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WAVELENGTH INTENSITY INDICES IN RELATION TO TREE CONDITION AND LEAF-NUTRIENT CONTENT

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ABSTRACT

Citrus blight is a decline which accounts for the loss of more than 1/2 million trees per year in Florida. The random and non-random occurrence of citrus blight is too costly and time consuming to assess with conventional techniques. The main objective of this study was to use wavelength intensity indices as an alternative for assessing tree health status and nutrient leaf contents (Zn, Na, K, Mg, Ca, P, Cu, and Al). Tree conditions were visually rated on a 0-3 scale. The results from chemical analysis showed that the leaves of declined trees had a tendency to be low in K and Mg and high in Na, Ca, and Al. Kodak 2443 aerial color infrared film was used to photograph the citrus grove. The film was analyzed by spectral densitometry. The monochrometer was scanned in 10 nm steps from 400 to 690 nm of wavelength. The spectral curves have two maximum intensity measurements, I_1 and I_2. The I_1 is near 480 nm (i.e. λ_1) and I_2 is near 600 nm (i.e. λ_2). The results from spectral analysis showed that nine parameters of wavelength intensity indices [λ_1, I_1, λ_2, I_2, $\lambda_2-\lambda_1$, $|I_1-I_2|$, I_1/I_2, $(\lambda_2-\lambda_1)/(I_1/I_2)$, and $(\lambda_2-\lambda_1)/|I_1-I_2|$] were all significantly related to the tree conditions. The declined tree had a lower value of $\lambda_2-\lambda_1$, $(\lambda_2-\lambda_1)/(I_1/I_2)$ and $(\lambda_2-\lambda_1)/|I_1-I_2|$ but it had a higher value of I_1/I_2 and $|I_1-I_2|$. Finally, the $(\lambda_2-\lambda_1)/|I_1-I_2|$ is strongly recommended to be used for assessing tree conditions; and parameters of λ_1, I_1, λ_2, $|I_1-I_2|$, and $(\lambda_2-\lambda_1)/|I_1-I_2|$ are recommended to be used for assessing the nutrient contents in the leaf.

I. INTRODUCTION

Citrus production is Florida's largest agricultural incoming-producing enterprise. In 1984, there were 308,000 hectares of citrus in Florida with an on-tree value of more than 1 billion dollars (Anonymous, 1984). Citrus blight is considered to be the most serious of the declines which account for an estimated loss of more than 1/2 million trees per year in Florida. Blighted trees have altered zinc distribution (Smith, 1974a), plugging of trunk xylem elements (Cohen, 1974), and mild wilt and delayed flushes in the early spring (Smith, 1974b). Citrus blight was first reported in 1874 (Rhoads, 1936), but as of now no causal agent has been identified nor has any control been developed. However, growers can select rootstocks for replants or new plantings which have a relatively lower rate of blight incidence (Young et al., 1980, 1984).

Environmental stresses appear to hasten the onset and development of citrus disorders. Temperature governs all biological processes and is an important parameter influencing citrus growth and freeze damage (Wiltbank and Oswalt, 1984). Thus, any low temperature stress (freezing or chilling) could hasten the development of citrus blight (Shih, et al., 1984).

The random and non-random occurrence of citrus blight (Cohen, 1980) is too time consuming to assess with conventional techniques. Recently, remote sensing techniques have been used to study the citrus blight problems (Blazquez and Horn, 1980; Edwards et al., 1981, 1984; Shih et al., 1984). Remote sensing techniques depend mainly upon the spectral radiance response difference from tree leaves. The leaf nutrient contents have been shown to be related to wavelengths (Gausman, 1973). However, a detailed technique for assessing citrus blight and leaf nutrient contents has not been emphasized. Therefore, the objectives of this study were:

(1) To study the relationship between tree conditions and leaf nutrient contents;

(2) To develop wavelength intensity indices for assessing the tree conditions; and

(3) To study the possibility of using wavelength intensity indices to assess the leaf nutrient content.

II. MATERIALS AND METHODS

A. EXPERIMENTAL SITE

The study area was in the Hunt Brothers' citrus grove (28° latitude, 82° longitude) in Polk county located 40 km southeast of Lake Alfred, Florida. The soil series was a Candler fine sand (hyperthermic uncoated, Typic Quartzipsamments). The Candler series consists of deep, excessively drained, very rapidly permeable soils formed in thick beds of eolian or marine deposits of coarse textured materials. The water table was at depths greater than 2 m. The Candler series was chosen due to its agricultural importance for citrus production and the grove was chosen because of the high incidence of citrus blight in certain areas. The grove was planted in 1960 with Sweet orange 'Valencia' (Citrus sinensis Osbeck) on rough lemon (C. jambhiri Lush.) rootstock. Row spacings were 9 m and tree spacing within the row was 6 m. The grove was separated into the east and west sides. Each side had 10 rows with 25 tree spaces in each row.

B. TREE CONDITIONS

The tree conditions were visually rated on a 0-3 scale in May, 1983, 0 = healthy, 1 = slight decline, 2 = moderate decline, 3 = near dead.

C. LEAF NUTRIENT ANALYSIS

Leaf samples were collected in November, 1983 from 4 rows each 25 trees long on the east and west side of the road. Each sample consisted of 100 (5- to 6-month-old) non-fruit spring-flush leaves at 5-feet above ground level at the drip-line from each tree. The samples were collected and placed in paper bags, transferred to the cold room, and later individually washed with a sponge and detergent, rinsed with distilled water, oven-dried at 70°C for 48 hours, and ground to pass a 20 mesh sieve in a Wiley mill.

The macronutrient elements (Ca, Mg, K), microtrient elements (Cu, Zn), and Na, P and Al were determined in each sample after dry ashing with sulfuric acid. One gram of dried, ground leaf sample was placed in a 50-ml beaker. The sample was wetted to saturation with a solution of 5% H_2SO_4 in ethyl alcohol and the excess alcohol in the beaker was burned off. The beaker was placed in a cool furnace and the temperature was gradually increased to 500°C and held for 4 hours. After cooling the ash was wetted with deionized water and then 10 ml of 3N HCl added. The solution was heated to a slow boil on the hot plate. The silica in the dissolved ash was filtered into a 100-ml volumetric flask, washed with deionized water and the filtrate diluted to a volume of 100 ml. All elements except phosphorus were determined either by atomic absorption or emission spectrophotometry. Phosphorus was determined colorimetrically using a spectrophotometer to determine the optical density (absorbance) of the standards and unknowns. The color developing agents included amonium molybdate, antimony potassium tartrate, sulfuric acid and ascorbic acid (Johnson and Ulrich, 1959).

D. AERIAL COLOR INFRARED PHOTOGRAPHS

Kodak 2443 aerial color infrared film exposed with the appropriate minus blue filter was used to photograph the citrus grove in May 1983. The photos were taken by plane at 1220 m above ground level with a 15.2 mm lens and a forward overlap of 60%. This altitude gave a scale on the transparence of 1 cm = 40 m.

E. SPECTRAL DENSITOMETER ANALYSIS

The color infrared transparencies were analyzed by using a spectral densitometer. A total of 301 trees with visual ratings were examined in this study of which 108 trees had chemical leaf analysis.

The spectral densitometer was an assembledge of a microfilm reader, a monochromatic fiber optic probe and a photometer as previously described (Shih et al., 1984' Edwards, et al., 1984).

The monochrometer was scanned by hand in 10 nm steps from 400 to 690 nm of wavelength. The spectral curves of each analyzed tree has two maximum intensity measurements, I_1 and I_2, which are unitless, but relative. The I_1 is near 480 (i.e. λ_1) and I_2 is near 600 nm (i.e. λ_2).

F. STATISTICAL ANALYSIS

Lillesand et al. (1979) reported that urban tree stress can be quantified with microdensitometer when meaningful combinations of ground observations are statistically analyzed to arrive at a series of stress indices. However, no single spectral density measurement or combination of measurements will give an analyst an overall picture of tree vigor under all conditions. Althoug the measured parameters of λ_1, λ_2, I_1 and I_2 could be analyzed for assessing the citrus stress, these four parameters are sometimes difficult to use for assessing the tree conditions due to the inability to obtain constant film from roll to roll. Thus, three other parameters which were formulated between the two maximum wavelength intensities were also analyzed by Shih et al. (1984). The first parameter was the deviation between λ_2 and λ_1 (i.e., $\lambda_2 - \lambda_1$). The second parameter was the absolute deviation between I_1 and I_2 (i.e., $|I_1 - I_2|$). The third was the ratio of I_1/I_2. Furthermore, two additional parameters of $(\lambda_2-\lambda_1)/|I_1-I_2|$ and $(\lambda_2-\lambda_1)/(I_1/I_2)$ were also used in this study. These five and the four individual parameters were statistically analyzed to determine the best wavelength intensity index for assessment of tree conditions.

Moreover, if a parameter is shown to be an important factor which could be used to assess the tree condition, the following regression equation is used to establish a prediction model, i.e.

$$T = a + b\,X \qquad [1]$$

where T = tree condition;

X = the statistically important parameter of either leaf nutrient or wavelength intensity indices for assessing the tree condition; and

a, b = coefficients, obtained by analysis of data using regression analysis.

III. RESULTS AND DISCUSSION

A. STATISTICAL INFORMATION

The sample size, mean, standard deviation, minimum and maximum values of tree condition rating, wavelength intensity indices [λ_1, I_1, λ_2, I_2, $\lambda_2-\lambda_1$, $|I_1-I_2|$, $(\lambda_2-\lambda_1)/|I_1-I_2|$, I_1/I_2, $(\lambda_2-\lambda_2)/(I_1/I_2)$] and leaf nutrient contents (Zn, Na, K, Mg, Ca, P, Cu, and Al) are listed in Table 1. According to the leaf analysis data for citrus as listed in Table 2 (Koo, 1984), several observations can be made. First, the average Zn content (23 ppm) and K content (1.2%) in the leaf appear low. Second, the average CU contents (64 ppm) in the leaf is far in excess of the normal condition. Third, the Mg and Ca contents are within normal conditions.

B. TREE CONDITION AND LEAF NUTRIENT CONTENTS

Regression coefficients (a and b as shown in Equation 1) of leaf elemental contents (Zn, Na, K, Mg, Ca, P, Cu, and Al) on tree conditions are listed in Table 3. Several observations are apparent. First, the Zn, Ca, and P contents in the leaf were not related to the tree conditions. However, the Na, K, Mg, Cu, and Al contents were all significantly related to the tree conditions. Particularly, the Na, Mg, and K were highly significantly related to the tree conditions. Second, the leaves of declined trees had a tendency of deficiencies of K and Mg and an excess of Na, Cu, and Al.

C. TREE CONDITIONS AND WAVELENGTH INTENSITY INDICES

Regression coefficients (a and b as shown in Equation 1) of wavelength intensity indices on tree conditions are listed in Table 4. Several observations are made as follows. First, the nine parameters of wavelength intensity indices were all significantly related to the tree conditions. Second, the positive b in λ_1 and I_1 means that the declined tree not only had a higher intensity measurement of I_1 but also the λ_1 occurred at a higher value. Third, the negative b in $_2$ and I_2 imply that the declined trees not only had a lower intensity measurement of I_2 but also the λ_2 occurred at a lower value. This implies that the declined trees had lower values for $\lambda_2-\lambda_1$, $(\lambda_2-\lambda_1)/(I_1/I_2)$ and $(\lambda_2-\lambda_1)/|I_1-I_2|$ and the negative regression coefficient b of these parameters also supports this statement. Furthermore, the declined trees tend to have higher values of I_1/I_2 and $|I_1-I_2|$, and the positive b value of these parameters also supports this contention. Fourth, any one of the nine wavelength intensity indices could be used to assess tree condition. However, the optimum one would be the one with the largest range of difference. The larger range difference leads to a relatively easy way for identifying the parameter. For example, as shown in Table 1, the range difference for the λ_2 parameter is 23 and should be chosen instead of λ_1; and I_1 is better than I_2. Similarly, the $(\lambda_2-\lambda_1)/|I_1-I_2|$ is better than either $(\lambda_2-\lambda_1)$, $|I_1-I_2|$, or I_1/I_2. Thus, the $(\lambda_2-\lambda_1)/|I_1-I_2|$ is strongly recommended for use in assessing tree conditions.

D. LEAF NUTRIENT CONTENT AND WAVELENGTH INTENSITY INDICES

The regression coefficients of wavelength intensity indices on leaf nutrient contents are listed in Table 4. There is no relationship between the Mg, P, and Al contents in the leaf and the wavelength intensity indices. But the Zn, Na, K, Ca and Cu contents in the leaf are highly related to the wavelength intensity indices. For instance, the higher Zn content leads to a lower value of either λ_1, λ_2, or $(\lambda_2-\lambda_1)/|I_1-I_2|$ and with a higher intensity measurement of either I_1 or $|I_1-I_2|$.

The higher Na content in the leaf leads to a lower value of λ_2 and with a higher intensity measurement of either I_1, I_2, or $|I_1-I_2|$.

The K and Cu contents in the leaf do not appear to be related to the wavelength indices except that λ_1 index shows some potential applications for assessing these two elements.

Using wavelength intensity indices to assess the Ca content in the leaf shows a great encouragement. For instance, the higher Ca contents leads to a higher value of either $|I_1-I_2|$ or I_1/I_2 and leads to a lower value of either λ_1, $(\lambda_2-\lambda_1)/(I_1-I_2)$, or $(\lambda_2-\lambda_1)/|I_1-I_2|$.

Finally, the λ_1, I_1, λ_2, $|I_1-I_2|$, and $(\lambda_2-\lambda_1)/|I_1-I_2|$ parameters of wavelength intensity indices show the most promises for use in assessing the nutrient contents in the leaf.

IV. SUMMARY AND CONCLUSION

The main objective of this study was to use wavelength intensity indices as an alternative for assessing tree health status and nutrient contents (Zn, Na, K, Mg, Ca, P, Cu, and Al) in the leaf. Kodak 2443 aerial color infrared film was used to photograph the citrus grove. The film was analyzed by spectral densitometry. The spectral curves have two maximum intensity measurements, I_1 and I_2. The I_1 is near 480 nm (i.e. λ_1) and I_2 is near 600 nm (i.e. λ_2).

The Na, K, Mg, Cu, and Al contents in the leaf were all significantly related to the tree conditions, but not Zn, Ca, and P nutrients.

Nine parameters of wavelength intensity indices

[λ_1, I_1, λ_2, I_2, $(\lambda_2-\lambda_1)/(I_1/I_2)$, $\lambda_2-\lambda_1$, $|I_1-I_2|$, I_1/I_2, and $(\lambda_2-\lambda_1)/|I_1-I_2|$] were all significantly related to the tree conditions. But the parameter of $(\lambda_2-\lambda_1)/|I_1-I_2|$ is strongly recommended to be used for assessing the tree conditions.

The Zn, Na, K, Ca, and Cu contents in the leaf are highly related to the wavelength intensity indices; this was not true for Mg, P, and Al contents. The use of λ_1, I_1, λ_2, $|\lambda_1-\lambda_2|$, and $(\lambda_2-\lambda_1)/|I_1-I_2|$ indices show the most promise for assessing the nutrient contents of leaves.

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Table 1. Statistical data for different parameters.

Parameters	Sample size	Mean	Std. dev.	Ranges Min.	Max.	Diff.
Tree condition	301	0.59	0.80	0	3	3
λ_1, nm	301	497	2.3	479	502	23
I_1	301	0.39	0.07	0.178	0.637	0.459
λ_2, nm	301	600	5.2	570	609	39
I_2	301	0.20	0.04	0.10	0.36	0.26
$\lambda_2-\lambda_1$, nm	301	104	6.3	69	121	52
$\lvert I_1-I_2 \rvert$	301	0.18	0.05	0.07	0.39	0.32
$(\lambda_2-\lambda_1)/\lvert I_1-I_2 \rvert$	301	620	205	198	1586	1388
I_1/I_2	301	1.9	0.33	1.41	3.4	2.02
$(\lambda_2-\lambda_1)/(I_1/I_2)$	301	55.5	10.66	24.0	94.7	70.8
Zn, ppm	108	23	5	17	56	39
Na, %	108	0.044	0.015	0.02	0.09	0.07
K, %	108	1.243	0.221	0.54	1.68	1.14
Mg, %	108	0.405	0.050	0.29	0.59	0.30
Ca, %	108	4.004	0.686	2.30	5.70	3.40
P, %	108	0.132	0.940	0.10	0.18	0.08
Cu, ppm	108	63.5	25.12	16	150	134
Al, ppm	108	232.4	80.68	100	400	300

Table 2. The average analysis for citrus leaves (Koo, 1984).

Element	Deficient	Low	Optimum	High	Excess
P, %	< .09	.09-.11	.12-.16	.17-.29	> .30
K, %	< .7	.7-1.1	1.2-1.7	1.8-2.3	>2.4
Ca, %	<1.5	1.5-2.9	3.0-4.9	5.0-6.9	>7.0
Mg, %	< .20	.20-.29	.30-.49	.50-.70	> .80
Zn, ppm	< 17	18-24	25-100	101-300	>300
Cu, ppm	< 3	3-4	5-16	17-20	> 20

Table 3. Regression coefficients of leaf nutrient contents on tree conditions.

Parameter	Reg. coef.	Zn	Na	K	Mg	Ca	P	Cu	Al
Tree	a	-0.057	-0.376	1.004	1.515	-0.084	1.090	0.015	-0.04
condition	b	0.0169	16.101**	-0.539**	-2.917**	0.104	-5.749*	0.005*	0.001*

* t-test significant at 0.05 level.
** t-test highly significant at 0.01 level.

Table 4. Regression coefficients of wavelength intensity indices on tree condition and leaf nutrient.

Parameter	Reg. coef.	λ_1	I_1	λ_2	I_2	$\frac{\lambda_2-\lambda_1}{(I_1/I_2)}$	$\lambda_2-\lambda_1$	$\lvert I_1-I_2 \rvert$	I_1/I_2	$\frac{\lambda_2-\lambda_1}{\lvert I_1-I_2 \rvert}$
Tree	a	-45.30	-0.718	61.43	1.403	3.365	9.268	-1.259	-2.827	1.914
condition	b	0.0924**	3.376**	-0.101**	-4.026**	-0.052**	-0.084**	10.102**	1.762**	0.0021**
	a	253.66	16.772	356.32	21.616	28.025	26.981	16.163	16.175	27.058
Zn	b	-0.465*	16.851**	-0.554**	7.618	-0.086	-0.036	39.605**	3.668	-0.0062*
	a	0.073	0.017	0.811	0.024	0.042	0.101	0.030	0.048	0.053
Na	b	0.0001	0.072**	-0.0013*	0.099**	0	-0.001	0.077*	-0.002	0
	a	-6.253	1.380	-7.519	1.272	1.157	1.281	1.397	1.398	1.159
K	b	0.0151*	-0.363	0.0145	-0.147	0.002	0	-0.878	-0.002	0.0001
	a	0.665	0.398	-0.171	0.376	0.350	0.335	0.430	0.473	0.395
Mg	b	-0.0005	0.018	0.0010	0.141	0.001	0.001	-0.143	-0.036	1.5714
	a	30.36	3.019	31.77	3.937	5.019	3.631	2.716	2.423	4.702
Ca	b	-0.0531*	2.601**	-0.0462	0.333	-0.018*	0.004	7.294**	0.831**	-0.0011**
	a	-0.031	0.132	-0.390	0.129	0.124	0.106	0.135	0.138	0.130
P	b	0.0003	-0.001	0.0008	0.014	0	0	-0.021	-0.003	0
	a	990.54	47.85	941.71	59.72	69.74	42.69	46.35	44.36	73.205
Cu	b	-1.8685*	41.260	-1.4610	18.607	-0.101	0.198	97.04	10.05	-0.0154
	a	1445.0	178.49	2307.1	188.77	222.13	276.79	210.81	259.25	252.77
Al	b	-2.4641	142.30	-3.4514	215.68	0.183	-0.42	122.32	-14.10	-0.0323

*t-test significant at 0.05 level.
**t-test highly significant at 0.01 level.

BIOGRAPHICAL DATA

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