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Site-specific Nitrogen Management for Irrigated Corn

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Applying different amounts of nitrogen (N) fertilizer in different parts of the field according to soil conditions seems intuitively obvious. 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 nitrogen 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 nitrogen supply or crop nitrogen demand within a field. Yet, in practice, researchers and producers alike have found it difficult to profitably implement site-specific nitrogen management (SSNM) for most agronomic crops. This publication reviews recent research in site-specific nitrogen management and recommends how irrigated corn producers in Nebraska might implement this technology on their farms.

Research History

The earliest research efforts investigating the potential for variable rate fertilization were based on grid soil sampling. This research was initially conducted in Corn Belt states in the late 1980s for the non-mobile nutrients phosphorus and potassium. Interest developed in the early 1990s in extending the use of grid soil sample information for variable rate nitrogen fertilization. Research on site-specific nitrogen management began in 1990 in Nebraska with studies exploring the potential for grid soil sample information to generate nitrogen application maps for irrigated corn. Since yield monitors and resulting yield maps were not yet available in the early 1990s, this approach relied on generating a recommended nitrogen rate for each grid point in the field based on a uniform expected yield, as well as grid-based soil organic matter and residual nitrate-N.

Various research studies in Nebraska, completed in the late 1990s, found generally no advantage to site-specific nitrogen management over uniform management (UM) using this approach. While the applied nitrogen rate varied considerably within most fields using site-specific nitrogen management, there was little difference in the total amount of nitrogen fertilizer used, grain yield or residual nitrate-N between site-specific or uniform nitrogen management. This approach was particularly limited due to the fact that yield maps were not yet available, and thus the approach did not account for variation in crop nitrogen demand within a field. Also, historically fertilizer nitrogen recommendations were liberal prior to and into the 1990s and tended to mask soil spatial variability. Grid soil sampling is an expensive, time-consuming process and requires substantial economic benefit to site-specific nitrogen management for it to be profitable. There are isolated examples of profitable grid sample-based site-specific nitrogen management (sugar beet fertilization in the Red River Valley, for example), but for row crops in Nebraska, this approach is unlikely to be profitable.

Research in the late 1990s and early 2000s has focused on the use of management zones and remote

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sensing as potential tools for site-specific nitrogen management. Management zones can be developed in many ways, but in general the process relies on using multiple layers of existing spatial information to define areas within fields needing more or less input than the field mean. The simplest approach to management zone delineation uses a base map — such as an aerial photograph — with hand-drawn boundaries based on experience from farming the field over several years. More sophisticated approaches integrate a variety of spatial resources into management zones, or yield potential zones, using data layers which are relatively inexpensive and spatially dense compared to grid soil sample data. These include yield maps over years, color and near-infrared aerial imagery, soil apparent electrical conductivity (ECa), soil surveys, elevation and other resources. Management zones derived from these resources can be used to direct soil sample collection within zones.

The use of remote sensing to detect crop status such as nutrient or water stress, and to predict final yield, has been a developing science over the past 20 years. Initially, efforts focused on satellite-based sensors. To date, satellite imagery has been of limited value for in-season management of agronomic crops due to resolution, weather, response time or frequency limitations. Aerial imagery or ground-based sensors recently have become the primary research tools for assessing crop nitrogen status. The primary advantage of sensor-based nutrient management is that the plant integrates soil and climatic influences on nutrient availability and expresses the outcome through canopy appearance. For corn, the crop takes up most of its total nitrogen between V6 and silking. Research in Nebraska and other states has shown that monitoring the canopy color during this period can track the chlorophyll status of the plant, which is an indicator of nitrogen supply.

Approaches to Site-Specific Nitrogen Management

Based on research in Nebraska with irrigated corn, we suggest producers consider three options for varying nitrogen rate within fields: a predictive approach (zone-based yield potential), a reactive approach (sensor-based) and one that uses localized references within yield potential zones.

Predictive Approach

A predictive approach to nitrogen management is one in which the time and amount of nitrogen application is prescribed prior to planting, accounting for soil nitrogen supply, crop nitrogen demand, fertilizer nitrogen efficiency and fertilizer and crop prices. A site-specific predictive approach relies primarily on the use of multiple layers of spatial information to generate yield potential zones within fields. Accordingly, a field is a good candidate for site-specific nitrogen management only if it appears to have some significant variability — in texture, elevation, management or some other known factor. If a field appears to be quite uniform in nature, it is not likely a good candidate for varying nitrogen rate spatially within the field.

Spatial Data Collection

The first step in this approach is to collect spatial data. The starting point should be at least three years of yield maps. If the field has been in a row-crop rotation, we suggest normalizing yield to allow comparison across crops. One approach to normalization is to express relative yield as a ratio of the actual yield to the field average. For example, if the actual yield for a point is 197 bushels per acre, and the field average for that year is 235 bushels per acre, the relative yield is 0.838. *Figure 1* illustrates actual yield and relative yield for two successive years, one in which corn was grown and the second when soybean was grown. Note that the patterns of actual and relative yield are exactly the same — just the units are different. Having corn and soybean yield expressed in relative terms allows quantitative comparison of yield over years. Normalization of yield for a given year's data should only occur after yield measurements collected with a combine yield monitor have been cleaned to remove outliers. Yield-cleaning algorithms are built into some yield mapping software packages or are available as stand-alone programs. Examples of free yield-cleaning software are Yield Check (University of Nebraska–Lincoln, *soilfertility.unl.edu*) and Yield Editor (University of Missouri, *www.ars.usda.gov/Services/docs.htm?docid=4776*) .

Various other spatial data layers should be considered as well. The following information layers are suggested, in order of cost efficacy: soil series, aerial imagery, soil ECa and elevation. Digitized soil series boundaries (Soil Survey Spatial and Tabular Data – SSURGO), elevation (digitized elevation models – DEM), aerial imagery (Digital Ortho Quadrangles – DOQ) and other geospatial information layers are available free from a variety of on-line resources, such as the Nebraska Department of Natural Resources (*www.dnr.ne.gov/databank/spat.html*) and the Natural Resources Conservation Service (*datagateway.nrcs.usda.gov/*). Several recent years of aerial imagery may be available from the NRCS at little or no cost. Files can be downloaded from Web sites at no cost or ordered on CD-ROM for the cost of duplication and mailing. Downloading spatial datasets generally requires a high speed Internet connection due to file size.

The use of publicly available aerial imagery to generate management zones should be considered with caution, however. The resolution of such images may be lower than purchased images and near-infrared bands, which are useful for creating vegetative indices, are not available. Also, photographs may be dominated by management practices unrelated to soil variability such as partially tilled fields, different crops, weather damage or differing irrigation amounts or precipitation which just happened to be captured at the time of the photograph.

Aerial photographs taken specifically of your fields by a service provider give some control over field conditions at the time the photograph is taken, generally will be higher resolution and allow the collection of near-infrared images as well. While not free, images taken from an aerial imagery service will still be relatively low cost on a per-acre basis and provide greater utility than on-line DOQs for specific fields. Soil ECa is another spatial resource that must be purchased, but it is also relatively low cost on a per-acre basis. Several crop consultants and fertilizer dealers in Nebraska now offer soil ECa mapping. Soil ECa integrates variability created from several soil properties, but relates most to texture in Nebraska soils. There often may be similar patterns to soil ECa and mapped soil series. Generally, soil ECa will need to be collected only once for a field, while aerial imagery and yield maps collected over multiple years are helpful.

Creating Yield Potential Zones

Once several layers of spatial information are available, integrate those layers into three to five yield potential zones — areas of distinctly differing yield potential which are consistent from year to year. Currently, that is easier said than done. The simplest approach is to lay out various maps on a table, compare them side-by-side, and look for common features over space and time. Based on this visual comparison, manually draw boundaries for yield potential zones on a base map. The capability of quantitative management zone delineation may exist in various agriculturally oriented software packages, but details will vary from system to system. One free software resource which integrates multiple layers of spatial information into management zones is Management Zone Analyst (MZA). This software, which is available from the University of Missouri, uses a fuzzy clustering algorithm (fsb.

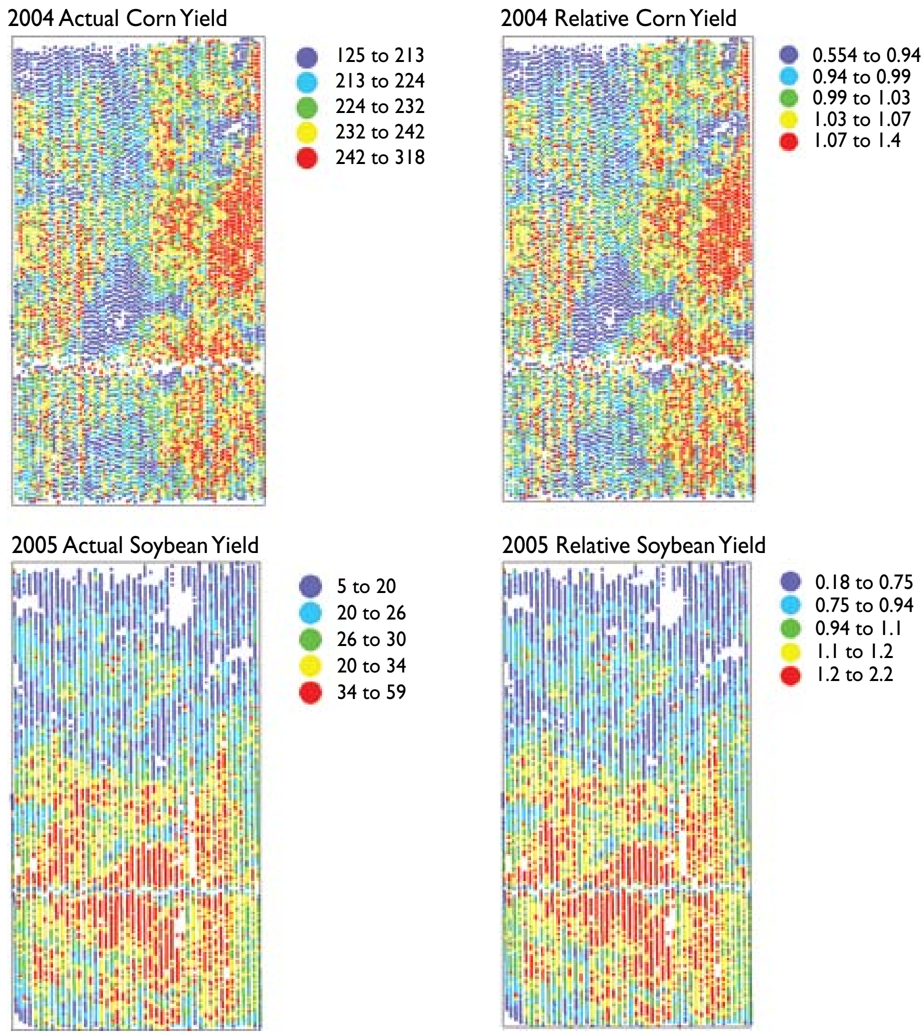

Figure 1. Actual and relative corn and soybean yield. Note striping in 2004 corn yield due to hybrid comparison strips.

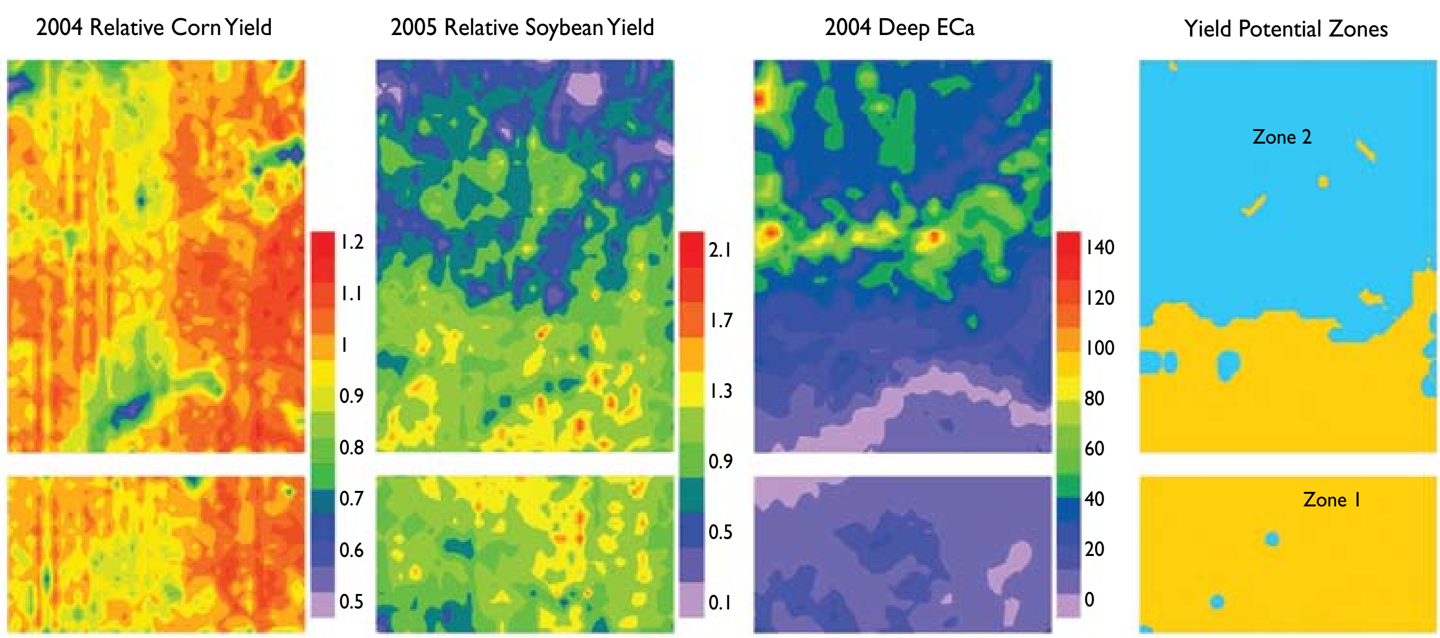

Figure 2. Delineation of yield potential zones based on two years relative yield and apparent soil electrical conductivity. Note striping in 2004 corn yield map due to hybrid comparison strips.

missouri.edu/ars_software/mza_reg.asp*). *Figure 2* is one example of delineating yield potential zones. In this example, two years of relative yield (2004 corn and 2005 soybean) are combined with deep ECa (0-3 feet) and yield potential zones defined using MZA software. For this example, using two yield potential zones is most appropriate. Small inclusions of each zone within the other are relatively minor and can be ignored, as they are too small to manage practically. As software options are continually refined, the process of delineating yield potential zones should become easier. The producer needs to agree in principle with the zones delineated by software. There should be some reasonable explanation for why different zones exist, the number of zones and where boundaries occur. Yield potential zones may not be contiguous — that is, areas with similar yield potential may be in different areas of the field. These can and should be treated as one zone, as their properties and yield potential are the same.

Soil Sampling

Once yield potential zones for a field have been created, these provide direction for soil sampling in the field. General fertility soil samples should be collected to a depth of 8 inches. These samples can be analyzed for soil organic matter, pH, phosphorus, potassium, zinc and nitrate-N. Typically, collect 15-20 cores from each zone, then composite these samples and keep a well-mixed subsample to send to the lab. Deep soil samples for residual nitrate-N should be collected from 8-10 cores in each zone to a depth of 3 feet. These can be separated into depth increments or treated as a single continuous core, but must be well mixed before saving a subsample to send to the lab. Samples should exclude areas, such as old feedlots or farmsteads, that may tend to skew soil test results. (If these areas are large enough, they should be considered as separate zones.)

This process will provide soil test results which are average for the zone, at significantly less cost than grid soil sampling. If yield potential zones are not contiguous, as will often be the case, normally these should be sampled and composited as one zone to minimize sampling cost. *Figure 3* is an illustration of soil sampling patterns for a field with five yield potential zones. In this case, Zone 2 has two patches within the field. Since soil characteristics and yield potential are the same for each of the patches of Zone 2, samples from the two patches can be combined for analysis.

Nitrogen Recommendations

Set the expected yield for the middle yield potential zone as the field average. Set expected yield for higher or lower yield potential zones accordingly, but don't differ from the field average more than about 30 percent. Use the University of Nebraska–Lincoln nitrogen rate algorithm for corn to generate nitrogen recommendations for each yield potential zone. Use the zone-specific expected yield, organic matter and residual nitrate-N. A spreadsheet is available at *soilfertility.unl.edu* to calculate economically adjusted nitrogen rates for corn, using current corn and fertilizer prices.

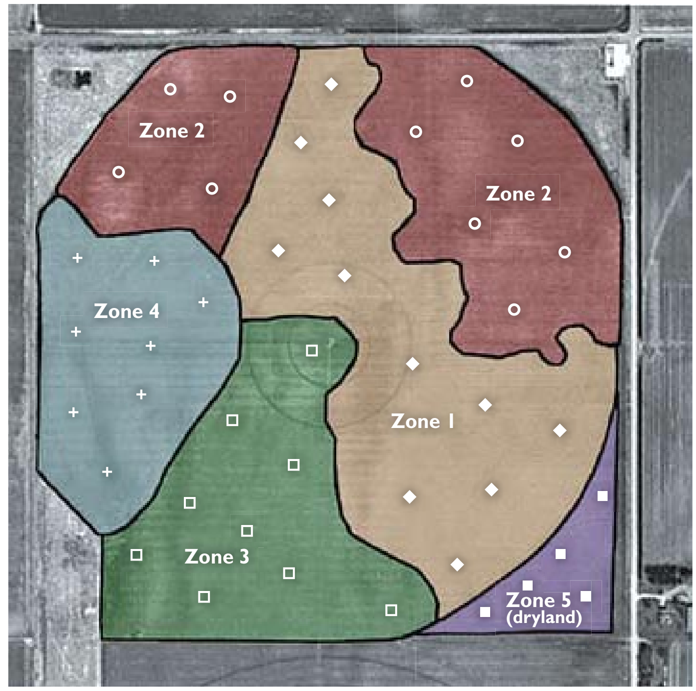

Figure 3. Soil sampling patterns for five yield potential zones within a field, superimposed on a digital ortho quarter quad–rangle (DOQQ) base map. Note that Zone 2 is in two patches.

This process will result in fertilizer nitrogen recommendations which are uniform within each yield potential zone. We suggest that site-specific nitrogen management using this approach be used with preplant or sidedress application only, not fall application. If fertigation through a center pivot irrigation system is planned for the field and will apply nitrogen uniformly across the field, adjust variable nitrogen rates downward according to the planned fertigation amount.

There may be situations where producers have access to more detailed information to further refine nitrogen rates within zones, rather than applying a uniform rate for each zone. The most likely situation is the use of detailed soil organic matter data. Since the University of Nebraska–Lincoln nitrogen recommendation algorithm for corn uses soil organic matter as a variable, it may make sense to use detailed soil organic matter within zones, along with zone average residual soil nitrate and expected yield. Soil organic matter can be predicted fairly accurately from high resolution bare soil aerial photographs. In addition, there are several prototype on-the-go soil sensors for soil organic matter measurement which may be available soon. *Figure 4* is one example from a site where six yield potential zones were delineated, then fertilizer nitrogen rate was varied within zones according to the soil organic matter map.

Reactive Approach

Reactive nitrogen management allows the timing and amount of fertilizer nitrogen to be regulated through diagnostic tools that assess soil or crop nitrogen status and yield potential during the growing season. Reactive nitrogen management for irrigated corn was made possible initially by the chlorophyll meter. The

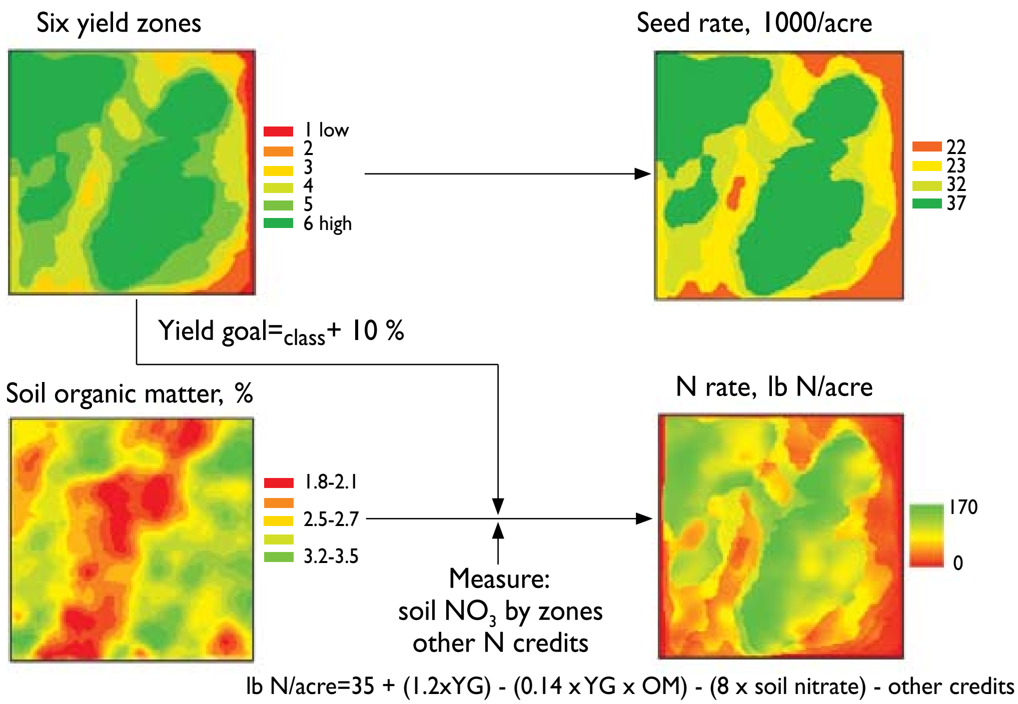

Figure 4. Illustration of one potential process to derive seeding rate from yield potential zones, and fertilizer nitrogen rate from yield potential zones and soil organic matter.

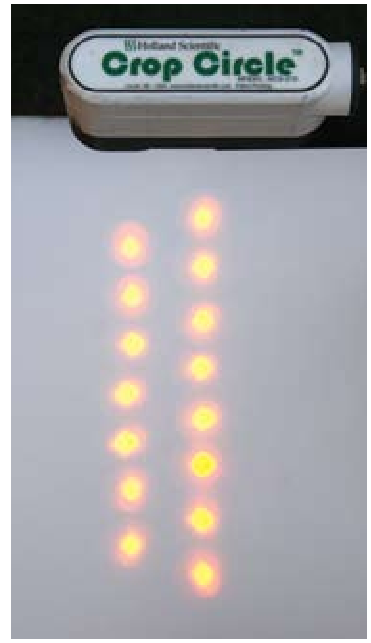

Figure 5. Crop canopy sensor (Crop Circle, Holland Scientific) illustrating the emitted light pattern.

University of Nebraska–Lincoln has guidelines on using a chlorophyll meter (NebGuide G1632, *Using a Chlorophyll Meter to Improve Nitrogen Management*). However, a chlorophyll meter is time-consuming to use correctly, and it is difficult to accurately scout large acreages. In addition, nitrogen application must occur after data are collected and analyzed.

More recently, research has focused on the use of either passive or active vehicle-mounted sensors for real-time nitrogen management. Passive sensors rely on canopy reflectance from the sun, while active sensors use their own light source. Consequently, passive sensors must be used during daylight hours, and factors influencing canopy reflectance from the sun, such as clouds and solar angle, may influence spectral data. Active sensors are designed to cancel out solar influences, relying solely on reflectance from the internal light source, and thus can be used anytime, day or night, regardless of cloud cover. Active sensors generally are designed to emit light in both visible and near-infrared wavelengths, and use ratios of these spectra, called vegetation indices, to determine canopy chlorophyll status and thus nitrogen status, as well as biomass. Examples of commercial active crop canopy sensors are the Greenseeker (*www.ntechindustries.com/*) and the Crop Circle (*www.hollandscientific.com/*) *(Figure 5)*. Aerial photographs also can be used for reactive nitrogen management, especially if both natural color and near-infrared images are available.

Soil Sampling

This step can be considered optional if nitrogen management will be sensor-based. Soil test information collected prior to the growing season may be useful in establishing a target nitrogen rate for the field, but is not essential. If soil samples are collected, use sampling procedures recommended in UNL Extension EC155, *Nutrient Management for Agronomic Crops*.

Initial Nitrogen Application

Prior to or at planting, apply a portion of the anticipated fertilizer nitrogen requirement for the crop. The primary need is to supply adequate nitrogen for the crop until the canopy nitrogen status can be accurately sensed, at about the V8 leaf stage. This amount will depend on soil residual nitrate-N and organic matter levels, but typically will be in the range of 40-70 lb nitrogen per acre. At the same time, apply nitrogen to at least two reference strips crossing the range of soils found in the field. The nitrogen rate applied to these reference strips should be high enough to ensure that nitrogen will not limit corn yield potential throughout the growing season, but not excessively high. We suggest rates of 200 lb nitrogen per acre following soybean, or 250 lb nitrogen per acre following corn, which can be adjusted if soil residual nitrate-N levels are known. For successive years of site-specific nitrogen management, rotate the location of reference strips.

Measure Canopy Nitrogen Status

If reactive site-specific nitrogen management is planned, use an active sensor to measure canopy nitrogen status at the V10-V12 growth stage. This is when plant nitrogen uptake is rapidly increasing, and the crop canopy appearance can accurately reflect soil nitrogen supply. First, measure the reference strips and determine canopy reflectance. From this calculate a vegetation index (VI), where nitrogen is non-limiting (VIref). Then, using reflectance values from reference strips as a baseline, adjust nitrogen rate in the rest of the field according to local VI values

(VIbulk). This can be done by creating a map of VI ratios while driving the sensor across the field, then entering the map into a VRT applicator or more likely, by using the sensor on a VRT applicator and adjusting nitrogen rate on-the-go according to VI ratios *(Figure 6)*. Appropriate ratios of VIbulk/VIref to trigger nitrogen application and the appropriate nitrogen rates to apply given a specific ratio are still topics of research. However, we suggest as a trigger point a VIbulk/VIref ratio of 0.95 and a nitrogen rate range of 0-100 lb nitrogen per acre, increasing with lower ratios. In addition, there should be a lower VIbulk/VIref ratio threshold established below which no nitrogen is applied — perhaps 0.6 or lower. This will prevent additional nitrogen application to areas with very low or no plant population, or which are experiencing some other form of stress unrelated to nitrogen status.

In-season canopy nitrogen sensing can be useful even if site-specific nitrogen management is not planned, but uniform fertigation is an option. Crop canopy sensing can still be done with sensors on a high clearance vehicle or with aerial photographs, but nitrogen application will occur later through the irrigation system. Canopy sensing should be complete no later than V16. Nitrogen application rates should be calculated in the same manner as previously described. Apply nitrogen at the rate of 20-30 lb nitrogen per acre per irrigation within two weeks after silking.

Figure 6. Active crop canopy sensor mounted on fertilizer applicator.

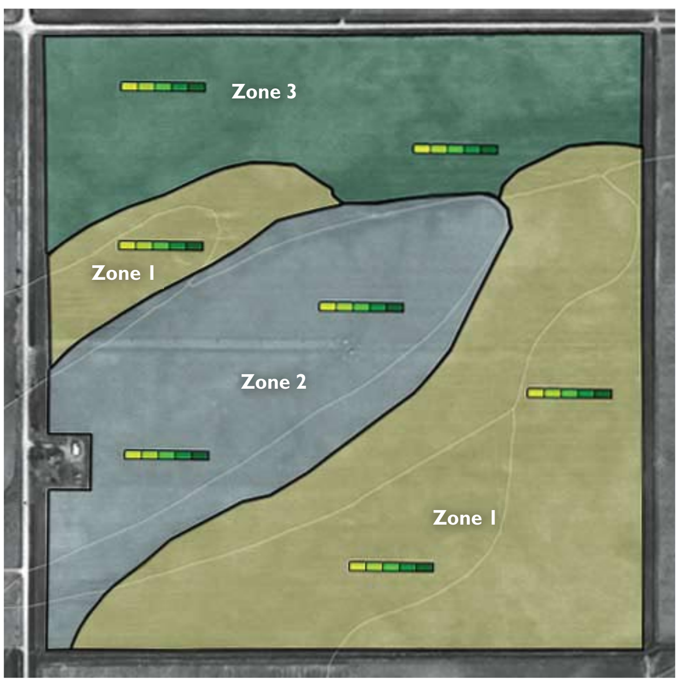

Figure 7. Example of localized nitrogen references within a field. Base map is a DOQQ image with soil series boundaries overlaid. Yield potential zones are derived from multiple years of relative yield and aerial imagery. Note that in this example there are similar, but not exact, relationships between mapped soil series and yield potential zones. Nitrogen fertilizer rates applied in localized references should be the same for each zone — 0.5, 0.75, 1.0, 1.25 and 1.5 times the average field recommended nitrogen rate.

Vegetation Indices

A vegetation index is a means of relating information from aerial or satellite photographs to plant growth. Growing plants absorb light in the photosynthetically active radiation (PAR) spectral region and reflect light in other spectral regions — particularly near-infrared. Vegetation indices use combinations of multiple wavelengths to evaluate crop growth. Natural color photographs, for example, are combinations of red, green and blue wavelengths. The most commonly used index is the Normalized Difference Vegetation Index (NDVI). It is calculated as the normalized difference between red and near-infrared bands:

$$\text{NDVI} = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}}$$

Where: NIR = wavelength of near-infrared band
Red = wavelength of red band

However, NDVI is affected by atmospheric properties and can saturate with large amounts of biomass, such as may occur with corn by the V10-V12 stage. Calculating the normalized difference between green and near-infrared bands, instead of red, results in an index which does not saturate as easily with large amounts of biomass:

$$\text{GNDVI} = \frac{\text{NIR} - \text{Green}}{\text{NIR} + \text{Green}}$$

Another vegetation index which may be useful is the Chlorophyll Index, which research has shown has a steeper slope than NDVI and may be more sensitive in determining accurate nitrogen fertilizer rates:

$$\text{CHL} = \frac{(\text{NIR} - \text{VIS})}{1}$$

Where: VIS = visible green or amber wavelengths

Table 1. Example for a simple economic analysis of site-specific nitrogen management (SSNM) in corn. In this hypothetical study, pre-plant nitrogen fertilizer applications in the SSNM treatment were varied according to yield goal zones, a map of soil organic matter and average soil nitrate values for each yield goal zone.

N strategy	Avg. N rate	Avg. corn yield	N fertilizer cost[1]	N application cost[2]	Total cost of N program[3]	Gross return (GR)[4]	GRF[5]	Profit change[6]
	lb/ac	bu/ac	$/ac	$/ac	$/ac	$/ac	$/ac	$/ac
Uniform	177	243.7	40.71	6.00	46.71	536.10	489.39	—
SSNM	159	247.5	36.57	9.00	45.57	544.50	498.93	9.54

[1] Assuming anhydrous ammonia as fertilizer source for pre-plant nitrogen @ $375 per ton = $0.23 per lb of N, e.g., nitrogen cost uniform = 177 lb/acre x $0.23/lb = $40.71/acre

[2] Nitrogen application cost. For SSNM, we add here an estimate of the extra cost associated with the technology.

[3] Cost of nitrogen fertilizer plus application.

[4] Gross return = corn yield x value of corn (including government payments). We assume here a corn value of $2.20 per bushel, e.g., Gross return uniform = 243.7 bu/acre x $2.20/bu = $536.1/acre.

[5] GRF = gross return above fertilizer cost = GR – cost of nitrogen program, e.g., GRF uniform = 536.10 – 53.80 = $482.30/acre.

[6] Profit (net return) increase or loss in comparison to uniform application = GRFSSNM – GRFUniform. This assumes that all other variable and fixed costs (production inputs) are the same and only the nitrogen management program differs.

Localized References

The use of localized references is another option to field length, fixed nitrogen rate reference strips. Localized references, also termed calibration ramps (Oklahoma State University), are relatively small areas with differential nitrogen rates. To be most effective, these should be located after yield potential zones have been determined, using procedures described earlier. Within each yield potential zone, locate nitrogen rate blocks of 0.5, 0.75, 1.0, 1.25 and 1.5 times the field average nitrogen rate *(Figure 7)*. Nitrogen should be applied preplant or at planting, in order to ensure an adequate nitrogen supply early in the growing season. Localized references can be used in several ways. If they are relatively small (perhaps 50-100 feet long), the primary use will be to calibrate nitrogen sensors within each yield potential zone. If larger nitrogen rate blocks are used — perhaps 300 feet long — they will be large enough to yield map accurately. The highest nitrogen rate can serve as a reference for crop canopy sensors in the same manner as a fixed rate, field-length strip. They also can be useful in interpreting aerial photographs. Larger localized references also can be used without sensors, by collecting data on yield response to nitrogen within separate yield potential zones. This information provides field and zone-specific nitrogen rate calibrations which will help fine-tune nitrogen management in future years. As with field-length reference strips, be sure to place localized references in different locations each year to ensure that nitrogen response is not influenced by residual effects of the prior years' treatment.

Economic Analysis

A complete economic analysis of the profitability of site-specific nitrogen management is often difficult to perform because it requires calculating all costs associated with the technology in comparison with a standard nitrogen management approach. Compared to uniform field management, specific additional costs may include extra labor, equipment, laboratory costs, software for GPS positioning, detailed soil sampling, yield monitoring, remote sensing, spatial data analysis and interpretation and variable rate application of fertilizers. Some of those costs can be easily estimated on a per acre basis (e.g., soil sampling and mapping), whereas others depend on the overall area treated and equipment depreciation over time (e.g., yield monitors, variable rate controllers/fertilizer spreaders, etc.). *Table 1* shows a minimum approach for an economic analysis of site-specific nitrogen management. In the example shown, site-specific nitrogen management produced an average gain of $9.54 per acre, but with only a rough estimate of the extra costs involved. This was achieved by a combination of savings in nitrogen fertilizer (18 lbs/acre less) and a slight increase in corn yield (+3.8 bu/acre).

In general, larger profit gains require more substantial yield increases, which reiterates the importance of accurately delineating yield potential zones and setting realistic yield goals for those. To implement this type of economic analysis requires conducting side-by-side comparisons of uniform and site-specific management strategies in the form of simple strip trials, i.e., treatment strips that go across the entire field length and are replicated three or more times in the same field. It is not possible to compare results of one management strategy in one field with those of another strategy in a different field. If strip trials cannot be conducted, the only alternative is to attempt calculation of net return for the entire production system, including all fixed and variable input costs for the specific management system implemented, either uniform or site-specific.

Note

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