

Surveying kaolin-treated cotton plots with airborne multispectral digital video imagery

Reginald S. Fletcher*, Allan T. Showler

United States Department Agriculture, Agricultural Research Service, Kika de la Garza Subtropical Agricultural Research Center,
2413 East Highway 83, Weslaco, TX 78596, United States

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Abstract

Airborne multispectral digital video imagery was evaluated as tool for surveying kaolin-treated cotton (*Gossypium hirsutum* L.) plots, with emphasis on decision support. Images of experimental plots were obtained on 12 June 2002 and 16 June 2004 with an electronic digital video imaging system acquiring blue (447–455 nm), green (555–565 nm), red (625–635 nm), near-infrared (814–826 nm), and mid-infrared (1631–1676 nm) imagery. We qualitatively and quantitatively evaluated the single band images and color and false color composite images to compare the image responses of treated plots with the image responses of untreated plots. Blue, green, and red imagery separated the treated plots from the untreated plots (Dunnett's test and *t*-test; $P=0.05$), with the blue imagery being the most responsive to the treatment. Treated plots were readily differentiated from untreated plots with natural color and false color composite imagery. This separation was attributed to the images that were sensitive to some portion of the visible spectrum (i.e., blue, green, and red light). These results indicate that airborne electronic imaging systems have great potential as tools for surveying cotton fields treated with kaolin particle film, supporting application of the imagery as a decision support tool. Published by Elsevier B.V.

Keywords: Remote sensing; Surround wettable powder; Electronic digital video imagery; Multispectral

1. Introduction

Kaolin-based particle film has been studied as an alternative to agricultural chemicals to suppress pests affecting crops (Stanley, 1998; Glenn et al., 1999; Knight et al., 2000; Lapointe, 2000; Purterka et al., 2000; Unruh et al., 2000), including cotton (*Gossypium hirsutum* L.) (Showler, 2002a, 2003). Showler (2002b) reported that particle film applications to cotton canopies did not induce water deficit or cause light reduction stress. Other researchers have indicated that cotton plants treated with kaolin particle film used less water (Stanhill et al., 1976) and had higher yields (Moreshet et al., 1979; Makus, 2000).

Kaolin-based particle film is marketed as surround wettable powder (WP) crop protectant, which contains processed white kaolinite (90% pure kaolinite), a 1:1 aluminosilicate clay, having a brightness quality greater than 85% (Harben, 1995). Surround WP is combined with water and applied directly to crops as a suspension (Glenn et al., 1999). After the water evaporates, a white powdery residue remains on surfaces of leaves, fruits, and branches, causing them to have a white color. Adhesiveness of the particle film to plant components determines longevity of the white color. Rainfall

* Corresponding author. Tel.: +1 956 969 4834; fax: +1 956 969 4893.
E-mail address: rletcher@weslaco.ars.usda.gov (R.S. Fletcher).

and/or other natural forces remove the particles from the plant over time. In addition, kaolin does not protect the new growth of leaves, fruits, and branches occurring after application, so repeated applications are needed to protect new growth. It has met the specifications of the Organic Materials Review Institute, allowing growers to use kaolin particle film in organic farming systems. Cotton producers using it in sustainable or conventional systems need assistance in surveying large fields (≥ 16 ha) so that they can make better decisions on when to reapply the kaolin particle film.

Researchers have used airborne electronic imaging systems to assess crop biophysical parameters (Gopalapillai and Tian, 1999; Yang and Andersen, 1999; Campanella, 2000; Yang et al., 2000), to detect disease and insect infestations (Everitt et al., 1991, 1994; Cook et al., 1999; Fletcher et al., 2001), to determine general health status of plants (Pearson et al., 1994; Fletcher et al., 2004), and to evaluate damage to crops caused by severe weather events (Pearson et al., 1994; Peters et al., 2000). The near-real time availability of the imagery, simplicity of using these systems, immediate compatibility of the imagery with computer systems, and ease of altering the spectral sensitivity of the cameras by changing the filters have made these systems ideal tools for assessing agricultural fields. Therefore, imagery acquired from airborne electronic imaging systems may provide the information producers need for surveying large cotton fields treated with kaolin particle film. The objective of this study was to evaluate airborne multispectral digital video imagery as a tool for surveying kaolin-treated cotton plots, with emphasis on decision support.

2. Materials and methods

2.1. Experimental plots

This study was conducted during 2002 and 2004 on on-going experimental studies located at the Kika de la Garza Subtropical Agricultural Research Center (26°09'N, 97°57'W) near Weslaco, TX, USA. On 11 March 2002, a 2.0 ha experimental plot having rows 1 m apart was planted with cotton (Deltapine 5415 RR). The study was arranged in a randomized complete block design consisting of five blocks and three treatments, kaolin, kaolin and Nufilm (Nufilm, a spreader sticker, prevents rainfall and wind erosion removal of agricultural chemicals from crop plants), and control. Treatment plots were 0.072 ha in size. A 0.5 ha plot having rows 1 m apart was planted to cotton (Deltapine 5415 RR) on 2 March 2004. A randomized complete block design containing six blocks and two treatments, kaolin and control, was used in this study. Treatment plots were 0.025 ha in size.

The kaolin particle film used for these experiments had a particle diameter less than or equal to 2 μm , a bright white color (greater than or equal to 85%), and a proprietary synthetic hydrocarbon coating. The kaolin mixture consisted of 22.7 kg of kaolin per 378 L of water. For the kaolin plus Nufilm plot (2002 only), 444 ml of Nufilm per 3.78 L of water was added to the kaolin and water mixture. A tractor mounted boom sprayer with Teejet 8003 E¹ nozzles was employed to apply the kaolin (with and without Nufilm) suspension to the plant canopies (i.e., 2002 and 2004). To maximize the coverage, the kaolin was applied in two passes, resulting in an application rate of 56 kg ha⁻¹. In 2002, the kaolin particle film was applied monthly starting in March; the 2004 applications occurred bi-weekly starting in April.

For both years, the plots were chemically treated immediately after planting and thereafter hand-rogued to control weeds. They were furrow irrigated approximately 2 weeks before planting and at the start of bloom. No insecticides were applied to the experimental plots.

2.2. Image acquisition

An airborne multispectral digital video imaging system mounted in a hole in the belly of a fixed-winged aircraft acquired blue (447–455 nm), green (555–565 nm), red (625–635 nm), near-infrared (814–826 nm), and mid-infrared (1631–1676 nm) imagery of the experimental plots on 12 June 2002 and 16 June 2004, 2 days after kaolin application. Imagery was acquired from an altitude of 456 m above ground level between 1300 and 1430 HRS Central Standard Time under partly cloudy skies. Clouds were not covering the target locations when the imagery was acquired. At this altitude, the imagery covered approximately 240 m (horizontal) by 180 m (vertical), and each pixel represented an area of approximately 0.14 m² on the ground surface.

¹ Trade names are included for the benefit of the reader and do not imply endorsement of or preference for the product listed by the United States Department of Agriculture.

Visible (i.e., blue, green, and red) and near-infrared imagery were obtained with COHU Model 4810 solid state cameras containing a high-resolution 1.69 cm format charged coupled device imaging sensor with 754 (horizontal) by 488 (vertical) pixel resolution. These cameras were equipped with a narrowband interference filter and were fitted with a Schneider Xenoplan 1.4/17.0 mm fixed focal length lens.

Mid-infrared imagery was acquired with a Sensors Unlimited Model SU320-1.7RT camera containing a 2.54 cm indium gallium arsenide sensor with 320 horizontal and 240 vertical pixels. This camera was fitted with a mid-infrared interference filter and was equipped with an Electrophysics 1.4/25.0 mm focal length lens. The focal length of the lens was different for this camera compared with the COHU cameras. The difference was attributed to the size of the sensors in the Sensors Unlimited and COHU cameras. The 25 mm focal length lens used with the Sensors Unlimited camera permitted it to have a similar viewing area as the COHU cameras.

The system's computer has an AMD Athlon processor (550 MHz) and a SNAPPER-24 multichannel digitizing board that has 640 (horizontal) by 480 (vertical) pixel resolution. The digitizing board converts the analog video signal to digital format. The digital data for each image are saved to the hard drive of the computer.

2.3. Post-processing

After each flight, the images saved to the computer hard drive were transferred to a magnetic optical diskette or compact disc for further analysis in the laboratory. For each date, blue, green, red, near-infrared, and mid-infrared images not geometrically distorted and affected by noise were selected for further analysis. These images were transferred to the Earth Resource Data Analysis System (ERDAS Imagine, version 8.4) software to register the images to each other and to georeference the imagery. For each date, the blue, green, near-infrared, and mid-infrared images were registered to the red image. These images were georeferenced to the Universal Transverse Mercator Coordinate System (UTM north Zone 14) and resampled to have pixels that had 1 m × 1 m resolution. A first order polynomial and the nearest neighbor resampling technique were used in the georeferencing process. Coordinates of ground control points determined with a global positioning system that had sub-meter accuracy were used to georeference the imagery.

The georeferenced imagery was transferred to the IDRISI Kilimanjaro Software (version 14.02) to perform data extraction. Blue, green, red, near-infrared, and mid-infrared digital count values were extracted from a 16 m² area (4 pixels by 4 pixels) located in the center of the treatment plots for both years. For each image, digital count values were also extracted from canvas calibration tarps (9 m² area, 3 pixels by 3 pixels) placed adjacent to the experimental plots prior to image acquisition. Data collected from these tarps were used to develop equations for converting the image digital count values to reflectance. The Extract module of the IDRISI software was used to collect the data. This module allowed extraction of the data from all plots or tarps simultaneously.

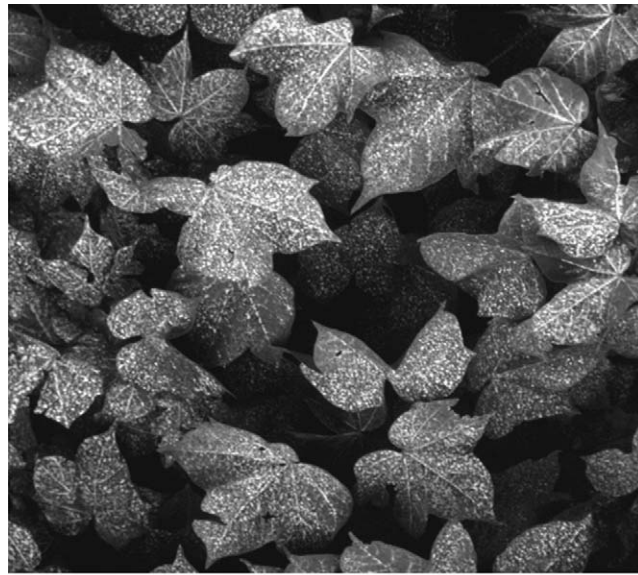
2.4. Ground reflectance measurements

The canvas calibration tarps used in this experiment were manufactured to have 4%, 16%, 32%, and 48% reflectance values. However, the original reflectance values of these tarps can change because of soiling and normal wear and tear. Therefore, actual reflectance of each tarp was determined with a Barnes Handheld Spectroradiometer, recording data in the blue (450–520 nm), green (520–600 nm), red (630–690 nm), near-infrared (760–900 nm), and mid-infrared (1550–1750; 2080–2350 nm) regions of the electromagnetic spectrum. These reflectance readings provided the true reflectance for each tarp. The reflectance values used for the tarps were an average of 10 and 15 readings for 2002 and 2004, respectively. The radiometer was calibrated to reflectance with a barium sulfate standard.

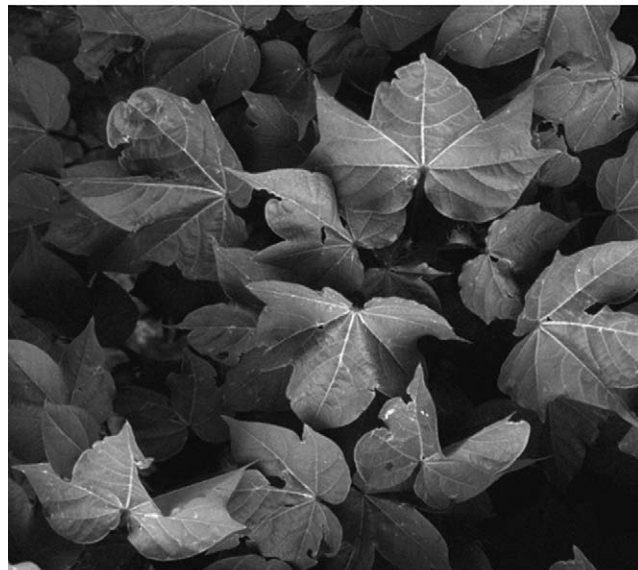
2.5. Statistical analysis

Algebraic or regression equations along with the ground spectral data and the digital numbers extracted from each tarp were used to convert the digital numbers extracted from the treatments to reflectance values. The equations ($r^2 \geq 0.99$) were image and date specific.

For 2002, Dunnett's test (Steele and Torrie, 1960) was employed to compare the kaolin treatments (with and without Nufilm) with the control ($P = 0.05$; $n = 5$). It is the appropriate test to use when treatments are compared with a control and not compared with each other. For 2004, differences between treated and untreated plots were determined with the unpaired t -test ($P = 0.05$; $n = 6$). The regression equations, Dunnett's tests, and unpaired t -tests were calculated with



(a)



(b)

Fig. 1. Close-up photographs showing (a) kaolin-treated and (b) untreated cotton canopies.

the StatMost software (version 3.2). Sensitivity analysis (Carter, 1991) was also performed on the data to determine the image band most responsive to the treatment. It was calculated by subtracting the average value of the untreated plots from the average value of the treated plots and dividing the difference by the average value of the untreated plots.

3. Results and discussion

From ground observations, leaves of treated plants appeared brighter than leaves of untreated plants (Fig. 1). This difference was attributed to the bright white color of the kaolin particle film.

The qualitative and quantitative analyses of the imagery for both years provided similar results. Therefore, the 2004 imagery was used as an illustrative example.

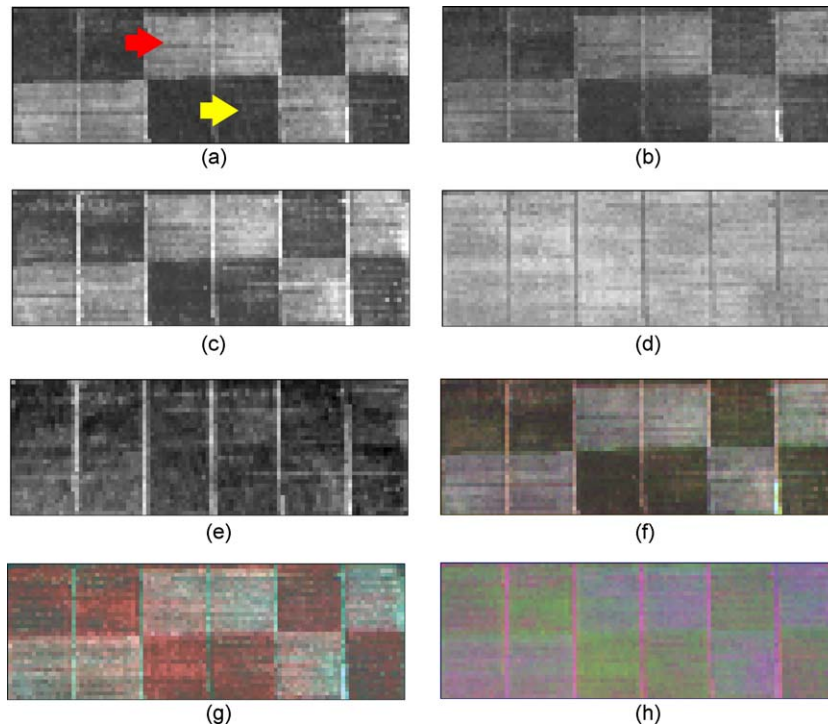


Fig. 2. Airborne digital video images of the 2004 kaolin experimental plot. Imagery was acquired at an altitude of 456 m above ground level on 12 June 2004: (a) blue (447–455 nm); (b) green (555–565 nm); (c) red (625–635 nm); (d) near-infrared (814–826 nm); (e) mid-infrared (1631–1676 nm) imagery; (f) natural color composite-band/color assignments are red = red, green = green, and blue = blue; (g) color-infrared composite-band/color assignments are near-infrared = red, red = green, and green = blue; (h) false color mid-infrared composite-band/color assignments are mid-infrared = red, near-infrared = green, and red = blue. Red and yellow arrows point to treated and untreated plots, respectively.

On blue, green, and red grayscale images (Fig. 2), treated plots appeared in light gray to white tones compared with dark gray to black tones of untreated plots. Blue, green, and red image reflectance values of treated plots were significantly ($P=0.05$) greater than blue, green, and red image reflectance values of untreated plots (Tables 1 and 2). Chlorophyll in healthy green leaves of plant canopies strongly absorb blue and red light and moderately reflect green

Table 1
12 June 2002 image results for the kaolin-treated and untreated cotton plots

Treatment ($n=5$) [‡]	Image spectral reflectance ^a (%)				
	Blue	Green	Red	NIR	MIR
Kaolin	6.8 ± 0.2	10.5 ± 0.22	8.7 ± 0.4	43.5 ± 2.1	29.1 ± 1.3
Kaolin + Nufilm	7.0 ± 0.1	11.0 ± 0.3	9.0 ± 0.4	44.7 ± 1.3	30.2 ± 1.1
Control	3.8 ± 0.2	7.3 ± 0.5	5.0 ± 0.7	42.4 ± 2.0	27.4 ± 1.1

^a NIR: near-infrared; MIR: mid-infrared.

[‡] Means ± standard errors appearing in bold letters within a column were significantly different from the control at $P=0.05$ (Dunnett's test).

Table 2
16 June 2004 image results for the kaolin-treated and untreated cotton plots

Treatment ($n=6$) [‡]	Image spectral reflectance ^a (%)				
	Blue	Green	Red	NIR	MIR
Kaolin	9.9 ± 0.5	14.2 ± 0.7	10.8 ± 0.6	45.6 ± 1.3	23.3 ± 0.8
Control	2.8 ± 0.2	8.1 ± 0.5	5.4 ± 0.4	46.7 ± 2.5	22.0 ± 0.3

^a NIR: near-infrared; MIR: mid-infrared.

[‡] Means ± standard errors appearing in bold letters within a column were significantly different from the control at $P=0.05$ (Dunnett's test).

Table 3

12 June 2002 and 16 June 2004 sensitivity (response to kaolin) results for the kaolin-treated and untreated cotton plots

Sensitivity ^a	Date	Blue	Green	Red	NIR	MIR
Kaolin	12 June 2006	0.79	0.44	0.74	0.03	0.06
Kaolin + Nufilm	12 June 2006	0.84	0.51	0.80	0.05	0.10
Kaolin	16 June 2004	2.53	0.75	1.0	−0.02	0.06

^a Sensitivity was calculated by subtracting the average value of the untreated plots from the average value of the treated plots and dividing the difference by the average value of the untreated plots.

light (Knippling, 1970; Jensen, 2000; Campbell, 2002). These results indicated that kaolin particle film on leaf surfaces partially reflected incoming blue, green, and red light, leading to greater visible reflectance values of the treated plots. These results also suggested that visible bands were more responsive to the kaolin particle film than near-infrared and mid-infrared bands (Tables 1 and 2 and Fig. 2), with the blue band being most responsive to the treatments (Table 3).

The cotton canopies did not completely obscure the soil background when the imagery was acquired. From ground-based observations, the soil in treated plots was slightly lighter in color compared with the soil of the untreated plots. The lighter color was attributed to kaolin particle film on the soil surface, also contributing to the increased visible spectral reflectance of treated plots.

Color and false color composite images are primarily used for qualitative assessment of natural resources because human eyes are more sensitive to color than grayscale imagery (Moik, 1980; Jensen, 2000). Fig. 2f–h are natural color, color-infrared, and false color mid-infrared images, respectively, developed from various combinations of the single band images projected through the red, green, and blue inputs of the computer. From these combinations, we determined that kaolin-treated plots could be distinguished from untreated canopies. This separation was attributed to the images that were sensitive to some portion of the visible spectrum.

To put this study into perspective, several points have to be clarified for potential users of this technology. Conversion of the images' digital counts to reflectance was used for scientific and statistical purposes only. In real world situations, qualitative assessment of the imagery should suffice for making decisions, reducing the burden of extracting data from the imagery. For comparisons, it is believed that the best results can be achieved when an untreated plot is included within the field. When no noticeable differences are observed between treated and untreated areas on the imagery for the majority of the field, the grower can opt to reapply the kaolin.

Based on the sensitivity results, treated fields could be examined with one simple camera, indicating systems less sophisticated than this one could be used during airborne flights. Thomson and Sudbrink (2004) have installed multispectral video cameras and still-digital cameras into agricultural aircraft to survey agricultural fields. Installing these systems on agricultural aircraft should reduce the cost of the imagery because these planes are used daily for agricultural purposes.

4. Conclusions

This study indicated that airborne electronic imaging systems can be used for surveying kaolin-treated cotton fields and showed that imagery recorded in the visible region of spectrum was the most appropriate for field surveillance. The imagery would be extremely useful for assessing large fields and in assisting producers in making decision on when to reapply the kaolin. The benefits of using these systems are the near-real time availability of the imagery and the area covered in one image.

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