SENSOR BASED PREDICTION OF COTTON GROWTH, LEAF NITROGEN, AND BIOMASS NITROGEN

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Abstract

Ground-based sensors utilizing the Green Normalized Difference Vegetation Index (GNDVI) have the potential to direct variable cotton N applications. However, there is a need for a more precise definition of the relationship between GNDVI, cotton leaf reflectance, and cotton plant height. The objective of this study was to examine the effectiveness of a ground-based sensor to predict cotton growth and leaf N. Field trials were conducted in 2008 and 2009 at the Plant Science Research Farm in Mississippi State, Mississippi. Fertilizer N rates of 0, 40, 80, and 120 lb N/acre were applied to establish wide growth differences. The Yara N Sensor was utilized to collect canopy reflectance across wavelengths at several physiological stages. Also, plant height and leaf N were determined at these stages. Although unfavorable growing conditions led to poor relationships at a few sampling dates in 2009, general trends of increasing relationships between GNDVI and leaf N and GNDVI and plant height occurred in both years. The strength of these relationships increased throughout the growing season to peak flower. A combination of leaf N and GNDVI data from both years indicated the consistency of readings across growing seasons. Although strong relationships occurred at a date past which a fertilizer N application would impact yield, late season readings may have the potential to direct sampling or N applications in the following growing season.

Introduction

Variable rate N applications have the potential to increase N use efficiency ratios and decrease detrimental environmental impacts caused by over-application. Available soil N is spatially and temporally variable and must be measured annually to accurately direct N to deficient areas and utilize residual N. Leaf reflectance has been proven as a tool to indicate N levels in cotton when N is the limiting growth factor (Fridgen and Varco, 2004). Also, N content of cotton leaves is highly correlated to the 550 nm wavelength (Buscaglia and Varco, 2002). These tools have the potential to be used to monitor real-time N concentrations in cotton and serve as the basis of N fertilizer management (Zhao et al., 2005). However, more information is needed on the relationship between cotton leaf N content, plant height, and Green Normalized Difference Vegetation Index (GNDVI). The objective of this study was to examine the effectiveness of a ground-based sensor to predict cotton growth and leaf N.

Materials and Methods

Data was collected in 2008 and 2009. The trial was conducted at the Mississippi Agricultural and Forestry Experiment Station, in Starkville, Mississippi both years. Each of 16 plots was composed of 12 rows by 125 ft with treatments arranged in a randomized complete block design. Delta and Pine Land BG/RR 445 cotton was planted at a row spacing of 38 in and 4.3 seed/ft. Treatments consisted of a split (50% at planting / 50% at early square) application of UAN 32% N solution to total 0, 40, 80, and 120 lb N/acre applied during the growing season.

Reflectance values were acquired on clear sunny days between 11 a.m. and 12 p.m. using the Yara N Sensor (tec5Hellma, Inc. Plainview, NY) tractor mounted 76 in above the ground. The Yara N Sensor is a passive spectrometer which has four fiber optic inputs feeding to one central spectrometer and an irradiance sensor. Two fiber optic inputs are located on each end of the sensor unit and each senses the crop between 58º and 70º at an off-nadir view. The tractor was driven at 3.5 mph above rows 6 and 7 allowing the Yara N Sensor to sense rows 2, 3, 4, 9, 10, and 11. Wavelengths recorded were 450, 500, 550, 570, 600, 620, 640, 650, 660, 670, 680, 700, 710, 720, 740, 760, 780, 800, 840, and 850 nm. The bandwidth was + or – 5nm. GNDVI was calculated by the following equation:

$$GNDVI = (R_{840} - R_{550}) / (R_{840} + R_{550})$$

GPS location for each value was acquired by a Trimble Pro XR Receiver (Sunnydale, CA). Five plant measurements were taken from each of four marked sub-locations corresponding to sensed rows in each plot. Leaf samples were obtained on the same dates as canopy reflectance data collection. Five recently matured leaves were obtained 5 to 6 nodes from the terminal on the main stem at each of the four marked sub-locations in each plot. Leaves were oven dried at 65°C and ground through a 20 mesh sieve in a Wiley Mill. Leaf N concentration was determined on 4 to 6 mg of ground leaf samples by a Carlo Erba N/C 1500 dry combustion analyzer (Carlo Erba, Milan, Italy).

One meter plant samples excluding the root system were taken from each of the four marked sub-locations in each plot. The seed cotton was removed from all bolls larger than a dime. Next the plant samples were dried and ground to pass a 40 mesh sieve. Plant N concentration was determined on 4 to 6 mg of ground plant. Cotton in sensed rows was picked using an automated spindle picker. Yield was calculated on a per plot basis.

Table 1: 2008-2009 Cultural and sensing/sampling dates

Cultural Dates	**2008**	**2009**
Planting	7-May	20-May
First N Application	21-May	2-Jun
Second N Application	9-Jun	26-Jun
Harvest	16-Oct	6-Nov
Sensing/Sampling Dates	**2008**	**2009**
Pre-Square	6-Jun	-
Early Square	11-Jun	25-Jun
Week 2 Square	19-Jun	1-Jul
Week 3 Square	25-Jun	8-Jul
Week 4 Square	2-Jul	-
Early Flower	9-Jul	15-Jul
2^{nd} Week of Flowering	-	24-Jul
Peak Flower	30-Jul	6-Aug
Whole plant harvest	11-Sep	1-Oct
Seed cotton harvest	22-Oct	6-Nov

Results and Discussion

Rainfall

Rainfall in 2008 (Fig. 1) was evenly distributed and probably contributed to the significant relationships found at almost every sensing date. Most importantly, there were significant rainfall events (over a half of an inch) after both N applications, which moved the N down into the root zone where it could be accessed by the plant. Rainfall in 2009 (Fig. 2), however, was not as well distributed as in 2008. Several significant rainfall events did occur after the first N application, which may help explain a very significant relationship between leaf N and GNDVI at 2009 early square. However, after the second N application, a significant rainfall event did not occur for three weeks. Sensing data from the second week of squaring, third week of squaring and early flower failed to show strong relationships between GNDVI and leaf N. This was most likely due to a failure of N to move down into the root zone. After early flower in 2009 significant rainfall events allowed the N to enter the root zone, resulting in strong relationships by second week of flowering that continued through to peak flower in 2009.

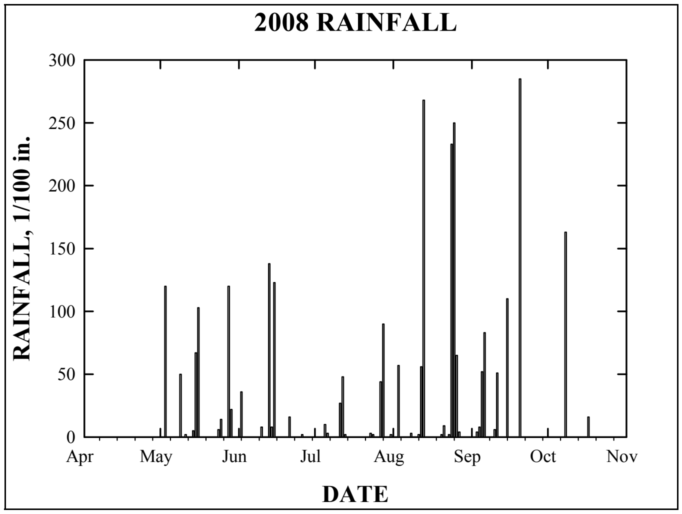

Figure 1: 2008 Rainfall

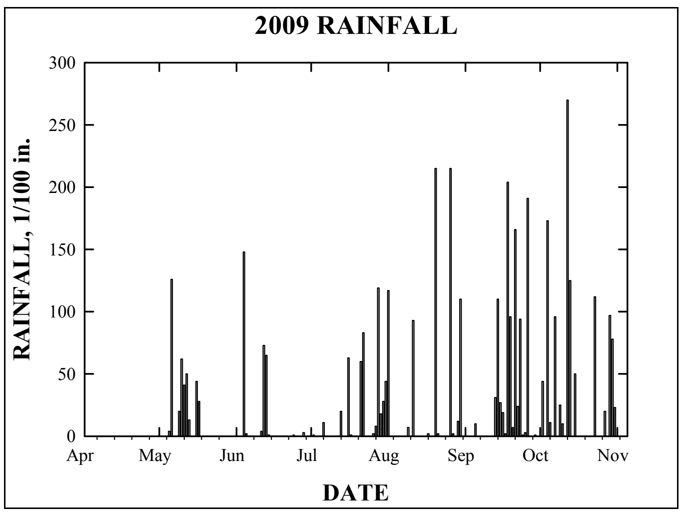

Figure 2: 2009 Rainfall

<u>Total N Uptake and Lint Yield</u>

Total N uptake for 2008 (Fig. 3) increased as applied fertilizer N increased. A strong positive relationship of 0.95 was found between total N uptake and fertilizer rate. Total N uptake for 2009 hasn't been determined at this time.

Lint yield for 2008 (Fig. 4) and 2009 (Fig. 5) followed a similar trend. It is apparent that an agronomic optimum lies near 75 lb N/acre applied for both years. Also, in both years a treatment rate of 120 lb N/acre applied yielded less than the 40 lb N/acre rate. These two yield graphs emphasize that rates of 0, 40, 80, and 120 lb N/acre applied maximize yield differences and allowed for an agronomic optimum to not only be reached but exceeded.

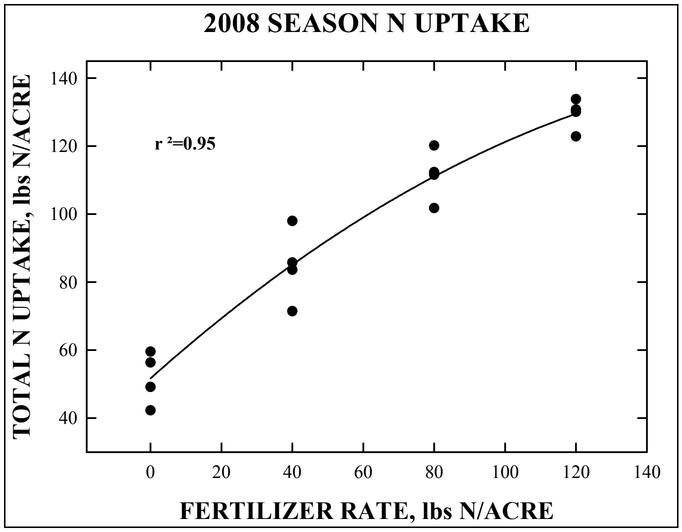

Figure 3: 2008 Total N uptake

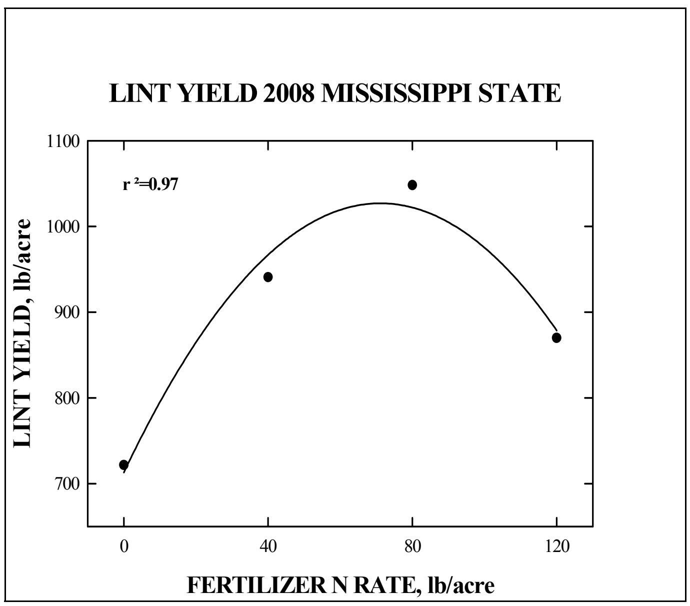

Figure 4: Lint yield 2008 Mississippi State

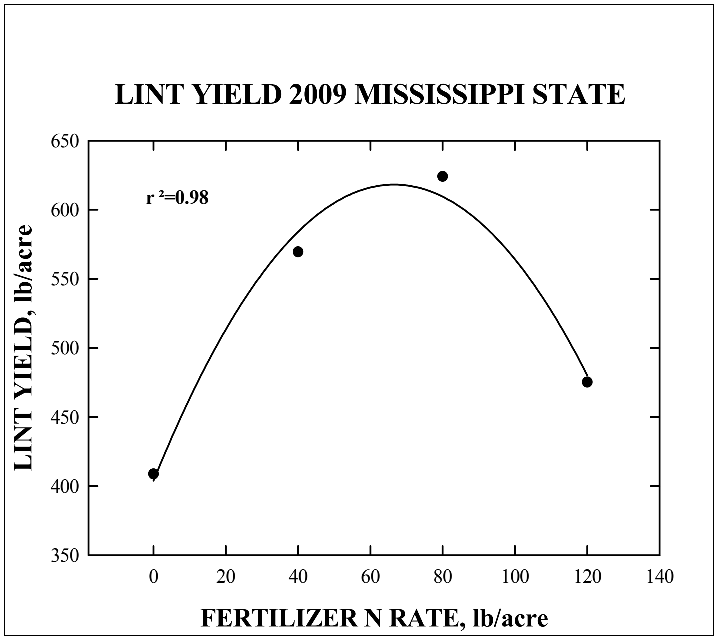

Figure 5: Lint yield 2009 Mississippi State

GNDVI and LEAF N, %

The GNDVI values at early square in 2008 (Fig. 6) did not appear to be good estimators of leaf N across different N rates. Although a linear trend is present, the scatter is high. The relationship was poor (r^2=0.22) and the regression line covered a minimal GNDVI range at early square in 2008. By early flower in 2008 (Fig. 7) separation across fertilizer N treatments was evident and a much stronger relationship was present. The regression line also had a greater GNDVI range near 0.08. At peak flower in 2008 (Fig. 8) the most significant relationship for the year was shown between leaf N and GNDVI at 0.90. Maximum treatment separation was evident at peak flower and GNDVI range was again near 0.08.

Similar trends occurred in 2009 with respect to early square (Fig. 9) and peak flower (Fig. 12). However, at early flower in 2009 (Fig. 10) there was a very poor relationship and a very small GNDVI range. Again, this is most likely due to the effect of rainfall on fertilizer N availability. Immediately following the early flower sensing date, several significant rainfall events occurred. This allowed applied N to move down into the root zone and improved response differences. By the second week of flowering (Fig. 11) a much greater relationship between GNDVI and leaf N of 0.61 existed. Peak flower (Fig. 12) again showed the greatest relationship of 2009 at 0.87 and a regression line with a GNDVI range near 0.09.

A regression created by contributing data from physiologically corresponding dates across the two years showed a slight relationship, but a small GNDVI range at early square (Fig. 13). However, a combined 2008 and 2009 graph for peak flower (Fig. 14) showed a much stronger relationship and a greater GNDVI range.

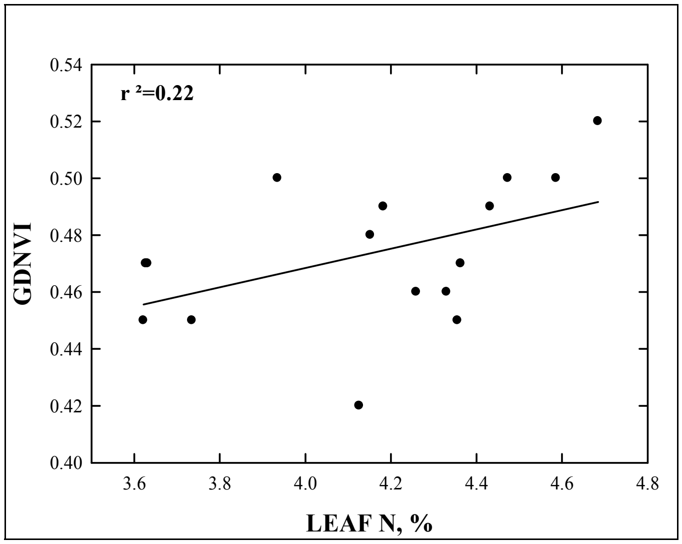

Figure 6: 2008 Early square

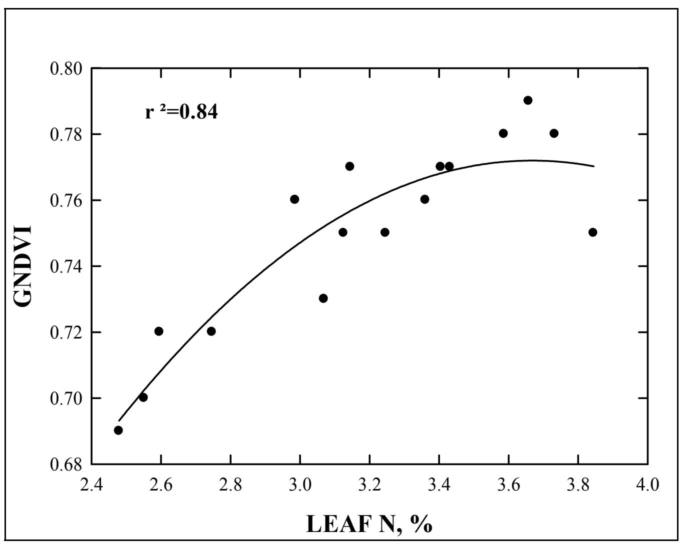

Figure 7: 2008 Early flower

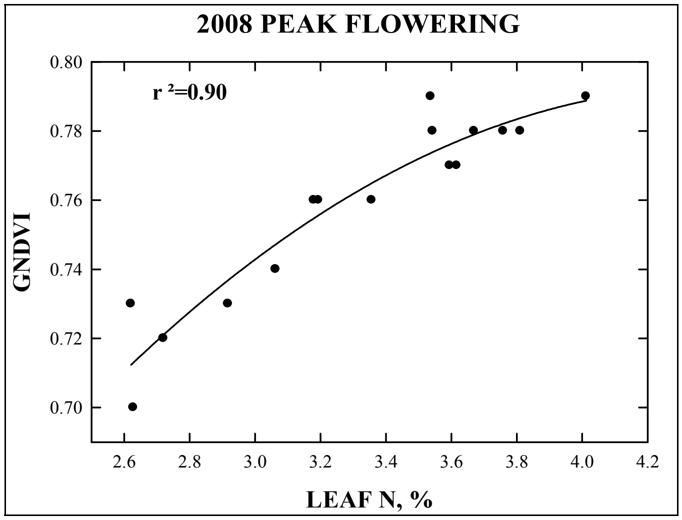

Figure 8: 2008 Peak flower

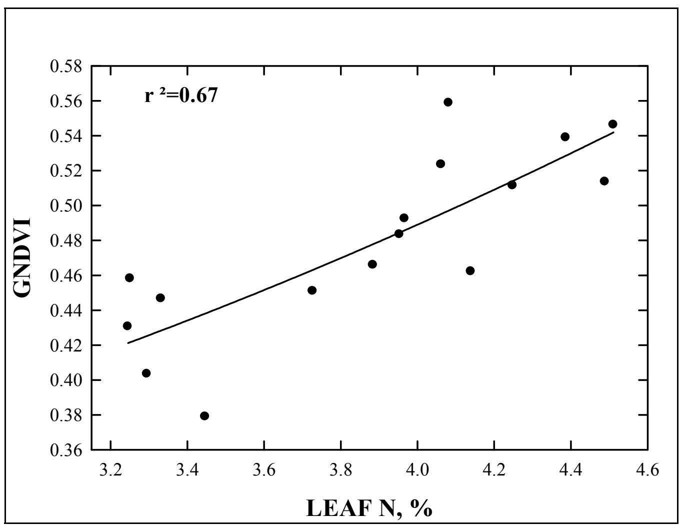

Figure 9: 2009 Early square

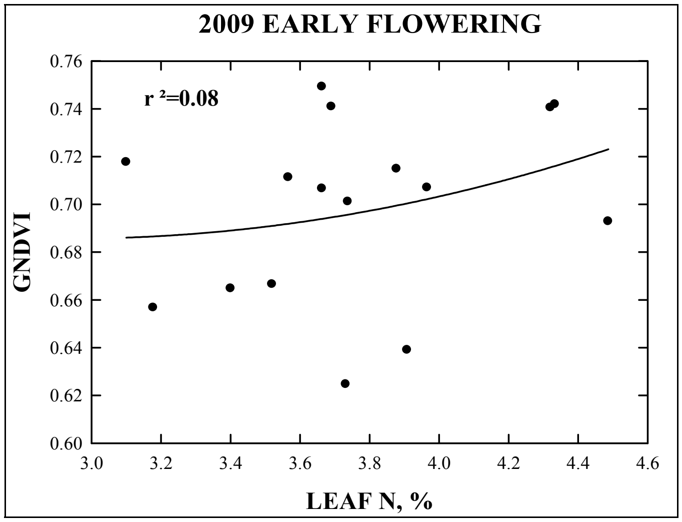

Figure 10: 2009 Early flower

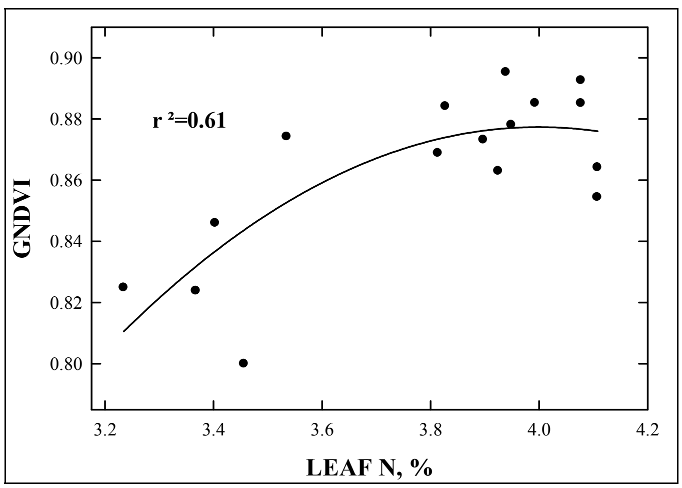

Figure 11: 2009 Second week of flowering

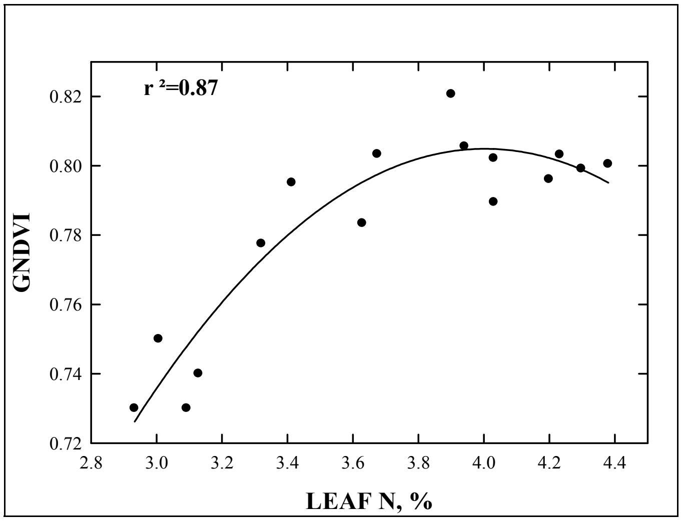

Figure 12: 2009 Peak flower

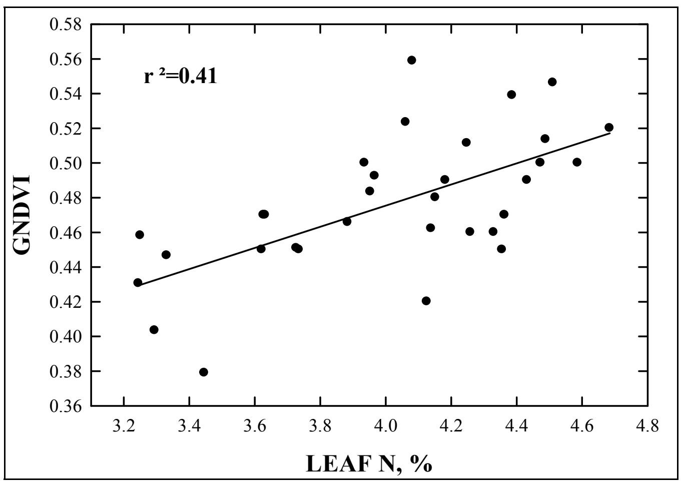

Figure 13: 2008/2009 Early square

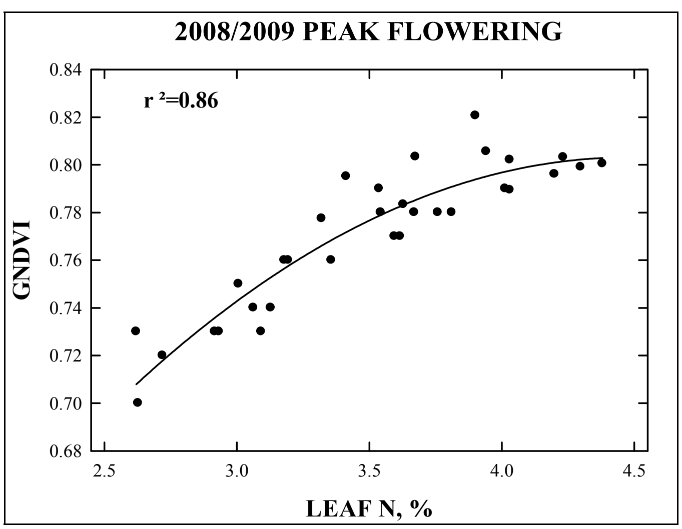

Figure 14: 2008/2009 Peak flower

GNDVI and PLANT HEIGHT, cm

Strong relationships between GNDVI and plant height in 2008 were apparent across all dates. The weakest relationship in 2008 was at early square (Fig. 15) and was most likely due to a lack of treatment separation early in the growing season. The GNDVI range for 2008 early square was near 0.07. Early flower in 2008 (Fig. 16) and peak flower in 2008 (Fig. 17) had strong relationships and GNDVI ranges were very close to 0.08. Maximum treatment separation was evident at peak flower in 2008; however, the relationship was decreased slightly at early flower in 2008. Typically relationships have increased across growing seasons and this decrease has yet to be explained.

Relationships between GNDVI and plant height in 2009 strengthened throughout the growing season to peak flower (Fig.18 to 20). The GNDVI range actually decreased from 0.16 at 2009 early square to 0.10 at 2009 early flower. The GNDVI range for 2009 peak flower remained near 0.10. Again, treatment separation increased and relationships strengthened through to peak flower.

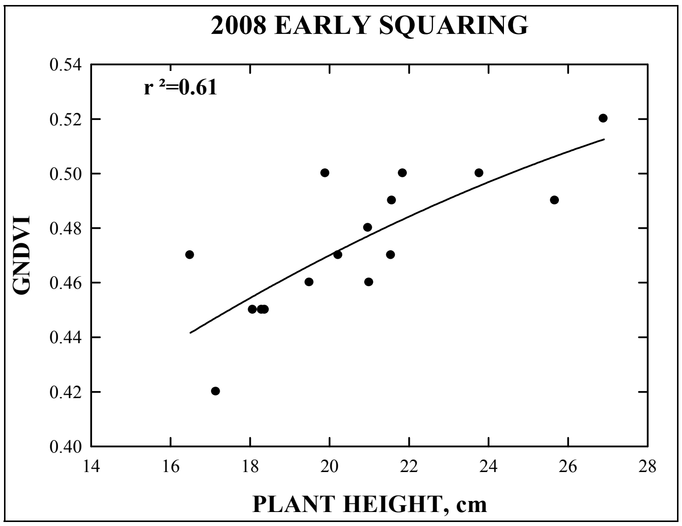

Figure 15: 2008 Early square

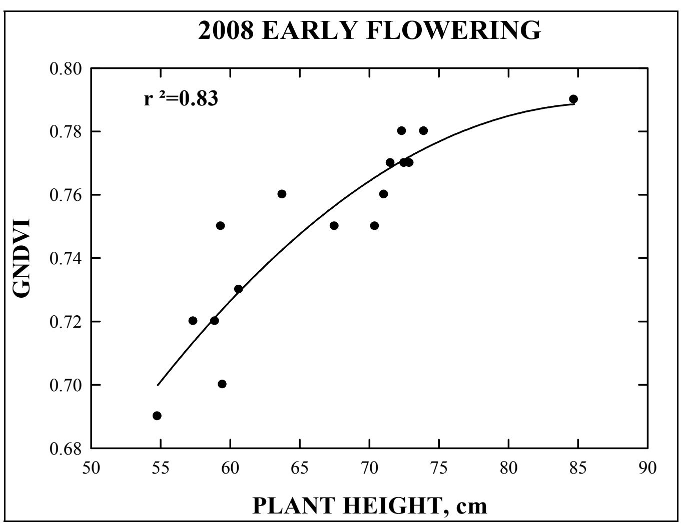

Figure 16: 2008 Early flower

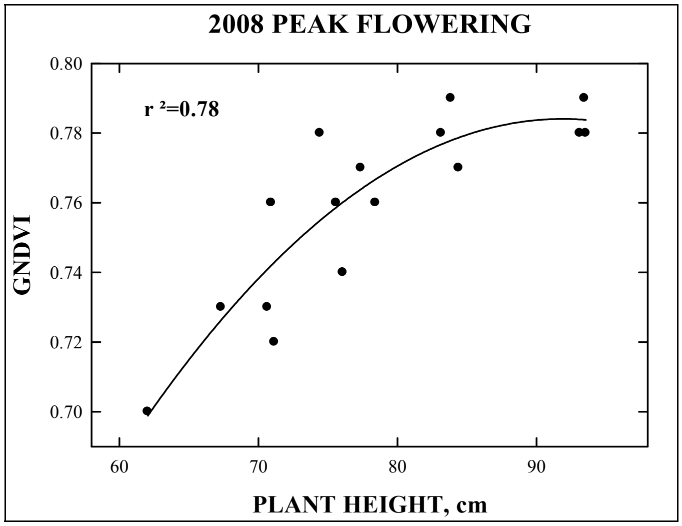

Figure 17: 2008 Peak flower

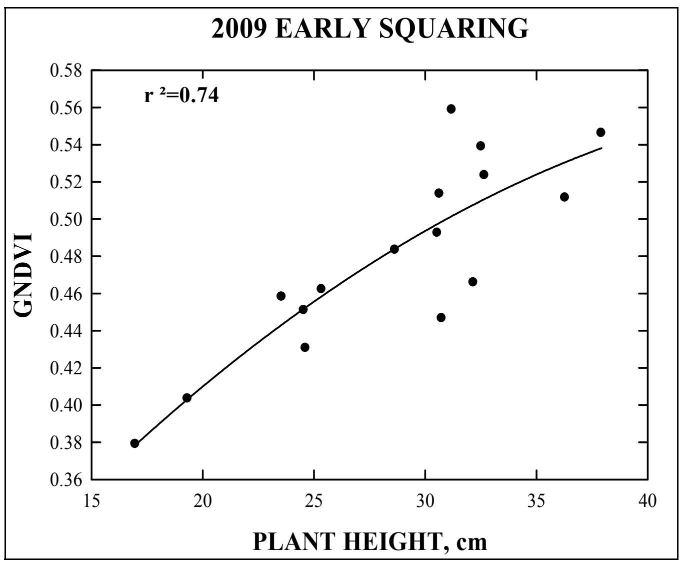

Figure 18: 2009 Early square

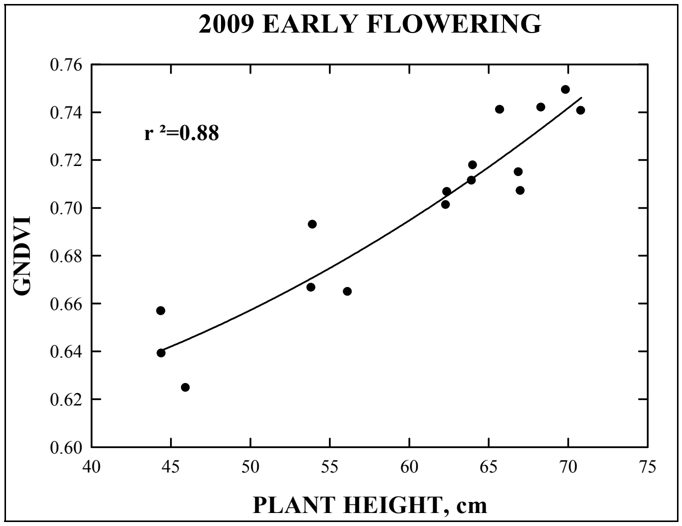

Figure 19: 2009 Early flower

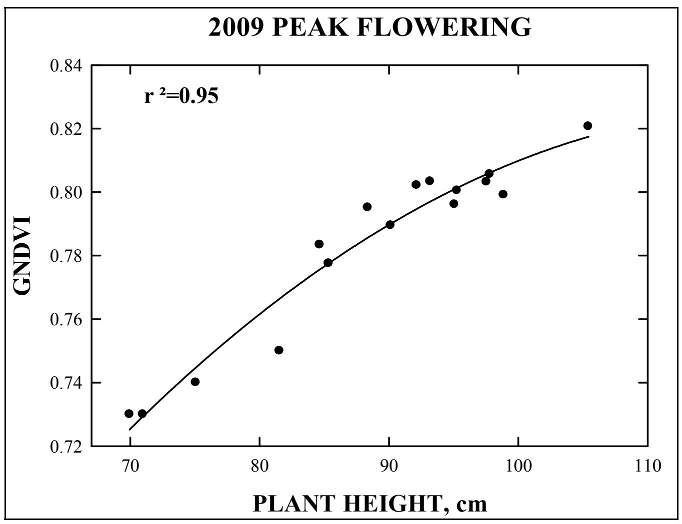

Figure 20: 2009 Peak flower

Conclusions

The GNDVI values were most strongly related to leaf N beginning at early flower. Early square relationships between GNDVI and leaf N were typically low and inconsistent. Strong relationships between GNDVI and plant height were found for all measured physiological stages and define GNDVI as a stable and reliable estimator of plant height beginning at early square in both years. The relationships between GNDVI and leaf N and GNDVI and plant height improved through to peak flower, with the strongest relationships at peak flower. Late season treatment separation probably contributed to this increase.

Consistency across growing seasons supports the utility of this measurement. This conclusion can be drawn from the strong relationships of the 2008/2009 peak flower combined leaf N graph (Fig. 14). Unfortunately, consistency in sensing data occurs past a date at which an N application could significantly impact yield. However, these late season readings may prove beneficial to N management in following growing seasons.

References

Buscaglia, H. J., and Jac J. Varco. 2002. Early detection of cotton leaf nitrogen status using leaf reflectance. J. Plant Nutr. 25:2067–2080.

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

Zhao, Duli, K. Raja Reddy, Vijaya Gopal Kakani, John J. Read, and Sailaja Koti. 2005. Selection of Optimum Reflectance Ratios for Estimating Leaf Nitrogen and Chlorophyll Concentrations of Field-Grown Cotton. Agron. J. 97: 89-98.