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Technical Memorandum 80312

Assessing Soybean Leaf Area And Leaf Biomass By Spectral Measurements

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JULY 1979

ASSESSING SOYBEAN LEAF AREA AND LEAF

BIOMASS BY SPECTRAL MEASUREMENTS*

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ABSTRACT

Red and photographic infrared spectral radiances have been correlated with soybean total leaf area index, green leaf area index, chlorotic leaf area index, green leaf biomass, chlorotic leaf biomass, and total biomass. The most significant correlations were found to exist between the ir/red radiance ratio data and green leaf area index and/or green leaf biomass (r^2 = 0.85 and 0.86, respectively). These findings demonstrate that remote sensing data can supply information basic to soybean canopy growth, development, and status by non-destructive determination of the green leaf area or green leaf biomass.

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INTRODUCTION AND REVIEW

Previous research has reported that linear combinations of red and photographic infrared spectral data were significantly correlated to the green or photosynthetically active portions of plant canopies for a variety of cover types (Jordan, 1969; Colwell et al., 1977; Deering, 1978; Tucker, 1979). In addition, other workers have applied Landsat red and near infrared data (MSS 5 and MSS 6 or MSS 7) to a variety of vegetation analyses (Rouse et al., 1974; Carnegie et al., 1974; Blair and Baumgardner, 1977; Ashley and Rea, 1975; Maxwell, 1976; Richardson and Wiegand, 1977; among others).

Successful application of red and photographic infrared linear combination data to a variety of vegetation situations strongly supports the contention that these data are sensitive to basic biotic properties of vegetated surfaces. We now report on an experiment in which red and photographic infrared spectral data were collected from soybean plots and were correlated with leaf area, leaf biomass, and total biomass.

EXPERIMENTAL METHODS

A soybean field (<u>Glycine max</u> (L.) Merr.) on Elinsboro sandy loam soil located on the USDA Beltsville Agricultural Research Center, Maryland was selected for study. Sixty circular 0.25 m^2 plots were used with four plots being sampled per week for fifteen weeks. They soybeans were planted on May 20, 1978, and had a row spacing of 76 cm and 5 cm within the row. The crop emerged in early June and reached 100% canopy cover in early August. The first freeze occured on October 11, 1978.

Each week four pairs of red (0.63 – 0.69 μm) and photographic infrared (0.775 – 0.825 μm) spectral data were collected for each of the four plots measured with a hand-held radiometer similar to Pearson et al. (1976). Concurrent agronomic data pertaining to crop development, estimated canopy cover, number of leaves, and plant height were recorded before each of the 0.25 m^2 plots

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were harvested. All of the above ground vegetation was immediately harvested and the total wet biomass determined. Subsequently, the total wet biomass was stratified into wet green leaf biomass, wet chlorotic leaf biomass, and wet stem biomass. The wet green and wet chlorotic leaf biomasses were immediately run through an automatic leaf area meter to determine the green leaf area and chlorotic leaf area. The wet biomass fractions were then force air dried at 60°C for 48 hours before the dry green leaf biomass, dry chlorotic leaf biomass, and dry stem biomass determinations were made. The stem biomass determinations included reproductive organs.

The spectral radiance data were collected at approximately one week intervals and were collected in direct sunlight under cloudless or partly cloudy skies between the hours of 1030-1430 EDT. Atmospheric conditions varied from very clear with low humidity, to hazy with high humidity. A solar irradiance reading was taken from a $BaSO_4$ panel prior to measuring each plot with the hand-held radimeter. Radiance data were used in the analysis because the two bands in question (0.63 − 0.69 and 0.775 − 0.825 μm) are close together in a spectral sense and atmospheric transmission characteristics are similar for both bandwidths.

The radiance data were used to form the ir/red radiance ratio and the normalized difference of (ir red)/(ir+red) after Rouse et al. (1974). All radiance data were averaged for each plot (i.e., the mean of the four observations) and the averaged values used thereafter in the statistical analysis. The data analysis correlated and regressed the red radiance, the photographic ir radiance, ir/red radiance ratio, and the normalized difference (ND) with respect to the various plant canopy variables measured (Table 1).

RESULTS AND DISCUSSION

The data analysis showed conclusively that red and photographic infrared spectral data were highly related to the green LAI and the green leaf wet and dry biomass (Table 2; Figure 1). The ir/red radiance ratio was the most highly correlated spectral variable with the green LAI and the green leaf biomass and had a linear trend with respect to these canopy variables. The ND, by comparison, was decidely nonlinear with respect to the same canopy variables (Figure 1). This

difference in nonlinearity for these red and photographic infrared variables has previously been reported for moderate to high green leaf biomass situations (Colwell et al., 1977 and Tucker et al., 1979a). The nonlinearity of the ND restricts its usefulness for high leaf biomass situations.

The discussion of our results will henceforth focus principally upon the ir/red radiance ratio because it was found to be the most useful spectral variable in this study (Table 2; Figure 1). The red and photographic infrared radiances, while useful in some regards, did not compensate for differences in the spectral irradiance at the times of data collection (i.e., they are proportional to the instantaneous incident spectral irradiance). We, therefore, will deal with the ratioed data which minimizes this variation in the spectral data.

The ir/red radiance ratio was more highly correlated with the green LAI than were the total LAI or the chlorotic LAI (Figure 2; Table 2). The same relationship(s) existed between the ir/red radiance ratio and the green leaf biomass, chlorotic leaf biomass, and total leaf biomass (wet and dry, for all three cases), respectively. The ir/red radiance ratio was not highly correlated with any of the "chlorotic" variables, the total wet biomass or total dry biomass, or the wet stem biomass. This further establishes the apparent fact that the ir/red radiance ratio can be used for accurate nondestructive estimations of projected *in situ* soybean green leaf area or biomass.

Green or photosynthetically active LAI data is one of the basic state or system level variables for primary production modeling. This dynamic biotic entity, which responds rapidly to abiotic and/or biotic influences, in effect integrates the various conditions affecting plant growth and development. The green LAI also represents the potential for primary productivity at a given point of time. It follows that the green LAI is where photosynthesis occurs and is highly related to the amount of primary productivity which results as are several other abiotic and biotic variables. Remote sensing can thus supply information which is basic to plant growth and development. These data, monitored through time and combined with other types of data (soil water, climate, etc.), offer the potential to nondestructively monitor vegetation *in situ*.

The commonly recorded agronomic variable "estimated crop cover" has been considered fundamental to crop canopy condition. We also evaluated the relationship of the spectral data to

estimated crop cover in a high leaf density situation. The red radiance was found to be highly correlated to estimated crop cover. Both of these variables were asymptotic and when 100% canopy cover was reached the red radiance also ceased to change (Figure 3a). We observed a poor relationship between estimated crop cover and the green LAI (Figure 3b). It is thus apparent that estimated crop cover is a poor choice for quantifying *in situ* canopy condition for a soybean crop.

CONCLUSIONS

1. The ir/red radiance ratio was found to be linearly and highly correlated with soybean green leaf area index, green wet leaf biomass, and green dry leaf biomass.

2. The normalized difference was exponetially related to the green leaf area index, green wet leaf biomass, and green dry leaf biomass. The asymptotic nature of this relationship prohibits the use of the normalized difference for estimating these plant canopy variables in high leaf density vegetation canopies.

3. Estimated crop cover and the red radiance individually were poor choices to evaluate crop canopy condition for high green leaf biomass situations.

4. Spectral estimation of the projected green or photosynthetically active leaf area of plant canopies by use of red and photographic infrared spectral data can provide a crucial input to primary productivity models.

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Table 1. Statistical Summary of the Sampled Plot Variables

Variable	Sample Size	Range	Mean	Standard Deviation
Green LAI	52	0.05-7.61	3.52	1.95
Green Wet Leaf Biomass (g/m²)	60	0.0-1262.4	494.77	331.70
Green Dry Leaf Biomass (g/m²)	60	0.0-292.8	121.92	81.29
Chlorotic LAI	40	0-1.22	0.26	0.29
Chlorotic Wet Leaf Biomass (g/m²)	42	0.0-182.4	37.07	42.82
Chlorotic Dry Leaf Biomass (g/m²)	40	0.0-47.0	9.0	11.45
Total LAI	40	0.0-7.95	3.98	2.01
Total Wet Leaf Biomass (g/m²)	42	0.0-1310.4	631.71	327.32
Total Dry Leaf Biomass (g/m²)	40	0.0-301.0	150.04	77.26
Wet Stem Biomass (g/m²)	42	76.80-4749.6	2379.26	938.61
Dry Stem Biomass (g/m²)	40	110.4-1070.4	566.69	287.24
Total Wet Biomass (g/m²)	60	48.0-5121.6	2337.96	1466.25
Total Dry Biomass (g/m²)	60	4.8-1209.6	553.66	360.16
Crop Cover (%)	60	5-100	78.3	32.95

Table 2. Linear Correlation Coefficients between the four Spectral variables and the Plant Canopy variables. The sample sizes are noted in parenthesis.

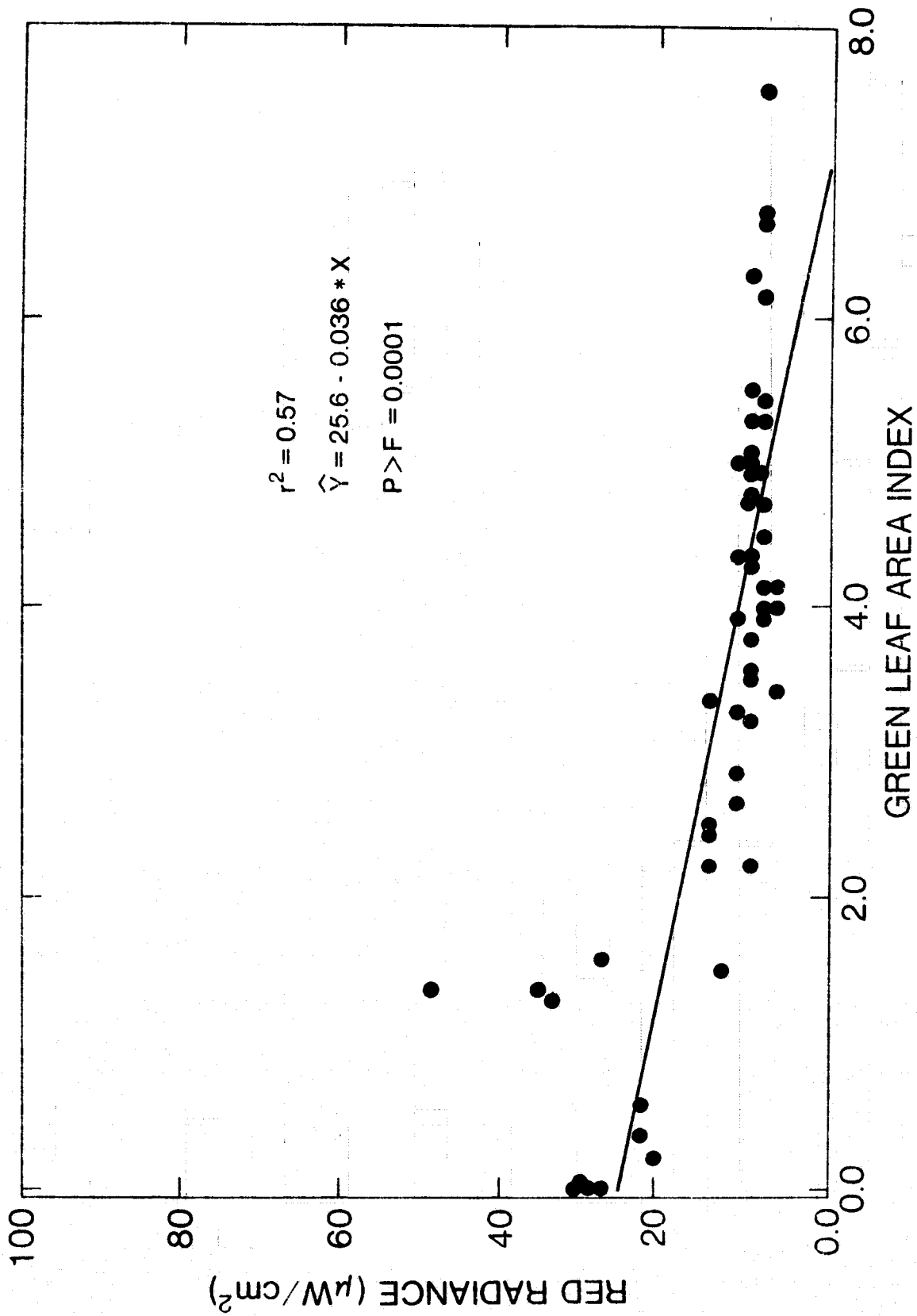| Canopy Variable	Red	IR	IR/Red	ND
Green LAI (52)	−0.75	0.75	0.92	0.81
Green Wet Leaf Biomass (60)	−0.67	0.79	0.93	0.82
Green Dry Leaf Biomass (60)	−0.68	0.75	0.92	0.83
Chlorotic LAI (40)	0.02	−0.14	−0.30	0.07
Chlorotic Wet Leaf Biomass (42)	0.01	−0.12	−0.29	0.07
Chlorotic Dry Leaf Biomass (40)	0.03	−0.20	−0.34	0.05
Total LAI (40)	−0.84	0.85	0.89	0.84
Total Wet Leaf Biomass (42)	−0.82	0.85	0.90	0.82
Total Dry Leaf Biomass (40)	−0.84	0.82	0.88	0.83
Wet Stem Biomass (60)	−0.32	0.00	0.05	0.35
Dry Stem Biomass (40)	0.55	−0.74	−0.74	−0.54
Total Wet Biomass (60)	−0.73	0.31	0.65	0.71
Total Dry Biomass (60)	−0.58	−0.14	0.26	0.36
Estimated Crop Cover (60)	−0.93	0.48	0.79	0.87

Figure Captions

Figure 1. The green leaf area index plotted against (A) red radiance, (B) photographic infrared radiance, (C) ir/red radiance ratio, and (D) the normalized difference. Note the superiority of the ir/red radiance ratio for predicting green leaf area.
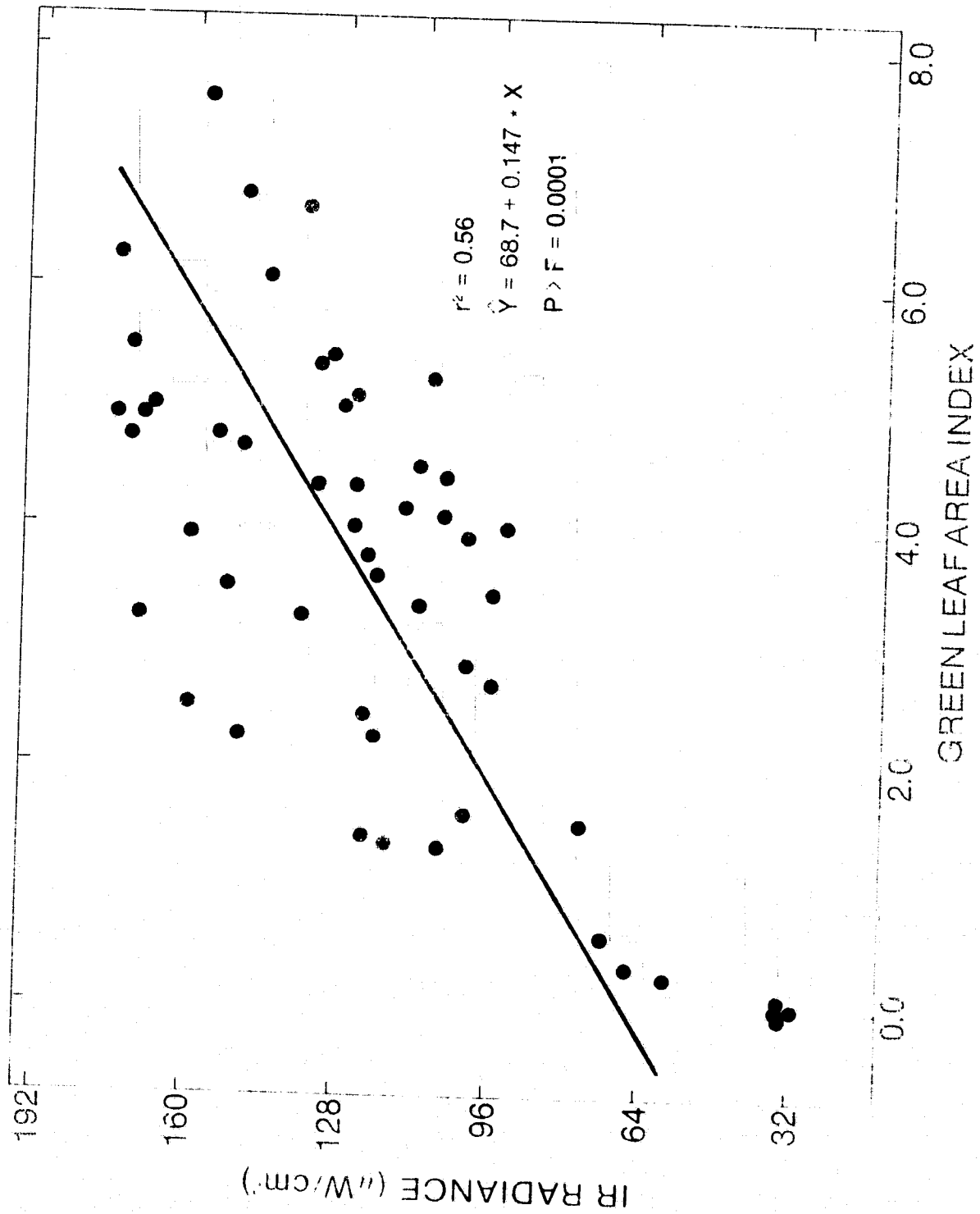
Figure 2. The ir/red radiance ratio plotted against (A) the chlorotic leaf area index, (B) the green leaf area index, and (C) the total leaf area index.

Figure 3. The relationship between estimated canopy cover and (A) the red radiance and (B) the green leaf area index. Note how the green leaf area index continues to increase while estimated canopy cover remains at 100%. Estimated canopy cover is thus a poor descriptor of plant canopy density for medium to high density plant canopies.

Figure 1. The green leaf area index plotted against (A) red radiance, (b) photographic infrared radiance, (C) ir/red radiance ratio, and (D) the normalized difference. Note the superiority of the ir/red radiance ratio for predicting green leaf area
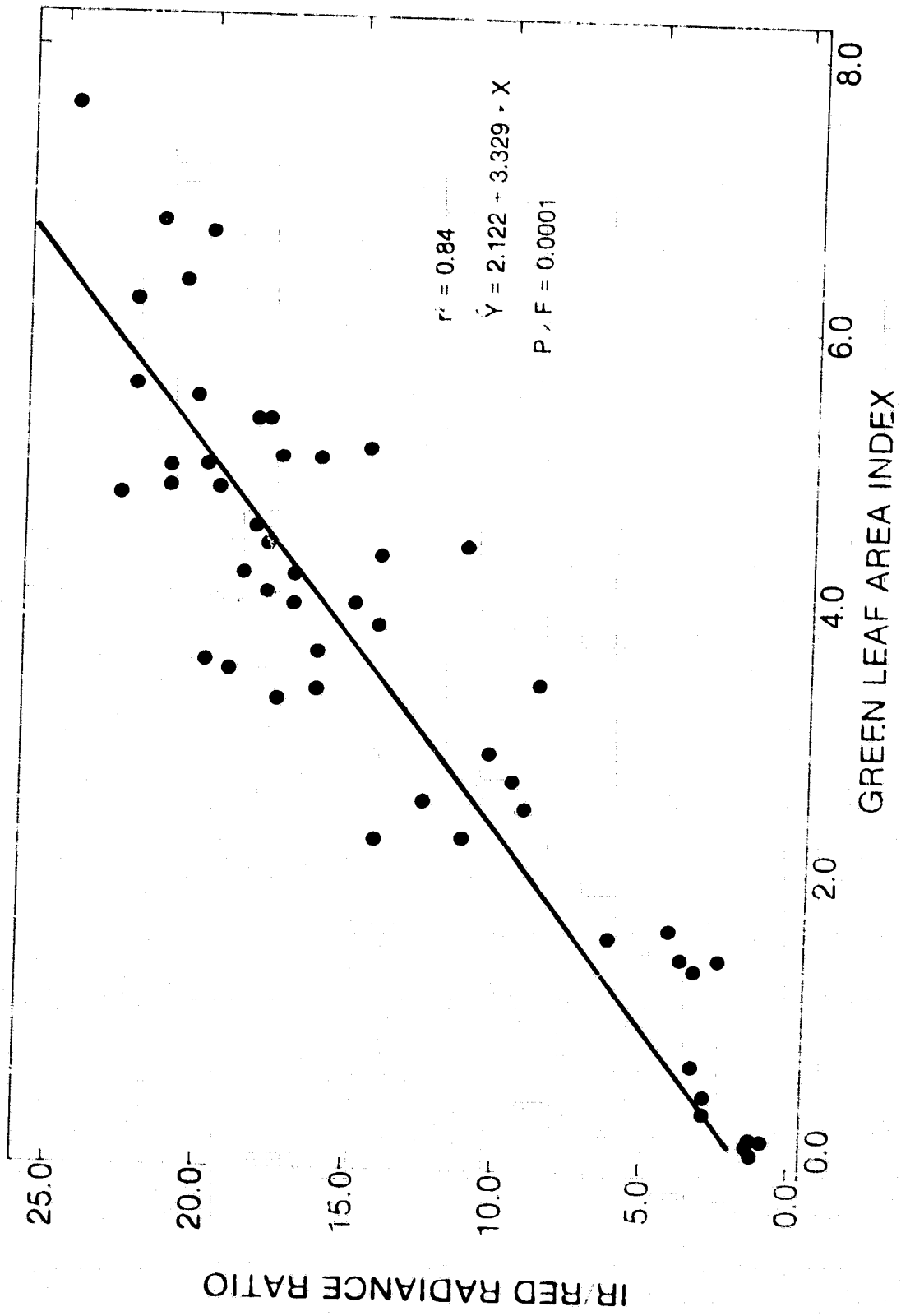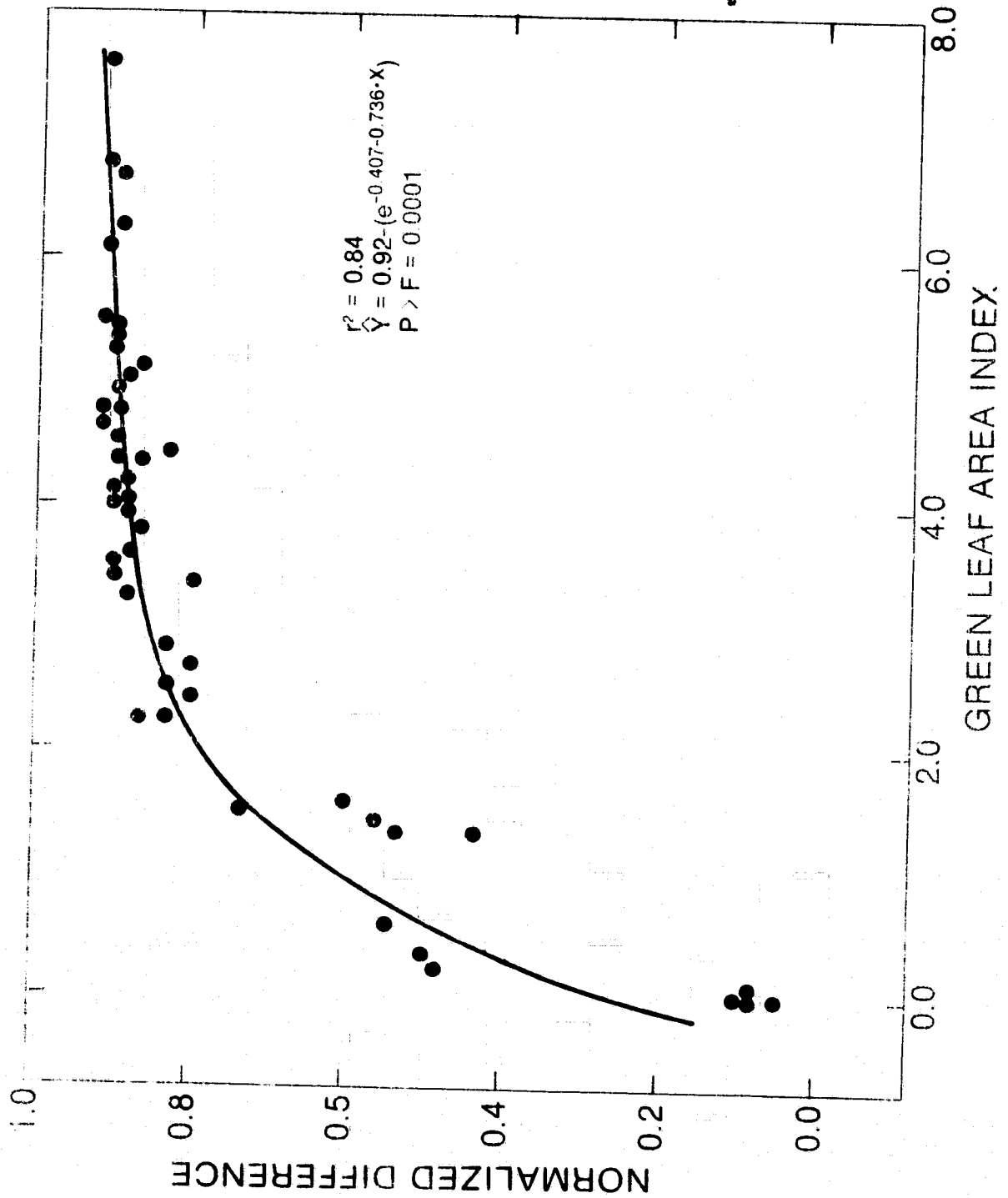
$r^2 = 0.57$

$\hat{Y} = 25.6 - 0.036 * X$

$P > F = 0.0001$

RED RADIANCE ($\mu W/cm^2$)

GREEN LEAF AREA INDEX

Figure 1B. (Continued)

$r^2 = 0.56$

$\hat{Y} = 68.7 + 0.147 * X$

$P > F = 0.0001$

GREEN LEAF AREA INDEX

IR RADIANCE ($\mu W/cm^2$)

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IR/RED RADIANCE RATIO

GREEN LEAF AREA INDEX

$r^2 = 0.84$

$\hat{Y} = 2.122 + 3.329 \cdot X$

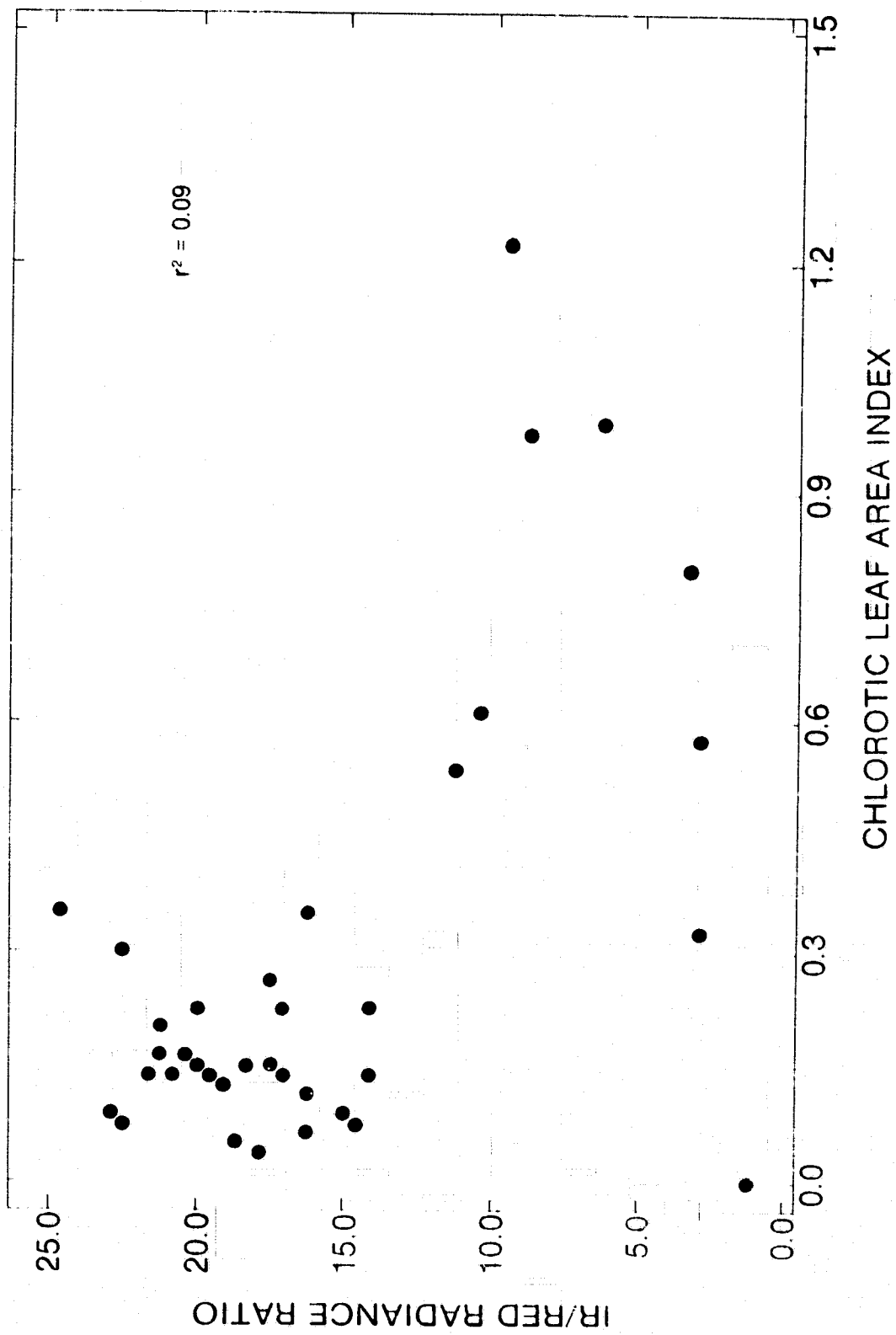$P > F = 0.0001$

Figure 1C. (Continued)

Figure 1D. (Continued)

Figure 2. The ir/red radiance ratio plotted against (A) the chlorotic leaf area index, (B) the green leaf area index, and (C) the total leaf area index
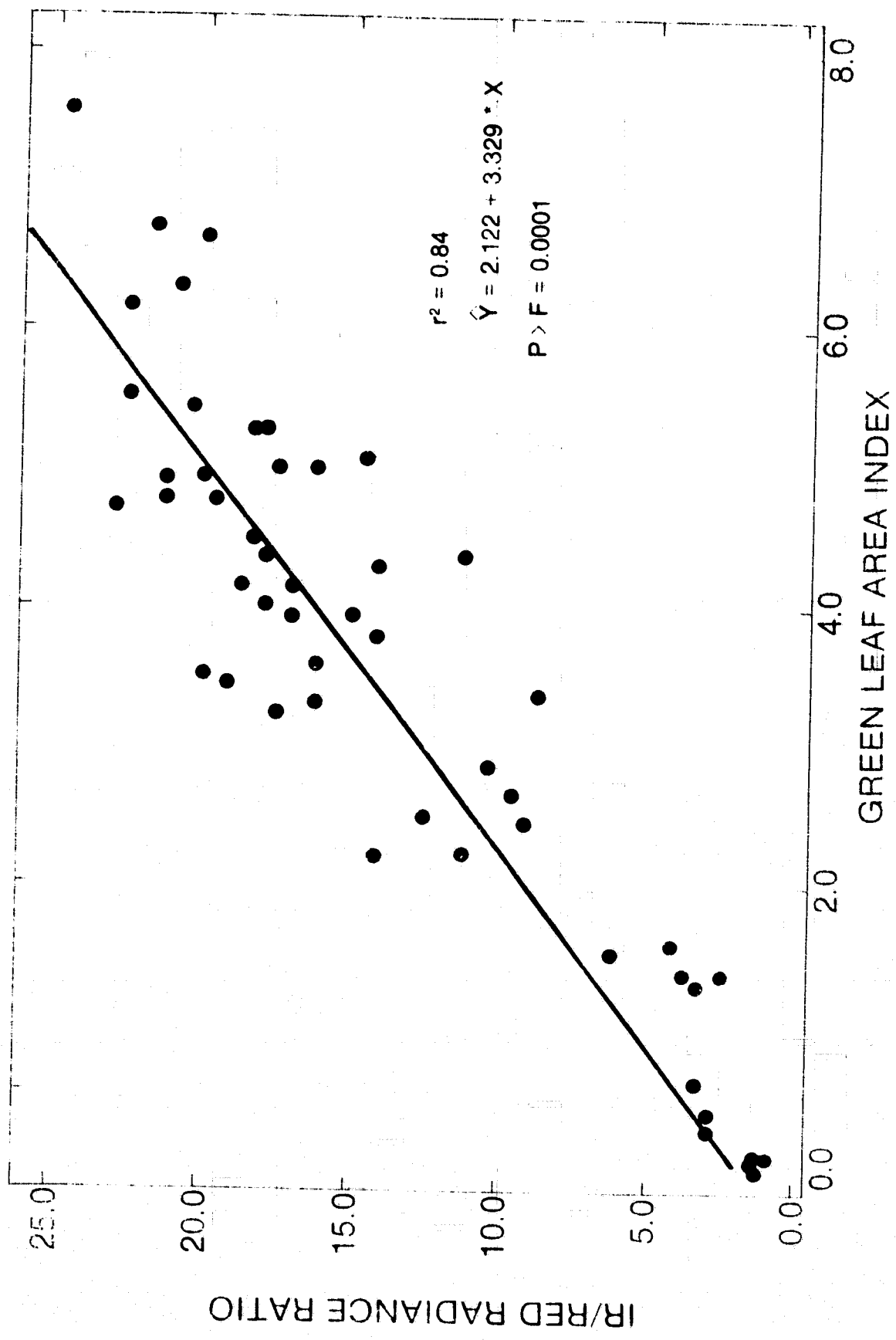
r² = 0.84

Ŷ = 2.122 + 3.329 * X

P > F = 0.0001

GREEN LEAF AREA INDEX
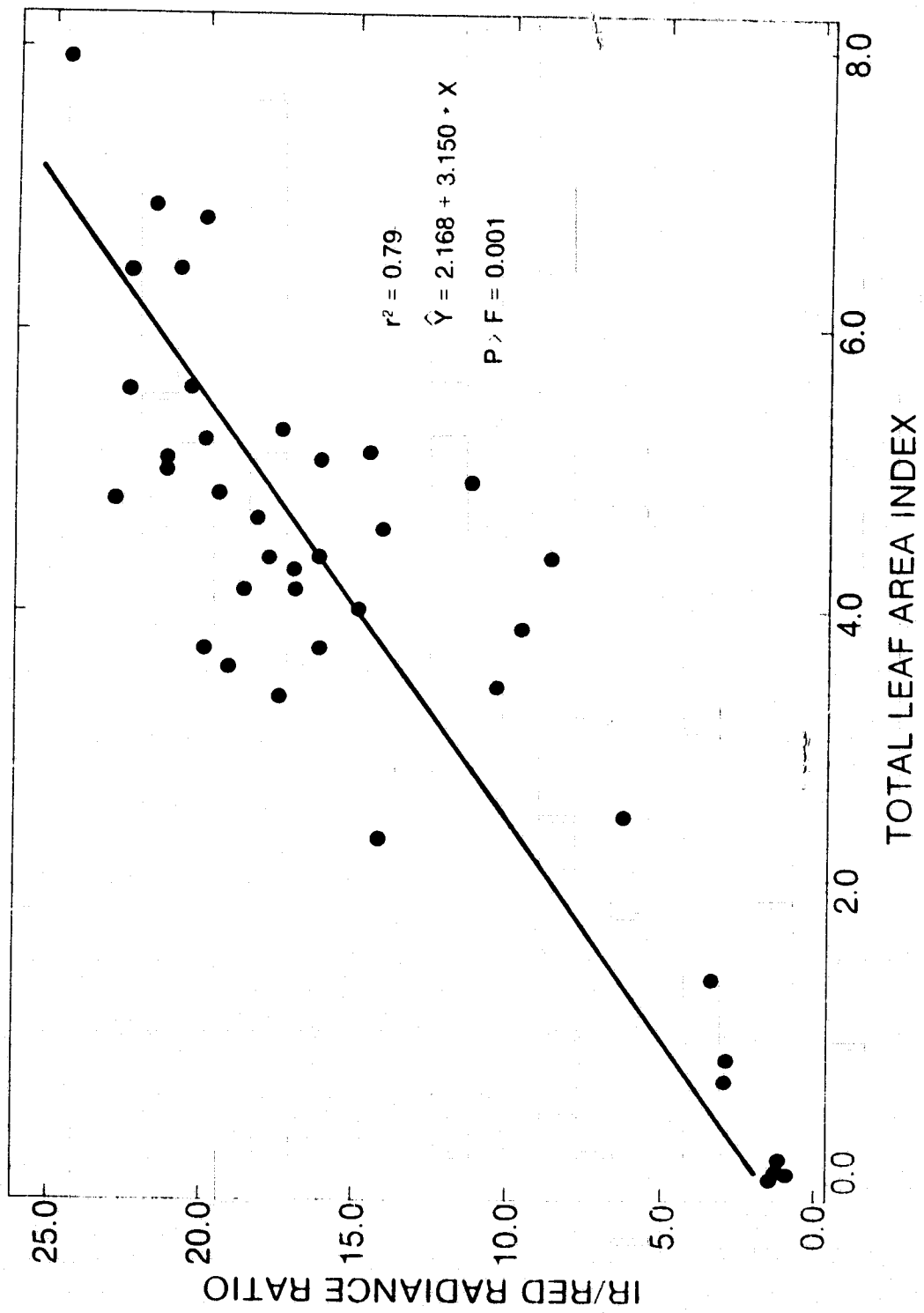
IR/RED RADIANCE RATIO
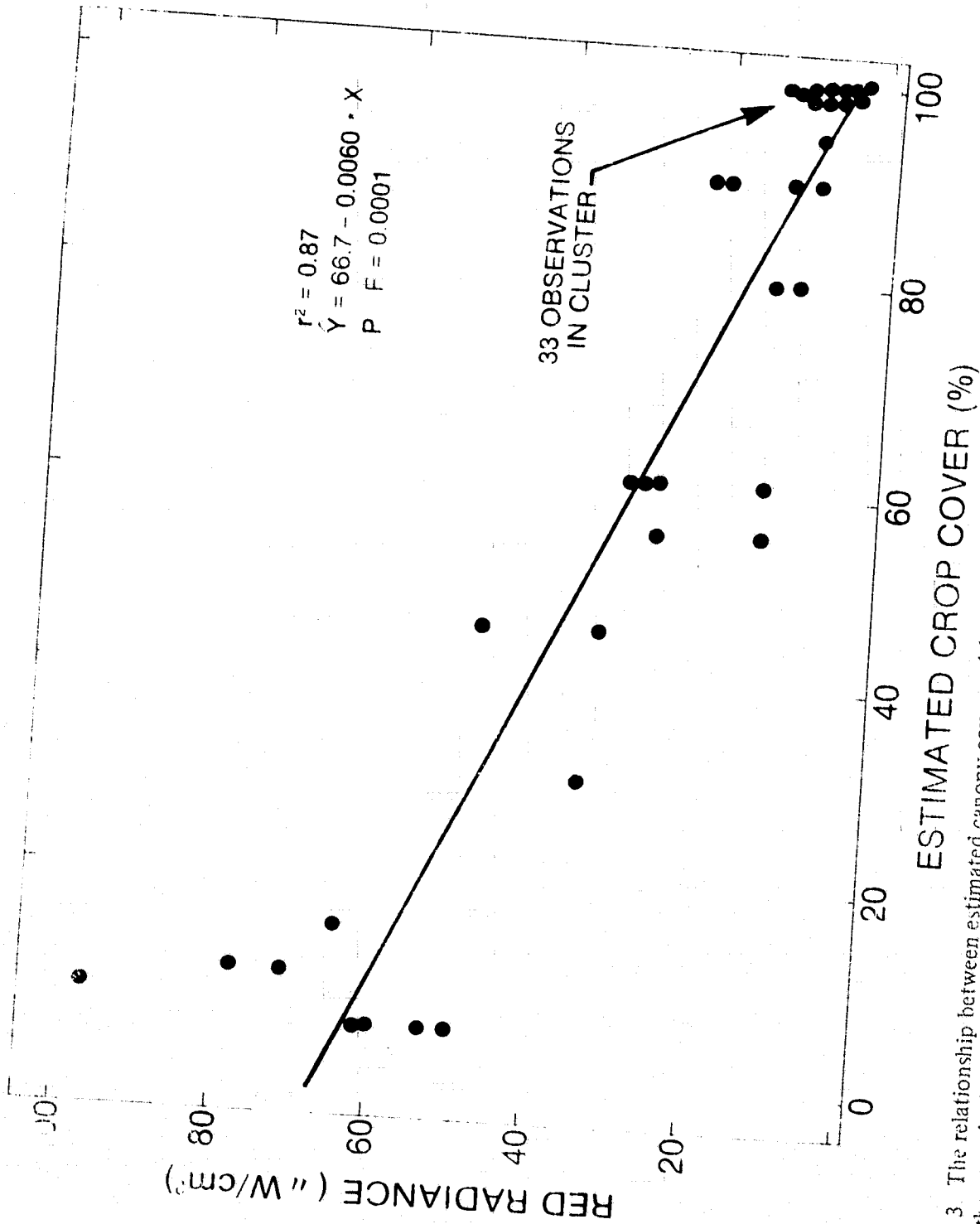
Figure 2B. (Continued)

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Figure 2C. (Continued)

Figure 3 The relationship between estimated canopy cover and (A) the red radiance and (B) the green leaf area index. Note how the green leaf area index continues to increase while estimated canopy cover remains at 100%. Estimated canopy cover is thus a poor descriptor of plant canopy density for medium to high density plant canopies.
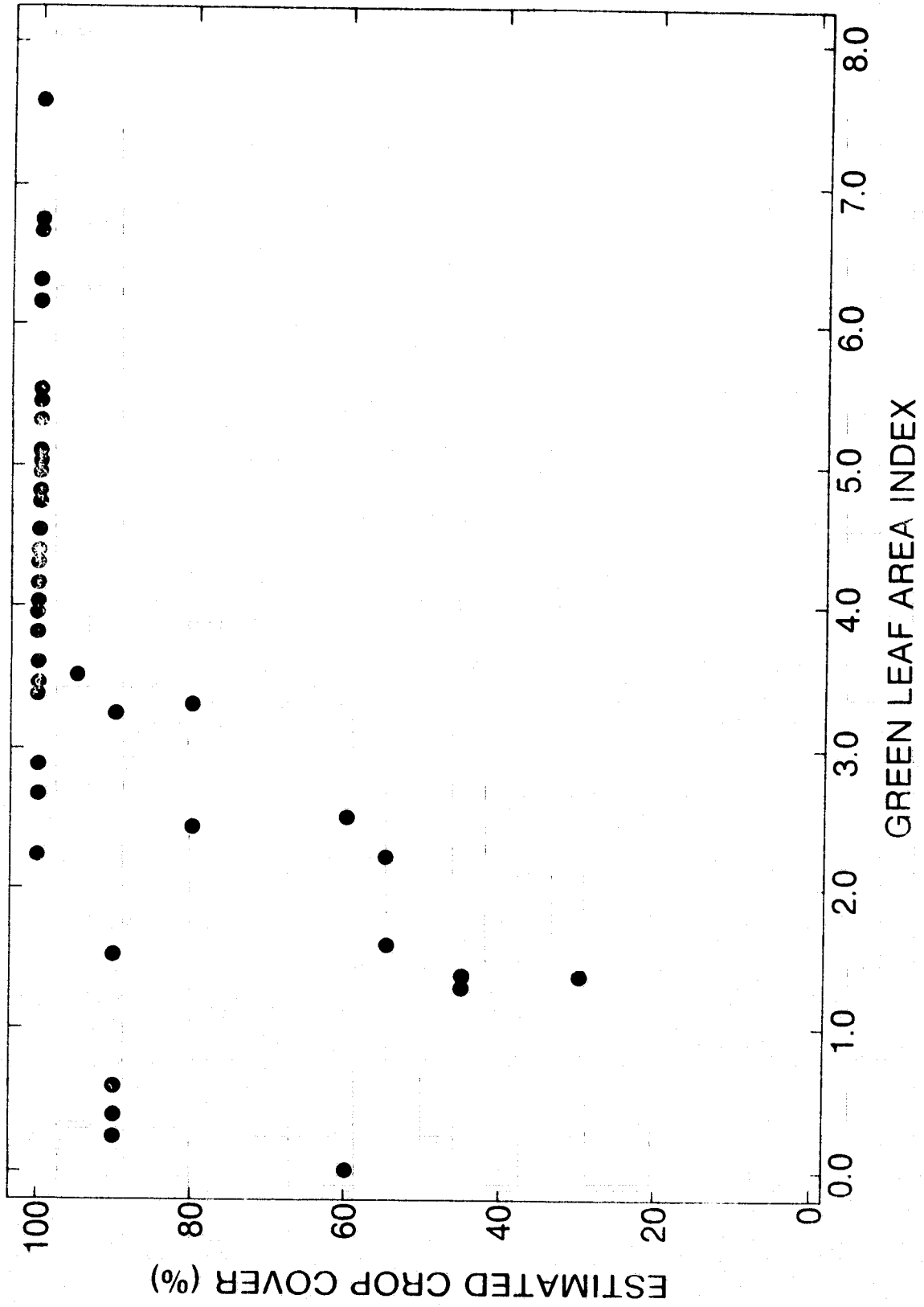
Figure 3B. (Continued)