IN SEASON CROP N MANAGEMENT

J.F. Shanahan, F. Solari, J.S. Schepers, and D.D. Francis
USDA-ARS and University of Nebraska, Lincoln, NE
jshanahan1@unl.edu (402) 472-1511

ABSTRACT

We are testing a prototype high-clearance tractor configured with active crop canopy sensors, drop nozzles with electronic valves, and a variable rate controller as means to deliver in-season variable rates of liquid N fertilizer based on crop needs as an alterative to preplant uniform applications of N. The active sensor we're evaluating is the model ACS-210 Crop Circle made by Holland Scientific. It generates its own source of modulated light in the amber and near infrared (NIR) bands and then measures the percent of source light reflected back from the crop canopy. The specific objectives for this research were to determine the most appropriate 1) vegetation index and 2) phenological growth stage for maximum sensitivity in assessing variation in corn canopy greenness or N status. To generate variability in canopy N status for the purpose of remote sensing, we established small plots at 2 study sites in the 2005 season involving treatments receiving N application at different timings and rates. Active sensor readings were collected on four growth stages (V11, V16, R2, and R4) along with ground truth SPAD chlorophyll meter readings. Output from the two sensor bands was in turn converted into two separate vegetation indices, the traditional NDVI and the more recently developed chlorophyll (Chl) index. Sensor readings converted into the NDVI and chlorophyll (Chl) vegetation indices were positively correlated with SPAD meter readings only during vegetative growth (V11 and V16) stages, with the Chl index being more sensitive than the traditional NDVI in detecting variation in canopy greenness. Our findings from this work suggest the active sensor system we evaluated is capable of detecting variations in corn leaf N status and can be used to direct in-season variable rate N applications, reducing the need for preplant uniform rate N applications.

INTRODUCTION

Over-application of N fertilizer on corn has resulted in elevated levels of N in ground and surface waters. A major factor contributing to decreased N use efficiency and environmental contamination for traditional N management schemes is the routine pre-season application of large doses of N, well before the time when the crop can effectively utilize this N. Previous work by Blackmer and Schepers (1995) and Varvel et al. (1997) using the Minolta SPAD 502 chlorophyll meter to monitor crop chlorophyll or N status and applying fertilizer N as needed, demonstrated that 1) the chlorophyll meter could be used as a research tool to maintain an adequate N supply for corn by fertilizing as needed and 2) yields could be maintained with reduced N rates relative to a single preplant application of N. Our findings show that it is realistic for producers to move away from the uniform early season approach to N management and toward a more reactive approach involving crop evaluation and in-season N application to coincide better with crop N uptake. Our long-term research goal is to reduce N over-applications on corn by using remote sensing to assess crop N status and to direct fertilizer only to areas needing N at times when the crop can most efficiently utilize the N. We have built a prototype high clearance in-season N applicator configured with on-the-go active sensors, controller, and nozzle/valve system to deliver variable rates of liquid N fertilizer (Fig. 1). Key hardware components of this applicator consist of 1) on-the go active crop canopy sensors, 2) drop nozzles with electronic valves delivering liquid N fertilizer, 3) commercial controller system connected via serial port to PC running commercial measurement and control software (Fig. 2). The active sensor used in this study was the Crop Circle ACS-210 by Holland Scientific (http://www.hollandscientific.com/). The sensor operates by using a single bank of diodes to generate modulated light (pulsed at ~40,000 Hz) in two wavebands, amber (590nm +/-5.5nm) and NIR (880nm +/-10nm). These bands are sensitive to plant properties like chlorophyll content and biomass. Photodetection of modulated light reflected from the crop canopy back to the sensor is accomplished with silicon photodiodes located in the sensor head, with sensitivity in a spectral range of 320 to 1100 nm. The sensor field of view is 32 degrees by 6 degrees, producing a sensor footprint of approximately 10 x 50 cm wide when the sensor is held at around 1 m above the surface of the canopy (Fig. 2). While initial testing on the active sensor system has been encouraging, further research is needed to validate and refine recommendations. The specific objectives for this research were to determine the most appropriate 1) phenological growth stage and 2) vegetation index for maximum sensitivity in assessing variation in corn canopy greenness or N status.

MATERIALS AND METHODS

To generate variability in canopy N status for the purpose of remote sensing, we established small plots at 2 study sites in the 2005 season involving treatments receiving N application at different timings and rates. Site 1 was situated on the Nebraska Management Systems Evaluation Area (MSEA), and site 2 on farmer's field, both located near Shelton, NE. Soils at both locations were classified as Hord Silt Loam. Site 1 was planted on May 9th and site 2 on April 25th with Pioneer Hybrids 33G30 and 34N42, respectively. The treatments consisted of factorial combination of four N rates (0, 45, 90, and 270 kg ha^{-1}) applied at V4 with five N rates (0, 45, 90, 135, and 180 kg ha^{-1}) applied around V12. The experimental design was a split-split plot design with timing as the whole plot and application rate the split-split plots. Individual plots consisted of 8 rows (0.91 m apart) by 15.2 m long. Nitrogen fertilizer was applied at the appropriate rates and timings as a 28 % N solution. Phosphorus was also applied as starter fertilizer at planting at both sites to avoid any P stress. Phenological growth stages and weather data (electronic weather station) were recorded throughout the growing season for both sites.

On each data collection event, the sensor was calibrated using a 20% universal reflectance panel with the sensor placed in the nadir position above the panel. Sensor amplifiers for each waveband were adjusted so that a value of 1.0 was obtained from the 20% reflectance panel at 90 cm from the target. Readings were collected at ten times per second, so each recorded value is the average of about 4000 readings. Digital output from the sensor represents pseudo-reflectance values for each band that allow calculation of different vegetation indices.

To determine the most appropriate phenological growth stage and vegetation index for assessing variation in corn canopy greenness or N status the sensor was mounted on the high clearance vehicle, placed about 80 cm above the canopy (the plot with higher N rate was used as a reference), coupled with a GPS unit (Garmin, model 16A) and reading collected on four different phenological growth stages (V11, V16, R2, and R4). Sensor distance to the ground was kept constant during data acquisition for a given date and field. The vehicle ran at about 4 to 4.5

miles/hr. All sensor data were collected and archived to computer files. Individual sensor readings within a given plot were averaged to produce one value per plot. Within 24 hours of sensor readings, "ground-truth" chlorophyll SPAD meter data were also taken, collecting 30 reading per plot from the uppermost-expanded leaf and averaged to produce one reading per plot. After tasseling, SPAD readings were taken on the ear leaf.

We used the amber and NIR bands from the sensor to compute the traditional normalized NDVI (Rouse et al., 1973) and the newer Chlorophyll (Chl) index developed by Gitelson et al. (2003) where:

NDVI = (NIR - Amber) / (NIR + Amber)
Chl index = (NIR / Amber) - 1

We normalized these indices as well as SPAD units within replicates and N source using the highest N rate at planting as the denominator (i.e. Rel. SPAD= $SPAD_{plot\ i}$ / $SPAD_{highest\ N\ rate}$). Data normalization accounts for variations on hybrids color, differences among SPAD instruments, and distances to the target effects on active sensor readings.

The effects of time of N application, N rate, site, and growth stage and their interactions on relative SPAD and vegetation indices were evaluated using PROC MIXED, available in SAS. Regression analysis was used to determine the relationship between relative SPAD units and relative vegetation indices using PROC REG in SAS.

RESULTS

The analysis of variance (data not shown) revealed that timing and rate of N application, growth stage, and their interactions all had significant effects on active sensor readings (amber and NIR bands), vegetation indices, and SPAD readings. Thus, the imposed N treatments produced significant variability in canopy greenness. To explore the association between sensor-derived vegetation indices and independent assessments (SPAD) of canopy greenness, relative (normalized to highest N rate) means for the two vegetation indices (NDVI and Chl Index) were correlated with relative SPAD meter values for both fields and for each of the four growth stages that data were collected (Fig. 3). The vegetation indices were only associated with SPAD readings for the two vegetative growth stages (V11 and V16), with higher associations for field 2 vs. field 1. The poorer association between relative vegetation indices and SPAD readings was attributed to more variable crop stands for field 1 vs. field 2. The lack of association between sensor-derived vegetation indices and SPAD readings for R2/R4 growth stages is difficult to explain. Perhaps the presence of tassels (with no chlorophyll) on the corn may interfere with accurate sensing of chlorophyll status of the leaves below the tassel.

To determine which of the two sensor-derived vegetation indices would be most sensitive in detecting canopy variability in N status, we compared the slopes of the two respective relationships depicting relative SPAD vs. relative vegetation index. The Chl index relationship was found to have a greater slope than the NDVI relationship for both vegetative growth stages and both sites (Fig. 3). This would suggest that the Chl index would be more sensitive than the NDVI in detecting small difference in canopy greenness.

In summary, findings from this work suggest the active sensor system we evaluated is capable of detecting variations in corn leaf chlorophyll status induced by varying levels of N application and can be used to identify N deficiency during the time that the crop is still able to take up N and overcome an N deficiency. Given the option of using high-clearance applicators configured with the active sensor system (Fig. 1), a GPS and application rate controller, the potential for reducing pre-season N applications and emphasizing in-seasons variable N applications exists.

REFERENCES

Blackmer, T.M. and J.S. Schepers. 1995. Use of a chlorophyll meter to monitor N status and schedule fertigation for corn. J. Prod. Agric. 8:56-60.

Gitelson, A.A., Gritz, U. and Merzlyak M.N. 2003. Relationships between leaf chlorophyll content and spectral reflectance and algorithms for non-destructive chlorophyll assessment in higher plant leaves. J Plant Physiol, Vol. 160, No 3, 271-282.

Varvel, G.E., J.S. Schepers, and D.D. Francis. 1997. Ability for in-season correction of nitrogen deficiency in corn using chlorophyll meters. Soil Sci. Soc. of Am. J. 59:1233-1239.

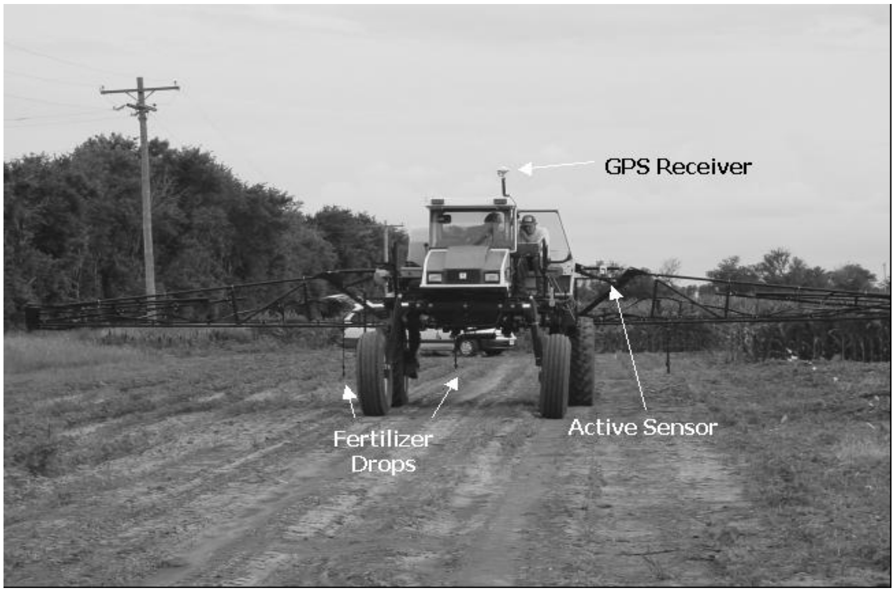

Fig. 1. Pictured above is the high clearance N applicator configured with active crop canopy sensors mounted on front and liquid N fertilizer delivery system, consisting of two-drop nozzles/valves placed at alternating rows of corn. Depending on the configuration of valves turned on/off, the system can deliver a multiple of four (i.e., (0, 45, 90, 135 kg N/ha) rates of liquid N fertilizer on-the-go as directed by the controller system interfaced to the active sensor or with a prescription map.

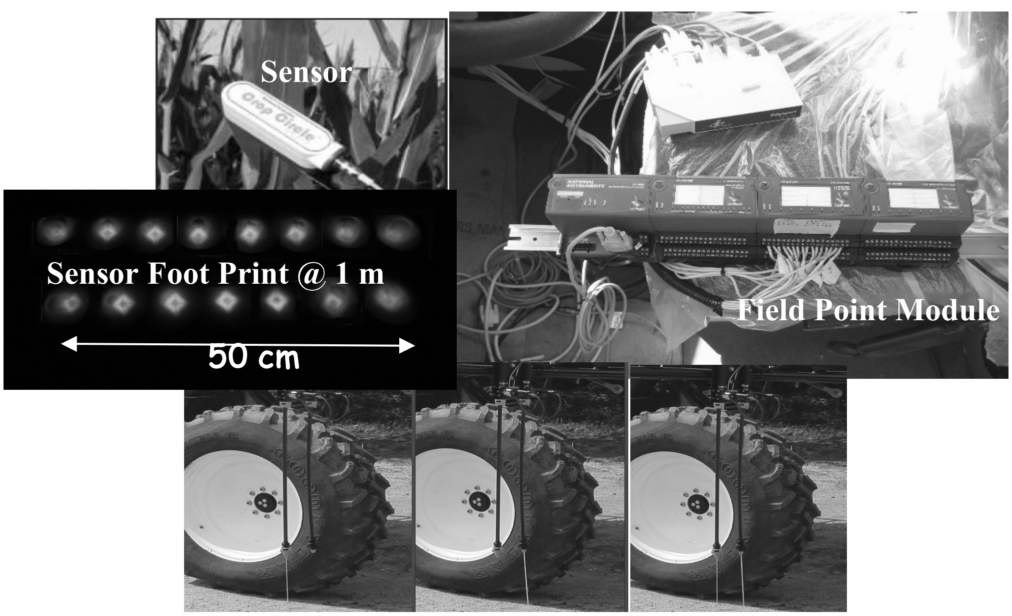

Fig. 2. Key system hardware components include a Holland Scientific Active sensor, Field Point Control Module that is interfaced to the sensors and PC running software that is controlling electronic valves delivering varying amounts of liquid N fertilizer.

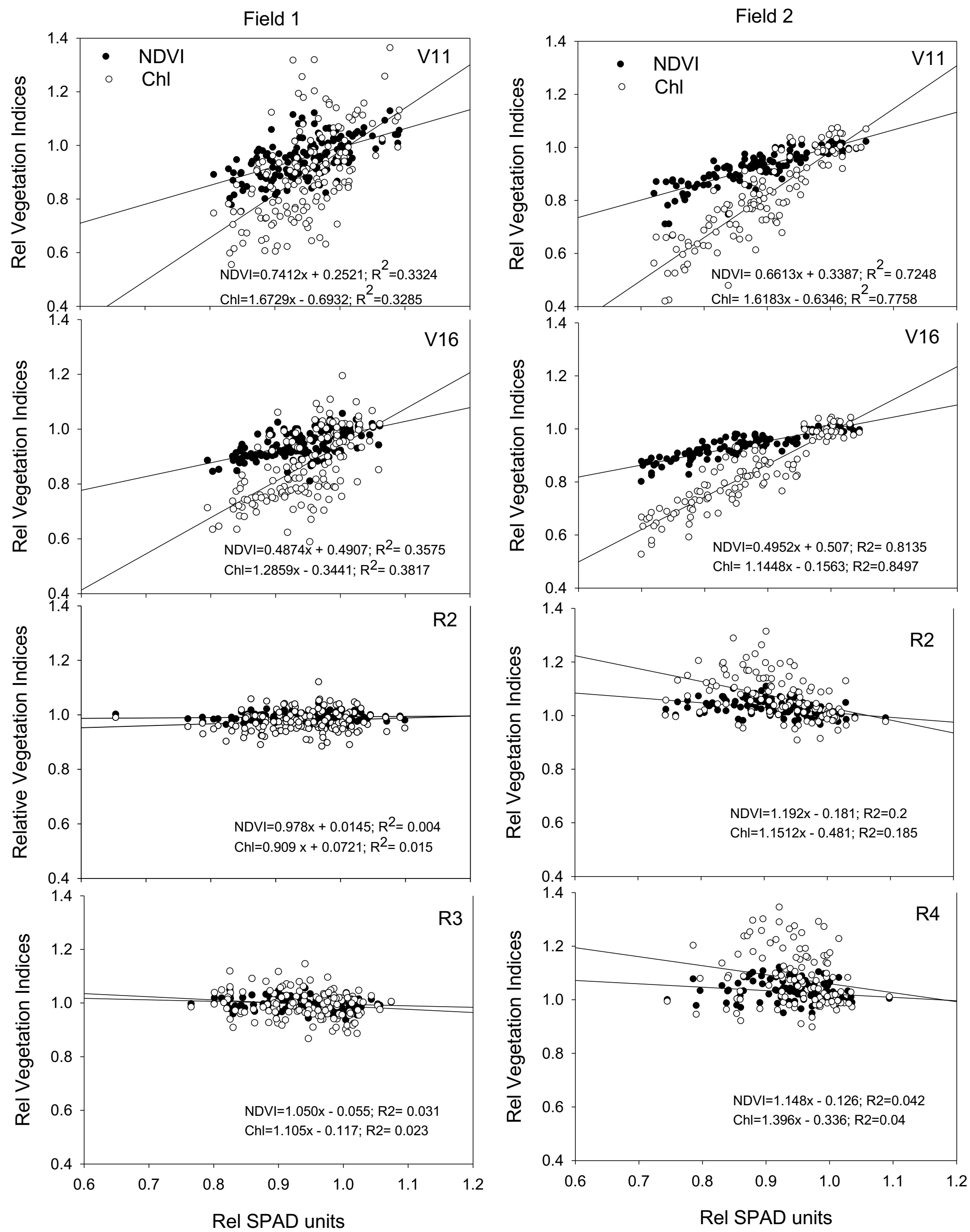

Fig. 3. Relative vegetation indices (NDVI and chlorophyll (Chl)) vs. relative SPAD readings for four crop growth stages (V11, V16, R2, and R3/R4) and two field study sites. Vegetation indices were computed from amber and near infrared (NIR) band output from active sensor readings over plots receiving different amounts and timings of N application.