Spectral densitometric measurements of aerial color infrared (ACIR) photographs of citrus trees made from outer crown and tree center correlated well with visual grading of the photographs. Measurements made from 400 to 700 nm identified two intensity peaks at 480 to 490 nm ($I_1$) and another between 610 to 620 nm ($I_2$). Spectral ratios (SR) ($I_1/I_2$) <0.69 were associated with healthy trees visual grade 0 (VG 0, 0% stress), ratios >0.86 were associated with moderate and severely stressed trees (VG 1, 2, 3; 25%, 50%, and 75% stress, respectively), and ratios >1.28 were found only in dead trees (VG 4; 100% stress). A formula whereby the absolute difference between wavelengths of the two peaks (DSR) was divided by the SR improved the accuracy of analysis of the densitometric measurements, making the separation of stressed trees more distinct. Image analysis of color infrared transparencies of groves indicated positive correlations between: 1) transmitted light brightness and dark class 1, 2) dark classes 1 and 2, and 3) gray levels 2 and 3. These results suggest that densitometric measurements were equal or better than visual grading and could be used in an automated system to count and separate stressed from healthy trees.

Citrus grove information may be obtained periodically by walking or driving through groves and recording information (1). Portable computers that store information in memory for analysis at a later date are especially useful for this purpose (4). Visual analysis (VA) of aerial color infrared (ACIR) film has been incorporated by some growers as a management tool to record groove information (6). Observations made while walking through a grove are usually recorded in numbers, letters, or symbols representing the condition of the trees or groves. These records cannot reproduce an image for future re-interpretation, while photographs do have this valuable advantage.

The main disadvantages of photographic interpretation are: 1) relative short period of an interpreter’s efficiency, and 2) changes in color balance of the film. The short period of interpretation efficiency and the variability in grading are problems that will have to be overcome if aerial photography is to produce reliable groove information on a consistent and economical basis.

Densitometric studies have been conducted by investigators (7, 11, 12) to ascertain consistent differences in reflectance that may be used to separate classes of vegetation or levels of stress or disease. Efforts have been made to determine if densitometry would be consistent enough to classify tree conditions (10-12) or disease levels (7). Image analysis has also been used to separate levels of disease (2, 5, 8, 14). Investigations have been conducted to establish the accuracy of visual on-site observations of plant condition or size (2-4, 9-12). Literature reviews suggest that both photointerpretation (6, 7) and visual observations (2, 3, 9, 13, 15) have degrees of inconsistency. Visual ratings of size, stress, or injury frequently depend on the intuitive knowledge and experience of the observer, rather than on the accuracy of the systems.

Photointerpretation of ACIR transparencies is a procedure with a very brief period of endurance and efficiency resulting in decreasing accuracy with longer periods of work. The purpose of this investigation was the comparison of visual arbitrary stages of stress with densitometric readings and gray levels of image analysis and to determine which method may be suitable for use in an automated system of photointerpretation.

A Valencia grove located in Polk County, Fla., was selected for aerial photography and experimentation because of the unique tree condition and fairly consistent records of tree loss. Eighteen-year-old trees growing on rough lemon (Citrus jambhiri Lush.) rootstock were planted at a distance of 6 x 9 m. The majority of the trees were in good condition, with the exception of a corner near wetlands, where a higher incidence of tree loss was observed. A block was selected near the corner to have trees at various levels of stress. The initial ground survey was made 2 weeks before photographing the field to select areas of study. General observations were made, but no detail map of the grove was prepared. The field was visited again after photographing to determine the accuracy of the photointerpretation.

An arbitrary method of visual grading (VG) was used in ground survey and photointerpretation experiments (4, 6) to select various classes of damage and tree sizes. Healthy trees were marked as 0 (0% stress), while stressed trees were numbered 1, 2, 3, and 4, depending on the degree of stress (25%, 50%, 75%, and 100%, respectively). The term stress is used to indicate lack of health due to an unknown cause or condition or a combination of factors such as lack of water, root damage, disease, poor soil, or injuries due to mechanical damage.

ACIR photography was taken with a 23 x 23 cm RC-8 Wild camera, with a 15-cm focal length lens and a “C” yellow filter using Aerochrome 2443 aerial color film. The camera was powered by the electrical system of the plane. Photographs were developed in a standard Versamat color processing unit to positive transparencies. Photographs were taken from an altitude of 610 m, resulting in a scale on the transparencies of 1 cm on the film = 40 m on the ground. Each photograph covered 92 ha.

A halogen 682 bulb was used as a light source in a Jenoptik Jena GmbH dokumator DL-2 microfiche reader with four magnifications (6.5, 9, 13, and 17.5). The projection screen was replaced with an aluminum plate covered with white poster board. A Gamma Scientific 914 x 3.18-mm flexible fiberoptic probe was installed near the center of the plate. The face of the probe was held flush with the face of the screen by a brass plate on the underside of the aluminum plate. The other end of the fiberoptic probe was connected to a Gamma Scientific monochromator Model 700-3 with a brass coupling. A Bausch and Lomb visible grating (no. 33-66-76) was mounted in the monochromator case. Light from the monochromator was measured through a Gamma Scientific 0.75-mm C exit slit mounted in front of an R-777 Hamamatsu photomultiplier, and the resulting output was read on a Photovoltaicmultiplier-Photometer Model 250-A. Spectral analysis of each tree was made by positioning the transparency over the aperture. The monochromator was scanned by hand in increments of 10 nm from 400 to 700 nm, with the light intensity displayed in the photometer and the data manually entered into a BASIC computer program. The data were specifically for an Apple II+ computer. Five readings at each wavelength were made, resulting in 31 clusters of 155 densitometric readings per tree. The computer program analyzed the data and produced spectral curves for each reading and an average curve of the five readings. The program also measured the integrals for each curve and summarized the data entered. Spectral analysis of the data was made by dividing the two maximum intensities, determining a spectral ratio (SR), and investigating the effect of incorporating wavelength peak differences with the ratio to possibly produce better separations between classes of stress (DSR). SR and DSR
Table 1. Correlation matrix of densitometric readings run with Pearson’s correlation statistical system program comparing the standard ratio \((I_1/I_2 = SR)\) absolute wavelength difference/spectral intensity ratio \((\lambda_1 - \lambda_2)/SR = DSR\); brightness readings taken with a linear measuring system, three classes of darkness (D1, D2, D3); three levels of gray (G1, G2, G3).

<table>
<thead>
<tr>
<th>VG</th>
<th>DSR</th>
<th>SR</th>
<th>MXWL</th>
<th>Bright</th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>G1</th>
<th>G2</th>
<th>G3</th>
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</thead>
<tbody>
<tr>
<td>DSR</td>
<td>-0.87178**</td>
<td>-0.90334**</td>
<td>-0.89148**</td>
<td>0.06892</td>
<td>0.07974</td>
<td>-0.01708</td>
<td>-0.13791</td>
<td>0.12563</td>
<td>0.10737</td>
<td>-0.33445</td>
</tr>
<tr>
<td>SR</td>
<td>0.90344**</td>
<td>-0.95690**</td>
<td>0.88409**</td>
<td>0.01381</td>
<td>0.00487</td>
<td>0.08441</td>
<td>0.23227</td>
<td>-0.19604</td>
<td>-0.13613</td>
<td>0.18792</td>
</tr>
<tr>
<td>MXWL</td>
<td>0.89148**</td>
<td>0.88409**</td>
<td>-0.89917**</td>
<td>0.04108</td>
<td>0.01448</td>
<td>-0.07092</td>
<td>-0.16896</td>
<td>0.16401</td>
<td>0.13613</td>
<td>-0.17971</td>
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<tr>
<td>Bright</td>
<td>0.06892</td>
<td>0.00487</td>
<td>0.04108</td>
<td>0.01381</td>
<td>0.00487</td>
<td>0.08441</td>
<td>0.23227</td>
<td>-0.19604</td>
<td>-0.13613</td>
<td>0.18792</td>
</tr>
<tr>
<td>D1</td>
<td>0.07974</td>
<td>0.00487</td>
<td>0.01448</td>
<td>-0.09450</td>
<td>0.77152**</td>
<td>0.06826**</td>
<td>0.13381</td>
<td>0.10730</td>
<td>0.07190</td>
<td>0.00118</td>
</tr>
<tr>
<td>D2</td>
<td>-0.01708</td>
<td>0.08441</td>
<td>-0.07092</td>
<td>-0.00587</td>
<td>0.65826**</td>
<td>0.90379**</td>
<td>0.10730</td>
<td>0.36016</td>
<td>0.65234*</td>
<td>-0.02929</td>
</tr>
<tr>
<td>D3</td>
<td>-0.13791</td>
<td>0.23227</td>
<td>-0.16896</td>
<td>0.12057</td>
<td>0.13381</td>
<td>0.10730</td>
<td>0.36016</td>
<td>0.65234*</td>
<td>0.24264</td>
<td>-0.10125</td>
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<tr>
<td>G1</td>
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<td>-0.16313</td>
<td>0.13028</td>
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<td>0.42501*</td>
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<td>-0.15588</td>
<td>0.42501*</td>
<td>0.51820*</td>
<td>0.65234*</td>
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<td>0.51820*</td>
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<tr>
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<td>-0.17971</td>
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<td>-0.27770</td>
<td>-0.47804</td>
<td>-0.52734*</td>
<td>0.07190</td>
<td>-0.61386*</td>
<td>-0.91440**</td>
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<td>AREA</td>
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<td>-0.02929</td>
<td>-0.10125</td>
<td>0.07518</td>
<td>0.06788</td>
<td>0.08503</td>
<td>0.17821</td>
<td>-0.09199</td>
<td>0.00849</td>
<td>0.02730</td>
</tr>
</tbody>
</table>

* Values of correlation coefficient significant at the 5% level. ** Values of correlation coefficient significant at the 1% level.

Fig. 1. (A) Black and white copy of an aerial color infrared (ACIR) transparency showing part of a ‘Marsh’ grapefruit grove with trees in varying degrees of health. Rows are numbered from upper left hand corner to lower left and trees (columns) are numbered from left to right. (B) Diseased tree with broken branches and off color canopy. (C) Tree with part of the crown damaged by disease showing different colorations within the canopy area.

were determined by the following formulas:
1) intensity 1 \((I_1)/intensity 2 (I_2) = \text{spectral ratio}\) \((I_1/I_2 = SR)\), where \(I_1 = \text{maximum intensity (first peak)}\) in spectral curve, 480 to 490 nm, \(I_2 = \text{maximum intensity (second peak)}\) in spectral curve, 610 to 620 nm; and
2) absolute wavelength difference/spectral intensity ratio \((\lambda_1 - \lambda_2)/SR = DSR)\), where \(\lambda_1 = \text{maximum wavelength (MXWL)}\) and \(\lambda_2 = \text{minimum wavelength (MNWL)}\) and the absolute difference divided by the SR value.

Densitometric measurements were taken in the outer perimeter of the crown (opposite each other, in the form of a cross) and one in the center of the trees from 35 randomly selected trees (Table 1).

Comparisons between SR, DSR, intensity peak values, and visual disease ratings were made with 1) a correlation program using the formula: 3) \(Y = MX + B\), where \(M\) was the slope and \(B\) was the intercept to determine the relationship between correlation values \((r)\) and the VG and 2) Pearson’s correlation coefficient formula and analysis of variance \((16)\) to determine possible associations between observations and calculations in separating stress levels. An Apple II+ computer with 48K of memory was used with a program to process correlation coefficients and estimate visual grades.

The ACIR transparencies were placed on a light table for back lighting and recorded with a video camera for digitizing with a linear measuring system (LMS) microprocessor. The LMS transfers the processed image to two monitors (one black and white and one color), where it can be displayed at various levels of gray and color-coded according to the desired number of density levels. Two close-up lenses (magnifications of +1 and +2) were attached to the video.
camera lens to digitize individual trees. After determining the tree area, gray levels were selected by assigning brightness and darkness values to damaged (bluish coloration) and healthy canopy (magenta hue). The LMS allows printing images or just numerical values of all gray levels. The same trees used for densitometric readings were measured with the LMS in an effort to determine if both systems coincided or differed in stress detection. Throughout the experiment, all trees were labeled by row (from top to bottom of transparency) and tree column (from left to right) (Fig. 1). Image analysis of the ACIR transparencies was done by selecting one degree of brightness, three classes of darkness, and three levels of gray with their respective ratios.

Densitometric measurements of ACIR transparencies indicated that healthy trees could be distinguished from dead trees, but other parameters tested (I1, I2, MXWL, and MNWL) were not as definitive in separating stressed from healthy trees. Correlation analysis between VG and SR values were significant at the 1% level when correlation analysis was done using formula 3.

The r value obtained with formula 3 indicated that SR was positive (r = 0.87), while the DSR values were negative (r = -0.88). Correlation values between MXWL, MNWL, I1, I2, and VG were not significant.

Pearson's correlation (16) analysis of LMS images indicated that positive highly significant correlations (1% level) existed between the SR and MXWL with the VG, between brightness and dark classes 1 and 2, and between dark classes 1 and 2 (Table 1). Negative correlations (highly significant at the 1% level) were found between DSR and VG, SR and DSR, MXWL and VG, MXWL and SR, gray level 3 and dark class 2, and gray level 1 and 2 (Table 1).

Attempts to relate visual grades to either the SR or the DSR did not indicate a distinct relationship or association. The five VGs (0, 1, 2, 3, and 4) used in previous experiments (6) agreed only in the two extremes of the scale, the healthy VG 0 (0% stress) and the dead tree VG 4 (100% stress) grades. Mixed densitometric readings of the ACIR transparencies were obtained in VGs 1, 2, and 3 in both SR and DSR.

Three major groups were observed, one of healthy trees (VG 0), one of stressed trees (VGs 1, 2, and 3), and one of dead trees (VG 4).

Discrepancies found between VG and densitometric readings may be due to a lack of uniformity of the tree's canopy. In some trees, only part of the canopy was observed as stressed, while the rest appeared to be healthy. A few trees had some branch damage, sufficiently increasing densitometric readings to alter SR and DSR values. There were some trees with sectoring, showing distinct differences from the rest of the canopy, completely modifying the VG and the densitometric readings (Fig. 1 B and C). Gradual changes in color were more easily detected by densitometry than by arbitrary VGs (Table 1). Human errors in observation and photointerpretation varied considerably and were not as consistent as the densitometric readings.

Inclusion of wavelength measurements, MXWL and MNWL, in formulating a ratio between the two intensity peaks in the DSR did not appear to improve the separation of stressed trees from healthy trees and it is quite similar to the ratio of the intensities (SR), except that its correlation was negative rather than positive. Correlation analysis with formula 3 indicated that using ratios for the intensities (SR) may be a better method for measuring stress and separating healthy and stressed trees into at least three grades and was as consistent as arbitrary visual interpretation.

The numerical values of classes of darkness and levels of gray in analysis of ACIR transparencies obtained with the LMS system indicated positive and negative highly significant (1% level) correlations between them. These correlations suggest that image analysis procedures may have the capability of separating trees into classes of stress.

In these experiments, densitometry appeared to have better correlation with VGs than image analysis in classifying trees. Densitometry and image analysis results suggest that it may be possible to automate photointerpretation by combining both methods of analyzing ACIR transparencies to produce a computer-driven automated image analysis system.

**Literature Cited**