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FINAL TECHNICAL REPORT

RELATING THEMATIC MAPPER BANDS  
TM3, TM4, and TM5  
to  
AGRONOMIC VARIABLES FOR CORN, COTTON, SUGARBEET,  
SOYBEAN, SORGHUM, SUNFLOWER AND TOBACCO

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VARIABLES FOR CORN, COTTON, SUGAR-  
BEET, SOYBEAN, SORGHUM, SUNFLOWER,  
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## TABLES

1. Planting Dates of Seven Crops

2. Plant Height of Seven Crops

Previous research in the BARC-GSFC Cooperative Program had validated the hand-held radiometer technique, developed a spectral crop calendar, related these data to corn and soybean biomass, percent cover, plant height, chlorosis and related these data to alfalfa drought stress. However, all of these works were conducted with two-band radiometer having red band ( $.065 - .070 \mu\text{m}$ ) and a photographic infrared band ( $0.775 - 0.825 \mu\text{m}$ ). A three-band hand-held radiometer corresponding to thematic mapper band TM3, TM4, and TM5 is used in this study to collect in situ field data from various crops. This will not only provide hand-held in situ data from TM5 ( $1.55 - 1.75 \mu\text{m}$ ), but will also provide in situ evaluation of TM3 ( $0.63 - 0.69 \mu\text{m}$ ) and TM4 ( $0.76 - 0.90 \mu\text{m}$ ) as well.

The objectives of this study are: (1) to compare spectral reflectance values and their transformed parameters among crops for the entire growing season, growing under the same environmental conditions. This objective is intended to repeat the same kind of field investigation done last year with only a one-crop change in order to see the result from different years; (2) To find out the correlation between spectral reflectance values, especially near infrared (TM5) and tissue water content in soybean under controlled water conditions.

#### MATERIALS AND METHODS

This research was conducted at USDA, Beltsville Agricultural Research Center (BARC), Beltsville, Maryland, in cooperation with the on-going BARC-GSFC agricultural remote sensing research program. The crops included in this investigation were corn, cotton, soybean, sugarbeet, sorghum, sunflower and tobacco.

The three wavelength bands selected for this study were  $0.63 - 0.69 \mu\text{m}$  (TM3),  $0.76 - 0.90 \mu\text{m}$  (TM4), and  $1.55 - 1.75 \mu\text{m}$  (TM5).

The 0.63 - 0.69  $\mu$  m band is highly absorbed by plant pigment. Thus, it is poorly reflected. This spectrum region shows an inverse relationship between the amount of living vegetation and the resulting spectral radiance. The 0.76 - 0.90  $\mu$  m band is essentially unabsorbed by foliage; hence, it shows a direct relationship between the amount of living vegetation and the resulting spectral radiance. The 1.55 - 1.75  $\mu$  m band is primarily absorbed by tissue water.

Fourteen (14) 6 x 6 meter square plots (two plots for each crop) were used to obtain reflectance values. Crops were either planted or transplanted between May 14 and June 18, 1981 (Table 1). All crops were at the beginning stages of their development when measurements were started. Spectral measurements coupled with plant height, leaf area and percent coverage have been made between 5 and 12 days, depending on the weather condition. All spectral measurements were made between 10:00 a.m. and 3:00 p.m. under clear skies. A total of 9 readings were taken from each plot to cover the entire canopy. These were averaged to account for variability. A solar intensity calibration reading was taken from a BASO<sub>4</sub> panel for reference. The averaged red (0.63 - 0.69  $\mu$  m), photographic infrared (0.76 - 0.90  $\mu$  m), and near infrared (1.55 - 1.75  $\mu$  m) were transformed into the PIR/RED and P<sup>IR</sup>/NIR ratios.

Flats of 30" x 30" x 5" size were used to grow soybeans for short-term water stress study. When plants reached full canopy, the following watering schedule was applied: <sup>1</sup>water daily, <sup>2</sup>water every 2 days, <sup>3</sup>water every four days, <sup>4</sup>water every eight days. Daily plant height, plant water content, leaf area, and spectral radiance measurements were made after the starting of water treatment.

| <u>Crops</u> | <u>Planting Dates</u>       |
|--------------|-----------------------------|
| Corn         | June 9, 1981                |
| Cotton       | June 8, 1981 (Transplanted) |
| Sorghum      | May 21, 1981                |
| Soybean      | June 9, 1981                |
| Sugarbeet    | May 14, 1981                |
| Sunflower    | June 18, 1981               |
| Tobacco      | June 8, 1981 (Transplanted) |

Table 1: Planting Date of Seven Crops

## RESULTS AND DISCUSSION

Results show that photographic infrared reflectance values increased as the green biomass increased. About 40 days after germination, these values reached maximum and dropped quickly after this date in corn, sorghum, tobacco and sugarbeet (Figures 1 and 2). In cotton, soybean and sunflower, the PIR values increased gradually and peaked after approximately 70 days of germination (Figure 3). This indicated that cotton and soybean have longer periods of greenness and this phenomena had clearly demonstrated in the field. The PIR radiance patterns for corn and sorghum proved extremely similar except that sorghum has a higher value than corn since the former has more and thicker leaf than the latter. Higher PIR radiance values found in the late tobacco growing season was caused by the green suckers which continued to grow.

As to the red reflectance values, it decreased with time for all crops. The only difference was that the values for cotton and soybean decreased at a slower rate (Figure 4, 5, and 6). Similar radiance patterns have been found in near infrared for all crops with higher values at the early stages of development but tipping off gradually and slightly for the rest of the growing season (Figures 10, 11, and 12).

PIR/Red radiance ratios, a good transformation parameter to indicate plant growth and development, also showed slightly different patterns among crops. In corn and sorghum, the values peaked about 40 days after germination and stayed on peak for one week, then gradually decreased (Figure 7). For tobacco and sugarbeet, the ratio values reached maximum also about 40 days after germination; however, it stayed on maximum for about 30 days, much longer than corn and sorghum (Figure 8). The ratio values on soybean and cotton reached peak about 70 days after germination and stayed on peak for about 30 days.

From all radiances and their transformation parameter values observed, the seven crops tested may arbitrarily be divided into three radiance pattern groups based on their morphology and duration of green biomass. One group consists of sorghum and corn, monocotyledons with similar leaf anatomical structure and vein arrangement. The second group includes tobacco and sugarbeet, dicotyledon and broad-leaved with large blades. The third group includes cotton, soybean, and sunflower, dicotyledon and broad-leaved, but leaf sizes are smaller than the second group. This confirmed the same results found last year.

In the short term water stress experiment, the results show that infrared reflectance values decreased as water content in plant tissue decreased (Figure 13). On the other hand, the red and NIR values increased as the tissue water decreased. As to the PIR/Red and PIR/NIR ratio values, the opposite is true. When the spectral radiance values were compared with leaf area in different water levels, it was found that reflectance values of PIR, PIR/Red ratio, PIR/NIR ratio have positive relationship with leaf area whereas the reflectance value of Red and NIR expressed a negative relationship with leaf area. This demonstrated that leaf area was directly related to water amount in plant tissue. All five radiance parameters mentioned above are good indicators for monitoring both leaf area and water content in this investigation. However, one should be reminded that this experiment was performed under small-scale conditions and water could be easily controlled. A large scale field investigation with controlled water levels should be performed in order to find out the relationship between plant water content and reflectance patterns under real agricultural ecosystems.

## CONCLUSIONS

1. The three radiances and their related transformation parameters could be used as indicators to help to differentiate crop types based on their morphology, leaf size, and leaf arrangement.
2. The reflectance radiance values could also be used to show the duration of green biomass for crops in growing season.
3. Among five parameters used, the values of red, PIR and PIR/Red ratio proved to be more useful to demonstrate the crop growth pattern.
4. All five parameters proved to be good indicators to monitor plant tissue water in this investigation.
5. The near infrared radiance values shown in the crop growing season is somewhat parallel with the red radiance values.
6. Three-band hand-held radiometer was demonstrated once again to be a useful instrument to monitor the growth and development of crops.

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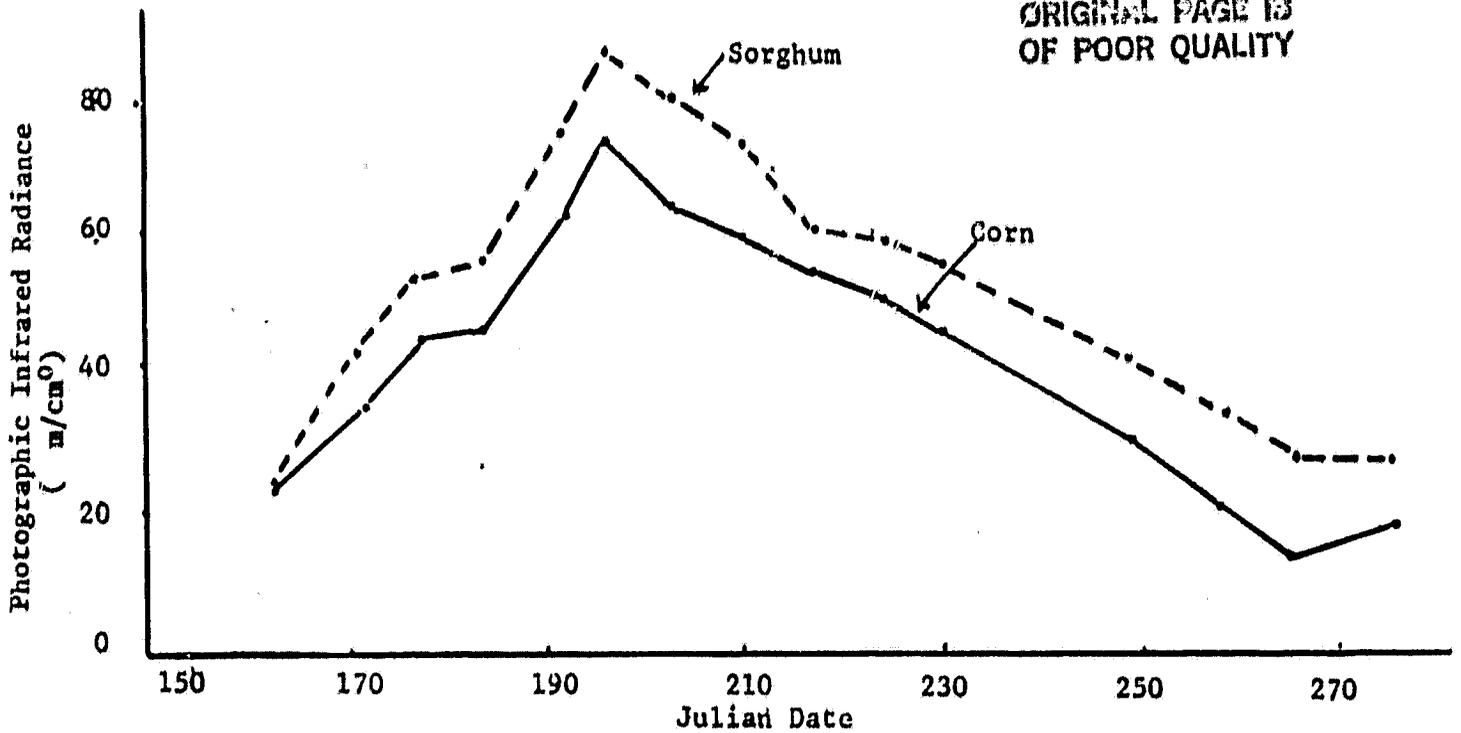


Figure 1: Photographic Infrared radiance plotted against Julian date for dorn and sorghum.

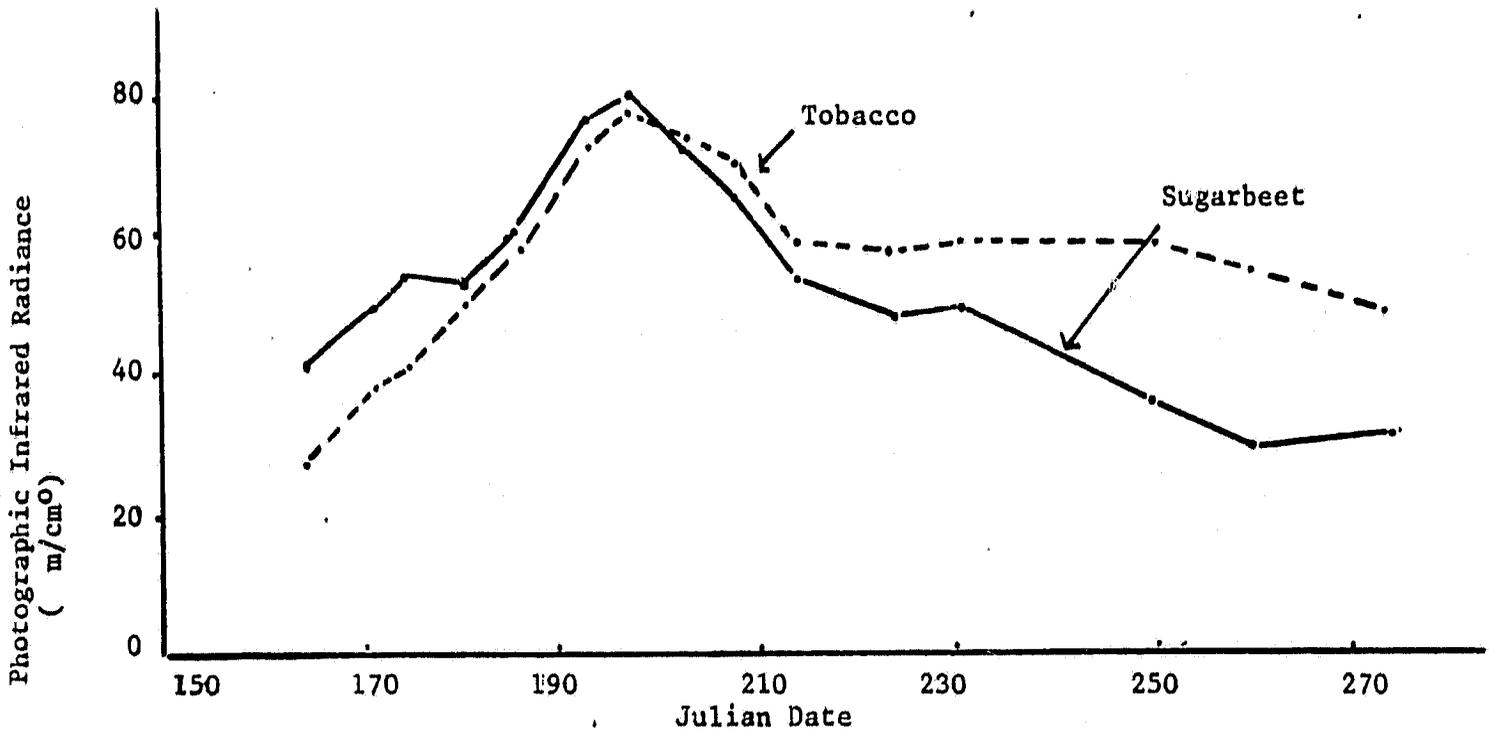


Figure 2: Photographic infrared radiance plotted against Julian date for tobacco and sugarbeet

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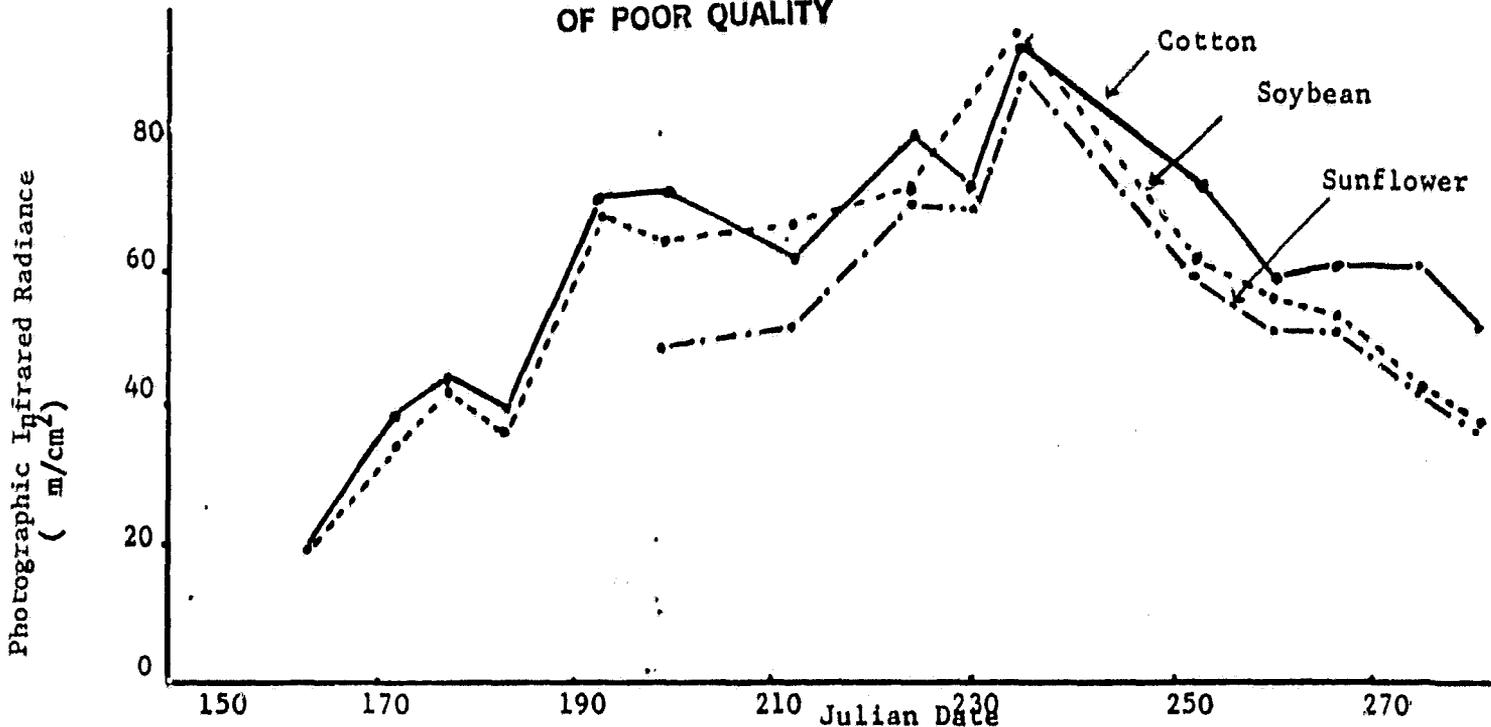


Figure 3. Photographic infrared radiance plotted against Julian date for cotton, soybean and sunflower

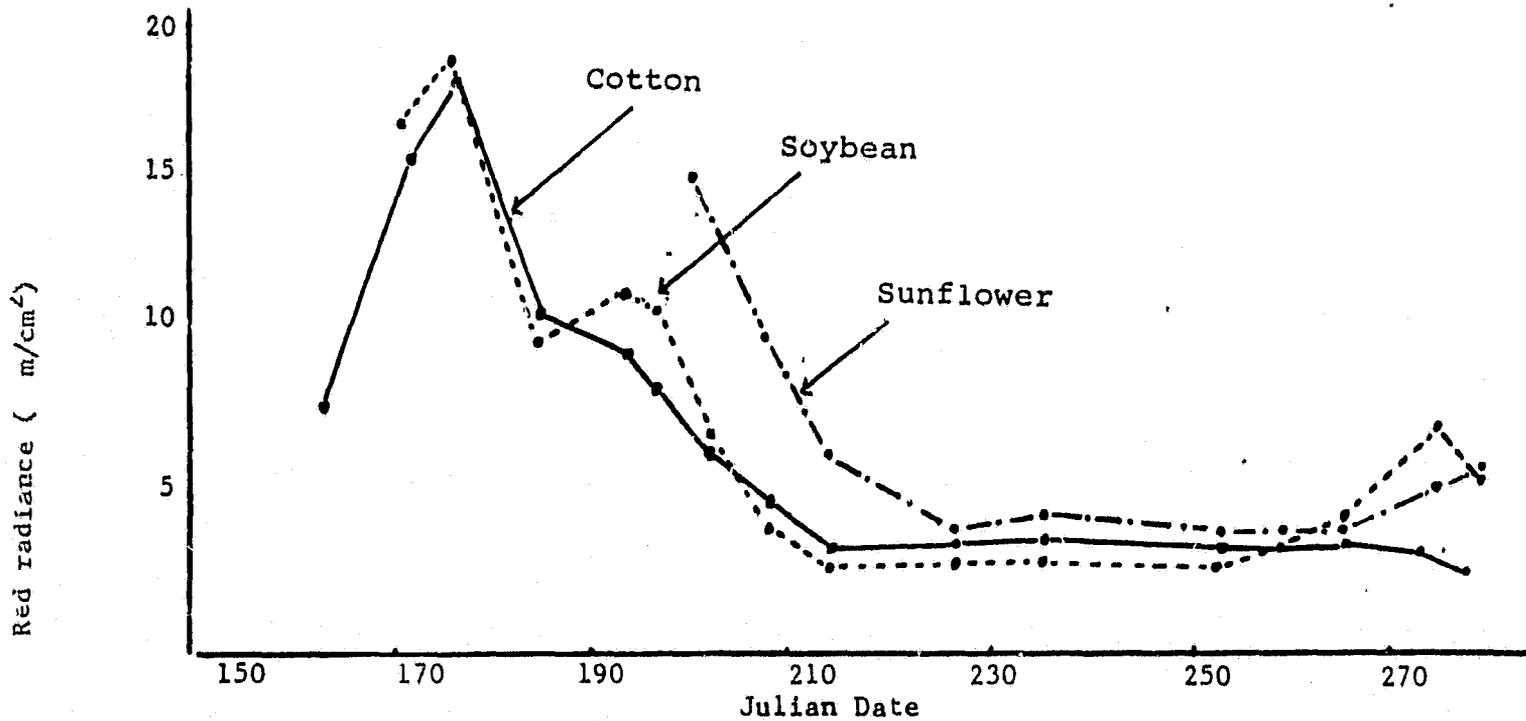


Figure 4. Red radiance plotted against Julian date for cotton, soybean and sunflower.

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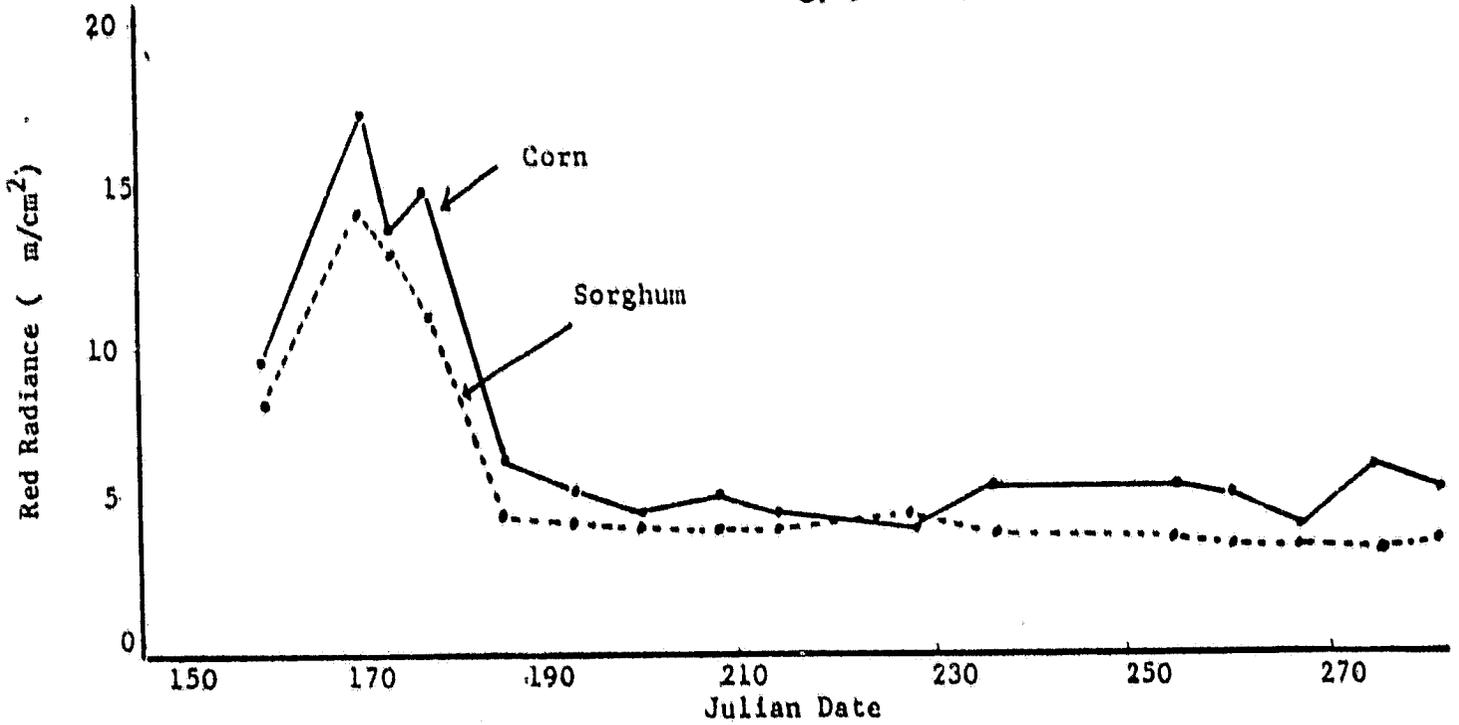


Figure 5. Red radiance plotted against Julian date for corn and sorghum.

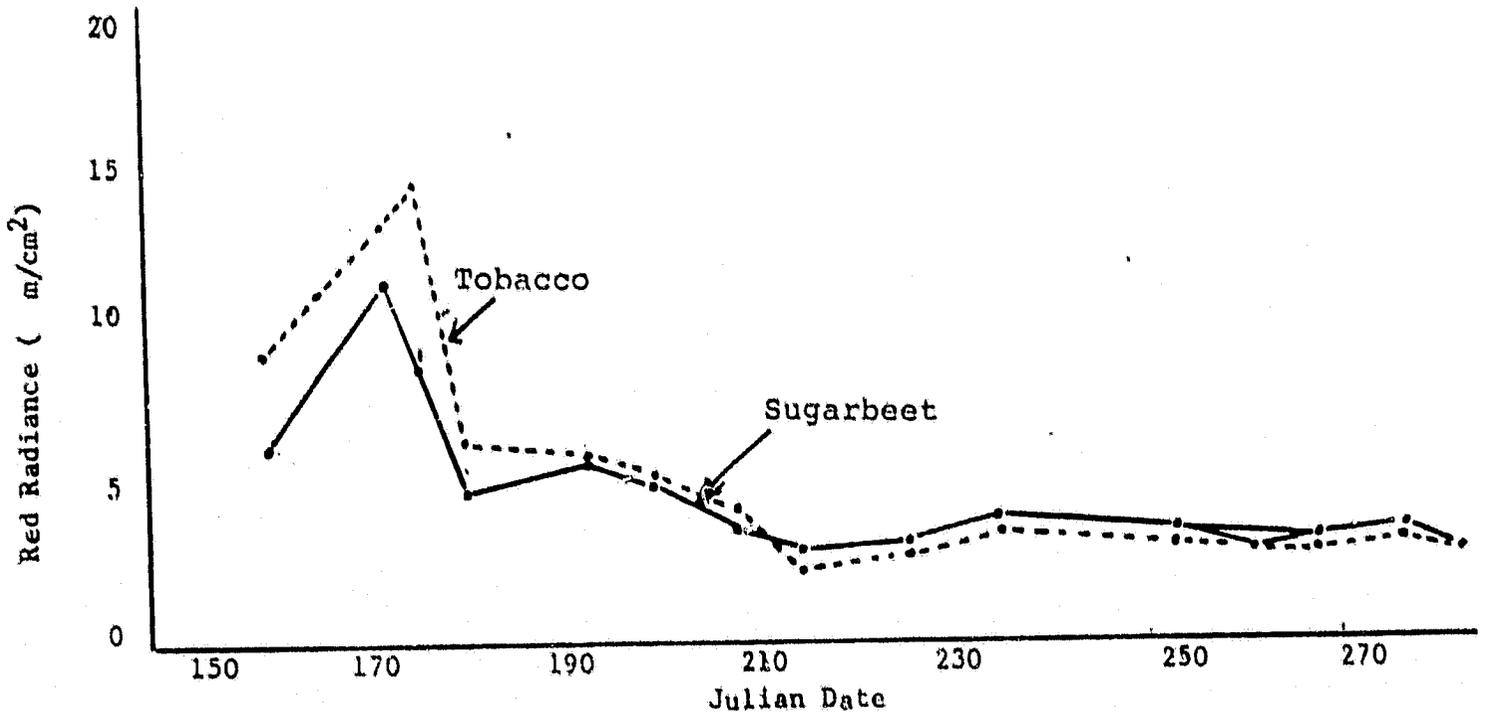


Figure 6. Red radiance plotted against Julian date for tobacco and sugarbeet.

Photographic Infrared/Red Radiance Ratio

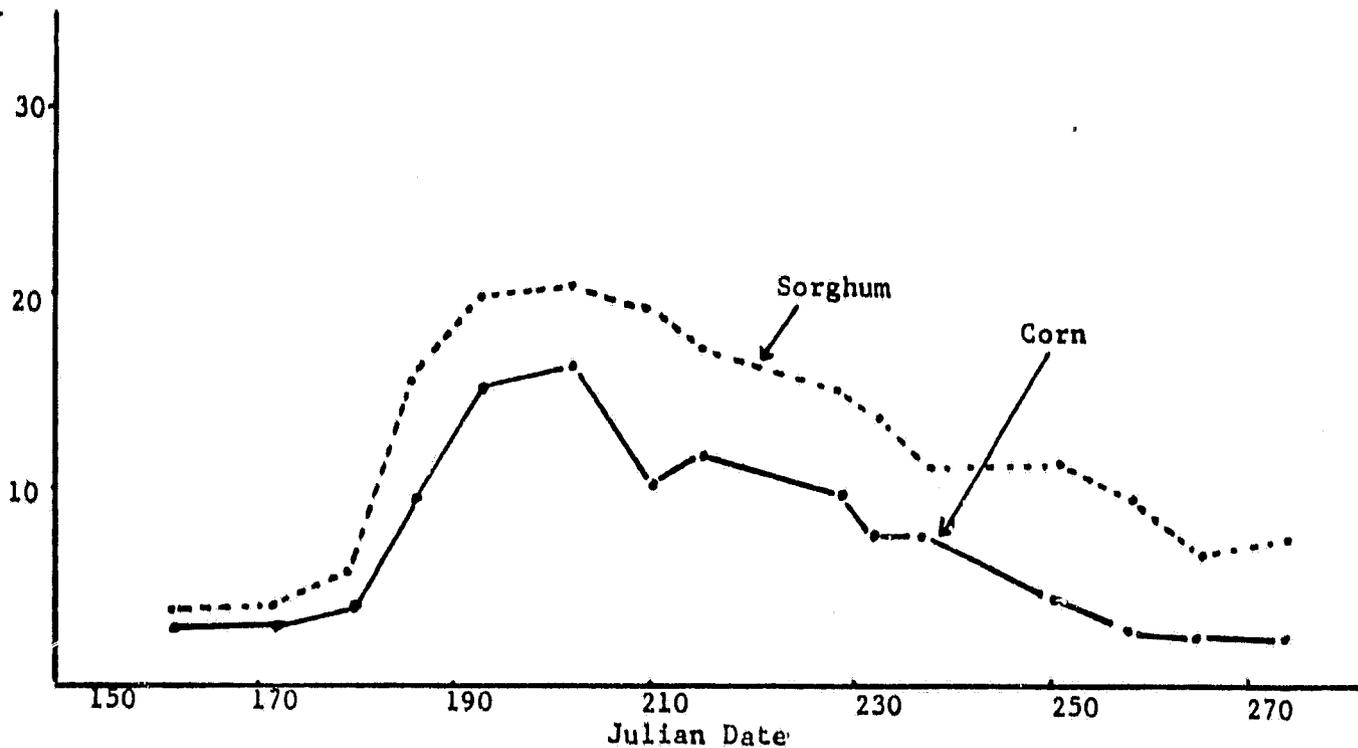


Figure 7. PIR/Red radiance ratio plotted against Julian date for corn and sorghum

Photographic Infrared/Red radiance ratio

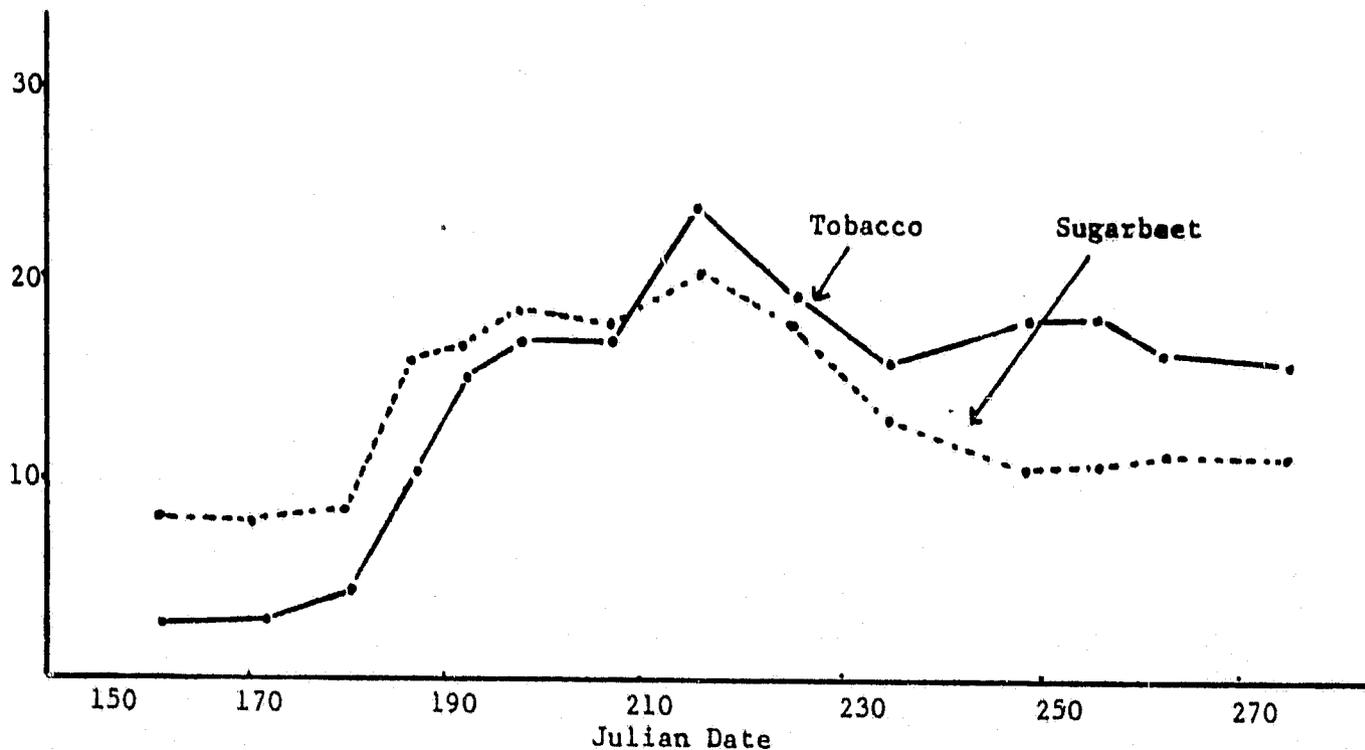


Figure 8. PIR/Red radiance ratio plotted against Julian date for tobacco and sugarbeet.

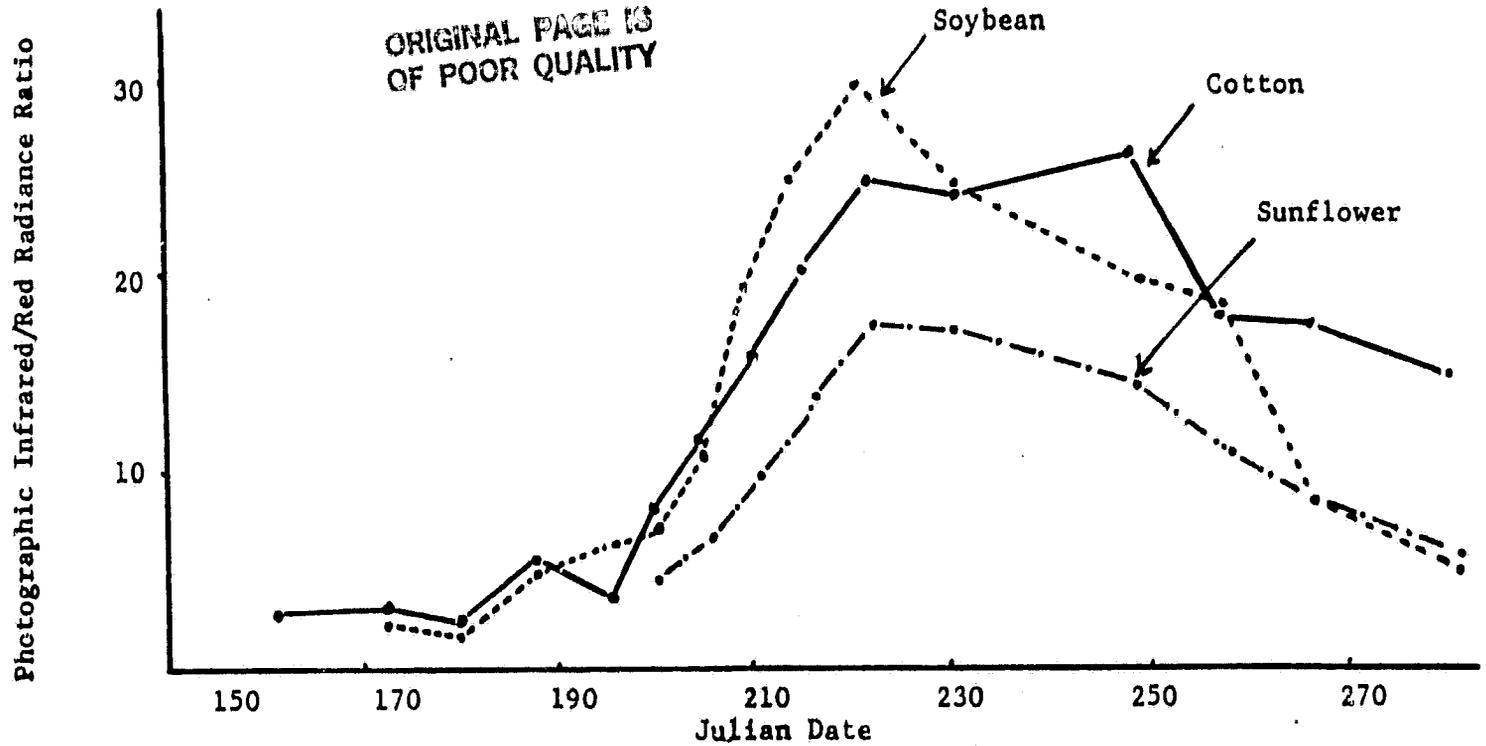


Figure 9. PIR/Red radiance ratio plotted against Julian date for cotton, soybean and sunflower.

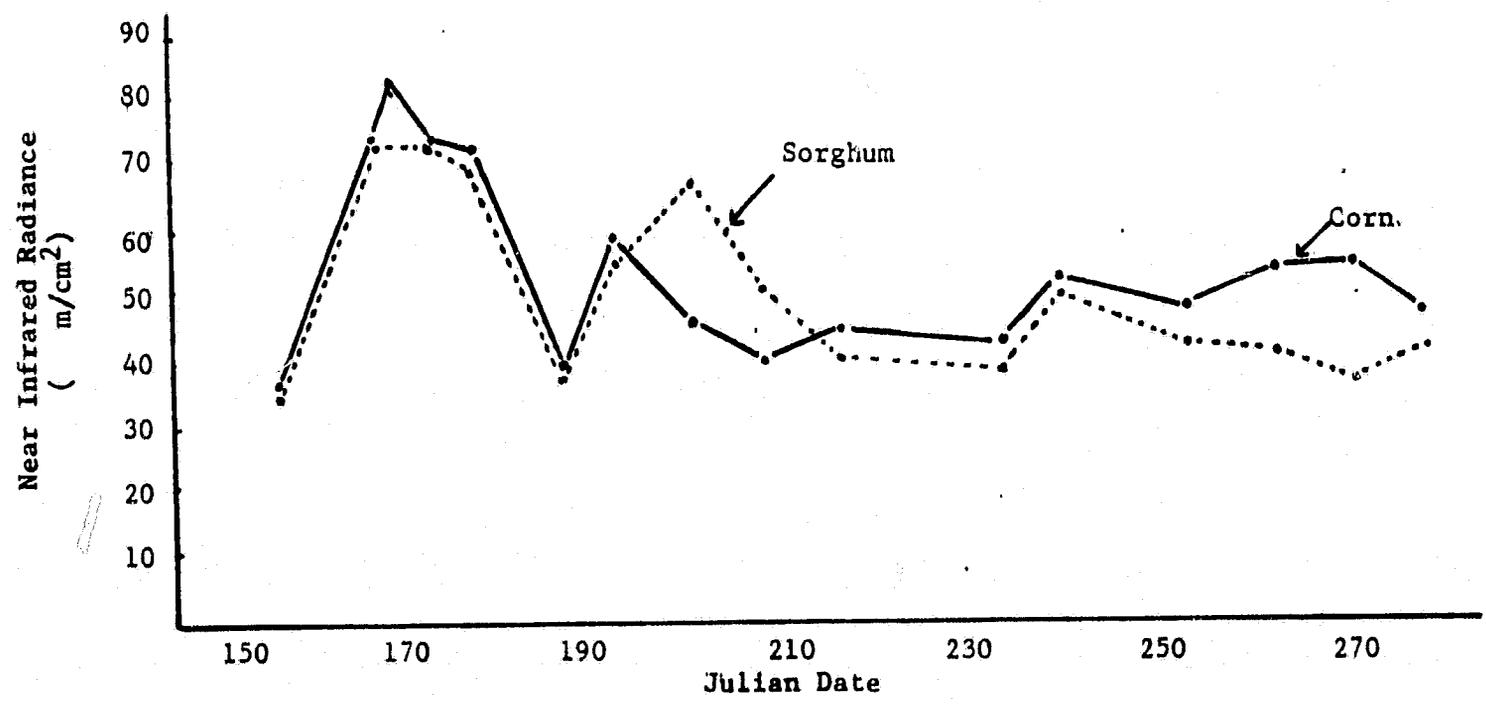


Figure 10. Near Infrared radiance plotted against Julian date for corn and sorghum.

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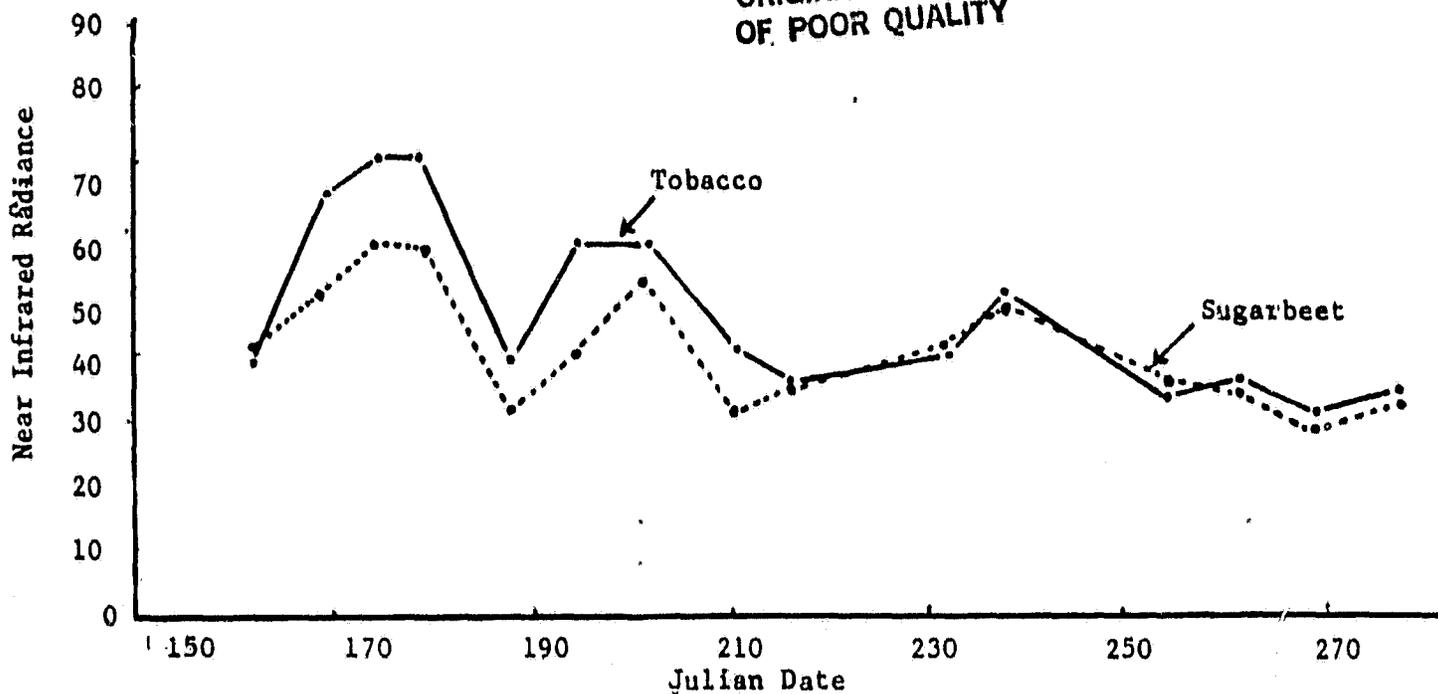


Figure 11. Near infrared radiance plotted against Julian date for tobacco and sugarbeet.

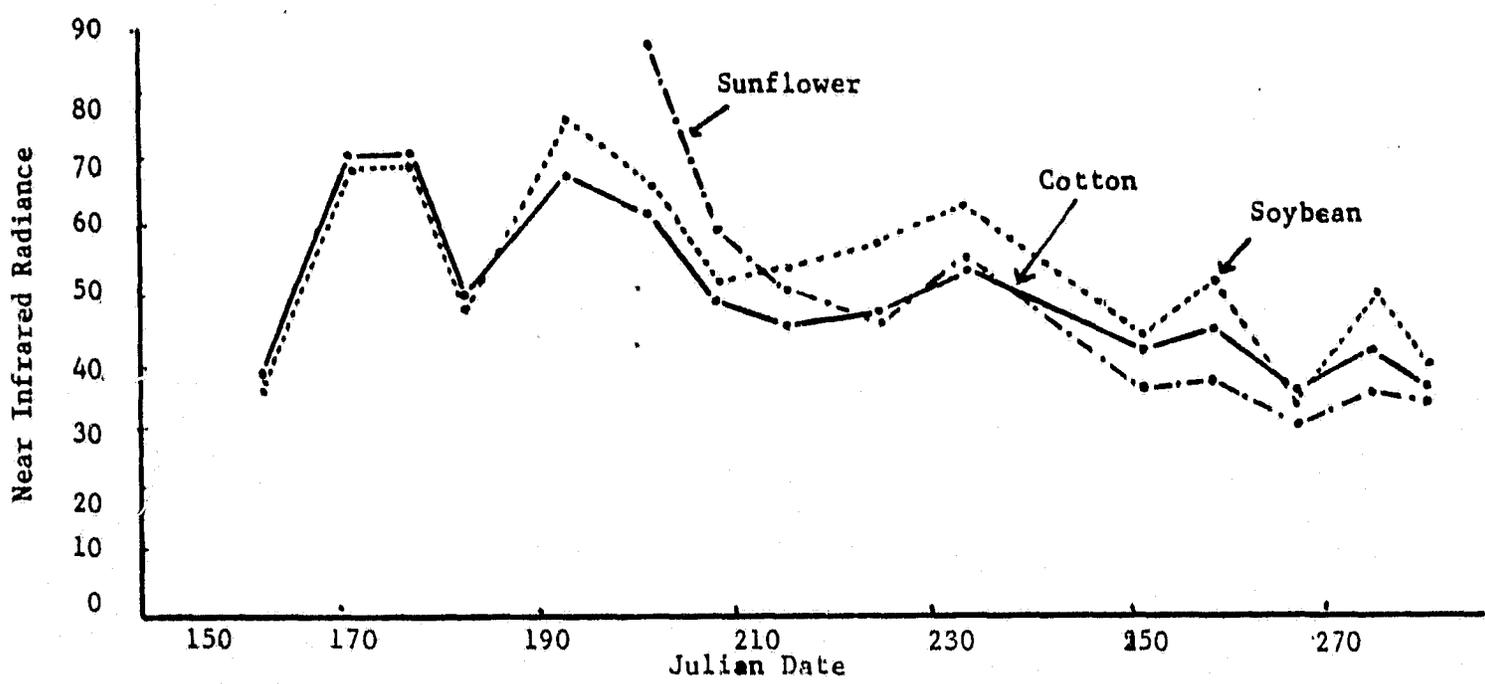


Figure 12. Near infrared radiance plotted against Julian date for cotton, soybean, and sunflower.

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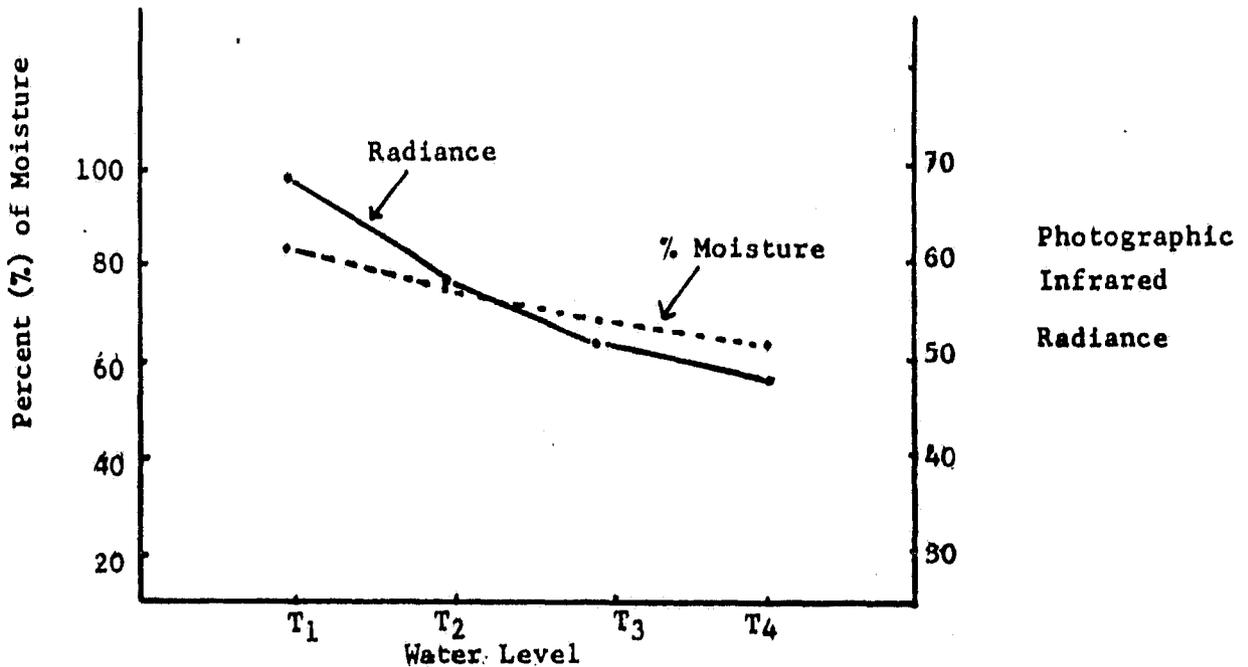


Figure 13. Relationship between percent moisture and photographic infrared radiance for soybean under four water levels (T<sub>1</sub> water daily, T<sub>2</sub> water every two days, T<sub>3</sub> water every four days, T<sub>4</sub> water every eight days).

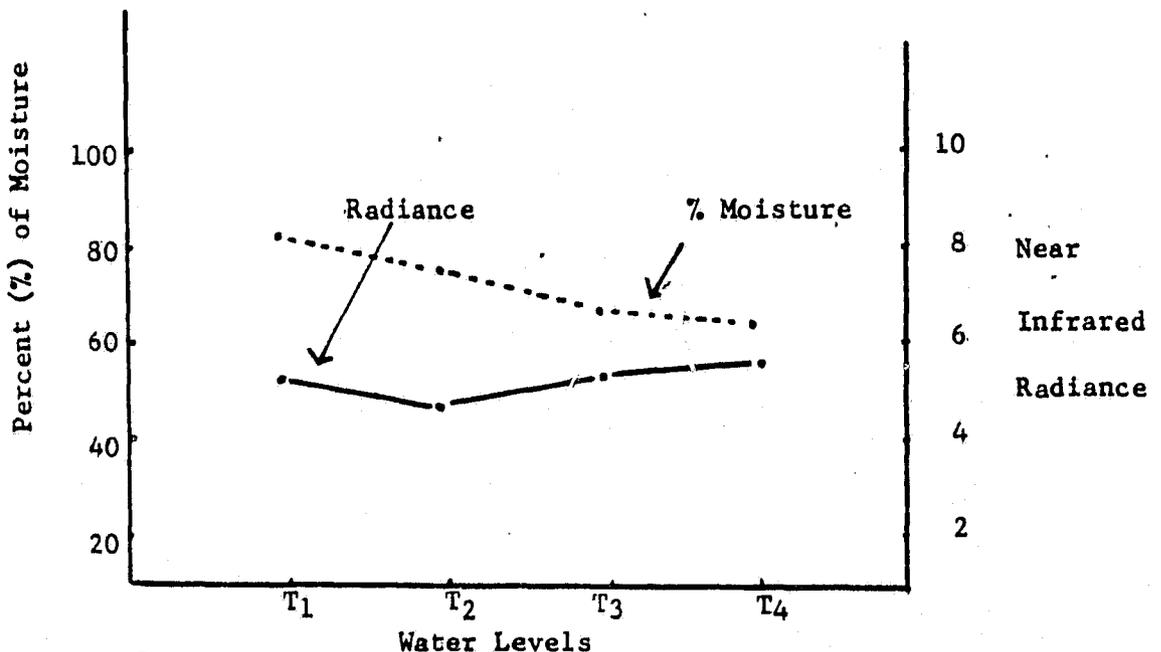


Figure 14. Relationship between percent moisture and near infrared radiance for soybean under four water levels (T<sub>1</sub> water daily, T<sub>2</sub> water every two days, T<sub>3</sub> water every four days, T<sub>4</sub> water every eight days).

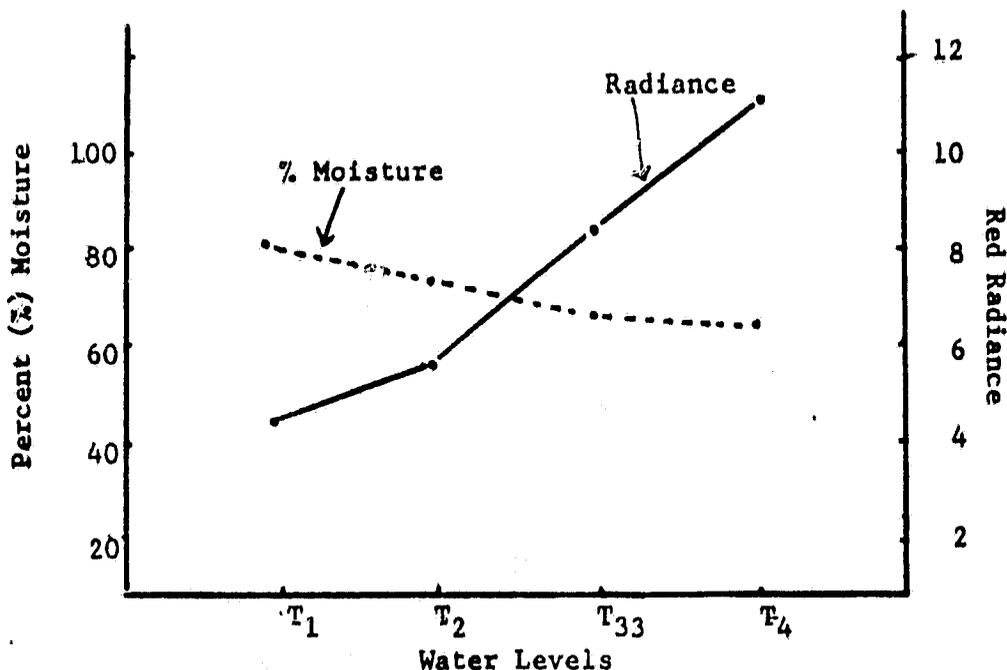


Figure 15. Relationship between percent moisture and red radiance for soybean under four water levels (T<sub>1</sub> water daily, T<sub>2</sub> water every two days, T<sub>3</sub> water every four days, T<sub>4</sub> water every four days).

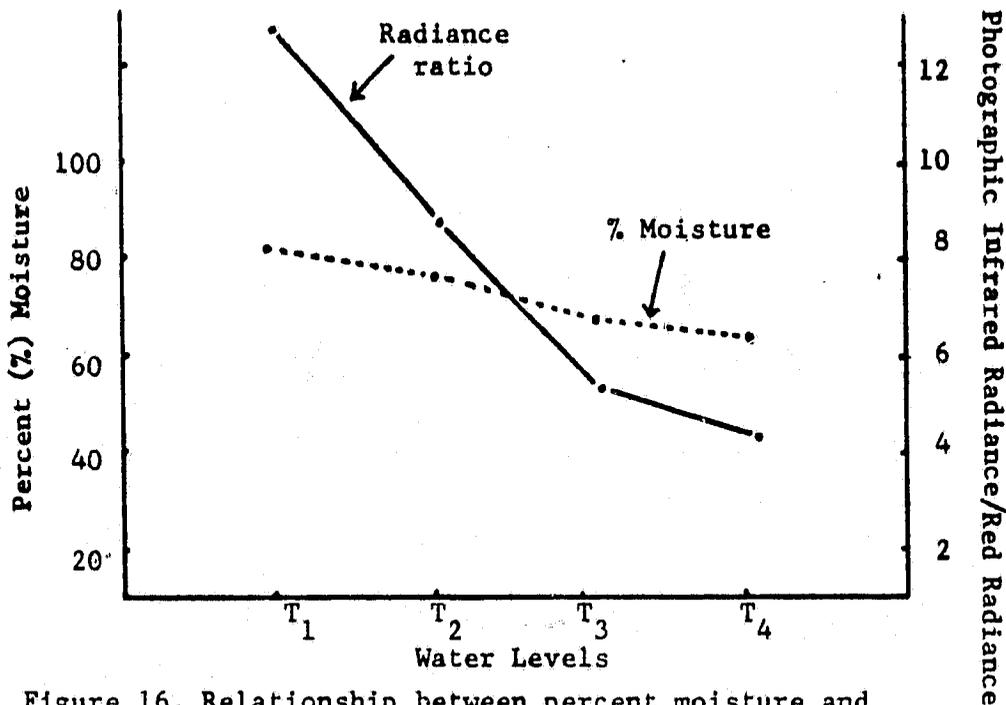
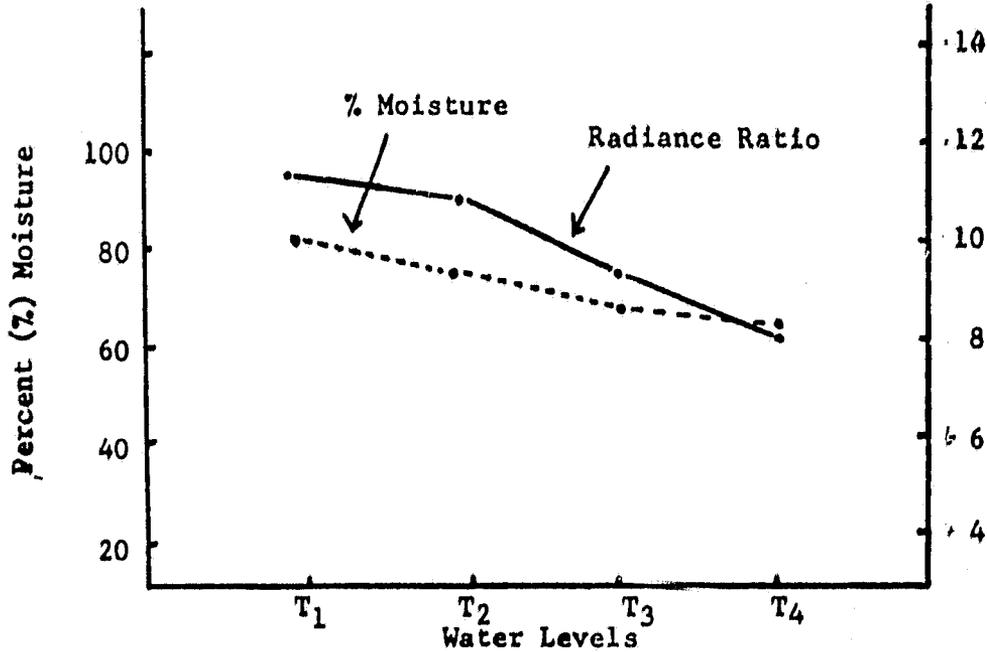
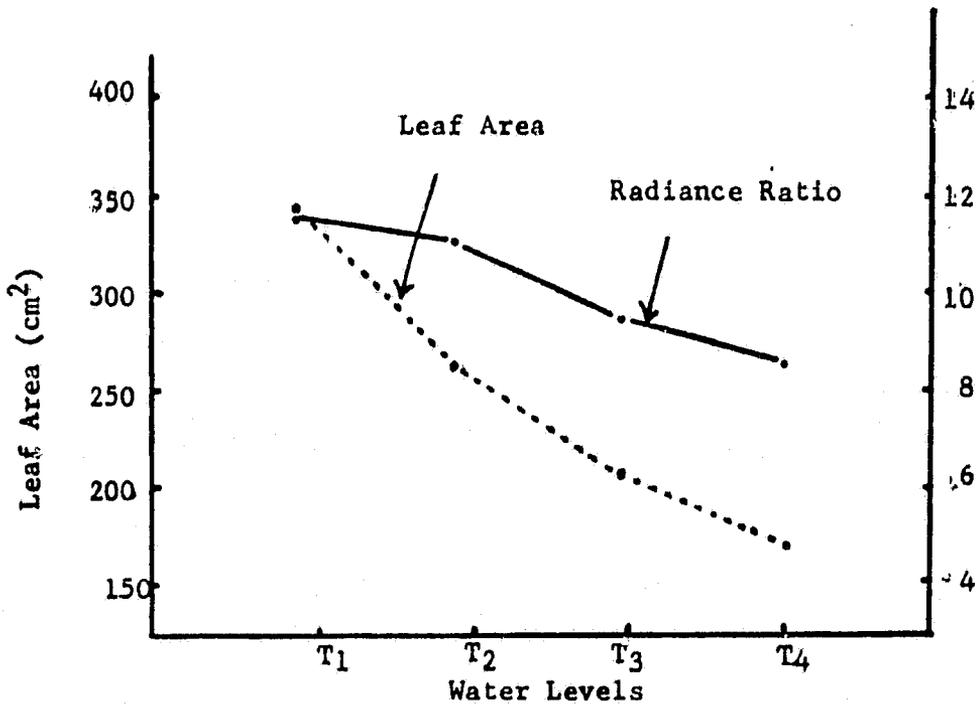


Figure 16. Relationship between percent moisture and PIR/Red radiance ratio of soybean under four water levels (T<sub>1</sub> water daily, T<sub>2</sub> water every two days, T<sub>3</sub> water every 4 days, T<sub>4</sub> water every eight days).



Photographic Infrared/Near Infrared  
Radiance Ratio

Figure 17. Relationship between percent moisture and PIR/NIR radiance ratio of soybean under four water levels (T<sub>1</sub> water daily, T<sub>2</sub> water every 2 days, T<sub>3</sub> water every four days, T<sub>4</sub> water every four days).



Photographic Infrared/Near Infrared  
Radiance Ratio

Figure 18. Relationship between leaf area and PIR/NIR radiance ratio for soybean under four water levels (T<sub>1</sub> water daily, T<sub>2</sub> water every two days, T<sub>3</sub> water every four days, T<sub>4</sub> water every eight days.)

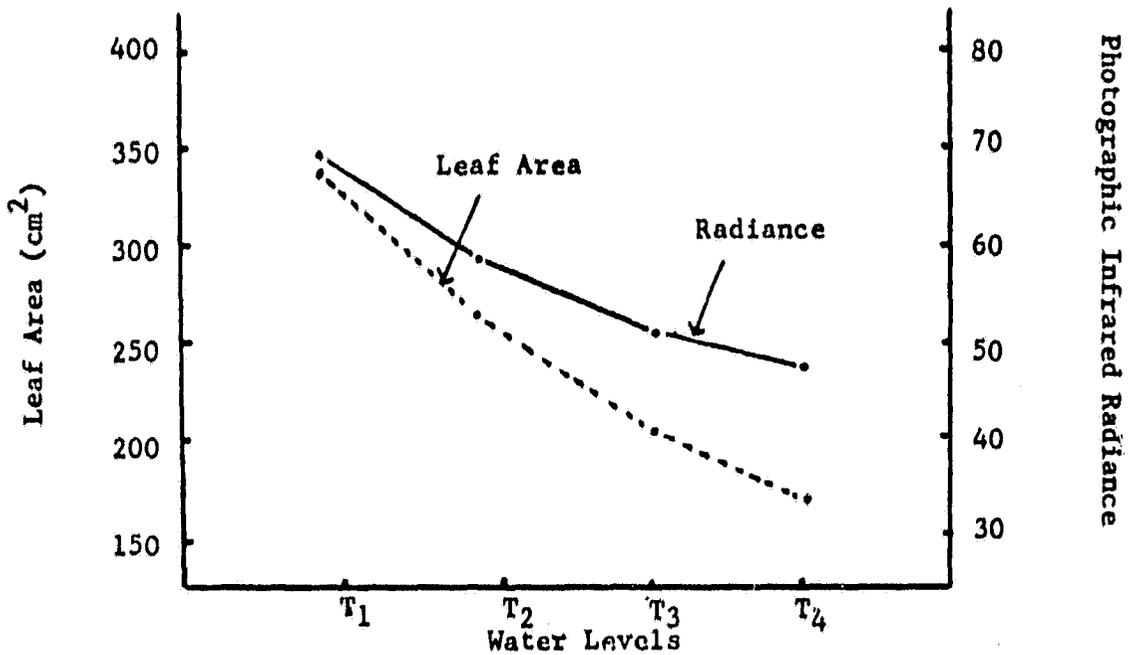


Figure 19. Relationship between leaf area and photographic infrared radiance for soybean under four water levels (T<sub>1</sub> water daily, T<sub>2</sub> water every two days, T<sub>3</sub> water every four days, T<sub>4</sub> water every eight days).

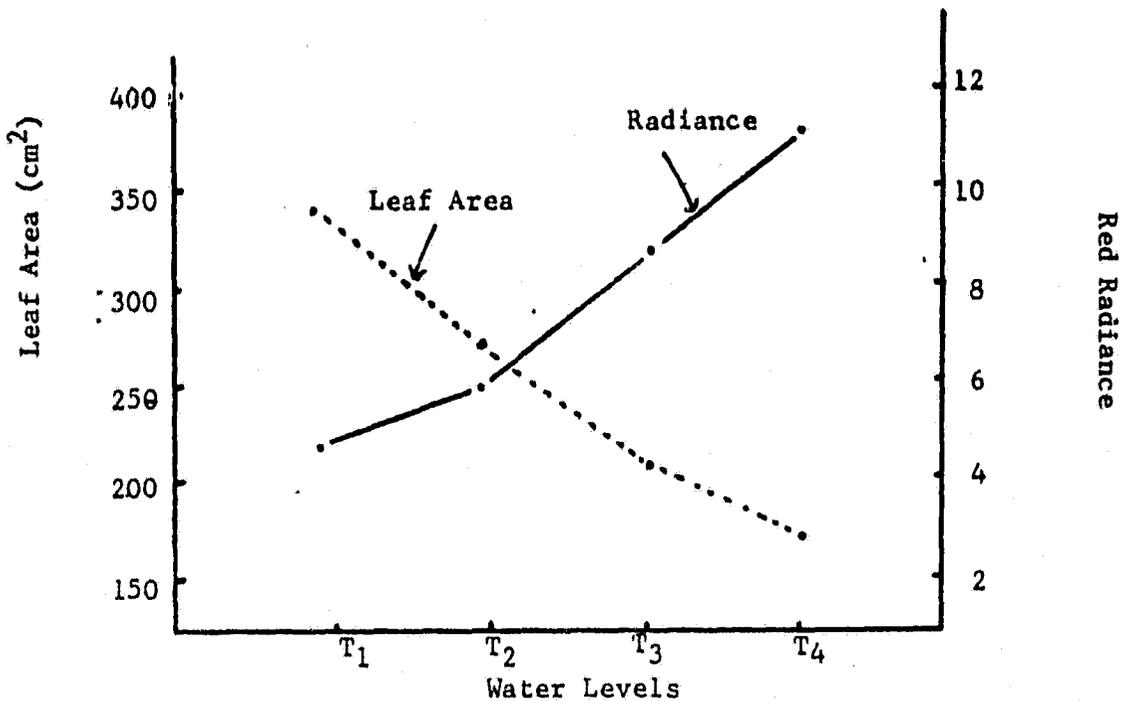


Figure 20. Relationship between leaf area and red radiance ratio for soybean under four water levels (T<sub>1</sub> water daily, T<sub>2</sub> water every two days, T<sub>3</sub> water every four days, T<sub>4</sub> water every eight days).

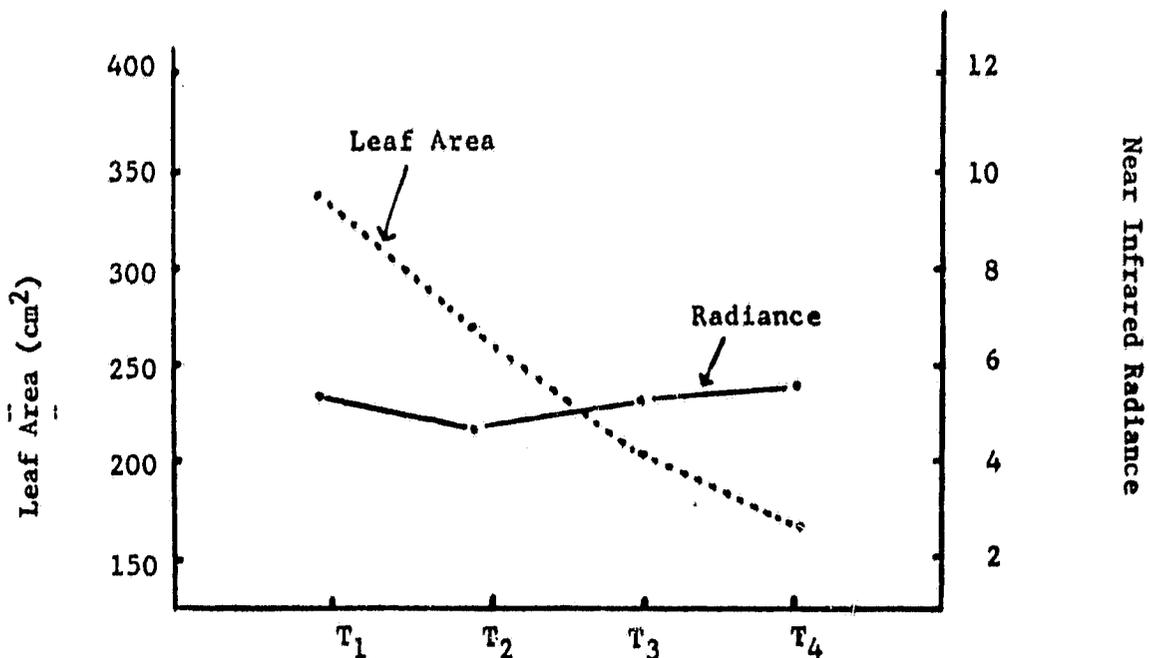


Figure 21. Relationship between leaf area and Near Infrared Radiance ratio for soybean under four water levels (T<sub>1</sub> water daily, T<sub>2</sub> water every two days, T<sub>3</sub> water every four days, T<sub>4</sub> water every eight days).

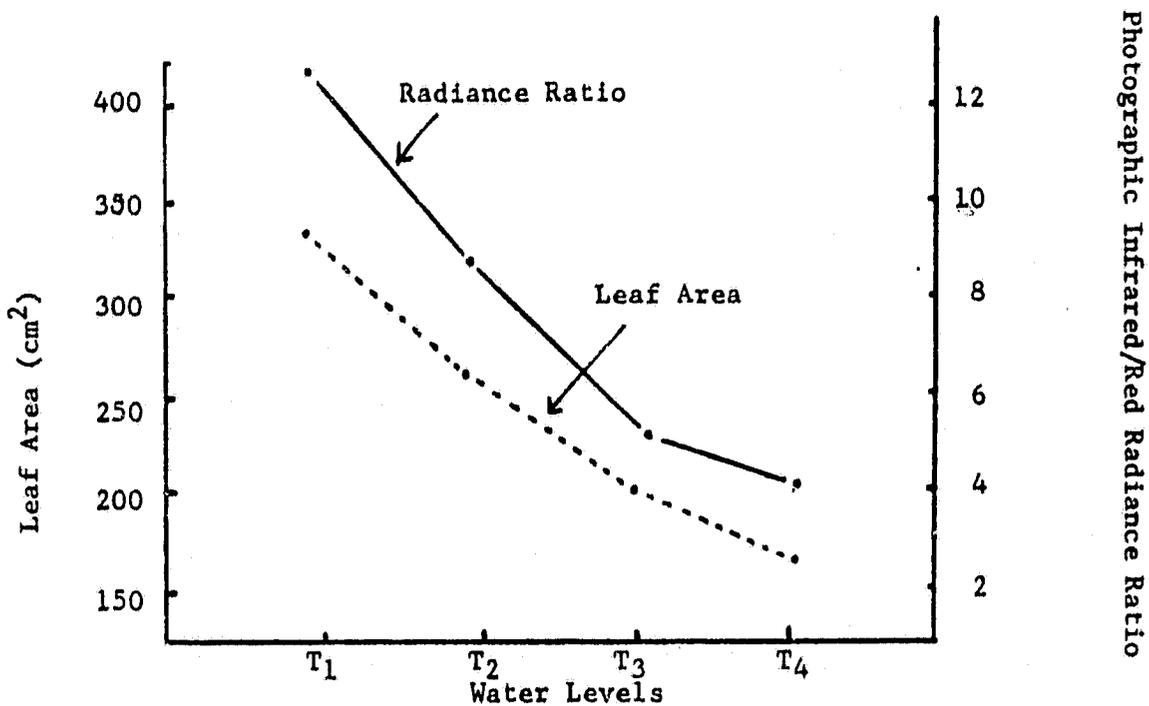


Figure 22. Relationship between leaf area and PIR/Red radiance ratio for soybean under four water levels (T<sub>1</sub> water daily, T<sub>2</sub> water every two days, T<sub>3</sub> water every four days, T<sub>4</sub> water every eight days).

TABLE 2. PLANT HEIGHT (cm) OF SEVEN CROPS

| Julian Date | Corn  | Cotton | Sorghum | Soybean | Sugarbeet | Sunflower | Tobacco |
|-------------|-------|--------|---------|---------|-----------|-----------|---------|
| 166         | 8.6   | 22.2   | 11.5    |         | 21.1      |           | 17.8    |
| 174         | 32.2  | 22.4   | 28.4    | 7.7     | 36.1      |           | 26.8    |
| 176         | 39.2  | 31.6   | 31.6    | 8.5     | 39.0      |           | 27.3    |
| 181         | 42.8  | 25.2   | 47.6    | 11.7    | 36.7      |           | 33.3    |
| 188         | 71.6  | 27.8   | 71.8    | 20.2    | 46.4      |           | 49.3    |
| 196         | 99.2  | 39.5   | 77.8    | 25.3    | 44.3      |           | 47.7    |
| 198         | 186.5 | 42.9   | 94.4    | 30.7    | 48.0      |           | 72.9    |
| 204         | 162.8 | 48.0   | 105.6   | 37.2    | 58.2      | 9.3       | 87.1    |
| 211         | 212.2 | 62.4   | 98.4    | 52.6    | 44.7      | 22.4      | 149.9   |
| 217         | 225.6 | 66.4   | 118.7   | 64.3    | 50.5      | 38.9      | 177.9   |
| 226         | 203.3 | 84.8   | 118.9   | 87.9    | 57.8      | 94.7      | 147.6   |
| 237         | 215.4 | 105.8  | 120.9   | 97.5    | 39.8      | 139.1     | 100.8   |
| 252         | 223.0 | 106.3  | 132.4   | 101.3   | 30.6      | 163.4     | 149.9   |
| 261         | 209.6 | 108.3  | 125.7   | 98.3    | 36.4      | 155.3     |         |
| 267         | 208.2 | 111.3  | 118.3   | 88.8    | 35.4      | 172.3     |         |
| 276         | 178.5 | 108.6  | 127.2   | 91.3    | 38.7      | 167.5     |         |
| 281         | 175.6 | 114.9  | 123.6   | 94.2    | 36.7      | 169.7     |         |