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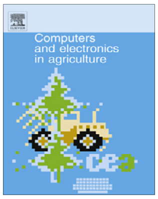

Employing broadband spectra and cluster analysis to assess thermal defoliation of cotton ☆

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ABSTRACT

Growers and field scouts need assistance in surveying cotton (*Gossypium hirsutum* L.) fields subjected to thermal defoliation to reap the benefits provided by this nonchemical defoliation method. A study was conducted to evaluate broadband spectral data subjected to unsupervised classification for surveying cotton plots subjected to thermal defoliation. Ground-based reflectance measurements of thermally treated and non-treated cotton canopies were collected at two study Sites (Site 1 and Site 2) with a handheld hyperspectral spectroradiometer. The hyperspectral data were merged into eight broad spectral bands: coastal blue (400–450 nm), blue (450–510 nm), green (510–580 nm), yellow (585–625 nm), red (630–690 nm), red-edge (705–745 nm), near-infrared (770–895 nm), and panchromatic (450–800 nm). Also, a broadband normalized difference vegetation index (NDVI) was created with the red (630–690 nm) and near-infrared bands (770–895 nm). For each study Site, two datasets were analyzed: (1) two-class case (thermally treated cotton observations and non-treated cotton observations) and (2) five-class case (thermally treated cotton observations and non-treated cotton observations and three additional classes created with the weighted average of the thermally treated cotton observations and non-treated cotton observations). The clustering algorithm referred to as CLUES (CLUstEring based on local Shrinking) was employed to automatically group the data into clusters without the user selecting the number of clusters. Cluster validation was determined with the average silhouette width; also accuracy was assessed with contingency matrixes. Clustering analysis worked well in dividing the data into appropriate groups, with the best cluster structure occurring for the NDVI. User's and producer's accuracies for the NDVI were greater than 86%, indicating an excellent classification. Findings support future endeavors to assess airborne and satellite-borne systems equipped with sensors sensitive to the wavelengths deemed useful in this study and unsupervised classification techniques that automatically determines the numbers of clusters to evaluate thermal defoliation of cotton fields.

1. Introduction

Over the last ten years, thermal defoliation has shown promise as a nonchemical alternative for terminating cotton growth and defoliating cotton canopies (Funk et al., 2004, 2006; Showler et al., 2006), making it an ideal harvest aid for cotton grown under organic farming methods (Funk et al., 2006, 2012). The technique involves using propane to heat air that is applied directly to the plant canopy to quickly kill the leaves. Unlike traditional defoliation methods, it does not require optimal weather conditions to apply the treatment, and producers are able to harvest fields twenty-four hours after treatment if needed (Showler et al., 2006). Additionally, producers can use this form of defoliation in conventional systems to prepare fields threatened by severe weather, increasing their ability to harvest fields before the arrival of the inclement weather (Showler et al., 2006). Finally, thermal defoliation has shown potential for late-season pest control (Bundy et al., 2006; Funk et al., 2012).

There are several risks associated with incomplete thermal defoliation. Staining of the cotton fiber may occur in areas where leaf kill is incomplete, reducing the price grade of the cotton. Additionally, juices in green leaves may increase gum build-up on

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picker spindles, requiring stoppage to clean the spindles and thus increasing harvesting time per field. Therefore, rapidly identifying areas, not responding to thermal treatment can support producer decision making regarding re-treating these areas. This would maintain the price grade of the cotton throughout treated fields and reduce the time required to harvest them.

Variation of cotton growth within the field is usually the same from year to year within a field. If re-treatment is not an option for the current year, growers do need a record showing areas not responding to treatment. In the following year, producers can adjust the defoliation process; for example, reducing the speed of the defoliating apparatus in areas not responding to treatment in the previous year would increase leaf kill. For these reasons, growers need assistance in surveying fields subjected to thermal defoliation to reap the benefits provided by this nonchemical defoliation method.

Ground-based and airborne remote sensing systems have shown potential as tools for monitoring defoliation of cotton. Yang et al. (2003) demonstrated applications of ground-based reflectance data and airborne color-infrared (CIR) and normalized difference vegetation index (NDVI) imagery to differentiate cotton plants exposed to different defoliants from a control and other chemical treatments. They noted that differences between control and treated plants were statistically significant for green, red, and NDVI recorded data. Ground-based reflectance indices based on red-edge measurements provided accurate and consistent defoliation estimates for cotton subjected to chemical treatment (Ritchie and Bednarz, 2005). Fletcher et al. (2007) showed that CIR photography had potential for differentiating thermally defoliated cotton plants from control plants. Color-infrared film is no longer sold, eliminating it as an option for consultants and producers to use for surveying thermally defoliated cotton fields. Most remote sensing research have focused on chemical defoliates and have concentrated on visual, statistical, and modeling efforts (Ritchie and Bednarz, 2005; Yang et al., 2003, 2011). No information is available on using classification algorithms as a means to group thermally defoliated plants based on their spectral properties.

Cotton plants exposed to thermal treatment may be perfect candidates for remote sensing instruments. Heat kills the leaves, causing them to turn brown within a few hours. Showler et al. (2006) reported that up to 60% of the desiccated leaves remain on the cotton plant until harvest.

Supervised and unsupervised classifications are general approaches used to derive maps from image data or group unknown reflectance data into classes. Supervised classification uses a set of user-defined spectral signatures to assign samples to groups (Campbell, 2002; Mather, 2005). Unsupervised classification requires minimum input from the operator; no training samples are used, and subdivision of the feature space is achieved by identifying natural groupings of the measurement vectors (Campbell, 2002; Mather, 2005). Clustering is the most widely used unsupervised procedure. It involves development of structures in unlabeled data by grouping pixel data into groups with similar properties. Pixel values within clusters are similar to each other, but are not similar to pixel values in other clusters.

Clustering algorithms such as K-means and the Iterative Self-Organizing Data Analysis Technique requires the user to input the number of clusters to create. For the user, deciding the number of clusters is often a difficult task. Researchers have developed clustering algorithms that automatically estimate the number of clusters without user input. These procedures are divided into methods that select the number of clusters by optimizing a measure of strength of the clusters (Tibshirani et al., 2000), that assemble the data into small clusters followed by merging these clusters until no further merging can occur (Frigui and Krishnapuram, 1999), that extract one cluster at time (Zhung et al., 1996), that uses a bump hunting technique to determine the number clusters (Wang et al., 2007), and that iteratively move data points toward cluster centers and then use the number of convergent points as the number of clusters (Wang et al., 2007).

Broadband (spectral bands greater than 10 nm) panchromatic and multispectral remote sensing products are readily available to the public through commercial companies via airborne or satellite platforms. It was hypothesized that cotton plants effectively treated by thermal defoliation could be separated from non-treated plants using broadband spectral data and unsupervised classification based on clustering analysis. The objective of this study was to evaluate ground-based broadband spectral data and cluster analysis as tools for surveying cotton plots subjected to thermal defoliation to prepare them for harvesting. Spectra simulating the broadbands of the WorldView 2 satellite were examined in this study: coastal blue (400–450 nm), blue (450–510 nm), green (510–580 nm), yellow (585–625 nm), red (630–690 nm), red-edge (705–745 nm), near-infrared (770–895 nm), and panchromatic (450–800 nm). These bands were chosen because the blue, green, red, near-infrared, and panchromatic bands are similar to those found on other high spatial resolution broadband satellite sensors. The coastal blue, yellow, and red-edge bands provide additional information relevant to identifying and mapping vegetation (Digital Globe, 2009). Also, the spectral bands are easy to fabricate for filters to use in multispectral cameras flown in aircraft. Furthermore, the study focused on using a clustering algorithm that determined the number of clusters without user input and application of multispectral, panchromatic, and vegetation index forms of the data as input into the clustering algorithm to separate adequately treated plants from inadequately treated or non-treated plants.

2. Materials and methods

2.1. Study sites

Data were collected from two study Sites, referred to as Site 1 and Site 2. The study Sites were located near the Kika de la Garza Subtropical Agricultural Research Center, Weslaco, Texas (26°09′N 97°57′W). These Sites were being used for on-going studies to compare thermal defoliation to chemical defoliation. The experiment at each study Site was a randomized complete block design consisting of three treatments (thermal defoliation, chemical defoliation, and control) replicated six times (blocks). Treatments within each replicate contained twelve rows planted to Deltapine 5415RR (Delta Pine and Land Co.; Scott, MS). Row spacing was 1 m, resulting in an area of 0.19 ha per treatment. The objective of the current study was to compare the thermally defoliated cotton and the control cotton; therefore, subsequent analyses focused on these two treatments. The thermal treatment occurred on 27 July 2005. It involved using the two row thermal defoliator prototype described by Funk et al. (2006) to apply heat at 193 °C to the cotton canopies.

2.2. Field spectra collection

Reflectance measurements (referred to as reflectance) of the non-treated and thermally treated cotton canopies were collected on 8 August and 1 August 2005 at Sites 1 and Sites 2, respectively, with a FieldSpec Handheld spectroradiometer (Analytical Spectral Devices, Inc., Boulder, CO) having a spectral range of 325–1075 nm. The device has a spectral resolution of 3 nm; however, the data is resampled to 1 nm intervals by the software used to operate the instrument. The data output range is between 0 (0% reflectance) and 1 (100% reflectance). The instrument has a 25°