NDVI response of cotton to nitrogen application rates in Georgia, USA

G. Vellidis[1], H. Savelle[1], R. G. Ritchie[2], G. Harris[2], R. Hill[1] and H. Henry[1]
[1]*Biological & Agricultural Engineering Department, University of Georgia, USA*
[2]*Crop & Soil Science Department, University of Georgia, USA*
yiorgos@uga.edu

Abstract

A project to quantify response of NDVI and other vegetation indices (VI) of cotton to different nitrogen application rates in Georgia, USA was conducted during 2010. The project consisted of a replicated experiment which compared seven treatments of nitrogen. The treatments (45 replicates) consisted of 4-row strips 30 to 60 m long in a 2.5 ha field. Treatments comprised a combination of two side-dress N applications. Total side-dress rates ranged from 0 to 100 kg N/ha. Total N rates (pre-plant + side-dress) ranged from 25 to 125 kg/ha. All other inputs (herbicides, plant growth regulators, etc.) were applied at constant rates. A GreenSeeker RT200 was used to monitor crop reflectance in the field at weekly intervals beginning in mid-June. The red and NIR reflectance response of each sensor was recorded individually and used to calculate 6 different vegetation indices (VIs) including NDVI. The paper presents the results from this project including NDVI and yield response to the N treatments. Early in the growing season, NDVI generally responded to N application rates over time. In late July however, NDVI values of all treatments receiving side-dress N peaked and converged. Yield increased consistently with the total side-dress N. Results from this project will be used to develop a variable rate N algorithm specific to Georgia conditions.

Keywords: variable rate application, vegetation index, GreenSeeker.

Introduction

In the United States, cotton is grown in 17 states and is a major crop in 14 of those states. The Cotton Belt spans the southern half of the United States, stretching from Virginia to California. Over the last three years, the area planted to cotton ranged from 5.1 to 6.3 Mha. Cotton is an intensively managed crop which requires careful nitrogen applications to prevent rank growth, plant growth regulators (PGRs) to maintain a balance between vegetative and reproductive growth, and defoliants at the end of the season to allow for mechanized harvesting. Additional inputs are needed for pest management.

Recent research (Vellidis *et al.*, 2009; 2010) has documented the uneven distribution of plant biomass in cotton fields. This uneven distribution is a result of variability in soil parameters such as nutrients, moisture, pH, texture and variability in microclimate and disease and pest pressures. Yet most American cotton producers still apply agrochemicals at uniform rates across the entire field. Common sense as well as recent research suggests that variable rate application (VRA) of nitrogen, PGRs, and defoliants compensates for the uneven distribution of plant biomass and is a good management practice.

Vellidis, G., H. Savelle, R. G. Ritchie, G. Harris, R. Hill, and H. Henry. 2011. NDVI response of cotton to nitrogen application rates in Georgia, USA. In: J.V. Stafford (Ed.), Precision Agriculture 2011 – Proceedings of the 8th European Conference on Precision Agriculture (8ECPA), Prague, Czech Republic, pp. 358-368.

Vellidis *et al.* (2009; 2010) demonstrated that applying higher rates of PGR or defoliant to sections of the field with high biomass and lower rates to sections with low biomass will result in more uniform plant growth or defoliation. In contrast, constant rate applications frequently result in over-application or under-application and subsequently uneven growth or defoliation. Uniform growth and defoliation results in higher harvesting efficiency, higher fiber quality, and an earlier harvest with an increased recoverable yield. Uneven growth or defoliation sometimes induces cotton producers to apply additional agrochemicals.

VRA techniques for cotton

VRA on cotton can be implemented using various techniques. The use in this study entails using vehicle-based sensors to create vegetation index (VI) maps as surrogates for plant biomass, delineating the map into management zones with similar biomass, ground-truthing the maps, creating appropriate agrochemical prescriptions for the zones, and then using a variable rate controller to apply the prescriptions. VI maps are typically created from multi-spectral images captured by cameras on airborne or satellite platforms or by vehicle-based sensors.

VIs are mathematical ratios of light reflectance at specific wavelengths. Although dozens of vegetation indices have been developed, the one most commonly used for quantifying biomass is the Normalized Difference Vegetation Index (NDVI). NDVI is calculated as shown below. In the equation, NIR and RED are reflectance in the near infrared and in the red range, respectively.

$$NDVI = \frac{NIR_{reflectance} - Red_{reflectance}}{NIR_{reflectance} + Red_{reflectance}} \quad (1)$$

Several studies have shown very good correlations between NDVI and plant biomass and practitioners frequently refer to NDVI as an index which measures biomass (Plant *et al.*, 2000; Reddy *et al.*, 2003; Zarco-Tejada *et al.*, 2005; Vellidis *et al.*, 2009; Porter *et al.*, 2010).

VRA of nitrogen on cotton

As with PGRs and defoliants, most farmers currently apply uniform rates of nitrogen (N) fertilizer. In Georgia, USA, typically, about 20-25% of the N is applied at planting with the remaining 75-80% of the N applied 7-10 weeks later as a liquid or granular side-dress treatment. Physiologically, side-dress N is applied from first square (flower bud) to early flower – a window of about 21 days. During 2008 alone, approximately 450,000 t N was applied to cotton in the USA.

Cotton can benefit from VRA of N for the reasons discussed above. However, the timing and rate of side-dress N is far more critical for achieving yield potential. Because yield potential is driven by soil texture, water availability, nutrient availability and many other parameters inherent to the field, VRA of N holds great promise for fields with high soil variability.

In the past five years, several research teams in the USA have experimented with using vehicle-mountd optical sensors to schedule VRA of side-dress N on cotton. Khalilian *et al.* (2008) and Porter *et al.* (2010) reported that VRA application of N in South Carolina, USA resulted in a 30% reduction in N usage with no reduction in yield. Similar results were reported in experiments conducted in Oklahama, USA (Sharma *et al.*, 2008). Because even a 10% reduction in N usage will save USA cotton producers over USD 15 million, several researchers across the cotton producing region of the USA are developing algorithms for cotton nitrogen fertilization based on optical sensors (Arnal *et al.*, 2008; Khalilian *et al.*, 2008; Scharf *et al.*, 2009). These algorithms calculate N requirements based on an in-season estimate of the potential or predicted yield estimated from VI response, determine the likely yield response to additional nitrogen fertilizer and, finally, calculate N required for obtaining that additional yield (Raun *et al.*, 2005). These algorithms tend to be region and variety specific.

Because of the potential increase in production efficiency, cotton producers in Georgia, USA, are very interested in VRA of N. During 2009, a 3-year study was initiated to determine the feasibility of using optical sensors to schedule VRA of N on cotton under Georgia conditions. This paper reports on experiments conducted during 2010 to measure the vegetation index response of newly released cotton varieties to different N application rates.

Materials and methods

The experiment was established in the 2.5 ha NESPAL field located on the University of Georgia's campus in Tifton, Georgia, USA (31°28'14"N, 83°30'53"W). The field was planted to Roundup-Ready® DP0935 B2RF cotton on 19 May 2010 using a 0.91 m row spacing. DP0935 is a recently released cotton variety that has generated interest from many cotton producers. Twenty kg/ha N in the form of granular fertilizer were applied to the field prior to planting. The field was divided into 45 4-row plots with plots ranging in length from 45 m to 90 m. Plot length was a function of soil texture differences as well as the pressence of grassed berms (terraces) used for past water quality studies. Treatments consisted of a combination of two liquid N side-dress applications (Figure 1). The first N side-dress applications of 0, 20, or 40 kg N/ha were applied 24 June 2010. The second N side-dress applications of 0, 20, 40, or 60 kg N/ha were applied 7 July 2010. Total liquid N side-dress rates ranged from 0 to 100 kg N/ha. Total N applied (pre-plant plus side-dress) ranged from 20 to 120 kg/ha. All other agrochemicals (PGR, herbicides, insecticides, defoliant) were applied at uniform rates. Irrigation was also applied uniformly from a center pivot irrigatin system as needed.

Data collection

Reflectance data were collected from mid-June to the end of August at weekly intervals using the the GreenSeeker RT200 on-the-go variable rate application and mapping system (Ntech, Ukiah, CA, USA) installed on a John Deere 6700 high clearance sprayer.

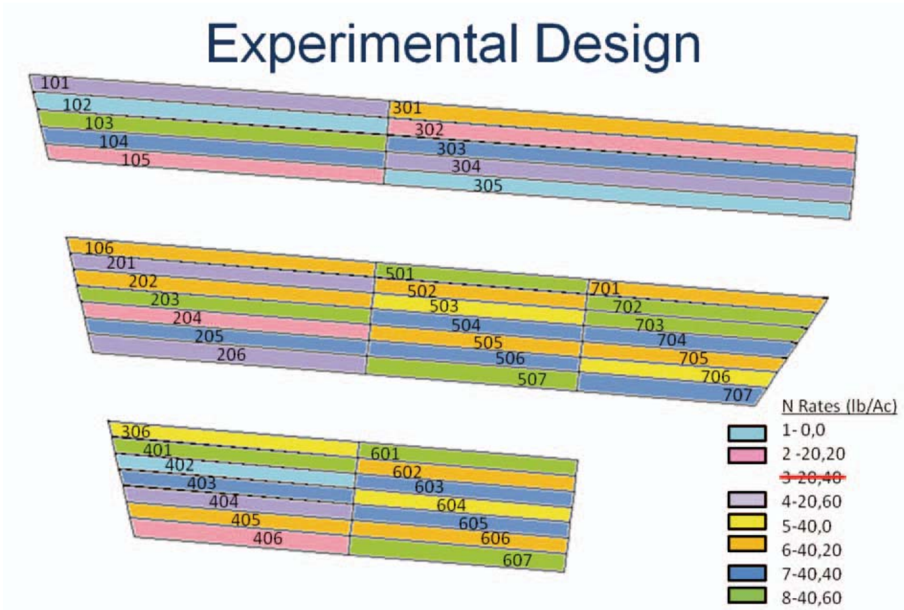


Figure 1. The experimental design as established at the 2.5 ha NESPAL field contained 7 treatments within 45 plots. The number of replicates per treament differed and ranged from 4 to 8. Plot lengths were determined by soil texture changes.

The system consists of 6 GreenSeeker sensors, ruggedized PDA interface with color display, and desktop and PDA software. The sensors were mounted on the spray boom (Figure 2). The RT200 allows for reflectance data (red and NIR wavelengths) to be stored individually. In this study, only the data from sensors measuring reflectance from the inner 2 rows of cotton from each plot were used. The individual sensor responses were averaged to produce average red and NIR reflectance for the 2 rows. Reflectance data were used to calculate NDVI and several other VIs however, only NDVI response will be discussed in this paper. The GreenSeeker system was linked to a DGPS receiver and all data were georeferenced in real time.

Figure 2. Two of the 6 GreenSeeker® sensors mounted on the spray boom of the JD 6700 high clearance sprayer used in the study.

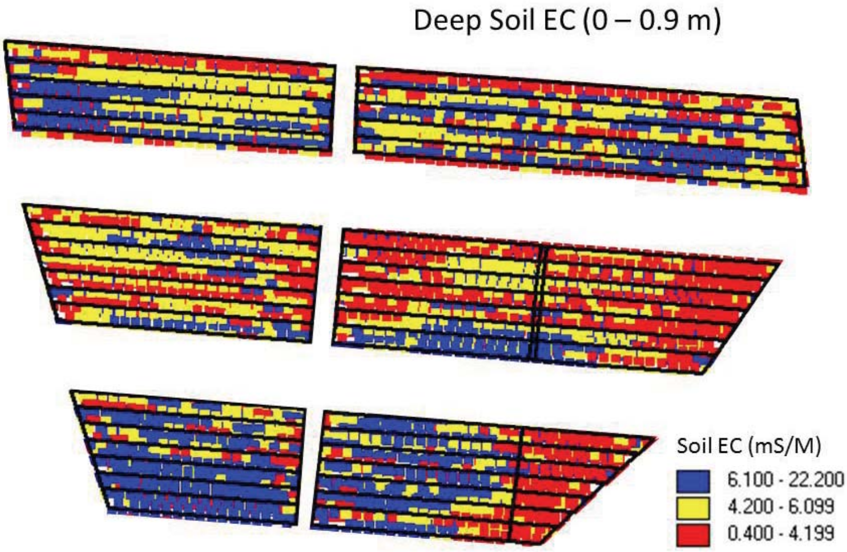


Figure 3. Soil electrical conductivity map of the NESPAL field.

Leaf samples for N tissue analysis were collected three times from a fixed sampling area within each plot. The centroid of the sampling area was randomly selected within the 2 sensed rows (but away from the beginning and end of the plot). The sampling area was 2 rows wide (1.82 m) × 7.3 m wide. The plots were harvested and bagged on 15 October 2010 with a 2-row bagging picker. Because of the varying length of the plots, yield is reported in terms of kg of cotton lint/ha.

Prior to planting, soil electrical conductivity (soil EC) was measured
with a Veris 3100. The Veris 3100 reports integrated values of the soil EC in the soil profile between 0-0.3 m (shallow) and 0-0.9 m (deep) in terms of mS/m. Soil EC values are commonly used as a surrogate for soil texture and have been adopted by researchers and producers as a means of delineating soil management zones in fields. Lower soil EC values (0 - 10 mS/M) tend to indicate sandy soils while higher values tend to indicate soils with finer soil particles. Most fields in the coastal plain physiographic province of Georgia have sandy soils with soil EC values below 15 mS/m. All georeferenced data were stored and maninupalted using Desktop Mapper (FarmWorks Software, Hamilton, IN, USA).

Results

Soil EC maps of the field showed high variability for both the shallow and deep soil profiles (Figure 3). Soil cores taken in 5 locations in the field indicated that the topsoil ranged from 0.2 - 0.25 m in depth and consisted of 77 - 83% sand. Deeper soil horizons ranged from 59 - 76%

sand. In the NESPAL field, soil EC is also a function of soil moisture at depth as shallow water tables in the southern section of the field tend to increase the value of soil EC.

NDVI

Reflectance data were collected at weekly invervals except when weather conditions interfered (rain or high wind). In those instances, data were collected on the next possible day. These data were used to create NDVI maps of the field (Figure 4). The data was ground-truthed by walking through the plots and visually assessing whether the patterns displayed in the maps were visible in the field. The effect of the inherent variabiliy of the field was most pronounced in the NDVI maps prior to the first side-dress application on 23 June 2010. However, even after the application of side-dress N, the inherent soil variability affected the growth of cotton with plant size and vigor visibly different although dampened along the length of individual plots. This variability can be seen in the NDVI maps throughout the growing season even though the variability was dampened by the N treatments (Figure 5).

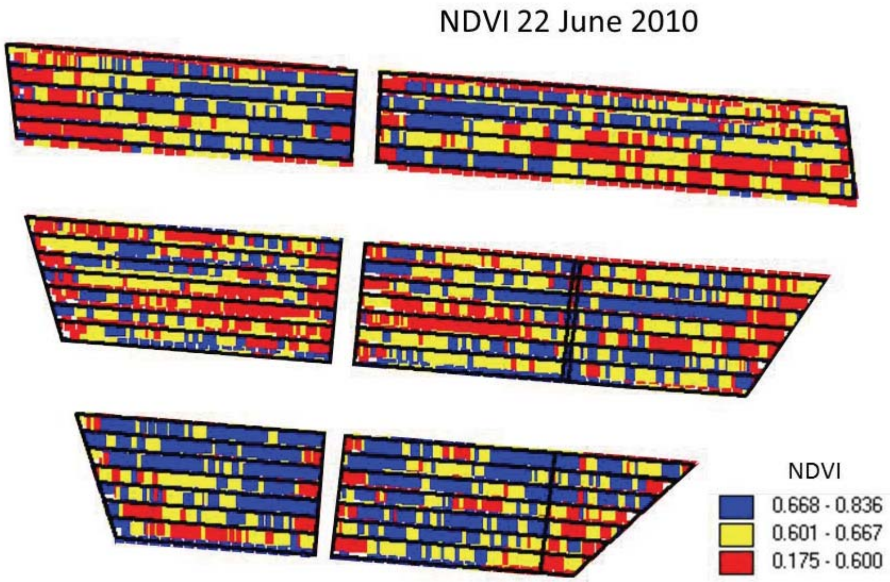


Figure 4. NDVI map created from reflectance data collected on 22 June 2010. Data are grouped into 3 equal-numbered ranges.

Figures 4 and 5 clearly indicates that the DP0935 B2RF cotton variety under Georgia growing conditions exhibits enough NDVI variability and range of variability between first square and first flower to allow for the use of NDVI as a means of driving VRA of side-dress N. The issue then becomes, how to develop algorithms which allow the producer to variably apply the N rates which will achieve the yield potential of the field. From the reflectance data, an average NDVI value was calculated for the entire length of the plot. A second NDVI value was extracted for leaf tissue analysis sample area. Treatment averages were created by averaging the plot values.

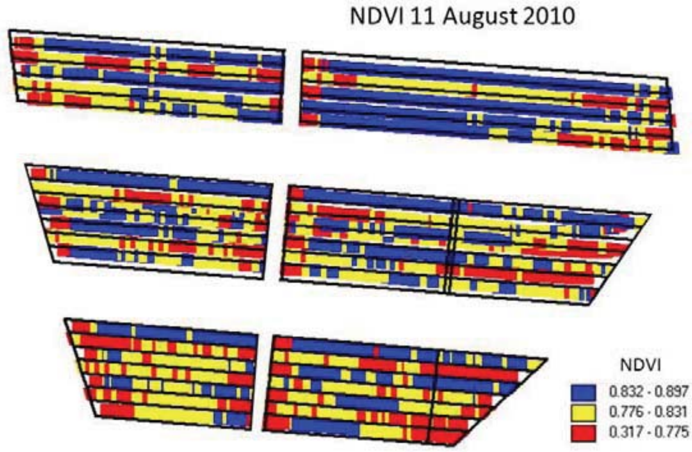


Figure 5. NDVI map created from reflectance data collected on 11 August 2010. Data are grouped into 3 equal-numbered ranges.

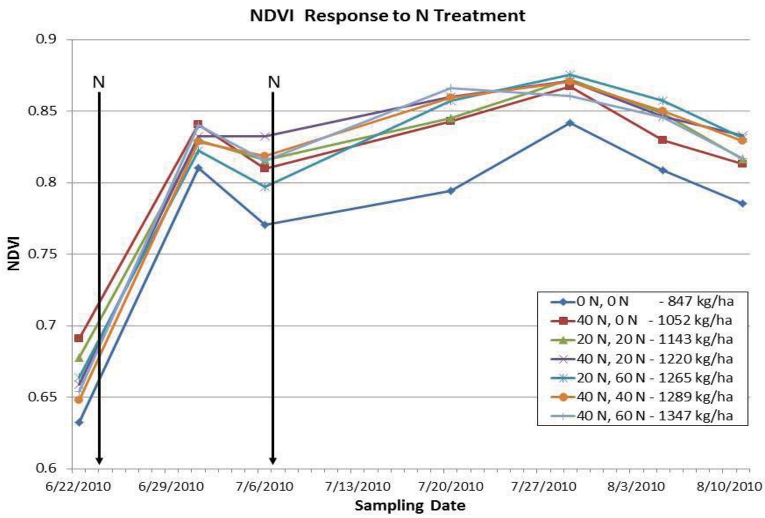


Figure 6. NDVI response to the seven N application rates. NDVI data for each date are an average of all plot area included in the treatment. The arrows indicate N side-dress applications. Also reported in the legend is the cotton lint yield for each treatment.

<u>Response of NDVI to N applications</u>

In general, NDVI responded to N application rates over time. In other words, the higher the N rate received by the treatment, the higher the treatment's average NDVI with time until mid-July (Figure 6). The treatment receiving no side-dress N resulted in the lowest NDVI values throughout the growing season. Because of the relatively large differences between replicates of the same treatment, the differences between NDVI of treatments receiving side-dress N were not statistically significant for individual sampling dates.

In late July, NDVI values of all treatments receiving side-dress N peaked and converged. This coincides with the closing of the canopy throughout the field so the optical field of the sensor was filled with green leaves. This date also coincided approximately with the time during which cotton stops flowering and, as is commonly referred to, as cut-out. Cut-out is an important physiological period in the cotton plant's life. Thereafter, NDVI began a gradual decline for all treatments. The decline corresponds to the plant transitioning from producing biomass and flowers to maturing of the fruit.

Leaf N

Leaf N tissue analyses corresponded directly to the timing and rates of N applied to the crop (Figure 7). Samples for the first and second leaf tissue analyses were collected just prior to the two side-dress applications of N. The third group of samples was collected about two weeks after the second side-dress application. There were only slight numerical differences between the average leaf N content of the treatments. In contrast, there were statistically significant differences between treatments for each of the subsequent samplings. Results from the 20 July sampling event show leaf N content increased with N application rates. Furthermore, for treatments which received the same overall rate, those with split applications contained higher leaf N at cut-out. In general, the treatments with the highest leaf tissue N content had the highest NDVI values (Figures 6 and 7).

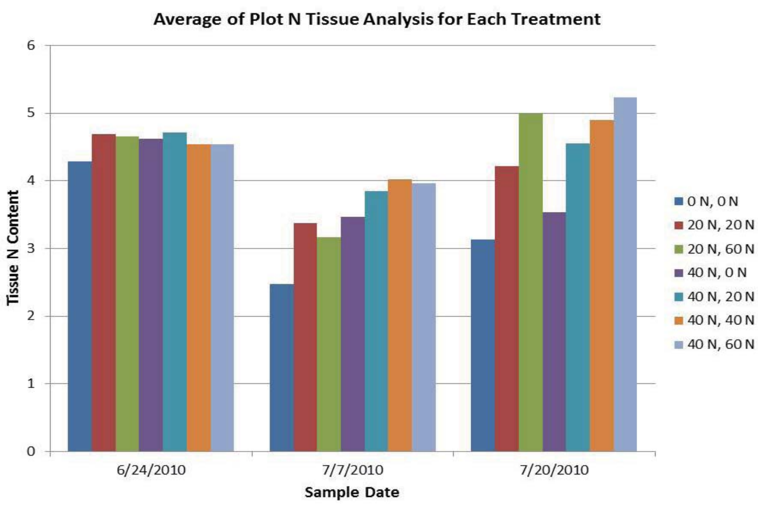
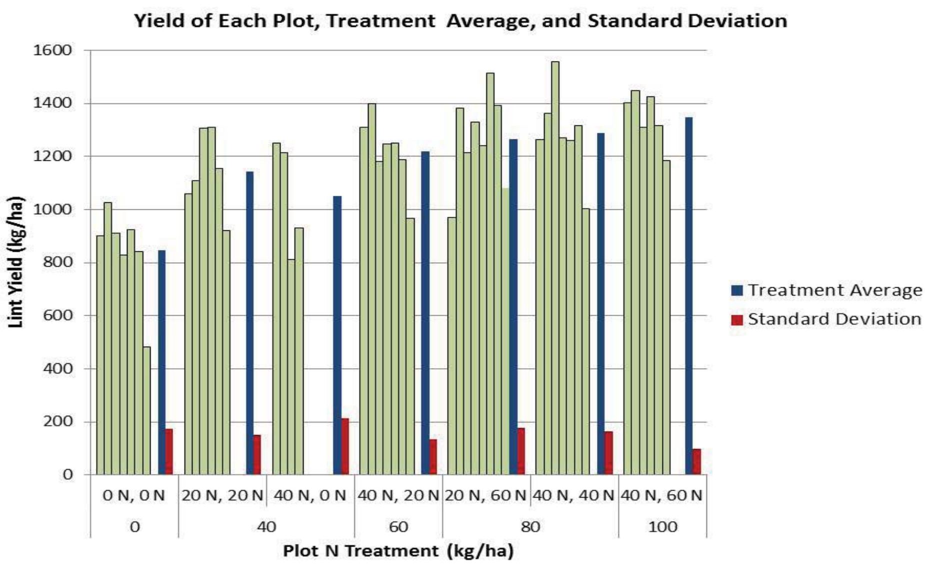


Figure 7. Leaf N content reported as % for the three sampling dates. Each bar represents the average leaf N content for that treatment calcuated from the samples collected in each of the treatment's plots.

Yields
Yield increased consistently with the total side-dress N applied to the treatment. Figure 8 presents the yield of each plot within a treatment as well as the average yield and standard deviation of the treatment. As with leaf N, yields were higher for treatments in which side-dress N was distributed evenly. For example, two treatments received total side-dress rates of 40 kg N/ha. However, the treatment receiving two 20 kg N/ha applications significantly outperformed the treatment receiving 40 kg N/ha on 24 June and 0 kg N/ha on 07 July. The same is true for the two treatments receiving a total of 80 kg N/ha. Standard deviation tended to decrease with increasing N rates. The rate of yield increase decreased at the higher application rates.

Discussion

The in-field varibility of NDVI maps created between first square and early flower (mid-June to early July) exhibit enough variability to indicate that NDVI and perhaps other VIs can be used to schedule side-dress N applications. Because leaf N concentrations prior to the first side-dress N application (24 June) were fairly uniform, the variability in the NDVI maps was not a function of N deficiency. Rather, the variability was caused by other field variables which controlled plant growth. This makes creating the prescription for side-dress N more difficult to develop because the prescripton must take into account the variable yield potential within the field.



Future work

The data collected from this study will be used to develop algorithms for calculating N side-dress requirements. The algorithms will be based on an in-season estimate of the potential or predicted yield estimated from VI response, determine the likely yield response to additional nitrogen fertilizer and, finally, calculate N required for obtaining that additional yield. The algorithm must take into account the factors limiting growth and soil EC may be a parameter which can be used to project yield potential of management zones within the field.

Conclusions

Vegetation indices hold great potential as tools which can be used to predict side-dress N requirements for agronomic crops. There is great interest in Georgia for such tools because of producers' desire to improve their efficiency. The study reported here demonstrated that NDVI can be used to capture the variability of new cotton varieties early in the growing season. NDVI can potentially be used to develop side-dress N applications.

Acknowledgements

Funding for this project was provided by the Georgia Cotton Commission, Cotton Inc., and by Hatch and State funds allocated to the Georgia Agricultural Experiment Stations.

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