REMOTE IDENTIFICATION OF POTENTIAL BOLL WEEVIL HOST PLANTS: AIRBORNE MULTISPECTRAL DETECTION OF REGROWTH COTTON

John K. Westbrook
Charles P.-C. Suh
Chenghai Yang
Yubin Lan
Ritchie S. Eyster
USDA-ARS, Areawide Pest Management Research Unit
College Station, TX

Abstract

Regrowth cotton plants can serve as potential hosts for boll weevils during and beyond the production season. Effective methods for timely area wide detection of these host plants are critically needed to expedite eradication in south Texas. We acquired airborne multispectral images of experimental regrowth cotton fields that contained various developmental stages, sizes, and densities of cotton plants. Airborne multispectral and ground-based hyperspectral reflectance measurements of cotton plants and soil were analyzed using the linear spectral unmixing technique to identify 'pure' image pixels of cotton and 'fuzzy' image pixels of cotton mixed with soil. The capability to accurately detect cotton plants from medium- or high-resolution images could result in earlier detection and subsequent management of regrowth cotton plants on an area wide basis.

Introduction

Improved detection of volunteer and regrowth cotton plants, both of which can serve as hosts for boll weevils during and beyond the production season, is critical for completing eradication in central and south Texas. South Texas is susceptible to heavy rains that often impede cotton stalk destruction and promote regrowth of cotton plants (Summy et al. 1986). However, given the expansive cotton acreage and habitat diversity that can support volunteer cotton plants, timely detection of such plants is a challenging process. Technology such as aerial remote sensing may be useful for detecting re-growth and volunteer plants over large areas. Preliminary work with multispectral and hyperspectral sensors indicates that cotton plants possess unique spectral reflectance properties that can be used to distinguish cotton plants from other row crops (Zhang et al. 2012). However, this work needs to be expanded to include spectral signatures of image pixels containing mixed plant coverage.

Airborne multispectral images of fields containing specific developmental stages, sizes, and stand densities of cotton plants intermixed with and without other vegetation can be acquired efficiently over large areas. However, ground-based observations of plant distribution and growth characteristics are needed to associate spectral reflectance values of cotton plants with actual plant distributions that vary by location and date. New information is needed to derive the likelihood that volunteer and re-growth cotton plants contribute to the spectral reflectance of "fuzzy" individual image pixels that also incorporate spectral reflectance from the soil and various plant types. The use of the linear spectral unmixing (LSU) technique (Yang et al. 2007) may provide the capability to accurately detect cotton plants from 'fuzzy' images, and could result in earlier detection of small cotton plants and increased utility of medium-resolution images covering large areas.

The objective of this study was to apply airborne remote sensing techniques to compare spectral properties of regrowth cotton plants and estimate the canopy coverage of regrowth cotton plants.

Materials and Methods

An experimental field in Burleson County, TX was prepared and planted with cotton (Deltapine 1050) on 1.02-m (40-inch) rows. A non-shredded control and three treatments sprayed with defoliant (Thidiazuron 4 SC, Arysta Lifescience North America Corp., Cary, NC) on 16 July, 30 July, and 13 Aug., and shredded on 30 July, 13 Aug., and 27 Aug. were replicated four times (blocks) in a randomized complete block design to produce various stages of regrowth cotton plants. Each treatment plot (50 rows of 15.24-m (50-foot) length) was divided in half to yield a total of 32 sub-plots (eight sub-plots of 24 rows each per treatment).
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 of the cameras recorded a color image (broadband red-green-blue, RGB) and the other 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 from flights at an altitude of

approximately 309 m AGL. Four reflectance tarps (4%, 16%, 32%, and 48%) near the field were present within the field of view of each airborne multispectral image. Multispectral imaging flights and ground-based hyperspectral measurements (described below) were made on 29 June, 16 July, 26 July, 9 Aug., 22 Aug., 6 Sept., 20 Sept., 4 Oct. and 19 Oct. before the mandatory cotton stalk destruction date of 31 Oct. (extended to 15 Nov. 2012).

Ground-based hyperspectral reflectance measurements of 10 cotton plants and five bare soil locations were acquired on multiple dates in each sub-plot using a Fieldspec Handheld2 hyperspectral instrument (Analytical Spectral Devices, Inc., Boulder, CO). A dark current and white reference measurement of a spectralon reflectance disk was recorded to initially calibrate the system, and thereafter before acquiring hyperspectral reflectance measurements in each sub-plot. Twenty hyperspectral reflectance measurements of the four reflectance tarps were used to establish the regression fit between the absolute digital number and relative value of airborne multispectral reflectance for each of the four spectral bands.

The RGB and NIR images were processed to create 4-band multispectral images. Concurrent pairs of RGB and NIR images were imported into ArcMap 10.1 (Esri, Redlands, CA). A minimum of nine control points (three each on the left, center, and right sections of the images) were selected using the locations of obvious features such as trees and fence posts. To correct for misalignment of the RGB and NIR images, maps were rectified using linear transformation with nearest neighbor interpolation. The rectified images were saved in Erdas Imagine format and imported to Idrisi Taiga GIS and Remote Sensing software (Clark Labs, Worcester, MA) using the ErdIdris module with Erdas Imagine format. A raster group file was created that contained each of the four spectral band images (red, green, blue, NIR). A 10 m x 15 m area of interest (AOI) was created in the center of each sub-plot from the multispectral images from which 100 x 150 pixel arrays were extracted for use in multispectral analysis. Multispectral reflectance values of 'pure' pixels of soil and cotton plants were extracted from several locations in the AOI. Multispectral reflectance signature files of soil and cotton plants were created using the makeSig module in Idrisi. Linear spectral unmixing classification was performed using the four spectral bands and two signature files. Histograms of estimated surface identity (soil and/or cotton) were generated to estimate percent canopy cover of cotton plants. The Histo module was performed to create histograms of the soil and cotton multispectral reflectance signature files, and to calculate mean digital number (DN) values of each of the four multispectral bands for soil and cotton. The mean DN values for each band were entered into the EndSig module to create signature group files from the two EndSig signatures for soil and cotton.

Additionally, the height and width of ten cotton plants were measured within each sub-plot on each sampling date to provide supporting biological information.

Results and Discussion

A sequence of nine airborne color images of the experimental regrowth cotton field displays the visual characteristics of the sub-plots just prior to and following the treatments (Figure 1). The two upper panels (29 June and 16 July) show uniform vegetative growth in all sub-plots, which is consistent with the pre-treatment phase of the study. The panel for 26 July reveals a sparser plant canopy in the first set of sub-plots that had been treated with defoliant; subsequently, the panels for 9 Aug., 22 Aug., and 6 Sept. represent the first, second, and third shredding treatments, respectively. Therefore, only panels for 6 Sept., 20 Sept., 4 Oct., and 19 Oct. represent images on dates when all sub-plots were post-treatment.

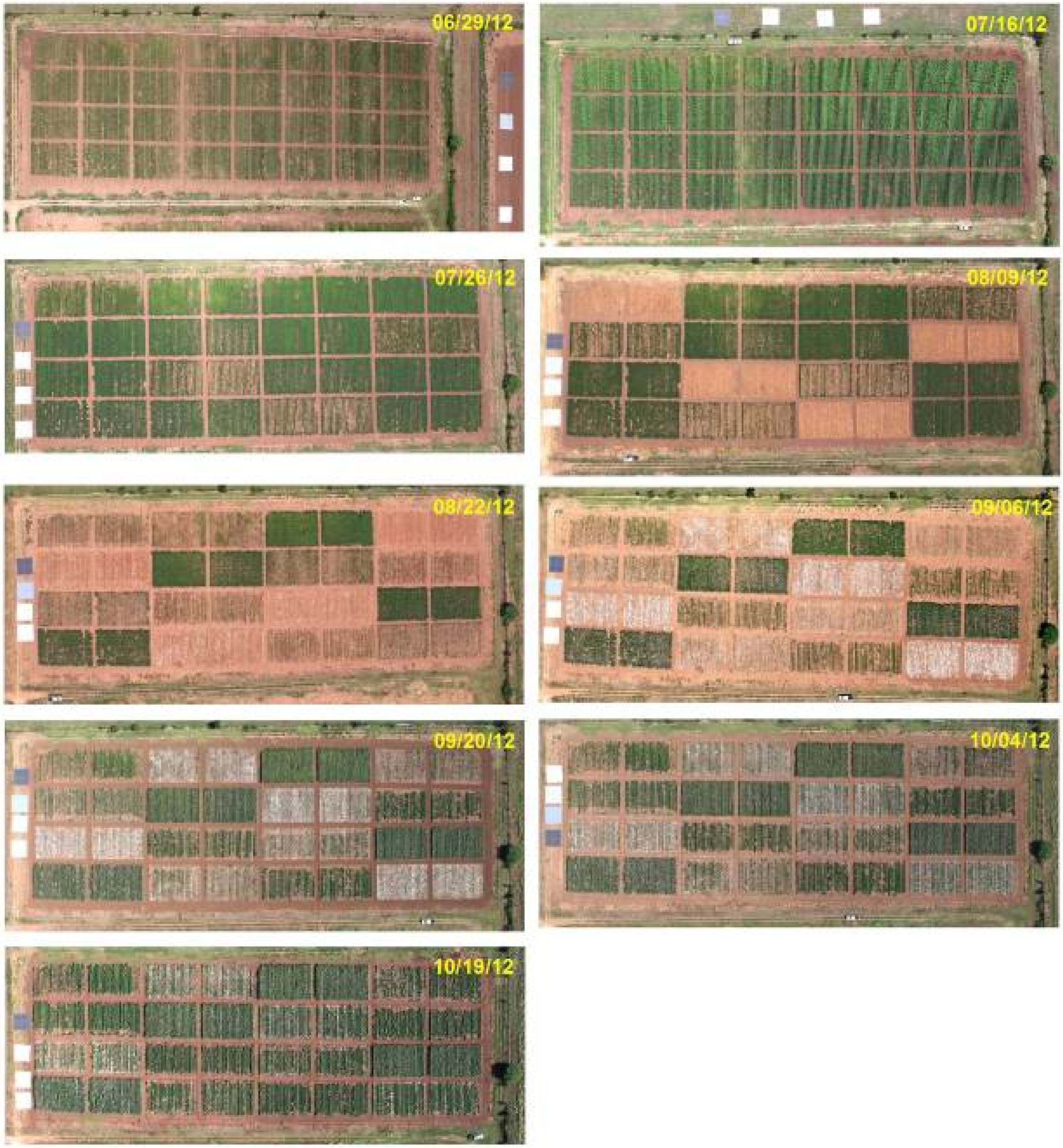

Figure 1. Airborne color images of regrowth cotton plots and reflectance calibration tarps in Burleson Co., TX, in 2012.

Mean spectral reflectance and plant growth characteristics were derived for sub-plots assigned to each shredding date. Table 1summarizes the mean spectral reflectance and reflectance indices for the pre-treatment date of 29 June and the four post-treatment dates (6 Sept., 20 Sept., 4 Oct., and 19 Oct.). There were no significant differences between mean values of the four spectral bands, NDVI, or GNDVI for any of the sub-plot groups on 29 June. Mean red, green, and blue reflectance values of regrowth cotton sub-plots converged toward the reflectance values of the control sub-plots as the growing season progressed. Mean NIR reflectance values were not significantly different among shredding treatments but were significantly different from the control until 4 Oct. when mean NIR reflectance values of the earliest shredded sub-plots were not significantly different from those of the control sub-plots. NDVI and GNDVI values were significantly different among all shredding treatments and the control through 20 Sept. However, NDVI and GNDVI values were not significantly different between the earliest shredding treatment and the control on 4 Oct., and were not significantly different between the two earliest shredding treatments and the control on 19 Oct.

The size of regrowth cotton plants remained significantly different from the size of cotton plants in the control plots (Table 2). The regrowth cotton plants were smaller and shorter than the cotton plants in the control plots. Also, the heights of regrowth cotton plants were significantly different among shredding treatments through 4 Oct. However, there was no significant difference in plant height between the 30 July and 13 Aug. shredding treatments on 19 Oct. Regrowth cotton plant width was significantly different among shredding treatments through 20 Sept., after which there was no significant difference in plant width between the 13 Aug. and 27 Aug. shredding treatments.

Table 1. Mean spectral reflectance and reflectance indices of regrowth cotton plots in Burleson County, TX, in 2012.

		Shred Date			
Date	Feature	30 July	13 Aug.	27 Aug.	Control
29 June	Red band	0.0881A	0.0857A	0.0914A	0.0893A
	Green band	0.0847A	0.0838A	0.0866A	0.0851A
	Blue band	0.0337A	0.0333A	0.0344A	0.0344A
	NIR band	0.3583A	0.3677A	0.3592A	0.3618A
	NDVI	0.6051A	0.6249A	0.5951A	0.6064A
	GNDVI	0.6160A	0.6284A	0.6114A	0.6199A
6 Sept.	Red band	0.0878C	0.1231B	0.1520A	0.0469D
	Green band	0.1285C	0.1628B	0.2078A	0.0977D
	Blue band	0.0604C	0.0864B	0.1239A	0.0455D
	NIR band	0.3091B	0.2903B	0.3134B	0.3858A
	NDVI	0.5561B	0.4044C	0.3463C	0.7820A
	GNDVI	0.4119B	0.2819C	0.2021D	0.5950A
20 Sept.	Red band	0.0390C	0.0643B	0.0928A	0.0268C
	Green band	0.0564C	0.0756B	0.1072A	0.0540C
	Blue band	0.0345C	0.0564B	0.0922A	0.0331C
	NIR band	0.2784B	0.2437B	0.2307B	0.3573A
	NDVI	0.7508B	0.5793C	0.4300D	0.8605A
	GNDVI	0.6626B	0.5234C	0.3679D	0.7369A
4 Oct.	Red band	0.0358C	0.0548B	0.0759A	0.0297C
	Green band	0.0530B	0.0677B	0.0912A	0.0538B
	Blue band	0.0316C	0.0472B	0.0725A	0.0350BC
	NIR band	0.2958AB	0.2631B	0.2507B	0.3283A
	NDVI	0.7819A	0.6498B	0.5405C	0.8348A
	GNDVI	0.6940A	0.5859B	0.4696C	0.7188A
19 Oct.	Red band	0.0333B	0.0390AB	0.0583A	0.0370AB
	Green band	0.0449B	0.0492B	0.0634A	0.0522B
	Blue band	0.0159B	0.0178B	0.0285A	0.0209AB
	NIR band	0.3155A	0.2930A	0.2791A	0.3305A
	NDVI	0.8061A	0.7603AB	0.6641B	0.7994A
	GNDVI	0.7485A	0.7089AB	0.6345B	0.7280A

Row means identified with the same letter are not significantly different at $\alpha = 0.05$.

Table 2. Mean plant height (cm) and plant width (cm) in regrowth cotton plots in Burleson County, TX, in 2012.

		Shred Date			
Date	Feature	30 July	13 Aug.	27 Aug.	Control
29 June	Plant height	66.0A	68.6A	64.7A	65.9A
	Plant width	57.0A	60.4A	58.3A	58.2A
6 Sept.	Plant height	45.9B	24.8C	11.7D	106.0A
	Plant width	45.2B	24.4C	7.3D	91.0A
20 Sept.	Plant height	57.2B	37.8C	23.4D	109.5A
	Plant width	53.4B	37.1C	23.7D	90.0A
4 Oct.	Plant height	63.0B	49.6C	32.3D	111.9A
	Plant width	63.8B	46.6C	35.3C	86.0A
19 Oct.	Plant height	69.5B	62.9B	49.1C	116.1A
	Plant width	71.7B	57.8C	50.3C	100.5A

Row means identified with the same letter are not significantly different at $\alpha = 0.05$.

The proportion of canopy cover of the regrowth cotton plots and control plot was estimated using the LSU technique (Figure 2). The estimated canopy cover for the three shredding treatments followed the expected pattern of a steep decrease in canopy cover after defoliation and shredding, and a steep increase in canopy cover during the regrowth phase. By the end of the study (19 Oct.), the estimated canopy cover ranged from about 0.45 to 0.55 as compared to about 0.75 for the control plots. The estimated canopy cover for the control plots declined from a peak of about 0.9 on 9 Aug. and leveled out at about 0.6 until increasing to about 0.75 on 19 Oct.

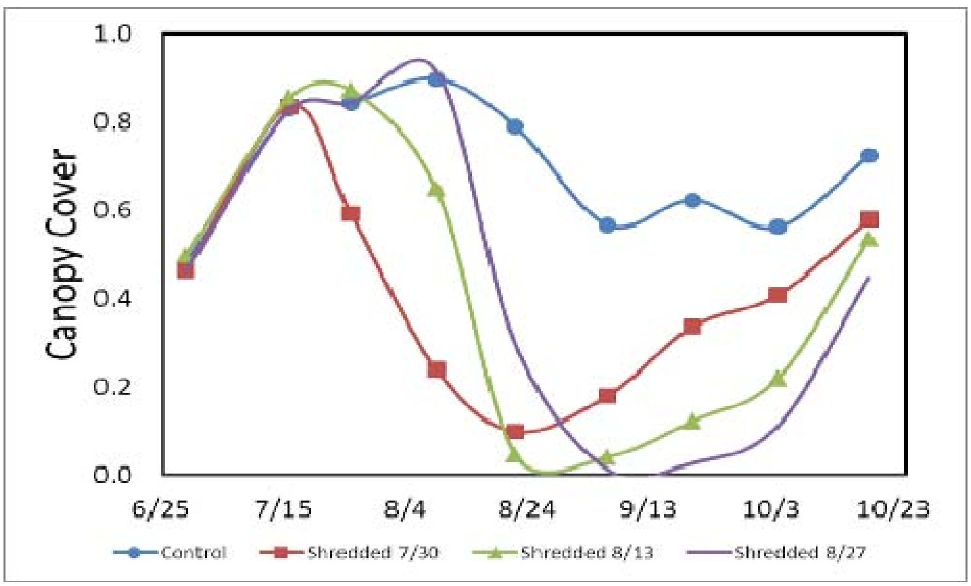

Figure 2. Linear spectral unmixing (LSU) estimates of experimental plots of regrowth cotton plants in Burleson Co., TX, in 2012.

A linear regression model was fit to the LSU estimates of canopy cover for all shredding treatments and control plots and the mean ratio of plant width to row width (Figure 3). The estimated canopy cover substantially underestimated the mean ratio of plant width to row width when the plant width was less than about half of the row width, or about 0.5 m. Estimated canopy cover closely matched the mean ratio of plant width to row width when the plant width was greater than half of the row width.

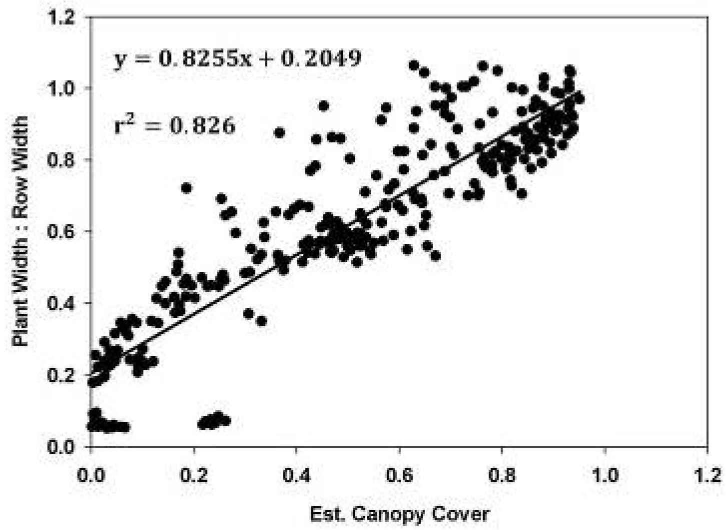

Figure 3. Linear regression of linear spectral unmixing (LSU) estimates of canopy cover versus the mean ratio of plant width to row width in regrowth cotton plots in Burleson Co., TX, in 2012.

A comparison of hyperspectral spectra for the three shredding treatments and control plot on 6 Sept. is shown in Figure 4. The spectrum for the 27 Aug. shredding date was distinctly different from the other two shredding treatments and the control, especially in the visible wavelengths (400 – 700 nm). The abundance of lint in the plots that were shredded on 27 Aug. likely contributed to the increased reflectance in the visible range.

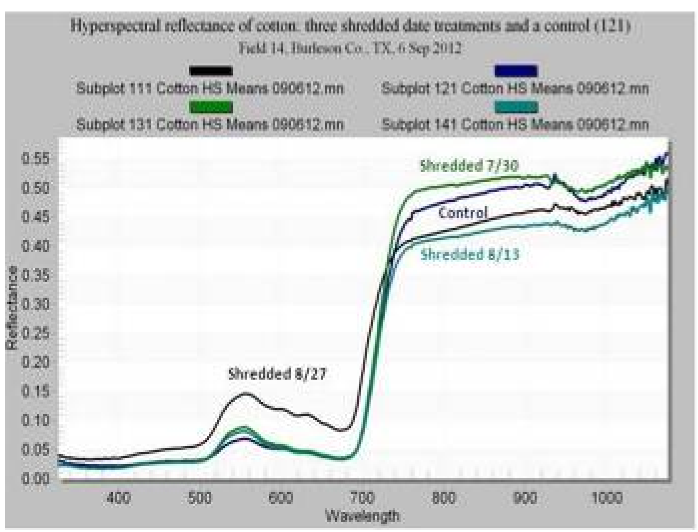

Figure 4. Hyperspectral reflectance on 6 Sept. 2012 of cotton plots shredded on 30 July, 13 Aug., and 27 Aug. and a non-shredded control.

Summary

The results show that airborne multispectral imagery can be used to estimate the development of regrowth cotton fields. Although the LSU technique estimated canopy cover from mixed pixel reflectance, the detection threshold of about 0.5 m was higher than expected. The non-uniformity (skippiness) of the regrowth plants was obvious at the onset of the regrowth stage and likely contributed to inflated measured ratios of plant width to row width. Incorporation of additional reflectance signatures (e.g., cotton lint) in the LSU analysis may improve the accuracy of canopy cover estimates. The LSU estimates of the development of regrowth cotton plants will provide boll weevil eradication program managers with a tool for timely detection of regrowth cotton in previously-harvested fields for which the cotton stalks have not been destroyed due to limited access (e.g., flooding) or neglect.

Acknowledgements

We thank the Cotton Foundation (general project #5002-009-00) and Cotton Inc. (core project #10-776) for funding this project, and Mike O'Neil, Parker Knutson, Fred Gomez, Lee Denham, and Cody Wall for their technical assistance. Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. USDA is an equal opportunity provider and employer.

References

Summy, K.R., M.D. Heilman, L.N. Namken, and W.G. Hart. 1986. Control of boll weevils (Coleoptera: Curculionidae) through crop residue disposal: Destruction of subtropical cotton under inclement conditions. J. Econ. Entomol. 79:1662-1665.

Yang, C., J.H. Everitt, and J.M. Bradford. 2007. Airborne hyperspectral imagery and linear spectral unmixing for mapping variation in crop yield. Precision Agric. 8:279-296.

Zhang, H., Y. Lan, C.P.-C. Suh, J.K. Westbrook, R. Lacey, and W.C. Hoffmann. 2012. Differentiation of cotton from other crops at different growth stages using spectral properties and discriminant analysis. Trans. ASABE 55:1623-1630.