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EVALUATION OF COTTON REGROWTH CONTROL USING REMOTE SENSING

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Abstract

A field experiment was conducted to examine the usefulness of remote sensing technology for evaluating cotton (*Gossypium hirsutum* L.) regrowth control strategies for post-harvest destruction of cotton stalks. Ten treatments (one control and nine combinations of three herbicide mixtures and three application timings) were assigned to 30 shredded cotton plots according to a randomized complete block design in a south Texas cotton field in 2002. Ground reflectance spectra were collected on randomly selected sites from each plot 32 days after the first three of the nine herbicide treatments were applied. Meanwhile, airborne multispectral digital imagery was obtained from the field and plant regrowth was visually rated at five levels ranging from no live plants to mostly healthy plants based on ground observations. The reflectance spectra were able to separate regrowth differences among some of the treatments, though a large number of spectra were needed to achieve reliable results. The airborne imagery did not provide sufficient visual differentiation among the treatments, but the reflectance information extracted from the imagery allowed quantitative separations among the treatments. Seven spectral variables, including the green, red, and near-infrared (NIR) bands of the multispectral imagery and four vegetation indices derived from the three bands, were used to compare the differences among the treatments. Multiple comparisons showed that the green band and the four vegetation indices detected significant differences among some of the treatments as detected by the visual efficacy rating. These results indicate that remote sensing can be a useful tool for evaluating cotton regrowth control strategies.

Introduction

Cotton stalk destruction is an important cultural practice for managing overwintering boll weevils. This practice controls boll weevil populations by reducing or eliminating the habitat and food available to the insect. The Cotton Pest Control Law in Texas requires that producers in each regulated county plant and destroy cotton within an authorized period (Texas Department of Agriculture, 2002). For example, in the Lower Rio Grande Valley of Texas, cotton can be planted between 1 February and 1 March and must be destructed by 1 September each year. The recommended destruction method is shredding and plowing. Although this method is effective, recent increases in minimum tillage and no tillage systems have made it challenging. Therefore, other alternative cotton stalk destruction methods such as chemical applications have been tested and practiced. Sparks et al. (2002) evaluated the efficacy of Savage (2,4-D) and Harmony Extra for post harvest cotton stalk destruction. Both herbicides performed better when applied to shredded stalks than to standing stalks. Savage applied to shredded cotton appeared to provide excellent regrowth control, while Harmony Extra delayed but did not prevent regrowth.

Currently, only limited research has been conducted to identify effective herbicides as well as their application methods for cotton stalk destruction. Moreover, there is no accepted procedure to evaluate the effectiveness of various regrowth control methods. Sparks et al. (2002) used visual ratings and plant physical measurements to quantify the differences among several stalk destruction treatments. This approach seems to be reliably, but it is time consuming and labor-intensive. From the perspective of remote sensing, regrowth plants from shredded cotton stalks treated with different herbicides would have different spectral responses. Therefore, spectral characteristics of the regrowth plants may be used to differentiate the effectiveness among various herbicide treatments. Yang et al. (2002) successfully evaluated the effectiveness of different cotton defoliation strategies using airborne multispectral imagery. The objective of this study was to examine the feasibility of ground reflectance measurements and airborne multispectral imagery for evaluating the effectiveness of various regrowth control treatments as compared with traditional visual observations and ground measurements.

Materials and Methods

Experimental Design

A field experiment was conducted on an irrigated cotton field located at the South Research Farm of the USDA-ARS Kika de la Garza Subtropical Agricultural Research Center at Weslaco, Texas in 2002. The field was planted to cotton (cultivar Deltapine 50) in early march and normal production practices were used in the field during the growing season. A randomized complete block design was established within the field at the time of cotton harvest. Ten treatments, including one control and nine combinations of three herbicide mixtures and three application timings, were randomly assigned to 30 shredded experimental plots in three blocks (Figure 1). Cotton plants within all the plots were shredded at 8-10 cm from the soil line with a two row rotary shredder. The shredded plots were 2 rows (2.0 m) wide and 112 m long and separated by two rows of standing (non-shredded) cotton as a buffer. The herbicides used included Amine 4 2,4-D Weed Killer (Dimethylamine salt of 2,4-dichlorophenoxyacetic acid, Platte Chemical Company, Fremont, Nebraska), Clarity (Diglycolamine salt of 3,6-dichloro-o-anisic acid, BASF Corporation, Research Triangle Park, North Carolina), Valor WP (Flumioxazin, Valent USA Corporation, Walnut Creek, California), and Roundup UltraMAX (Glyphosate, –(phosphonomethyl)glycine, Monsanto Company, St. Louis, Missouri). Amine (2,4-D) and Clarity were each used alone, while Valor and Roundup were used together as one herbicide mixture. A Spider Spray Trac sprayer (West Texas Lee Company, Inc., Idalou, Texas) was used to apply the herbicides to the designated plots on three dates: 26 July (immediately after shredding), 2 August (7 days after shredding), and 9 August (14 days after shredding). The sprayer was equipped with multiple booms and three of the booms were used to apply Amine (2,4-D), Clarity, and the mixture of Valor and Roundup, respectively. The sprayer covered two rows (the width of the individual plots) at a time with one nozzle spraying a 25-cm band over each row. Application rates for the herbicides were 2.34 L/ha (1 qt./ac) of Amine (2,4-D), 1.17 L/ha (1 pt./ac) of Clarity, 73 ml/ha (1 oz./ac) of Valor, and 2.34 L/ha (1 qt./ac) of Roundup. The volume of spray solution (water) used was 126 L/ha (13.5 GPA) for Amine (2,4-D), Clarity, and the mixture of Valor and Roundup. The applications were made early in the morning when wind was calm so that drift between plots was minimized.

Ground Reflectance, Airborne Imagery and Plant Physical Data Collection

Ground reflectance spectra were collected from each plot with a FieldSpec HandHeld spectroradiometer (Analytical Spectral Devices, Inc., Boulder, Colorado) on 27 August (32 days after shredding). The spectroradiometer was sensitive in the visible to NIR portion of the spectrum (350-1050 nm) with a nominal spectral resolution of 1.57 nm. Five spectra were taken on five randomly selected canopies from each plot and each spectrum was an average of 10 sample spectra over each canopy.

Airborne color-infrared (CIR) imagery was acquired using a digital imaging system described by Escobar et al. (1997) from the cotton field on the same date ground reflectance data were taken. The imaging system consisted of three Kodak MegaPlus digital charge coupled device (CCD) cameras. The original acquisition computer in the imaging system was replaced in 2002 by a fast computer equipped with more advanced image grabbing boards and software to enhance acquisition speed and take advantage of the full resolution of the cameras. The enhanced system had the capability of obtaining images with 1280 × 1024 pixels as compared with the 1024 × 1024 pixels the old system had. The cameras were sensitive in the visible-to-NIR regions (400-1000 nm) and had a built-in analog-to-digital (A/D) converter that produced a digital output signal with 256 gray levels. The three cameras were filtered for spectral observations in the green (555-565 nm), red (625-635 nm), and NIR (845-857 nm) wavelength intervals, respectively. A Cessna 206 aircraft was used to acquire imagery at an altitude of approximately 460 m between 1200 and 1400h local time under sunny conditions. The ground pixel size achieved was approximately 0.2 m. For radiometric calibration of the imagery, four 8 m by 8 m tarpaulins with nominal reflectance values of 4, 16, 32 and 48%, respectively, were placed at the north edge of the field during image acquisition. The actual reflectance values from the tarpaulins were measured using the FieldSpec spectroradiometer.

Plant regrowth in each plot was visually rated on a 1-to-5 scale based on ground observations. The ratings are as follows: 1-no live plants; 2-some plants alive, but appear sick; 3-most plants alive, but appear sick; 4-some plants appear healthy; and 5-most plants appear healthy.

Airborne Imagery Processing

The NIR, red and green band images in the CIR composite image were registered to one another to correct the misalignments among the bands. The registered band images were converted to reflectance based on three calibration equations (one for each band) relating reflectance values to the digital count values on the four tarpaulins. Image registration and calibration were performed using ERDAS IMAGINE (ERDAS, Inc., 1999). Reflectance values of the regrowth plants within each plot were extracted and averaged from each of the three band images. Four vegetation indices were derived from the three bands to measure vegetation vigor and abundance. Two of the vegetation indices were band ratios defined as

$$NR = NIR/Red \qquad (1)$$
$$NG = NIR/Green \qquad (2)$$

The other two were normalized differences (ND) defined as

$$NDNR = (NIR-Red)/(NIR+Red) \qquad (3)$$
$$NDNG = (NIR-Green)/(NIR+Green) \qquad (4)$$

NDNR is commonly referred to as the normalized difference vegetation index (NDVI).

Statistical Analysis

The five ground reflectance spectra collected from each plot were averaged to produce a mean reflectance spectrum for the plot. Analyses of variance were performed on the seven spectral variables and the regrowth rating. Multiple comparisons on means were made using Fisher's protected least significant difference (LSD) procedure (SAS Institute Inc., 1988).

Results and Discussion

Reflectance Spectra of Cotton Plants

Figure 2 presents representative reflectance spectra for normal cotton plants, regrowth plants after shredding, and bare soil in the visible-to-NIR region of the spectrum. In the visible portion of the spectrum, reflectance for normal plants is higher in the green region than in the blue and red regions. Toward the red end of the visible spectrum, reflectance rises sharply and gradually flattens out in the NIR portion. The reflectance curve for bare soil is close to a straight line and soil reflectance increases with wavelengths gradually in the visible to NIR region of the spectrum. The reflectance curve for regrowth plants falls somewhere between the reflectance curves for the normal plants and bare soil. Although the general shape of the reflectance spectrum for regrowth plants is similar to the reflectance spectrum for normal plants, the reflectance is much higher in the visible region and much lower in the NIR region than the reflectance for normal plants. Moreover, the difference between the green and red bands becomes minimal for regrowth plants. These deviations in reflectance are mainly attributed by relatively small regrowth plants and large soil exposure within the field of view of the spectroradiometer. These spectral behaviors are the basis for the separation of different regrowth control methods.

Since the spectra from some of the ten treatments are similar and difficult to visually differentiate, they are shown in three separate figures by application timing. The spectra for the control and bare soil are also shown in the figures for comparison. Figure 3 presents representative reflectance spectra of regrowth plants when the three herbicide treatments were applied immediately after shredding. The spectra for the control and the plots treated with the mixture of Valor and Roundup are almost identical, indicating applying this herbicide mixture immediately after shredding had little effect on regrowth control. The spectra from the plots treated with Amine (2,4-D) and Clarity deviate apparently from the spectrum for the control, indicating that these two herbicides applied immediately after shredding effectively curbed cotton regrowth. However, the difference between the two treatments was very small. Figures 4 and 5 show representative reflectance spectra of regrowth plants when the herbicide treatments were applied 7 days and 14 days after shredding, respectively. The spectra for all tree herbicide treatments differed from the spectrum for the control, indicating applying these herbicides 7 days and 14 days after shredding had an apparent effect on regrowth control. Although clarity applied on these two timings did not seem to be as effective as Amine (2,4-D) and the mixture of Valor and Roundup, the differences among the three were subtle based on the spectra.

Since plots receiving effective regrowth control tended to have fewer regrowth plants with healthy leaves, the reflectance from these plots was higher in the visible region and lower in the NIR region than the reflectance from the control. Moreover, the reflectance from these plots tended to have lower reflectance in the visible region and lower or higher reflectance in the NIR region than bare soil, depending on the amount of regrowth. Based on the spectral behaviors of different treatments relative to the spectra of the control and bare soil, the effectiveness of the treatments can be evaluated.

As indicated in Figure 3-5, spectra can be a useful tool for differentiating the effectiveness of various herbicide treatments. However, it is not always easy to obtain reliable spectra because of spatial variability within the treatments, limited amount of regrowth, and variations in the field of view of the spectroradiometer. For example, regrowth after shredding in this experimental field was very small due to the effects of the herbicides and dry weather. The average width of regrowth plants varied from 0 (no regrowth) to approximately 24 cm 32 days after shredding. The spectroradiometer used in this experiment had a field of view angle of 15°and covered a circular area of 26 cm in diameter when held 1 m above the canopy. Thus each sample spectrum was based on a circular area wider than the width of regrowth plants. Clearly, the resulting spectra taken from such a small area were affected by the variability in plant growth, position of the instrument, and amount of shadow and soil background within the field of view. Therefore, many samples are needed to obtain accurate and reliable spectra.

Visual Comparisons of Herbicide Treatments with Digital Imagery

Figure 6 shows a CIR image acquired from the cotton field on August 27, 32 days after cotton stalks were shredded. Because of limited amount of regrowth, it is extremely difficult to visualize the differences among the treatments. Although minor differences could be seen among some of the treatments when the image was enlarged, it was difficult to obtain reliable separations from the image. As indicated previously, the pixel size of the image was about 0.2 m, so each row is only 1 to 2 pixels wide on the image. Therefore, use of airborne imagery for visual evaluation of the differences among various herbicide treatments requires high spatial resolution imagery. Although the image of the experimental plots was not fine enough for visual evaluation, it contained important spectral information concerning plant regrowth for every area of the field. This quantitative reflectance information can be used to statistically determine the differences among the treatments.

Comparisons of Herbicide Treatments Using Spectral Indices

Table 1 shows the mean values of the NIR, red and green bands and the four vegetative indices by treatment based on the field image taken on 27 August. The red band and the four vegetation indices detected significant differences among the treatments, while the NIR and green bands did not reveal any statistical difference. Compared with the three bands, the four vegetation indices were more effective and consistent in differentiating among the treatments. As can be seen from the spectra shown in Figures 3-5, more plant regrowth would have higher reflectance in the NIR band and lower reflectance in the red and green bands than less regrowth. Similar to the NIR band, the four vegetation indices tend to have higher values when the amount of plant regrowth is more abundant. In other words, more effective herbicide treatments, which result in less plant regrowth, should have higher reflectance in the red and green bands and lower reflectance in the NIR as well as lower values for the four vegetation indices. The data in Table 2 clearly indicate that all the herbicide treatments except treatment 4 had varying degrees of effectiveness for cotton regrowth control. There was no statistical difference between the control and treatment 4, indicating application of Valor and Roundup immediately after shredding had little effect on regrowth control. However, this herbicide mixture was more effective in curbing regrowth if being applied one week or two weeks after shredding, though no difference existed between the two application timings. Treatments with Amine (2,4-D) were very effective and there were no significant differences among the three application timings, indicating application timing might not be sensitive for this herbicide. Clarity applied immediately after shredding was as good as Amine (2,4-D), but its effectiveness decreased significantly when applied one or two weeks later. In fact, Clarity applied 2 weeks after shredding was the least effective treatment only second to the mixture of Valor and Roundup applied immediately after shredding.

Table 2 presents plant regrowth ratings among the ten treatments based on ground observations made 31 days after shredding or one day before the reflectance and image data were collected. The ground observation results generally agreed well with those from the airborne imagery for the experiment field. In fact, the correlations between the regrowth rating and each of the four vegetation indices were 0.89 for NR, 0.88 for NG, 0.89 for NDNR, and 0.88 for NDNG. Although a statistical difference was detected between the control and treatment 4, the difference was small and may be partly due to the coarse rating scale. Moreover, the airborne imagery considered every regrowth area within each plot, while the visual rating was based on ground observations over a few areas of the plot. Therefore, airborne imagery should provide accurate and reliable information about cotton plant regrowth. However, care has to be taken in interpreting the remote sensing results and limited ground measurements and observations are always necessary to validate the remote sensing results.

Summary and Conclusions

This study illustrates how reflectance spectra and airborne multispectral imagery can be used to evaluate the effectiveness of different cotton regrowth control methods. Ground reflectance spectra can be used to differentiate among treatments if they are taken from a sufficient number of canopies representing the regrowth conditions. Airborne multispectral digital imagery provides a continuous view of the imaging area and has the potential for quick visual comparisons among treatments. However, because of the limited amount of cotton plant regrowth and relatively coarse spatial resolution of the digital imaging system used in this study, it was very difficult to visually separate the differences among the treatments based on the imagery. Nevertheless, the imagery contained spectral information for every area of the field and allowed quantitative separations of these treatments. Vegetation indices derived from individual image bands can be more informative than the individual bands themselves. The two band ratios and the two normalized difference vegetation indices used in this study were effective for separating the treatments. Compared with traditional ground observation and measurement approaches, the remote sensing-based approach is more effective and efficient especially if many treatments are to be evaluated over large fields. Although ground observations and measurements are necessary to validate remote sensing results, it is clear that the remote sensing technique is a useful tool for evaluating the effectiveness of cotton regrowth control methods. Moreover, high resolution digital imaging systems and photographic cameras may allow quick visual evaluation of cotton regrowth treatments and provide more detailed plant regrowth information for more accurate and reliable evaluation.

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Table 1. Comparisons of means for seven spectral variables among ten cotton regrowth control treatments based on airborne image data obtained 32 days after cotton stalks were shredded in a field at Weslaco, Texas in 2002.

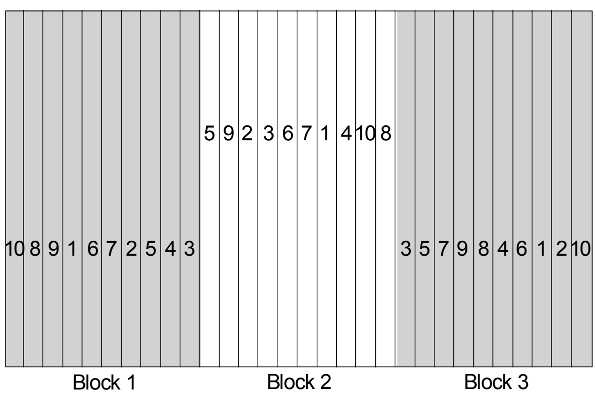
Treatment	NIR (%)	Red (%)	Green (%)	NR	NG	NDNR	NDNG
1. Control	22.1	14.4a	12.5	1.534a	1.763a	0.211a	0.276a
2. Amine (2,4-D) (D0)	21.4	15.3bc	12.9	1.400cd	1.662bcd	0.166cd	0.248bcd
3. Clarity (D0)	21.0	15.3bc	12.8	1.367d	1.639cd	0.155d	0.242cd
4. Valor+Roundup (D0)	22.1	14.3a	12.3	1.551a	1.792a	0.216a	0.283a
5. Amine (2,4-D) (D7)	21.4	15.7c	12.9	1.366d	1.639cd	0.155d	0.242cd
6. Clarity (D7)	21.4	15.0b	12.8	1.426bc	1.680bc	0.175bc	0.254bc
7. Valor+Roundup (D7)	21.4	15.1bc	12.3	1.416bcd	1.677bcd	0.172bcd	0.252bcd
8. Amine (2,4-D) (D14)	21.1	15.3bc	12.9	1.377cd	1.635d	0.159cd	0.241d
9. Clarity (D14)	21.6	14.8ab	12.8	1.458b	1.694b	0.186b	0.257b
10. Valor+Roundup (D14)	21.3	15.2bc	12.3	1.396cd	1.680bc	0.165cd	0.254bc

[1] D0, D7, and D14 represent applying herbicides immediately, 7 days, and 14 days after shredding, respectively.
[2] NR = NIR/Red, NG = NIR/Green, NDNR = (NIR-Red)/(NIR+Red), and NDNG = (NIR-Green)/(NIR+Green).
[3] Means within a column followed by the same letter are not significantly different at the 0.05 level according to Fisher's protected LSD procedure following an analysis of variance on a randomized complete block design.
[4] Treatment effect for NIR: df =9, F=1.69, p=0.1632, no LSD test.
Treatment effect for Red: df =9, F=4.90, p=0.0021, LSD=0.59.
Treatment effect for Green: df =9, F=1.38, p=0.2669, no LSD test.
Treatment effect for NR: df =9, F=14.07, p<0.0001, LSD=0.0524.
Treatment effect for NG: df =9, F=12.36, p<0.0001, LSD=0.0446.
Treatment effect for NDNR: df=9, F=13.81, p<0.0001, LSD=0.0175.
Treatment effect for NDNG: df=9, F=12.24, p<0.0001, LSD=0.0122.

Table 2. Comparisons of means for visual efficacy rating among ten cotton regrowth control treatments based on ground observations made 31 days after cotton stalks were shredded in a field at Weslaco, Texas in 2002.

Treatment	Rating
1. Control	5.0a
2. Amine (2,4-D) (D0)	2.7cd
3. Clarity (D0)	2.3d
4. Valor+Roundup (D0)	4.2b
5. Amine (2,4-D) (D7)	2.8cd
6. Clarity (D7)	2.7cd
7. Valor+Roundup (D7)	2.5d
8. Amine (2,4-D) (D14)	2.8cd
9. Clarity (D14)	3.3c
10. Valor+Roundup (D14)	3.0cd

[1] D0, D7, and D14 represent applying herbicides immediately, 7 days, and 14 days after shredding, respectively.
[2] Rating scale: 1-no live plants; 2-some plants alive, but appear sick; 3-most plants alive, but appear sick; 4-some plants appear healthy; and 5-most plants appear healthy.
[3] Means within a column followed by the same letter are not significantly different at the 0.05 level according to Fisher's protected LSD procedure following an analysis of variance on a randomized complete block design.
[4] Treatment effect for rating: df =9, F=11.94, p=0.0001, LSD=0.718.



Treatment
1. Control
2. Amine (2,4-D) sprayed immediately after shredding
3. Clarity sprayed immediately after shredding
4. Valor+Roundup sprayed immediately after shredding
5. Amine (2,4-D) sprayed 7 days after shredding
6. Clarity sprayed 7 days after shredding
7. Valor+Roundup sprayed 7 days after shredding
8. Amine (2,4-D) sprayed 14 days after shredding
9. Clarity sprayed 14 days after shredding
10. Valor+Roundup sprayed 14 days after shredding

Figure 1. Layout of ten cotton regrowth control treatments across three blocks in a randomized complete block design for a cotton field in 2002.

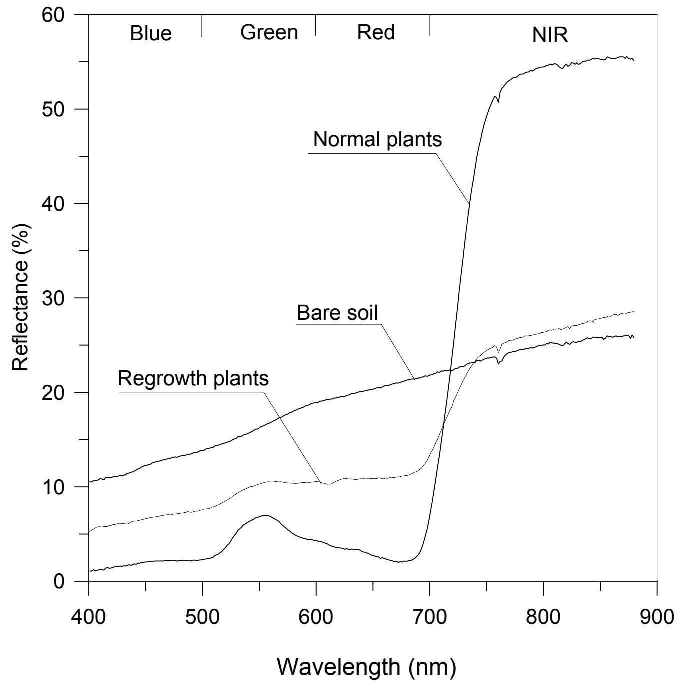


Figure 2. Representative reflectance spectra for normal cotton plants, regrowth plants and bare soil in the visible (400-700 nm) to NIR (700-900 nm) region of the spectrum.

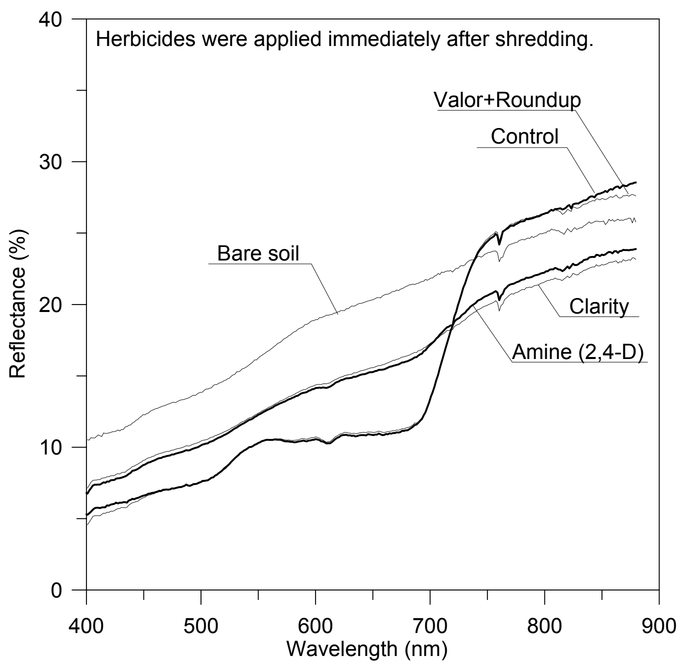


Figure 3. Reflectance spectra of regrowth cotton plants for the control and three herbicide treatments obtained 32 days after cotton stalks were shredded. For comparison, a representative spectrum for bare soil in the field is also shown.

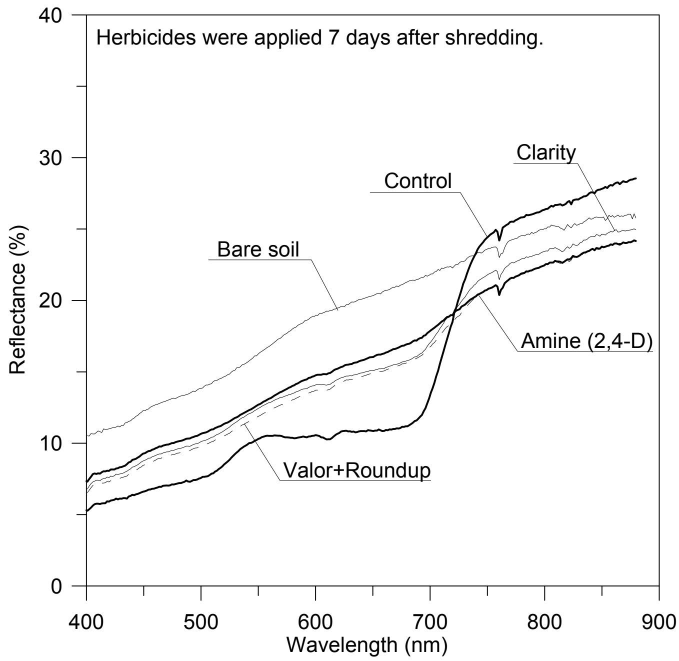


Figure 4. Reflectance spectra of regrowth cotton plants for the control and three herbicide treatments obtained 32 days after cotton stalks were shredded. For comparison, a representative spectrum for bare soil in the field is also shown.

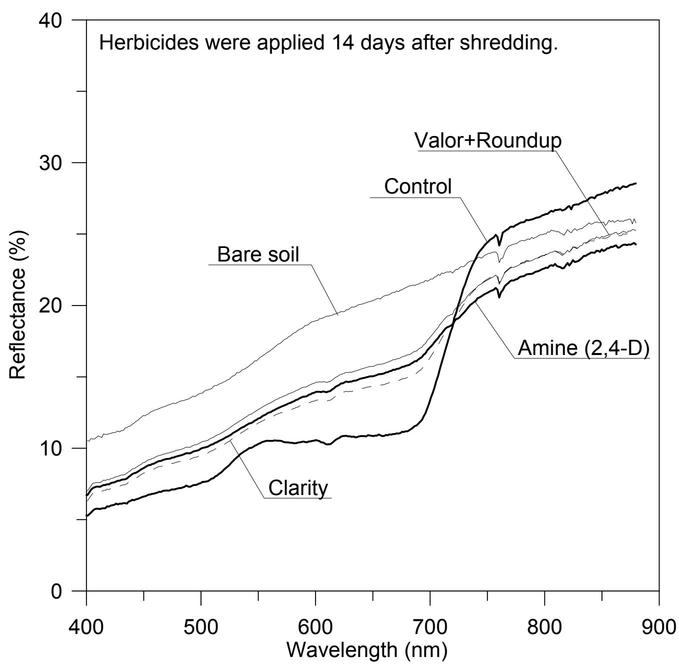


Figure 5. Reflectance spectra of regrowth cotton plants for the control and three herbicide treatments obtained 32 days after cotton stalks were shredded. For comparison, a representative spectrum for bare soil in the field is also shown.

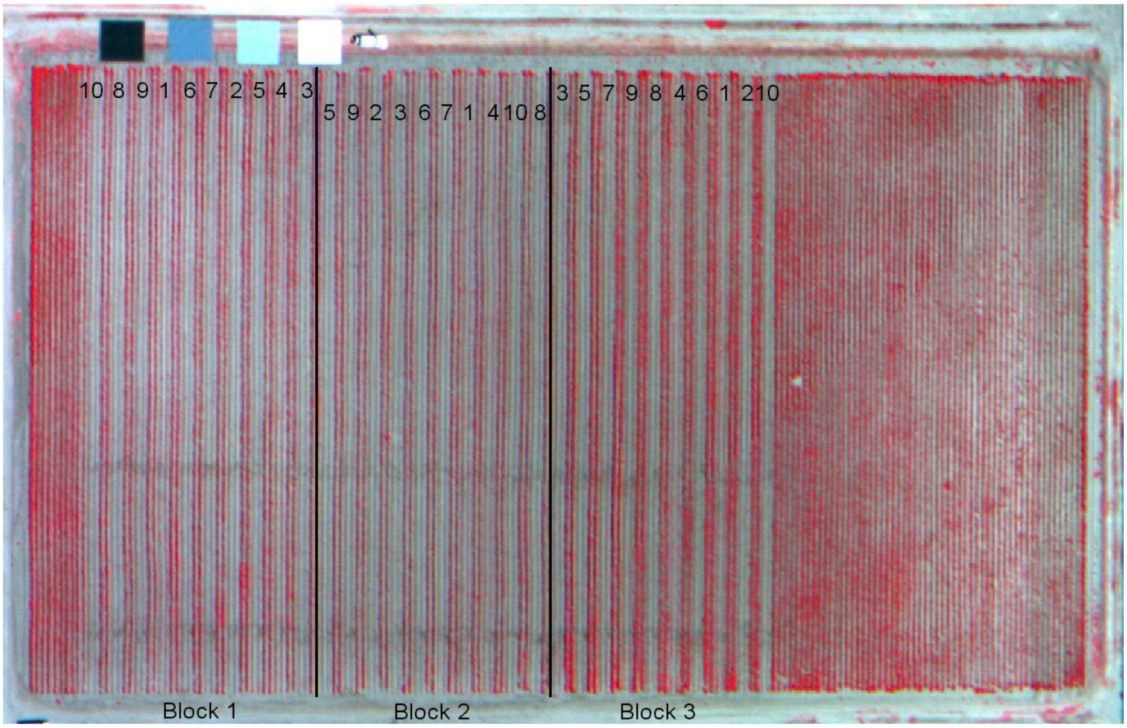


Figure 6. Color-infrared digital image of a cotton field acquired 32 days after cotton stalks were shredded. Ten cotton regrowth control treatments were assigned across three blocks in a randomized complete block design. Treatment numbers are defined in Figure 1. Each experimental plot consisted of two shredded rows (grayish color), and was separated by two rows of standing stalks (reddish color).