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# SPECTRAL SIGNATURES OF MOISTURE-STRESSED WHEAT

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**ABSTRACT**

One of the important parameters affecting crop yield is the availability of soil moisture to the crop. Lack of it may bring about moisture stress in plants which manifests itself in terms of changes in the spectral reflectance and emittance properties of plants. An experiment involving radiometric measurements over six wheat plots subjected to different irrigation schedules was conducted to test this hypothesis. Vegetation index defined in terms of crop reflectances in 0.6 to 0.7 and 0.8 to 1,1 micrometer bands was found to be a sensitive parameter to distinguish normal plants from moisture-stressed plants. The optimum period for the discrimination of such plants through remote sensing techniques has been indicated to be 45-80 days after sowing. The experiment also demonstrates that yield per unit area is linearly related to the maximum leaf-area index of the crop thus providing a possible method of crop yield prediction.

## INTRODUCTION

Identification of crops, determination of the area they cover and estimation of their yield per unit area are three important steps in any remote sensing programme designed to forecast agricultural production. Large Area Crop Inventory Experiment (LACIE) jointly conducted by the three U.S. Government agencies namely National Aeronautics and Space Administration (NASA), US Department of Agriculture (USDA) and National Oceanic and Atmospheric Administration (NOAA) has achieved a fair degree of success in carrying out these tasks from satellite-based observation (MacDonald and Hall, 1977). However, LACIE relied essentially on statistical agrometeorological models for the yield per unit area Efforts have been made by Idso et al. (1977 a, b; 1978) to correlate yield per unit area with the intensity of reflected solar radiation and/or canopy temperature. The limitation of soil moisture availability to plants produces internal plant water deficit which in turn, limits photosynthesis and restricts crop yield. The physiological changes that occur due to moisture stress result in changes in spectral reflectance/emittance of plants. A high correlation between red and photographic infrared spectral data and estimated moisture stress has been observed earlier (Tucker *et al*., 1980). Plants under moisture stress may not be able to maintain their thermodynamic equilibrium through evapotranspiration resulting in a higher canopy temperature than the ambient temperature.

To study the relationship between spectral response and moisture availability, an experiment was conducted over six wheat plots subjected to different irrigation schedules. Preliminary results were reported earlier (Sahai *et al.*, 1980).

## EXPERIMENTAL DETAILS

The experiment was conducted on wheat crop (variety : Junagadh-24) at the agricultural farm of Bhav Nirjhar located near the Space Applications Centre. The soil is sandy alluvial having light olive brown colour (Munsell notation 2.5 Y 5/4). The field was given an initial application of 50 kg/ha of nitrogen fertilizer. After sowing, the field was divided into six plots of 5×4 m size. Plot 1A was similar to 1 in all respects except that an extra application of 50 kg/ha of nitrogen fertiliser was given to 1A before the second irrigation. Details of irrigation schedule are given in Table 1. Each time 6 to 8 cms of water was used for irrigation. There was no precipitation during the entire growth period of the crop.

TABLE 1

*Irrigation Schedule*

| Date | Plot No. 1 & 1A | 2 | 3 | 4 | 5 | Days-after-sowing |
|---|---|---|---|---|---|---|
| 13 Dec. 1979 | × | × | × | × | × | 23 |
| 28 Dec. 1979 | | × | | | | 38 |
| 4 Jan. 1980 | × | | | | | 45 |
| 11 Jan. 1980 | | × | × | | | 52 |
| 18 Jan. 1980 | | | | × | | 59 |
| 25 Jan. 1980 | × | × | | | × | 66 |
| 8 Feb. 1980 | | × | × | | | 80 |
| 15 Feb. 1980 | × | | | | | 87 |

Radiometric measurements were carried out over all the plots every week throughout the growth cycle of the crop using a four-band portable radiometer with spectral bands matching those of the Landsat Multispectral Scanner and having a field of view of 15°. The radiometer was mounted about 170 cm above the ground on a horizontal long arm provided on the tripod. Radiance measurements of the crop canopy were taken between 10.00 and 14.00 hrs at one hour interval. Irradiance measurements were made using a $BaSO_4$-coated white reflectance panel alongwith radiance measurements. Every time at least three sets of observations were made.

Reflectance measurements of 'leaves' from all the plots were carried out in the laboratory using a Beckman Acta M IV Spectrophotometer (range 0.4 to 2.4 micrometer). The leaf samples plucked from different plants were immediately placed in the polyethylene bag and quickly brought to the laboratory for measurements.

Crop canopy temperature (blackbody) measurements were made using a Heimann KT-24 infrared radiation thermometer (spectral sensitivity 8 to 35 micrometer). The measurements were made with the radiation thermometer looking at the plant canopy from an angle so that soil background is avoided. The crop canopy temperature measurements were made between 13.00 and 14.00 hours every week throughout the growth cycle of the crop. Ambient tempera ture measurements were also made along with these observations.

Different biometric parameters like plant height, plant population, ear-head length etc. were noted. Leaf-area index (LAI) defined as the total area of the leaves per unit soil area was determined. Measurement of area of each leaf being very tedious and cumbersome an alternate method was used. In this method. an empirical relationship between the actual leaf area and the product of its length and maximum width was determined.

$$\text{Leaf Area} = K \times L \times W$$

where L = Length of the leaf

W = Maximum width of the leaf

K = A factor characteristic of the crop determined empirically

A large number of leaves (about 100) were plucked from plants in different plots and their actual area was measured using dot-grid method. The dot-grid used had 16 dots/$cm^2$. The length and maximum width of each leaf was also measured and noted down. The coefficient K was determined and was fonnd to be 0.76. This value of K was used in determining leaf-area index for all the ptots. Such a method for determining K has been used earlier by Ashley *et al.* (1963) for cotton. Total number of leaves per unit area was determined by counting the number of plants, number of tillers per plant and number of leaves per tiller.

After the maturity stage i.e. 104 days after sowing, the crop was harvested from one square meter area in each plot. Plot 2 was disturbed by animals and hence abandoned. The ear-heads were allowed to dry in the sun for 15 days and then the grain yield per unit area from each plot was determined.

## RESULTS AND DISCUSSION

Incident solar radiation interacts with terrestrial vegetatation canopy resulting in the absorption and reflectance of radiation in certain wavelength regions. A strong absorption takes place by plant pigments like chlorophyll in the wavelength regions 0.35 to 0.50 and 0.6 to 0.7 micrometer. The wavelength region 0.5 to 0.6 micrometer is characterised by higher reflectance in the green region with a maximum around 0.54 micrometer. There is a steep increase in the reflectance in 0.7 to 0.74 micrometer region and high level reflectance in 0.7 to 1.1 micrometer range. The wavelength region 1.1 to 2.4 micrometer is characterized by two broad water absorption bands (Fig. 1).

Figure 2 shows that MSS 5 (0.6-0.7 micrometer) reflectance decreases with crop growth and again increases reaching a maximum at the maturity stage. At the early growth stage and maturity, the reflectance values in this band are very close for all plots but during the period 45 to 80 days after sowing significant differences are observed. The radiance in the red band is reduced during this period because of increased chlorophyll absorption by green biomass. Moisture stress would be expected to reduce the *in vivo* chlorophyll concentration by limiting the water available for photosynthesis (Tucker *et al.*, 1980; Rouse *et al.*, 1973). Thus in the stressed wheat plots, the radiance in the red region is higher ( ig. 2).

Figure 3 shows the behaviour of vegetation index (VI) for some plots against days-after-sowing. VI is defined as (Rouse *et al.*, 1973)

$$VI = (MSS\ 7 - MSS\ 5)\ /\ (MSS\ 7 + MSS\ 5)$$

In the early stages of growth, VI is almost same for all the plots. There is a general increase in VI in early stages and a decrease with senescence setting in. Plot 1 has a distinctly higher VI than the other plots during maximum vegetative cover. This suggests that the optimum period for the discrimination of wheat under moisture stress would be 45 to 80 days-after-sowing, provided the wheat variety and the environmental conditions are similar.

Figure 4 shows LAI as a function of crop growth for plot 1, 1A and 5. The maximum value of LAI is reached in case of plot 1A which was given an extra input of fertilizer. Maximum LAI, in case of moisture-stressed plot 5, is 0.8 reached 45 days after sowing. In the case of plots 1 and 1A, the maximum is reached in about 60 days. The maximum value of LAI is about 1.8 which is less than the normally expected value (Simth *et al.*, 1975). This may be due to poor soil conditions under which the crop was grown.

Figure 5 shows the final yield (gm/m$^2$) plotted against maximum leaf-area index of the plot. It shows a linear relationship and suggests a method of directly relating yield with the leaf-area index. LAI can be estimated using remote sensing techniques (Pollock and Kanemasu, 1979). Vegetation indices defined in terms of reflectances in different bands can be correlated with ground observations of LAI. Once, such a relationship is established, then a method of correlating final yield of crop with vegetation indices, which can be determined using satellite based data with minimum amount of ground checks, becomes available.

Black-body temperature measurements of the plant canopy to detect crops under various degrees of moisture and, therefore, photosynthetic stress have been successfully done by Idso (1977) referred to earlier. Vegetative stress increases leaf temperature above the ambient temperature. Figure 6 shows the difference between the canopy temperature $T_c$ and the ambient temperature $T_a$ plotted as a function of crop growth period. $T_c$ was measured between 13.00 and 14.00 hrs The stressed plants have a higher $T_c$-$T_a$ whereas $T_c$-$T_a$ is near zero or negative for normal plants in agreement with Idso *et al* (1977).

Under the conditions the experiment was conducted, certain assumptions were made. One of them was that the soil attained its field capacity each time the irrigation was given. The scheduling was one weekly basis and staggered rather than on the basis of field capacity measurements of the soil. Improvements in the experiment design are possible by incorporating moisture/field capacity measurements and growing the crop under better soil conditions. Such improvements are being incorporated in further eperimentation on the wheat crop.

## CONCLUSION

Vegetation index VI defined in terms of crop-reflectance in 0.6-07 and 0.8-1.1 micrometer bands can be used as a sensitive parameter to distinguish moisture stressed plants from normal plants. The normal plants are assumed to be the ones which receive the normal quota of irrigation appropriate to the soil and the prevalent practice in the region (Plot 1 in this case). The optimum period for discrimination of moisture stressed wheat plants by remote sensing techniques is 45-80 days after sowing provided the wheat variety and environmental conditions are similar. The experiment also demonstrates that yield per unit area can be linearly related to the maximum leaf-area index of the crop; thus providing a method of crop yield prediction.

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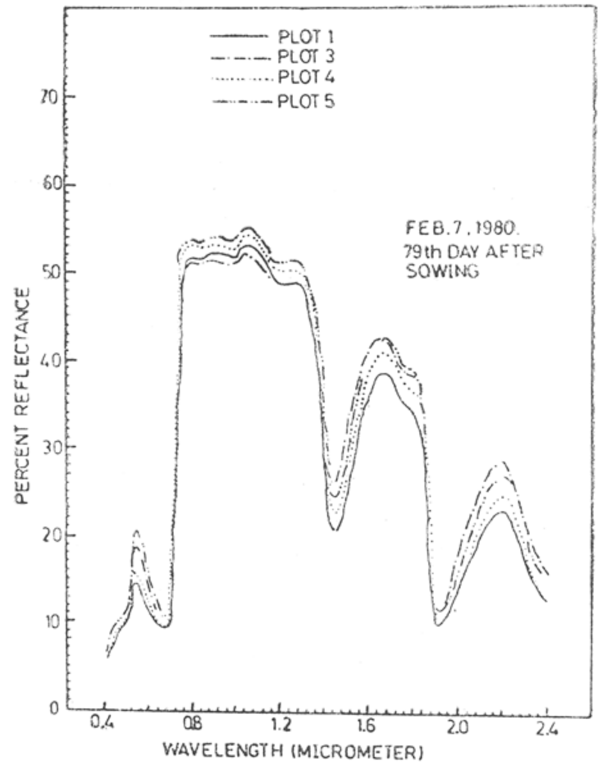


Fig. 1. Reflectance spectra of leaves plucked from different plots measured in the laboratory.

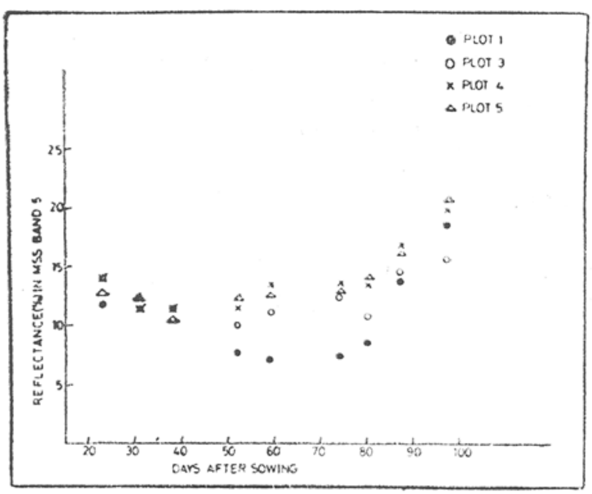


Fig. 2. Reflectance of different plots in 0.6 to 0.7 micro-meter range (MSS 5) plotted agaist days-after-sowing.

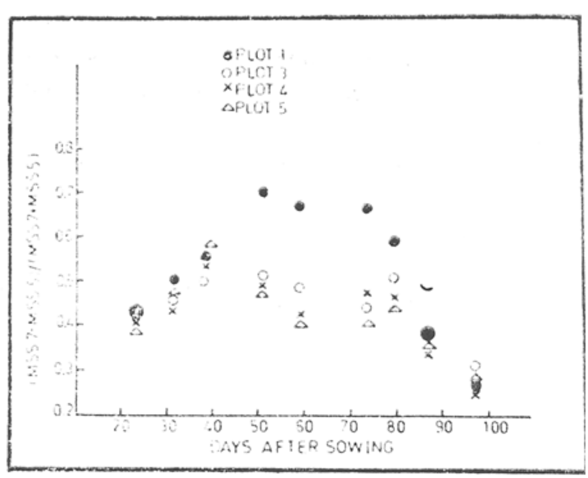


Fig. 3. Vegetation Index of different plots against days-after-sowing.

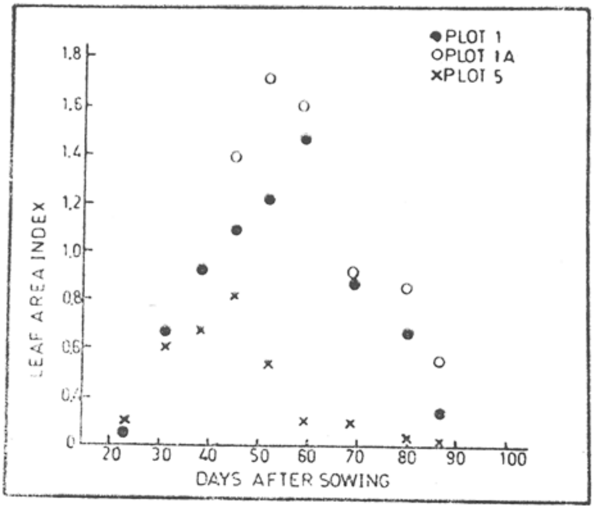


Fig. 4. Leaf-area index against days-after-showing.

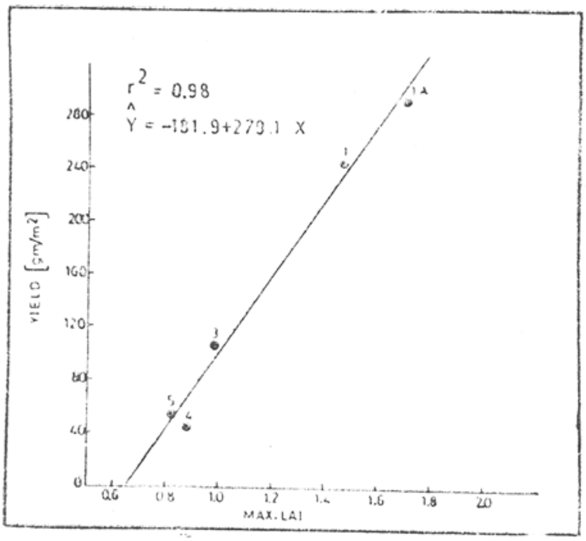


Fig. 5. Yield per unit area plotted agaist maximum LAI values attained by different plotes.

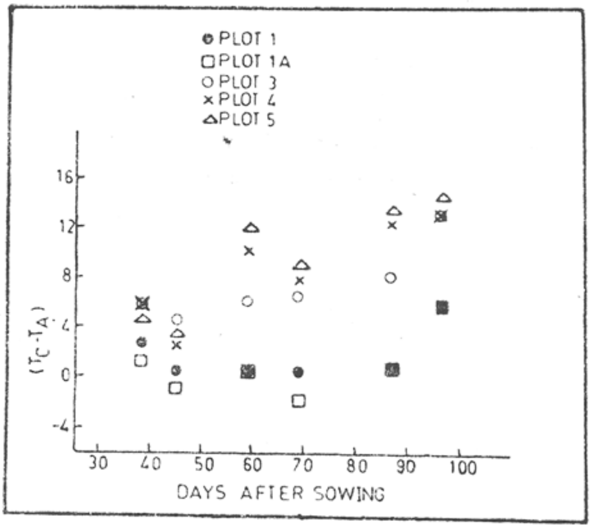


Fig. 6. Difference of crop canopy temperature $T_C$ and the ambient temperature $T_A$ plotted against days-after-sowing.

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