if it were surface applied the majority would simply go into the air. Urea and UAN solutions can be surface applied, but injection avoids potential volatile losses. Applying in a concentrated band within the root zone can ensure N placement where roots can access the N, which can be especially important in dry conditions. Surface banding liquids, like UAN, can increase product contact with soil and reduce volatile loss. In small grains, surface banding UAN instead of broadcasting can help avoid plant foliage injury. Banding N beside and below the seed placement at planting is a viable approach to have a high N starter available for early growth – something shown to be effective in no-till corn production and especially when sidedressing the major N application. Due to seed safety issues, placing N with seeds limits the application rate. This application may be helpful for very early growth, but cannot be used as a replacement to meet early season crop demands. In addition, urea should not be placed with seeds due to ammonia injury potential.

Broadcast

Broadcast applications uniformly distribute N across the soil and are often applied preplant or prior to emergence. In conjunction with incorporation, applied N is mixed uniformly within the upper rooting zone. This can be particularly important for solid seeded or close row spaced crops when banding is not viable. As mentioned before, surface broadcast applications of urea-based fertilizers and high ammonium containing manure sources should be incorporated to minimize volatile losses. Broadcast fertilizer application after crop emergence should be carefully evaluated due to potential for crop injury. Application when plants are small or use of low application rates will help minimize potential injury. Product use also has a large effect on potential foliar injury, with dry materials like urea having much less injury potential than UAN solutions.

Fertigation

Irrigation systems, especially pivot systems, can be fitted with equipment to apply N solutions with the irrigation water. This method has the advantage of avoiding a separate field operation to apply N and allows for multiple applications throughout the season to “spoon feed” the crop. This is especially useful on coarse textured soils with high leaching loss potential. Nitrogen fertigation has the disadvantage that timely rains may reduce or eliminate the need for irrigation, thus limiting N application opportunities.

Case Study

There are many different nitrogen (N) management strategies for crop production that are used by producers across the U.S. It is impossible to give one example representative for all geographic areas, crops, current management systems, and options for improved N use. These would vary by producer philosophy, crop, rotation, climate, available fertilizer or manure, and application equipment. The following example describes a N management system being used for a specific farm in the U.S. Corn Belt, and possible practices the producer could consider to improve crop N use efficiency, economic return from N application, and reduce nitrate loss to surface waters.

Example Scenario

- A 1,500 acre farm in North Central Iowa.
- Soils are prairie-derived, glacial till parent material silt loam and silty clay loam, with variability between fields in soils from well drained (not excessively drained) to poorly drained with subsurface tiles for improved drainage.
- The farm has fields with continuous corn and corn rotated with soybean.
- Each year some fields have solid chicken layer manure applied as a nutrient input.
- The producer always applies chicken manure early in the fall for the next corn crop, and fertilizer N in the late fall (after soils cool below 50°F) as anhydrous ammonia. No N is applied in the spring or after planting.
- The N fertilizer application does not account for any N supply from the applied chicken manure, with the manure solely viewed as a P and K nutrient source.
- The anhydrous ammonia rates are based on a yield goal system (corn yield times 1.2 minus a soybean credit), with historical yields of 190 bu/acre in continuous corn and 210 bu/acre in corn following soybean in good production years. However, yields are considerably lower in years with excessive rainfall. The N rates are not adjusted by field, are based on the years with best yields, and average 220 lb N/acre for corn following corn and 200 lb N/acre for corn following soybean. The rates are not adjusted for corn price or N cost, and no in-season N diagnostic tools are used to adjust rates.

In wet years, and especially in the fields with poorly drained soils, the producer has noticed yellow corn late in the growing season, indicating N loss via leaching and/or denitrification. This has occurred despite improved drainage with tile.

This example scenario is not uncommon in many areas of the U.S. Corn belt, and emphasizes the potential benefits from development of an improved N management plan.

Following are management options to consider. These are listed in order of greatest potential to improve N use and provide tools to adjust N rate in season for varying climatic conditions.

Practice One

The rate of N application has a large impact on corn yield and nitrate loss to water systems. Therefore, the rate decision process should change from the old and no longer recommended yield goal times a yield factor system to the current system used across the Corn Belt that is based on current N response trials, N and corn prices (Maximum Return To N, MRTN), and results from the Corn N Rate Calculator for the specific state and production system. The N rate recommended will change depending on the current N and corn prices. For example in Iowa, at a price for anhydrous ammonia of $800/ton ($0.49/lb N) and a corn price at $6.00/bu, the recommended rate for corn following soybean is 140 lb N/acre (MRTN rate), with a profitable range of 129 to 151 lb N/acre. For corn following corn, the MRTN rate is 199 lb N/acre with a profitable range of 185 to 209 lb N/acre. The rate change from the current practice for corn rotated with soybean would be 60 lb N/acre lower and for continuous corn would be 20 lb N/acre lower. Both rates would improve economic return (less N cost and unlikely impact on yield) and have less impact on N loss via tile flow or leaching to groundwater. The largest impact on reducing nitrate loss to water systems would come from the rate change in the corn-soybean rotation. That system has the highest corn yield and N removal, but research has also shown it to have much lower N fertilization need than derived from yield based recommendations.

Practice Two

For the fields receiving fall poultry manure applications, a priority would be to account for the crop available N in the manure application. In addition, the N component of the poultry manure should be accounted for in the total crop available N application. According to Iowa research and recommendations, 50 to 60% of the total poultry manure N applied is crop available in the year of application and 10% is available in the second year. Subtract appropriate manure N supply amounts from the corn N recommendations. Accounting for available N from the poultry manure should be done in conjunction with the switch to the MRTN rates, and then apply the remaining N need as fertilizer. Try to schedule applications for late fall or spring to help reduce conversion of N to nitrate. In addition, if possible incorporate the manure to reduce volatile ammonia-N loss on fields where fall tillage will not increase chance of soil erosion.

Practice Three

With the reduced MRTN-based N rate recommendations for both cropping systems, N application management should be improved to help reduce nitrate losses in spring and early summer and therefore avoid potential yield issues. Instead of a fall application of anhydrous ammonia to all fields, fall application should be targeted only to fields with well drained soils and also should consider use of a nitrification inhibitor along with a late fall application. For fields with more poorly drained soils, N application should be switched to spring or post-emergence sidedress application. The producer can continue to use anhydrous ammonia for either timing. If spring application is preferred, then anhydrous ammonia would be a preferred source. Another option could be use of a coated urea product to slow release of N. If sidedressing is preferred, either anhydrous ammonia or N solutions could be used. When sidedressing, use of a split application (some preplant or at planting and the largest amount at sidedress) would ensure adequate N for the corn until sidedressing – which would be especially important for late sidedress applications (V5 or later) in corn following corn. These N options spread out the N application workload, and still allow use of a least cost N source such as anhydrous ammonia, but may not always result in significant further reduction of nitrate loss in addition to practices outlined in option 1 and 2.

Practice Four

In fields that have poultry manure applied, and where sidedress fertilizer N application will be practiced, in-season diagnostic tools can be used to adjust corn N fertilizer inputs. One tool is the soil nitrate test (called LSNT in Iowa, PSNT in other areas). This test can help to better account for available N from the poultry manure, including in the second corn year following manure application, and adjust for seasonal effects on soil and manure N supply. For this test, soil is sampled in late spring to a one foot depth when corn is 6 to 12 inches tall. The sidedress fertilizer rate is then adjusted based on the results of the test. Use of this nitrate test does not mean that no preplant N should be applied, especially in continuous corn.

An alternate in-season diagnostic tool is the emerging use of active canopy sensors at the mid-vegetative corn growth stage to determine potential N shortages by sensing the plant N status and vegetative growth. In years with excess wetness, this practice may allow for application of additional N if shortages occur during the early season. This practice could be especially helpful when there is no soil nitrate testing and where it is difficult to collect representative soil samples (due to N banding) for a soil nitrate test. Canopy sensing can be used in addition to previously suggested N-rate reduction practices, in fields with manure application, or where N was applied well in advance of plant need such as late fall ammonia. Use of this canopy sensing technology requires well fertilized reference areas across fields (known non-N deficient reference) to compare against, so additional planning is required for implementing these references. In addition, the sensing is conducted after corn has reached a height that will likely not allow use of traditional sidedress application equipment, and instead will require high clearance applicators that can dribble or coulter inject N solutions, or broadcast dry fertilizer such as urea. Use of this tool does not mean that no preplant N should be applied, especially in continuous corn. Trial use of this technology could be targeted to fields with known history of N loss and crop N shortages when climatic and field conditions are conducive to N loss.