AERIAL IDENTIFICATION OF INDIVIDUAL COTTON PLANTS

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Abstract

Boll weevils can infest individual cotton plants as well as cotton fields. However, volunteer and regrowth plants may grow where seed has scattered along roadsides and waterways, and in fields following rotation from cotton production. Timely areawide detection of these potential host plants is critically needed to expedite boll weevil eradication and prevent re-infestation in southern Texas. We acquired a temporal sequence of airborne multispectral images of individual cotton plants from vegetative to open boll stages. Probability guided unmixing of multispectral reflectance images revealed that the likely contribution of cotton plants to spectral reflectance values increased throughout the growing season, and exceeded 50% when plant height and plant width exceeded 50 cm (corresponding to the third-grown square growth stage). Application of a percent threshold of likely contribution of cotton plants to georeferenced spectral reflectance images will yield likelihood maps of estimated distribution of cotton plants. Timely identification of volunteer and regrowth cotton plants will aid eradication program personnel in locating and destroying these hostable plants.

Introduction

Timely notification of the locations of individual cotton plants is critical for boll weevil eradication personnel to effectively destroy non-production cotton plants that may be hostable for boll weevils. However, eradication personnel may receive late or no notification of the presence and location of volunteer and regrowth cotton plants, which increases the risk that boll weevil infestations may remain undetected. New techniques are needed to help eradication personnel promptly detect the presence of individual cotton plants on an areawide scale (e.g., eradication program zone).

Fully-developed plant canopies during the growing season have been imaged by satellite-based and airborne remote sensing platforms to quantify the growth of cotton and other vegetation over large areas (Yang et al. 2007, 2011). Airborne identification of cotton fields using high-resolution multispectral images has achieved high accuracy in distinguishing large cotton fields from other row crops (Yang et al. 2017). Spectral unmixing of high-resolution multispectral images has been used to identify small plots of regrowth cotton (Westbrook et al. 2015) and individual volunteer and regrowth cotton plants (Westbrook et al. 2016). However, the high-resolution multispectral images were acquired with camera technology (Yang et al. 2014) that used Bayer pattern pixel interpolation which confounds pixel-level spectral characteristics of the viewed surface. New multi-channel multispectral camera technology is available for use in exploring early detection of cotton fields and of individual volunteer and regrowth cotton plants within mixed vegetation.

The objectives of this study were to identify individual cotton plants at associated plant widths, plant heights, and growth stages throughout the growing season using airborne multispectral images.

Materials and Methods

The remote sensing study was conducted in a research field at the Texas A&M University farm (Burleson Co., TX). The field was comprised of four cotton plots, one milo plot, one corn plot, and one soybean plot. Each plot was 20 rows by 31-m long and all plots were planted with the respective crops on 15 April 2016. Once cotton plants reached the 1st or 2nd true leaf stage, plants in a 5-m section at one end of each cotton plot were thinned to create an array of 100 individual cotton plants spaced 1 m apart in each plot. The height, width, and growth stage of all the individualized cotton plants within the contiguous area of each plot were measured on 15 June, 1 July, 14 July, 2 August, 7 September, and 27 October. Half of the rows in each cotton plot, including the individualized cotton plants, were defoliated on 25 August and shredded on 9 September. Shredded plants were allowed to regrow until the stalks were destroyed on 16 November.

Airborne multispectral imaging of the cotton fields was conducted on 16, 17, and 30 June, 14 July, 2 August, 1 September, and 27 October using a RedEdge 5-channel (red, blue, green, red edge, and near-infrared (NIR)) broad-band multispectral camera (MicaSense, Seattle, WA) mounted within a Cessna 206 fixed-wing aircraft to capture 2-MP images. Camera sensitivity was specific to each spectral band: red (0.78828), green (1.79429), blue (1.70204), red edge (0.76355), and NIR (1.40562). The camera was set to operate at 0.44-ms manual exposure and a 1.5-second image acquisition interval. Each image was geotagged with data acquired by an attached GPS receiver (MicaSense, Seattle, WA). Airborne multispectral images (132-m x 97-m viewing area with 0.1-m pixel ground resolution) were acquired at a flight altitude of approximately 152 m AGL. Reflectance calibration tarps (4%, 16%, 32%, and 48%) were placed adjacent to the field plots for each imaging flight. Image reflectivity values (digital numbers (DN) were converted to reflectance values using linear regression equations derived from the reflectivity (DN) versus reflectance (%) for each spectral band measurement of the four reflectance calibration tarps.

Geotagged images were processed using Drone2Map (Esri, Redlands, CA) to create mosaicked images. The mosaicked 5-band images were imported into ArcMap 10.4.1 (Esri, Redlands, CA) to locate plot boundaries and 0.5-m-radius circular areas-of-interest (AOI) centered on each individual plant location. Spectral endmembers for cotton were obtained for one of the four cotton plots which contained the least number of weeds, and excluded the section of 100 individual cotton plants. Spectral endmembers for cotton, corn, milo, soybean, grass weeds, broadleaf weeds, and soil were obtained from the spectral density histograms of each of the five spectral bands for the contiguous area of the corn, milo, and soybean plots. Spectral endmembers for broadleaf weeds, grassy weeds, and soil were obtained from smaller selective areas. Spectral endmembers of each plant type were derived by selecting the modal value of spectral reflectance density at the lower end of the histograms, except at the upper end of the histograms for the NIR band. Spectral endmembers of soil were derived by selecting the modal value of spectral reflectance density at the upper end of the histograms, except at the lower end of the histogram for the NIR band. The Normalized Difference Vegetation Index (NDVI) was calculated for each pixel and used as a sixth spectral parameter for spectral unmixing analysis.

Probability guided unmixing (PGU) of mosaicked multispectral images using TerrSet 18.2 (Clark University, Worcester, MA) was calculated to identify the likely contribution of cotton plants to the total reflectance within each pixel. Spectral unmixing is intended to identify sub-gridscale features, such as parts of cotton plant canopies that fill less than the full image ground pixel resolution (e.g., approximately 10 cm in this study). The maximum value of PGU_{cotton} within each AOI was assigned to the respective plant.

Graphing and statistical analysis of the spectral data and physical measurements of plants were performed using JMP 12.1.0 (SAS, Cary, NC).

Results and Discussion

Plant phenological development

Mean cotton plant height (± SEM) increased continuously from 26.1 ± 0.4 cm on 15 June to 111.0 ± 1.8 cm on 27 October. Correspondingly, plant width also increased from 24.2 ± 0.4 cm to 94.9 ± 1.1 cm. The majority of cotton plants on 15 June and 1 July were in the matchhead square stage (0.5% exceeded this stage) and third-grown square stage (6.8% exceeded this stage), respectively. Between 14 July and 2 August 85% of plants were at the boll stage, and 100% of plants were at the open boll stage between 1 September and 27 October.

Spectral endmembers and NDVI

Spectral endmembers of crops, weeds, and soil were computed by analysis of the spectral density histogram respective for each crop, weed, or soil plot or selected area of interest. The five spectral endmembers and the NDVI value revealed minor differences between plant types in the red, green, blue, and red edge bands throughout the study period (Fig. 1). However, cotton plants were generally distinctive from the soil and all other plants except broadleaf weeds in the NIR band and NDVI value. Cotton plants became more distinctive from broadleaf weeds in the NIR band (1 September) and in both the NIR band and NDVI value (27 October).

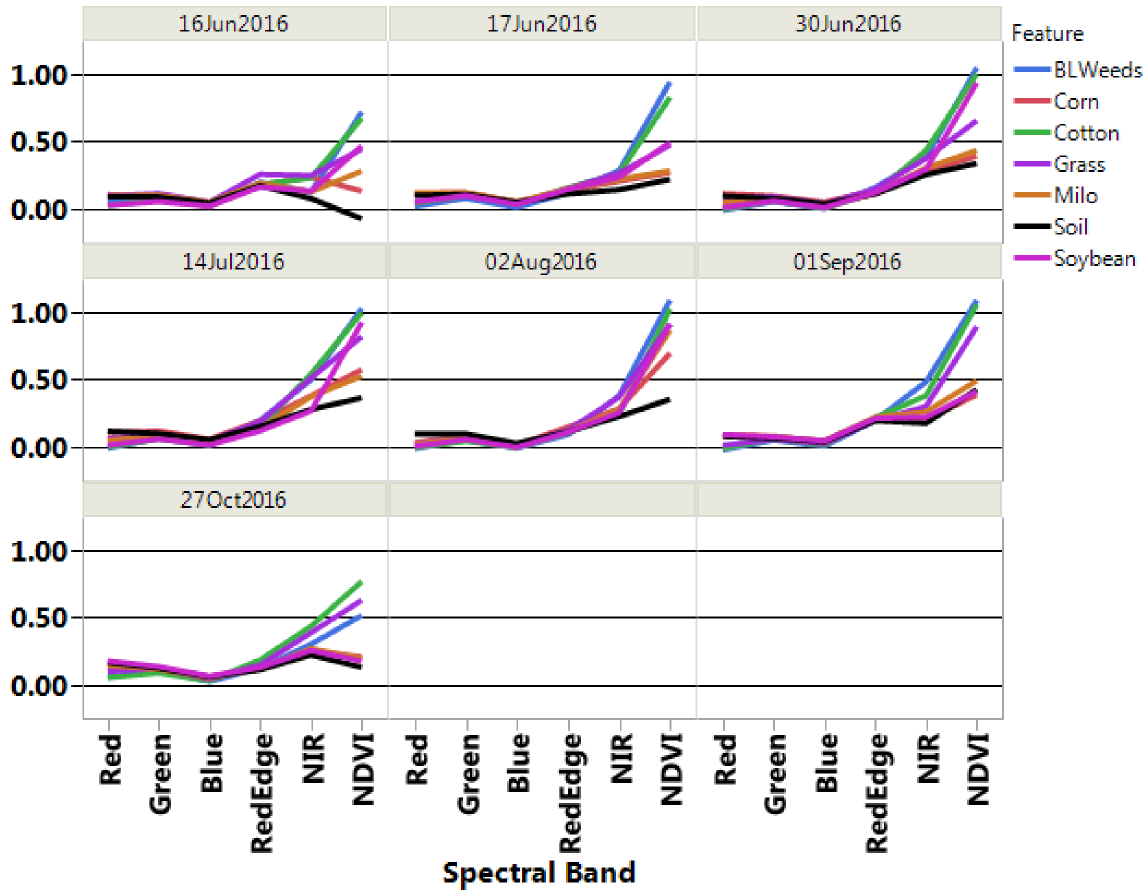

Figure 1. Spectral endmember reflectance (%) and NDVI of cotton, corn, milo, soybean, broadleaf weed, and grass weed plants for research plots in Burleson County, TX, in 2016.

Spectral unmixing

Mean values of PGU_{cotton} varied by imaging date ($F_{6,\ 2373} = 351.7$, $p < 0.0001$), increasing throughout the growing season except for a minimum that occurred when the cotton plants were in the open boll stage on 1 September (Fig. 2). Student's t pairwise comparisons revealed that mean values of PGU were significantly different on each date ($p \leq 0.0001$). The sharp increase in PGU_{cotton} from 16 June to 2 August suggests rapidly-increasing accuracy in identifying cotton from other crops and weeds during this time period.

Cotton plant width was found to be significantly related to PGU_{cotton} values ($F_{12,\ 2358} = 231.3$, $p < 0.0001$). Mean values of PGU_{cotton} increased significantly from 0.18 at 10-20 cm plant width to 0.90 at 100-110 cm plant width (Fig. 3). Mean values of PGU_{cotton} decreased to 0.85 for plant widths at 110-120 cm and 0.77 for plant widths at 120-130 cm.

Mean PGU_{cotton} values continued to increase throughout the growing season as plants grew taller (Fig. 4). Mean values of $PGU_{cotton} = 0.14$ for plants < 20 cm tall, but increased to 0.99 for plants that were 130-140 cm tall.

Cotton phenological development was associated with increased mean PGU_{cotton} values ($F_{6,\ 2364} = 391.6$, $p < 0.0001$) (Fig. 5). Mean values of PGU_{cotton} were significantly higher for each successive plant growth category, except there was no significant difference between the third-grown square and flower bloom stages.

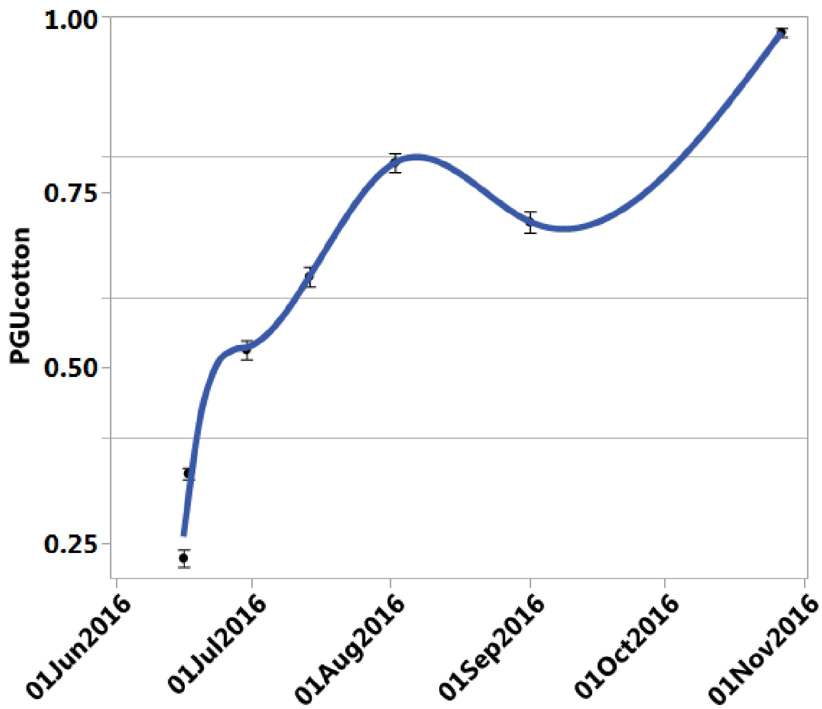

Figure 2. Mean (± standard error of the mean) probability-guided unmixing (PGU_{cotton}) of the estimated contribution of individual cotton plants to spectral reflectance for research plots in Burleson County, TX, in 2016.

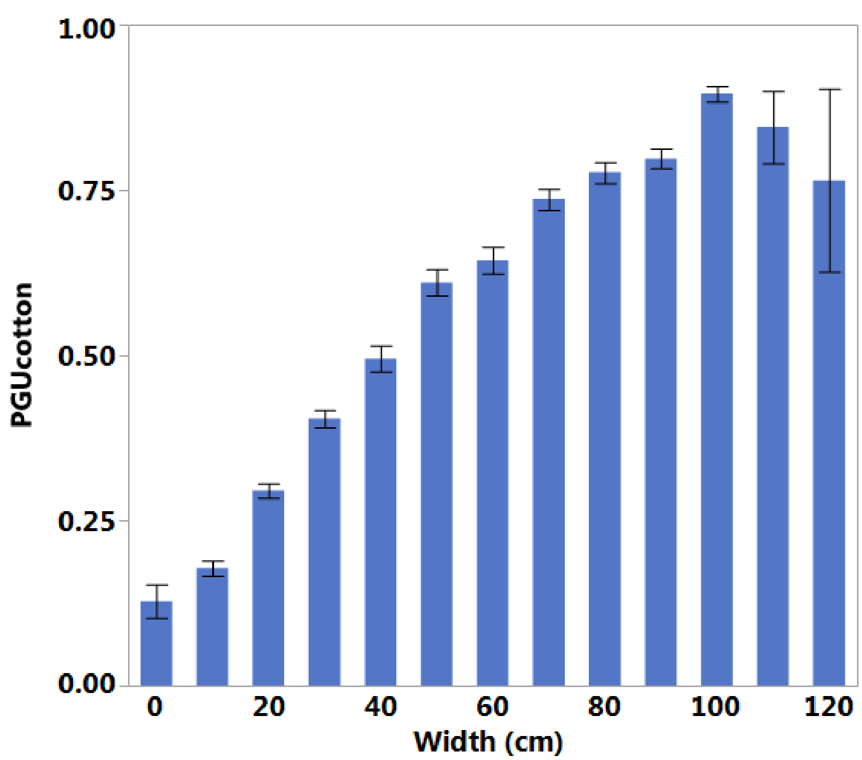

Figure 3. Estimated contribution to spectral reflectance by individual cotton plants of different width for research plots in Burleson County, TX, in 2016.

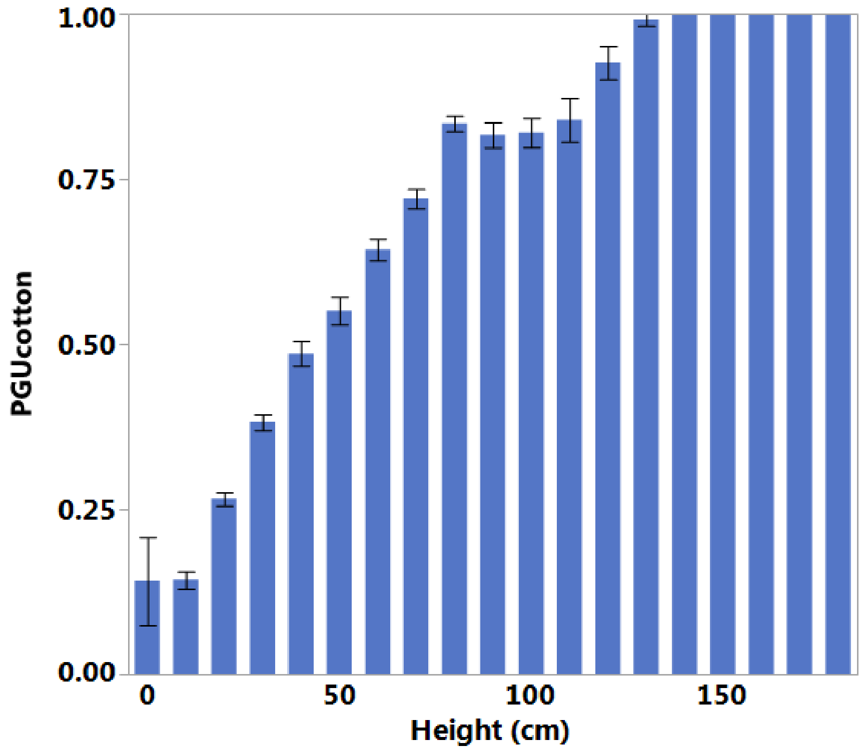

Figure 4. Estimated contribution to spectral reflectance by individual cotton plants of different height for research plots in Burleson County, TX, in 2016.

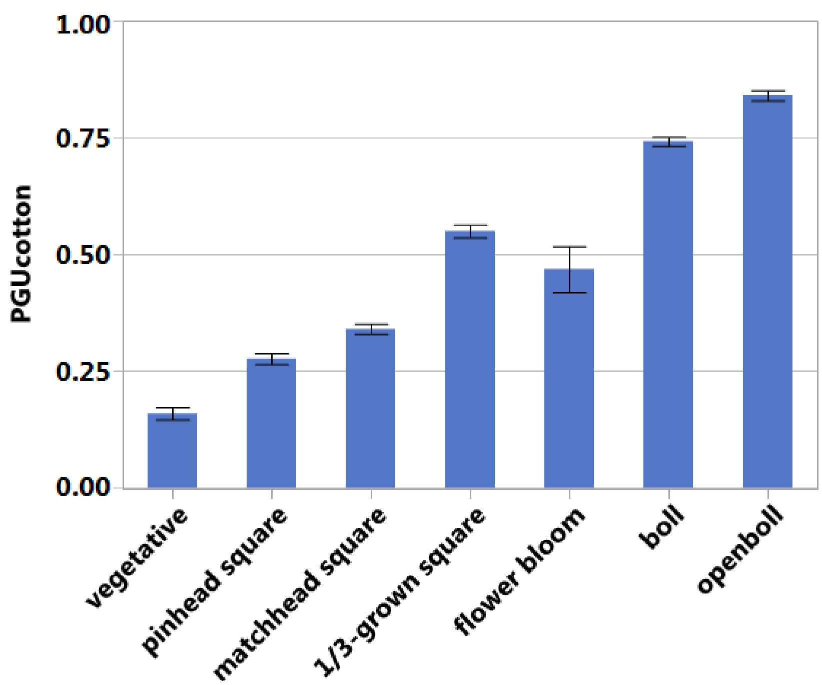

Figure 5. Estimated contribution to spectral reflectance by individual cotton plants of different growth stages for research plots in Burleson County, TX, in 2016.

Identification of cotton plants in mixed-plant environments

The process to identify cotton plants using airborne multispectral images is illustrated for 27 October in Fig. 6. First, a color (red, green, blue) image (subset of the 5-band multispectral image) (Fig. 6A) shows the field plot layout. The field plots included four cotton plots (half of the rows in each plot had been shredded on 9 September), corn, milo, and soybean plots that had been shredded; and a mixed plot of grass and broadleaf weeds. Probability guided unmixing of the multispectral image revealed the likely contribution of cotton plants to the spectral reflectance of each image pixel (Fig. 6B). Although Fig. 6B emphasizes the standing cotton plants, there are widespread areas with substantial likelihood of cotton where cotton plants did not exist. However, by setting a threshold value (0.8 in this case) for PGU_{cotton}, the areas of sub-threshold PGU_{cotton} values are masked and the super-threshold PGU_{cotton} values are emphasized (Fig. 6C).

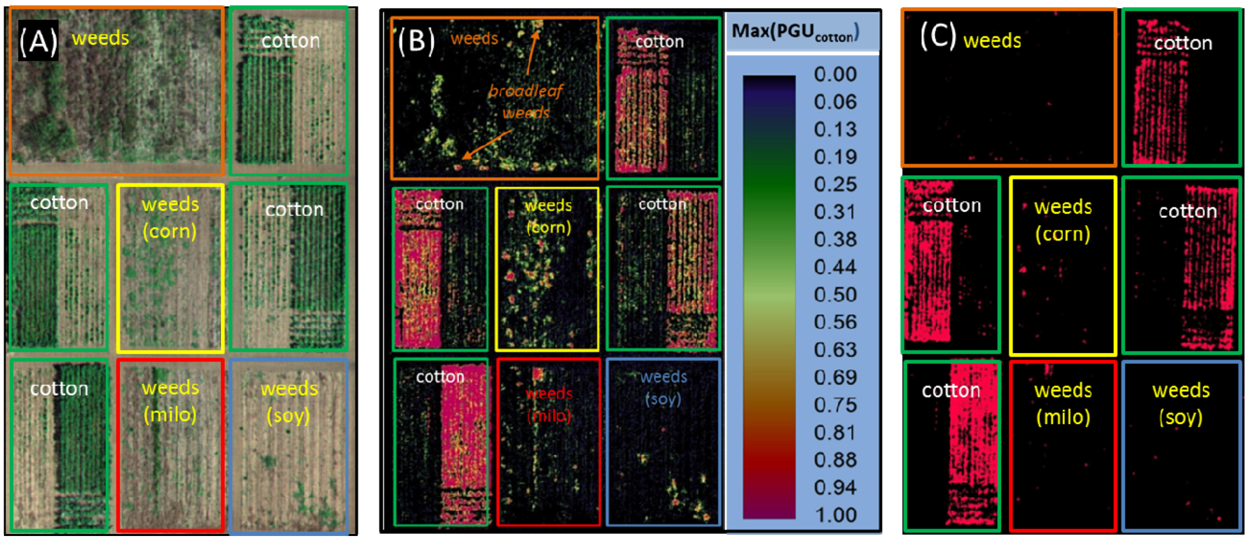

Figure 6. Airborne (A) color image of cotton plants and weeds, (B) derived thematic map of PGU_{cotton}, and (C) derived thematic map of $PGU_{cotton} \geq 0.8$ in research plots in Burleson County, TX, on 27 October 2016.

Summary

Spectral imaging and unmixing analysis identified percent likelihood of detection of cotton plants. Spectral unmixing estimates percent contribution of cotton plants to spectral reflectance, and accentuates points or areas in which cotton plants cover a majority of the ground represented by the image pixel. Spectral unmixing values for cotton increased throughout the growing season as cotton plants grew larger and as spectral differences increased relative to other vegetation (e.g., due to senescence). In deriving spectral endmembers from entire field plots, it was noticed that high reflectance along the cotton plot borders may have created misrepresentative endmembers. The high-reflectance edge effect was noticeable on 2 August, when cotton plants were wilted. The overall low reflectance in the red, green, and blue spectral bands led to minor spectral differences between plant types. Use of spectral unmixing of airborne multispectral images will aid rapid areawide identification of individual cotton plants as well as cotton fields that may not be reported to eradication personnel in a timely manner. Current image acquisition and analysis technology was shown to identify cotton plants with increasing likelihood throughout the growing season. Future research incorporating spectral unmixing techniques using higher-resolution images, three-dimensional rendering (to obtain height) of vegetation, other spatial features, and additional spectral bands may greatly enhance the accuracy of detection. Regardless, thematic maps of the likelihood of cotton plants, derived from spectral unmixing of airborne multispectral images, will allow boll weevil eradication program managers to specify detection thresholds and allocate personnel and other resources to locations of highest likelihood of hostable cotton plants.

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