WHAT ARE THE BENEFITS OF CANOPY SENSING FOR VARIABLE-RATE NITROGEN CORN FERTILIZATION?

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Abstract

Canopy reflectance sensing for assessing crop N health has been proposed as a technology on which to base top-dress variable-rate N application. The objective of this research in Missouri was to evaluate the economic and environmental benefit of active-light crop-canopy reflectance sensors for corn N rate decisions. A total of 16 field-scale experiments were conducted over four seasons (2004-2007) in three major soil areas. Multiple blocks of randomized N rate response plots traversed the length of the field. Each block consisted of 8 treatments from 0 to 210 lbs N/ac on 30 lbs N/ac increments, top-dressed between V7-V11 vegetative growth stages. Canopy sensor measurements were obtained from these blocks and adjacent N-rich reference strips. A sufficiency index calculated from the sensor readings correlated with optimal N rate, but only in 50% of the fields. While soil type, fertilizer cost, and corn price all affected our analysis, a modest ($10 to $20/ac) profit using canopy sensing was found. Fertilizer savings of 10 to 40 lbs N/ac could be expected in most situations, but savings also varied by reflectance readings, soil type, and fertilizer and grain prices. These results affirm using crop-canopy reflectance sensors for detecting corn N fertilizer needs.

Introduction

The quest for precision N management, both by improved prediction of crop N needs (i.e., fertilizer rate) and by synchronizing fertilizer application with plant N uptake, has prompted numerous recent investigations exploring the potential of active-light, crop-canopy reflectance sensors (Raun et al., 2002; Mullen et al., 2003; Dellinger, 2008; Shanahan et al., 2008). These sensor systems contain light emitting diodes (LEDs) that illuminate modulated light onto the canopy (thus the term “active”) and detect reflectance of the modulated light from the canopy with photodiodes (Stone et al., 1996). At least two (one visible and one NIR) wavelengths are typically included, so that reflectance can be interpreted in terms of commonly used vegetative indices, like the normalized difference vegetative index (NDVI), useful in assessing crop growth and crop N status. With their own light sources, these sensors are less sensitive to diurnal variations than sensors that rely on ambient sunlight. Operationally, these sensors can be mounted on N fertilizer applicators equipped with computer processing and variable rate controllers, so that sensing and fertilization is accomplished in one pass across a field.

Typically evaluation of these sensors has been obtained by comparing the crop in an area known to be non-limiting in N to the crop in areas inadequately fertilized. Measurements from the two areas are used to calculate a relative reflectance to represent the potential need for additional N fertilizer. This relative reflectance approach has been accomplished with spectral radiometer measurements and active-light crop reflectance sensors (Teal et al., 2006; Dellinger, 2008; Solari, et al., 2008). This approach somewhat normalizes the confounding effects of numerous management (e.g., hybrid) and environmental (e.g., soil conditions) factors on understanding the specific N need for the crop and field in question.

Methods for varying N both within and among fields are justified by the spatially variable nature of mineralization and N loss potential over non-uniform agricultural landscapes. Previous field studies have indicated both economic and environmental benefit for spatially-variable N applications across a variety of agricultural landscapes (Mamo et al., 2003; Scharf et al., 2005; Hong et al., 2007).

Research is needed to test active-light crop-canopy reflectance sensing on corn production fields showing spatially-variable need for N fertilizer. Such investigations provide the relevant information to develop and test algorithms for making N fertilizer rate decisions. This paper reports on studies in Missouri for evaluating the economic and environmental benefit of active-light crop-canopy reflectance sensors for corn N rate decisions.

Approach

A total of 16 field-scale (1200 to 2600 ft in length) experiments were conducted over four growing seasons (2004-07) in three major soil areas of Missouri: river alluvium, deep loess, and claypan. In general, these fields were representative of other cropped fields in their locale, with some within-field variability evident in landscape and soil. Cooperating producers selected the planting date, hybrid, planting population, and prepared and planted each field with their own equipment. Most fields were rainfed only.

Multiple blocks of randomized N rate response plots were arranged end-to-end so that blocks traversed the length of each field. Each block consisted of eight N treatments from 0 to 210 lbs N/ac on 30 lbs N/ac increments, top-dressed sometime between vegetative growth stages V7 and V11. For 2006 and 2007 experiments, a complete second field-length set of blocks was also established where either 30 or 60 lbs N/ac was uniformly applied over the second set of blocks shortly after corn emergence. The 30 lbs N/ac rate was used when the producer had applied ~ 30 lbs N/ac rate during pre-plant operations. This second set of treatments was added in response to farmers expressing concern over an N management system where little or no N fertilizer was provided to the crop during emergence and early growth. Therefore this second set tested the sensitivity of the reflectance sensors for assessing N fertilizer need when the crop was generally not as N stressed. The number of treatment blocks varied from 3 to 28 per field. Adjacent to and on both sides of the response blocks, N-rich (210 lbs N/ac) reference strips were also established and were treated shortly after corn emergence.

An AGCO Spra-Coupe (AGCO Corp., Duluth, GA) high-clearance applicator equipped with an AGCO FieldStar Controller was used to top-dress urea ammonium nitrate (UAN) solution (28 or 32% N) fertilizer between corn rows for the N rate treatments. Fertilizer was not incorporated. A label-prescribed amount of urease inhibitor (Agrotain) was mixed with the UAN. To achieve the different N rates, the Spra-Coupe was outfitted with a set of three drop nozzles per fertilized row, each nozzle with a different-sized orifice plate to achieve 1x, 2x, and 4x (1x = 30 lbs N/ac) application rates. Combinations of these three nozzles being turned on accomplished the different rates. Activation of the nozzle booms was controlled by in-house software running on a tablet PC, while the Field Star controller compensated for variations in ground speed.

Crop canopy reflectance sensor (model ACS-210, Holland Scientific, Inc., Lincoln, NE) measurements were obtained from the corn canopy of the N response blocks at the same time the Spra-Coupe was used to apply N rate treatments. Two sensors were mounted on the front of the applicator at ~ 24 in above rows 2 and 5 of the 6-row corn strip. On the same day N rate treatments were applied to the N response plots, reflectance sensor measurements were also obtained from the N-rich reference strips.

Grain yield measurements were obtained either by hand harvesting (2004) or by harvesting with an Ag Leader Yield Monitor 2000 (Ag Leader Technology, Ames, IA). Data analysis of the 16 field studies included four major steps: 1) determining optimal N with quadratic-plateau modeling (Scharf et al., 2005); 2) processing of canopy reflectance sensor data from response plots and the N-rich reference areas, 3) relating modeled optimal N from step 1 with sensor measurements from step 2; and 4) empirically deriving the N fertilizer rate that when using these sensors returned the maximum profit, relative to a single-rate N application. For this last step, maximum marginal profit was run with a number of different ratios of N fertilizer cost to grain price (FGR; table 1), to investigate profitability across a range of potential economic conditions.

Table 1. Fertilizer to grain ratio (FGR), using SI units, for various combinations of N fertilizer and corn grain prices. Equivalent prices in non-SI units are also shown in the shaded areas.

	corn grain price (\$ kg^{-1})							
N fertilizer cost	0.079	0.118	0.158	0.197	0.236	0.276	0.315	N fertilizer cost
---- \$ kg^{-1} ----	------------------------FGR ----------------------							- \$ lb^{-1} -
0.44	5.6	3.7	2.8	2.2	1.9	1.6	1.4	0.20
0.66	8.4	5.6	4.2	3.4	2.8	2.4	2.1	0.30
0.88	11.2	7.5	5.6	4.5	3.7	3.2	2.8	0.40
1.10	14.0	9.3	7.0	5.6	4.7	4.0	3.5	0.50
1.32	16.8	11.2	8.4	6.7	5.6	4.8	4.2	0.60
1.54	19.6	13.1	9.8	7.8	6.5	5.6	4.9	0.70
1.76	22.4	14.9	11.2	9.0	7.5	6.4	5.6	0.80
1.98	25.2	16.8	12.6	10.1	8.4	7.2	6.3	0.90
2.21	28.0	18.7	14.0	11.2	9.3	8.0	7.0	1.00
	2.00	3.00	4.00	5.00	6.00	7.00	8.00	
	corn grain price (\$ bushel^{-1})							

Results

This analysis only included fields and N response blocks that were relatively high-yielding for Missouri conditions. Within fields, the range of optimal N rate varied by more than 90 lb ac^{-1} in

13 of the 16 fields. This within-field variation is similar to a previous corn N rate analysis where the conclusion was that variable-rate N may be warranted for many Missouri fields (Scharf et al., 2005). Range in optimal N for 2006 and 2007 was generally greater than for 2004. We attribute this difference to particularly well-suited growing conditions during the 2004 growing season.

Optimal N was examined relative to SI, similar to what others have done with the chlorophyll meter (Scharf et al., 2006). Conceptually, canopy sensing could be used to successfully determine N rate if optimal N rate increased as the sensor-based SI decreased. Combined across all 16 fields, a poor relationship was found between optimal yield and SI ($R^2 = 0.08$). However by individual field, a linear relationship between these two was found for about half the fields. Although the linear relationship between optimal yield and SI was weak with all fields combined, we surmised that the trend in the dataset could be used to empirically derive the N rates that would be most profitable relative to N rates historically used on these same fields. Figure 1 graphically provides a summary of those N fertilizer rates determined to give the highest marginal profit using the reflectance sensors. The broken lines connected by different colored points represent different FGR values. Across all soils, the amount of N for optimal profit increased as SI decreased from 0.9 to 0.75. This expression, as seen in the graph, validates the canopy sensor's ability to delineate corn N need. Based on findings in Scharf et al. 2009, we developed in 2004 an algorithm that farmers could use with the reflectance sensors for adjusting N fertilizer rate. This line is shown as a black line in Figure 1. For typical FGR values, this study validates that algorithm as useful.

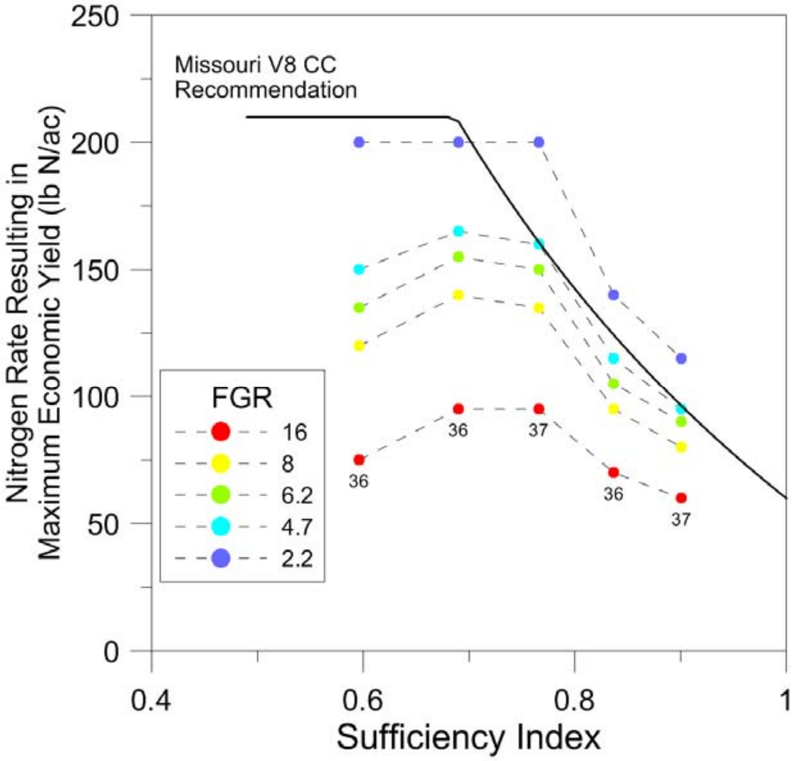

Figure 1. Nitrogen N fertilizer rates that gave the maximum economic return, relative to producer practice on these same fields, were determined and are shown relative to canopy sensor sufficiency index. For this analysis, results were compiled for all data. The N rate for highest marginal profit was determined with a number of different N fertilizer cost to grain price ratios (FGR; see table 1), as shown with dashed lines.

Below 0.75 the most profitable N rate stayed approximately the same or decreased slightly. Agronomically, the downward turn in the most profitable N rate seen for the lowest SI values suggests that yields of corn with greater N deficiency cannot be compensated by increasing the amount of fertilizer. We believe this to be corn that was severely N stressed early in the season when yield components were being defined, thus yield potential was lost. The exception would be when fertilizer N is very inexpensive relative to grain prices (i.e., low FGR); then the most profitable N rate is the maximum (210 lb/A in our analysis). The upward shift in lines with decreasing FGR values in Figure 1 indicates that the most profitable N rates increase as FGR decreases. When the cost of fertilizer relative to grain price increases (high FGR values), the highest profit is achieved by applying less N fertilizer. In other words, N costs become a more important factor in the marginal profit.

Another way of looking at the impact the FGR has on profit is illustrated in Figure 2. Here profit using the sensors increased in an exponential fashion as the FGR increased. Conversely, as fertilizer cost decreased relative to grain price, the value of using canopy sensors for N management diminished. We found that with all soils combined and with FGR values typical of what producers have seen in the past decade, profit using the sensors will range from \$10 to \$20/A. However, the price paid for corn grain can have a significant effect. With corn priced at \$2/bu, profit ≥ \$10/A could only be accomplished when the FGR was ~13 or greater. However, with corn priced at \$6/bu, that same profit or more could be achieved when the FGR was ~ 7. In this scenario, corn price tripled while N price only increased by a factor of 1.6. Therefore,

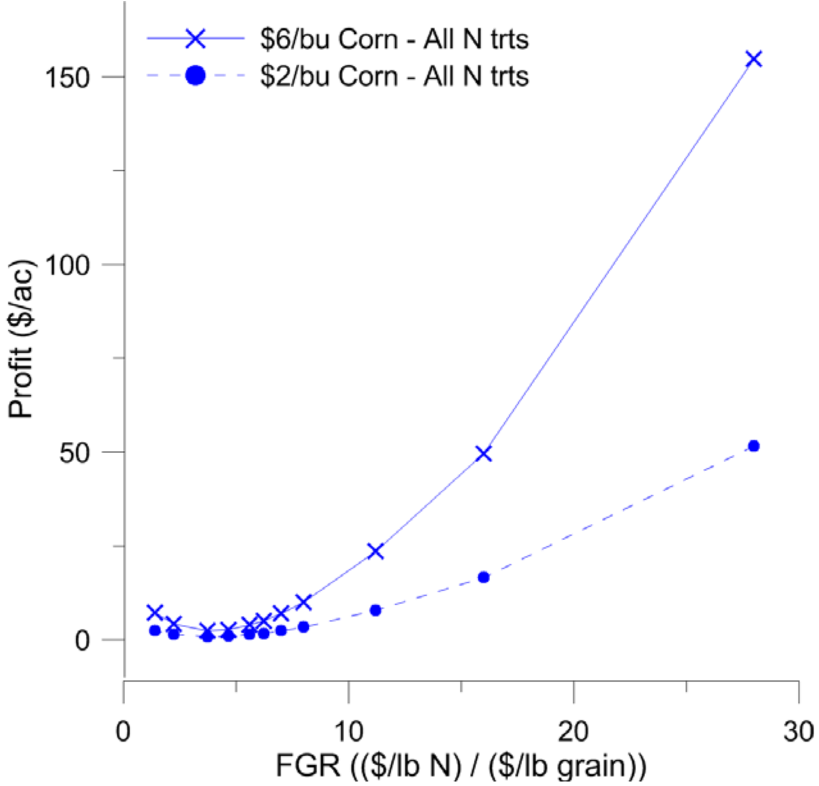

Figure 2. Marginal profit associated with the N rates dsplayed in Figure 1 in relation to N fertilizer cost to corn price ratio (FGR). Data for all soils combined and separated by soil type are presented for two different corn prices.

equivalent profit was achieved with the higher grain price and lower FGR. Thus, as illustrated in Figure 2, both the FGR and the absolute grain price will determine the profit potential.

Differences were apparent among the three major soil types (data not shown). For claypan soils at SI values > 0.85 results showed it would be most profitable to apply N at or below the producer N rate and accept a yield loss. For SI < 0.85 maximum profit would be achieved by applying more N (i.e., less N saved). In loess soils profitability was generally maximized by applying considerably less fertilizer than the producer N rate. The optimal N rate for the loess fields of this study were often found to be less than the producer N rate and therefore these fields would provide the greatest opportunity for N saved. Results from alluvial soils were unique. They not only had substantially lower SI values than both claypan and loess soil fields, but the savings was greatest at the extremes of SI values. At high SI values N savings was generated because the crop needed less N than the producer rate. At low SI values we concluded the crop was so compromised relative to N health that top-dress N additions using sensors could not fully recover yield, and therefore less N would be recommended and N would be saved. This highlights the need for early season N so yield is not compromised.

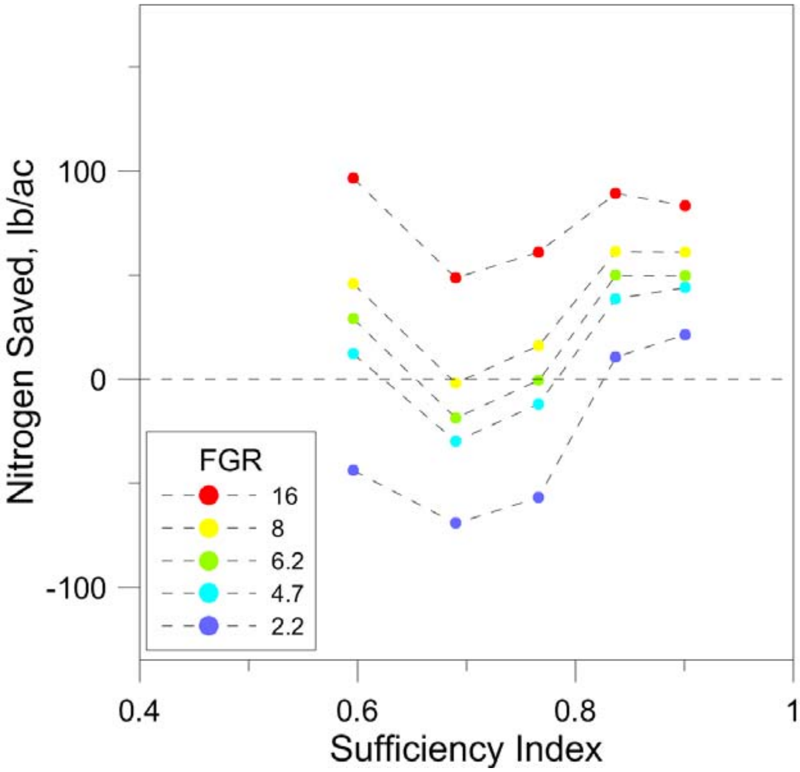

Figure 3 Nitrogen saved relative to sensor-based N sufficiency index (SI) across all soils. These are presented with a number of different ratios of N fertilizer cost to grain price (FGR), and are shown with colored dashed lines.

In addition to potential economic benefits, we projected the environmental implications of sensor-based N management. For many fields, the calculated optimal N rates were less than the current producer N rate for these same fields. Thus, to the extent the canopy sensors could estimate optimal N rate, we found higher yield efficiency, higher N fertilizer recovery efficiency, less unaccounted for N, and less post-harvest inorganic soil N (data not shown). Our results generally showed that sensor-based N application would apply less N in many field situations (Figure 3). Combined over all soil types and at FGR values typical in recent years (range from 4 to 9), N savings of 10 to 45 lb/A could be expected. In a few situations when SI values were especially low, sensor-based strategies would actually call for more N than the producer N rate, but doing so was the more profitable strategy.

Summary

For the development of new N management procedures, and ultimately decision algorithms, economic scrutiny is required. This research was conducted to assess the relationship between crop canopy sensor data and corn response to side-dress N fertilization. Additionally, these findings were used to examine the potential profit and environmental benefit that could be achieved by using this sensing technology to control variable-rate N fertilizer.

Crop canopy sensor information was related to in-season N fertilizer need about 50% of the time in these studies. Yet even with these mixed results, N rates more profitable than blanket applications were derived which followed established agronomic principles relative to N management. While soil type, fertilizer cost, and corn price affected our findings, we generally found the potential for a modest profit increase using canopy sensing for N applications. The advantage of using crop canopy sensors increased as FGR increased.

These investigations support the idea that sensor-based N application can reduce the amount of N applied for corn production. Since the sensor-driven applications are site-specific, the reduction would undoubtedly be from areas receiving excess N when single-rate fertilization is applied over the whole field. A pre condition to realizing an environmental benefit is that the sensor information can be processed by a decision-rule algorithm into an N rate that approximates optimal N rate. Certainly this study supports continued development and application of reactive reflectance sensing technologies for improved N fertilizer use in corn.

We have noted from these research fields and other producer demonstration trials that use of the canopy sensors for N management is generally more applicable when certain field conditions are present, such as: extreme within-field variability in soil type; following recent animal manure applications; and when cropland was recently converted from pasture, hay, or CRP management. We surmise that any time conditions are present where uncertainty is high about how much N the soil will provide a crop, canopy sensors may be an appropriate strategy for in-season N applications. This is especially true when conditions driving N availability vary across the field landscape. Other examples of such situations include corn grown following a leguminous cover crop, applying rescue N fertilizer because excessive spring and early summer rainfall have caused loss of pre-plant N, and for a crop grown following a droughty growing season where N carry-over is likely.

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