IN-SEASON N RECOMMENDATIONS

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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 it's 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 objective for this research was to determine the most appropriate 1) distance from the canopy to position sensor, 2) phenological growth stage, and 3) vegetation index 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. After varying the distance of the sensor over the canopy from 40 to 120 cm, it was determined that placing the sensor around 80 cm above the canopy was optimal for accurate sensor readings. Furthermore, sensor readings were positively correlated with SPAD meter readings only during vegetative growth (V11 and V16) stages. Finally, the Chl index was more sensitive than the traditional NDVI in detecting variation in canopy greenness. In summary, 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 (Fig. 1). 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. 2). 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. 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 a 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. 3). While initial testing on the active sensor system has been encouraging, further research is needed to validate and refine recommendations. The specific objective for this research was to determine the most appropriate 1) distance from the canopy to position sensor, 2) phenological growth stage, and 3) 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 farmers 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 distance from the canopy to position the sensor, the sensor was attached to garage door opener and located directly over a cornrow in the nadir position.

Sensor readings were logged as the garage door opener was activated and distance of the sensor from the canopy was allowed to vary between 40 and 120 cm vertically above the canopy. Sensor readings were collected over several locations within a plot for a limited number of N treatments (example of typical reading seen in Fig. 4).

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:

$$\text{NDVI} = (\text{NIR} - \text{Amber}) / (\text{NIR} + \text{Amber})$$
$$\text{Chl index} = (\text{NIR} / \text{Amber}) - 1$$

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= $\text{SPAD}_{\text{plot i}}$ / $\text{SPAD}_{\text{highest N rate}}$). 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

Sensor output or reflectance from the amber and NIR bands is portrayed in Fig. 4 as a function of sensor distance from the canopy target. First, these data show that reflectance values are much greater for the NIR vs. amber band at any given sensor distance, which is consistent with remote sensing literature that shows plant canopies are more reflective in the NIR band then in visible portions of the spectrum. Secondly, this figure illustrates the inverse distance square law of radiation reflectance (i.e. reflectance = 1/distance^2. This simply means reflectance values for both bands are much more responsive to change in sensor distance at close range (40-100 cm) than at greater distances (>100 cm). The practical implication of this is the amount of energy for the amber and NIR bands radiating from the source diode to the target and reflecting back to the photodetector rapidly loses sensitivity beyond 100 cm. These results indicate that the sensor should be placed between 40 and 100 cm above the canopy to remotely assess canopy variation in greenness. Thus, our sensor was positioned at 80 cm above the canopy for all small plot readings.

The analysis of variance revealed (data not shown) 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. 5). 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. 5). 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 (Fig. 1). Given the option of using high-clearance applicators configured with the active sensor system, a GPS and application rate controller, the potential for reducing pre-season N applications and emphasizing in-seasons variable N applications exists.

References

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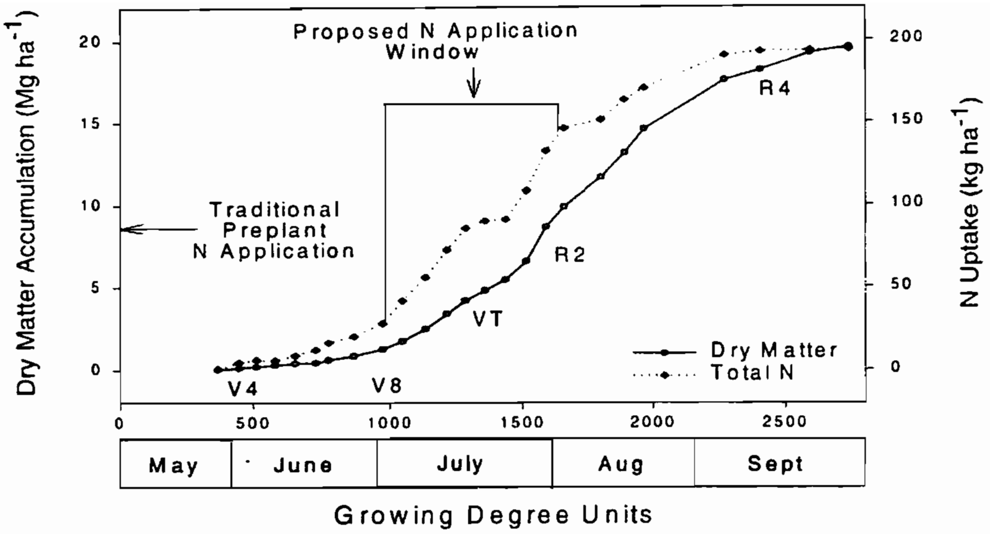

Fig. 1. Corn N uptake versus accumulated growing degree units. Response curve derived from unpublished data from a study with six corn hybrids grown over two growing seasons at Shelton, NE in replicated plots. Crop dry matter and N accumulation were determined on a weekly basis throughout the entire growing season. Calendar dates and important phenological dates are depicted. Timing of N application for traditional versus proposed crop-based management scheme is also shown on the figure.

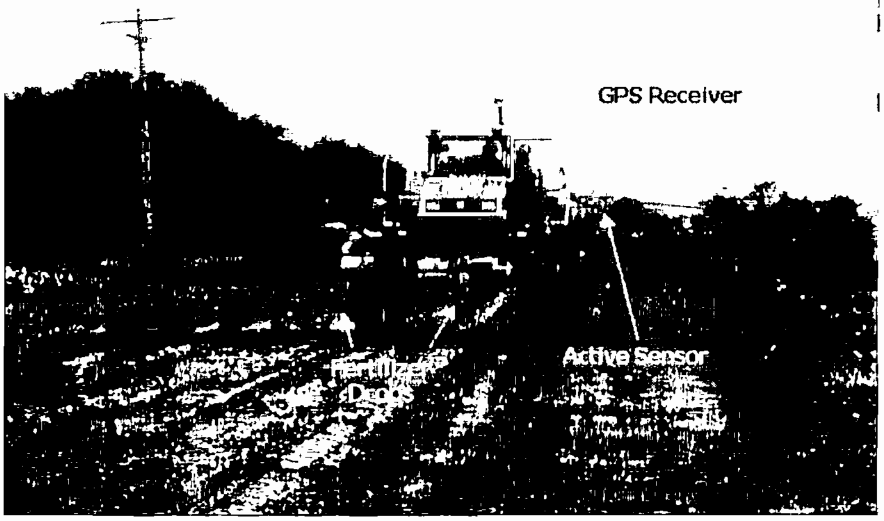

Fig. 2. Pictured above is the high clearance N applicator configured with active crop canopy sensors mounted on front and liquid N fertilizer delivery system, consisting of two-drop nozzles/valves placed at alternating rows of corn. Depending on the configuration of valves turned on/off, the system can 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.

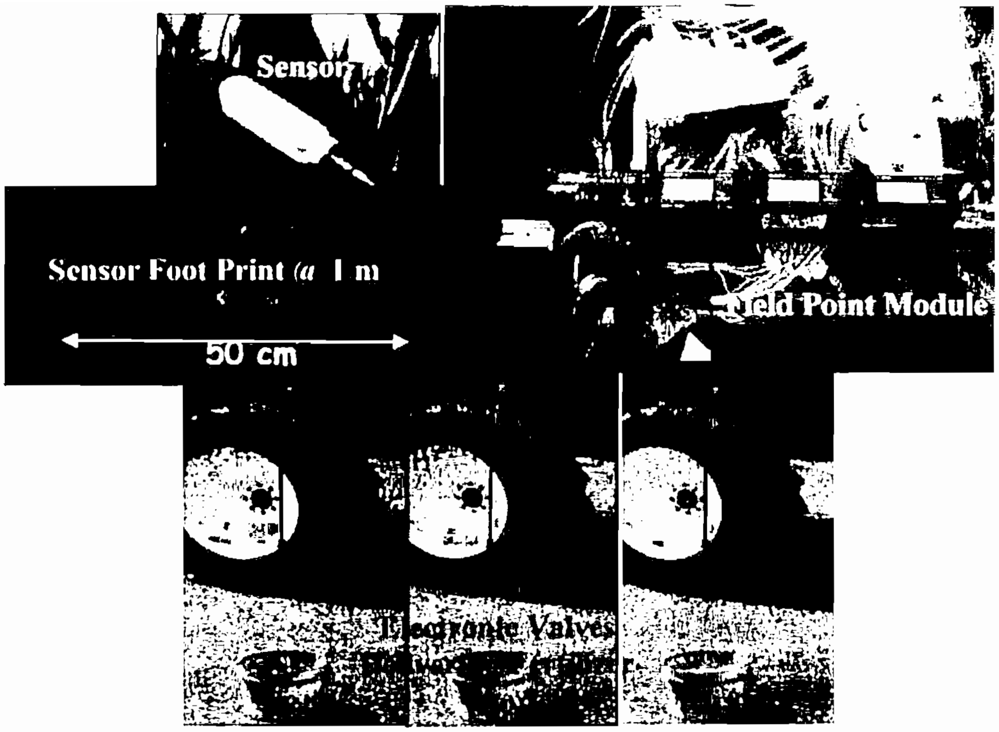

Fig. 3. Key system hardware components include a Holland Scientific Active sensor, Field Point Control Module that is interfaced to the sensors and PC running software that is controlling electronic valves delivering varying amounts of liquid N fertilizer.

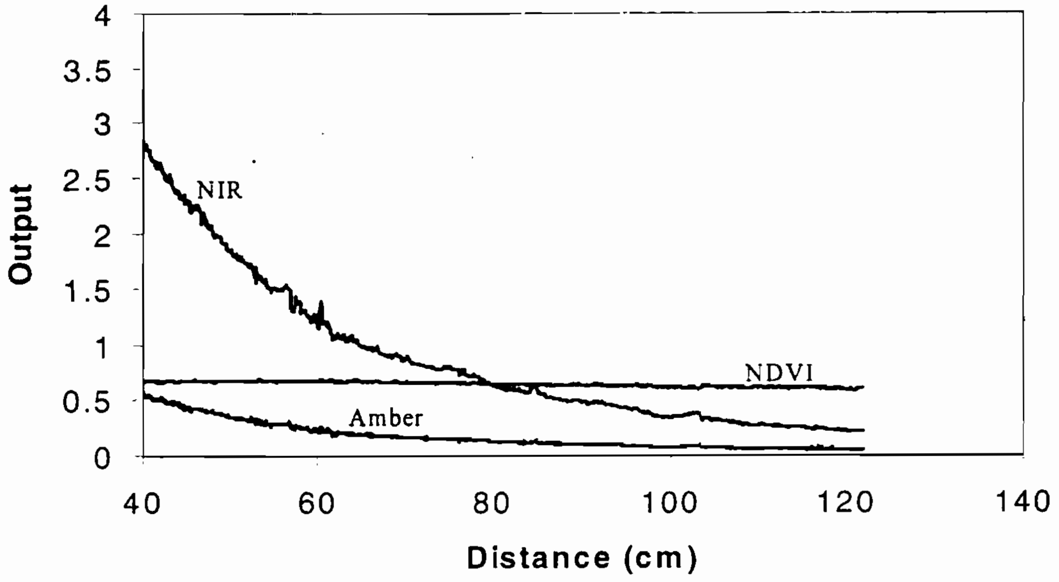

Fig. 4. Effect of sensor distance from target on sensor output or reflectance in the amber and NIR wavebands as well as the calculated NDVI for a typical corn canopy at V10 growth stage.

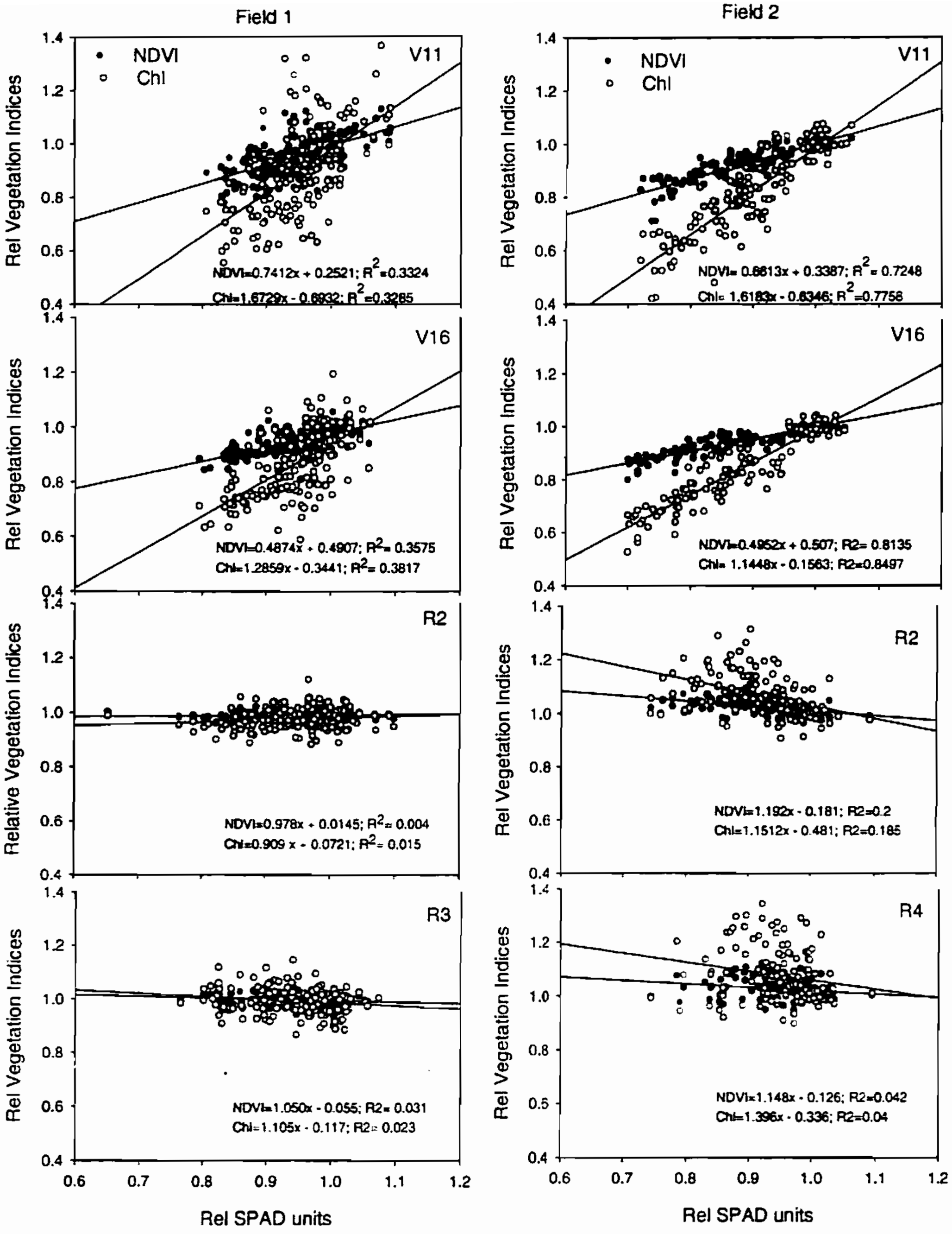

Fig. 5. Relative vegetation indices (NDVI and chlorophyll (Chl)) vs. relative SPAD readings for four crop growth stages (V11, V16, R2, and R3/R4) and two field study sites. Vegetation indices were computed from amber and near infrared (NIR) band output from active sensor readings over plots receiving different amounts and timings of N application.

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