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What's Right Amount of N? Using Sensors May Provide Better Answer

For variable-rate applications, in-field on-the-go sensors may be just the ticket for applying the correct amount of N.

SUMMARY
The best opportunity (economic or environmental) for using sensors to make variable rate nitrogen (N) applications is where uncertainty is high about the right amount of N to apply in 1) fields with extreme variability in soil type, 2) fields experiencing a wet spring/ early summer (loss of applied N) and where additional N is needed, 3) fields that have received recent manure applications, 4) fields receiving uneven N fertilization because of application equipment failure or because of mis-calibrated equipment, 5) fields coming out of pasture, hay or CRP management, 6) fields of corn-after-corn, particularly when the field has previously been cropped in a different rotation, and 7) fields following a droughty growing season.

When GPS-aided sampling came along in the early 1990s, it was believed that the extra expense to derive soil nutrient maps would be offset by an increase in value obtained from improved crop-use efficiency with map-based, variable-rate fertilizer applications. While improvements have been made, by relying on the conventional soil sampling methods, the perceived value for many farmers in doing this type of sampling and mapping has been marginal.

A decade later we find in grain crop production areas of the U.S. moderated use of soil sampling for spatial characterization of soil nutrients. In some cases, government support is used to encourage producers to grid or zone sample for developing variable-rate nutrient applications.

In 2006, while about 40 to 50 percent of the agri-service providers in the Midwest provided spatial soil sampling and mapping services, a lower percent of farm acres actually received these services. The conclusion of many is that more efficient and less expensive tools and procedures are needed for wide-scale adoption of managing within-field nutrient variability.

Soil sensing

Six different design concepts for on-the-go soil sensing are 1) electrical conductivity (or resistance) sensors, 2) optical and radiometric sensors, 3) mechanical force sensors, 4) acoustic sensors, 5) pneumatic sensors, and 6) electrochemical sensors. The ideal sensor would respond to only the soil attribute of interest. Additionally, the sensor-based measurements ought to be highly related with conventional analytical measurements so that the interpretation and fertilizer recommendation can be based on the decades-old databases of likely crop response.

The reality is that most of these sensor types are affected by a multitude of soil properties and thus the interpretation is confounded. As an example, soil electrical conductivity can provide an indirect indicator of many soil properties including clay or sand content, soil water content, varying depths of conductive soil layers, temperature, soil salinity, organic compounds, cation exchange capacity (CEC), soil pore size, and metals. Soil electrical conductivity has been explored as a soil property that could be used to improve nutrient management.

The most helpful soil sensors for nutrient management would be those that directly measure the soil property of interest. Probably the commercially available sensor that has shown the most promise is the Veris Technologies® 1 on-the-go soil pH mapping system. With this system, a soil sample is taken while traveling through the field and pulled up against a ruggedized ion-selective membrane electrode sensor. After measurement, the sensor is washed and ready for a new sample. The device cycles about every 10 to 12 seconds, allowing for a quick field assessment and at a spatial resolution much greater than typical soil sampling methods. While this type of field sensing has greater error than laboratory measurements, that error is easily offset by the increased resolution obtained with the number of samples one can take for a given field area.

Plant sensing

Argument for. Because soil types within individual fields can be highly variable, the nutrient availability provided by these different soil types to support crop production can also be highly variable (Figure 1). As a result, when a uniform rate of fertilizer is applied over the entire field, substantial areas can be over-fertilized (wasting nutrients) while other areas are under-fertilized. Climate factors such as precipitation and temperature also cause soil nutrients (especially N) to behave differently each year. Ideally, the amount of fertilizer added during a given growing season should be both climate-sensitive and site-specific. Applying N at sidedress so that it is synchronized with crop N uptake helps reduce potential N loss, but applying the correct amount of N is equally if not more beneficial in reducing losses. Research has shown that when N fertilizer rates exceed what is needed, there are higher levels of post-harvest soil nitrate and a high risk of N loss to the environment (Figure 2).

N status. Plant measurements for determining crop N status are generally a sufficiency/deficiency strategy. Plant measurements serve as indicators for within-season N additions, or, if measured at crop maturity, to diagnose whether or not conditions provided deficient, sufficient, or excessive N for the crop. Since plants integrate soil, climate, management, and other environmental influences on crop N health, they can be used as an indicator of N need. However, issues related to plant N measurements need to be consid-

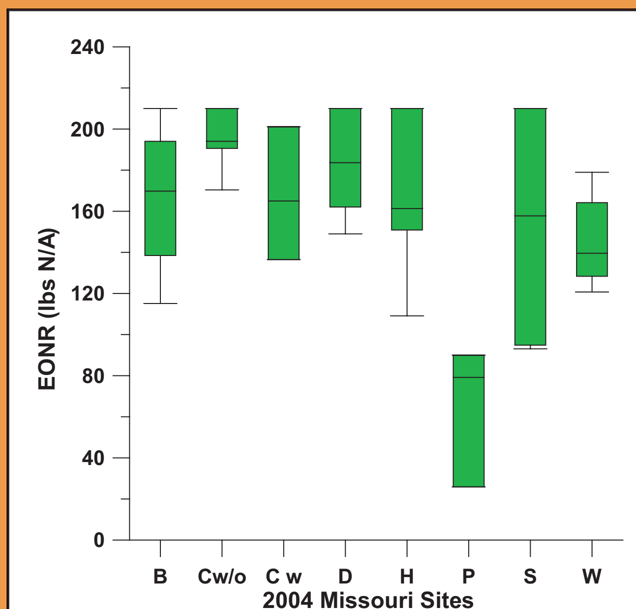

Figure 1. Economic optimal N rate (EONR) varies tremendously between farmers' fields and within fields (box represents the 25th to 75th percentile).

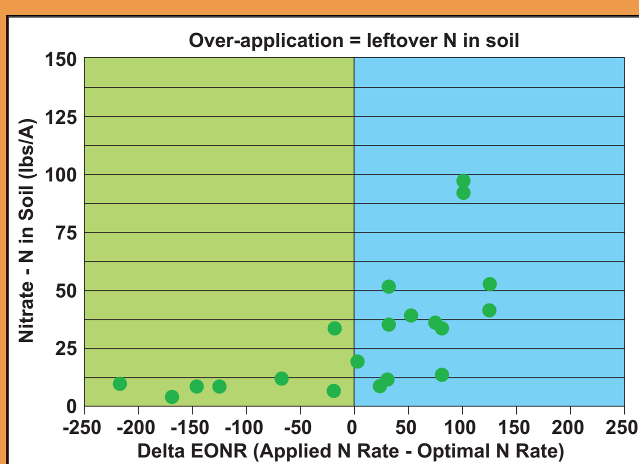

Figure 2. Post-harvest residual soil NO_3-N content when N fertilizer applied is either below (green box) or above (blue box) the economically optimal N rate. "0" on the x axis represents the economically optimal N rate.

ered before incorporating these tools in the N management plan, including: 1) uncertainty of determining full-season N status and fertilizer needs from young crop plants, when an opportunity for N addition still exists, 2) a reported wide range in sufficiency critical values, 3) varying sufficiency critical values as the crop matures, 4) varying critical values from various plant parts, and 5) the need for maintaining an N sufficiency block or strip for reference that adequately represents N needs of the remaining field.

Because N is a primary constituent of plant chlorophyll pigments, leaf or crop canopy color can be used to evaluate crop N health. An obvious advantage of using plant color and biomass for within-season N input decisions is there is little time delay between measurement and interpretation, such as occurs in soil sampling and analysis. Furthermore, because each plant expresses crop N status for its given location, plant sensing provides the best opportunity for quantifying detailed spatial variability of crop N need. A primary disadvantage of using the plant for assessing N need is that it narrows the window of time when N applications can take place.

Sensing options

Hand-held meter. A commercial hand-held chlorophyll meter (Minolta SPAD-502) measures leaf transmittance centered at red (650 mm) and near infrared (940 mm) wavelengths and has been shown to be sensitive to N stress in many crops. To operate, the meter is clamped onto a single leaf to prevent interference from external light. The meter senses transmittance through a very small area of leaf with each reading. A recent investigation in the U.S. Midwest provided ample evidence that the SPAD meter could be used for making effective N recommendations (Figure 3). While individual plant readings can be rapidly obtained, acquiring a representative value for large cornfields is time consuming. It is especially difficult to obtain representative plant N measurements for fields with significant spatial variability. For this reason, chlorophyll meter sensing to assess production-scale crop N health and variable-rate N may not be practical for many producers.

Reflectance radiometers. By definition, crop reflectance is the ratio of the amount of light leaving the canopy to the amount of incoming light. Digital reflectance sensors (spectral radiometers) and photographic images are commonly calibrated against a standardized reference panel to assess the amount of incoming light. To remove the varying effects of sunlight (e.g., sun angle and cloudiness) on reflectance measuring, an active type of reflectance sensor system has been employed that emits its own source of modulated light onto the crop canopy at user-determined wavelengths using light-emitting diodes and then detects with photodiodes canopy reflectance at those same wavelengths.

In Missouri from 2004-2006, investigations using these sensors demonstrated on farmers' fields an average profit of between $5 and $10/A with an N reduction of about 30 lbs/A (data not published). Interest for further exploring this way of managing N is growing. As an example, in 2007 the Missouri USDA-NRCS provided $60/A ($20/A for three-year contracts) in EQIP support for farmers who qualify to do variable-rate N management using these sensors.

Aerial imaging of crop fields is also appealing to producers because it is low cost, has quick turnaround, provides whole-field information that is spatially accurate, and can be used as a diagnostic tool for assessing many different types of crop stress. It gives producers an immediate visual assessment of conditions. With familiar field landmarks also visible on an image (such as field boundaries, trees, or structures) producers are quickly able to estimate the extent of crop stress as well as associate stress areas with soil and landform features.

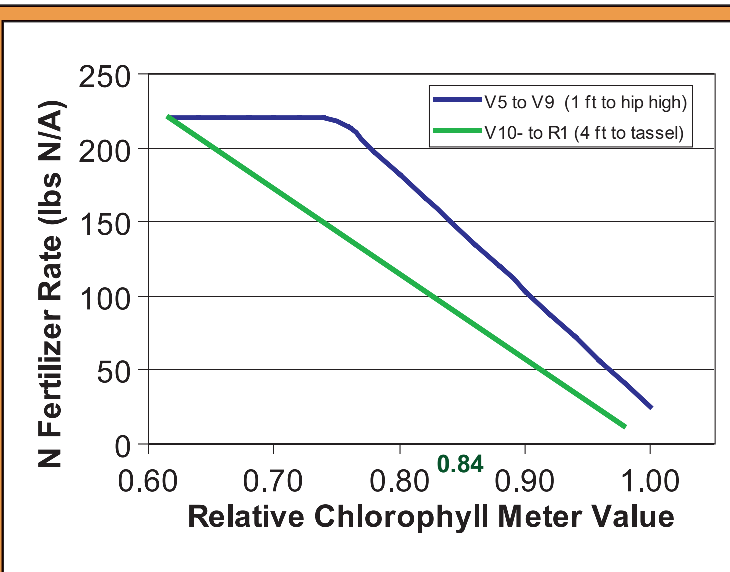

Figure 3. Nitrogen fertilizer recommendation using a SPAD meter.

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[1] Mention of trade names as commercial products is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture or its cooperators.