Table 2. Effect of herbicide treatments on weed control (%) in a young citrus grove under flatwoods conditions over a 2-yr period.

Treatment	Rate lb./acre	% Control 1984 Spring	Fall	Average	1985 Spring	Fall	Average
Oxyfluorfen	2.0	62	34	48	49	20	35
2Oxyfluorfen	4.0	72	42	58	69	38	54
Oxyfluorfen	2.0						
& Oryzalin	2.0	62	42	52	55	31	43
Oryzalin	2.0	60	38	49	46	26	36
Oryzalin	4.0	62	48	55	68	36	52
Oryzalin	4.0						
& Diuron	1.6	65	68	66	81	76	79
Oryzalin	4.0						
& Simazine	3.0	78	55	66	76	68	72
Norflurazon	4.0	85	72	78	82	76	79
Norflurazon	3.0						
& Simazine	3.0	82	70	76	78	86	82
Norflurazon	3.0						
& Diuron	1.6	89	80	84	86	81	84
Norflurazon	4.0						
& Oxyfluorfen	1.0	62	85	74	88	88	88
Bromacil	2.0						
& Simazine	3.0	82	75	78	76	82	79
Bromacil	1.6						
& Diuron	1.6	84	82	83	83	88	86
Bromacil	2.4						
& Diuron	2.4	88	88	88	90	86	88
Bromacil	1.6						
& Diuron	0.8	72	85	78	80	68	74
Bromacil	2.1						
& Diuron	1.1	82	88	85	80	87	84
Glyphosate	1.0	55	45	50	67	70	69
Untreated check		0	0	0	0	0	0

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PRELIMINARY EXPERIMENTS WITH REMOTE SENSING TO DETECT CITRUS CANKER

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Abstract. **Aerial and ground remote sensing techniques, utilizing 35 mm natural color film, color infrared film, and narrowband filtered black and white video were used to examine leaves affected by citrus canker. Where the leaf spot or spots were less than 0.5% of the total viewing area, it was neccesary that the camera be close enough to examine 3 or 4 leaves. Grapefruit (*Citrus paradisi* Macf.) leaves were examined from plants that had been infected for 7 to 69 days. Natural color transparencies taken 7 days after inoculation revealed small yellow-green spots against a light green background. Color infrared transparencies showed the same area as yellow-white spots against a magenta background. Photography could be used to detect canker on color and color infrared film up to 12 feet from the infected plant. Aerial color and aerial color infrared film could not differentiate infected nursery trees from healthy nursery trees at a scale of 1 to 150. Narrowband filtered video of 7-day infected leaves with the 550 and 700 nm bands yielded the best contrast for image**

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analysis. The image analysis of a canker suspect in the field was compared to the 30-day infected plant in the greenhouse. The digitized image of the canker lesion was the brightest area on the leaf, whereas the digitized image of the suspect lesion (negative for canker) was the darkest area in the leaf.

Color infrared photography and narrowband filtered video have been used for the detection of vegetation stress, adverse soil conditions (1, 10), foliage diseases of potatoes (8), leaf spot of peanuts, and freeze damage (2, 3, 5). For example, of the 2 types of leaf spot disease of peanuts, early and late (*Cercospora archicola* and *Cercospora personata*), one has a halo while the other does not when examined with a 10 nm bandpass 700 nm filter (3). Freeze damage to citrus plants or trees, 1 hr or 4 months after the freeze, appears black for the frozen leaves and white for the non-frozen leaves (2, 5).

Video recordings have an advantage over photographs in that the subject can be viewed as it is being recorded. It is particularly useful in remote locations where processing is not available (9).

Color infrared film has been used for many years for the detection of stress and disease in plants and trees. Stressed plants show a loss of infrared reflection and thus the color infrared image changes from magenta to blue depending on the amount of stress (4).

Near infrared reflection (IR) from leaves has little relation to the visible color of the leaf. The IR reflection is controlled by the properties of the epidermal layers, stomata, nuclei cell walls, crystals, and cytoplasm (7). Dr. R. H. Biggs, University of Florida, Institute of Food and Agricultural Sciences, found no internal change in the healthy portion of the canker inoculated leaf, as seen by electron microscopy (personal communication). Without an internal change in the whole leaf, there would not be a large IR reflection change to distinguish an infected plant from the uninfected plants when sensed remotely (7).

The purpose of this study was to evaluate color infrared photography and image analysis of narrowband video recorded images to remotely sense citrus canker.

Materials and Methods

Grapefruit (*Citrus paradisi*) seedlings inoculated with the canker bacterium, *Xanthomonas campestris* pv. *citri* (Hasse) Dowson, were photographed with video, color, and color infrared film at the Division of Plant Industry's (DPI) greenhouse at Gainesville. Images were recorded from leaves that had been infected 7 to 69 days. Plants under study were set up in an empty greenhouse. No artificial light was used to make the images. All equipment and personnel were sprayed for sanitation before leaving the quarantine greenhouse. Aerial 9 × 9 inch color and color infrared photographs were made of a canker-infected nursery in Polk County by a commercial aerial photographer where 2.54 cm on the film equals 45.7 m on the ground. A 2.5-yr-old grapefruit tree, with a suspect canker lesion, was photographed and video recorded near Ft. Pierce. This tree tested negative for canker by the Florida Division of Plant Industry.

Konica T-3 and Konica T-4 cameras, equipped with a Konica 50 mm, f 1.7 lens, were used to make the color and color infrared transparencies. Natural color transparencies were made with 35 mm Ektachrome 64 film. Color infrared was produced with Ektachrome 35 mm color infrared film using a Wratten #12 filter. Ektachrome film was exposed at an ASA of 64, while the color infrared was bracketed using ASA's of 125, 100, and 80. A *Kodak* 20 step gray scale was exposed at each ASA value with the infrared film. Computing the log and density values for each step of the exposed gray scale, a Harter and Driffield (HD) curve was plotted to check for proper exposure and color balance (6). Photographs were taken 3, 6, and 12 to 14 ft from the seedlings.

Video recordings were made with a RCA 2055/C black and white (B&W) camera on a heavy duty tripod. The camera was equipped with RCA 8844 Vidicon tube and a Cannon TV zoom lens, V6 × 18, 18 to 105 mm, 1:2.5. The camera images were recorded on a ½ inch VHS video recorder, Hitachi Model VT 5600 A. The viewfinder and monitor was a Hitachi Model 1-16, 9 inch B&W TV set.

Corion 2 × 2 inch narrowband filters, from 400 to 850 nm were used in 50 nm steps. Filters from 400 to 700 nm, had a 10 nm bandpass while the 750 to 850 nm had a 25 nm bandpass. The f stop was stepped from f 2.5 to f 16 during the recording to insure an image of suitable contrast for the image analysis.

Color video images of the same plants were recorded with a Panasonic Model PK-550 camera as a backup. The B&W video images were analyzed with a Measuronic Linear Measuring Set System (LMS) image analyzer. The LMS computer programs used in this study were:

1. Image transfer—to reference the total number of pixels on the monitor to the scene under analysis and a sub-program, print, to print out the bargraph of gray levels and a digitized image.
2. Scale—to calibrate for area measurements.
3. Bargraph—for density slicing, up to 9 levels of gray, a pixel count of the scene of each gray level, and area measurement of each gray level.
4. Textwrite—to label images generated.
5. Legend—to make a key of the cross hatches of the digitized image.
6. Color—to form the cross hatch representing the colors in the legend.
7. Mapshades—to form a composite image of the digitized gray levels of the scene.

Results and Discussion

Canker-inoculated plants studied in DPI's greenhouse in Gainesville gave the following results on color film: 7 day infection—small yellow-green spots on a light green leaf; 30 day infection—a dark green leaf with a white area around a yellow-green area, with a tan spot in the center; 69 day infection—a dark green leaf, a brown area with a tan center. Some had a black center.

Close-up color infrared transparencies showed the following: 8 day infection—small white spots on a magenta background; 28 day infection—a white-yellow area with a tan ring surrounding a white spot on a magenta background; 69 day inoculation—a magenta leaf with a yellow area surrounding a white area.

At 28 and 69 days after inoculation, lesions could be seen 6 ft away with color and color infrared film. By knowing where to look, the spots could be seen on the 28 and 69 day leaves when the camera was up to 12 ft from the plants. Based on these observations and previous work (3),

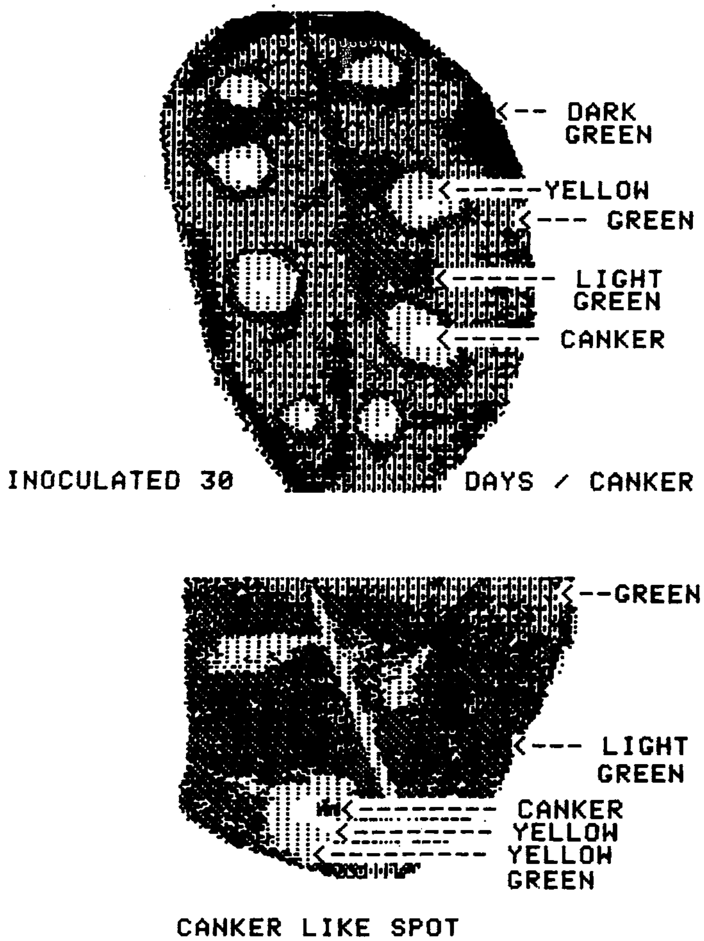

Fig. 1. Image analysis of 550 nm spectral sliced video of a 30-day-old infected leaf and a leaf from a suspect tree in a grove. The center lesion image is white while suspect lesion image is black.

the lesions must be at least 0.5% of the viewing area to be easily detected.

A suspect canker lesion on the 2.5-yr-old grapefruit tree in the grove appeared visually and on color film as a yellow halo with a dark-brown center on a dark green leaf. On color infrared film, the yellow halo was white and the dark brown center was black on a magenta-colored leaf.

Spectrally sliced video recordings of the leaf with the suspect lesion were made with narrowband filters from 400 to 850 nm. The image analysis of the 550 nm filtered image showed the digitized image as white surrounding a black spot (Fig. 1). The 700 nm digitized image showed only a white area for the canker-like spot. The 750 nm image showed a black spot in a large white area. The 550 nm filter gave the best contrast between the lesion and the leaf. Image analysis of the 550 nm spectrally sliced video image of a leaf infected for 30 days showed the digitized lesion as white (Fig. 1). This was not the same as the suspect tree in the field. Further studies should be made of other canker-like lesions to see if this characteristic is unique to canker.

Aerial photographs of a canker-infected nursery did not show any visual change over the non-infected area on color or color infrared film when photographed at a scale of 2.54 cm to 45.7 m. This was probably due to lack of internal change of the leaf components which controls the near infrared leaf reflectance as observed by Biggs and the work of Gausman (7).

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