UPDATE ON USING ACTIVE SENSORS TO MANAGE N APPLICATION ON CORN

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ABSTRACT

We are testing a prototype high-clearance N applicator configured with active crop canopy sensors, electronic valves, and a variable rate controller to deliver in-season variable rates of nitrogen (N) fertilizer based on crop needs in lieu of uniform at-planting N applications. The active sensor used is the Crop Circle model ACS-210 manufactured by Holland Scientific (Lincoln, NE), and it measures canopy reflectance in the visible (centered around yellow at 590+/-5.5 nm, VIS_{590}) and near infrared (centered at 880+/-10 nm, NIR_{880}) bands. This paper represents a progress report on efforts to: 1) develop sensor use protocols for accurate assessment of canopy N status, 2) develop an algorithm for translating sensor readings into corrective N applications, and 3) validate a sensor algorithm in on-farm research trials. Research to address items 1 and 2 was conducted in 2005 and involved a series of small plot studies with treatments receiving N application at different timings and rates. Active sensor readings were collected on 2 vegetative (V11 and V15) and 2 reproductive (R1 and R3) growth stages, and readings converted to $NDVI_{590}$ or chlorophyll index (CI_{590}) values. Chlorophyll meter (CM) readings were collected at the same time. Final grain yields were also determined. Results showed that sensor readings were most highly correlated with CM and grain yield assessments when sensor data were collected during vegetative growth and expressed as CI_{590} values, indicating sensor-determined CI_{590} values collected during vegetative growth are best suited for assessing canopy N status. Additionally, a sensor algorithm was developed that utilizes sensor-determined CI_{590} values in formulating corrective N applications rates required for maximizing grain yields. In 2007, the sensor algorithm was tested in several on-farm trials where different N application strategies were compared, using the traditional approach of uniform at-planting N application as the check. Our work showed that using active sensors and sensor algorithm to direct spatially variable rates of in-season N resulted in an overall savings of total N application of up to 45% compared to traditional N management, while maintaining similar grain yields.

INTRODUCTION

Traditional N fertilizer management schemes for U.S. corn production systems have resulted in low N use efficiency (NUE), reduced water quality, and considerable public debate regarding N use in crop production. We have built a prototype high clearance N applicator configured with on-the-go active sensors, controller, and nozzle/valve system to deliver spatially variable rates of N fertilizer (Fig. 1) in lieu of uniform at-planting N applications. Key hardware components of this applicator consist of active crop canopy sensors, drop nozzles with electronic valves delivering liquid N fertilizer, controller system connected via serial port to PC running measurement and control software. This paper represents a progress report on efforts to: 1) develop sensor use protocols for accurate assessment of canopy N status, 2) develop an algorithm for translating sensor readings into corrective N applications, and 3) validate a sensor algorithm in on-farm research trials.

MATERIALS AND METHODS

Sensor Description and Small Plot Treatments

The active sensor used in this study is the Crop Circle ACS-210 manufactured by Holland Scientific (http://www.hollandscientific.com/), and measures canopy reflectance in the visible (centered around yellow at 590 nm +/-5.5nm, VIS_{590}) and NIR (880 nm +/-10 nm, NIR_{880}) bands. These bands are sensitive to plant properties like chlorophyll content and biomass.

To generate variability in canopy N status, 3 small plot studies were established in 2005 near Shelton, NE. Treatments consisted of a factorial combination of 4 N rates (0, 40, 80, and 240 lbs/A) applied at planting and five N rates (0, 40, 80, 120, and 160 lbs/A) applied at both V11 and V15 growth stages with 3 replications. Individual plots consisted of 8 rows, 36 in. apart by 50 ft. long. Phenological growth stages and weather data (electronic weather station) were recorded throughout the growing season for both sites.

Acquisition of Sensor Data and Development of Sensor Algorithm

Sensor readings were collected at 4 crop growth stages, 2 vegetative (V11 and V15) and 2 reproductive (R1 and R3). To accomplish this task, the sensor was mounted on an adjustable height boom on a high clearance vehicle to maintain the sensor at 2.5 ft. above the canopy and positioned directly over a center plot row in the nadir view, producing a sensor "footprint" of approximately 4 x 20 inches, with the long dimension oriented perpendicular to row direction. The sensor was interfaced to a computer, and readings logged as the vehicle traveled through the plots at 5 to 6 mph, acquiring approximately 200 readings per plot. The VIS_{590} and NIR_{880} bands from individual sensor readings were converted to 2 different vegetation indices, the $NDVI_{590}$, and chlorophyll index (CI_{590}), using the following equations and the appropriate band reflectance values, where: $NDVI_{590} = (NIR_{880} - VIS_{590}) / (NIR_{880} + VIS_{590})$, $CI_{590} = (NIR_{880} / VIS_{590}) - 1$, according to Gitelson et al. (2003). Leaf chlorophyll content was also assessed with a chlorophyll meter (CM) on the same day sensor readings were acquired. The sensor algorithm was developed using the relationship that exists between CM and sensor readings (Fig. 2) and from long term research results (10 yr) showing that CM readings can be used to determine rate of in-season applied N (Varvel et al., 2007).

Validation of Algorithm in On-farm Studies

The sensor algorithm developed in 2005 was evaluated in 4 on-farm trials in 2007 (2 presented here). Briefly, 5 treatments (Table 2) were established involving a comparison of field-length replicated strips (see Fig. 4) where N was either applied uniformly at planting (treatment 2), or a combination of at planting and sensor-delivered N (treatments 3 & 4). Treatment 5 was included to provide unlimiting N conditions for calibration of sensor algorithm, and treatment 1 to create limited N conditions to evaluate yield response to N. Treatments effects were assessed comparing total amounts of N applied (at plant + sensor applied) and average grain yields (Table 2).

RESULTS AND DISCUSSION

Sensor Protocols and Algorithm

The imposed N treatments in created significant variation in grain yields, CM readings, and sensor-determined vegetation indices at all 3 study sites in 2005 (data not shown). Relationships among grain yield and CM readings vs. the 2 vegetation indices ($NDVI_{590}$ and CI_{590}) were assessed using linear regression. These analyses (Table 1) revealed that vegetation indices ($NDVI_{590}$ and CI_{590}) were more highly associated with CM readings during vegetative (maximum r^2 of 0.85) than reproductive (maximum R^2 of 0.55) growth, which was attributed to inability of sensor to detect canopy variation due to interference from tassels present during reproductive growth (Solari, 2006). The slope was greater for the CI_{590} relationship than the $NDVI_{590}$ relationship (Fig. 2), suggesting the CI_{590} is more sensitive than $NDVI_{590}$ in detecting variation in canopy greenness. Similar results were observed for grain yield relationships (data not shown). Because CI_{590} values were found to be more sensitive than $NDVI_{590}$ in assessing canopy N status and yield potential, we conclude that sensor readings acquired during vegetative growth and expressed as CI_{590} would be best suited for directing spatially-variable in-season N applications. The sensor algorithm developed in this work (Fig. 3) illustrates that sensor readings acquired during vegetative growth can be used to determine corrective in-season N application rates.

Validation of Sensor Algorithm

Results from 2 of the 4 on-farm studies conducted in 2007 (Table 2) showed that treatment 4 (80 lbs N/A + sensor directed N application), resulted in the greatest savings in total applied N (ranging from a 26% savings at site 2 to 45% at site, compared to the traditional N management strategy (treatment 2), while maintaining similar grain yields. If these findings our confirmed in the additional on-farm studies, it suggests using active sensors to direct spatially variable N applications has potential for economic and environmental benefits.

REFERENCES

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Table 1. Regression coefficient of determination (R^2) for linear relationships between variation in relative chlorophyll meter (CM) readings and relative values for 2 vegetation indices ($NDVI_{590}$, normalized difference vegetation index; CI_{590}, chlorophyll index) collected on 4 growth stages (GS, 2 vegetative and 2 reproductive), for corn receiving varying amounts of N applied at different growth stages during the 2005 growing season at the MSEA 1, 2, and 3 sites near Shelton, NE.

GS and GDD+	$NDVI_{590}$	CI_{590}
	MSEA 1	
V11 (600)	0.468**	0.495**
V15 (700)	0.784***	0.812***
R1 (800)	0.524**	0.546**
R3 (1000)	0.33**	0.663***
	MSEA 2	
V11 (600)	0.339***	0.339***
V15 (700)	0.364***	0.389***
R1 (800)	NS	NS
R3 (1000)	NS	NS
	MSEA 3	
V11 (600)	0.725***	0.776***
V15 (700)	0.821***	0.847***
R2 (900)	0.201***	0.185***
R3 (1000)	0.042*	0.040*

*, **, *** significant at 0.05, 0.01, 0.001 levels, respectively.
NS, nonsignificant.
+, GS, growth stage; GDD, growing degree days.

Table 2. Total N applied and grain yields for various N application strategies for studies conducted at 2 on-farm sites during the 2007 growing season.

	Site #1		Site #2	
Treatment, N Application Strategy	Total N	Yield	Total N	Yield
	lbs N/A	Bu/A	lbs N/A	Bu/A
1. 40 lbs N/A at planting	40	164	40	77
2. UNL soil-based algorithm at planting*	209	199	172	158
3. 40 lbs N/A at planting + sensor delivered N	143	196	176	141
4. 80 lbs N/A at planting + sensor delivered N	116	200	127	156
5. High N reference at planting	250	196	210	163
LSD (0.05)	43	10.4	12.4	9.6

*UNL soil-based algorithm approach involved using soil testing to establish residual soil N present at planting along with the use of appropriate N credits and a yield goals to determine N rate at each research site.

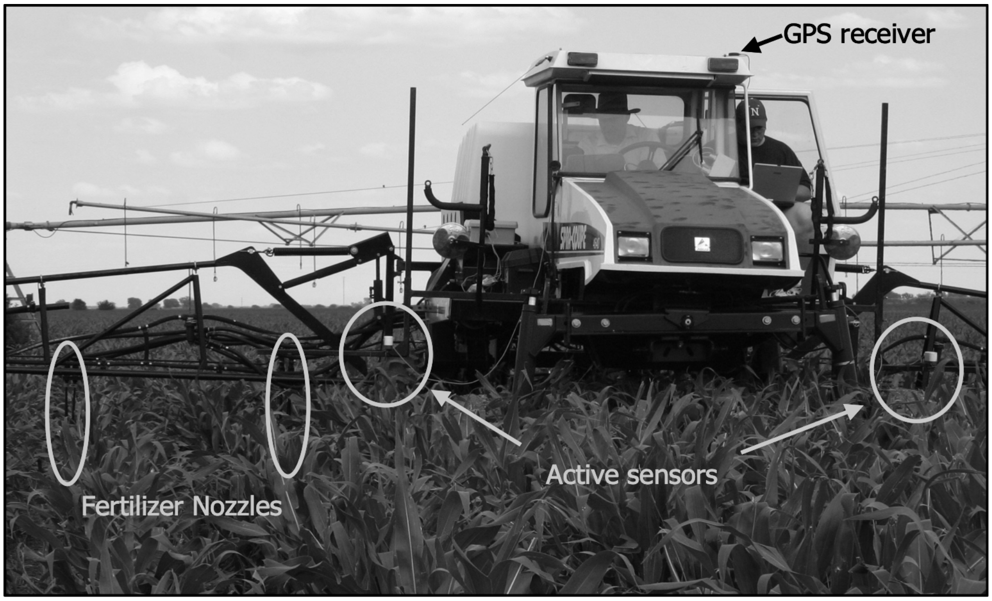

Fig. 1. Pictured above is the high clearance N applicator configured with active crop canopy sensors along with fertilizer delivery system, consisting of two-drop nozzles/valves placed at alternating rows of corn. Depending on the configuration of valves turned on/off, system can deliver a multiple of 4 rates of liquid N fertilizer on-the-go as directed by the controller system interfaced to the active sensor.

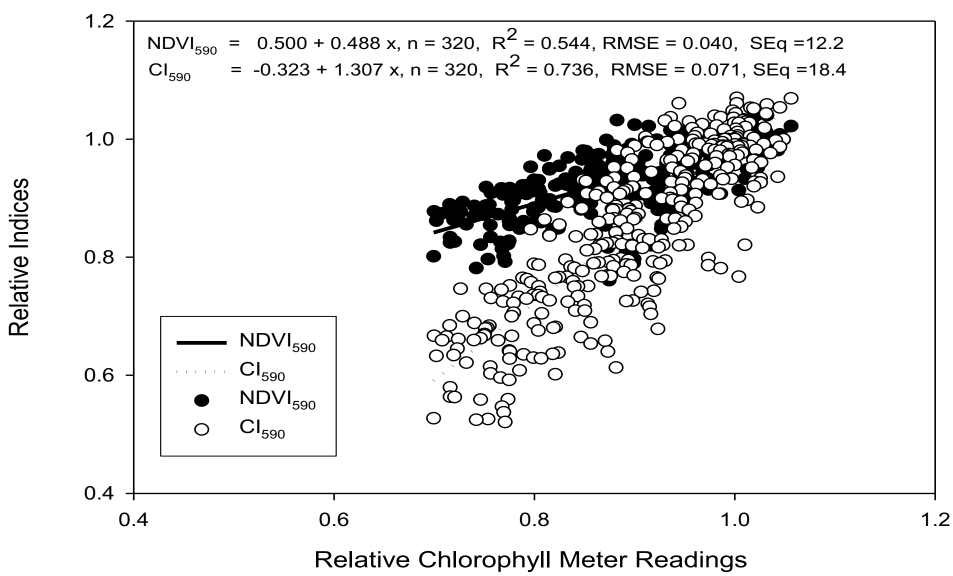

Fig. 2 Relationships between variation in relative chlorophyll meter readings and 2 sensor-determined vegetation indices ($NDVI_{590}$, normalized difference vegetation index; CI_{590}, chlorophyll index) for data collected on 2 vegetative growth stages (V11 and V15) during the 2005 growing season at the MSEA 1 and 3 sites near Shelton, NE for corn receiving varying amounts of applied N. Other parameters provided include linear regression equation, sample number (n) coefficient of determination (R^2), RMSE (root mean square error), and sensitivity equivalent (SEq, SEq= slope / RMSE).

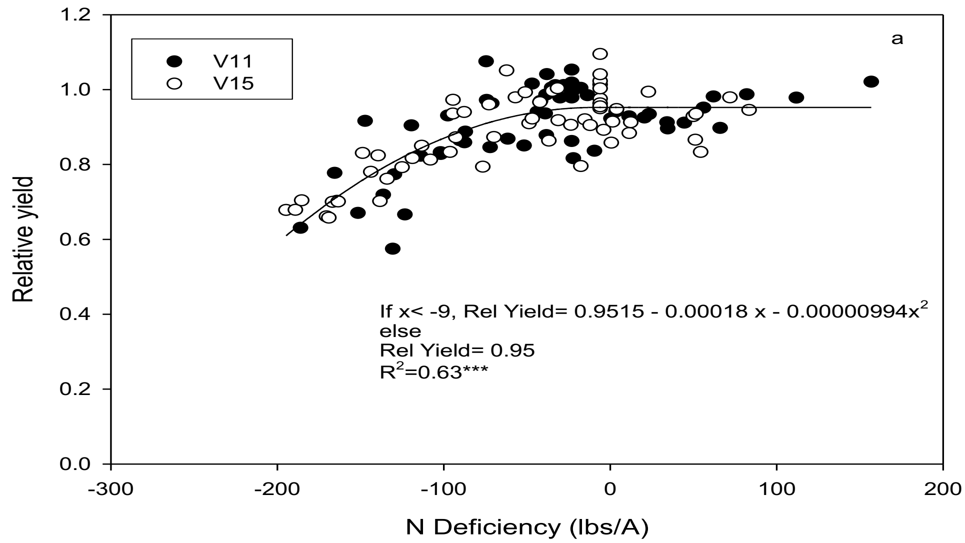

Fig. 3. Nitrogen algorithm depicting relative yield vs. sensor-determined N deficiency, as described by a quadratic-plateau regression model. Briefly, algorithm was developed by collecting sensor readings on 2 in-season N applications dates (V11 and V15) in 2005 small plot studies receiving varying amounts of N applied at planting and 2 in-season dates, converting sensor readings to CI values, and relating CI values to yield responses to N.

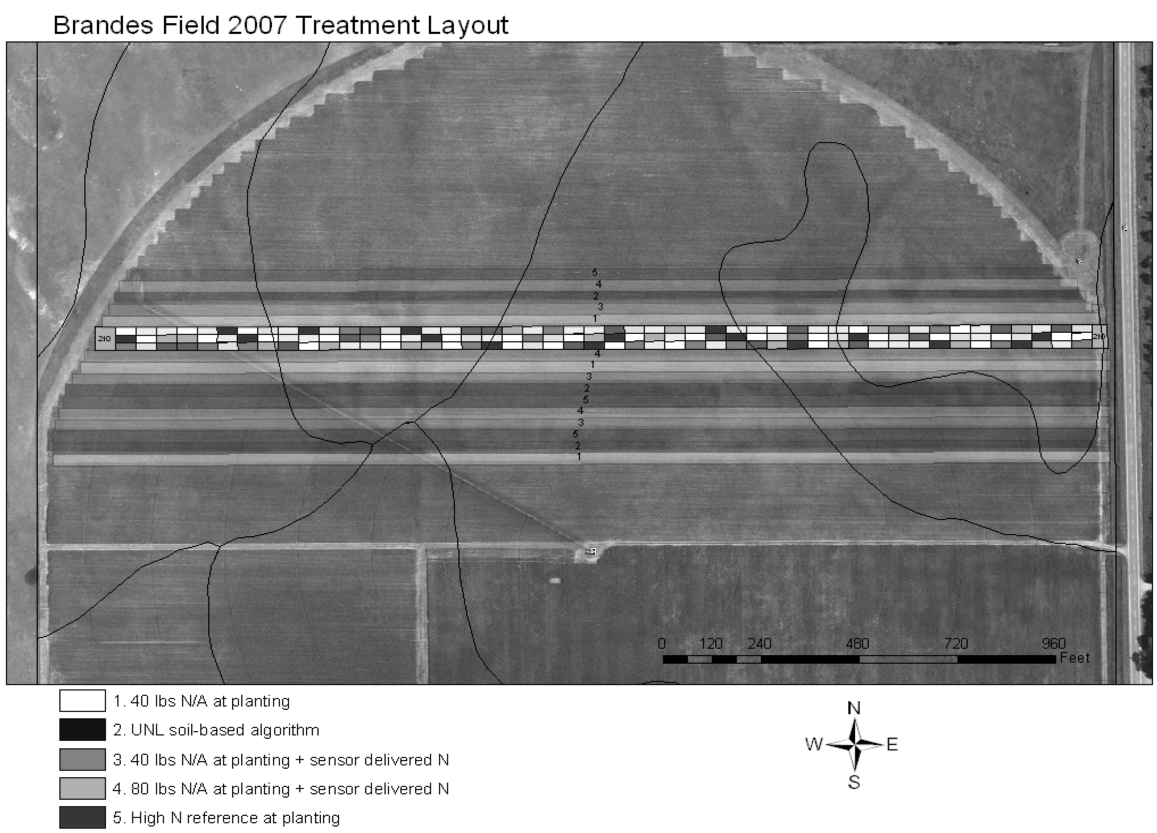

Fig. 4. Aerial photograph of 1 of the on-farm studies conducted in 2007, depicting the layout of different N applications strategies (see Table 2 for treatment description).