NORMALIZED DIFFERENCE VEGETATION INDEX (NDVI) VARIATION AMONG CULTIVARS AND ENVIRONMENTS

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Abstract

Although Nitrogen (N) is an essential nutrient for crop production, large preplant applications of fertilizer N can result in off-field loss that causes environmental concerns. Canopy reflectance is being investigated for use in variable rate (VR) N management. Normalized difference vegetation index (NDVI) data, calculated from reflectance, are relatively easy to collect. Furthermore, the amount of NDVI data available to farmers is expected to increase with the large numbers of unmanned aerial vehicles anticipated for agricultural use. However, given the large number of cotton varieties and the relatively quick turnover, little is known about how commercial varieties vary in their NDVI response. The objective of this study was to compare NDVI readings among 31 cotton varieties growing in a range of environments in the Missouri cotton Official Variety Test (OVT). Cotton was planted in early May and NDVI sensing was conducted in mid-July at four sites. Since the data were all from 2014, environmental effect among sites was primarily associated with soil differences. The findings suggest that the study at one site had smaller plants and more variability, which is consistent with visual observations. While differences were observed in the NDVI values, this initial comparison did not indicate large differences within a site. Correlations with yield comparing a single variety across environments, analogous to many Mid-South field situations, showed fairly consistent values, but additional years of observations will be needed to better understand the relationships observed in this study.

Introduction

Although Nitrogen (N) is an essential nutrient for crop production, current N management often results in low N fertilizer use efficiency, which can lead to economic losses and environmental contamination (Cassman et al., 2002). N deficiency in cotton causes reduced vegetative growth, reduced numbers of bolls and seeds, and low fiber yield, length, and strength (Malavolta et al., 2004). On the other hand, N excess leads to excessive vegetative growth (McConnell et al., 1993), increasing production cost by increasing the need for growth regulator (McConnell et al., 1992), defoliant (McConnell et al., 1993), and insecticide (Cisneros and Godfrey, 2001).

Large preplant applications of fertilizer N can result in high levels of inorganic soil N long before rapid crop uptake occurs (Cassman et al., 2002). Off-field loss of this N can cause environmental concerns through leaching or greenhouse gas emissions. While uniform application of fertilizer N to spatially-variable landscapes is still the normal practice, numerous field studies have indicated economic and environmental justification for spatially variable N applications to crops (e.g., Scharf et al., 2005). Uniform applications discount the fact that N supplies from the soil, crop N uptake, and crop response to N are not uniform (Inman et al., 2005). Furthermore, commonly used N recommendations based on target yield ignore the influence that in-season weather has on yield potential.

Diagnosing N status can help avoid both N deficiency and excess N application and minimize production cost while maximizing yield and quality. However, most current diagnostic tools available to cotton producers are labor-intensive and time-consuming and therefore not well-suited as the basis for variable rate (VR) N management. Ground-based active-light canopy reflectance measurement is currently being investigated for use in VR N management (Kitchen et al., 2010). Active sensors emit modulated light onto the canopy and detect reflectance of the modulated light by the canopy (Stone et al., 1996). Visible and near infrared (NIR) wavelengths are typically included, and reflectance is often translated to a normalized difference vegetation index (NDVI). Algorithms based on crop-canopy reflectance sensing have been used to make VR N recommendations for wheat (Raun et al., 2002), corn (Solari et al., 2008), and cotton (Oliveira et al., 2013). NDVI sensing has also been the basis for VR application of plant growth regulators and defoliants in cotton. However, N-algorithm refinement is needed to account for fields where large soil differences occur (Shanahan et al., 2008), including many Mid-South fields. One notable attempt at refining the N algorithms has been to combine data from a number of individual studies to develop a combined multi-state relationship (Griffin et al., 2014).

With sensors, questions persist about the appropriate time to take the readings to obtain accurate information about the N status. Zhao et al. (2004) reported early-, mid-, and late-season reflectance differences between N treatments. However, Buscaglia and Varco (2002) reported that reflectance readings at the second week of flowering growth stage had better capability of differentiating the N rates than the readings at second week of squaring, when only the lowest N rate had constantly higher reflectance in the visible range than the other rates. Drought stress can influence the color, size, and orientation of leaves and thereby affect reflectance. Plant et al. (2000) studied the relationship between NDVI and water stress and suggested that NDVI might be dependent on water stress for reasons that include effects on leaf optical properties, canopy structure (e.g., due to wilting), and reduction in LAI. Vories et al. (2014) investigated timing of multiple sensor readings on irrigated and rainfed cotton with a range of N treatments. They observed the strongest correlations with yield for postflower NDVI and height.

NDVI data are relatively easy to collect and used in many applications. Furthermore, the amount of NDVI data available to farmers is expected to increase with the large numbers of unmanned aerial vehicles (UAVs; a.k.a., “drones”) anticipated for agricultural use. However, many studies have been conducted on just one or two varieties, which may not still be available by the time the study is published. Given the large number of commercially available cotton varieties and the relatively quick turnover for most varieties, little is known about how commercial varieties vary in their NDVI response. This information is critical since variety-specific algorithms for using NDVI in crop management are probably not practical.

Universities in Missouri and other cotton-producing states conduct official variety tests (OVT) of commercially available crops produced in their state. Typically seed companies provide the seed and pay an entry fee. All entries are produced with the same management in multiple locations within the state. The results are available to anyone who is interested and are often posted on university websites (e.g., http://agebb.missouri.edu/cotton). In this way, both the seed companies and local producers can compare varieties produced in locations of interest and learn how the varieties respond under different environments. The objective of this study was to compare NDVI readings among several cotton varieties growing in a range of environments in the Missouri cotton OVT.

Materials and Methods

The Missouri cotton OVT is conducted annually on several University of Missouri and on-farm locations in southeast Missouri. Four of the studies are located on the Fisher Delta Research Center, with one on the Rhodes Farm in Dunklin County near Clarkton (36.48° N, 89.96° W) and three on the Lee Farm near Hayward (36.40° N, 89.61° W). The Rhodes site was approximately 32 km west of the Lee sites, has very sandy soil and sprinkler irrigation, and was planted 5 May. The Lee sites included a clay soil with furrow irrigation, a silt loam soil with furrow irrigation, and a silt loam soil with rainfed production, and each was planted on 7 May. The clay site was approximately 1 km southeast of the silt loam sites, which were adjacent to each other. Each test was planted on bedded soil with a 97-cm row spacing. Table 1 includes the 31 varieties included in 2014.

Table 1. Varieties included in 2014 Missouri cotton Official Variety Test.

BRS-269	FM 1944 GLB2	PX3003-04WRF
BRS-286	HQ110CT	PX3003-10WRF
BRS-293	HQ210CT	PX3003-14WRF
BRS-335	MON 12R224B2R2	PX3122-b51WRF
DG 2285 B2RF	NG 1511 B2RF	PX4444-13WRF
DG 2570 B2RF	PHY 333 WRF	ST 4946 GLB2
DG 2355 B2RF	PHY 339 WRF	ST 4747 GLB2
DG CT 14515	PHY 427 WRF	ST 5032 GLT
DP 0912 B2RF	PHY 495 W3RF	ST 5289 GLT
DP 1311 B2RF	PHY 499 WRF	UA 222
DP 1321 B2RF		

NDVI sensing was conducted in mid-July with a RapidSCAN CS-45 sensor (Holland Scientific, Lincoln, Neb.). The unit is handheld with a built-in Global Positioning System (GPS) sensor and datalogger. It includes a 670 nm visible light source, a 780 nm NIR source, and a 730 nm red edge (RE) source. Data were collected by walking through the

OVT plots at the four Fisher Delta Research Center sites with the sensor held approximately 1.2 m above the ground over the row. No readings were taken from the outside approximately 1m of each plot. Plot-average values of NDVI, normalized difference red edge (NDRE), and visible, NIR, and RE relflectance were collected, but only NDVI was included in this report. Data were collected at the Rhodes site on 9 July (65 days after planting, DAP) and at the Lee sites on 16 July (70 DAP).

Data were analyzed using the Statistical Analysis System (SAS 9.2 for Windows; SAS Institute Inc., Cary, N.C.) PROC GLM. Tests were considered significant at the 0.05 level of probability and Fisher's protected least significant difference (LSD) was used to compare treatment means for significant ($p \leq 0.05$) effects.

Results and Discussion

Since the data in this report are all from the 2014 growing season and given the close proximity of the four sites, any weather differences would have been negligible; therefore, any environmental effect among sites was primarily associated with soil differences. While one of the silt loam sites was rainfed, rainfall was adequate prior to reflectance data collection to prevent large water stresses from developing. More pronounced water stress was observed later in the season. When all of the data were analyzed together, environment, variety, and the environment by variety interaction were all highly significant ($p<0.02$), making inferences difficult. The significant interaction was especially concerning since it suggested that the differences among varieties was not consistent.

To investigate further, the four sites were analyzed separately (Table 2). Since NDVI values are correlated to biomass (Boelman et al., 2003), the findings suggest that the study at Rhodes had smaller plants and more variability, which is consistent with visual observations at the site. Furthermore, since the instrument height was consistent among the sites, the effect of the smaller plants was probably exaggerated. Although clay soils tend to produce smaller plants, differences among the Lee sites were much less. As expected due to the frequent early-season rains, observations from the two silt loam sites were quite similar.

Table 2. NDVI variation among varieties at four Missouri cotton OVT sites.

Site	Normalized Difference Vegetation Index (NDVI)				
	Average	Maximum	Minimum	LSD(0.05)	Correlation with yield
Rhodes	0.560	0.691	0.475	0.087	0.765
Lee clay	0.821	0.859	0.757	0.046	0.422
Lee silt loam irrigated	0.879	0.894	0.844	0.020	0.044
Lee silt loam rainfed	0.875	0.890	0.835	0.017	0.078

Another question of interest is how well the NDVI values observed in July correlated to the yield and high volume instrument (HVI) quality parameters associated with harvest in October. Although hail or early frost would impact the findings, no such events occurred in 2014. Looking at the correlation with yield at each location (Table 2), only Rhodes had a very large correlation, which can be explained by the smaller range of values at the other sites. However, a more meaningful comparison would be how an individual variety varied across environments. As stated before, the main environmental difference was soil type and the irrigated/rainfed difference at the silt loam site. Many center pivot irrigated fields in the Mid-South have dry corners and areas of sand, silt loam, and clay, but fewer contain more than one or two varieties. The correlation with yield was fairly consistent among varieties (Table 3). The negative correlations with micronaire, length, and strength were strong among some of the varieties but much weaker among others. Of course, data from additional years will be needed to fully investigate the relationships.

Table 3. Correlations between NDVI and yield and HVI values.

parameter	Overall correlation with NDVI	Correlation extremes among varieties across sites	
		Maximum	Minimum
Yield	0.765	0.960	0.487
Micronaire	-0.536	-0.273	-0.898
Length	-0.327	-0.020	-0.816
Strength	-0.408	-0.177	-0.846

Conclusions

Although many studies have addressed the response of NDVI to differences in N rate and other factors, fewer have looked at how NDVI varies among varieties and environments for similarly managed cotton crops like those in an OVT. While differences were observed in the NDVI values, this initial comparison did not indicate large differences within a site. Correlations between NDVI and yield were weak for all but the Rhodes location; however, comparing a single variety across environments, analogous to many Mid-South field situations, showed more consistent values. Additional years of observations will be needed to better understand the relationships observed in this study.

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