EFFECTS OF IMAGE SPATIAL AND RADIOMETRIC RESOLUTIONS ON THE DETECTION OF COTTON PLANTS

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Abstract

Accurate and timely detection of volunteer and regrowth cotton plants is important for the eradication of boll weevils in south Texas. Airborne remote sensing imagery has the potential to identify volunteer and regrowth cotton plants over large geographic regions. The objective of this study was to determine how image spatial and radiometric resolutions affect the detection of cotton plants. Airborne four-band, 16-bit images with five pixel sizes (0.1, 0.2, 0.3, 0.4, and 0.5 m) acquired from a cotton field in south Texas were used in this study. Each 16-bit image was converted to four images with reduced radiometric resolutions (8, 10, 12, and 14 bits). The images with 25 different combinations of spatial and spectral resolutions were classified to detect cotton plants using four classifiers. Results showed that spatial resolution had a significant effect on plant identification and canopy cover estimation, while radiometric resolution reduced from 16 bits to 8 bits had little effect on cotton canopy estimation within the cotton field. The four classifiers produced similar image classification results. These preliminary findings will be useful for determining the appropriate spatial and radiometric resolutions and classification methods for identifying volunteer and regrowth cotton plants.

Introduction

Volunteer and regrowth cotton plants are not only a nuisance weed, but also negatively influence the Texas Boll Weevil Eradication Program (TBWEP). These plants may appear in rotation crops and also in non-crop areas. They can cause yield loss in grain crops due to the competition for water and nutrients and serve as a source for food and reproduction for boll weevils (Morgan et al., 2011). Cotton stalk destruction following harvest is an important cultural practice for minimizing populations of overwintering boll weevils and is mandated by the Texas Department of Agriculture (TDA). Mechanical destruction (shredding followed by plowing) is generally effective and herbicide applications are an alternative. Eliminating volunteer and regrowth cotton plants is critical to the success of TBWEP in south Texas.

Remote sensing has the potential to identify volunteer and regrowth cotton plants over large geographic regions. Ground reflectance, airborne imagery, and satellite imagery have been used to distinguish planted cotton from other crops (Yang et al., 2007, 2011; Zhang et al., 2012). However, volunteer and regrowth cotton plants generally form small, isolated stands. It can be a challenge to distinguish these plants from the surrounding vegetation. Can airborne and satellite imagery be used to detect volunteer and regrowth cotton plants? What spectral, spatial, and radiometric resolutions are needed to detect them? What image processing and classification techniques (traditional hard pixel or more sophisticated classifiers) are needed? At what growth stages and under what growing conditions (with or without other crops) can they be detected? To answer these questions, a series of field experiments and image analyses need to be performed. The specific objective of this study was to determine how image spatial and radiometric resolutions affect the detection of cotton plants in a commercially-planted cotton field in south Texas.

Materials and Methods

Study Site

A furrow-irrigated cotton field in the Rio Grande Valley of south Texas was selected for this study. The center coordinates of the field were (26°25'33.63" N, 98°3'32.28" W).

Airborne Multispectral Image Acquisition

A two-camera imaging system was used to take images from the field. The system consisted of two Canon EOS 5D Mark II digital cameras with a 5616 x 3744 pixel array (Canon USA Inc., Lake Success, NY). One camera captured normal color images with blue, green and red bands, while the other camera was equipped with a 720-nm long-pass filter to obtain near-infrared (NIR) images. The two cameras were mounted next to each other to cover approximately the same geographic area. A remote control device was used to trigger both cameras simultaneously for image acquisition. Images from each camera were stored in 16-bit RAW and 8-bit JPEG files on a CompactFlash card.

Images were captured at altitudes of 305, 610, 914, 1219, and 1524 m (1000, 2000, 3000, 4000, and 5000 ft) to achieve ground pixel sizes from 0.1 to 0.5 m at 0.1-m increments. A Cessna 206 single-engine aircraft was used to acquire imagery on 10 and 19 April and 7 and 17 May 2012 between 1130h and 1430h local time under sunny conditions. Only the images taken on 17 May were presented in this paper.

Image Alignment

An image-to-image registration procedure was used to align the color image and the NIR image taken at each altitude. Nine common control points approximately evenly distributed across the imaging area were identified from each image to establish the transformation model. Either a first-order or a second-order polynomial transformation model with nearest neighborhood resampling was used to rectify the NIR image to the color image. The rectified NIR image was then merged with the color image to create the four-band image. All procedures for image rectification and merging were performed using ERDAS Imagine (ERDAS Inc., Norcross, GA).

Generating Images with Different Radiometric Resolutions

The digital counts (DC) in the original 16-bit images range from 0 to 65535. Each 16-bit image was converted to 8-, 10-, 12-, and 14-bit images using the following formulas:

$$DC_{8\text{-bit}} = DC_{16\text{-bit}} * 255 / 65535$$
$$DC_{10\text{-bit}} = DC_{16\text{-bit}} *1023 / 65535$$
$$DC_{12\text{-bit}} = DC_{16\text{-bit}} *4095 / 65535$$
$$DC_{14\text{-bit}} = DC_{16\text{-bit}} *16383 / 65535$$

Thus the five original images and the 20 generated images (5 spatial and 5 spectral resolutions) were available for classification.

Image Classification

Each of the 25 images was classified into two spectral classes using ISODATA (Iterative Self-Organizing Data Analysis) unsupervised classification (ERDAS, 2010). One spectral class represented cotton plants and the other bare soil. The signatures for the two classes were then used as endmembers for four supervised classifiers, including minimum distance, Mahalanobis distance, maximum likelihood, and spectral angle mapper (SAM) (ERDAS, 2010; Kruse et al., 1993). Since the signatures from the ISODATA classification were used, the minimum distance classifier produced the same classification as the unsupervised classification. Therefore, four unique classification maps were generated for each of the 25 images.

Plant Width Measurements

Plant width and other plant physical data were measured at 10 random locations in the field on the same date the images were taken. The crop was predominately at the third-grown square stage.

Results and Discussion

Figure 1 shows the color and color-infrared (CIR) images acquired at 305 m with a pixel size of 0.1 m. On the normal color image, cotton plants had a greenish color, while bare soil had a light gray color. On the CIR image, cotton plants exhibited a reddish-magenta tone, while bare soil had a light gray or cyan color. The small gray or cyan circular areas were harvester ant mounds. In both images, crop rows can be clearly distinguished. The dimension of the images is 5616 pixels by 3744 pixels or approximately 560 m by 370 m. The yellow square box on the images contains an array of 2520 by 2510 pixels or an area of 252 m by 252 m. The square area was used as the area of interest for each of the 25 images.

Figure 2 shows the color and CIR images acquired at 610 m with a pixel size of 0.2 m. The pixel array was the same, but it covered an area of approximately 1120 m by 750 m, four times as large as the area covered by the image at

305 m. Similarly, the images with pixel sizes of 0.3, 0.4 and 0.5 m covered respectively 9, 16, and 25 times the area covered by the image with a pixel size of 0.1 m.

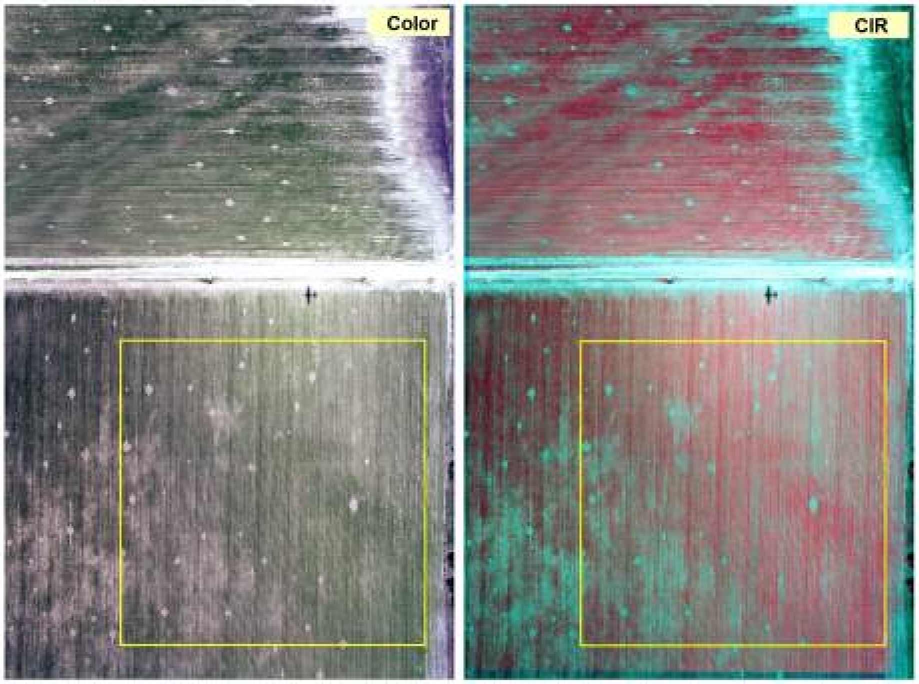

Figure 1. A normal color image and color-infrared (CIR) image taken at 305 m with a pixel size of 0.1 m from a cotton field in south Texas in 2012. The yellow box represents an area of 252 m by 252 m that was used for analysis.

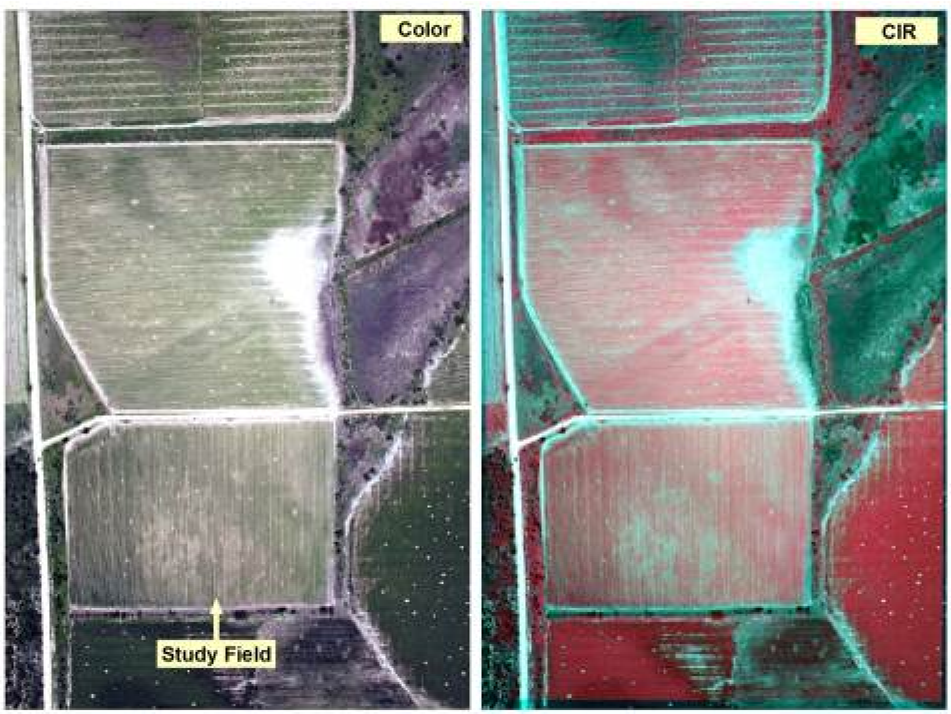

Figure 2. A normal color image and color-infrared (CIR) image taken at 610 m with pixel size of 0.2 m from a cotton field in south Texas in 2012. The images covered four times as large an area as the image in Figure 1.

Figure 3 shows the extracted CIR images taken at five different altitudes. Figure 4 shows zoomed-in CIR images at the five spatial resolutions for the center area with 1/6 of the dimensions. The south-north row direction can still be clearly seen in each image, but crop rows cannot be readily distinguished if the pixel size is greater than 0.3 m.

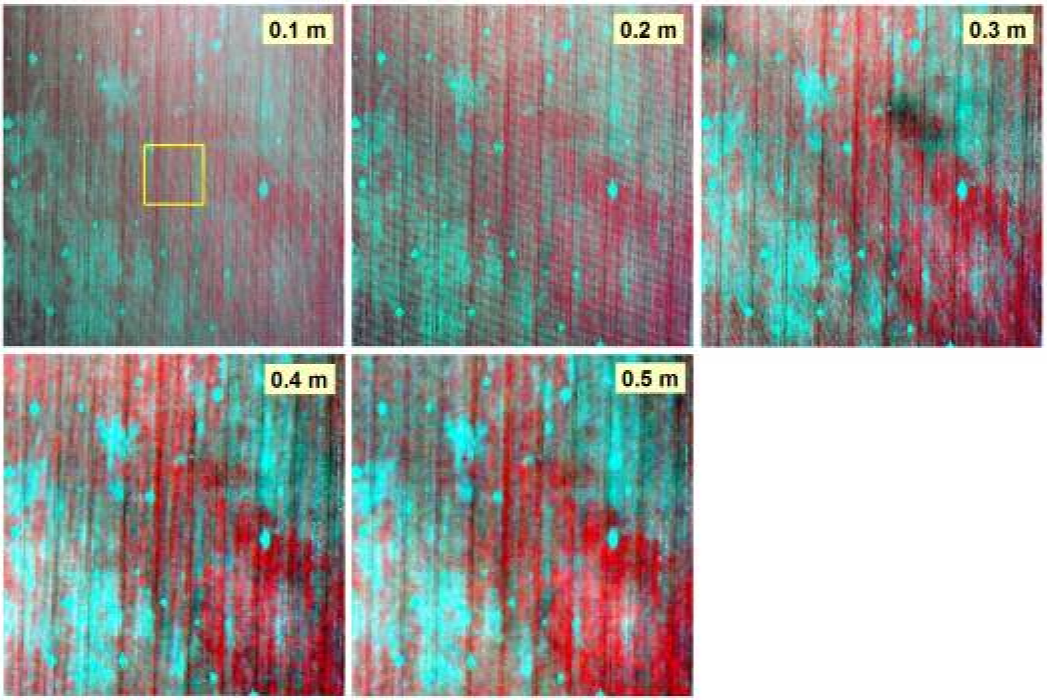

Figure 3. CIR images covering an area of 252 m by 252 m extracted from the images taken at five different altitudes.

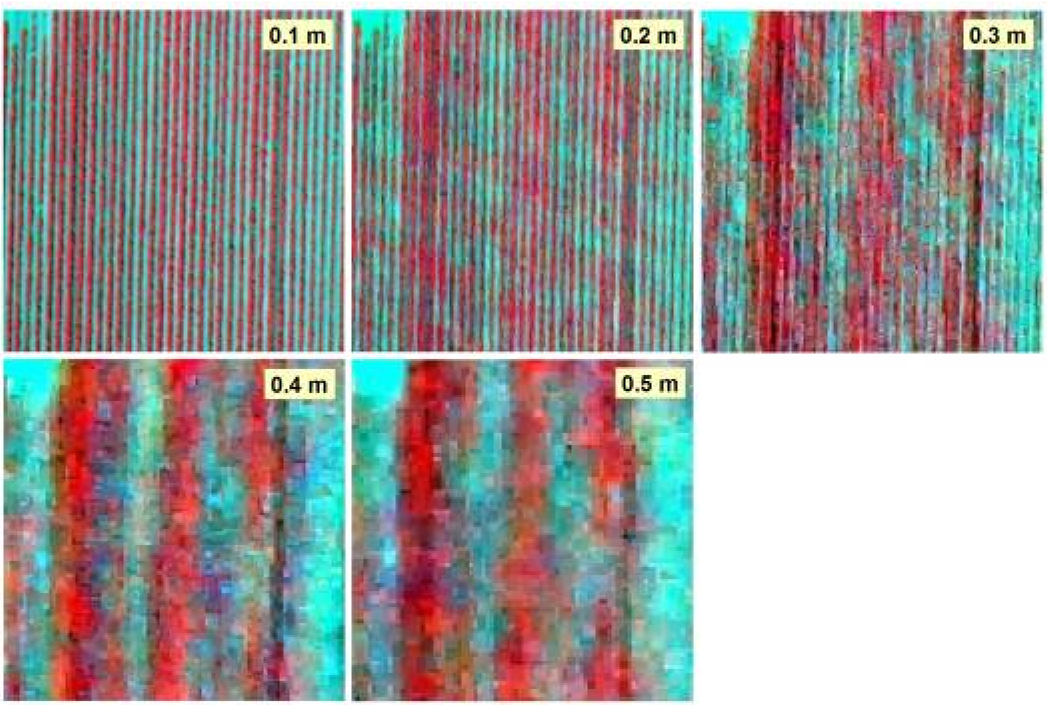

Figure 4. Zoomed-in CIR images at five spatial resolutions for the center area (as shown by the yellow box in Figure 3) with 1/6 of the dimensions (i.e., 42 m by 42 m).

Figure 5 shows the zoomed-in classification maps for the images at the five spatial resolutions based on unsupervised classification. The 0.1- and 0.2-m images correctly distinguished crop canopy from bare soil, but the other three coarse-resolution images did not correctly identify cotton plants.

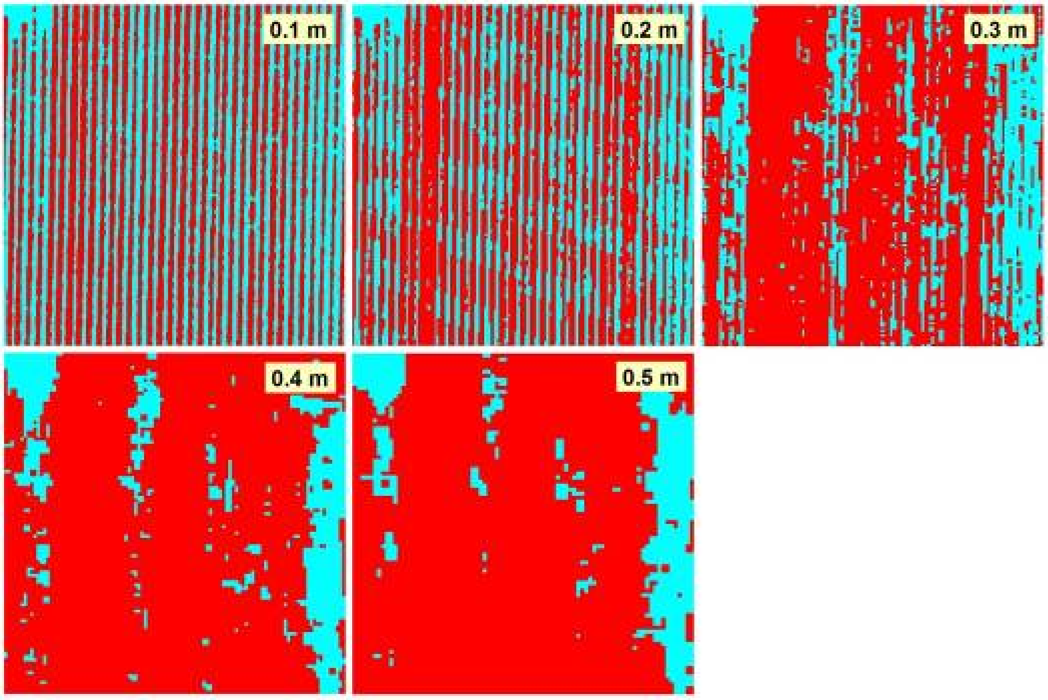

Figure 5. Zoomed-in classifications maps at five spatial resolutions for the center area with 1/6 of the dimensions.

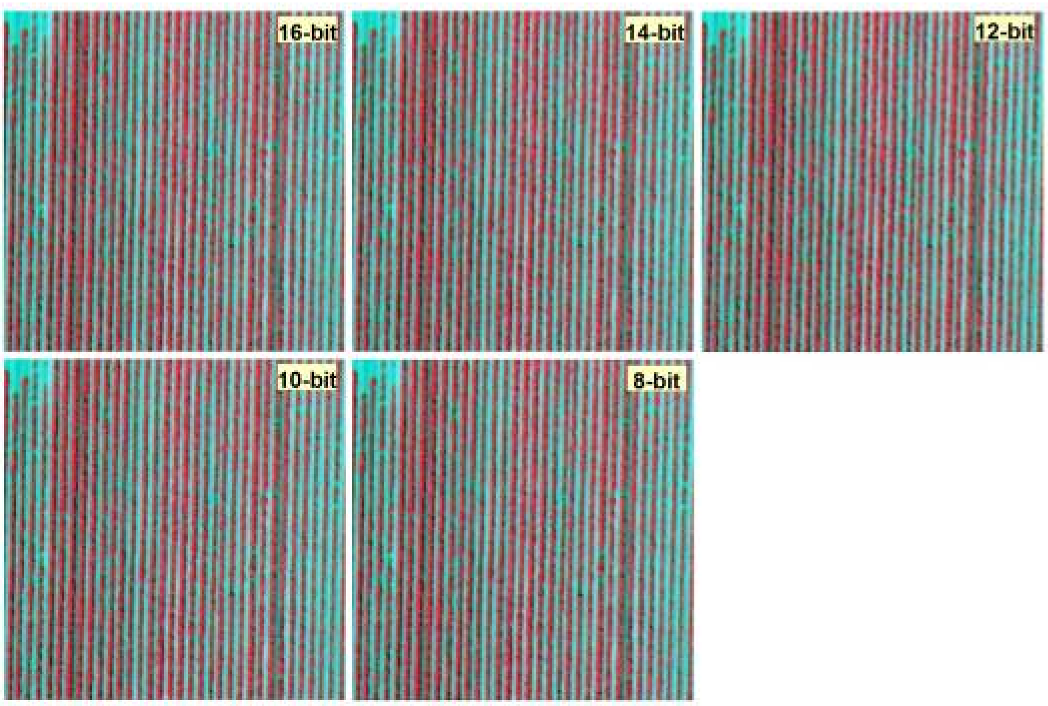

Figure 6. Zoomed-in CIR images with 0.1-m pixel size at five radiometric resolutions.

Figure 6 shows the zoomed-in CIR images with the 0.1-m pixel size at the five radiometric resolutions. The five images looked alike. The five corresponding classification maps (not shown) also looked almost identical, indicating that radiometric resolution had little effect on the detection of cotton plants with a single crop.

Table 1 summarizes the crop canopy cover estimates at the five spatial and the five spectral radiometric resolutions based on the ISODATA unsupervised classification. At the original 16-bit radiometric resolution, crop cover estimates at 0.1- and 0.2-m spatial resolutions were respectively 47.55% and 47.57%. These estimates were almost identical and should represent the best estimates of the crop canopy cover at the time of the image acquisition. Since the row spacing was 96.5 cm (38 in.), the estimated average canopy width was 45.9 cm (96.5 cm × 47.546%). The actually measured plant width based on the ten measurements was 44.3 cm. The canopy cover estimate at the 0.3-m pixel size was close to that at the 0.1-m pixel size, but the classification map showed that the canopy cover was overestimated at the areas with high canopy cover and underestimated at areas with low canopy cover. The estimates at the 0.3 and 0.4 m pixel sizes were very similar and higher than the actual canopy cover. The estimates among the five radiometric resolutions were essentially the same for each spatial resolution, indicating radiometric resolution had very little effect on canopy cover estimation when there was only a single crop.

Table 1. Crop cover estimates (%) based on images taken from a cotton field at five different spatial resolutions and five radiometric resolutions using unsupervised classification.

Radiometric	Spatial Resolution (m)				
Resolution	0.1	0.2	0.3	0.4	0.5
8-bit	47.546	47.574	49.425	56.365	56.537
10-bit	47.547	47.594	49.397	56.373	56.583
12-bit	47.545	47.590	49.423	56.356	56.609
14-bit	47.545	47.587	49.417	56.349	56.585
16-bit	47.545	47.586	49.418	56.346	56.582

Figure 7 shows the zoomed-in classifications maps for the 16-bit image at the 0.1-m pixel size based on the four supervised classifiers. The four maps looked very similar to each other.

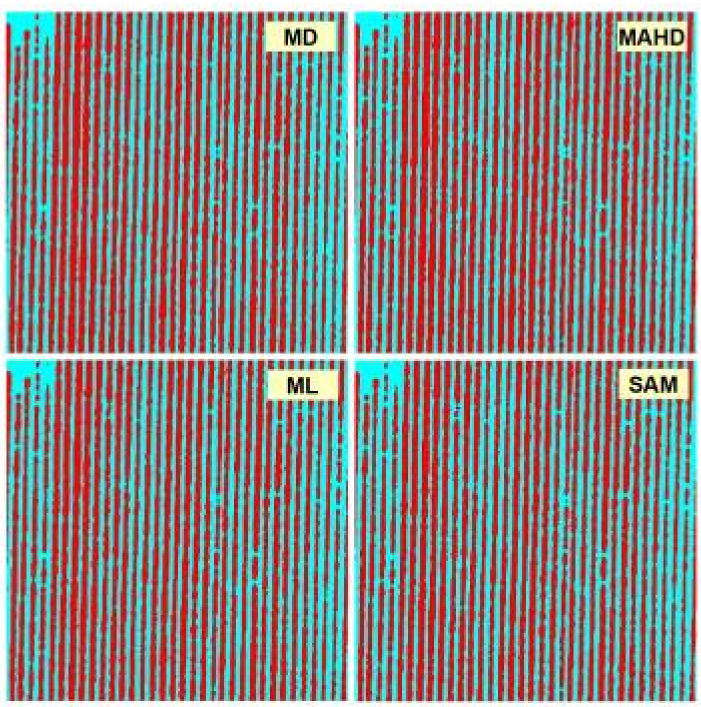

Figure 7. Zoomed-in classifications maps for a 16-bit image at the 0.1-m pixel size based on four supervised classifiers (MD = minimum distance, MAHD = Mahalanobis distance, ML = Maximum likelihood, and SAM = spectral angle mapper).

Table 2 gives the crop cover estimates based on the 16-bit images taken from a cotton field at five spatial resolutions using the four supervised classifiers. Canopy cover estimates varied from 45.7% for spectral angle mapper to 50.3% for maximum likelihood at the 0.1-m pixel size. For other pixel sizes, estimates were similar among classifiers.

Table 2. Crop cover estimates (%) based on 16-bit images taken from a cotton field at five different spatial resolutions using four supervised image classification techniques.

Image Classifier	Spatial Resolution (m)				
	0.1	0.2	0.3	0.4	0.5
Minimum distance	47.5	47.6	49.4	56.3	56.6
Maximum likelihood	50.3	48.8	51.6	54.1	54.5
Mahalanobis distance	48.3	47.8	49.1	55.2	55.5
Spectral angle mapper	45.7	46.2	49.4	55.5	55.0

Conclusions

The results from this study illustrated how image spatial and radiometric resolutions affected the detection and estimation of cotton canopy cover. Spatial resolution had a significant effect on plant identification and canopy cover estimation. If spatial resolution was less than half of the plant width, crop canopy cover was accurately estimated using hard pixel classifiers; otherwise, mixed pixels affected the estimation results and crop canopy cover was not accurately estimated using the four classifiers. Reducing radiometric resolution from 16 bits to 8 bits had little effect on single crop identification and the four classifiers produced similar results. More research is needed to examine how spatial and spectral resolutions affect the identification of volunteer and regrowth cotton plants under various growing conditions.

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