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Nitrogen Management in Field Crops with Reference Strips and Crop Sensors

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Introduction

Scientists and crop producers around the world are using crop canopy sensors to evaluate crop nutrient status, estimate crop biomass production and yield potential, detect crop stress and disease infestation, breed and select new crops, make fertilizer recommendations, and prescribe variable-rate fertilizer and chemical applications.

The purpose of this publication is to improve growers' knowledge and understanding of how crop canopy sensors and in-field reference strips can be utilized for effective nitrogen (N) management. The overall goal is to improve the use efficiency of N fertilizer resources and increase producers' competiveness and sustainability. The publication provides information about how crop sensors work, their benefits, and proper methodology for use and gives examples from growers who succeeded in incorporating sensors into their nutrient management decisions.

Why Is It So Difficult To Manage N?

It's all about variability! Do farmers produce the same yields in the same field from one year to the next, even when they use the same variety, seeding and fertilizer rates, and application timing? The answer, of course, is—No! Temporal variability in yield (variability over time) is usually caused by the combined environmental effects of rainfall frequency, soil and air temperatures, precipitation/temperature and landscape interactions, and soil characteristics. Variability in these conditions from one growing season to another has an incredibly significant impact on both crop yield potential and the amount of N required by the crop.

Because it is difficult to predict temporal yield variability, fertilizer recommendations are often made using yields from previous years. Research by the Oklahoma State University precision agriculture team, however, has revealed that the chance of N need in one year being the same as in the previous year is only about 1% (Smith, 2008).

The concept of precision agriculture evolved from the idea that it may be beneficial to vary agricultural inputs to address variability in plant growing conditions (Robert, 1993). What if growers could know precisely what their crop yield will be, and what if fertilizer management decisions could be made using real-time knowledge of the crop's need for N? There is an "app" for that! Precision crop sensors, in combination with reference strips, are an excellent tool for efficient N management.

What Is So Special About Crop Sensors?

Using sensors versus visual evaluations

In the everyday world, the word "sense" refers to the five human senses, and "making sense" describes our efforts to absorb and understand information that may seem confusing or conflicting. Field scouting and visual crop evaluations are routine for the majority of crop producers and provide invaluable information about crop growth, development, and nutrient status as well as about pest, weed, and disease pressures. This information is very effectively utilized to prescribe management practices such as herbicide treatments and irrigation water applications. Severe stress due to nutrient deficiencies, water shortage, or plant disease or pest infestations is easily identified with the naked eye. However, more subtle or just-developing plant stress issues may not be as obvious and could go unnoticed or misinterpreted.

Remote sensing literally means "sensing from a distance." Precision crop sensors are tools that allow us to acquire information about a plant's vigor and nutrient status by detecting from a distance—sensing—the amount of energy reflected or emitted by that plant. In other words, remote sensing is the acquisition of information about an object or phenomenon, without making physical contact with the object.

One of the most common perceptions is that we don't need sensors because "we can tell that the crop is stressed or deficient just by looking at it." Yet precision sensing has three main advantages over traditional visual evaluation:

1. Sensors are much more reliable and objective than visual assessment
2. Sensors provide quantitative information (numeric data that can be measured and compared) versus qualitative information (descriptive data that can be observed, but not measured)
3. Sensors can function within regions of the electromagnetic spectrum where human eyes are unable to operate.

Sensor models

There is a variety of crop sensors on the market today including, but not limited to, GreenSeeker (Trimble, Sunnyvale, CA), OptRx (AgLeader Technology, Ames, Iowa), and Yara N-Sensor (Yara UK Limited, Grimsby, UK). For example, the GreenSeeker crop sensing system helps growers to precisely manage crop inputs (N or herbicides) on the go. With a GreenSeeker sensor, producers can address field variability by applying the right amount of fertilizer, in the right place, at the right time.

How Crop Sensors Work

Optical properties of plants

Crop sensors utilize the optical characteristics of plants and their associated vigor and health properties. The reason that most plants appear green is because they contain chlorophyll, a green pigment that absorbs light in the red (long wavelength) and the blue (short wavelength) regions of the visible light spectrum and reflects green light. Unhealthy, less-vigorous plants have less chlorophyll and appear less green.

Near-infrared is a small portion of the infrared region between the visible and microwave portions of the electromagnetic spectrum. Because near-infrared has longer wavelengths than visible light, it exhibits unique properties that can be exploited for remote sensing applications such as detecting crop stress, including water and nutrient stress, and weed/pest infestations. Strong reflectance within the near-infrared region is due to near-infrared light not being absorbed by any plant pigments. As near-infrared light travels through plant tissues, it interacts with the spongy mesophyll cells and about half of its energy is transmitted through the plant biomass and the other half is reflected.

Sensor output—vegetative indices

Crop sensors are designed to precisely measure the ratio between the amounts of absorbed and reflected

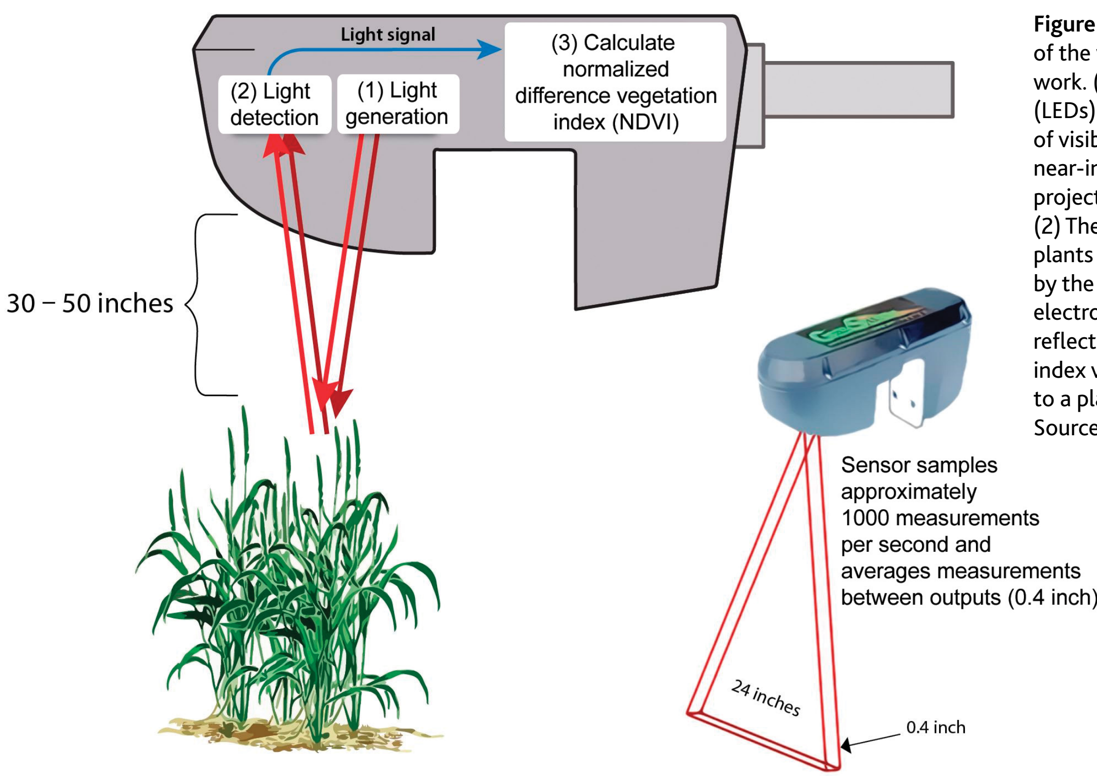

Figure 1. Schematic illustration of the way the crop sensors work. (1) Light-emitting diodes (LEDs) produce a combination of visible red and invisible near-infrared light, which is projected onto the plants. (2) The light reflected from the plants is registered ("sensed") by the detector. (3) The built-in electronic circuit converts the reflectance data into NDVI index values, an index related to a plant's green biomass. Source: Tubaña et al. (2013).

light of specific wavelengths, such as red and near-infrared (figure 1). The numeric reflectance data are exported as vegetative indices. The Normalized Difference Vegetative Index (NDVI) is one of the most commonly used indices in crop sensing. The NDVI is highly correlated with the amount of green biomass/vegetation produced by the plants. NDVI values range from 0 to 1, with bare soil or unhealthy plants ranging between 0.2 and 0.4 and vibrant, green, vigorous, healthy plants ranging between 0.5 and 0.9.

Using sensors in the field

Systematic research focused on correlating specific optical properties of plants with particular plant characteristics—including biomass production, vitality, and N status—has led to the development of step-by-step guidelines that growers can use to manage N better. To assess plant health and vigor, crop sensors are held horizontally between 2 and 4 feet from the top of the plant canopy and walked within representative parts of the field. The sensors can be mounted on an ATV or a tractor to obtain more measurements in a timely manner. A step further entails on-the-go, sense-and-spray systems for larger areas and prescribing variable rate fertilizer applications.

Why Do I Need A Reference Strip?

Great! We have crop sensors that can more accurately measure plant N status than other methods such as plant tissue or soil sample analysis. So now we can estimate the amount of N the crop needs, and we can easily calculate the N rates we need to apply. Right? Not exactly. Everything must be understood in comparison. It is difficult to detect N deficiencies in actively growing crops without comparison to plants with an adequate N supply. The easiest way to do that is to establish reference strips with adequate N—N applied at non-limiting amounts. These strips can be monitored throughout the growing season and compared to the rest of the field (figure 2).

Comparing reference strips to "farmer practice" capitalizes on the reality that this year's environment and growing conditions are going to differ from those the crop experienced last year. Extensive research worldwide in many major food crops shows that both crop yield potential and crop response to applied N change year to year (temporal variability) and field to field (spatial variability).

Consider two different types of growing conditions. You could have a year when yield potential is high but the crop does not respond to additional N. This could be the case after a warm, wet winter when sufficient N was mineralized from soil organic matter and N was deposited in precipitation. In this environment, added N would not be expected to increase crop yield even though yields were projected to be high. On the other hand, in a year when the winter months were cool and dry, but where an excellent plant stand was achieved, N demand would likely be greater and the yield potential lower, and the topdress N application rate might be moderate to high.

This is exactly why, in order for a grower to get sound estimates of N fertilizer demand, both the crop yield potential and the crop's ability to respond to additional N must be known. Scanning the reference strip with crop sensors provides an accurate estimate of how much N was supplied to the crop "for free" (N from soil mineralization and rainfall) for the period from planting to sensing. Even if planted late, the reference strip can serve as a powerful visual indicator of whether a grower should apply additional N mid-season. The reference strip compared to the farmer practice is a simple and effective tool that integrates environmental change into one, clearly defined variable—crop demand for N.

Reference Strip + Crop Sensor = Higher N Efficiency

Establishing reference strips

The reference strip is an indicator of a crop's yield potential with application of N fertilizer. Reference strips should be established just before or at seeding to allow sufficient time for N uptake and for fertilized plants to reveal any increase in yield potential due to applied N. When the N rate for the whole field will be prescribed based on a reference strip assessment, the strip needs to be located within a representative area of the field.

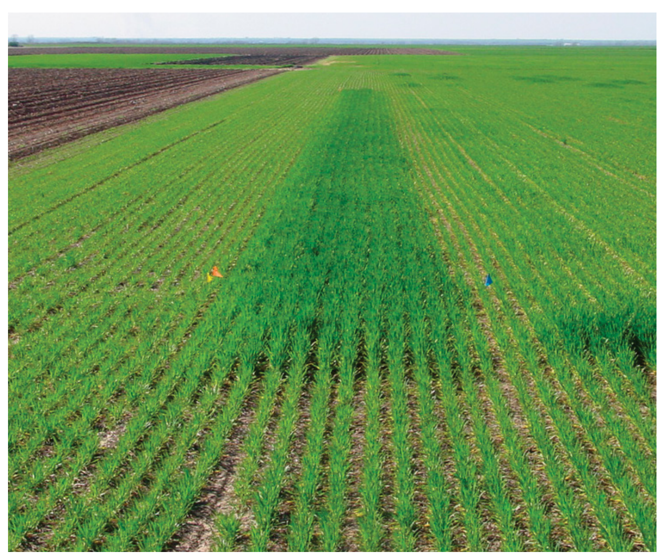

Figure 2. A nitrogen reference strip in a wheat field, Oklahoma. Photo by Brian Arnall, used by permission.

The reference strip should be located across a portion of the field that you believe is most representative of the entire field. If your field has areas that are distinctly different, or where you have noticed substantial differences in production, establishing a separate reference strip in each of those areas is a good idea.

Timing fertilizer applications

A general recommendation is to apply between 30 and 50% of the anticipated total N needed at seeding time and postpone the decision on added N until the middle of the growing season. If no differences between the reference strip and the rest of the field are detected by sensors at that time, it is unlikely that added N will result in increased yields. Conversely, if differences are large, there is likely a high demand for added N.

Calculating response index

Dividing the sensor readings from the reference strip by the readings from the rest of the field allows us to calculate the response index (RI). The RI reflects the likelihood of crop response to applied N fertilizer. When no differences exist between the reference strip and the rest of the field, it means one of two things: (1) enough N had been mineralized from soil organic matter or deposited in the rain/snow to meet all of the plant's N needs or (2) plant growth was likely restricted by some other variable that masked the ability to detect N deficiencies.

Achieving higher N use efficiency, improved bottom line with crop sensors

The use of crop sensors, in combination with reference strips, has been shown to produce savings of $10–$20 per acre in N fertilizer costs and increase N use efficiency (Andrews, 2011). Li et al. (2009) and Tubaña et al. (2008) showed that GreenSeeker sensors utilized as an N management tool can improve N use efficiency with significant increase in net profits. Raun et al. (2002) reported that at least a 15% increase in N use efficiency could be achieved with sensor-based variable-rate N fertilization.

As with any novel practice or technology, most crop sensor systems require some background education and also often represent a substantial initial monetary investment. Crop sensor prices range from $500 for smaller portable units for easy field scouting to $25,000 for large, farm-scale systems with on-the-go variable-rate application capabilities. On the other hand, costs of most crop sensing systems can be recovered within 1 to 2 years due to fertilizer savings and/or increased revenues from improved crop production.

Table 1 summarizes the results of on-farm studies conducted by the Iowa Soybean Association On-Farm Network. The documented benefits (in terms of yield and revenue) are obvious and consistent (Gerhardt, 2008).

Other Important Considerations

I routinely soil sample my fields. Do I still need reference strips?

Yes! Soil testing for ammonia-N and nitrate-N (plant-available inorganic N fractions in the soil) is commonly used to detect N deficiencies. However, concentrations of both these fractions change considerably depending on soil moisture, growing conditions up until the sampling time, time of year, and depth to which the sample was taken. In addition, soil testing for inorganic N does not reflect the N released from soil organic matter during the growing season. A combination of soil testing and reference strips will provide a more complete information on the status of your crop.

Do reference strips work only for N?

References strips for other nutrients, including phosphorus (P), potassium (K), and sulfur (S), have shown potential for visual detection of deficiencies and for "yes/no" fertilization decisions. Sometimes, even at high soil test values, growers can observe a substantial response to fertilizer. If a grower suspects that a particular macro- or micronutrient is limiting yield at a particular location, establishing a reference strip by applying that nutrient at a non-limiting rate can easily verify the potential response to that nutrient.

What if the reference strip was not established at planting?

Better late than never! However, the reference strip will provide more accurate information if established at or immediately prior to seeding. If a grower chooses to apply the reference strip after seeding, the later in the growing season, the less benefit will come from comparing the reference strip and farmer practice. For example, for winter wheat, reference strips are recommended to be established at seeding in August or September. However, they can be established as late as December for making topdress N decisions the next spring.

Do reference strips need to be established every year?

Yes. The application rate must be a non-limiting rate, not excessive to the point of causing damage to the crop or environmental N losses. Reference strip locations within fields must be changed every year to avoid carryover effects.

Table 1. Yields and revenues in rotations under sensor-based N fertilization and traditional farmer fertilization. (Adapted from Gerhardt, 2008)

Rotation, N source	Preplant N, lb N/acre	Sidedress N, lb N/acre	Total N applied, lb N/acre	Change in total N, lb N/acre	Grain yield, bu/acre	Change in yield, bu/acre	Revenue, $/acre	Change in revenue, $/acre
Corn/Soybean, Fall NH_3								
Farmer	135	0	135	29	224	5.0	$997	$9
GreenSeeker	135	29	164		229		$1,006	
Corn/Soybean, Sidedress UAN								
Farmer	120	31	120	31	205	10.0	$914	$32
GreenSeeker	120	0	151		215		$946	
Corn/Soybean, Fall swine manure								
Farmer	122	0	122	37	181	8.0	$799	$20
GreenSeeker	122	37	159		189		$818	
Corn/Corn, Sidedress NH_3								
Farmer	0	100	100	37	148	4.0	$653	$1
GreenSeeker	0	137	137		152		$654	
Average, all trials								
Farmer			94	34	190	6.8	$841	$15
GreenSeeker			153		196		$856	

Grower success with crop sensors

What most growers tend to pay close attention to are other producers' success stories—the stories that affirm a particular method or practice truly works. There are a lot of success stories available in the current press and online. Here are a few of them.

Brent Rendel, wheat and corn grower, Miami, Oklahoma. Rendel has reported savings in N fertilizer inputs of over $60,000 in two growing seasons on his 4,000-acre farm (Raun, 2008; Smith, 2008).

Dave Geils, corn producer, Harvard, Illinois, responding to a grower survey (Raun, 2007). "Everybody is trying to figure out how to control costs. The biggest way you can save money is with N. We used it [GreenSeeker system] on 4,000 acres and reduced nitrogen application about 20 pounds an acre on average. We didn't lose any yield. We saved at least 20 units across the board. The total nitrogen savings was about $24,000. So I paid for the cost of sensor system the first year. That is just good business."

Lee Moats, crop producer, Riceton, Saskatchewan, Canada, in an interview with the *The Western Producer* (Lyseng, 2012). "'I put down our usual low rate of 40 pounds nitrogen when I seeded and didn't put down a single pound after that. Normally I do a split application to top up the crop. But not in 2011. I did actually take the GreenSeeker out of the shed and ran it over some crop just to see if we needed more nitrogen. It told me zero N everywhere I drove, so it went back into the shed and stayed there. It had done its job for the year.'

Skipping his typical in-crop split nitrogen application saved Moats $25,000 in fertilizer costs for 2011, which is about what the machine cost him in 2009. Moats said it was a significant cost saving in a year when he expected to buy a lot of extra nitrogen.

'What could be better for your pocketbook than spending less money on inputs while maintaining high yields? And it's better for the environment as well.'"

Herb Oehlke, wheat farmer, Ledger, Montana, from an article in *The Prairie Star* (Ruckman, 2008). "'Last year, I saved 5.3 gallons of fertilizer per acre—that kind of input adds up,' said Oehlke. Though GreenSeeker does not guarantee an increase in crop production, it can happen. Oehlke not only realized a fertilizer savings with his GreenSeeker, but also an increase in crop production."

Robert Blair, crop producer, advocate for sustainable agriculture, and a precision agriculture pioneer, Kendrick, Idaho, described in an article in *Precision Ag News*, Australia (Leonard, 2012). "The cost benefits he has calculated for variable rate application are even greater at between 20 to 25 percent. Having the right data to identify variation is central to managing variation. In-crop data is proactive data. It can be used to support decisions that influence productivity and profitability of the current crop. Remote sensing is the most efficient way to collect large areas of in-crop data."

Remote Sensing and Variable-Rate N Applications for Crop Production in Idaho

Optical sensing technology combined with variable-rate spray controller hardware makes it possible to apply N in-season at an unprecedented small scale. Research by Bowen et al. (2005) conducted in eastern Idaho in potato and malt barley clearly indicated that sensors were effective in accessing "greenness" attributed to the N rate applied. Sensors were able to pinpoint N deficiencies before they became visible. Two weeks prior to row closure was identified as the optimum time for sensing in potatoes. Late tillering was found to be the best time for sensing malt barley.

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Grower resources

Idaho Crops & Soils. Blog for Idaho growers by Olga Walsh and others. http://idcrops.blogspot.com

Idaho Crops & Soils News. Monthly newsletter from UI Extension serving Idaho crop producers.

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