Correlation of Densitometric Measurements of Aerial Color Infrared Photography with Visual Grades of Citrus Groves

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ABSTRACT

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Aerial color infrared photographs taken in April 1986 and April 1989 were used to select three blocks of a citrus grove for image analysis. In ground surveys, trees were counted and classified according to percent stress and canopy growth. Measurements, made on the positive color infrared transparencies with a scanning densitometer over the 500- to 520-nm and 600- to 620-nm spectral ranges, correlated with visual grades assigned in surveys. Ratios of the spectral range integrals and the peak transmittances of the two spectral curves showed significant correlations with the visual grades. In the 1989 photographs, significant correlations were found between visual grades and the integral and transmittance of the first peak. Visual grades assigned through photointerpretation were comparable with densitometric measurements of both years, suggesting that the scanning densitometer may be a good tool for interpretation because it was not affected by the different color balance or the hue found in the 1986 and 1989 aerial color infrared photographs while measuring stress and growth.

Aerial photography has been used extensively by researchers in agriculture and forestry for the last 50 yr (1,3–6,10, 17–19) to detect and measure stress and diseases of crops and timber, as well as to monitor changes not easily observed from the ground. The improved resolution of today's photography can provide a greater amount of detail, thus allowing earlier detection of disease (4). Aerial photography combines the benefits of synoptic observations with a permanent record of events in a large area with a single photograph, whereas ground observations are restricted to viewing a small part of an area. Periodic photographs of the same area have made it possible to detect changes and make comparisons. The recent development of automated image analysis systems in 1989 (22) has added another dimension to the ability of photographs or electronic images (such as video, analog, and digital scanner data) to provide additional information.

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Consistent color balance of infrared color transparencies is difficult to obtain because of the varying age of film and problems in processing (9). Considerable effort was required to obtain the same color balance when the first CIR photographs (18) were processed in a research laboratory. The term "color balance" in this presentation is restricted to the color differences in the magenta and cyan hues of transparencies. Some investigators in forestry (10,14,17,18,21) have established specific parameters for color balance, particularly for standardizing resulting colors (8,9) and explaining the comparisons between CIR and normal color (12). Large users of CIR film were able to run densitometric measurements to determine how to use batches of film that varied in age and dye sensitivity (7), but most investigators have relied on using recently purchased film (18).

Densitometric measurements of CIR transparencies (2,4,12) have been used in efforts to obtain reliable and consistent information on tree stress and diseases (7,14,16,20). However, because of the variety of instruments used, it has been difficult to make comparisons between results obtained.

Results of photointerpretation vary because of problems in measuring human signal detection performance (6). Thus, a scanning densitometer was used (4) to measure positive transparencies of citrus trees under different levels of stress, and the measurements were significantly related with visual grades assigned on ground surveys. In a more recent experiment, working with one set of images, good correlation was obtained between visual grades and ratios of densitometric integral and transmittance measurements that separated the visual grades into three different groups (1). Comparisons between photographs of citrus groves taken in different years have not been measured with a scanning densitometer to determine changes in tree spectral reflectance. The purpose of this experiment was to compare two sets of photographic transparencies of the same grove (taken within 3 yr of each other with different batches of film) and to evaluate the correlations between densitometric measurements and visual interpretations.

MATERIALS AND METHODS

The aerial photographs used in these studies were taken from a commercial project carried out in Florida as a routine aerial survey of an 872.7-ha (1,920-acre) Polk County grove. Valencia orange (*Citrus sinensis* (L.) Osbeck) trees planted in the grove on rough lemon (*C. jambhiri* (Lush.)) rootstock were photographed with an RC-8 Wild 23 × 23 cm (9 × 9 in.) camera (powered by the electrical system of a low-wing, twin-engine aircraft) using a 15-cm (6-in.) focal length lens with a yellow "C" filter and Kodak 2443 CIR film. Photographs were taken on 4 April 1986 and 19 April 1989 at approximately 10:00 a.m. eastern daylight saving time. Photography with a 60% forward lap and 30% side lap resulted in a total of 81 positive transparencies of the entire grove taken from an altitude of 610 m (2,000 ft). The transparencies were at a scale of 1 cm = 40 m (1 in. = 330 ft) on the ground, and each covered 93.6 ha (206 acres). The film was processed in a standard Versamat color processing system to positive transparencies.

Photointerpretations were taken from blocks 3, 4, and 5, selected because trees of similar age were located in the same sets of frames from 1986 and 1989. Photointerpretation, tree counts, and verification ground surveys were done within 2 wk of the photography (Table 1). Twenty-five trees from each block were visually graded as 0, 1, 2, 3, or 4, with 0 = healthy, 1 = 1–25% stress, 2 = 26–50%, 3 = 51–75%, and 4 = 76–100% stress (dead tree). Stress can be due to an unknown cause or condition or to a combination of factors such as drought, root damage, disease, poor soil, nutritional deficiencies, and mechanical injuries. However, the purpose of photointerpretation was to identify trees under stress, not to determine the cause.

A scanning densitometer (4) was used to determine spectral curves of single trees from aerial color infrared transparencies placed on a microfiche reader. The transparency was positioned over the light aperture, and a wheel that tilts a monochromator grating (Gamma Scientific, Model 700-3, San Diego, CA) was advanced manually for 31 sequences, with each sequence producing a spectral transmission measurement. Wavelength readings were displayed as transmittance numbers on a photovoltmultiplier/voltmeter (Photovolt Corp., Model 250-A, New York City) and a digital voltmeter (Data Precision Model 248). The 31 measurements (in increments of 10 nm) produced a spectral curve from 400 to 700 nm, with one peak at 500–520 nm and a second at 600–620 nm. After each set of 31 measurements from each area was made, the transparency was moved so that a different area of the tree canopy was positioned over the light aperture. The shifting of the transparency was done in a cross pattern so that five sets of 31 measurements were made from each canopy, resulting in a total of 155 measurements. The program calculated the integrals (area under the peaks) of each curve and summarized the data (Table 2). Analysis of the spectral data was made by calculating the ratio of the integrals and transmittances according to the following formulas: 1) integral 2/integral 1 (I 2/I 1) = spectral integral ratio (SIR), where I 1 = integral 1 under the first spectral curve peak (500–520 nm) and I 2 = integral 2 under the second peak (600–620 nm); and 2) transmittance 2/transmittance 1 (T 2/T 1) = spectral transmittance ratio (STR), where T 1 = maximum transmittance of the first spectral curve peak (500–520 nm) and T 2 = maximum transmittance of the second peak (600–620 nm).

The relationships between SIR, STR, I 1, I 2, T 1, T 2, and visual stress ratings were determined with Pearson's correlation coefficient formula and analysis of variance (Table 2) (23).

Table 1. Comparison between Valencia orange tree counts (in absolute numbers) from photographs of a Polk County grove taken in 1986 and 1989 showing variability in tree loss per block and changes in tree classifications

Block no.	Year	Degree of stress (%) Healthy	25	50	75	Dead	Condition of trees Young	Medium	Resets	Skip	Double
3	1986	14,119	34	6	4	24	305	904	991	323	0
	1989	13,937	170	26	24	38	1,253	826	86	50	554
	Diff.	182	136	20	20	14	948	78	905	273	554
4	1986	9,688	83	7	6	34	656	1,518	992	428	0
	1989	9,521	178	37	29	85	1,505	1,355	92	6	1,004
	Diff.	167	95	30	23	51	849	163	900	422	1,004
5	1986	12,806	32	5	6	8	112	437	406	115	0
	1989	11,965	64	18	12	27	468	1,096	42	24	220
	Diff.	841	32	13	6	19	356	659	364	91	220

Table 2. Correlation coefficient (*r*) of the spectral transmittance ratio (transmittance 1/transmittance 2 = STR) and spectral integral ratio (integral 1/integral 2 = SIR) when compared with visual grades assigned to healthy and stressed Valencia orange trees photointerpreted from 1986 and 1989 aerial color infrared transparencies[a]

Year	Visual grade	I 1	I 2	SIR	T 1	T 2	STR
1986	0	45.94	40.55	1.13	0.52	0.49	1.07
	1	9.16	6.49	1.41	0.10	0.07	1.32
	2	10.24	5.04	2.03	0.10	0.06	1.67
	3	26.87	12.10	2.22	0.28	0.16	1.78
	4	25.28	10.69	2.36	0.27	0.14	1.94
	r	−0.25	−0.59	0.97	−0.29	−0.54	0.98
1989	0	6.30	9.74	0.62	0.07	0.12	0.56
	1	10.14	10.05	1.00	0.11	0.12	0.94
	2	10.99	9.03	1.22	0.12	0.11	1.12
	3	13.32	9.86	1.35	0.15	0.12	1.21
	4	18.53	10.26	1.86	0.21	0.13	1.69
	r	0.97	0.29	0.98	0.97	0.44	0.97

[a]Curves were made to fit the equation $Y = MX + B$. Level of significance: 5% = 0.88, 1% = 0.96.

RESULTS AND DISCUSSION

The method used in this experiment for determining stress is different from the ones normally used to estimate disease (11,13,15). Trees in the three blocks selected for comparison changed in visual grades between 1986 and 1989 and had to be visually regraded. The changes between the two sets of images (1986 and 1989) could be attributed to a number of parameters involved in growth (size), disease (percent canopy loss), and horticultural practices (double setting) (Table 1). Although the purpose of this comparison was not to analyze the results of tree counts (total number of trees in each block), it did reveal the valuable potential of combining aerial CIR photography with densitometric measurements to accurately measure tree health conditions (3).

The 1989 photographic set showed a slight decline in healthy trees, while the trees with various degrees of stress showed increases in severity. All of the changes in the total number of trees, however, were below the 1% level of significance (Table 1).

The 1986 CIR photography was darker in hue than the 1989 photography, which made it more difficult to determine tree stress. Visual comparisons of both sets of photographs with photographs in existing manuals (10,19,21) indicated that the color balance of the 1989 photography was better than that of the 1986 transparencies.

In the 1986 photographic set, reset trees were harder to detect because they were partially covered by shadows of nearby larger trees. The canopy of the large trees had a lighter magenta hue that allowed a better color distinction for separating reset trees.

The lighter hues of the 1989 photographs made it possible to detect more subtle differences in tree condition than the darker 1986 photographs. The lighter hues made it easier to detect partial stress (visual grades 1 and 2) characterized by

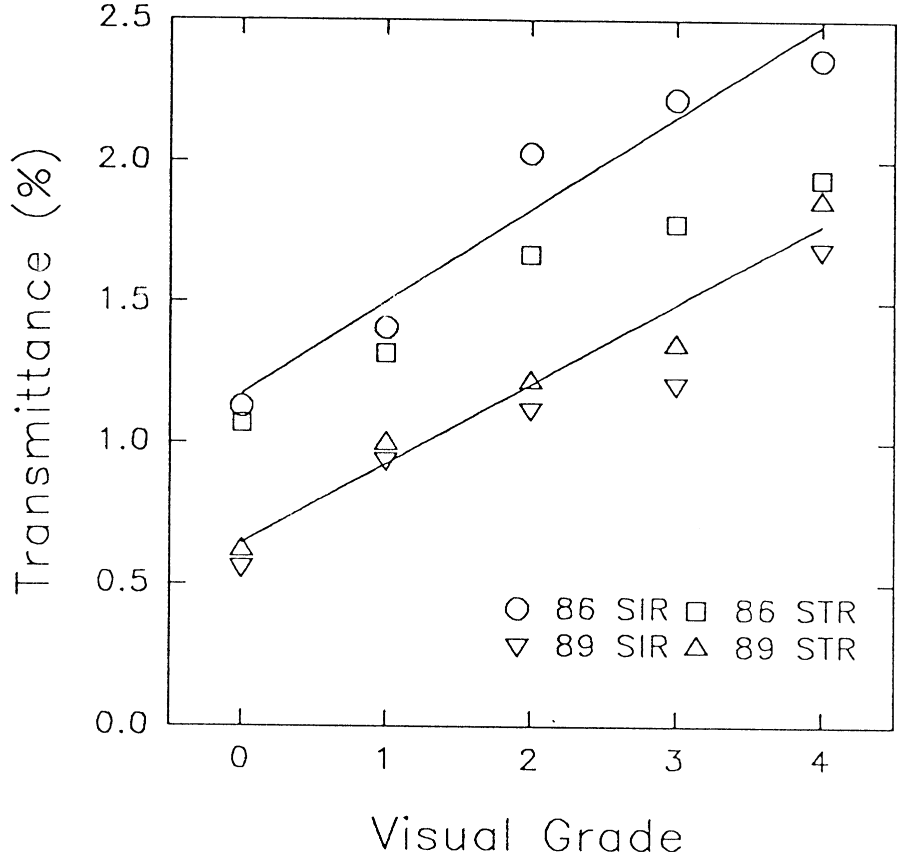

Fig. 1. Regression curves of comparisons between visual grade and integral ratios (SIR) and transmittance ratio (STR) from color infrared photographs taken in 1986 and 1989 of a citrus grove.

cyan, when compared with healthy trees (visual grade 0), which were magenta. Comparisons between photographs of the 2 yr indicated that there was variability in tree loss and changes in tree classifications (Table 1), while differences in densitometric measurement correlated well in the ratio of the integrals and the transmittance of both years (Table 2).

Because the instability of CIR film, due to its chemical layers and age, has made it quite difficult to set standards of exposure to obtain identical color balance between different batches of film (3), it is best to conduct photography with film of similar age. In experimental photography, calibrated targets of known densitometric values are placed near trees before photographic missions to determine changes in transparencies due to film age and processing procedures. In commercial photography, it is not economically feasible to set out targets; thus, the best approach is to determine differences between film batches by measuring ratios of transmittances and integrals of the visual grades from trees. In the 1986 photographic set, measurement of the first and second peak integrals (I 1, I 2) indicated that there was no correlation with the visual grades, since the r value was −0.25 for I 1 and −0.59 for I 2 (Table 2). Only the ratios of the integrals (SIR) and the transmittances (STR) were significant at the 1% level (0.97 and 0.98, respectively) (Table 2). In the 1989 photographic set, the integral (I 1) and the transmittance (T 1) of the first peak and the SIR and STR were significant at the 1% level (Table 2). These results were consistent with those obtained in a previous study with only one set of images where the spectral ratios of the integrals (SIR) and the transmittances (STR) reduced the five visual grades to three, since the five visual grades were not separated consistently (1).

The color balance and hue of the 1989 photography (with two sets of images), as well as the densitometric measurements of the frames, were better than those of the 1986 photography. The integral and transmittance values of the 1989 photography, as well as the SIR and STR numbers, correlated well with the visual grades (Fig. 1), suggesting that the use of ratios was a good procedure that gave reliable densitometric values of the visual grades, as it did in a previous experiment (1).

Densitometric values combined with image analysis programs may make it possible to develop artificial intelligence systems to rapidly count trees and classify tree health, thus quickly providing more accurate information to grove owners, managers, county agents, and property appraisers.

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