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COLD TEMPERATURE AND WAVELENGTH INTENSITY INDICES RELATED TO CITRUS STRESS

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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 remote sensing techniques as an alternative for assessing tree health status. The results showed that the geostationary satellite (GOES) could aid in the understanding of the cold temperature distribution which appears to be well related to the citrus decline. The cold temperature appears to be an important parameter related to the rate of tree decline. Kodak's 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 (i.e. λ_1) and I_2 is near 600 nm (i.e. λ_2). The results showed that the parameters of $\lambda_2-\lambda_1$, $|I_1-I_2|$, and I_1/I_2 appear to be very important factor which could be used to assess and predict the tree conditions.

I. INTRODUCTION

Citrus production is Florida's largest agricultural income-producing enterprise. In 1982, there were 345,000 hectares of citrus in Florida with an on-tree value of more than 1 billion dollars. Citrus blight is considered to be the most serious of the declines which account for the 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., 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. However, evidence is inclusive on whether it is possible to observe if any relationship can be found between citrus blight development and low temperature. No attempt has been made to quantitate the relative impact of low temperatures on citrus blight incidence. This lack of emphasis by previous researchers on dealing with low temperature and blight incidence could have three reasons. First, it is difficult to assess the regional low temperature. In the past, the surface temperature over a region was estimated based on point measurements. The temperature distribution over a region is difficult to assess accurately due to the spatial variation of surface temperature existing within a region. Recently, this difficulty has been overcome to some extent by using the geostationary satellites (GOES), (Chen et al., 1979; McMillin and Govindaraju, 1983; Shih and Chen, 1984; and Chen and Shih, 1984). In other words, the satellite could be used to improve the regional temperature estimation.

Second, the historical developments of citrus blight for most groves were not monitored continuously. Thus, it is difficult to establish a possible relationship between citrus blight development and low temperature stress. However, a recent study has been initiated to determine the rates of decline of six major rootstocks on a biannual basis (Young, et al., 1980, 1984).

Third, the random and non-random occurrence of citrus blight (Cohen, 1980) is too costly and 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, 1983). However, a detailed technique for assessing citrus blight and land use conditions has not been emphasized. Therefore, the remote sensing technique can provide an alternative approach to assess citrus blight, and a further study is urgently needed. The objectives of this study were: (1) to use GOES thermal data for improving the assessment of tree decline; (2) to study the possibility of tree decline in relation to freeze temperatures; and (3) to develop wavelength intensity indices for assessing the tree conditions and land use.

II. MATERIALS AND METHODS

A. EXPERIMENTAL SITE

The Pineapple Orange Grove (Fig. 1) located at the Agricultural Research Center at Fort Pierce, University of Florida, was selected in this study. 476 young trees were planted in 1962. The groves contain 14 rows of Pineapple Orange [Citrus sinensis (L). Osbeck] on Cleopatra mandarin (Citrus reshni hort. ex Tanaka) rootstock with 34 trees in each row. Each bed contains two rows with a ditch between the beds. Row spacings are 6 m within the bed and 7.5 m between the beds. Tree space within the row is 4.5 m. The predominant soil series in the grove is Wabasso (sandy, siliceous, hyperthermic, alfic, hapalaquod).

B. SATELLITE THERMAL INFRARED DATA

The satellite infrared digital data were obtained from National Environmental Satellite Data and Information Service (NEDIS) and from the satellite Freeze Forecast System located at the Fruit Crops Department, University of Florida (Martsolf, 1981). The data were from GOES East, in geostationary orbit over the equator at 75°W longitude. Infrared (IR) (10.5 - 12.6 microns) data resolution is 8 km (north-south) by 6 km (east-west) for the Florida sector (25-31°N latitude and 79-85°W longitude). Each satellite temperature represents an average value for an area of approximately 4,800 ha. A satellite map from 05 EST, 12 January 1982 as presented by Chen and Shih (1984) is also shown in Fig. 1.

C. WEATHER STATION'S FREEZE TEMPERATURE

In this study, the surface temperature is defined as freeze temperature when the temperature equals or is less than 0°C. The historical freeze temperature at the experimental site is not available. However, data are available from the Belle Glade Station (Fig. 1) where is located about 80 km southwest of the experimental site. A total of 23 freeze occurences between 1963 and 1983 are listed in Table 1.

D. TREE CONDITIONS

After citrus was planted in 1962, some blight symptoms showed up in 1973. The tree conditions were visually graded on a 0-3 scale: 0=healthy, 1=slightly decline, 2=moderate decline, 3=about dead. Over the 20 years they were graded eight times: Jan. 31, 1973; Jan. 9, 1974; Jan. 15, 1976; Oct. 17, 1976; May 24, 1979; Jan. 19; 1980; Jan. 15, 1981; and April 13, 1983. After grading, tree conditions were grouped into 5 categories for statistical analyses; i.e. 0, 0.1-0.5, 0.6-1.0, 1.1-1.5, and 1.5-2.5.

E. AERIAL COLOR INFRARED PHOTOGRAPHS

Kodak's 2443 aerial color infrared film exposed with the appropriate minus blue filter was used to photograph the citrus grove on May 5, 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 transparency of 1 cm = 40 m.

F. SPECTRAL DENSITOMETER ANALYSIS

The color infrared transparencies were analyzed by using a spectral densitometer. Two groups of trees were examined in this study. First, 476 trees were analyzed individually for studying the relationship between tree conditions and wavelength indensity indices. Second, trees #6 and #23 across the 14 rows which were graded as having decline symptom and healthy condition, respectively, were selected to study the land uses (trees, ditch, and grass) in relation to the wavelength intensity indices.

A Jenoptik Jena bH Dockumator DL-2 microfilm reader was the light source and image magnifying system used in this spectral densitometer assembledge. The projection screen of the DL-2 was replaced with a 14-guage aluminum plate covered with white poster board. A hole drilled near the center of the plate held a Gamma Scientific (GS) 914 mm x 3.18 mm (36 inch x 0.125 inch) flexable fiber optic probe. A brass plate was mounted on the under side of the plate to hold the face of the probe flush to the face of the screen. The other end of the probe was connected to a GS monochromator case Model 700-3. A Bausch and Lomb visiable grating, catalog No. 33-78-76, was mounted in the monochromator case. The monochromatic light sensed with R-777 Hamamatsu photomultiplier (PM). A GS exit slit 0.75 was mounted in front of the PM tube. The output of the PM was measured by a Photovolt Multipler Photometer, Model 520-A. A Data Precision Model 248 Digital Multimeter was connected to the external recorder output of the photovolt for a readout. The tree crowns were about 8 m in diameter, large enough to fill the face of the probe with the x6.5 magnification of the DL-2. Three other magnifications on the DL-2 were possible, x9, x13, and x17.5.

The monochrometer was scanned by hand in 10 nm steps from 400 to 690 nm of wavelength. The spectral curves of each analyzed subject (tree, ditch, and grass) have 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).

G. STATISTICAL ANALYSIS

Lillesand et al. (1979) reported that urban tree stress can be quantified with a microdensitometer when meaningful combinations of ground observations are statistically analyzed to arrive at a series of stress indicies. However, no single spectral density measurement or combination of measurements will tell an analyst about the overall picture of the vigor of a tree under all conditions. Although 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 color from roll to roll. Thus, three other parameters which were formulated between the two maximum wavelength intensities were also analyzed. The first parameter is the deviation between λ_2 and λ_1 (i.e., $\lambda_2-\lambda_1$). The second parameter is the absolute deviation between I_1 and I_2 (i.e., $|I_1-I_2|$). The third is the ratio of I_1 to I_2. These seven parameters were statistically analyzed to determine the best wavelength intensity index for assessment of tree and land-use conditions.

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

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

where

T = tree conditions;

X = the statistically important parameter of wavelength intensity indices for assessing the tree conditions; and

a, b = coefficients.

The coefficients of a and b were obtained from the experimental data by using the regression analysis.

H. DITCH AND GRASS

Each of the 8 ditches was 3 m wide and 0.6 m deep between the beds. The ditch contains weeds, bare soil and water. Bermulagrass [Cynodon dactylon (L). Pers.] and bahiagrass (Paspalum notatum Flugge) are grown within the bed.

III. RESULTS AND DISCUSSION

A. SATELLITE DATA FOR 1982 FREEZE

As Fig. 1 shows, two important features can be observed. First, the Pineapple Orange Grove was adjacent to a low temperature (-6°C). Although no tree damage was reported after the freeze, some trees might have undergone the cold temperature stress. Second, the low temperature in Belle Glade was similar to the Pineapple Orange Grove. Thus, if the historical low temperature was not available in the Pineapple Orange Grove, the Belle Glade Weather Station records could be used for references.

B. TREE CONDITIONS AND FREEZE TEMPERATURE

As Table 1 shows, although the total of 23 freezes occurred during the past 21 years, two freezes occurred in December 1983 after the May aerial photography. The 16 out of 21 freezes (i.e. 75%) occurred at three major periods. The first period with 5 freeze events occurred during the 14 months from Jan. 1970 to Feb. 1971. The second period with 5 freeze events happened during the 26 months from Jan. 1977 to Feb. 1979. The third period with 6 freeze events took place during the 24 months from Jan. 1981 to Dec. 1982. In other words, about 75% of the freeze events occurred during 25% (64 months of 252 months) of the period. This uneven freeze temperature distribution may affect the citrus acclimation.

The historical tree conditions with rating ranges 0.1-0.5, 0.6-1.0, 1,1-1.5, and 1.5-2.5 are shown in Table 2. Three important features can be observed. First, the tree decline is not steadily increased as the time progresses. In other words, the tree conditions showed that the decline symptoms could either increase or decrease as the time progresses. Second, three peaks of tree decline were shown on 1974, 1979, and 1983 gradings. Third, the reductions of tree decline were shown on 1976 and 1980 gradings.

After comparing the historical tree conditions with the historical freeze temperatures, two findings were made. First, the three peaks of tree decline were coincided with the three post major freeze occurrences. This implies that the cold temperature could cause a citrus stress from which a decline condition could be shown. Second, the two reductions of tree decline were well coincided with the periods when the freezes did not occur. This implies that tree decline would be reduced if there is a warm temperature in the winter.

C. TREE CONDITIONS AND WAVELENGTH INTENSITY INDIES

The tree conditions visually graded on April 13, 1983 were used to compare with the wavelength intensity indices. The number of trees involved in the ranges of 0, 0.1-0.5, 0.6-1.0, 1.1-1.5, and 1.5-2.5 were 268, 127, 51, 22, and 8 trees. The mean values of parameters of λ_1, λ_2, $\lambda_2-\lambda_1$, I_1, I_2, $|I_1-I_2|$, and I_1/I_2 were computed based on the five ranges of tree grading. The results are shown in Table 3. After Duncan's Multiple Range Test was implemented, several observations can be made.

The λ_1 is significantly different between the healthy tree and the decline tree. There is a tendency for the λ_1 to increase when the tree is in more declined.

The λ_2 in the tree grading of less than one is significantly different from the tree grading greater than one. There is a tendency for the λ_2 to decrease when the tree declines.

The difference between λ_1 and λ_2 could be used as an indicator for assessing the tree decline, because there is a significant difference among the different ranges of tree grading and there is about 30 nm (113-84 nm) of deviation to assess the citrus conditions.

Although the I_1 value is not significantly different between healthy and decline trees, the I_2 value is significantly different between healthy and decline trees.

The absolute deviations between I_1 and I_2 were significantly related to the tree conditions. The declined tree tends to have a large deviation. The absolute deviation is less than one when the tree is either healthy or grades less than 0.5. The absolute deviation is between 1 and 2 when the tree is slightly declined. The deviation is greater than 2 when the tree is moderate or severely declined.

The ratio between I_1 and I_2 were also significantly inversely related to the tree conditions. The healthy tree has a ratio of about one. The slightly declined tree has a ratio between 1 and 2. The moderate or severe declined tree has a ratio greater than 2.

D. TREE CONDITION PREDICTIONS

As mentioned, the λ_1, λ_2, I_1, and I_2 are varied from roll to roll of film. Thus, the tree condition prediction model as presented in Equation 1 was developed based on the parameters of $\lambda_2-\lambda_1$, $|I_1-I_2|$, and I_1/I_2. The results were:

$$T = 7.158 - 0.061\ (\lambda_1-\lambda_2) \qquad (r^2=0.75) \qquad [2]$$

$$T = -0.722 + 1.018\ |I_1-I_2| \qquad (r^2=0.96) \qquad [3]$$

$$T = -1.322 + 1.312\ (I_1/I_2) \qquad (r^2=0.91) \qquad [4]$$

Although the equation 2 could be used to predict the tree conditions based on the difference of wavelength, the $r^2=0.75$ was not as high as in Equations 3 and 4 which were developed based on the intensity of wavelength. The data and simulated results for predicting the tree conditions based on the $|I_1-I_2|$ and I_1/I_2 are plotted on Figs. 2A and 2B, respectively. As Fig. 2 shows, both equations based on $|I_1-I_2|$ and I_1/I_2 appear to be quite applicable for assessing the tree decline conditions.

E. LAND USES AND WAVELENGTH INTENSITY INDICES

The results of λ_1, λ_2, $\lambda_2-\lambda_1$, I_1, I_2, $|I_1-I_2|$, and I_1/I_2 under different land uses are shown in Table 4. As mentioned earlier, the 14 rows across the tree #23 are all healthy trees, and the tree #6 are all decline trees with an average grading scale of 0.72. The values as shown in Table 4 represent an average of 14, 8, and 7 measurements for tree, ditch, and grass, respectively. Several observations can be made from Table 4.

The parameters of λ_1, λ_2, and $\lambda_1-\lambda_2$ are all significantly different between tree and the others. There is no difference between ditch and grass.

The parameter I_1 in the tree is significantly less than that in the ditch and grass. A difference between ditch and grass under the decline tree area could be due to the more green shown in the grass as a result of less shading from the decline tree.

The I_2 in the decline tree is significantly different from the grass under decline tree area mainly due to the decline tree has less response to the λ_2.

The parameter $|I_1-I_2|$ in the tree is significantly different from others, except that in the decline tree is similar to in the ditch. The $|I_1-I_2|$ in the ditch under the healthy tree is significantly different from that under the decline tree.

The ratio I_1/I_2 in the healthy tree is significantly different from others.

According to the three models presented in Equations 2, 3, and 4, the scales of decline tree are predicted to be 0.69, 0.70, and 0.61 when the $\lambda_2-\lambda_1$, $|I_1-I_2|$, and I_1/I_2 are respectively equal to 106.1 nm, 1.39 and 1.47 as shown in Table 4. These predicted results are very close to the actual grading of 0.72. This implies that the techniques developed in Equations 2, 3, and 4 could be useful tools for assessing the citrus decline.

F. POTENTIAL APPLICATIONS

Several results drawn in this study could be potentially implemented to the practical application in the future citrus production.

The GOES satellite data could aid in the understanding of the cold temperature distribution which appear to be well related to tree decline.

The freeze temperature appears to be an important parameter related to the rate of tree decline. Thus, the practices implemented in the citrus grove for freeze protection should be also implemented for citrus decline protection.

The parameters of $\lambda_2-\lambda_1$, $|I_1-I_2|$, and I_1/I_2 appear to be very important factors which could be used to predict the tree conditions.

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Table 1. Freeze occurrence between 1963 and 1983 at the Belle Glade Weather Station.

Year	Freeze occurrence Jan.	Feb.	Dec.	Total occur.
1963				0
1964	1	1		2
1965				0
1966	1			1
1967				0
1968				0
1969				0
1970	2			2
1971	2	1		3
1972				0
1973			2	2
1974				0
1975				0
1976				0
1977	1		1	2
1978	1	1		2
1979		1		1
1980				0
1981	2		1	3
1982	2		1	3
1983			2	2

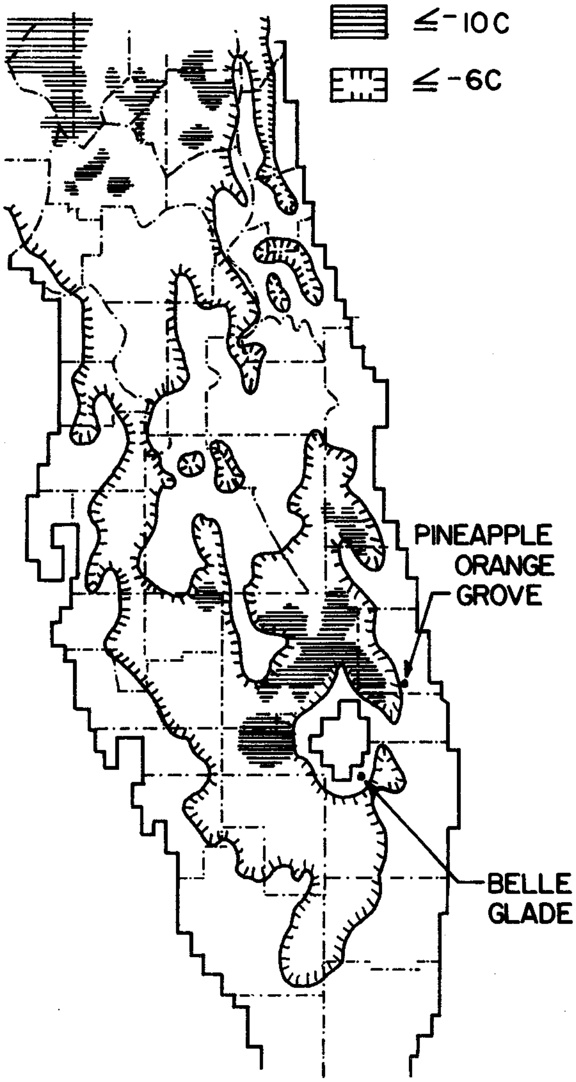

Figure 1. Geostationary Satellite Thermal Map for Peninsular Florida for January 12, 1982 Freeze.

Table 2. Tree decline varying with time in Pineapple Orange Grove. Agricultural Research Center, Fort Pierce.

Sampling Date	Tree decline rating range* 0.1-0.5	0.6-1.0	1.1-1.5	1.6-2.5	Total
	No. of trees				
1/31/1973	15	1	3	1	20
1/9/1974	19	16	2	4	41
1/15/1976	20	2	1	6	29
10/17/1976	11	11	4	0	26
5/24/1979	87	10	10	5	112
6/19/1980	36	15	8	1	60
6/15/1981	96	10	16	6	128
4/13/1983	127	51	22	8	208

*0 = healthy; 1 = slight decline; 2 = moderate decline; 3 = about dead.

Table 3. Comparison of wavelength and intensity between different ranges of tree decline conditions.

Tree* cond.	Rep.	Wavelength λ_1	λ_2	$\lambda_2-\lambda_1$	Intensity I_1	I_2	$\lvert I_1-I_2 \rvert$	I_1/I_2
		nm						
0	268	496.2d$^+$	608.6a	112.5a	4.30a	4.49a	0.76c	1.019d
0.1-0.5	127	496.7cd	606.2a	109.5ab	4.37a	3.62b	0.90c	1.269c
0.6-1.0	51	497.9c	602.9a	105.1b	4.57a	2.85bc	1.72b	1.710b
1.1-1.5	22	500.1b	584.9c	84.8d	4.64a	2.32c	2.32a	2.385a
1.6-2.5	8	501.9a	594.6b	92.8c	4.66a	2.13c	2.54a	2.304a

*0 = healthy; 1 = slight decline; 2 = moderate decline; 3 = about dead.

+Values within a column followed by the same letter are not different ($p < 0.05$) by Duncan's Multiple Range Test.

Table 4. Comparisons of wavelength and intensity among tree, ditch and grass under healthy and decline tree conditions.

Tree condition	Land use	Rep.	Wavelength λ_1	λ_2	$\lambda_2-\lambda_1$	Intensity I_1	I_2	$\lvert I_1-I_2 \rvert$	I_1/I_2
			nm						
Healthy tree #23	Tree	14	496.6b*	607.5a	110.9a	4.46c	4.40abc	0.75d	1.014b
	Ditch	8	503.9a	595.1c	91.2b	6.49b	3.60bc	2.89ab	1.802a
	Grass	7	504.7a	598.1c	93.4b	6.57b	4.32abc	2.25bc	1.565a
Decline tree #6	Tree	14	496.8b	602.9b	106.1a	4.35c	2.96c	1.39cd	1.551a
	Ditch	8	505.4a	596.9c	91.5b	6.75b	4.59ab	2.24bc	1.521a
	Grass	7	505.9a	595.9c	90.0b	8.73a	5.39a	3.34a	1.615a

*Values within a column followed by the same letter are not different ($p < 0.05$) by Duncan's Multiple Range Test.

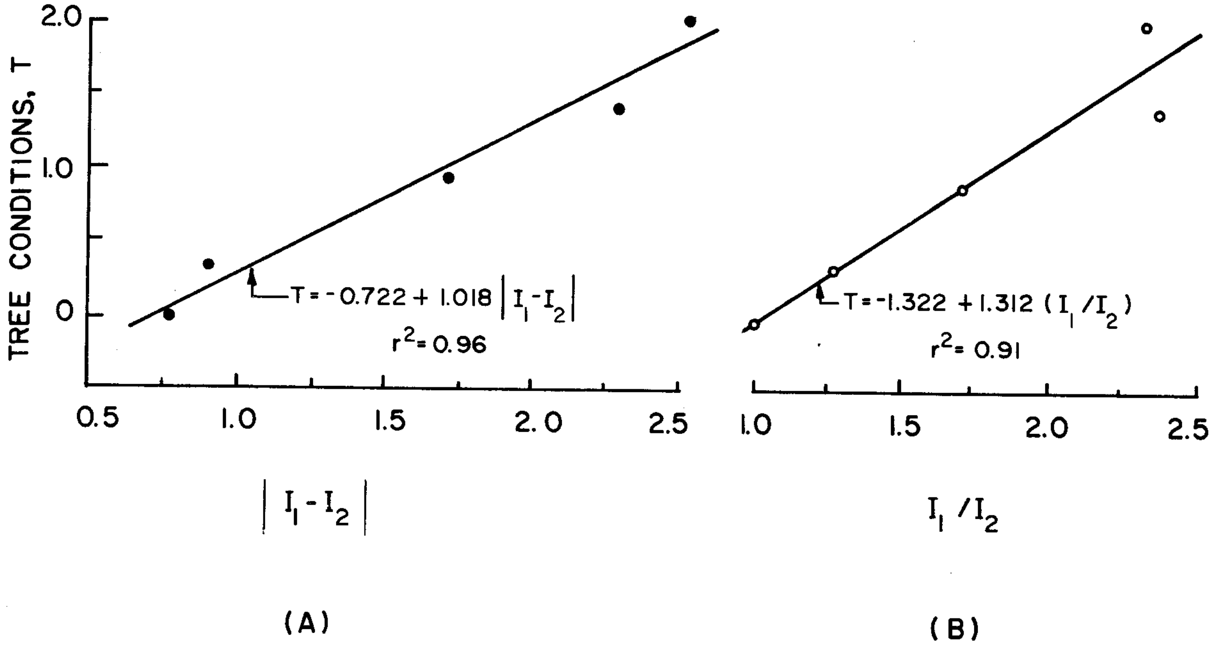

Figure 2. Tree Conditions Related to Absolute Deviation Between Two Wavelength Intensities (i.e. $|I_1-I_2|$), and the Ratio of the Two Wavelength Intensities (i.e. I_1/I_2).

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BIOGRAPHICAL DATA

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