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# Yield/Reflectance Relations in Cabbage

## The effect of nitrogen deficient and irrigation stress and, thus, yield were measurable on color infrared film exposed over a field study area

### Introduction

The values of reflectance from a crop canopy are affected in part by pigment concentrations, foliage density, plant height, plant geometry, and maturity. Environmental factors such as insects, diseases, nutrient toxicities or deficiencies, and water availability affect the canopy spectral response by modifying these plant characteristics. Because canopy spectral reflectance and crop yields often are affected by the same plant and soil factors, it may be possible to use remote sensing methods to predict yields under many conditions.

Aerial photography has been useful for detecting areas where plant growth was affected by diseases (Colwell, 1956), nutrient toxicities (Cardenas *et al.*, 1971), and insects (Hart and Myers, 1964). Thomas *et al.* (1966, 1967) found a close relationship between optical density of Kodak Ektachrome Infrared Aero Film viewed through various filters and the percent of ground covered by a cotton crop. The degree of effectiveness in expressing cotton yield as a function of film density depended on the stage of plant development and on the band-pass filter used in measuring the film color density. The most successful single filter was green (525 - 575 nm), accounting for 62 percent of the variation in lint yield measured one month later. Von Steen *et al.* (1969) found significant relationships between preharvest yield indicators and film optical density for cotton, grain sorghum, carrots, cabbage, and onions, but concluded that the precision desired may preclude a direct yield estimate.

The interaction of light with plant leaves may be specified from a knowledge of the optical parameters (absorption coefficient, scattering coefficient, and asymptotic (infinite) reflectance) (Allen and Richardson, 1968). These parameters may change as the leaves are stressed by factors such as water or nutrient deficiencies. Knowledge of the relations among the optical parameters and growth may be useful in adjusting yield estimates of crops in a stressed conditions.

We conducted this study in order to (1) measure the effects of nitrogen (N) stress on the absorption and scattering coefficients and asymptotic reflectance of light from green cabbage wrapper leaves; (2) evaluate the effects of N and water stress on reflectivity of a cabbage crop; and (3) relate observed film optical densities to cabbage yields.

### Materials and Methods

#### Greenhouse Study

Cabbage (*Brassica oleracea* var. capitata L.) plants were grown from seed in pots containing acid-washed sand. The plants were irrigated daily with Hoagland and Arnon's (1938) nutrient solution minus N for about two weeks, after which the plants were thinned to one plant/pot and the different N treatments initiated. The basic nutrient solution was adjusted with potassium nitrate so that it contained 14, 28, 84, 140, and 196 ppm N. A randomized complete block design with four replications was used. Ten weeks after seeding, two wrapper leaves were collected from each cabbage head. Wrapper leaves immediately subtended the head and were definitely cup-shaped. The samples were immediately Saran*-wrapped in order to minimize dehydration.

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ABSTRACT: *Use of ground surveys to obtain information on crop acreage and yield potential is time-consuming and costly. Since areas of low plant vigor are discernible on aerial photographs, we conducted this study to measure the effects of nitrogen (N) deficiency on the optical properties of cabbage leaves, to evaluate the effects of N and water stress on cabbage canopy reflectance, and to relate film densities to cabbage yields.*

*The growth of cabbage in sand culture under greenhouse conditions was varied by supplying N at rates of 14, 28, 84, 140, and 196 ppm to a basic nutrient solution. The absorption and scattering coefficients and asymptotic reflectance of light by the wrapper leaves at several wavelengths were calculated for each N treatment. In a field study, N and water-stressed plants were obtained by growing cabbage under five N fertilization levels and three irrigation regimes. Infrared color photographs of the cabbage were taken from a height of 600 m. Kodak Ektachrome Infrared Aero Film 8443 (EIR) was used with a Wratten 12 filter. The optical density of the film image of each plot was measured using a red (Wratten 92) band-pass filter with the microdensitometer.*

*Cabbage wrapper leaves from plants adequately supplied with N (>84 ppm) had significantly higher ($p=0.05$) absorption coefficients at the 550-and 650-nm wavelengths than leaves from plants receiving 14 and 28 ppm N. Asymptotic reflectance at 550 nm decreased significantly ($p=0.05$) as the amount of N supplied to the cabbage increased. Dry matter yields were significantly correlated with the absorption coefficients at wavelengths of 550 ($r=0.99$**) and 650 nm ($r=0.99$**).*

*Optical density of the EIR film was significantly ($p=0.01$) affected by the N and irrigation treatments. Differences in optical density were caused mainly by variation in the amount of plant material or biomass produced. Frequency of irrigation had more effect on biomass production than had the N treatments. Film optical density was significantly correlated with percent vegetation cover ($r=0.90$**) and marketable cabbage yields ($r=-0.91$**). The degree of yield decrease caused by N and water stresses was related to the ratio of transmission of light through the film in high versus low yield areas. Estimated yields were calculated as the product of the maximum yield and the ratio. This prediction method overestimated yields by 0.6 percent.*

A Beckman Model DK-2A spectrophotometer, equipped with a reflectance attachment, was used to measure diffuse reflectance and transmittance on the upper (adaxial) surface of single leaves. Data were collected over the 500- to 2500-nm wavelength interval, using MgO as a reference. Asymptotic reflectance and the absorption and scattering coefficients were calculated by the methods of Allen and Richardson (1968).

The total N concentration of the wrapper leaves was determined by a micro-Kjeldahl method. The water content of leaves was determined on a dry-weight basis.

FIELD STUDY

This investigation was carried out on cabbage plots of a N fertilizer rate-irrigation experiment. A full description of the experiment has previously been published (Thomas *et al.*, 1970). Briefly, the experiment consisted of three irrigation and five N fertilizer treatment combinations, each replicated three times. Each plot of the randomized complete block design consisted of four double-row cabbage beds occupying an area 15.2 by 3.9 m. Nitrogen, as ammonium nitrate, was applied at rates of 0, 90, 180, 270, and 360 kg/ha. In the irrigation treatments, water was applied when 40, 60, and 80 percent, respectively, of the available water in the surface 60 cm of soil had been depleted. The cabbage was planted in September and harvested January 17, and February 13 and 27, 1967.

Aerial photographs of the cabbage plots were taken on November 30 (Plate 1) and January 5 from an altitude of 600 m. A K-17 aerial camera containing 230 mm Kodak Ektachrome Infrared Aero film, type 8443 (EIR) with a Wratten 12 filter was used. Optical counts were made on EIR positive transparencies with a Joyce, Loebl recording microdensitometer, using a red (Wratten 92) band-pass filter in the light beam. The optical counts were converted to optical densities (O.D.) by the relation O.D. = [(optical counts − base reading) (wedge factor)] + step wedge density. Optical density values for each plot are means of three microdensitometer scan lines made across the cabbage rows. Optical density values were converted to percent transmission by use of the relation log % T = 2 − optical density.

The number of marketable heads and their total weight were determined by harvesting 55 $m^2$ of plot area. All cabbages were considered to be marketable except those with split and soft heads. Percent vegetative cover was determined from an aerial photograph as the ratio of the plant canopy width to the row spacing, multiplied by a hundred. Total N (Kjeldahl method) was determined for the whole plant and wrapper leaves. Variance and regression analyses were used to evaluate the effects of N and moisture stress on the spectrophotometric and photographic data.

## Results and Discussion

### GREENHOUSE STUDY

Limiting the formation of chlorophyll by inducing a N stress decreases radiation absorption and increases reflectance over the 500- to 700-nm waveband (Thomas and Oerther, 1972). The 550- and 650-nm wavelengths correspond to green reflectance and chlorophyll absorption bands, respectively. Figure 1 shows that diffused reflectance at 550 nm from the upper surface of the wrapper leaves was inversely related to their N concentration. The increase in reflectance from 18 to 30 percent was associated with a leaf color change from dark bluish-green to greenish-yellow. The relation between reflectance at 550 nm and leaf N concentration could be used to estimate quickly the N status of cabbage, as suggested by Thomas and Oerther (1972) for sweet peppers.

Nitrogen additions up to 140 ppm significantly increased dry matter yields and the N concentration of the wrapper leaves. The relation between the dry matter yields and leaf N concentration or reflectance at 550 nm is shown in Figure 2. The N-dry matter yield curve suggested that the critical N concentration was near 3 percent where plant growth began to decline. The N-reflectance curve (Figure 1) suggests that leaf reflectance was near 18 percent at the critical N concentration and changed very little at higher N concentrations. Visual symptoms of N deficiency were noted at leaf N concentrations near 2 percent. The inverse relation between dry matter production and reflectance from single leaves may indicate that N stress changed the optical properties of the leaves.

Table 1 shows the effect of N supply on the optical properties of cabbage wrapper leaves at selected wavelengths in the spectral range 500 to 2500 nm. Variance analysis indicated that varying the N supply from 14 to 198 ppm significantly affected the absorption coefficients at 550 and 650 nm and asymptotic reflectance at 550 nm.

Dry matter yields were significantly linearly correlated with the absorption coefficients at 550 (r=0.99**) and 650 (r=0.99**) nm (Figure 3). The regression coefficients suggests that a 0.1 percent decrease in the absorption coefficient de-

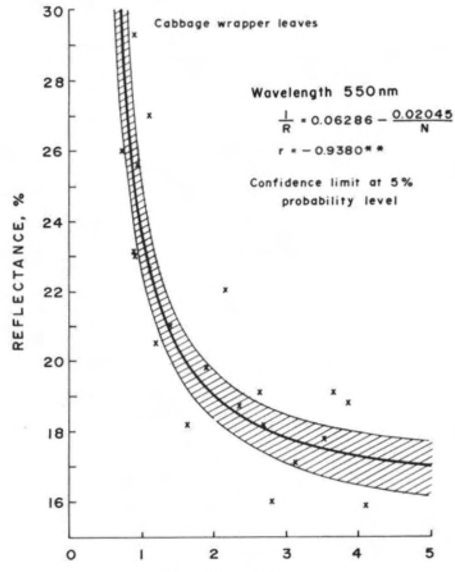


FIG. 1. Diffuse reflectance of cabbage wrapper leaves at the 550-nm wavelength as a function of their nitrogen concentration and showing the linear correlative coefficient and confidence interval at p = 0.05.

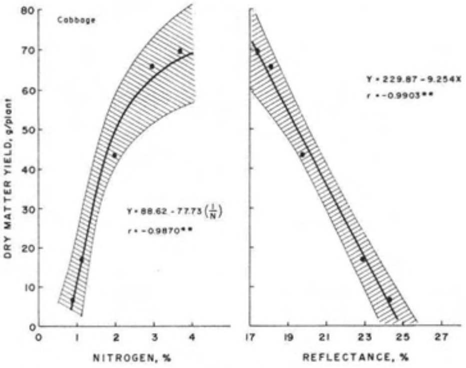


FIG. 2. Dry matter yields of cabbage as a function of the nitrogen concentration and diffused reflectance at the 550-nm wavelength of wrapper leaves and showing the linear correlation coefficients and confidence interval at p = 0.05.

creased yield by 8.9g. Chlorophyll deficiencies under low light intensities are known to limit photosynthesis (Kennedy, 1940).

The scattering coefficients were not significantly affected by N stress, suggesting similar internal structure in the N-deficient and nondeficient leaves. Myers and Allen (1968) stated that the scattering coefficient is determined by the number of hydrated cell wall-air interfaces along the mean optical path through the leaf, and Gausman and Allen (1973) found that the magnitude of the scattering coefficient was strongly associated with the development of intercellular spaces within the leaves. Apparently, wrapper leaf ontogeny was not affected by the low N supply because N moves readily from older to younger developing tissues.

Asymptotic reflectance (defined as the maximum reflectances delivered by leaves stacked sufficiently deep) simulates reflectance from a crop canopy provided there is no soil background reflectance. Asymptotic reflectance was significantly affected by the amount of N supplied to the plants only at the 550 - nanometer wavelength. Dry matter yields were inversely correlated with asymptotic reflectance (r=0.99**). The coefficient in the regression equation $Y = 325.1 - 13.0X$, where $Y$ is the percentage of maximum yields and $X$ asymptotic reflectance at 550 nm, suggests that a 1 percent increase in reflectance was associated with a

TABLE 1. EFFECT OF NITROGEN SUPPLY ON OPTICAL PARAMETERS OF CABBAGE WRAPPER LEAVES.[1]

| Wavelength | Nitrogen Supply (ppm) 14 | 28 | 84 | 140 | 196 |
|---|---|---|---|---|---|
| nm | | | Absorption Coefficient | | |
| 550 | 1.528 a[2] | 1.674 a | 2.044 b | 2.183 b | 2.223 b |
| 650 | 2.918 a | 2.973 a | 3.384 b | 3.537 b | 3.574 b |
| 850 | 0.126 a | 0.130 a | 0.137 a | 0.127 a | 0.133 a |
| 1450 | 3.100 a | 3.111 a | 3.126 a | 2.791 a | 2.814 a |
| 1650 | 1.015 a | 0.960 a | 1.070 a | 0.882 a | 0.913 a |
| 1950 | 5.684 a | 5.530 a | 5.472 a | 5.347 a | 5.264 a |
| 2200 | 2.338 a | 2.349 a | 2.368 a | 2.090 a | 2.106 a |
| | | | Scattering Coefficient | | |
| 550 | 1.311 a | 1.308 a | 1.247 a | 1.182 a | 1.133 a |
| 650 | 1.175 a | 1.150 a | 1.160 a | 1.209 a | 1.163 a |
| 850 | 1.552 a | 1.562 a | 1.580 a | 1.462 a | 1.438 a |
| 1450 | 0.640 a | 0.652 a | 0.704 a | 0.660 a | 0.649 a |
| 1650 | 0.890 a | 0.863 a | 0.951 a | 0.834 a | 0.854 a |
| 1950 | 0.632 a | 0.550 a | 0.597 a | 0.641 a | 0.603 a |
| 2200 | 0.567 a | 0.547 a | 0.570 a | 0.530 a | 0.523 a |
| | | | % Asymptotic Reflectance | | |
| 550 | 24.5 a | 23.0 ab | 19.7 bc | 18.1 c | 17.4 c |
| 650 | 14.5 a | 13.8 a | 13.0 a | 12.9 a | 12.4 a |
| 850 | 67.0 a | 66.6 a | 65.9 a | 66.0 a | 65.4 a |
| 1450 | 8.7 a | 8.7 a | 9.1 a | 9.6 a | 9.5 a |
| 1650 | 24.9 a | 25.2 a | 25.0 a | 26.1 a | 25.9 a |
| 1950 | 5.0 a | 4.5 a | 4.9 a | 5.4 a | 5.2 a |
| 2200 | 9.9 a | 9.6 a | 9.8 a | 10.2 a | 10.1 a |

[1] Values in body of table are means of four replications.
[2] Line means followed by a common letter are not significantly different at the 5% probability level according to Duncan's multiple range test.

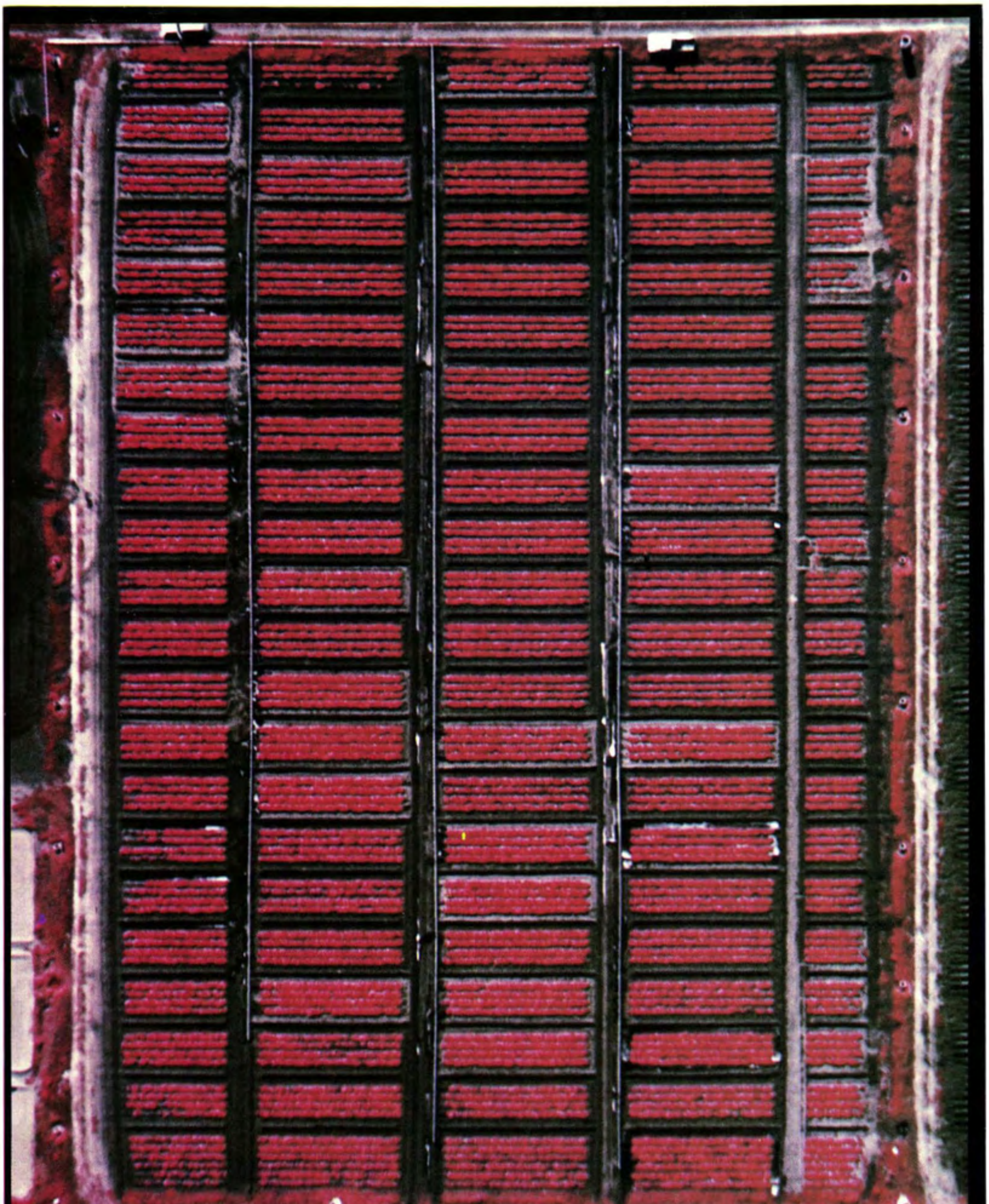

PLATE 1. A positive print of an infrared transparency showing the cabbage plots. Each plot is surrounded by a soil levee for irrigation purposes.

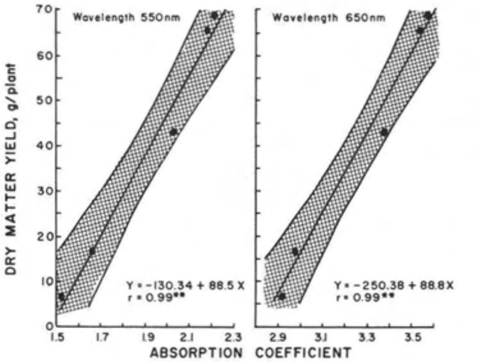


FIG. 3. Dry matter yields of cabbage as a function of the absorption coefficients at 550- and 650-nm wavelengths of wrapper leaves and showing the linear correlation coefficients and confidence interval at p = 0.05.

13 percent decrease in dry matter yields and single leaf reflectance (Figure 3). Maximum dry matter yields were 69.93g/plant.

#### FIELD STUDY

Variance analysis indicated that N fertilization (Table 2) and frequency of irrigation (Table 3) significantly affected the amount of biomass produced, percentage of ground covered by vegetation, and hence the optical density of a positive transparency of EIR film. Nitrogen fertilization also significantly increased the N content of the cabbage.

Differences in optical density were caused mainly by variation in the amount of biomass associated with the N and irrigation treatments. Figure 4 shows a significant linear relation (r=−0.90**) between optical density and percentage of vegetative cover. However, the data points suggest that optical density was weakly correlated with vegetative cover under low moisture regimes. The decrease in biomass caused by N and water stresses decreased the amount of near-infrared reflectance from the crop canopy and increased soil reflectance. Nitrogen stress also resulted in lighter green plants than those adequately fertilized with N. A decrease in chlorophyll concentration induced by the N deficiency would increase asymptotic reflectance in the spectral range 500 to 700 nm.

The relation of biomass (A) and leaf N concentration (B) to the optical density of EIR film is illustrated by the diagram in Figure 5, where U is the total sum of squares due to regression and the areas of the circle A and B represent that part of the total sum of squares due to these factors. The two parameters, leaf N and total amount of biomass, accounted for 82 percent ($R^2 \times 100$) of the variability in film density. The interaction between biomass and leaf N concentration is shown by the overlapping shaded area. The independent effects of biomass and leaf N concentration on optical density are shown by the clear areas within the circles. Multiple regression analysis showed that the independent effects of biomass (A after B), and N concentration of the leaves (B after A) and the N-biomass (AB) interaction accounted for 37.7, 1.6, and 42.7 percent, respectively, of the variation in optical density. Standard partial regression coefficients ($b'y_{1.2} = 0.761$ and $b'y_{2.1} = 0.206$) suggested that the amount of biomass had 3.7 times more effect on film optical density than leaf N concentration. Stanhill *et al.* (1973) found that N fertilization changed reflectance from wheat plots by affecting the leaf area index rather than through changes in the optical properties of the leaves.

Nitrogen and irrigation treatments significantly affected two yield components—head size and number of marketable heads. The relative contribution of these yield indicators to variation in optical density of EIR film was evaluated by multiple regression techniques. The coefficient of determination ($R^2 \times 100$) indicated that head size and

TABLE 2. EFFECT OF NITROGEN FERTILIZATION ON TOTAL NITROGEN CONTENT, TOTAL BIOMASS, VEGETATIVE COVER, AND OPTICAL DENSITY OF EKTACHROME INFRARED AERO FILM TYPE 8443.[1]

| Nitrogen applied | Total biomass | Nitrogen content | Vegetation cover | Optical density |
|---|---|---|---|---|
| kg/ha | Metric tons/ha | % | % | |
| 0 | 65.7 a[2] | 2.98 a | 65.8 a | 1.090 a |
| 90 | 76.0 b | 3.33 b | 68.0 b | 1.031 b |
| 180 | 81.8 c | 3.49 c | 68.3 b | 1.006 bc |
| 270 | 91.5 d | 3.60 d | 72.7 c | 0.969 c |
| 360 | 84.5 c | 3.68 d | 69.5 bc | 1.013 bc |

[1] Values in body of table are means of four replications of three irrigations treatments.
[2] Column means followed by a common letter are not significantly different at the 5% probability level according to Duncan's multiple range test.

TABLE 3. EFFECT OF IRRIGATION REGIME ON TOTAL NITROGEN CONTENT, TOTAL BIOMASS, VEGETATIVE COVER, AND OPTICAL DENSITY OF EKTACHROME INFRARED AERO FILM TYPE 8443.[1]

| Irrigation regime[2] | Total biomass | Nitrogen content | Vegetative cover | Optical density |
|---|---|---|---|---|
| % | Metric tons/ha | % | % | |
| 40 | 91.9 a[3] | 3.42 a | 72.6 a | 0.954 a |
| 60 | 83.6 b | 3.45 a | 68.3 b | 1.046 b |
| 80 | 63.9 c | 3.44 a | 66.2 c | 1.070 c |

[1] Values in body of table are means of four replications and five nitrogen treatments.
[2] Allowable depletion of available water in top 60 cm of soil profile.
[3] Column means followed by a common letter are not significantly different at the 5% probability level according to Duncan's multiple range test.

number of marketable heads accounted for 82 percent of the variation in optical density. Standard partial regression coefficients ($b'y_{1.2} = 0.72$ and $b'y_{2.1} = 15.25$) suggested that number of heads had 21 times more effect on optical density than did head size.

Marketable cabbage yields ($Y$ metric ton/ha) were significantly correlated ($r=-0.91^{**}$) with optical density ($X$) of EIR film when measured with a red filter in the densitometer's light path. The regression model describing this relationship, $Y = 159.7 - 113.8X$, could be used to predict yields from optical density measurements. However, because of variation in general film density of photographs taken at various times and differences associated with film exposure and processing, yield forecast based on this regression model could not be extended to fields photographed at other times.

A prediction method based on information contained in one photograph and potential yield would be more reliable. As the relationships among optical density, percent vegetation cover, and biomass were strongly linear, we assumed that yields decreased as does the ratio of transmission of light through film in high versus low yield areas. Table 4 shows the actual and estimated yields of cabbage grown under different N and irrigation treatments. Estimated yields ($Y_E$) were calculated as the product of potential yield ($Y_P$) and transmission ratio. Potential yield was taken as the mean maximum yield of marketable cabbage obtained in the study (Thomas *et al.,* 1970). In practice, a field would be divided into smaller areas which differ in percent vegetation cover, and the potential yield in an area having the highest percentage vegetation cover would be determined from head counts and expected mean head weights at harvest. Overestimates of yield ranged from 1.7 to 8.0 percent, while underestimates ranged from 0.5 to 13.2 percent. However, on a field basis, yields were overestimated by 0.6 percent.

The errors of estimation may be due to variation in background reflectance associated with bare soil and shadow areas between cabbage rows and wet and dry soil surfaces. Richardson *et al.* (1975) found that bare soil

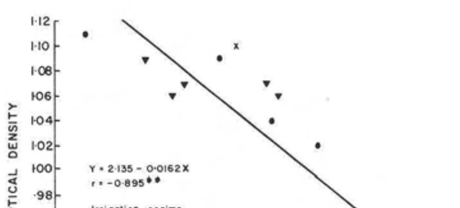


FIG. 4. Optical density of Ektachrome Infrared Aero film, type 8443, in relation to the percentage of ground covered by vegetation at three irrigation regimes.

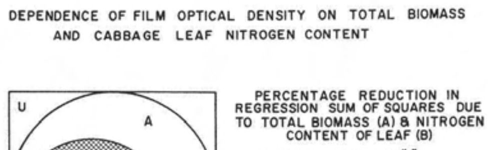


FIG. 5. Diagram illustrating the contribution of the biomass (A) and leaf nitrogen concentration (B) to the total sum of squares of regression due to optical density (U) of EIR film.

TABLE 4. ESTIMATION OF CABBAGE YIELDS FROM PERCENT TRANSMISSION OF EKTACHROME INFRARED AERO FILM TYPE 8443.

| Nitrogen applied | Irrigation regime[1] | Transmission $T_{obs}$ | $\frac{T_{obs}}{T_{max}}$[2] | Yields Actual | Yields Estimated[3] | Estimation error |
|---|---|---|---|---|---|---|
| kg/ha | % | % | | Metric tons/ha | | % |
| 0 | 40 | 7.94 | 0.616 | 34.9 | 37.7 | 8.0 |
| 90 | 40 | 11.48 | 0.891 | 51.5 | 54.5 | 5.8 |
| 180 | 40 | 12.02 | 0.933 | 53.1 | 57.1 | 7.5 |
| 270 | 40 | 12.88 | 1.000 | 61.2 | 61.2 | 0.0 |
| 360 | 40 | 12.02 | 0.933 | 55.1 | 57.1 | 3.6 |
| 0 | 60 | 7.76 | 0.602 | 37.9 | 36.8 | −2.9 |
| 90 | 60 | 8.13 | 0.613 | 43.2 | 37.5 | −13.2 |
| 180 | 60 | 9.12 | 0.708 | 43.5 | 43.3 | −0.5 |
| 270 | 60 | 11.22 | 0.871 | 52.4 | 53.3 | 1.7 |
| 360 | 60 | 9.55 | 0.741 | 48.4 | 45.3 | −6.4 |
| | | Mean | | 48.1 | 48.4 | 0.6 |

[1] Allowable depletion of available water in top 60 cm of soil profile.
[2] $T_{max}$ = 12.88 Potential yield = 61.2 metric tons/ha.
[3] $Y_E = Y_P X \frac{T_{obs}}{T_{max}}$

and shadow areas between cotton rows reduced vegetative reflectance from cotton. Colwell (1974) reported that reflectance at 650 nm from a grass canopy was 9.0 and 3.2 percent, respectively, on light- and dark-toned soil backgrounds with a 37 percent vegetation cover. Reflectance from vegetation other than cabbage would cause an overestimation of yields.

## CONCLUSION

Results of this study showed that in the visible spectral region N stress decreased the absorptive coefficent and increased asymptotic reflectance of cabbage leaves. The scattering coefficient was not affected by N deficiency. Information obtainable from aerial photographs was useful for predicting cabbage yields. Areas in a field, where cabbage growth was affected by N and water stresses, were detectable as changes in film optical density. Nitrogen and water stresses changed reflectance from the cabbage plots by affecting the amount of biomass produced. Marketable cabbage yields were significantly related with the optical density of EIR film. The ratio of transmission of light through EIR film of stressed versus unstressed vegetative areas decreased as cabbage yields decreased.

## ACKNOWLEDGMENT

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