Economic and Environmental Implications of Sensor-Based Nitrogen Management

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Active-light reflectance sensors are currently being studied as a tool to guide in-season "reactive" N application. A recent study evaluated the potential economic benefit and environmental implications for sensor-based N application in corn. Economic benefits and N savings were found for most fields. Results from this study support the continued development of sensor-based technology for in-season N management.

The quest for precision in 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; Raun et al., 2005; Teal et al., 2006; Freeman et al., 2007; Dellinger et al., 2008; Shanahan et al., 2008; Schmidt et al., 2009). These sensor systems contain light emitting diodes that emit 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). Both visible and near infrared (NIR) wavelengths are typically included, so that reflectance can be interpreted in terms of commonly used vegetative indices to assess crop growth and N status.

Typically, evaluations using this technology have been obtained by comparing the crop in an area known to be non-limiting in N to the crop in areas yet to be or inadequately fertilized. Measurements from the two areas are used to calculate a relative reflectance (sufficiency index, SI) to represent the potential need for additional N fertilizer. A value of SI = 1 would indicate a crop that looks as good as the non-N-limited crop, while SI = 0.4 would indicate an extremely N-stressed crop. Operationally, these sensors can be mounted on N fertilizer applicators equipped with computer processors and variable rate controllers, so that sensing and fertilization is accomplished in one pass over the crop.

Recent field-scale studies in Missouri evaluated these sensors' ability to determine corn N need on a variety of soils. From these studies, the fertilizer rates that returned the maximum profit relative to the current producer N rates were derived. Concurrently, the potential environmental benefits from using reflectance sensing for N fertilization were determined. Sixteen field-scale experiments were conducted over four seasons (2004 to 2007) in three major soil areas. Multiple blocks (182 total blocks) of N rate response plots traversed the length of each field, with each block consisting of 8 treatments (0 to 210 lb N/A on 30 lb N/A increments) applied at the same time as plant sensing, between V7 to V11 growth stages. Canopy reflectance readings were also obtained at this time from an adjacent non-N-limiting area. At the end of the growing season, yield and optimal N rate were determined for each block of N rate treatments, and plant, grain, and soil samples were analyzed for N content. A computer program was written to evaluate the most profitable N rate at different SI levels and fertilizer cost to corn grain price ratios (FGR). **Table 1** shows various FGR values in both metric and English units. Environmental indicators were also examined at the calculated optimal N rate and the producer N rate.

Abbreviations and notes: N = nitrogen.

Table 1. Fertilizer to grain ratio (FGR), using metric units and English units (gold shaded) for various combinations of N fertilizer and corn grain prices.

N fertilizer cost	Corn grain price, $/kg 0.079	0.118	0.158	0.197	0.236	0.276	0.315	N fertilizer cost
--$/kg--	FGR							--$/lb--
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, $/bu							

Economic Profitability

For site-specific management technology to be adopted at the farm level, it is essential to examine economic profitability. **Figure 1** shows the 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 sensors' ability to delineate corn N need. Based on preliminary findings later reported in Scharf and Lory (2009), we developed an algorithm in 2004 that farmers could use with reflectance sensors for adjusting N fertilizer rate. This line is shown as a solid black line in **Figure 1**. For typical FGR values, this study validates that algorithm as useful.

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 generally

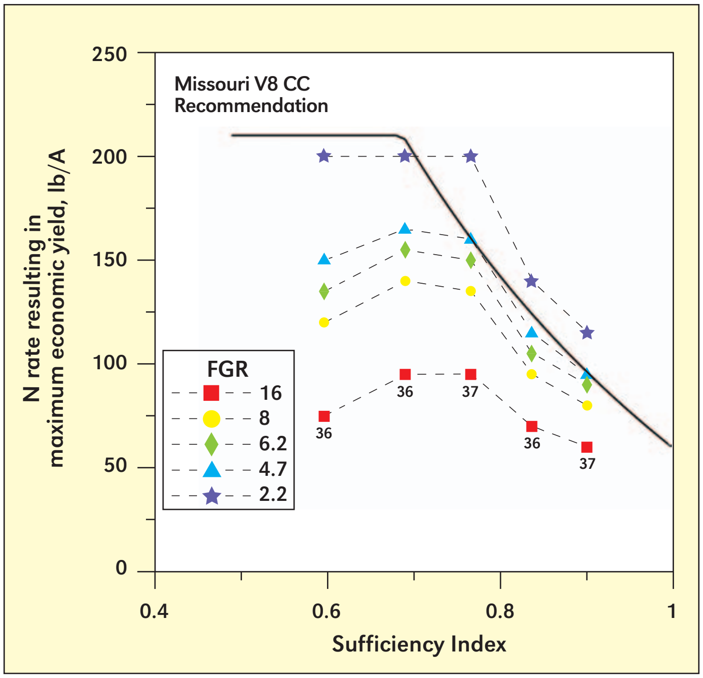

Figure 1. Nitrogen fertilizer rates that gave the maximum economic return compared to producer N rates are shown relative to the canopy sensor sufficiency index. The N rate for highest marginal profit was determined with a number of different FGRs for N.

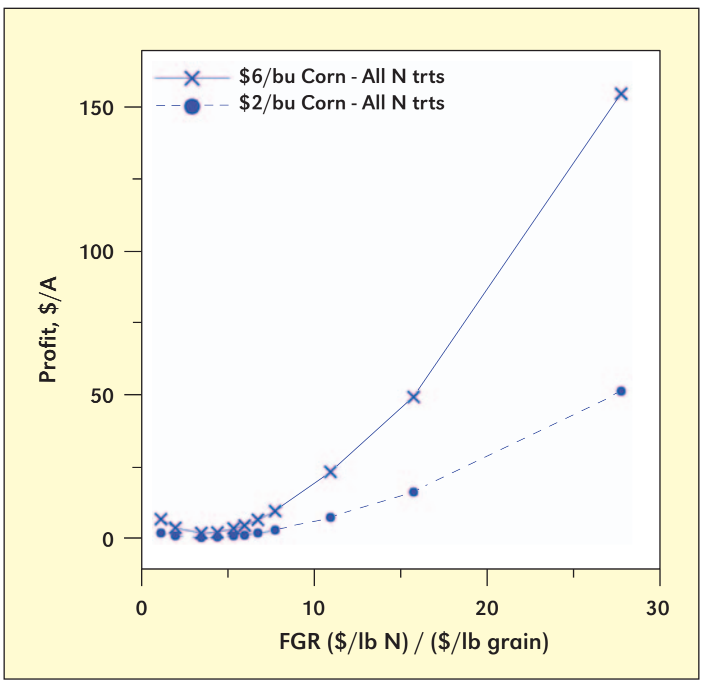

Figure 2. Marginal profit, defined as the difference in the N fertilizer cost and the value of yield gain or loss, relative to FGR.

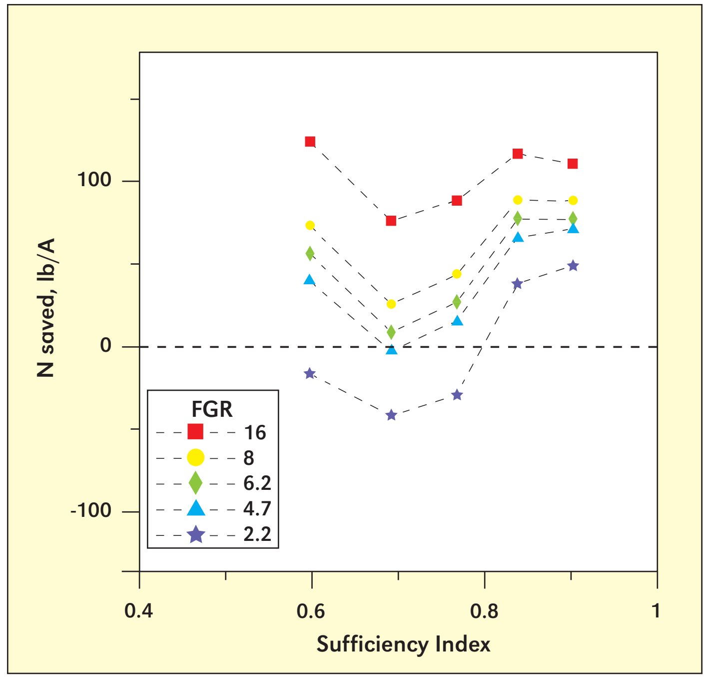

Figure 3. Nitrogen saved relative to the canopy sensor sufficiency index. This relationship for N was evaluated for a number of different FGRs.

cannot be compensated by increasing the amount of fertilizer. In general, 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 N/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 economic 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, on average, 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 increased by only a factor of 1.6. Therefore, 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.

Potential Environmental Benefits

In addition to potential economic benefits, we projected the environmental implications of sensor-based N management. For many fields, the calculated economic 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

A high clearance vehicle equipped with active-light reflectance sensors to guide in-season N application. Inset: The Holland Scientific Crop Circle™ ACS-210 Sensor (top) and NTech Industries GreenSeeker® Sensor (bottom) project their corresponding light pattern onto the soil surface.

few situations when SI values and FGR ratios 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.

Sensor-Based N Management

Our results affirm that in many fields crop-canopy reflectance sensing has potential for improving N management over conventional uniform N application. A precondition to the benefits of this sensor-based approach is that the sensor information can be processed by a decision-rule algorithm into a N rate that approximates the optimal N rate. The algorithm we have used since 2004 was a good first start. Including specific weather, soil, crop stage, landscape attributes, and corn market factors in the evaluation may be needed to improve estimations of N fertilizer requirements in relation to reflectance sensing. Our results support continued development of reflectance sensing technologies for improved N management. BC

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