A CROP-BASED APPROACH FOR IN-SEASON N MANAGEMENT OF CORN

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Abstract

Over-application of nitrogen (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 corn N management schemes is routine pre-season application of large doses of N before the crop can effectively utilize this N. Our long-term research goal is to reduce these over-applications by using remote sensing to direct fertilizer only to areas needing N at times when the crop can most efficiently utilize the N. We have finished an initial cycle of testing on an enhanced multispectral four band (blue, green, red and NIR) crop reflectance sensor system, which when mounted on a high-clearance tractor is intended to operate as an in-season N applicator. The specific goal of this work was to compare the performance of canopy reflectance measured with the sensor system to variations in leaf greenness or chlorophyll content determined with a chlorophyll meter. Treatments consisting of two hybrids and five N rates were grown under irrigation near Shelton, NE in 2000 and 2001. Sensor bands (blue, green, red, and NIR) and chlorophyll meter data were acquired on several dates during both seasons. Reflectance data were used to compute two vegetation indices, normalized difference vegetation index (NDVI) and a green version of NDVI. Hybrid treatments produced little effect on chlorophyll meter values or vegetation indices, while N application increased values by up to 33% for the chlorophyll meter, by up to15% for GNDVI, and by up to 5%for NDVI. GNDVI was more highly correlated with chlorophyll meter values than NDVI, with maximum correlations of 0.90 and 0.88 in 2000 and 2001, respectively. Our results suggest that the sensor system is capable of detecting variations in corn leaf chlorophyll content and could potentially be used in controlling an in-season N applicator.

Problems and Previous Research

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 nitrogen 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. Our long-term research goal is to reduce over-application by using remote sensing to direct fertilizer only to areas needing N at times when the crop can efficiently utilize the nutrient. Previous work by Blackmer and Schepers (1994), Blackmer et al. (1993) and Blackmer and Schepers (1995), using the Minolta SPAD 502 chlorophyll meter to monitor crop chlorophyll or N status and applying fertilizer N as needed, showed that crop-based approaches to manage N would be an improvement over traditional soil-based approaches. Nitrogen stress and grain yield losses were observed whenever chlorophyll meter readings for the "managed plots" declined below 95% of the meter values for reference strips receiving adequate to excess N at planting time. They suggested that the 95% value (sufficiency index) would be a reasonable trigger point to apply additional fertilizer N. Subsequently, Varvel et al. (1997) confirmed these findings in a small plot study involving "as needed" N applications directed by chlorophyll meter assessments from early vegetative growth (V8) through silking (R2). Collectively, the research demonstrated 1) that the chlorophyll meter could be used as a research tool to maintain an adequate N supply for corn by fertilizing as needed and 2) that 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.

We have finished an initial cycle of testing on an enhanced multispectral crop canopy reflectance sensor system, which when mounted on a high-clearance tractor is intended to operate as an in-season N applicator. By selecting the appropriate filters, the reflectance sensors can measure light reflected off the crop in various bands of the visible and NIR spectrum, which provide the greatest measure of difference between adequately fertilized and N-stressed corn canopies.

The specific goal of this work was to compare the performance of canopy reflectance measured with a multi-spectral reflectance sensor system to variations in leaf greenness or chlorophyll content determined with a Minolta (model SPAD 502) chlorophyll meter.

Materials and Methods

The study was conducted near Shelton, NE during the 2000 and 2001 growing seasons under sprinkler irrigation system. Field plots involved treatment combinations of four hybrids and five N application levels (0, 50, 100, 150, and 200 kg N ha^{-1}). The hybrids were selected for differences in canopy architecture (upright vs. planophile orientation).

The sensor system utilized to collect canopy reflectance measurements in our work (depicted in Figure 1) was developed by Holland Scientific (Lincoln, NE) in cooperation with USDA-ARS. It is comprised of a data hub, a GPS (optional), one or more up-looking optical sensors, one or more down-looking optical sensors and laptop PC software, connected via an RS-485 serial network. The data hub performs the function of sensor data collection, arbitration between the optical sensors and the laptop PC and recording the GPS data stream. The optical sensors implemented in the canopy reflectance system are fully programmable and multi-spectral, with each sensor configured with 4 optical channels, associated signal conditioning, and data acquisition hardware. All optical channels use miniature, narrow-band interference filters and low dark-current photodiodes. Output current produced by each photodiode is amplified and resultant signal voltages are then quantified by a 16-bit analog-to-digital converter and subsequently scaled and linearized by the sensor's micro controller. The four optical channels in each sensor were configured with the appropriate filters to measure light in four bands of the visible and NIR spectrum, which were blue (460nm) green (555 nm), red (680nm) and near infrared or NIR (800nm). Attached to the downward-viewing sensor head was a PVC optical field restrictor, providing a 28° field-of-view for the optical sensors. With the field-of-view restrictor in place, a down viewing sensor positioned one meter above the crop canopy would view a circular region of the crop canopy 0.5m in diameter.

For this study, the canopy reflectance system, with one up looking and two down-looking optical sensors, was mounted on an adjustable height platform on a high-clearance tractor to allow for maintenance of constant optical sensor distance from the growing crop canopy. The two down-looking sensors were positioned to be directly over two separate crop rows (nadir view) when traveling through a plot. Canopy reflectance measurements were acquired from the center two rows of each plot on two dates in 2000 and three dates in 2001 during the V-8 through R-2 crop growth stages around solar noon at three separate positions within each plot. The optical sensors were maintained at an approximate distance of one meter above the crop canopy for each measurement date.

Canopy reflectance (defined as the ratio of reflected to incident radiation flux, ranging from zero to one) for each band was calculated as ratio of the digital output from the four optical channels of the two down-looking sensors to digital output from the respective four channels of the up looking sensor. Thus, the impact of variations in incident radiation flux on canopy reflectance due to cloud clover, solar angle, etc. was accounted for when calculating canopy reflectance for a given spectral band. Reflectance values for the green, red, and NIR bands were used to calculate the two different vegetation indices (GNDVI and NDVI). The equations were: NDVI = (NIR-Red)/ (NIR + Red), according to Tucker (1979), and GNDVI = (NIR - Green)/(NIR + Green) according to Gitelson et al., (1996).

Variation in leaf greenness or chlorophyll content among treatments was assessed with the model 502 Minolta SPAD chlorophyll meter (Spectrum Technologies, Plainfield, IL) on the day of collection of crop canopy reflectance measurements. Measurements were taken midway between the leaf tip and base and midway between the margin and the midrib of the uppermost fully expanded leaf of 30 representative plants selected from the center two rows of each plot, and averaged.

Results

In general, increasing N levels produced dramatic increases in chlorophyll meter values across all dates of both years. The average increase in chlorophyll meter values for all dates in each year associated with N applications was around 21% in 2000 (not shown) and 33% in 2001 (Fig 2a). Nitrogen treatments affected vegetation indices to varying degrees in both years of the study, with the average effect of increasing N levels being less dramatic for NDVI then for GNDVI. Increasing N levels in 2000 produced an average 15% increase for GNDVI (not shown) and only a %5 increase for NDVI. Likewise, in 2001, increasing N application produced an average 14% increase for GNDVI (Fig. 2b) and only 4% for NDVI (Fig2c). In summary, the N treatments used in our work generated more variation in chlorophyll meter assessments than in the two vegetation indices, with GNDVI showing greater response or sensitivity to N than NDVI.

To explore the association between sensor reflectance data and chlorophyll meter assessments, values for the three bands (green, red, and NIR) as well as the two vegetation indices (GNDVI and NDVI) from individual plots (n=30) were correlated with chlorophyll meter values for the respective plots on each date that data was acquired. In all cases, correlations between vegetation indices and absolute chlorophyll meter values were considerably higher for the two indices than any of the individual spectral bands that comprised the two indices (data not shown). Since associations were higher for vegetation indices than individual spectral bands, only the former correlations were determined for the respective acquisition dates in 2000 (not shown) and 2001 (Fig. 3a). The general trends were for correlation values to increase with increasing age and/or canopy cover, and in nearly all instances GNDVI was more highly correlated with chlorophyll meter values than NDVI, with maximum correlation values around 0.90 and 0.88 on the final acquisition dates in 2000 and 2001, respectively. This suggests that GNDVI derived from the canopy reflectance sensor has the greatest potential for estimating leaf chlorophyll content as determined by the chlorophyll meter.

Research by Blackmer et al., (1993), Blackmer and Schepers, (1995), Varvel et al., (1997), using chlorophyll meters to assess crop chlorophyll status, has demonstrated that 95% sufficiency level is a reasonable trigger point for "spoon-feeding" N to the crop on an "as needed" basis during the V-8 through R-2 stages of growth. Results from our present work, in turn, show a good association between canopy sensor output and chlorophyll meter values acquired during the V-8 through R-2 growth stages. For example, the relationship between GNDVI and chlorophyll meter values for one hybrid at V-15 growth stages (Fig.4) shows that the GNDVI sufficiency level for the corresponding 95% chlorophyll meter sufficiency level agree reasonably well. For this relationship there was only one data point (noted on figure), identified as being N sufficient by chlorophyll meter assessment, which was shown to be N deficient by canopy sensor assessment (GNDVI). Nonetheless, these types of comparisons have not been made for field strips where factors other than N status can more easily effect crop chlorophyll status. Therefore, it will be important to determine the most appropriate trigger-point or threshold regarding sensor output for making supplemental N applications. It could be that the threshold should change with crop growth stage. This relationship may also vary with soil type and organic matter content. Thus, additional research is needed with the sensor system to address these issues.

Summary and Conclusions

In summary, findings from our work suggest the sensor system we evaluated is capable of detecting variations in corn leaf chlorophyll status induced by varying levels of N application, since variation in the sensor readings expressed as GNDVI was highly correlated with ground-based chlorophyll meter values in both years of the study. Our results suggest that the sensor system 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 (i.e., stages V8 to R2). Given the option of using high-clearance applicators configured with the sensor system, a GPS and application rate controller, the potential for reducing pre-season N applications and emphasizing in-seasons variable N applications exists.

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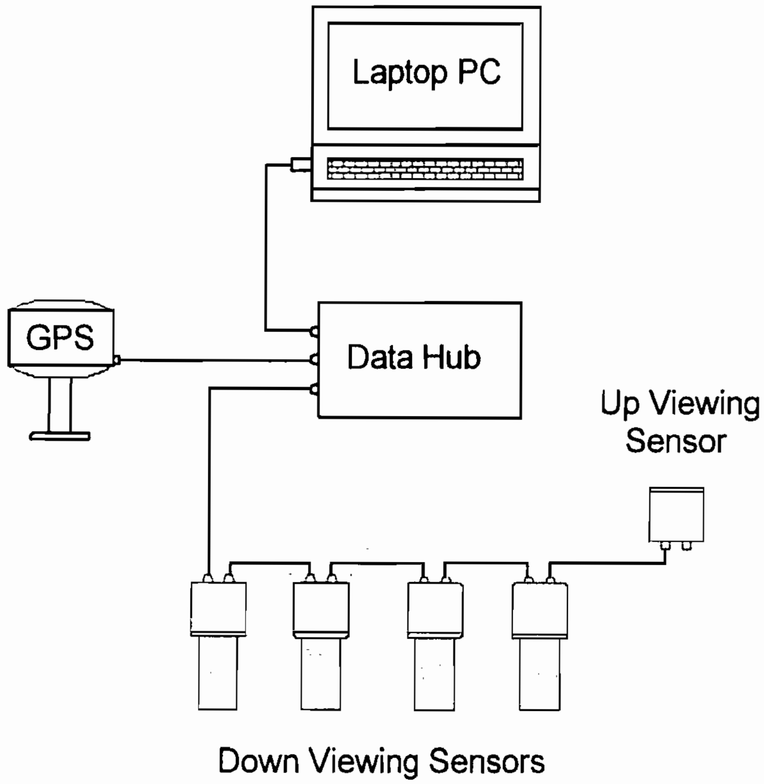

Figure 1. Schematic diagram depicting the major sensor system components, including upward- and downward-looking sensors, data hub, GPS, and laptop PC with data acquisition software.

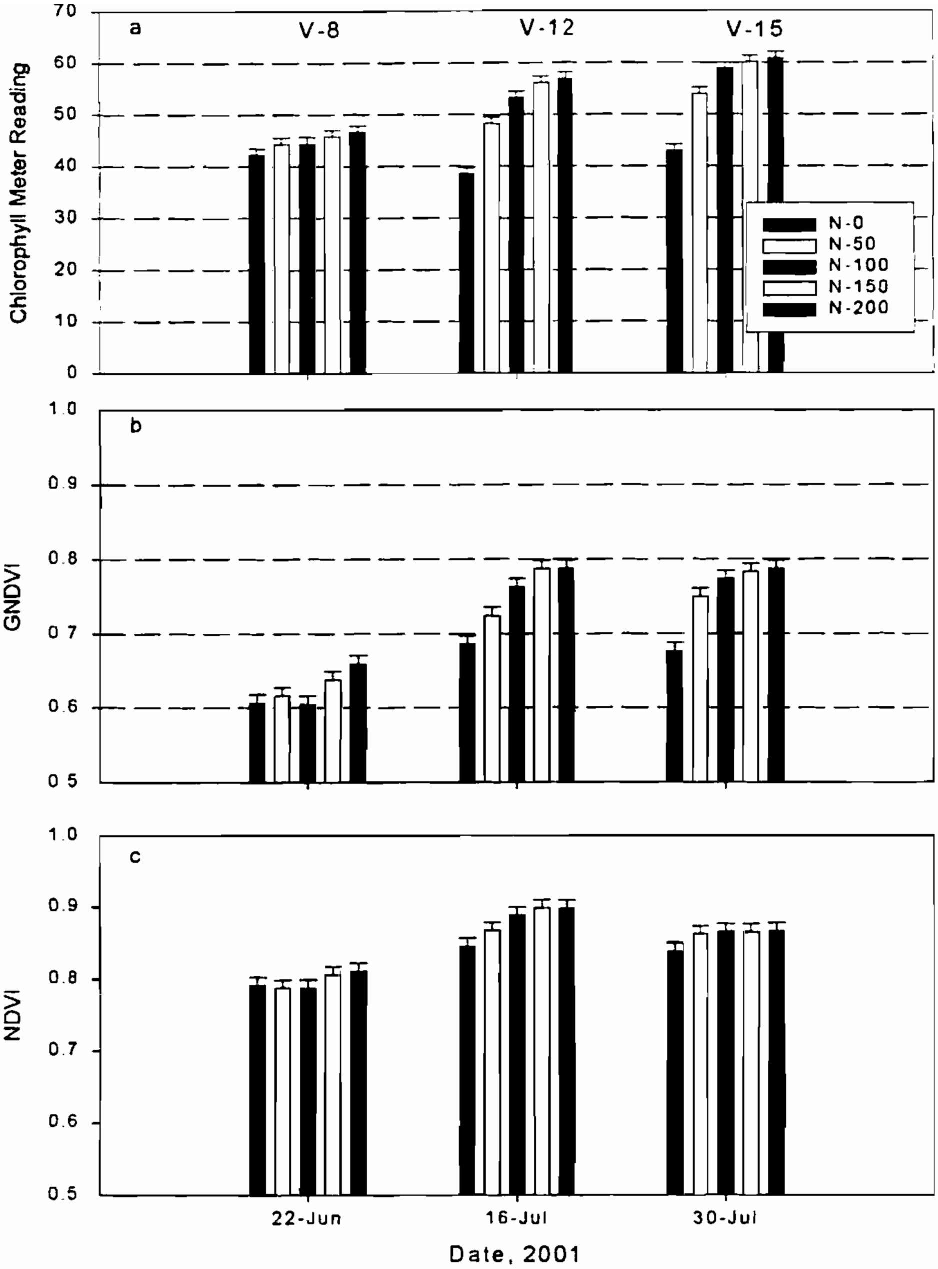

Figure 2. The response of (a) leaf chlorophyll (b) green normalized difference vegetation index (GNDVI) and (c) normalized difference vegetation index (NDVI) for two dates in the 2001-growing season. Important phenological dates for the average of all hybrids are also depicted. Standard error values are shown to compare N main effects vs. date.

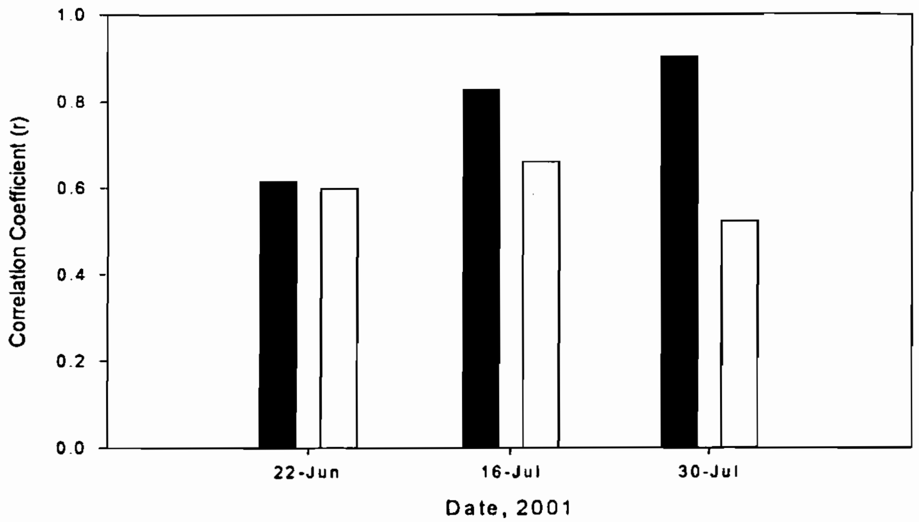

Figure 3. Correlation coefficients for the association of absolute vegetation indices vs. chlorophyll meter values for two dates in the 2001-growing season (a). Correlation values for normalized vegetation indices vs. chlorophyll meter values are shown in b. Important phenological dates for the average of all hybrid and N treatments are also depicted. Correlation values of 0.217 and 0.283 are significant at the 5 and 1% levels.

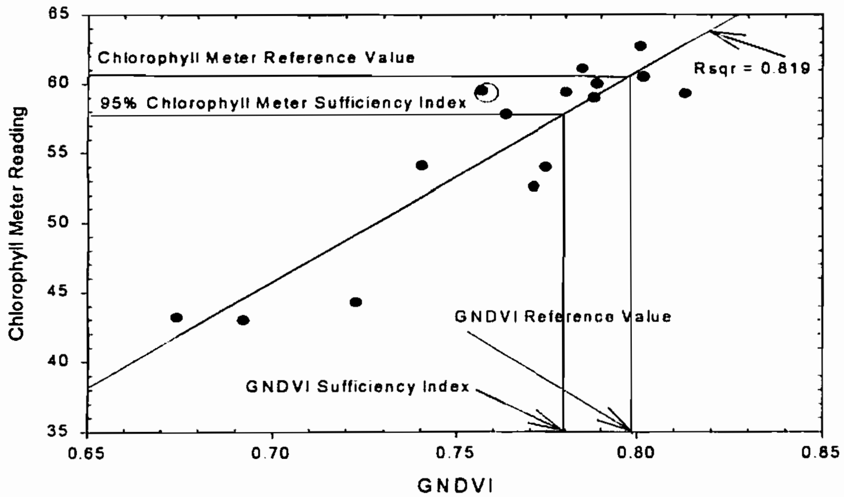

Figure 4. Relationship between green normalized difference vegetation index (GNDVI) versus chlorophyll meter values for hybrid 33G26 involving five N applications levels on July 30 of 2001. The chlorophyll meter reference value (60.7), which represents the average of three replicates values for the high N rate, along with the 95% sufficiency chlorophyll meter value (60.7 x 0.95 = 57.7) are also depicted on the graph. The data point designated with a circle represents the only data point where chlorophyll meter sufficiency values and GNDVI sufficiency values do not agree.

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