# Measurements of Citrus Tree Health with a Scanning Densitometer from Aerial Color Infrared Photographs

C. H. BLAZQUEZ, University of Florida, Institute of Food and Agricultural Sciences, Citrus Research and Education Center, 700 Experiment Station Road, Lake Alfred 33850

**ABSTRACT**

Blazquez, C. H. 1991. Measurements of citrus tree health with a scanning densitometer from aerial color infrared photographs. Plant Dis. 75:370-372.

Aerial color infrared (CIR) photographs of citrus trees were analyzed with a scanning densitometer (SCND) to obtain spectral curves for comparison with arbitrarily assigned visual grades (VG). Spectral curves derived from healthy and declining tree rows had one peak at 500–520 nm and another between 600 and 620 nm. Comparisons between VGs and integrals (peaks I 1 and I 2) showed little difference between them, nor between VGs and percentage of transmittance values (T 1 and T 2). Spectral ratios of the integrals (SRG) and spectral transmittance (SRT) separated the VGs into three different groups, suggesting that a reduction from five to three VGs would make densitometric measurements more realistic.

Aerial photography has been used since 1965 to delineate citrus grove locations, prepare inventories of tree types and varieties, record planting distances, record number of trees per acre, and prepare crop forecasts (3). Norman and Fritz (18) reported in the same year that color infrared (CIR) film was capable of detecting diseases and decline of citrus trees. Aerial photography with black-and-white infrared film has been used on other crops to detect diseases (6). Since that time, many reports (1,2,5,14–17,22) have indicated that photographs with CIR film reveal much more than stress in trees. For example, hydrological information for irrigation systems, the effect of fertilizer applications, and soil problems that may reduce tree growth have been detected. CIR film (using magenta, yellow, and cyan) (12) has been used by investigators to solve problems on other crops such as field beans (23), cotton (22), potato (16), St. Augustinegrass (19), and bracken ferns (15), as well as on forest damage (17) and elm tree damage (14). Natural color (NC) film (using natural colors red, green, and blue) (12) has also been used by investigators to identify tree species (10,20), forest damage (17), and stress in coniferous trees (20) and shrubs (8). Standard guidelines for commercial use of CIR film have been established to eliminate problems in processing (9). For the past 7 yr, a property appraiser in Florida (4) has been using CIR film to photograph nearly 4,450 ha of citrus to assign property values on acreages of productive trees. Two appraisers viewing the CIR photography were not able to photointerpret additional acreages because of eye fatigue (4). As interpretation time increased, detection effi-

Florida Agricultural Experiment Station Journal Series R-00664.

Accepted for publication 2 October 1990 (submitted for electronic processing).

ciency by the individuals was greatly reduced (7). This limiting factor will have to be overcome if CIR photography is to be used in Florida counties with large citrus acreages (8,100–60,700 ha). The use of densitometry (measuring light transmittance through a CIR transparency) has been used with photographs of tomato and potato (1), cucumbers (2), field beans (23), elms (14), and, more recently, citrus (5) and may be a more accurate method of analysis than visual interpretation.

This study was conducted to determine if arbitrary visual grades of health and stress in citrus trees correlated well with different spectral curves generated with a scanning densitometer (SCND).

## MATERIALS AND METHODS

An arbitrary method of visual grading (VG) previously described (5) was used in a ground survey and photo-interpretation experiment to select classes of damage and sizes of citrus trees in a Polk County, FL, grove during August. Fifty Valencia orange (*Citrus sinensis* (L.) Osbeck) trees on rough lemon (*C. jambhiri* (Lush.)) rootstock were located by a grid/cell system (3) and marked as 0 (healthy, 0% stress), 1, 2, 3, and 4, representing 25, 50, 75, and 100% stress, respectively. This method of determining stress on a basis of canopy damage is different from the ones normally used to determine disease (11,13). The term "stress" is used to indicate lack of health attributable to an unknown cause or a combination of factors such as lack of water, root damage, disease, poor soil, or mechanical injuries. Ground inspection of the grove was done on the same day as the CIR photography. A Wild RC-8 camera fitted with a 15-cm focal length lens with a yellow "C" filter and Kodak 2443 CIR film was used to photograph the grove at 10 a.m. EST. A low wing, twin-engined aircraft carried the camera, which was powered by the electrical system of the plane. Photographs taken from an altitude of 610 m resulted in a scale on the transparencies of 1 cm = 40 m on the ground with each photograph covering 83.4 ha. Photographs were developed in a standard Versamat color processing unit to positive transparencies.

A SCND previously described (5) was used to determine spectral curves of each tree in aerial CIR transparencies placed on a microfiche reader. Measurements from each tree were made by positioning the transparency over the light aperture and advancing by hand a wheel that tilts a monochromator grating (Model 700-3, Gamma Scientific, San Diego, CA). Wavelength readings were displayed as transmittance numbers on a photovoltmultiplier/voltmeter (Model 249, Photovolt Corp., New York, NY). Thirty-one measurements (in increments of 10 nm) were taken from five sites of each tree canopy producing five spectral curves from 400 to 700 nm. These five curves were averaged by a computer program into a single curve per canopy. The program also measured the integrals of each curve and summarized the data (18) (Tables 1–3). Analysis of the spectral data was made by dividing the two integrals (an integral is the area measured under a curve) and two transmittances to determine ratios by the following formulas: 1) integral 1/integral 2 (I 1/I 2) = spectral integral ratio (SRG) where I 1 = integral 1 (first peak) in spectral curve (510–520 nm) and I 2 = integral (second peak) at 600–620 nm; and 2) transmittance 1/transmittance 2 (T 1/T 2) = spectral transmittance ratio (SRT) where T 1 = maximum transmittance (first peak) in spectral curve (500–520 nm) and T 2 = maximum transmittance (second peak) at 600–620 nm.

Comparisons among SRG, SRT, integral, transmittance peak values, and visual stress ratings were made with Pearson's analysis of variance (21).

## RESULTS AND DISCUSSION

Densitometric measurements of aerial CIR transparencies indicated that healthy trees were easily distinguished from dead trees by comparing their spectral curves (Fig. 1). The spectral curves of citrus trees from CIR film had two peaks of high percentage of transmittance at 500–520 nm and at 600–620 nm. Curves of healthy trees (magenta) had a first peak that was much lower than a second peak of percentage of transmittance, while dead trees (cyan) had curves with a higher first peak and much lower second peak (Fig. 1). Trees visually graded as VG 2 also had two peaks. However, because they both shared the same percentage of transmittance (Fig. 1), they could be separated by their spectral curve from the other VG grades (0 and 4). These results agree with those obtained previously (5). Comparisons between the integral of the first peak (I 1) and VGs in a Duncan's multiple range test indicated that I 1 was not a good

**Table 1.** Comparisons of Duncan's multiple range tests between visual grade (VG) and scanning densitometric measurements (integrals 1 and 2) of color infrared (CIR) transparencies of 50 trees

| Integral 1 vs. visual grade[a] | | | Integral 2 vs. visual grade[a] | | |
|---|---|---|---|---|---|
| Mean values | Visual grade | Duncan's grouping[b] | Mean values | Visual grade | Duncan's grouping |
| 50.53 | 4 | a | 46.98 | 0 | a |
| 33.56 | 3 | a | 33.40 | 3 | b |
| 31.73 | 0 | ab | 32.83 | 4 | b |
| 24.96 | 2 | b | 30.38 | 1 | b |
| 20.50 | 1 | b | 22.66 | 2 | b |

[a] 10 trees per replicate.
[b] Mean separation in columns by Duncan's multiple range test, 5% level.

**Table 2.** Comparisons of Duncan's multiple range tests between visual grade (VG) and scanning densitometric measurements (integral ratio [SRG] and transmittance 1) of color infrared (CIR) transparencies of 50 trees

| Integral ratio vs. visual grade[a] | | | Transmittance 1 vs. visual grade[a] | | |
|---|---|---|---|---|---|
| Mean values | Visual grade | Duncan's grouping[b] | Mean values | Visual grade | Duncan's grouping |
| 1.52 | 4 | a | 0.51 | 4 | a |
| 1.05 | 3 | b | 0.42 | 3 | ab |
| 1.01 | 2 | b | 0.35 | 0 | b |
| 0.74 | 1 | c | 0.27 | 2 | b |
| 0.65 | 0 | c | 0.25 | 1 | b |

[a] 10 trees per replicate.
[b] Mean separation in columns by Duncan's multiple range test, 5% level.

**Table 3.** Comparisons of Duncan's multiple range tests between visual grade (VG) and scanning densitometric measurements (transmittance 2 and spectral ratio of transmittance) of color infrared (CIR) transparencies of 50 trees

| Transmittance 2 vs. visual grade[a] | | | Transmittance ratio vs. visual grade[a] | | |
|---|---|---|---|---|---|
| Mean values | Visual grade | Duncan's grouping[b] | Mean values | Visual grade | Duncan's grouping |
| 0.58 | 0 | a | 1.30 | 4 | a |
| 0.44 | 3 | ab | 0.98 | 3 | b |
| 0.40 | 4 | b | 0.91 | 2 | b |
| 0.32 | 1 | b | 0.86 | 1 | b |
| 0.28 | 2 | b | 0.61 | 0 | c |

[a] 10 trees per replicate.
[b] Mean separation in columns by Duncan's multiple range test, 5% level.

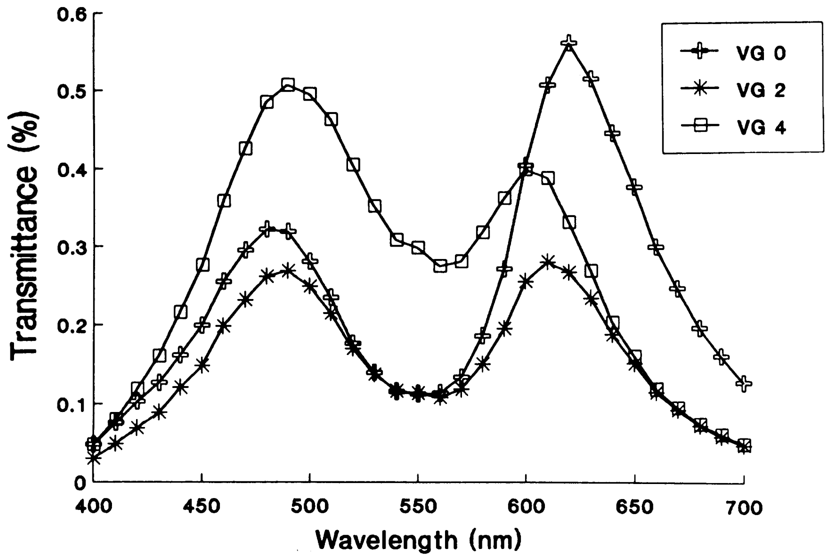


**Fig. 1.** Spectral curves of color infrared (CIR) aerial photographs indicating differences in reflectance peaks from healthy trees (VG 0), trees with 50% diseased canopy (VG 2), and dead trees (VG 4), showing the differences among peaks of three grades VGs 0, 2, and 4.

parameter for separating VGs (Table 1), because VGs 0, 3, and 4 were in the same group. The integral of the second peak (I 2) did not discriminate well among the different VGs (Table 1). The SRG gave a better separation of the VGs, although it did not detect differences between VGs 0 and 1, nor between 2 and 3 (Table 2). Comparisons between T 1 and T 2 combined the different VGs into two classes but in different groups (Tables 2 and 3). Their SRT separated the VGs into three distinct classes but combined VGs 1, 2, and 3, into one class (Table 3).

Results from the SRG indicate that the three VGs (1, 2, and 3) should be combined into one combination selected by the SRT, whereby healthy trees (VG 0) and dead trees (VG 4) were two distinct VGs with the intermediate degrees (VGs 1, 2, and 3) in a separate group.

Use of the SCND in combination with a computer program for the production of spectral curves from aerial CIR photography was a viable system. It was somewhat tedious to enter the densitometric measurements obtained from the digital voltmeter, but the computer program rapidly processed the data and plotted a spectral curve for each set of 31 readings. A companion averaging computer program summarized data from 50 sets of curves for each VG, so that a single curve was produced from all the 7,750 measurements. The system developed did not require measurements of the same target with three different filters (red, green, and blue) as was necessary with densitometers used by previous investigators (13,15,22). A set of five spectral curves was obtained within 20–30 min, making it possible to analyze a large number of spots within a day, because the operator did not have to visually grade the transparencies.

The use of a SCND in combination with a computer program made it possible to place greater reliance on densitometric measurements. The SCND was able to repeatedly determine transmittance without losing efficiency or accuracy, unlike human photo-interpreters, who were hampered by fatigue as interpretation periods were lengthened. These results also agree with those obtained previously (5) and with Lindow's (15) suggestion that it may be possible to develop an automated system with the current availability of image analysis systems and digitizing boards.

## LITERATURE CITED

1. Blazquez, C. H., and Edwards, G. J. 1983. Infrared color photography and spectral reflectance of tomato and potato diseases. J. Appl. Photogr. Eng. 9:33-37.
2. Blazquez, C. H., and Edwards, G. J. 1984. Densitometric studies of color and color infrared photographs of diseased cucumber leaves and plants. J. Imaging Technol. 10:79-84.
3. Blazquez, C. H., and Horn, F. W., Jr. 1980. Aerial color infrared photography: Applications in citriculture. NASA Ref. Publ. 1067, Washington, DC. 89 pp.
4. Blazquez, C. H., Lowe, O., Sisk, J. R., and Bilbrey, M. D. 1988. Use of aerial color photography, dual color video, and a computer system for property appraisal of citrus groves. Photogramm. Eng. Remote Sens. 54:233- 236.
5. Blazquez, C. H., Richardson, A. J., Nixon, P. R., and Escobar, D. 1988. Densitometric measurements and image analysis of aerial color infrared photographs. J. Imaging Technol. 14:37-42.
6. Brenchley, G. H. 1968. Aerial photography for the study of plant diseases. Annu. Rev. Phytopathol. 6:1-22.
7. Burges, A. E., Jennings, A. J., and Wagner, R. G. 1985. Statistical efficiency: A measure of human visual signal detection performance. J. Photogr. Eng. 8:76-78.
8. Driscoll, R. S., and Coleman, M. D. 1974. Color for shrubs. Photogramm. Eng. 40:451-459.
9. Fleming, J. F. 1985. Standardization techniques for aerial colour infrared film. Can. Dep. Energy Mines Resour. Surv. Map. Branch. 28 pp.
10. Heller, R. C., Doverspike, G. E., and Aldrich, R. C. 1964. Identification of tree species on large scale panchromatic and color aerial photographs. U.S. Dep. Agric. Handb. 261. 17 pp.
11. Horsfall, J. G., and Barratt, R. W. 1945. An improved grading system for measuring plant diseases. (Abstr.) Phytopathology 35:655.
12. Klein, W. H. 1982. Understanding color infrared photography. Cent. Appl. Stud. Sch. For. 16 pp.
13. Large, E. C. 1966. Measuring plant disease. Annu. Rev. Phytopathol. 4:9-28.
14. Lillesand, T. M., Meisner, D. M., French, D. W., and Johnson, J. L. 1981. Evaluation of digital photographic enhancement for Dutch elm disease detection. Photogramm. Eng. Remote Sens. 48:1581-1592.
15. Lindow, S. E. 1983. Estimating disease severity of single plants. Phytopathology 73:1576-1581.
16. Manzer, F. E., and Cooper, G. R. 1967. Aerial photographic methods of potato disease detection. Maine Agric. Exp. Stn. Bull. 646. 14 pp.
17. Murtha, P. A. 1972. A guide to air-photo interpretation of forest damage in Canada. Can. For. Serv. Publ. 1292. 62 pp.
18. Norman, G. G., and Fritz, N. L. 1965. Infrared photography as an indicator of disease and decline in citrus trees. Proc. Fla. State Hortic. Soc. 78:59-63.
19. Odle, W. C., and Toler, R. W. 1976. Remote Sensing of St. Augustinegrass Decline. Remote Sensing Center TR-77, Tex. A&M Univ. 164 pp.
20. Parry, J. T., Cowan, W. R., and Higinbottom, J. A. 1969. Color for coniferous forest species. Photogramm. Eng. 35:669-678.
21. SAS User's Guide. 1985. Basics Version 5. Statistical Analysis Systems Inc., Cary, NC. 1,042 pp.
22. Toler, R. W., Smith, B. D., and Harlan, J. C. 1981. Use of aerial color infrared photography to evaluate crop disease. Plant Dis. 65:24-31.
23. Wallen, V. R., and Jackson, H. R. 1971. Aerial photography as a survey technique for the assessment of bacterial blight of field beans. Can. Plant Dis. Surv. 51:163-169.