SPECTRAL CHARACTERISTICS OF POTASSIUM DEFICIENCIES IN MULTIPLE COTTON CULTIVARS AT THE CANOPY SCALE

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Abstract

The spatial variability of nitrogen (N) and the spectral response of crops to N have resulted in the utilization of canopy reflectance indices to drive on-the-go, variable rate applications of fertilizer N (VRN). However, spectral response to variety and available potassium (K) are not typically considered in the development of these indices. Response of each index to these variables must be considered to prevent inaccurate N applications and subsequent environmental and financial repercussions. The objective of this research was to examine the response of two contrasting indices to variety and available K. A randomized strip, complete block trial with five replications was conducted in 2012 at the Lon Mann Cotton Research Center in Marianna, AR. Prior to planting, soil samples were taken from each plot and analyzed. Treatments consisted of an untreated check, 30, 60, and 90 lb applied K_2O/acre to Phytogen 499 WRF, Stoneville 5458 B2RF, and DeltaPine 912 B2RF varieties. Reflectance measurements were taken by the Crop Circle ACS-470 (Holland Scientific Inc., Lincoln, NE). Measured wavelengths were used to calculate the Normalized Difference Vegetation Index (NDVI) and the Canopy Chlorophyll Content Index (CCCI). Interaction effects between available K and variety on NDVI were significant ($p \leq 0.10$), however, CCCI was only significantly affected by variety ($p \leq 0.05$). Results suggest NDVI based algorithms have the potential to recommend excessive fertilizer N quantities when K deficiencies are present. In contrast, CCCI does not appear to be susceptible to such errors. Still, both indices will require some correctional factor to adjust for varietal effects.

Introduction

The use of on-the-go, canopy reflectance sensors to drive VRN has increased in recent years in part due to volatile fertilizer prices and increased numbers of VRN-capable application equipment. Although the spectral response of crops to N stress has been thoroughly defined (Samborski et al., 2009), the spectral responses to changes in variety, available K, and many other variables have not been examined in such detail. As a result, sensitivities of these indices to variables other than N have been shown to result in over application of N when N is not the most limiting yield factor (Zillman et al., 2006).

While K deficiencies in many crops are not a major concern for sensor-driven VRN, cotton is particularly susceptible to the deficiency and often displays symptoms under K statuses in which other crops do not (Cope, 1981; Gulick et al., 1989). Cotton K deficiences have also been described as unpredictable (Oosterhuis, 2002), likely due to observations of deficiency symptoms under sufficient soil K levels (Cope, 1981). Although studies examining the response of cotton reflectance to changes in K are limited in number, moderate relationships of leaf reflectance and N status have been show to deteriorate when K is insufficient (Fridgen and Varco, 2004).

The large spectrum of structural features and maturities encompassed by modern cotton varieties is also troubling for sensor-driven VRN. Varietal characteristics of leaf area, canopy expansion and structure are particularly important to reflectance measurements, as only slight increases in soil interference can drastically change measurements of some wavelengths (Huete et al., 1985). More recent research has reported ground-based, sensor-measured NDVI to be sensitive to varietal characteristics during the flowering period, with relationships deteriorating later in the growing season (Benitez Ramirez and Wilkerson, 2010).

Consequently, response of each sensor-utilized index to changes in these variables must be considered to prevent inaccurate N applications and subsequent environmental and financial repercussions. Therefore, the main objective of this research was to examine the response of two contrasting indices to variety and changes in available K.

Materials and Methods

A randomized strip, complete block trial with five replications was conducted in 2012 at the Lon Mann Cotton Research Center in Marianna, AR. Soil samples were taken from bed shoulders at 6 inch depths from each plot (60 total plots) on 31 January 2012 and analyzed (Mehlich-3 extraction) by the University of Arkansas Soil Testing Laboratory in Marianna, AR. Treatments consisted of an untreated check (0 lb K_2O/acre), 30, 60, and 90 lb K_2O/acre applied to Phytogen 499 WRF, Stoneville 5458 B2RF, and DeltaPine 912 B2RF varieties. Cotton was planted on 8 May 2012 at a plant density of 3.5 plants/foot. Plots consisted of four rows, 50 feet in length. Row spacing was 38 inches. Fertilizer N was applied in a split application (60% at emergence and 40% at first square) to total 100 lb N per acre. All other inputs and thresholds were established and maintained to isolate K as the sole yield-restricting input.

Reflectance measurements were taken every two weeks beginning prior to first flower (7 July 2012) and ending after peak flower (22 August 2012) using the Crop Circle ACS-470 (Holland Scientific Inc., Lincoln, NE). The center two rows of each plot were measured at a sensor-to-canopy height of 36 inches. The three measured wavelengths were centered in the red (650 nm), red-edge (730 nm) and near infrared (760 nm) regions. Data was trimmed to exclude values taken within 5 feet of the plot ends. These wavelengths were then used to calculate two contrasting indices: NDVI, which has been shown to be sensitive to changes in plant structure and biomass (Bronson et al., 2003), and the Canopy Chlorophyll Content Index (CCCI) which has a heightened sensitivity to N stress and is less responsive to changes in plant biomass than NDVI (Raper and Varco, 2011).

$$NDVI = \frac{R_{760} - R_{550}}{R_{760} + R_{550}}$$ Rouse et al., 1974

$$NDRE = \frac{R_{760} - R_{730}}{R_{760} + R_{730}}$$ Barnes et al., 2000

$$CCCI = \frac{\text{NDRE}}{\text{NDVI}}$$ Clarke et al., 2001

Seedcotton yield was determined by mechanically harvesting the center two 50 foot rows of each plot. Regression analysis tested the response of seedcotton yield and index readings to changes in available K_2O. Analysis of variance was conducted for both reflectance dates and yield data in JMP 10 (SAS Institute Inc., Cary, NC). Independent variables in the model included block, available K, variety, and the interaction between available K and variety. The calculated amount of available K was chosen in lieu of the applied K fertilizer rate due to initial differences in soil K concentrations (Table 1). Available K_2O was calculated as [(ppm soil test K × 2 × 1.2) + lb K_2O fertilizer/acre] where 1.2 is the factor for converting K to K_2O and 2.0 is the factor for converting ppm to lb/acre assuming 2 million pounds soil/acre furrow slice.

Table 1: Soil test K (Mehlich-3) results and calculated available K_2O concentrations from soil samples taken January 2012 in Marianna, AR.

Replication	Mehlich-3-extractable soil potassium (ppm)		
	Min	Mean	Maximum
1	63	86	135
2	67	95	133
3	96	122	139
4	80	109	147

Replication	Calculated available soil potassium (lb K_2O/acre)[a]		
	Min	Mean	Maximum
1	181	259	349
2	160	258	349
3	260	341	391
4	232	316	442

[a]Calculated available soil K represents a conversion of soil parts per million (ppm) to lb of available K_2O per acre added to lb of applied K_2O fertilizer, with 100% availability of applied fertilizer assumed.

Results

Seedcotton yields

The response of seedcotton to changes in variety and available K_2O were significant ($p \leq 0.05$), as was the interaction between these two terms ($p \leq 0.10$) (Figure 1). Results suggest increases in available K_2O did not significantly increase Phytogen 499 seedcotton yields, but did increase DeltaPine 912 and Stoneville 5458 yields. As evident by the available K_2O levels and relatively high yields, severe K deficiencies were not noted. Sufficient soil K may have contributed to the failure of Phytogen 499 yields to respond to increased available K_2O. Still, the moderately strong response of Stoneville 5458 and slight response of DeltaPine 912 does suggest that increased K_2O availability could increase yields within this range for these two varieties.

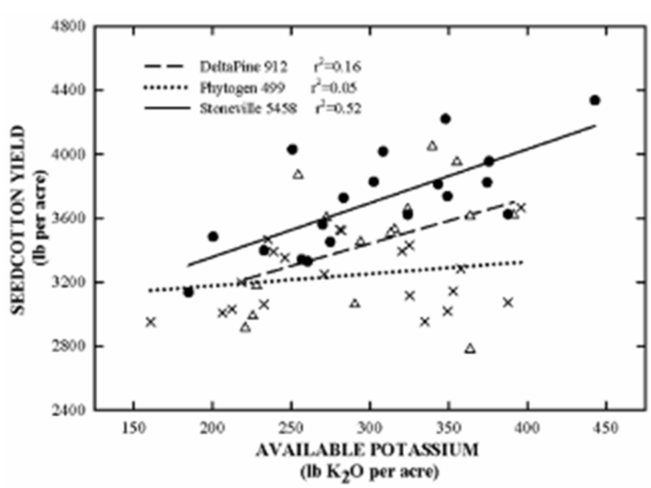

Figure 1: Response of seedcotton yield to available K_2O during the 2012 growing season.

NDVI and CCCI

Visible K deficiency symptoms were noted in control plots during the first week of flower in Stoneville 5458 plots, but were not consistent across the field until near peak flower. As a result, this paper will focus on reflectance measured near peak flower (7 August 2012) and after peak flower (22 August 2012). Visible differences noted on 22 August 2012 are shown in Figure 2 and Figure 3. Although noticeable visual K deficiencies were evident in the check DeltaPine 912 and Stoneville 5458 plots, noticeable differences were not noted in the Phytogen 499 check plots (Figure 3). Measured sensor responses from both included sampling dates were similar. The interaction effects between available K_2O and variety on NDVI readings were significant at both dates ($p \leq 0.10$) (Figure 4 and

Table 2). These results suggest NDVI is sensitive to variety and changes in available K_2O. The interaction between variety and available K_2O suggests that individual models will have to be developed to characterize specific NDVI response to an individual variety's sensitivity to changes in available K_2O. However, CCCI was significantly affected by variety alone ($p \leq 0.05$) (Figure 4). This suggests that a variety specific correction term could be developed and implemented for CCCI readings. It should be noted that significant response of an index to variety will be highly preferred over the response of an index to available K_2O, as variety is spatially consistent.

Figure 2: Visible differences from the variety and potassium treatments in Marianna, AR on 22 August 2012.

Figure 3: Visual deficiency characteristics between 0 and 90 lb applied K_2O per acre treatments in all three tested varieties.

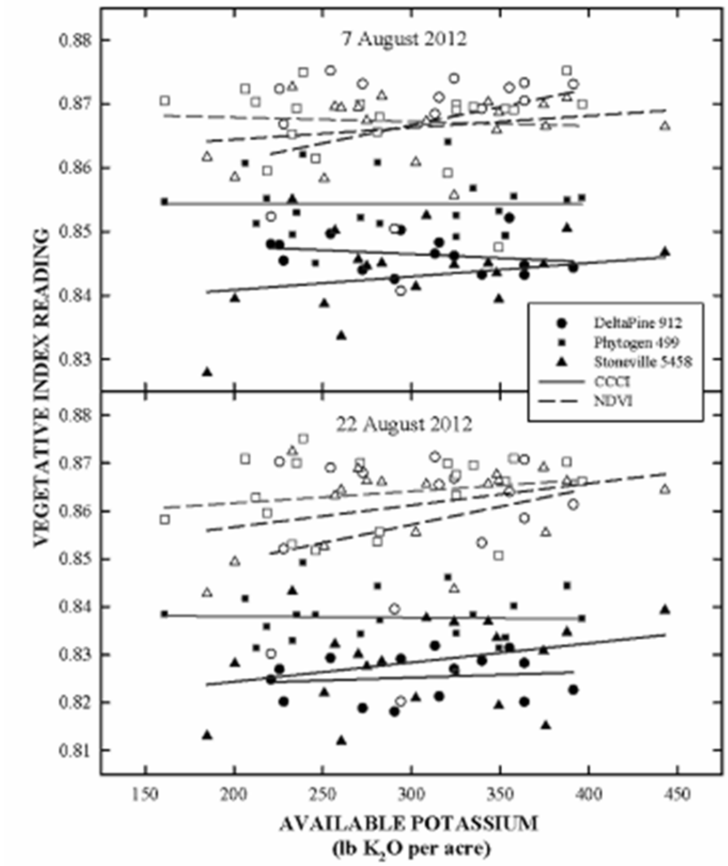

Figure 4: Response of the Normalized Difference Vegetation Index (NDVI) and the Canopy Chlorophyll Content Index (CCCI) by variety to changes in available K_2O.

Table 2: Coefficient of determinations (r^2) for response of the Normalized Difference Vegetation Index (NDVI) and the Canopy Chlorophyll Content Index (CCCI) by variety to changes in available K_2O.

Variety	Coefficient of Determination (r^2)			
	Canopy Chlorophyll Content Index (CCCI)		Normalized Difference Vegetation Index (NDVI)	
	7 Aug	22 Aug	[a]7 Aug	[a]22 Aug
DeltaPine 912	0.000	0.001	0.004	0.046
Phytogen 499	0.056	0.019	0.090	0.069
Stoneville 5458	0.038	0.086	0.064	0.122

[a]Interaction term of variety and available K_2O was only significant for NDVI ($p \leq 0.10$).

The relationships between seedcotton yield and reflectance data collected on 22 August 2012 displayed slight increases in NDVI as seedcotton yield increased, while CCCI readings decreased very slightly (Figure 5). Since increases in seedcotton yield were due to increases in available K, results from this analysis again suggest NDVI may be more sensitive to available K than CCCI; however, this response is weak.

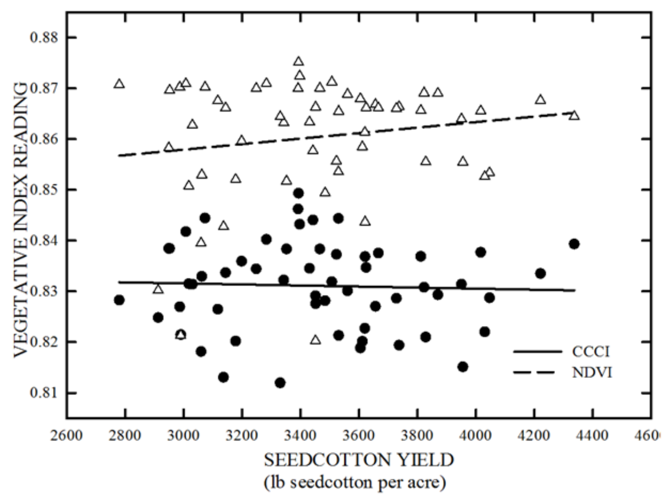

Figure 5: Response of the Normalized Vegetation Index (NDVI) and the Crop Canopy Chlorophyll Index (CCCI) to seedcotton yields.

Conclusions

Significant increases in yield due to increases in available K were noted in the Stoneville 5458 and DeltaPine 912 varieties. Similarly, deficiency symptoms in these two varieties were much more pronounced than in the Phytogen 499 variety. Significant responses of both CCCI and NDVI to changes in variety suggest some correctional factor for variety must be developed before on-the-go sensors utilizing these indices can be accurately used to drive VRN. Furthermore, significant increases of NDVI as available K increased suggests NDVI based algorithms have the potential to recommend increased fertilizer N when K deficiencies are present. In contrast, CCCI does not appear to be as susceptible to such errors.

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