INCLUDING BIOMASS ESTIMATES IN THE ANALYSIS OF NDVI

Marisol Benitez Ramirez
Philip B. Allen
John B. Wilkerson
William E. Hart
University of Tennessee
Knoxville, TN

Abstract

Researchers have been using spectral sensing in croplands for over two decades. The last decade has seen a shift from satellite and aerial sensing platforms to near-canopy ground-based platforms. Close proximity to crop targets allows simultaneous collection of additional information that is not possible at greater distances. Spatial resolution is also greatly increased. Even at high spatial resolution, spectral information from row crop canopies is significantly confounded by crop biomass. A multi-year production-scale manipulative study conducted in Milan, TN included three cotton seeding rates and four rates of nitrogen side-dress. Seeding rates were included to investigate potential interference of plant spacing and biomass on the ability to detect nitrogen status with NDVI measurements. Reflectance values used to calculate NDVI were made with a commercially available active light sensor mounted on a ground-based platform. Plant height was measured simultaneously with NDVI using ultrasonic sensors. Plant height measurements were included as a covariate variable during ANOVA analysis of NDVI. A small plant-removal study enabled testing of data processing methods to remove soil background impacts on NDVI. Results of these analysis and the benefits of supplementing NDVI with biomass information will be discussed.

Introduction

Remote sensing has been widely studied in cotton crops to correlate vegetation indices with plant growth, nutrient status, and lint yield. Many studies conducted over the course of the last decade have demonstrated high correlation between spectral reflectance indices and cotton leaf-nitrogen concentration (Bronson et al., 2005; Zhao et al., 2005; Fridgen and Varco, 2004; Bronson et al., 2003; Li et al., 2001). Because of these studies, reflectance sensors have seen increased adoption as a non-destructive method of evaluating crop canopies.

Ground based sensors have become dominant in agricultural spectral reflectance sensing because they are less subject to atmospheric, weather, and data-processing delays experienced by users of aerial or satellite platforms. The field of view from ground-based platforms is also significantly smaller than the typical pixel resolution of remote imagery, including only a portion of single plants (up to a handful of plants) rather than integrating an area that is typically 3-5m^2. Even with the change in the sensed area, in row crops, it has been repeatedly demonstrated that spectral reflectance information is significantly confounded by crop biomass (Carlson and Ripley, 1997). However, ground-based platforms allow additional data to be collected in concert with spectral information that would not be possible from greater distances. For example, distance to the plant canopy, measured ultrasonically from the platform, can be converted to plant height.

Three companies (AgLeader, Trimble, and Topcon) currently sell vehicle mounted spectral reflectance sensors to aid in agricultural decisions. One primary goal of these commercially available systems is to apply variable-rate nutrients in real time. Each of these systems computes simple vegetation indices from the component wavebands and use a selected index as the input to a predefined prescription algorithm. The most common vegetation index is the Normalized Difference Vegetation Index (NDVI) which is expressed as:

$$NDVI = \frac{\lambda_{NIR} - \lambda_{red}}{\lambda_{NIR} + \lambda_{red}}$$

where λ_{NIR} is the reflectance in the near infrared (NIR) region (770 ± 15 nm) and λ_{red} is the reflectance in the red region (650 ± 10 nm) of the electromagnetic spectrum.

The field of view of the commercially available spectral reflectance sensor used in this study (GreenSeeker RT100, Trimble, Ukia, CA) was 61cm wide (across the crop row) and approximately 1cm deep (along the crop row) when positioned 80-100cm above the crop. The narrow field of view parallel to the crop row and access to raw information for the component wavebands enables additional processing of data from this sensor. The objective of the following paper is to investigate the impact of plant biomass on NDVI readings, demonstrate the benefit of biomass estimates as a covariate during statistical analysis, and introduce a data processing method for removing soil background impacts on NDVI.

Methods

Field Experiment

A multi-year production-scale manipulative study conducted at the University of Tennessee Research and Education Center at Milan, TN included three seeding rates (Figure 1) and four rates of nitrogen side-dress (Figure 2). Seeding rates and nitrogen rates were assigned in a factorial design to a grid of plots that were eight 40 inch cotton rows wide and 100 feet long. There were approximately 650 plots distributed across the 40 acre field.

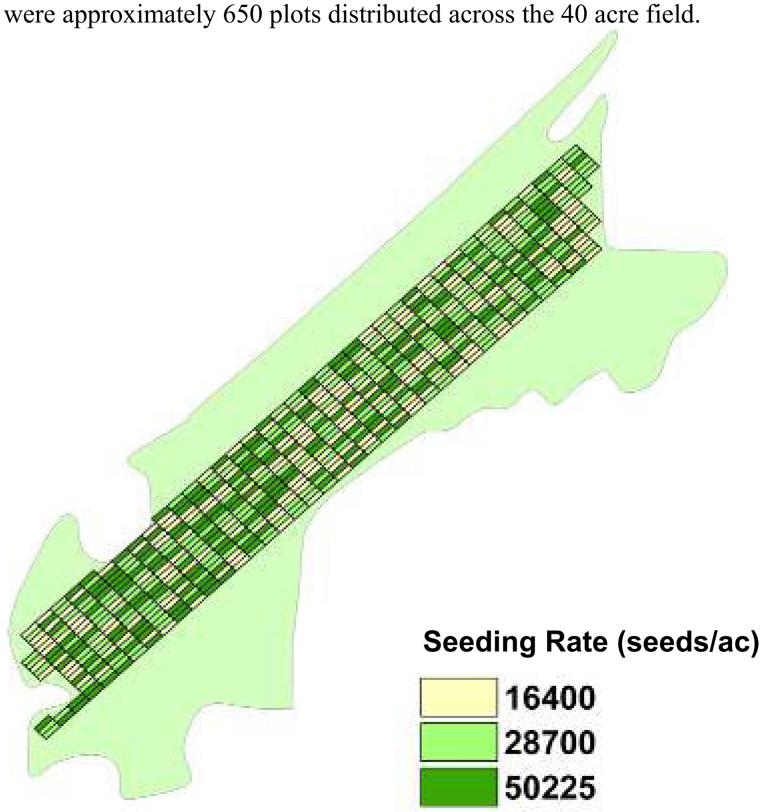

Figure 1. Three seeding rate treatments assigned to plots across the field.

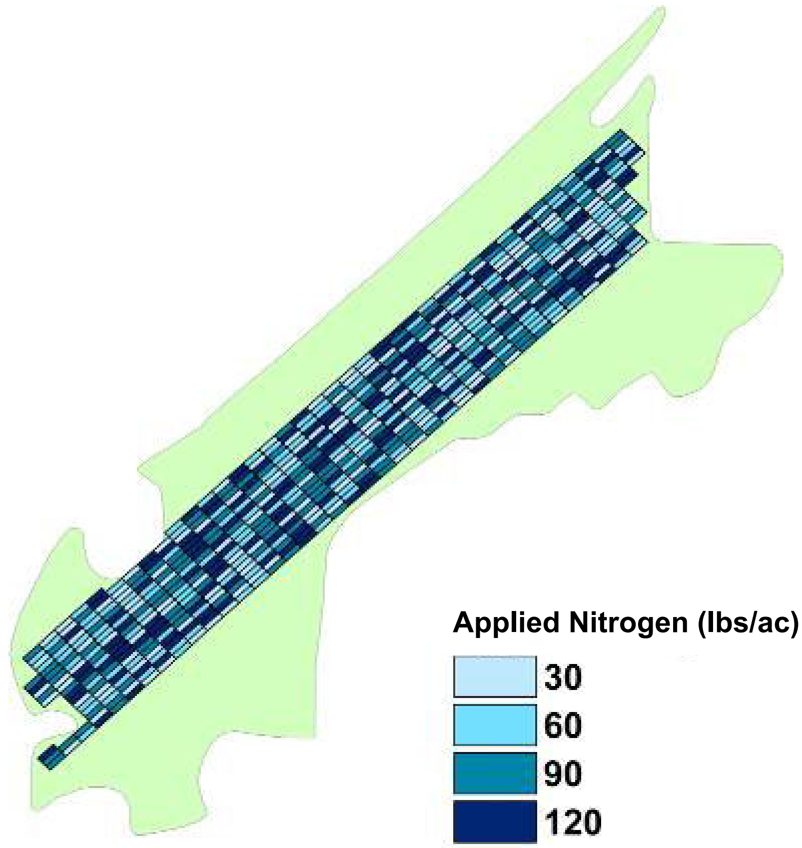

Figure 2. Four nitrogen rate (lbs/ac) treatments assigned to plots across the field.

These treatments were replicated across three cotton varieties, but cotton variety did not impact the results discussed in this paper and will not be discussed here. Plot populations were verified by manually counting a twenty foot length of the center two rows of 72 plots. The three plant populations were found to be significantly different from one another (Proc Mixed, SAS, Cary, NC) (Figure 3). Twelve leaf samples were taken from the center two rows of 72 plots before and after supplemental nitrogen application to verify the nitrogen treatments. Significantly different levels of leaf nitrogen were established using the treatments, but not all treatments differed from one another (Figure 4).

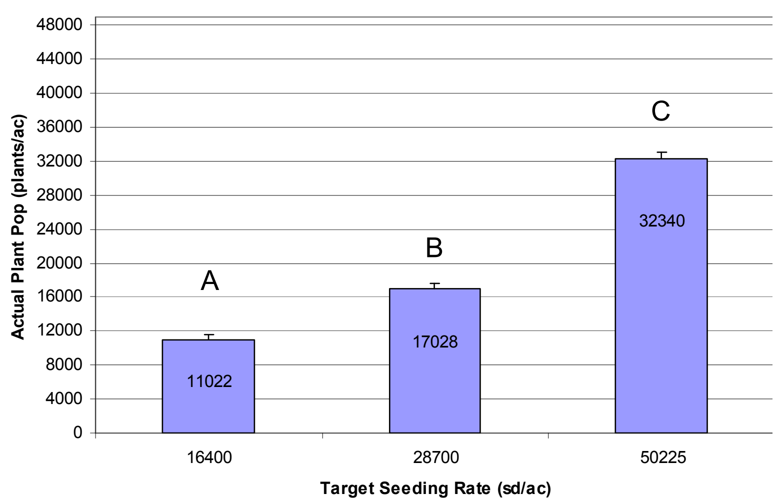

Figure 3. Plant counts verified three distinct plant populations. Different letters indicate statistical significance ($P<0.05$).

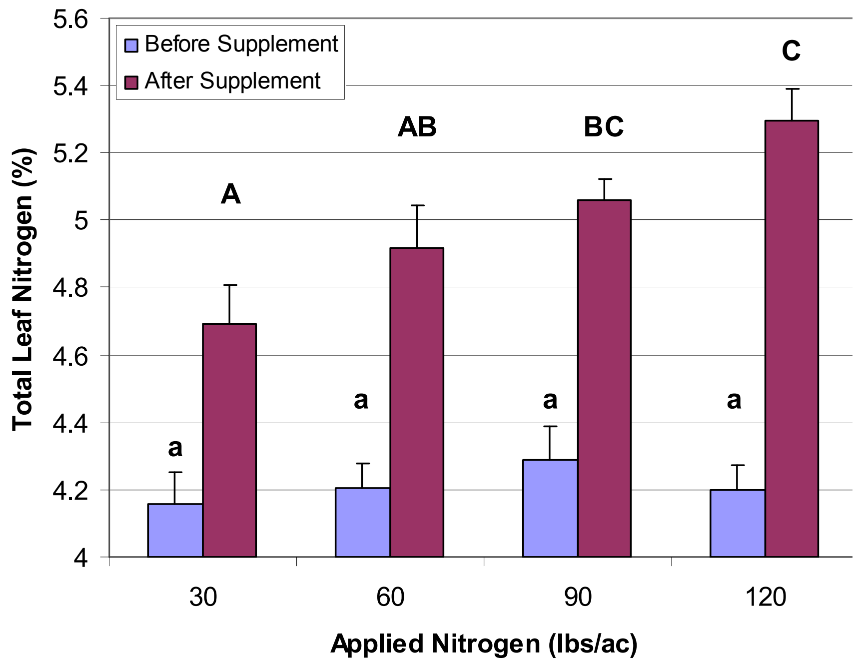

Figure 4. Leaf samples were analyzed for percent total leaf N. Significant differences existed after supplemental nitrogen application. Different letters indicate significant difference (P<0.05).

Data Collection Platform

A high clearance Spirit™ plot sprayer was modified to serve as a data collection platform (Figure 5). Two GreenSeekers were mounted on a four-bar-linkage boom that allowed for dynamic boom positioning. GreenSeeker sensors were maintained at a height of 36 inches above the crop canopy. Two custom ultrasonic plant height sensors were mounted on a fixed boom at the rear of the unit. Sensor data was logged along with GPS position on a single board computer using custom logging software (Figure 6).

Figure 5. GreenSeekers and ultrasonic sensors were mounted on a modified plot sprayer.

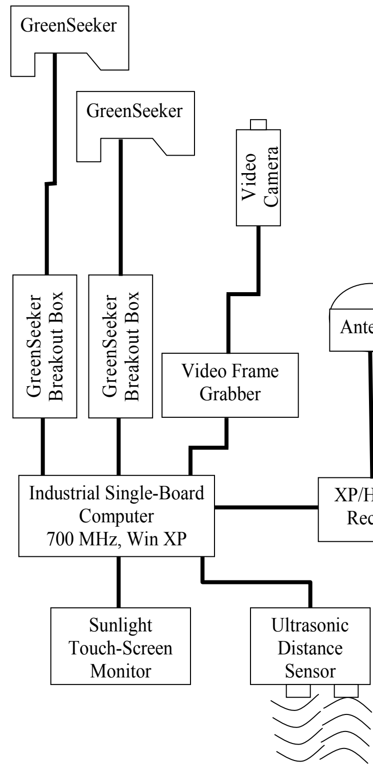

Figure 6. Sensor data and GPS position was logged on a single board computer.

Plant height was determined by subtracting the distance measured from the fixed boom to the crop canopy from the distance from the boom to the ground. Average manual plant height within a plot was recorded for 72 plots and was strongly correlated with the average ultrasonic plant height (Figure 7).

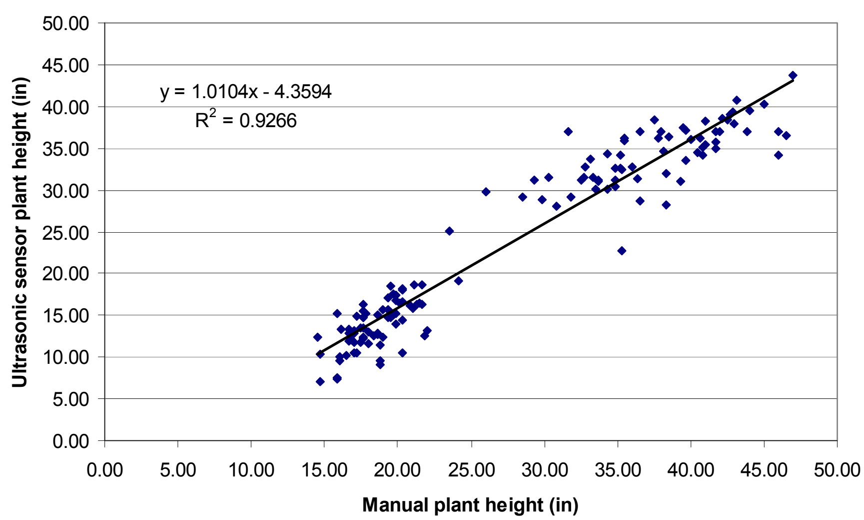

Figure 7. Ultrasonic plant height was strongly correlated with manual plant height

Full Experiment Data Collection and Processing

Sensor data was collected on nine dates over the course of the growing season beginning 40 days after planting (6/18/2008) and ending 88 days after planting (8/5/2008). GreenSeeker data, plant height data, and GPS position were recorded for the center two rows (rows four and five) of each plot at a rate of 10Hz and a ground speed of approximately five miles per hour. All data were spatially shifted using a custom tool in ArcMap (ESRI, Redlands, CA) to adjust for the distance between the GPS antenna and the sensors. Data that fell within ten feet of the plot edge was excluded. Sensor data was then averaged by plot using ArcMap.

Removal Study

In addition to data collection from the full experiment, plant canopies were manipulated in the border rows of twelve randomly selected plots. Ground speed of the sensing platform was maintained at approximately one mile per hour and sensor data was recorded at a rate of 10 Hz over the center four meters of rows two and three from a plot, producing a dataset with very high spatial resolution. The sensing platform was then backed up, every fourth plant was removed, sensor data was collected, and the process was repeated removing every third, and then every second plant (Figure 8). This resulted in four high resolution plot maps being created, within a short period of time, for each of the selected plots. Each subsequent pass saw a 25% reduction in plant canopy with no physiological change to the remaining plants. The objective of this study was to create a dataset with which data processing techniques for reducing soil background affects on spectral indices could be tested.

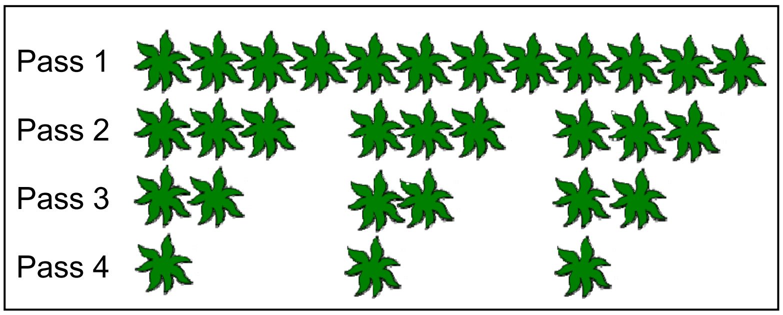

Figure 8. Illustration of plant canopy following subsequent plant removals

A large number of published algorithms that required only the red and near infrared wavebands were tested for their ability to reduce difference between passes. Four of the best known were the Red Ratio (RR), Normalized Red Ratio (NRR), Normalized Near infrared Ratio (NNR), and the Optimal Soil Adjusted Vegetation Index (OSAVI) that can be expressed as:

$$RR = \frac{\lambda_{red}}{\lambda_{NIR}} \qquad NRR = \frac{\lambda_{red}}{(\lambda_{NIR} + \lambda_{red})} \qquad NNR = \frac{\lambda_{NIR}}{(\lambda_{NIR} + \lambda_{red})} \qquad OSAVI = \frac{\lambda_{NIR} - \lambda_{red}}{\lambda_{NIR} + \lambda_{red} + 0.16}$$

Another method that involved shifting NDVI values using the standard deviation of the values from that plot was also tried. The shifted NDVI, or NDVI[1], was calculated as:

$$NDVI' = \overline{NDVI} + a * SD_{NDVI}$$

Where a is the number of standard deviations used in the analysis (a = 1 or 2). A final method used a subjective NDVI threshold to exclude values below 0.4. The threshold would have to change depending on the growth stage of the cotton. Maximum values were then selected from a ten point moving window to create a new dataset referred to as “Maximum Canopy Values”.

An avearge value for a pass was computed after each new index was calculated or processing method was applied. An ANOVA was then used to test for differences between passes of each index or processing method. The goal was to find an index or method that would result in no significant difference between passes.

Results and Disucssion

Full Manipulative Experiment

Ultrasonic plant height was well correlated with NDVI for seven of the nine dates (R>0.7, P<0.05). This supports prior findings that NDVI and plant height are closely linked, particularly early in the growing season when the canopy has not closed down the row. NDVI also significantly differed by seeding rate for the first seven of nine dates (Figure 9). Plant height had significant influence as a covariate for all observation dates (P<0.001). The incorporation of plant height as a covariate increased the ability to differentiate between nitrogen treatments and decreased the significance of the interaction between seeding rate and nitrogen rate (Table 1).

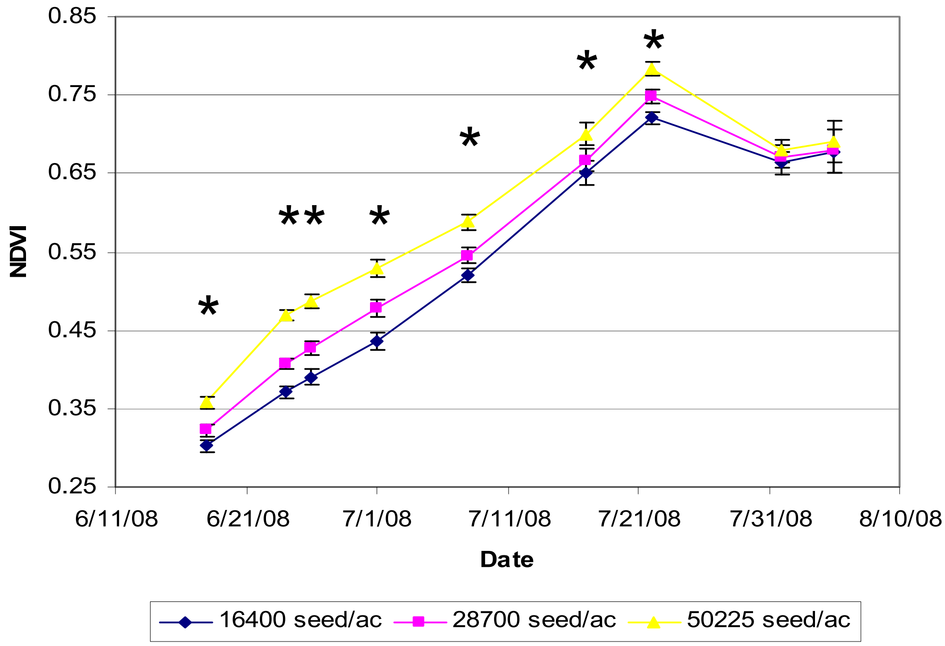

Figure 9. NDVI differed significantly by seeding rate for the first seven of nine dates. (* means significance P<0.05)

Table 1. Example ANOVA table shows reduction of N rate P value when height is included as a covariate

	NDVI	Height	NDVI + Height
Plant Pop	<0.0001	0.27	<0.0001
N rate	0.1609	0.57	0.08
Pop*N rate	0.7859	0.42	0.6673

Removal Study

As expected, average NDVI was significantly different by pass. Each pass was different from the other passes and tended to step down by approximately one NDVI unit (0.1) per 25% reduction in canopy (Figure 10). The other calculated indices also differed from pass to pass. Each pass was significantly different than the other passes for RR, NRR, NNR, and OSAVI. Shifting NDVI by the standard deviation scaled the values up, but did not reduce the difference between passes. Figure 11 shows an example data set created by the final technique that applied a subjective threshold and moving window to the data. This technique reduced the difference between passes significantly (Figure 12). Pass two was not different from pass three, but pass one differed from two/three and four. However, the difference in NDVI values as the canopy changed was reduced.

The newly created NDVI dataset (Maximum Canopy Values) not only had less difference between passes, the average value for pass one increased from approximately 0.59 to 0.71. The next steps in this analysis should include a correlation between this new filtered index and leaf nitrogen, and more importantly, cotton yield to see if it is truly a better plant estimate of status than traditional NDVI.

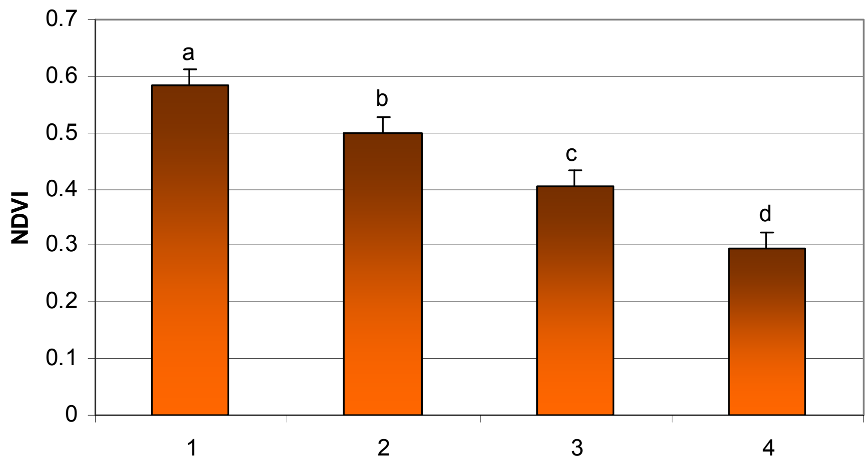

Figure 10. Average NDVI by pass as plant canopy was reduced.

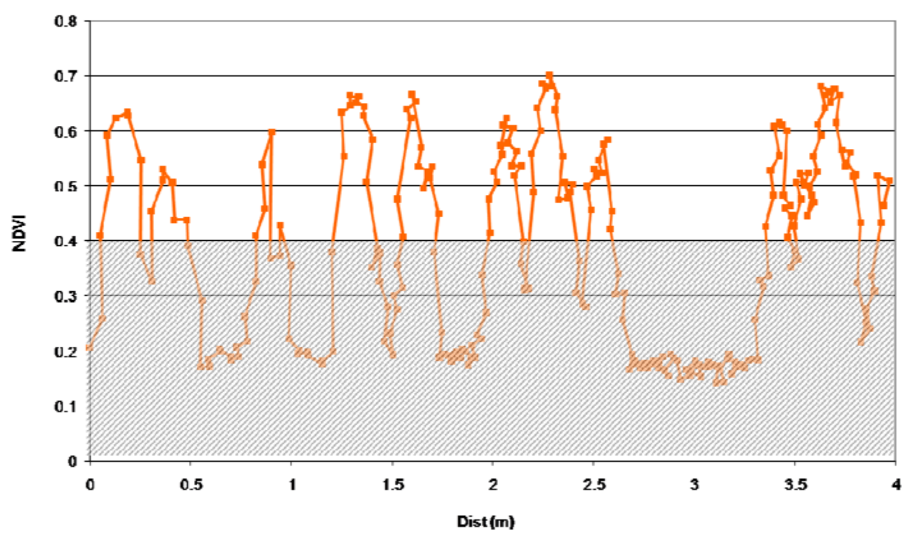

Figure 11. Example of dataset created during threshold/max window processing method (pass 2).

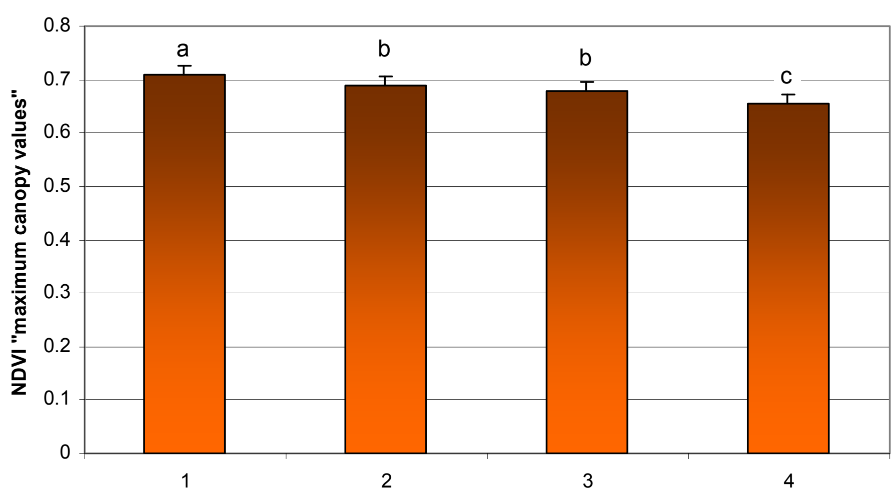

Figure 12. NDVI by pass following data processing.

Summary

Ground-based spectral sensing has gained momentum as a non-destructive method of evaluating crop canopies. Because of these sensors proximity to the crop, there is opportunity to collect additional information that can aid in analysis of NDVI. Prior research demonstrated that NDVI is strongly coupled to plant biomass, particularly early in the season. NDVI significantly differed by seeding rate treatment in this study. Plant height was successfully estimated on-the-go using an ultrasonic sensor, and that information was of significant importance during NDVI analysis. Incorporating plant height reduced P-values for differentiating between nitrogen treatments with NDVI and decreased the significance of the seeding rate*nitrogen rate interaction.

A removal study enabled the testing of several data processing methods for removing soil background influence on spectral indices. NDVI was significantly impacted by plant removal during each pass. The calculation of other indices did not improve this difference. Shifting indices using standard deviations shifted the data, but did not reduce difference by pass. A data filtering technique that incorporated subjective thresholding with a selection window was able to reduce differences between passes. The next steps are to test datasets created with this technique for their ability to predict leaf nitrogen content or cotton yield.

References

Bronson, K.F., T.T. Chua, J.D. Booker, J.W. Keeling, and R.J. Lascano. 2003. In-Season Nitrogen Status Sensing in Irrigated Cotton: II. Leaf Nitrogen and Biomass. Soil Sci. Soc. Am. J. 67:1439-1448.

Bronson, K.F., J.D. Booker, J.W. Keeling, R.K. Boman, T.A. Wheeler, R.J. Lascano, and R.L. Nichols. 2005. Cotton Canopy Reflectance at Landscape Scale as Affected by Nitrogen Fertilization. Agronomy Journal 97:654-660.

Carlson, T.N., and D.A. Ripley. 1997. On the Relation between NDVI, Fractional Vegetation Cover, and Leaf Area Index. Remote Sensing of Environment 62:241-252.

Fridgen, J.L., and J.J. Varco. 2004. Dependency of Cotton Leaf Nitrogen, Chlorophyll, and Reflectance on Nitrogen and Potassium Availability. Agronomy Journal 96:63-69.

Li, H., R.J. Lascano, E.M. Barnes, J. Booker, L.T. Wilson, K.F. Bronson, and E. Segarra. 2001. Multispectral Reflectance of Cotton Related to Plant Growth, Soil Water and Texture, and Site Elevation. Agronomy Journal 93:1327-1337.

Zhao, D., K.R. Reddy, V.G. Kakani, J.J. Read, and S. Koti. 2005. Selection of Optimum Reflectance Ratios for Estimating Leaf Nitrogen and Chlorophyll Concentrations of Field-Grown Cotton. Agronomy Journal 97:89-98.