TEMPORAL VARIABILITY OF SPECTRAL REFLECTANCE AND ESTIMATED CANOPY COVER OF COTTON PLANTS SUPPORTS EARLY DETECTION OF POTENTIAL BOLL WEEVIL INFESTATIONS

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Abstract

Boll weevils may infest cotton fields when plants begin to produce squares, but eradication program managers may not be notified of fields that have been planted with cotton until after plants are already blooming. Because pheromone traps become much less effective in detecting weevil populations when plants begin to produce fruiting structures, early detection of these potential host fields is critically needed to expedite eradication in South Texas. We acquired a temporal sequence of airborne multispectral images of experimental cotton plots and six production cotton fields from planting until first bloom. Multispectral images of cotton fields were analyzed to associate characteristic spectral reflectance values with plant width. Timely area wide detection of pre-fruiting cotton will aid eradication programs in identifying, mapping, and trapping cotton fields, and, subsequently, reduce the incidence of boll weevil populations escaping detection.

Introduction

Timely notification of fields planted in cotton is critical for boll weevil eradication programs to effectively map, trap, and treat the respective fields. However, eradication program managers may receive late or no notification of some cotton fields. Delayed deployment of pheromone traps at unreported fields increases the risk of boll weevil infestations that may remain undetected. New techniques are needed to help eradication program managers identify cotton fields in a timely manner.

Satellite-based and airborne remote sensing techniques have been used to quantify the growth of cotton and other vegetation types over large areas, often with an emphasis on fully-developed plant canopies during the growing season (Yang et al. 2007, 2011). More recently, airborne remote sensing of regrowth cotton using high-spatial-resolution multispectral images has been reported (Yang et al. 2013; Westbrook et al. 2013). One multispectral parameter known as the green normalized difference vegetation index (GNDVI) has been used to estimate plant leaf area index and biomass (Hunt et al. 2008). However, in order to aid in early detection of cotton fields, airborne remote sensing techniques need to be evaluated from planting to first bloom.

The objective of this study was to examine the relationship between GNDVI and cotton development (primarily plant width) to determine whether airborne multispectral images could be used to accurately classify early-season development of cotton plants.

Methods

Six production cotton fields and an experimental cotton field in the Brazos Valley near College Station, TX, were selected for the remote sensing study. The experimental field at the Texas A&M University farm was comprised of four cotton plots (16 rows by 20-m length) that were planted on 15 April 2013. The height, width, number of nodes, and growth stage of ten randomly-selected cotton plants were measured within each production field and within each plot of the experimental cotton field on each sampling date. Field samples were collected on 7 May, 23 May, 30 May, 4 June, 17 June, and 2 July. No data were collected from the production cotton fields on 2 July.

Airborne multispectral imaging of the cotton fields was conducted using a two-camera imaging system (Yang et al. 2013; Westbrook et al. 2013). A Cessna 206 fixed-wing aircraft equipped with two nadir-oriented, Canon 5D Mark II digital cameras captured 21-MP images defined by a 5616 x 3744 array of 16-bit pixels. One camera recorded a color image (broadband red-green-blue, RGB) and the other camera recorded a near-infrared image (broadband NIR). Airborne multispectral images (561.6-m x 374.4-m viewing area with 0.1-m pixel resolution) were acquired at a flight altitude of approximately 305 m AGL.

The RGB and NIR images were processed to create four-band multispectral images. Concurrent pairs of RGB and NIR images were imported into Idrisi Taiga (Clark Labs, Worcester, MA). Seven to ten control points were selected for image rectification using locations of obvious features such as trees and fence posts. Generated maps were rectified using linear transformation with nearest neighbor interpolation to correct for misalignment of the RGB and NIR images. A raster group file was created that contained each of the four spectral band images (red, green, blue, NIR). A 15 m x 20 m area of interest (AOI) (approximately 150 x 200 pixels) was defined for each plot and a 20 m x 20 m AOI (approximately 200 x 200 pixels) for each production field. Pixel arrays were extracted using the AOI on each spectral band for use in statistical analysis of multispectral reflectance.

The dimensionless green normalized difference vegetation index (GNDVI) was related to the mean growth stage of cotton plants using linear regression. The GNDVI is defined as: GNDVI = (NIR – green) / (NIR + green). Linear regression of plant width and GNDVI was analyzed using Proc Reg in SAS v. 9.3 (SAS Institute, Cary, NC).

Results

Field measurements were collected from 7 May through 2 July covering the period when cotton plants in experimental plots at the Texas A&M University farm in Burleson Co. grew from cotyledon to boll stage (Table 1). Cool temperatures in April and early May led to early growth of leggy plants in the experimental plots. An overcast sky reduced all spectral reflectance values on 23 May, but the normalized indices (NDVI and GNDVI) did not appear to be substantially affected by the sub-optimal spectral reflectance. By 17 June, 70% of the cotton plants in the experimental plots had developed squares (matchhead or larger).

Table 1. Mean growth characteristics and spectral reflectance of experimental cotton plots at the Texas A&M University farm, Burleson Co., TX in 2013.

	Height	Width			Spectral Reflectance (DN)					
Date	(cm)	(cm)	Nodes	Growth Stage	Red	Green	Blue	NIR	NDVI	GNDVI
7 May	4.8	3.9	0.0	100% co	19009	15540	11812	19297	0.007	0.107
23 May	11.4	8.2	5.3	100% ve	7741	6381	5096	8406	0.041	0.137
30 May	17.9	14.2	7.7	30% ph	17333	13871	11037	17457	0.003	0.114
4 June	22.1	23.1	9.4	88% ph	13507	11019	8137	20781	0.212	0.307
17 June	46.8	44.3	12.5	70% mh	14110	12279	8758	26614	0.302	0.364
2 July	63.8	56.8	.	100% bo	12186	12091	7537	32152	0.450	0.453

co=cotyledon, ve=vegetative, ph=pinhead, mh=matchhead or larger square, bo=boll

Substantial differences were observed in the development of cotton plants among the six production cotton fields (Table 2). Plants in the production fields were at the vegetative stage on 7 May. Pinhead squares were observed in at least one field by 22 May. Bloom tags were found in some fields on 31 May. The mean size of plants in producer fields was greater than in the experimental plots, although the differences diminished by 17 June.

Table 2. Mean growth characteristics and spectral reflectance of six production cotton fields, Burleson Co., TX in 2013.

Date	Height (cm)	Width (cm)	Nodes	Growth Stage	Spectral Reflectance (DN) Red	Green	Blue	NIR	NDVI	GNDVI
7 May	11.4	11.4	5.6	100% ve	20644	16610	12963	19668	-0.024	0.084
22 May	12.5	14.1	7.2	100% ve – 100% ph	11684	9588	6907	12932	0.048	0.144
31 May	24.0	28.8	10.7	70% ph – 30% tg	17264	14334	10489	19208	0.052	0.143
4 June	27.6	34.1	11.6	100% ph – 50% tg	16477	14037	10273	27855	0.259	0.330
17 June	47.3	48.6	14.3	20% mh – 50% bo	13652	11822	8222	26284	0.335	0.388

ve=vegetative, ph=pinhead, mh=matchhead or larger square, tg=bloom tag, bo=boll

Mean values of plant width and GNDVI increased slowly through 30 May and increased more rapidly thereafter. Fig. 1 shows the temporal patterns of mean plant width and GNDVI for an experimental cotton field at the Texas A&M University farm. Similar temporal patterns of mean plant width and GNDVI were observed among the six production cotton fields (Fig. 2). Linear regression of mean plant width and GNDVI for the experimental cotton field was calculated to be $y = 1.32x – 0.07$ (adj. $r^2 = 0.80$; c.v. = 31.6) (Fig. 3). Linear regression of mean plant width and GNDVI for the six production fields revealed a smaller slope (i.e., mean plant width increased more slowly with increases in GNDVI), resulting in the equation $y = 0.98x + 0.08$ (adj. $r^2 = 0.64$; c.v. = 28.5) (Fig. 4).

No matchhead or larger squares were observed in the experimental cotton field until after the 4 June sampling date. Therefore, cotton fields for which GNDVI ≤ 0.31 (e.g., as for a mean plant width of 23.1 cm in the experimental cotton field on 4 June) could be identified and reported to eradication program managers for critical field mapping and trap deployment before possible weevil infestation.

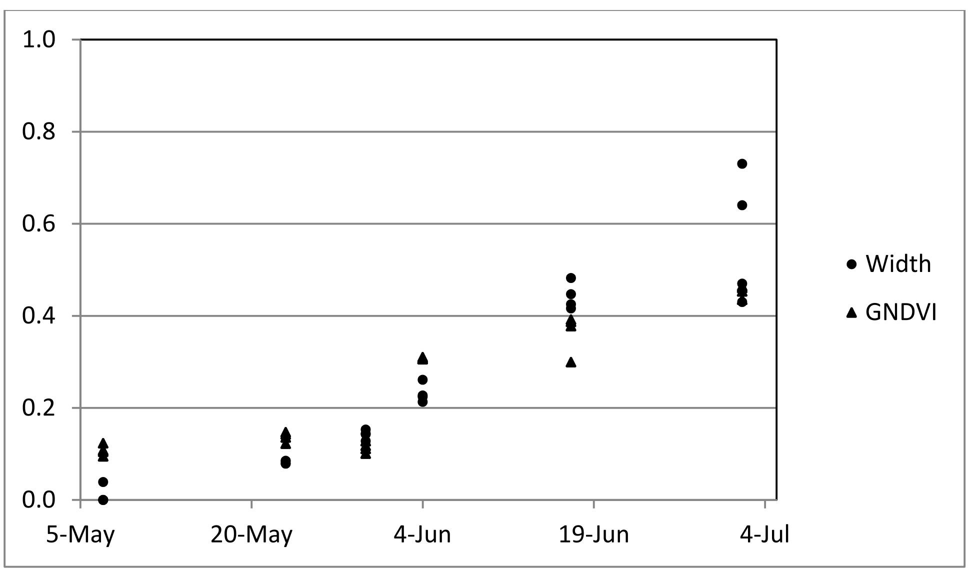

Figure 1. Mean plant width (m) and green normalized difference vegetation index (GNDVI) of experimental cotton plots at the Texas A&M University farm, Burleson Co., TX, in 2013.

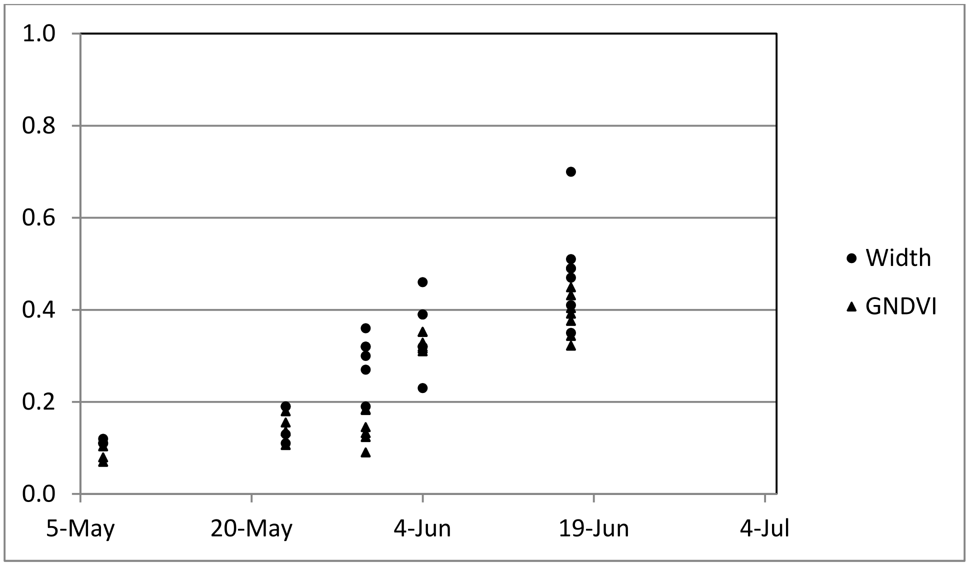

Figure 2. Mean plant width (m) and green normalized difference vegetation index (GNDVI) of six production cotton fields in the Brazos Valley, Burleson Co., TX, in 2013.

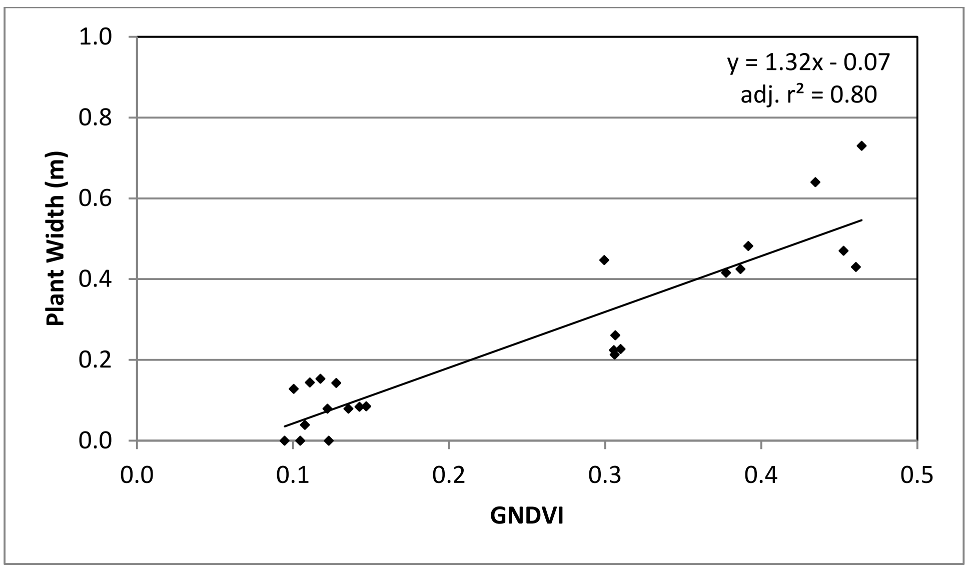

Figure 3. Linear regression of green normalized vegetation index (GNDVI) and mean plant width for experimental cotton plots at the Texas A&M University farm, Burleson Co., TX, in 2013.

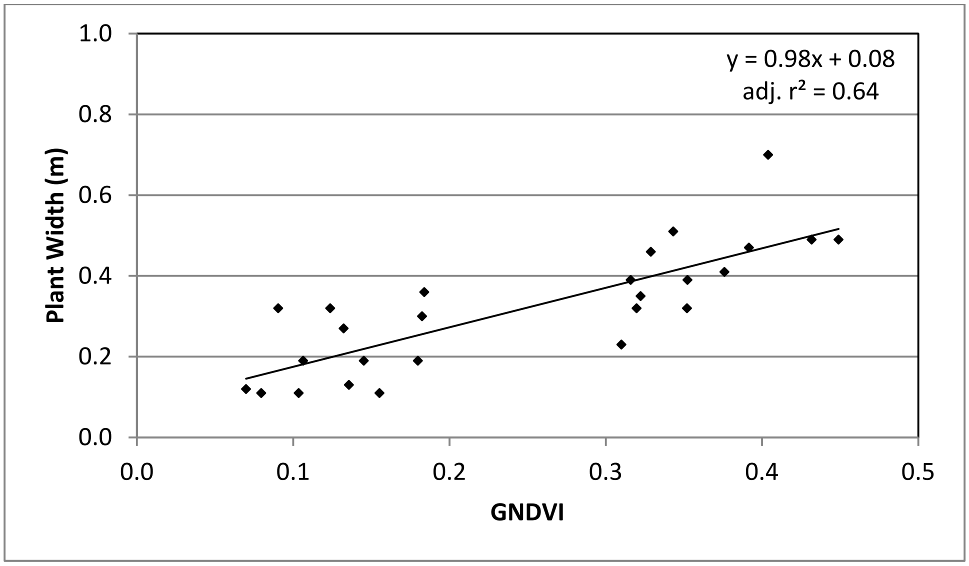

Figure 4. Linear regression of green normalized vegetation index (GNDVI) and mean plant width of six production cotton fields in the Brazos Valley, Burleson Co., TX, in 2013.

Discussion

The results show that GNDVI can be used to estimate the width of cotton plants during the period from cotyledon to first bloom. Although GNDVI accounted for 80% of the variation of mean plant width in an experimental cotton field, GNDVI accounted for only 64% of the variation of mean plant width among six production fields. Although efforts were made to extract and analyze multispectral data only for areas within each field where plant sampling data were collected, between-field variation in the density and type of weeds, soil condition, fertilization, planting date, etc. may account for much of the unexplained variation in mean plant width.

A data gap in the range of $0.2 \leq \text{GNDVI} \leq 0.3$ was unexpected given that multispectral measurements which spanned this range were made within a week of one another. Additional data points in the range of $0.2 \leq \text{GNDVI} \leq 0.3$ may reveal information that will enhance the detection of cotton fields which are beginning to enter the reproductive stage.

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