Real-Time Variable Rate - - - OR NOT ?

Variable Rate Technology Overview: Reasons for considering variable-rate applications of nitrogen (N) or other nutrients include 1) increasing productivity in yield-limited areas within a field, 2) conserving nutrients in parts of a field that are inherently fertile, 3) fertilizing to meet the yield potential of an area in field, and 4) reducing the potential for environmental losses or compensating for spatial N losses. Many of these goals are complimentary and should be considered in conjunction with appropriate fertilizer rates, selection of N sources that have a low potential for losses, and timing of applications that are closely synchronized with crop needs. Many considerations go into making a fertilizer N recommendation. A significant part of any N recommendation involves "anticipation" as to what the growing season will bring in terms of yield, estimation of N availability from all sources (manure, crop residues, organic matter, and nitrate in irrigation water), as well as chances for N losses. Fertilizing for exceptionally high yields is usually not cost effective because years with favorable growing conditions (light, temperatures, and precipitation) are also conducive to enhanced microbial activity in the soil. As such, organic matter decomposition (mineralization) is likely to accommodate the additional nutrient uptake needs of the crop. The exception is soils with low organic matter content.

Active Sensors as a Management Tool: Using the crop as a bio-indicator of plant vigor can be a fast and economical way to evaluate relative growing conditions in a field. A lack of vigor can be due to many factors, so the challenge becomes one of identifying those that are most limiting. If N availability is deemed to be the most limiting and the field has considerable spatial variability in terms of soil color and elevation, then it probably is a good candidate to benefit from variable rate application technologies. It is appropriate to caution potential variable-rate users about variability in other nutrients if soil color is variable. This is because variability in soil color is usually associated with differences in pH, water holding capacity, nitrate leaching potential, and nutrients supplied via mineralization. As such, a bare-soil image or map of soil color generated with an active crop canopy sensor can be very informative. Monitoring the growing crop for relative differences in leaf greenness and plant size can provide reliable clues as to what is likely to come in terms of yield if nothing is done to alleviate stresses.

Requirements for Variable Rate Applications: Sensor, map, or image based variable rate N applications realistically require more than what is commonly available on many commercial sprayer applicators. Sprayers that vary the rate of liquid discharge by changing the pressure and driving speed seldom offer the range in application rates required for true variable rate application of N fertilizers (zero to 100 lb N/acre or more). Systems that involve selected discharge from multiple nozzles with different sized orifices (i.e., 3 nozzles offer 7 rate combinations plus OFF) is one approach. Another is made possible using pulse-width modulated nozzles (manufactured by Capstan). This approach may have some limitations unless the required delivery rate is within the specifications of the nozzle. A final approach is via a variable-rate nozzle (manufactured by Delevan and perhaps others) that changes the delivery rate in response to pressure changes. It should be noted that application of urea ammonium nitrate (UAN) to vegetation is likely to burn leaf tissue if environmental temperature is >75 degrees F. For this reason, drop nozzles are frequently used to deliver the liquid fertilizer beneath the canopy. Accurate and timely delivery of variable rate liquid fertilizers using drop nozzles requires a low-pressure check valve at the point of discharge to insure that the delivery line between the solenoid valves that controls the flow does not drain in the OFF mode. Changing the delivery rate requires a controller that sends the appropriate electrical impulses to solenoid valves. Only special controllers are able to interpret sensor data or extract positional data from maps, or a combination of the two, to control solenoid valves. One of the biggest challenges when making spatially variable in-season N applications to being mechanically able to sense the crop and make near-instantaneous changes in application rates without incurring considerable expense.

Chlorophyll is Key: Chlorophyll is the compound that captures solar radiation in leaves during photosynthesis. Basically, leaf chlorophyll content regulates the amount of CO_2 and water that are uniquely combined to form structural (cellulose and lignin) and storage (starch and sugars) compounds in plants. It is appropriate to note that leaf chlorophyll "content" is the product of chlorophyll "concentration" and the leaf area involved in photosynthesis. As such, it is appropriate to think of leaf area (somewhat analogous to canopy biomass) as the size of the factory and leaf chlorophyll concentration as how fast the factory is able to operate. Therefore, it is important that attempts to assess crop vigor should focus on both the size of the factory that is available to capture solar energy and the concentration of chlorophyll in leaves that is available to initiate the synthesis of plant metabolites.

Waveband Properties: Photosynthesis involves the capture of blue and red light in the visible portion of the spectra. Radiation in other visible wavebands is captured less effectively (orange > yellow > green) by plants. Plants are not able to utilize near infrared (NIR) radiation. However, measuring the reflectance in this region of the spectra is useful because NIR radiation is strongly reflected by living vegetation (frequently referred to as biomass). This characteristic is why most attempts to assess crop vigor using remote sensing gather reflectance data from the NIR region (i.e., size of the factory). Studies relating canopy reflectance in the various wavebands to leaf chlorophyll concentration clearly show the strongest relationships in the green region (centered at 550 nm) and red-edge (~720 nm) regions and the weakest in the blue (~460 nm) and red (centered at 670 nm) regions. These findings involved leaves with near zero chlorophyll (very pale) to nearly 600 mg chlorophyll/m^2 (dark green). It is worth noting that red and blue reflectance changed little when chlorophyll content exceeds 100 mg/m^2 (yellow-green leaves). This is because chlorophyll is very effective at absorbing blue (92-95%) and red (95-95%) radiation. As such, it theoretically only takes a single layer of leaves (leaf area index, LAI of 1.0) to largely render red reflectance insensitive to leaf chlorophyll status. In reality, leaves are not perfectly oriented to effectively capture all of the radiation and as such red reflectance does not saturate until the LAI reaches ~2.0 (~V8 growth stage, eight fully expanded leaves).

Light Penetration: The tapered shape of a corn canopy (smaller size of the upper leaves) typically allows visible radiation to penetrate 5 to 7 levels deep. NIR radiation penetrates considerably deeper into a canopy because a portion of it is transmitted through leaves, but a full canopy can reflect ~90% of the NIR radiation. This value compares to ~20% reflectance from dark soil and perhaps up to 40% from light colored soil for NIR radiation.

Growth Stage: Don't stress corn plant very much before the 8-leaf growth stage because it can reduce yield potential. For unknown reasons, stressing corn plants at the 6- to 7-leaf growth stage can reduce yield potential in a way that can't be recovered, even with plenty of fertilizer and water. This conclusion was reached by putting tents that blocked 50% of the light over plants for either one week or two weeks. Plants that were shaded during the 6- to 7-leaf growth stage had lower yields than those either stressed before or after that period. Similar observations were made where wheat straw was incorporated into the soil to generate an early season N stress. Plots received 40 lb N/acre one time (i.e., at either week 1, week 2, or week 3, etc.) until week 8 when all plots received 120 lb/acre of additional N fertilizer. Again, there was something unique about encountering a stress the 6- to 7-leaf stage that should be avoided if possible.

Producers planning to take advantage of potential fertilizer savings that are possible with in-season N management need to have a good understanding of the temporal N requirements of the crop. Overloading the system with early-season N fertilizer can delay the onset of an N deficiency. As such, deficiency symptoms might not occur until after producers are able to make variable rate applications. For this reason, it is important to know how much N is in a typical corn plant at each growth stage and how that amount relates to the total amount of N in the above-ground biomass at harvest. The pattern of N uptake by corn was illustrated in "How a Corn Plant Develops" by Hanway et al. in 1957 (available from Iowa State Press). The nutrient uptake aspects of this report were repeated in a 1993-94 study (irrigated) involving five modern corn hybrids and one that dated back to the early 1970s (B73 x MO17). Plants were harvested weekly until silking and every several week thereafter to determine biomass accumulation and nutrient uptake. Statistical analysis showed that all hybrids accumulated biomass and took up N similarly until silking, but differed thereafter until harvest.

Calibration: Interpreting active and passive sensor data depends on the wavebands that are available for processing. Over the past 15 years, the concept of referencing sensor readings to an "N-Rich" area has been generally accepted as a reasonable way to calibrate imagery and sensors. The success of this simple approach is nested in the reality that factors like cropping history, cultivar, and growth stage can impact crop vigor and sensor readings. Involving readings from the "N-Rich" area serves to normalize data to a particular situation and thereby eliminates the need to develop a specific calibration function for each set of specific variables and local conditions.

It is appropriate to note that the N-Rich reference area concept was developed using data from small plots. This situation usually strives to minimize spatial variability in soil properties. However, when the concept is extended to entire fields there is likely to be considerable variability in soil properties and yield potential. As such, there are likely to be areas with a field or reference strip that appear to be more vigorous than others even though an entire strip is known to have excess N availability. Somehow this type of differential vigor needs to be considered when using the crop to assess N status and make in-season fertilizer recommendations. Researchers at Oklahoma State University have proposed the use of a ramped calibration strip to partially address the issue of spatial variability. This concept is discussed below. When aircraft imagery is used to assess crop vigor, pixel characteristics for the field are frequently ranked and categorized from which a group is designated as having high vigor to be used as the reference when calculating N sufficiency. This approach becomes problematic when areas that previously received manure or those that are inherently more fertile end up being used as the reference because it is unrealistic to think that any amount of added N fertilizer would be able to make the yields comparable. An example might be where the upper 20% of the pixels for greenness or biomass are designated as the reference or target for the rest of the field even though the yield potential is somewhat less. If this were to happen, over-application of N would result. This possibility is likely to be environmentally and economically unacceptable. One way to address this problem is to incorporate a preprocessed layer of information (i.e., previous yield maps, soil organic matter content or color, electrical conductivity, etc.) into the fertilizer rate decision that amounts to an adjustment factor in N rate for each part of the field. Other ways to generate a virtual reference value for the entire field are under development and show good promise.

Practical Sensor / Crop Relations: Many trade-offs need to be considered when using the crop as a bio-indicator of nutrient status. The value of a field-scale image to identify problem areas can be great. Likewise, having the ability to physically examine each plant for disease, access to light, relative growth stage, and symptoms of nutrient stress would be ideal. Each person's perception of reality may be different depending of economics, access to technologies, and understanding of the physical, chemical, and biological processes involved. Somewhere in the middle lies the fact that producers are likely to use yield-monitor combines and related yield maps as their measure of success when evaluating variable-rate technologies. This premise implies that the width of the harvesting equipment needs to be considered when determining the number of real-time sensors to place on an implement or the spatial resolution of imagery. What constitutes over-kill and what amounts to insufficient information will be an individual decision. The ultimate approach relates to the characteristics of the sensor technologies involved, the uniformity of the cultural practices (e.g., plant population, weeds, traffic patterns, etc.), the ability to spatially vary nutrient application across the span of application equipment, and the spatial variability of the landscape. While there may be some level of assurance by having multiple sensors across an implement, one must ask if the target crop is really that variable or if the characteristics of the sensors are not reliable enough to provide quality information with fewer sensors. At the very least, users should evaluate the stability of each sensor by monitoring its output in a stationary position over the target crop. Variability in sensor readings (instability) needs to be evaluated in terms of how it affects the decision to apply more or less fertilizer. Adding more sensors will buffer the average response to some extent and even further if readings are averaged over time (perhaps 10 readings or more), but this comes at the cost of the additional sensors.

Setting Up On-Farm Trials: Calibrating real-time sensors can be extremely time-consuming and results are likely to be site and growth stage specific because crops respond to current and past management practices, as well as being unique for each hybrid. For this reason, it works best to compare sensor results with those from an area known to be the same except for having received additional N fertilizer. It is not wise to use the greenest or most lush area in a field as a reference because such areas could be the result of different management practices (i.e., manure history, previous crops, landscape position, etc.). A better approach is to exceed the recommended N rate on selected strips by 10-20%. These strips should be placed in the field so as to traverse as many soil types and growing conditions as possible. An even more informative approach is to place several ramped calibration strips in a field. The strips can be implemented by programming a variable rate applicator to progressively apply higher N rates to discrete field sections (perhaps 30-50 ft long) in a strip. Six to eight rates should be adequate to cover a reasonable range of N application rates. Visual comparisons between the various N rates in the ramped calibration strip and the rest of the field can be used to indicate the appropriate N application rate. Collecting sensor data from plants in the ramped calibration strip helps make the fertilizer N recommendation more quantitative. Because of spatial variability in fields, producers gaining experience with variable-rate technologies may find it informative to position a ramped calibration strip adjacent to a reference strip that contains 10-20% extra N. Ramped calibration and reference strips should not be imposed on the same area year after year. Even ramped calibration strips can be problematic if soil properties affecting crop vigor change significantly within the length of one N-rate sequence. As noted above, greater accuracy will probably be possible by incorporating an integrated layer of soil information into any in-season N recommendation (i.e., augment real-time crop data with spatial soil and yield information).

Sensor Use Issues: Responses to variable rate N applications will probably first be expressed in terms of crop color. Sensor and imagery analysis should also reveal how well the crop is recovering in terms of leaf area and plant biomass. Yield and economics provide the ultimate way to evaluate the benefits of variable-rate technologies. At the end of the growing season, corn stalk samples should be tested for nitrate concentration to determine if the lowest N application rates still involved excess N availability (i.e., >2000 mg/L NO_3-N).

Producers considering variable rate N management should start slowly and consult with knowledgeable consultants and experts regularly.

On-The-Go Variable Rate Pitfalls: There is no substitute for common sense and being a keen observer. It can be reassuring to know that all sensors along a boom are providing comparable data.
Ask if this is possible and how to view this output. Check the delay time between when there should be a change in the application rate based on sensor information and how much later (i.e., relative field position) where the change actually occurs.
Don't assume that a few reference strips or ramped calibration strips will provide a reliable point of reference for adequately fertilized plants in all parts of the field. The concept of assessing crop N needs relative to an N-Rich area is sound as long as all inherent soil properties are the same except for N availability and the cultural practices and previous cropping history are comparable. If this test fails, which it will in most fields, be prepared to find ways to adjust the application algorithms accordingly.

Gaining Confidence: Making a visual comparison of crop vigor and color with canopy sensor output while driving through the field can provide considerable confidence in the technologies, even if in-season N application is not yet part of the management scheme. As with any technology, it behooves users to be keenly aware of the limitations and short-comings of the instrumentation. Driving a sprayer with sensors through an N-Rich reference strip or ramped calibration strip after the application algorithm has been entered into the controller is a good way to "smoke-test" the system. If the algorithm recommends applying significant amounts of fertilizer to areas that are known to have more than adequate N availability. then there is likely to be a problem with assignment of an appropriate reference value.