COMPARISON OF MULTI-SPECTRAL ANALOG AND IMAGING SYSTEMS FOR ASSESSING PLANT NITROGEN STATUS IN IRRIGATED CORN

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ABSTRACT

Uniform applications of nitrogen (N) across a field may result in over fertilization in some areas as well as under fertilization in others. Farmers, consultants, and other end users need rapid, robust techniques to spatially and temporally assess a crop's N status in order to apply N "as needed" and "where needed". The objective of this research was to compare the differences in response of a radiometer system and an imaging system for assessing the plant N status of irrigated corn (*Zea mays* L). The radiometer system utilized analog sensors that integrated the viewed target (sunlit and shaded plant components as well as sunlit and shaded background soil) into a single value while the other system acquired high-resolution images of the target for separating plants from the soil background. Small plots consisting of five imposed N levels replicated three times were established in a sandy portion of a commercial center pivot irrigated field [Valentine sand (mixed, mesic Typic Ustipsamments)]. Data collected consisted of ground-based spectral measurements, SPAD chlorophyll meter measurements, and plant samples for N content analysis. Response of the two multi-spectral systems expressed in terms of the N Reflectance Index (NRI) to plant N status in the form of leaf N content and the N Sufficiency Index (NSI) calculated from SPAD data were similar. No advantage was apparent from use of high-resolution images that allowed segmentation of the soil background from the plant components in the scene.

INTRODUCTION

Nitrogen (N) is an essential nutrient for plant growth. Farmers are inclined to manage fertilizer N to minimize the risk of N deficiencies, which may result in excessive applications of fertilizer. They may follow conventional practices and apply N fertilizer at rates based on optimistic yields but may not account for all sources of nutrients available to the crop. Spatial variability in residual NO_3^--N and soil organic matter across a field as well as N available from irrigation water, legumes and manure may be difficult to incorporate into conventional practices. Thus, procedures are necessary to assess plant N status quickly in order to apply N when and where required by the crop to improve N management.

Optical sensors have been used to assess N status in agronomic, vegetable, and ornamental plants. Various indices have been developed and evaluated that are pertinent to plant N assessment. One of these is the N Reflectance Index (Bausch and Duke, 1996) that requires measurements in the green (G) and near-infrared (NIR) portions of the electromagnetic spectrum. The N Reflectance Index (NRI) is defined as a ratio of the NIR/G for the area of interest to the NIR/G for a well N-fertilized reference. The concept was based on the N Sufficiency Index (NSI) (Peterson et al., 1993) calculated from SPAD chlorophyll meter measurements. Bausch and Duke (1996) showed that the NRI calculated from nadir view (perpendicular to the crop surface) radiometer measurements and the NSI produced a near 1:1 relationship for corn growth stages V11 [eleventh mature leaf (Ritchie et al., 1986)] through R4. The NRI has been evaluated by Bausch and Diker (2001) and Bausch and Delgado (2003) for in-season N management; results showed that seasonal N inputs were reduced from 39 to 112 kg N ha^{-1} compared to traditional farmer practices without reducing grain yield. Bausch and Duke (1996) mentioned that early season (V6 to V10) assessment of plant N in corn may be difficult to estimate with radiometers viewing the crop from a nadir view because of the soil background influence on the crop canopy and that procedures to separate the plant from the soil might be required to resolve this particular issue.

Thus, a Cooperative Research and Development Agreement (CRADA) between USDA-ARS Water Management Unit (WMU) and Case-IH (now CNH Global N.V.) was formed to evaluate a multi-spectral imaging sensor (MSIS) system for real-time assessment of N stress in corn. The system described by Kim et al. (2000) was designed and developed by the Agricultural Engineering Department, University of Illinois at Urbana-Champaign with input (funds and personnel) from CNH Global N.V. The CRADA with WMU was terminated by CNH Global N.V. in early 2001 after Case-IH and New Holland merged. The objective of this paper was to present and compare the radiometer system and the MSIS system responses to plant N status of irrigated corn during the 2000-growing season.

MATERIALS AND METHODS

The field experiment was conducted near Wiggins, CO in a commercial center pivot irrigated cornfield. Corn (Pioneer Hybrid 34G81, planophyle canopy) was planted on 12 May at 83 000 seeds ha^{-1}; a liquid fertilizer mix consisting of 28 kg N ha^{-1}, 34 kg P ha^{-1}, 6 kg S ha^{-1}, and 1 kg Zn ha^{-1} was applied to the side and below the seeds at planting. Row direction was 32° from north with a row spacing of 0.76 m. A small plot study consisting of three replicated blocks of five imposed N levels was established in a very sandy area of the field. Soil in this area was classified as Valentine sand (mixed, mesic Typic Ustipsamments) that consisted of 92% sand and 6% clay in the top 1.5 m of the soil profile. Individual plots were 16 rows wide by 15 m long; N levels were 28, 84, 140, 196, and 252 kg N ha^{-1}. The 252 kg N ha^{-1} plots were considered well N-fertilized reference plots. Soil samples acquired at the end of the 1999 growing season within this area of the field indicated 9 kg ha^{-1} residual NO_3^--N in the top meter of the soil profile; thus, residual N was ignored when applying N to the particular plots. Urea ammonium nitrate (UAN, 32% N) was dribbled on the soil surface after planting (15 May); the 28 kg N ha^{-1} plots did not receive N because it was applied at planting. N fertilizer was incorporated with 1.3 cm of irrigation water shortly after application.

The radiometer and image sensor were mounted on a platform attached to a boom, which was mounted on a high-clearance tractor for field access. The radiometer system consisted of two four-channel radiometers (Exotech 100BX[1], Exotech, Inc., Gaithersburg, MD) and a data logger (CR23X Micrologger, Campbell Scientific Inc., Logan, UT) to sample and store radiometer sensor voltages as well as time of measurement. The platform attached to the boom provided manual two-way leveling to keep the down-looking radiometer pointed perpendicular to the crop surface via leveling switches located on the tractor console. Another instrument platform attached to the tractor's roll over protection system provided automatic two-way

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[1] Mention of trade names is for the benefit of the reader and does not constitute endorsement by the authors or USDA over similar commercially available products.

leveling controlled by the data logger via inputs from an inclinometer; this platform carried an upward-looking radiometer to measure incoming irradiance. Both radiometers measured radiant energy in discrete wavebands in the blue, green, red, and near-infrared regions of the electromagnetic spectrum (i.e., 450 to 520 nm, 520 to 600 nm, 630 to 690 nm, and 760 to 900 nm, respectively). Data were acquired every 2 s when the data logger was triggered to record data. Position (longitude and latitude) of each data point was determined with real-time differential GPS (Racal LandStar MkIV with Ashtech G12 Lite GPS card, Racal NCS, Houston, TX). The GPS antenna was mounted directly above the down-looking radiometer. Canopy reflectance was calculated for each waveband based on an intercalibration of the up-looking and down-looking radiometers with respect to a calibrated $BaSO_4$ reflectance panel (Jackson et al., 1992). Green and near-infrared reflectance values specific to each plot (N level) and the associated reference plot were used to calculate the NRI value for that plot.

The MSIS system consisted of a three-channel video camera, an ambient illumination sensor, and a portable computer. The imaging sensor was mounted to one side of the Exotech radiometer on the platform attached to the boom. This camera was custom developed and contained three separate optical paths and charged couple device (CCD) detectors. Optical filters were installed in front of each detector to provide video channels of green, red, and near infrared light with center wavelengths of 550 nm, 650 nm, and 800 nm, respectively. Bandwidth of each filter was approximately 100 nm. Each CCD detector had a 640 x 480 pixel resolution. A serial interface provided external control of gain and exposure for each independent video channel. A frame grabber (FlashBus MV, Integral Technologies, Inc., Indianapolis, IN) was installed in the computer to acquire images through a high-speed PCI interface that supported 24-bit color video. Ambient illumination (AI) was measured by a four-channel Skye radiometer (SKR1850A, Skye Instruments Ltd., Powys, UK). The AI sensor was mounted on the up-looking platform adjacent to the Exotech radiometer. This sensor measured incoming irradiance in the green (550 nm ± 20 nm), red (650 nm ± 20 nm), near infrared (800 nm ± 20 nm) and a broadband (650 nm ± 250 nm). The AI sensor was connected to an I/O card to provide feedback to the camera. A control algorithm to position the gray-level distribution for each of the three channels near the center of their range, i.e. 128, dynamically adjusted gain and exposure to compensate for variations in ambient illumination. After reaching convergence with the control algorithm, the image was segmented to remove non-vegetation (soil and shadows). Image analysis was implemented with Image-Pro Plus software (Media Cybernetics, L.P.). GPS position was recorded with each image. Reflectance was calculated as a function of average gray-level value, ambient illumination, exposure, gain, and calibration coefficients related to MSIS response and absolute reflectance units. As with the Exotech data, green and near-infrared reflectance values were used to calculate plot specific NRI values.

Crop N assessments were made using ground-based spectral measurements, SPAD chlorophyll meter measurements, and plant sampling for N content analysis. Data were collected on Day of Year (DOY) 174, 181, 189, 196, 201, 208, and 223. Corn was in its V6 growth stage on DOY 174; tasseling (VT) occurred on DOY 208. Spectral measurements were taken around 2:00 pm standard time when the sun azimuth angle was nearly parallel to the corn rows. Clear sky conditions existed on sample days with the exception of DOY 189, which had high, thin hazy clouds. The MSIS system was not working properly on DOY 174 and the Exotech raw data file for DOY 189 was accidentally deleted.

SPAD measurements were collected using a Minolta SPAD 502 chlorophyll meter with RS-232 output. The meter was interfaced to a data logger (Spectrum StarLogger, Spectrum

Technologies, Plainfield, IL) and a backpack differential GPS receiver (Case AFS, SB2400, Case Corporation, Racine, WI). SPAD measurements were taken on the newest fully expanded leaf during vegetative growth; after tasseling, the ear leaf was sampled (Peterson et al., 1993). SPAD data were taken on plants outside the area designated for remote sensed measurements to minimize damage to the plants viewed by the radiometer and camera. Approximately 30 plants were measured in four assigned areas within each plot to obtain a good average value for the plot. The NSI was calculated for each specific plot based on its associated reference plot.

Eight plants were selected at random and removed from each plot on each sample date for plant N analysis. Again, these were taken outside the area designated for remote sensed measurements. The plants were separated into leaves and stems, dried at 55° C for at least 48 hr, ground, and analyzed for total C and N content by dry combustion with an automated C-N analyzer (Carlo Erba Instruments Nitrogen Analyzer 1500, Carlo Erba Strumentazione, Mila, Italy).

Leaf area was measured on 10 randomly selected plants in each plot on each sample date plus/minus one or two days using a portable area meter (Li-Cor LI-3000A, Li-Cor, Lincoln, NE). Leaf area index (LAI) was calculated based on the average plant population in each plot.

RESULTS AND DISCUSSION

Figure 1 shows the plant N status of corn for growth stages V6 through R2 resulting from the various N levels imposed. Growth stage at each sampling date is shown along the time axis.

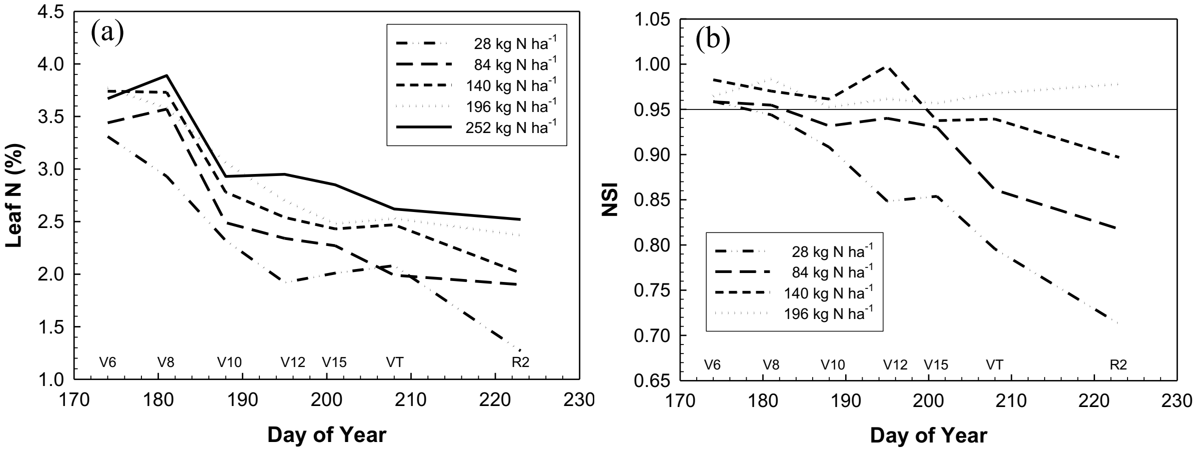

Figure 1. Temporal plots of (a) leaf N content and (b) NSI calculated from SPAD data.

Leaf N (Fig. 1a) decreased with time since all the fertilizer was applied at the beginning of the season. Leaf N content followed the order of N amount available to the plant, i.e., the 28 kg N ha^{-1} treatment had the least N content while the 252 kg N ha^{-1} treatment had the greatest. SPAD data transformed into the NSI (Fig. 1b) indicated that 196 kg N ha^{-1} (dotted line) maintained corn plants in an N sufficient state during this study (NSI > 0.95 threshold). The 252 kg N ha^{-1} treatment was used as the reference area, as such, the curve for that N level was not shown in Fig. 1b because it would be a horizontal line at NSI = 1. Corn in the 28 and 84 kg N ha^{-1} plots became N deficient around the V8 growth stage.

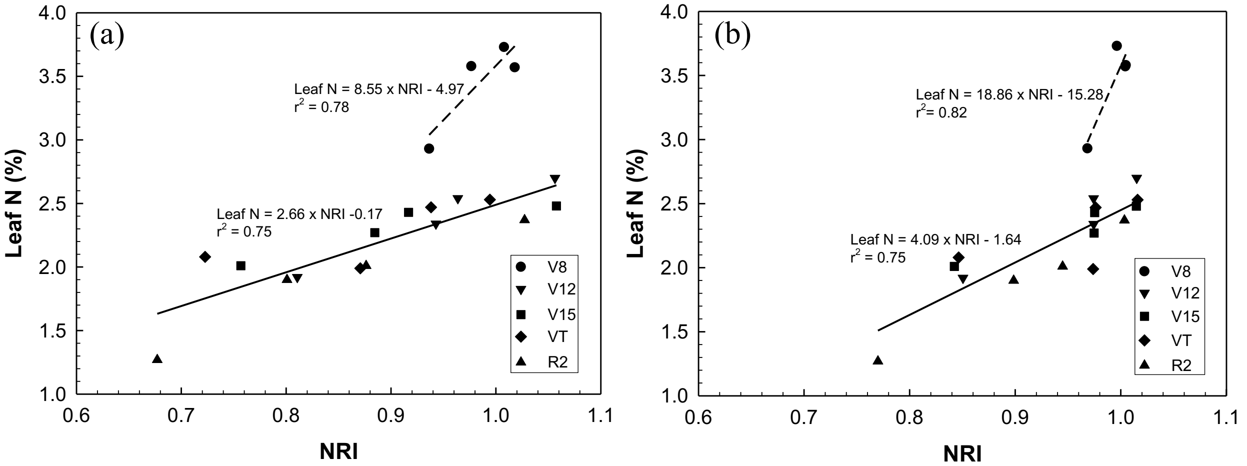

Figure 2. Leaf N vs. NRI calculated from (a) Exotech radiometer data and (b) MSIS data.

Spectral response expressed in terms of the NRI to corn leaf N is presented in Figs. 2a and 2b for the Exotech radiometer system and the MSIS system, respectively. System response to leaf N content was similar. Both systems showed that the V8 growth stage data were clearly different from the remainder of the data. Thus, segmenting the soil influence out of the canopy scene with high-resolution images did not achieve the desired result of clustering the data so that one regression line would describe the relationship between leaf N and the NRI. Evaluation of vegetative cover and accuracy of plant N assessment with the NRI by Schleicher et al. (2003) indicated that corn should have a LAI near 2.5 to have sufficient vegetative cover for accurate N status classification using a nadir-viewing radiometer. Corn on DOY 194 (two days prior to spectral measurements on DOY 196) varied from a LAI of 2.2 to 2.5. Corn was in its V12 growth stage. Spectral data at V10 (DOY 189, LAI ≈ 1.5) would have been helpful to determine the transition from a crop canopy that displayed considerable soil background (V8 growth stage, LAI around 0.9) to one where the soil background was effectively obscured by the canopy (V12).

SPAD chlorophyll meter data transformed into the NSI and plotted against the NRI produced a single linear relationship for the corn growth stages (V8 through R2) considered in this study as shown in Figs. 3a and 3b. Referencing data from a given area to an adequately fertilized area in the same field provides an easy comparison of data across fields, hybrids with unique “greenness” characteristics, growth stages, and years (Schepers et al., 1995). Again, the relationships in Fig. 3 were similar between systems; however, slightly less data scatter occurred with the Exotech radiometer system (Fig 3a).

CONCLUSIONS

Responses of the two multi-spectral systems to N status of irrigated corn were similar. No apparent advantage exited from using high-resolution images that allow segmentation of plant and soil components in a scene for removal of the soil background influence on crop canopy reflectance.

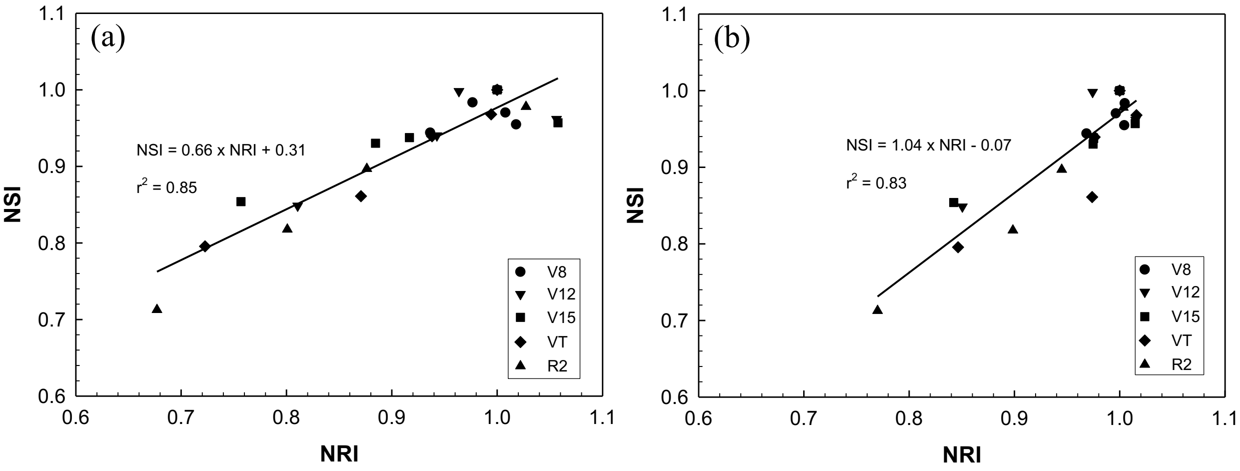

Figure 3. NSI vs. NRI calculated from (a) Exotech radiometer data and (b) MSIS data.

REFERENCES

Bausch, W.C. and J.A. Delgado. 2003. Ground-based sensing of plant nitrogen status in irrigated corn to improve nitrogen management. pp. 145-157. *In* T. VanToai, D. Major, M. McDonald, J. Schepers, and L. Tarpley (ed.). Digital Imaging and Spectral Techniques: Applications to Precision Agriculture and Crop Physiology. ASA Spec. Publ. 66. ASA, CSSA, SSSA, Madison, WI.

Bausch, W.C. and K. Diker. 2001. Innovative remote sensing techniques to increase nitrogen use efficiency of corn. Commun. Soil Sci. Plant Anal. 32:1371-1390.

Bausch, W.C. and H.R. Duke. 1996. Remote sensing of plant nitrogen status in corn. Trans. ASAE 39:1869-1875.

Jackson, R.D., T.R. Clarke, and M.S. Moran. 1992. Bidirectional calibration results for 11 spectralon and 16 $BaSO_4$ reference reflectance panels. Remote Sens. Environ. 40:231-239.

Kim, Y., J.F. Reid, A. Hansen, and M. Dickson. 2000. Evaluation of a multi-spectral imaging system to detect nitrogen stress of corn crops. ASAE Paper no. 00-3128. Am. Soc. Agric. Eng., St. Joseph, MI.

Peterson, T.A., T.M. Blackmer, D.D. Francis, and J.S. Schepers. 1993. Using a chlorophyll meter to improve N management. NebGuide G93-1171-A. Cooperative Extension, Institute of Agriculture and Natural Resources, Univ. of Nebraska, Lincoln.

Ritchie, S.W., J.J. Hanaway, and G.O. Benson. 1986. How a corn plant grows. Iowa State Ext. Serv. Spec. Rep. 48. Iowa State Univ., Ames.

Schepers, J.S., D.D. Francis, and J.F. Power. 1995. Tissue analysis to improve nitrogen management practices. pp. 195-198. *In* Clean Water – Clean Environment – 21st Century, Conf. Proc. Vol. II: Nutrients. Am. Soc. Agric. Eng., St. Joseph.

Schleicher, T.D., W.C. Bausch, and J.A. Delgado. 2003. Low ground-cover filtering to improve reliability of the nitrogen reflectance index (NRI) for corn N status classification. Trans. ASAE 46: 1707-1711.