CANOPY REFLEXTANCE AT MULTIPLE WAVELENGTHS AND INDICES FOR EARLY SEASON DETECTION OF COTTON NITROGEN STATUS

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Abstract

The Normalized Difference Vegetation Index (NDVI) is utilized by many commercially available crop sensors, but often fails to correlate strongly to early season cotton (*Gossypium hirsutum* L.) N status. The objectives of this study were to examine sensitivities of published indices calculated from passive canopy reflectance to changes in cotton biomass and N status, and to identify indices most compatible to current N management practices. Field trials were conducted from 2008-2010 at the Plant Science Research Farm, Mississippi State, MS. Fertilizer N rates of 0, 40, 80, and 120 lb N/acre were applied to establish wide growth differences. Plant height, leaf N, and proximal canopy reflectance were measured at various developmental stages each growing season. Results suggest difficulty in determining cotton N status using NDVI may be due to the index's stronger sensitivity to plant height than to leaf N or greenness. The index which was most sensitive to leaf N and least sensitive to plant height was the Canopy Chlorophyll Content Index (CCCI). This index was sensitive to N status early in the growing season and held a relatively consistent range of values throughout the application window.

Introduction

In-season determination of cotton N status is a useful tool which can help producers reduce over and under applications of fertilizer N. Active, on-the-go sensors have the potential to not only provide this information in a financially efficient and timely manner, but also drive a variable rate application during the measurement in real-time (Zhao et al., 2005). However, many commercially produced sensors currently in the market utilize the Normalized Difference Vegetation Index (NDVI). Although this index often correlates strongly to the N status of wheat and a few other crops, the relationship between NDVI measured from an active ground-based sensor and cotton N status has been observed as weak (Bronson et al., 2005; Li et al., 2001; Plant et al., 2000). Weak correlations have led to the investigation of other regions of cotton's spectral reflectance signature. One region which has shown strong correlations to cotton N status at the leaf reflectance scale is the red edge, or the region immediately between the red absorption region and the near-infrared reflection region highlighted in Fig. 1 (Fridgen et al., 2004; Buscaglia et al., 2002). The objectives of this study were to examine sensitivities of published indices calculated from passive canopy reflectance to changes in cotton biomass and N status, and to identify indices most compatible to current N management practices (e.g., early deficiency detection, insensitivity to changes in plant height, and a consistent range of values during application window across years).

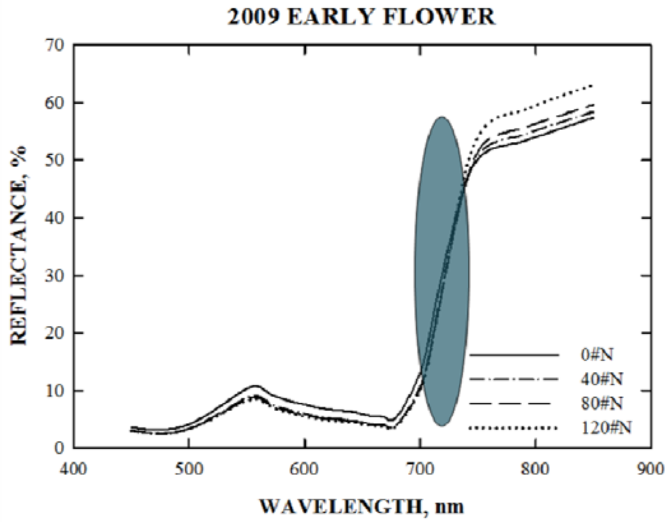

Figure 1: Signature reflectance curves at early flowering in 2009 (n=4 for each N rate). Highlighted region represents the red edge region of the reflectance curve.

Materials and Methods

Data was collected from 2008-2010. The trial was conducted at the Mississippi Agricultural and Forestry Experiment Station, in Starkville, Mississippi. Each of 16 plots was comprised of 12 rows by 125 ft in length with treatments arranged in a randomized complete block design. In 2008 and 2009, Delta and Pine Land BG/RR 445 and in 2010 DeltaPine BG/RR 1028 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 (Figure 2). 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. These measured reflectance wavelengths were used to calculate over 30 published ratios and indices. The five indices which represented the broadest ranges of response are listed in Table 1.

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 (Figure 2). 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. Total 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.

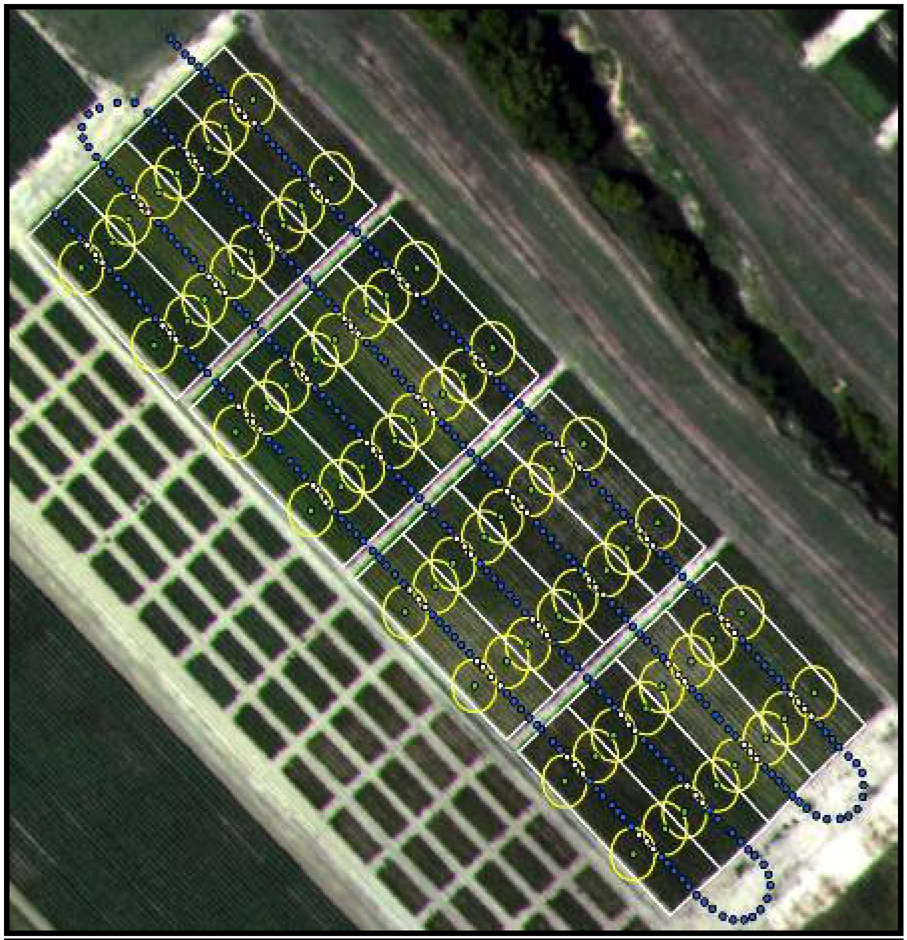

Figure 2: Image displaying reflectance measurement points (white and blue dots), plant sampling points (green dots), and applied buffer constraints (yellow circles) across field trial at one sampling date. Green Blue dots represent reflectance measurements which were excluded from analysis. White dots represent measurements which corresponded to plant sampling points and were therefore included in the analysis.

Table 1: Descriptions of five reflectance-derived ratios which represented the broadest range of response to leaf N status and plant height.

Acronym	Name	Vegetative Index	Reference
NDVI	Normalized Difference Vegetation Index	$(R_{NIR}-R_{RED}) / (R_{NIR}+R_{RED})$	Rouse et al. (1974)
GNDVI	Green NDVI	$(R_{NIR}-R_{GREEN}) / (R_{NIR}+R_{GREEN})$	Gitelson et al. (1996)
NDRE	Normalized Difference Red Edge Index	$(R_{NIR}-R_{EDGE}) / (R_{NIR}+R_{EDGE})$	Barnes et al. (2000)
CCCI	Canopy Chlorophyll Content Index	NDRE / NDVI	Barnes et al. (2000)
Guyot's REI	Linear Red Edge Index	$700 + 40[(R_{670}+R_{780})/2-R_{700}]/(R_{740}-R_{700})$	Guyot et al. (1992) Clevers (1994)
Gaussian REIP	Gaussian REIP	$6\ dR/D\lambda$	this work

Results and Discussion

Leaf N response to Fertilizer N Rate

Leaf N response to fertilizer N rate was significant at almost every sensing date, including those very early in the growing season (Figure 3). The response was frequently quadratic. The response of leaf N to changes in days after planting and year was inconsistent and most likely due to changing growing conditions (rainfall, temperatures, etc), and changes in varieties between 2009 and 2010 (Figure 4). Although these inconsistent shifts greatly complicated full-season modeling, differences between varying N statuses were noted at all sampling dates. These relatively large separations suggest that an index which is capable of measuring early season leaf N will be most useful in determining early season cotton N status.

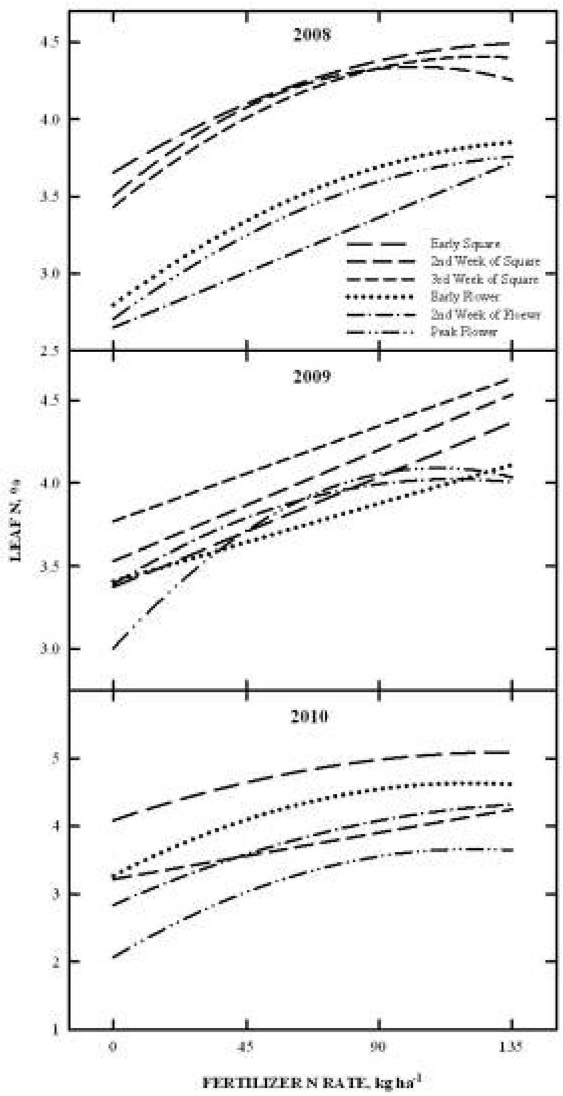

Figure 3: Leaf N response to fertilizer N rate at all sampling dates from 2008--2010.

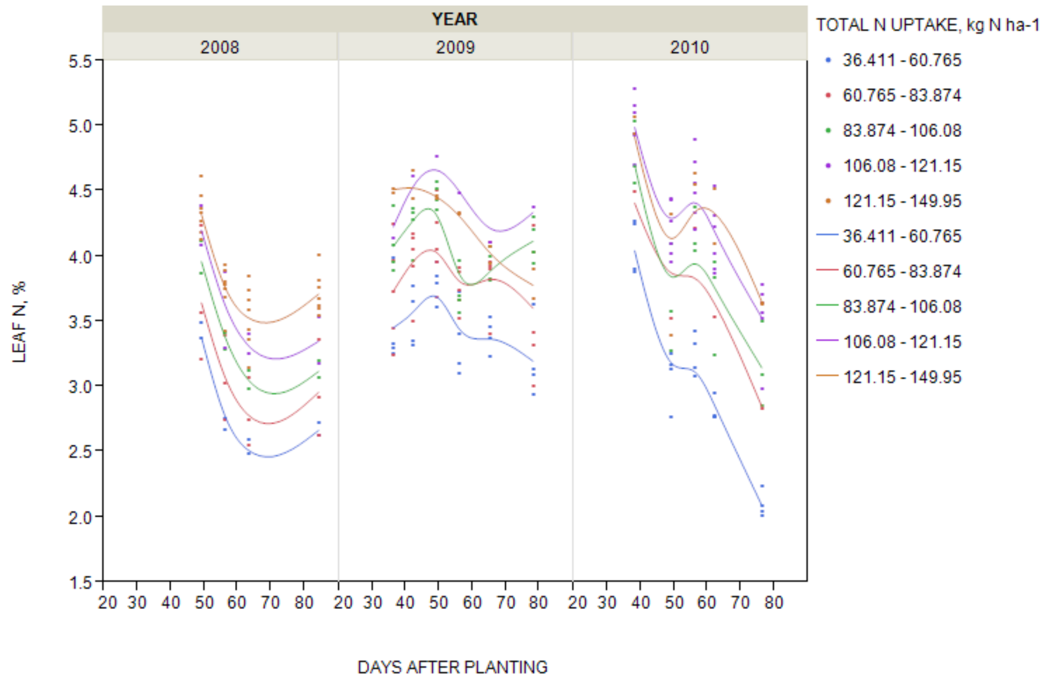

Figure 4: Leaf N response to days after planting each year by N availability (expressed as total N).

Plant Height and Fertilizer N Rate

Plant height response to fertilizer N rate was significant late in the growing season, but early in the growing season response was frequently very weak or not significant (Figure 5). Very late in the growing season a quadratic response was noted in 2009 and 2010, but the trend was generally linear with a very small slope early in the growing season. Response of plant height to changes in days after planting and year were very consistent, with maximum plant height shifting from year to year with growing season. Plant height increased as the growing season progressed, however, separation of total N values was not evident until later sampling dates (Figure 6). Insensitivity of plant height to changes in fertilizer N rate early in the growing season suggests an index which correlates strongly to N status may not be sensitive to changes in plant height.

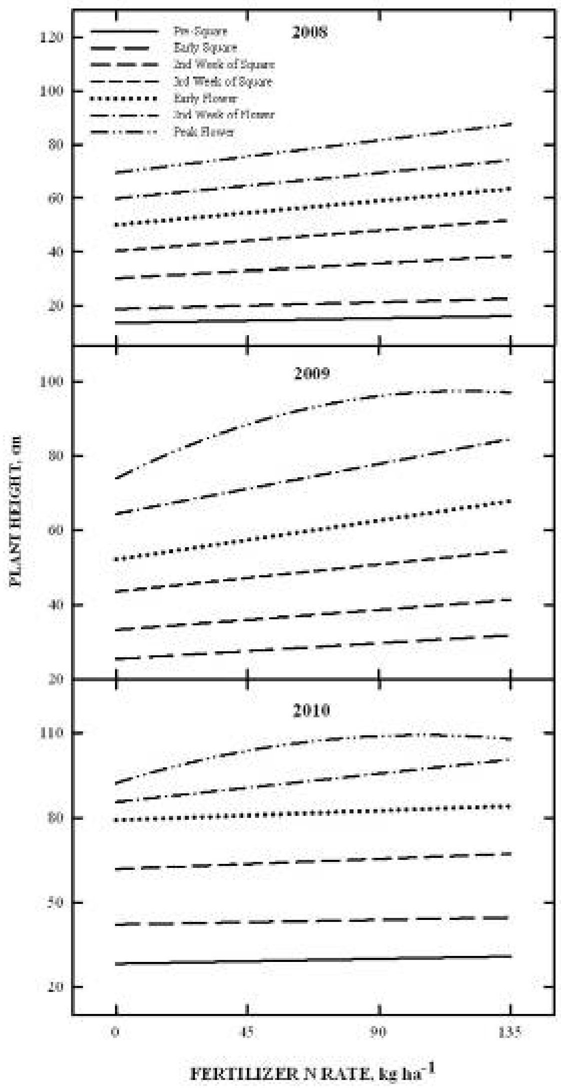

Figure 5: Plant height response to fertilizer N rate at all sampling dates from 2008-2010.

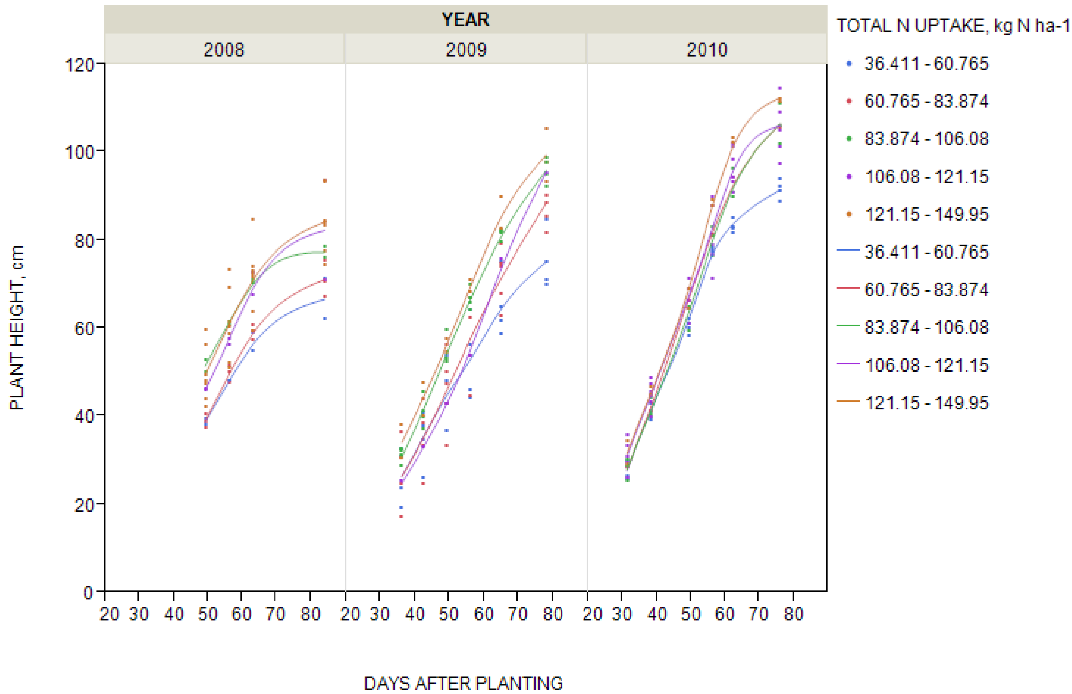

Figure 6: Plant height response to days after planting each year by N availability (expressed as total N).

Index Analysis

Due to significant year and day after planting effects, individual sensing dates were analyzed separately. Relationships between variables were examined using the PROC CORR procedure in SAS v. 9 (Cary, NC). An example correlation table output can be seen in Table 2. Similar results were noted at almost all sensing dates, with significant shifts in responses only noted late in the growing season. Early in the growing season, NDVI is very sensitive to changes in plant height, but not very sensitive to changes in leaf N. In contrast, CCCI was very sensitive to changes in leaf N, and only moderately sensitive to changes in plant height. Although REI and REIP both responded much like CCCI to changes in leaf N and plant height, REI's slightly less desirable responses requiring 4 reflectance measures and REIP's complicated calculation requiring 6 reflectance magnitudes makes both of these indices less desirable than CCCI. After building correlation tables, individual graphs examining index relationships with leaf N were constructed (Figure 7).

Table 2: Condensed correlation matrix for 2010 2nd week of square. Normalized Difference Vegetation Index sensitivity to leaf N was weak and not significant, but sensitivity to plant height was strong. Canopy Chlorophyll Content Index sensitivity to leaf N was very strong, and sensitivity to plant height was moderate. *Denotes statistical significance.

INDEX	FERT N RATE	LEAF N	PLANT HEIGHT
NDVI	0.46384*	0.27076	0.73281*
GNDVI	0.70968*	0.60238*	0.7717*
NDNE	0.77707*	0.7277*	0.75915*
CCCI	0.82081*	0.90484*	0.56218*
Gaussian REIP	0.81936*	0.89118*	0.64654*
Guyot's REI	0.82107*	0.89426*	0.61918*

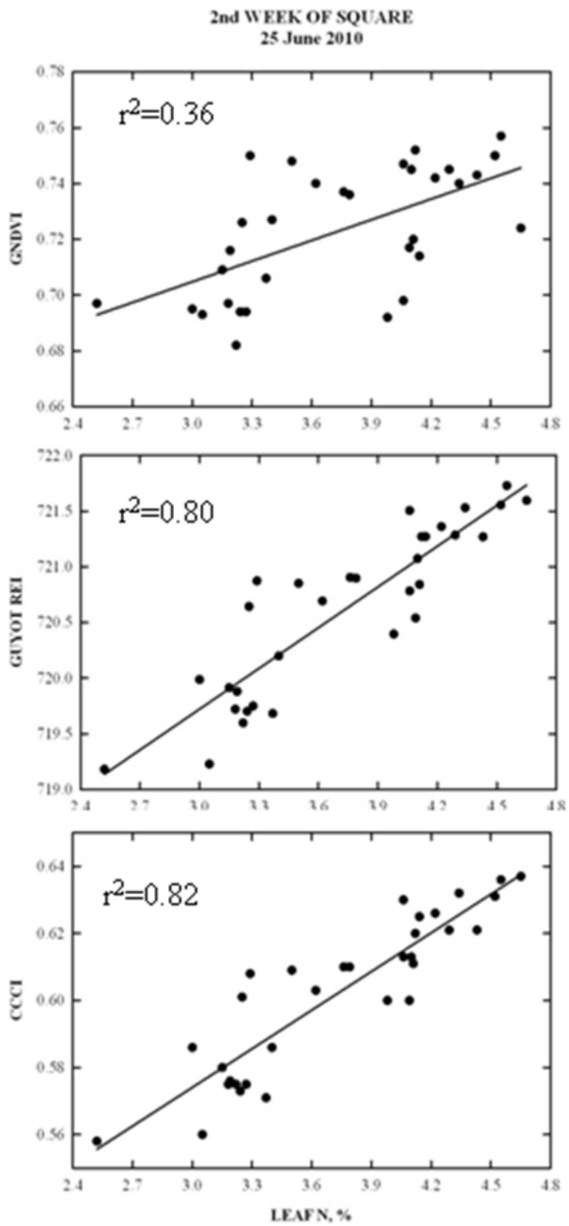

Figure 7: Relationships between the Green Normalized Difference Vegetation Index, Guyot's Red Edge Index, and Canopy Chlorophyll Content Index with leaf N at the 2nd week of square in 2010.

Compatibility of Indices to Production

Several index characteristics are important beyond the ability of the sensor to detect N status. Although year and days after planting were found to be significant, analysis of all data within the application window of interest was necessary to examine trends and applicability. All years of data were combined and CCCI and NDVI were graphed by days after planting with total N uptake overlain (Figure 8). By examining this graph, it is easy to see the range of NDVI values shifts with respect to time. This results in a moving target with respect to a critical NDVI value, or the theoretical value which represents the break point between N deficiency and N sufficiency. The increase in NDVI as days after planting increases is most likely due to the high sensitivity of the index to increases in plant height. Examination of CCCI, however, indicates that although a slight shift is noted early, the range of values is relatively consistent. This would allow the establishment of a critical CCCI value (graphed as a solid line at 0.615). It is also important to note the differences in separation of total N uptake values from NDVI to CCCI. In this application window, CCCI appears to separate out total N uptake values much better than NDVI.

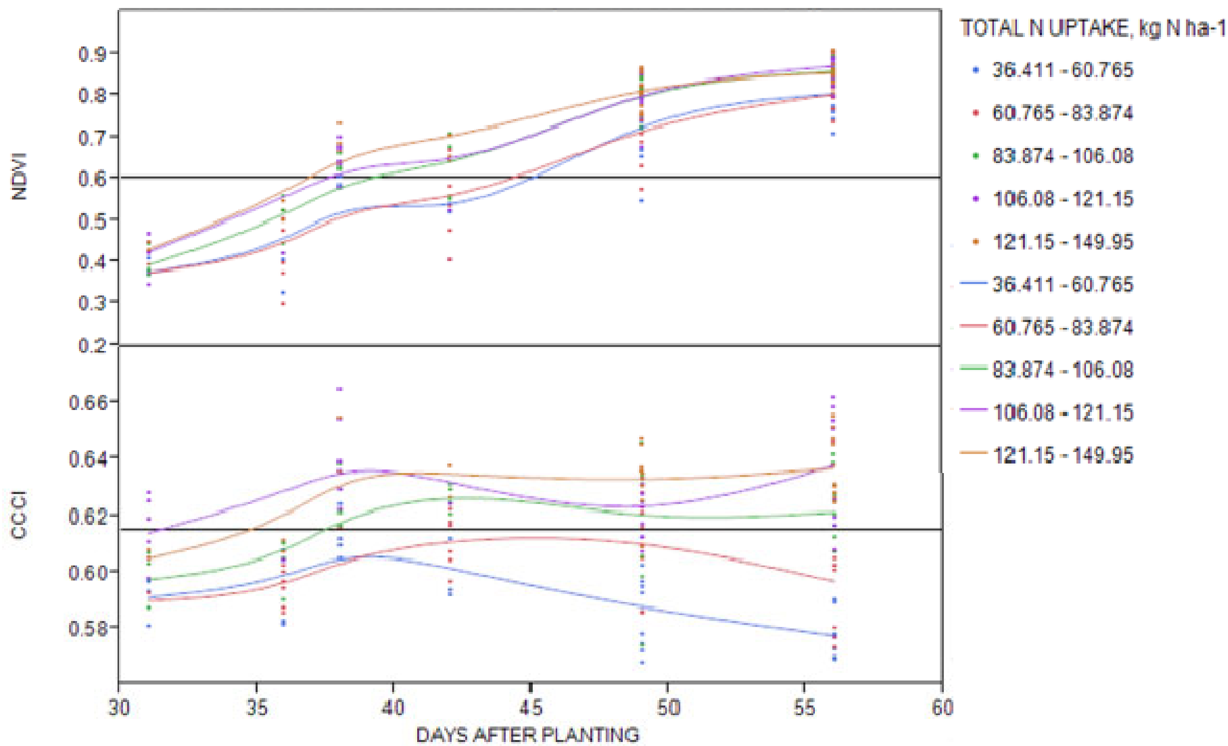

Figure 8: Examination of the Normalized Difference Vegetation Index and Canopy Chlorophyll Content Index trends associated with days after planting by N availability (expressed as total N).

Conclusions

Adoption of new indices which are more sensitive to early season cotton N status are necessary before a producer will be able to benefit greatly from an on-the-go sensor based variable rate N application. Examination of over 30 published indices suggests that NDVI and GNDVI are very sensitive to changes in plant height and not very sensitive to changes in leaf N. Furthermore, the range of these indices increases throughout the growing season with plant height, suggesting that even in situations where plant height is strongly related to N status these indices would have to be normalized to compare to a critical value. Still, late in the growing season, these indices are quite accurate at detecting differences in N status. From the indices examined in this project, CCCI demonstrated the greatest utility in determining early season cotton N status. This index utilizes only one more reflectance magnitude than NDVI, holds a fairly consistent range of values during the fertilizer side-dress application window, and is much less sensitive to plant height and more sensitive to leaf N than NDVI. Although other red-edge indices showed similar responses to changes in plant height and leaf N, they require more reflectance wavelength magnitudes and were slightly less sensitive to N status than CCCI.

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