Remote Sensing Applications: Society and Environment 4 (2016) 37–43

Contents lists available at ScienceDirect

Remote Sensing Applications: Society and Environment

journal homepage: www.elsevier.com/locate/rsase

Airborne multispectral identification of individual cotton plants using consumer-grade cameras

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ARTICLE INFO

Article history:
Received 14 September 2015
Received in revised form
23 December 2015
Accepted 2 February 2016
Available online 17 May 2016

Keywords:
Remote sensing
Linear spectral unmixing
Volunteer cotton
Regrowth cotton
Insect pest management

ABSTRACT

Although multispectral remote sensing using consumer-grade cameras has successfully identified fields of small cotton plants, improved detection sensitivity is needed to identify individual or small clusters of cotton plants that also can provide habitat for boll weevils. The imaging sensor of consumer-grade cameras is based on a Bayer pattern, which alternates red, green, and blue filters over individual sensor pixels. However, each pixel of the imaging sensor of consumer-grade cameras represents direct measurement of only one of the three spectral bands (red, green, and blue) and interpolation of the remaining two spectral bands. We present an analytical technique in which endmember sets were derived from bimodal histograms of each spectral band for cotton, other vegetation types and soil, and linear spectral unmixing was used to identify individual cotton plants. We achieved significant misclassification rates as low as 0.125 and 0.146 in frequently tilled plots for validation tests of remote sensing identification of volunteer okraleaf cotton plants and volunteer conventional cotton plants, respectively. Results of this study indicate that consumer-grade cameras can acquire multispectral images of sufficient quality to detect individual cotton plants at an early growth stage, which will aid boll weevil eradication programs in identifying and locating volunteer plants.

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1. Introduction

The boll weevil, *Anthonomus grandis* (Boheman), is a pest of cotton for which an eradication program in the USA has nearly been completed. After a century of efforts to control boll weevil infestations in USA cotton fields, only a remnant population of weevils in the Lower Rio Grande Valley production area of southern Texas. The eradication program functions by mapping all cotton fields, using pheromone traps to detect incipient weevil populations, and applying insecticides when and where justified by weevil captures or as preventive measures. Where cotton plants are grown in temperate regions, winter freezes kill the cotton stalks following harvest. However, in subtropical regions cotton plants must be destroyed after harvest to prevent regrowth of cotton fruit on which weevil populations can survive and reproduce until the ensuing cotton production period (Summy et al., 1986). Also, volunteer cotton plants can germinate from seed that remains in a field after harvest or that is inadvertently scattered by floods or by transport of harvested cotton to gins.

Volunteer and regrowth cotton plants must be located and destroyed to reduce the risk of sustaining remnant weevil populations, otherwise undermining the success of intensive eradication programs. For example, fruit from 80 volunteer cotton plants on one farm in southern Texas were found to have produced more than 500 boll weevils (Troxclair, 2010). However, volunteer and regrowth cotton plants are difficult to locate because they can be distributed within a large cotton production region or can be hidden by other vegetation.

Typically only the field perimeter is visually inspected for the presence of volunteer and regrowth cotton plants. Consequently, plants occurring in the center of large fields generally escape detection. Further, volunteer and regrowth cotton plants are typically obscured by the primary crop until crop senescence, defoliation or harvest. There is a lack of alternatives for detecting volunteer and regrowth cotton plants.

Although cotton producers are required to report the location of planted cotton fields to the USDA Farm Services Agency, this information is either unavailable or belatedly available to the boll weevil eradication program. However, airborne remote sensing has the capability to rapidly identify early growth of cotton fields (Bai et al., 2011) and volunteer and regrowth cotton plants within large regions. Yang et al. (2011) assessed defoliation treatments using remote sensing technology to detect regrowth of treated

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http://dx.doi.org/10.1016/j.rsase.2016.02.002
2352-9385/Published by Elsevier B.V.

cotton plants. Further, enhanced detection of cotton plants relative to other crops using remote sensing has been achieved by applying discriminant analysis of spectral properties of plants (Zhang et al., 2012) and by incorporating ground-based measurements (Zhang et al., 2013).

We evaluated the capability of airborne multispectral detection of individual volunteer and regrowth cotton plants – both conventional and okraleaf varieties – using consumer-grade cameras and linear spectral unmixing (Yang et al., 2007). Okraleaf cotton was evaluated in addition to conventional cotton in 2014 because the relatively sparse canopy of okraleaf cotton has been known to allow increased penetration of solar radiation, which heats and dessicates weevil-infested cotton squares that have abscised and fallen to the soil surface. Our objective was to quantify the likelihood of detecting individual cotton plants within diverse crop and weed plots.

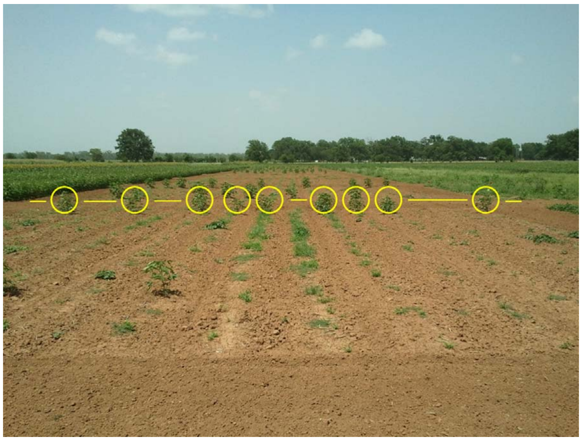

Fig. 1. Volunteer conventional cotton plants located in random rows along a transect within a tilled plot at a research field in Burleson County, TX, USA on 30 June 2014.

2. Materials and methods

In late June 2012, several individual regrowth cotton plants (Delta Pine DP1048, Monsanto Corp., St. Louis, MO, USA) or small clusters of adjacent cotton plants (N = 133) were identified in a weedy fallow plot at a research field in Burleson County, TX. Geographic coordinates of the regrowth cotton plants were obtained at an absolute accuracy of ≤ 20 cm using a Trimble GPS Pathfinder ProXRT receiver (Trimble Navigation, Ltd., Sunnyvale, CA, USA) with the Wide Area Augmentation System (WAAS) correction. Height, width, and largest fruit type were recorded for each regrowth cotton plant or clusters of plants.

We planted conventional (Phytogen PHY499, Dow AgroSciences, Indianapolis, IN) and okraleaf (Fibermax FM8279, Bayer CropScience, Research Triangle Park, NC, USA) cotton plants at a seed spacing of 10 cm (4 in.) and row spacing of 1.02 m (40 in.) in a research field in Burleson County, TX, USA, on 17 April 2014. The field was occasionally irrigated to sustain plant growth. Each crop was planted in 53-m (173.9-ft) plots within 16-row blocks replicated three times. Corn (Integra A1013698, Integra Seed, Ames, IA, USA) was planted on 17 March 2014 and milo (Pioneer 84P80, Dupont Pioneer, Johnston, IA, USA) were planted on 20 March 2014 and soybeans (Pioneer 94Y90, Dupont Pioneer, Johnston, IA, USA) were planted on 27 March 2014. Cotton plots and volunteer cotton plants (16 conventional cotton (CC) plants and 16 okraleaf cotton (OLC) plants randomly assigned to rows in two transects per plot (Fig. 1)) were planted in soybean (S), corn (C), milo (M), fallow (F), and tilled (T) plots on 15 April 2014. We applied the term “fallow” to describe a weedy plot that had been plowed and left unseeded for one growing season. Height, width, and growth stage were recorded for each volunteer cotton plant and non-cotton plant along all transects.

Aerial images of the research field were obtained on 29 June 2012, and on 15 May 2014 (Early period), 6 June 2014 (Mid period), and 30 June 2014 (Late period). We equipped a Cessna 206 fixed-wing aircraft with two nadir-oriented Canon 5D Mark II digital cameras (Canon U.S.A., Melville, NY), which captured 21-megapixel images defined by a 5616 × 3744 array of 16-bit pixels (Yang et al., 2014). One camera recorded a color image (broadband red-green-blue, RGB) (ISO 200, 2-ms exposure, f/10), and a second camera recorded a near-infrared image (broadband NIR) (ISO 200, 2-ms exposure, f/14). The spectral bands were 400–500 nm (blue), 500–600 nm (green), 600–700 nm (red), and 720–1000 nm (NIR). We acquired airborne multispectral images from an altitude of approximately 305 m above ground level (AGL) to cover a viewing area of 561.6 m × 374.4 m (0.1-m pixel ground resolution) (Westbrook et al., 2015). We placed four reference tarps of known reflectivity (4%, 16%, 32%, and 48%) within the field of view of each airborne multispectral image to establish a regression fit between measured spectral reflectance (absolute digital number, DN) and reflectivity (%) for each spectral band.

Images acquired on 29 June 2012 images were geo-referenced using a geo-referenced image for 5 July 2012. Locations of regrowth cotton plants were collected in WGS84 projection and converted to the UTM83Z14 projection of the image files. The relative position of individual plants in geo-referenced images was achieved at an accuracy ≤ 5 cm in 2012 and 2014. In 2014, we acquired global positioning system (GPS) coordinates of nine ground control points (0.41-m × 0.41-m white boards) around the research plots at Field 14 on 15 May 2014 and 29 May 2014. Only eight of the ground control points were available on subsequent dates in 2014 due to the loss of one reference stake.

Images acquired in 2014 were geo-referenced using ArcGIS Desktop Version 10.2.2 (Esri, Redlands, CA, USA). Images were imported as *.TIF files created from the RAW CR2 camera format using Photoshop version 5.5. The white board locations were imported as a point vector file. The 15 May 2014 images were geo-referenced using the point vector file and a quadratic equation with residuals ≤ 3 cm. All of the other images were geo-referenced using the 15 May 2014 color image with quadratic equations and residuals ≤ 5 cm.

All geo-referenced images from 2012 and 2014 were saved as Erdas Imagine format files in ArcGIS (Esri, Redlands, CA, USA) and imported to IDRISI Selva (Clark Labs, Worcester, MA, USA) using the ERDIDRIS module. Raster files created in IDRISI were used to analyze and test the identification of individual regrowth cotton plants. Images acquired in 2012 were clipped to the area of interest (AOI) in which 113 individual (or clusters of) regrowth cotton plants were randomly distributed. Images acquired in 2014 were clipped to the area encompassing 63 individual plots. The clipped images were used for faster and more efficient analysis.

Analysis and identification of individual cotton plants was performed using the UNMIX module, selecting the Linear Spectral Unmixing (LSU) utility for 2012 images and Exhaustive Search Unmixing (ESU) utility for 2014 images. The UNMIX module performed sub-pixel classification. The LSU and ESU utilities required development of signature files containing spectral band endmember digital number (DN) values of vegetation and soil. The LSU utility cannot process more endmembers than available image bands. In this case, there were four spectral bands and four endmembers. However, the ESU utility can process more endmembers than bands, but only at the number of spectral bands per analytical run. Both the LSU and ESU utilities produce values of percent likelihood that a medium (i.e., cotton plant) is responsible for the