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Spectral Assessment of Leaf Area Index, Chlorophyll Content, and Biomass of Chickpea

Reflectance of the Chickpea canopy measured at bands 665 to 685 nm (red) and 815 to 825 nm (IR) and their ratio, during a complete crop cycle, gives significant correlation with leaf area index, chlorophyll content, and biomass.

ABSTRACT: *The objective of this study was to investigate the potential usefulness of spectral measurements to estimate leaf area index, chlorophyll content, and biomass of chickpea* (Cicer arietinum L). *Reflectance in the red (665 to 685 nm) and infrared (815 to 835 nm) bands was measured with a hand-held radiometer. Measurements were made throughout a complete crop cycle in order to monitor chickpea growth and development under irrigated and stressed conditions in an experimental field at the Indian Agricultural Research Institute (IARI), New Delhi. Leaf area index, chlorophyll content, and biomass were measured concurrently with spectral measurements. Significant correlations exist between spectral data, like red reflectance, IR reflectance, their ratio, and the normalized difference, and leaf area index, chlorophyll content, and biomass. The spectral data are sensitive in detecting the effect of water stress in chickpea. The results of the experiment show conclusively that a hand-held radiometer can be used to collect spectral data which can supply information on chickpea canopy growth, development, and status by non-destructive determination of leaf area index, chlorophyll content, and biomass.*

INTRODUCTION

REMOTE SENSING TECHNIQUES have been used to monitor vegetative conditions for several crop covers. Red and photographic infrared reflectance and linear combinations of these bands are significantly correlated with the green or photosynthetically active portions of plant canopies for various cover types (Jordon, 1969; Colwell *et al.*, 1977; Deering, 1978; Tucker, 1979). These data have been used in estimating the leaf area index of tropical forests (Jordon, 1969), the green leaf area and biomass of soybeans (Holben *et al.*, 1979), alfalfa (Tucker *et al.*, 1980a), winter wheat (Wiegand *et al.*, 1979), forages (Pearson and Miller, 1972; Rouse *et al.*, 1973; Colwell, 1974; Carneggie *et al.*, 1974; Deering *et al.*, 1975; Pearson *et al.*, 1976; Maxwell, 1976; Tucker *et al.*, 1979), in monitoring crop conditions (Richardson and Wiegand, 1977; Tucker *et al.*, 1980b), and in predicting grain yield (Colwell *et al.*, 1977).

The relationship between remotely sensed data and crop conditions has been reported by several workers. Johnson (1965) located areas of low sugarcane vigor by using infrared photography. Gausman *et al.* (1975) used Landsat MSS data (0.60 to 0.70 μm) to identify chlorotic sorghum areas of

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0.48 hectare or larger. Thomas and Gerberman (1977) detected reductions in cabbage yield caused by nitrogen and water stresses by measuring the cabbage canopy reflectance. Thomas and Oerther (1977) detected nitrogen stress on sugarcane by using infrared photography.

Tucker *et al.* (1979) monitored corn and soybean growth and development by means of red and photographic infrared data collected throughout the growing season. They defined and related the five spectral stages to crop development; significant correlations were found between the radiance data and the biomass, plant height, percentage crop cover, percentage crop chlorosis, and percentage leaf loss for corn and soybean crops. Tucker *et al.* (1981) correlated the spectral data with total dry-matter accumulation in winter wheat.

Crop development has been monitored by several researchers using Landsat MSS data. Rouse *et al.* (1973) proposed a two-band approach for assessing leaf biomass. Ashley and Rea (1975) used Landsat MSS 5 and MSS 7 data to depict phenological change. The Vegetative Index, VI = (MSS 7 − MSS 5)/(MSS 7 + MSS 5), increased with foliage development and decreased with senescence. The VI reduced multiplicative effects such as solar elevation difference between overpasses (Ashley and Rea, 1975).

As part of our ongoing research program, we have been collecting handheld radiometer data for a variety of agricultural crops. This is done under a program of joint experiments conducted by the Indian Space Research Organisation (ISRO) and the Indian Agricultural Research Institute (IARI). The objective of the joint experiment is to define the various sensor parameters, including selection and evaluation of bands, radiometric resolution, frequency of coverage, and other considerations for vegetation studies. These parameters are intended for the Indian Remote Sensing Satellite (IRS), scheduled for launch in 1985. We also decided to study the potential of these spectral data to estimate the leaf area index, chlorophyll content, and biomass of chickpea (*Cicer—arietinum L*). Chickpea or Bengal gram is the most important pulse crop of India both in area and production, and was selected for the joint experiment. It is mostly grown as a rainfed crop, and its productivity depends on winter rain.

In this paper we present the results of the experiment conducted on chickpea to estimate leaf area index, chlorophyll content, and biomass from the crop spectral variables.

MATERIALS AND METHODS

The experiment was conducted from December 1980 to April 1981 on a chickpea crop in a field of sandy loam at the Indian Agricultural Research Institute (IARI), New Delhi. The field was irrigated and ploughed and chickpea (J-62) was sown on 4 December 1980. Before sowing, the field was fertilized with N at 20 kg/ha, P at 40 kg/ha, and K at 40 kg/ha levels. There were four experimental plots of 4.5 m by 7.5 m each, of which two plots were maintained irrigated while the other two had only presowing irrigation. The chickpeas were in rows 20 cm apart at a population of approximately 2,500,000 plants/ha. The maximum height and cover of the chickpea plants were approximately 50 cm and 95 percent, respectively.

The radiance data for all four plots were measured in the red (665 to 685 nm) and the infrared (815 to 835 nm) region. The radiance was measured using a modified version of UDT power meter/radiometer* having 15° field of view (FOV). The radiometer was mounted in the field on a flexible tripod stand, and radiance was measured normal to the ground surface at a height of approximately 1.8 m above the plant canopy. Ten spectral measurements per plot were averaged to account for the spatial variability present in each plot. Spectral data were collected in between 1100 and 1530 hours IST throughout the growing season (Table 1). Immediately after each spectral measurement on a given plot, solar irradiance was measured from a $BaSO_4$ panel. All spectral measurements were normalized with the irradiance obtained by the $BaSO_4$ panel.

Green leaf area index, dry biomass, and chlorophyll concentration were concurrently measured with the spectral data throughout the growing season. All plants in the 1.0 m^2 area were harvested at ground level, and leaf area was measured by an automatic leaf area meter (Model No. AAM7, Hayashi Denkoh and Co., Japan). The plants were oven dried at 80°C for 72 hours to give leaf and stem dry weights of the plants. Leaf area was used for computing the leaf area index. Chlorophyll concentration was measured using the method of Arnon (1949). The upper four leaves were taken for the determination of chlorophyll. The chlorophyll content is calculated in grams/m^2 of ground area. Leaf water potential was also measured around 1400 hours on each day of observation by pressure chamber (Model No. 3000, Soil Moisture Equipment Corporation, USA).

RESULTS AND DISCUSSION

The red and infrared reflectance were plotted against the days after sowing (Figures 1 and 2). The red reflectance decreased rapidly with time (Figure 1) due to an increase in chlorophyll concentration and leaf area index. After 120 days (for irrigated crop), red reflectance increased due to senescence as crop matured. The red reflectance for stressed

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* United Detector Technology (UDT 2644, 30th Street, Santa Monica, CA 90405). Power meter/radiometer, Model No. 21 attached with a 11CR-135 telescope having a 2.5° FOV. The instrument was modified by exchanging the optical head with one having a 15° field of view and focussing range from 1.5 m to infinity. The instrument has the spectral response range 400 to 1100 nm. The bands were selected by using filters.

TABLE 1. DATES WHEN RADIOMETER DATA WERE COLLECTED FROM CHICKPEA PLOTS

Sampling Sequence	Calendar Date (D/M/Y)	Days after Sowing	Time (IST)	Conditions/Comments		
				Temperature (ambient)	Sky	Wind Speed
1.	26/12/80	22	13.30-15.30	18.7°C	Clear	2.69 km/hr
2.	12/01/81	39	13.30-15.20	18.7°C	Scattered Clouds	2.61 km/hr
3.	29/01/81	57	14.00-15.25	20.9°C	Clear	3.29 km/hr
4.	12/02/81	70	11.30-13.00	25.3°C	Clear	5.43 km/hr
5.	2/03/81	88	12.20-13.30	23.1°C	Clear	5.42 km/hr
6.	16/03/81	103	11.45-12.50	24.2°C	Scattered Clouds	4.22 km/hr
7.	31/03/81	118	11.30-12.35	26.5°C	Clear	12.3 km/hr
8.	24/04/81	143	11.00-12.00	37.4°C	Clear	6.09 km/hr

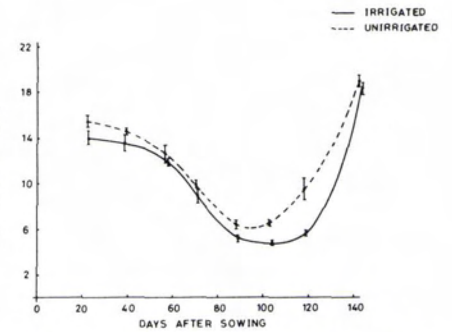

FIG. 1. Red reflectance plotted against the number of days after sowing for a typical experimental chickpea plot under irrigated and unirrigated conditions.

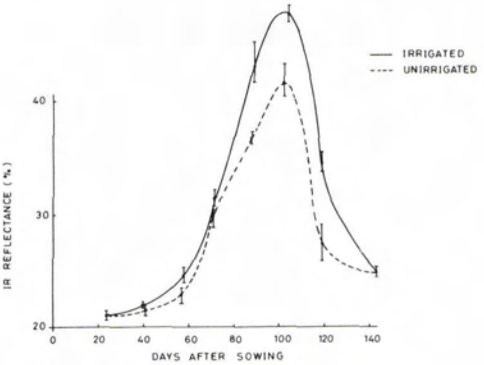

FIG. 2. The IR reflectance plotted against the number of days after sowing for a typical experimental chickpea plot.

plants was always higher than that for irrigated plants. The red reflectance difference between irrigated and unirrigated plants was highly significant† after the third sampling date. This was due to the fact that irrigation took place after the third sampling date (Table 2) and the effect of irrigation appeared only at fourth date, which is clear from Table 2.

The infrared reflectance (Figure 2) gradually increased with time and showed a maximum followed by a decrease due to senescence. Stressed chickpea plants have a lower maximum infrared reflectance than normal plants.

The change of the IR/red ratio with crop growth is shown in Figure 3. The maximum for the stressed crop is at a lower level than that for the unstressed crop. The normalized difference, ND = (IR − red)/(IR + red), is plotted in Figure 4. In the beginning the ND increased slowly and after 40 days it increased very fast as the crop cover increased (up to 80 days); once the green vegetative cover was complete, the ND reached a plateau. During the period of crop maturation and drying, the ND declined

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† Significant at the 0.01 level of probability.

TABLE 2. LEAF AREA INDEX, CHLOROPHYLL CONTENT, AND LEAF DRY BIOMASS AT SEVEN SAMPLING DATES FOR IRRIGATED AND UNIRRIGATED CHICKPEA CROP

Days after sowing	Leaf area index		Chlorophyll content (g/m^2)		Leaf dry weight (g/m^2)		Leaf water potential (bars)	
	Irrigated*	Unirrigated	Irrigated*	Unirrigated	Irrigated*	Unirrigated	Irrigated*	Unirrigated
22	0.18	0.18	0.06	0.06	9.4	9.4	−9.5	−9.5
39	0.71	0.71	0.11	0.11	8.6	8.6	−10.2	−10.2
57	0.94	1.27	0.62	0.69	41.0	45.0	−12.1	−12.1
70	1.55	1.48	0.66	0.61	52.5	50.0	−14.0	−14.6
88	1.72	1.39	1.84	0.78	97.5	75.0	−13.1	−15.5
103	2.14	0.97	1.83	0.60	102.5	60.0	−12.5	−16.0
118	1.67	0.50	1.78	—†	62.5	50.0	−14.0	−19.0

* Note that the crops were in the same water conditions until the third sampling date (57 days after sowing) as irrigation occurred on 10/02/1981. Leaf water potential given in the table represents the water status of the plants.

† Measurement not taken.

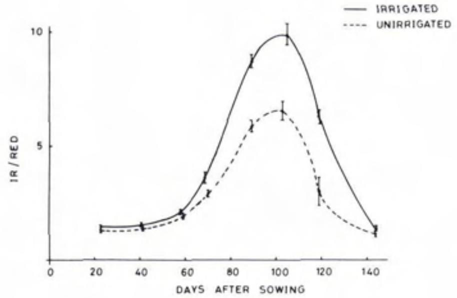

FIG. 3. The IR/red reflectance ratio plotted against the number of days after sowing for the typical experimental chickpea plots.

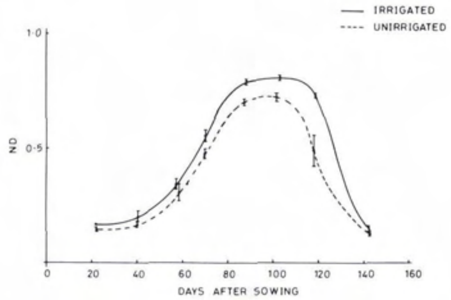

FIG. 4. The normalized difference, ND = (IR − red)/(IR + red) plotted against the number of days after sowing for a typical experimental chickpea plot. The curve shows a plateau. The plateau for the irrigated plot is at a higher level than that for the unirrigated one.

gradually. The ND plateau for the unirrigated crop was lower than the normally irrigated one.

The factors that adversely affect plant growth and development are readily apparent in the spectral data if they affect either the chlorophyll content or the green leaf area and biomass. The water stress condition restricts the plant growth by affecting chlorophyll concentration, leaf area index, and biomass. Table 2 shows the low value of these parameters for the unirrigated crop compared to the irrigated one. In this table, values of leaf water potential are also given for a comparison of the water status of the plants.

Figures 1 to 4 show the dynamic nature of the chickpea canopy and the effect of water stress. The effect of water stress on the crop is apparent in all

TABLE 3. LINEAR CORRELATION COEFFICIENTS BETWEEN THE FOUR SPECTRAL VARIABLES AND THE PLANT PHYSIOLOGICAL VARIABLES AND THE RANGE OF THE PLANT PHYSIOLOGICAL VARIABLES MEASURED. THE SAMPLE SIZE APPEARS IN PARENTHESES

Physiological Variables	Range	Correlation Coefficients			
		Red	IR	IR/red	ND
Leaf area index (19)	0.18-2.14	−0.79*	0.79*	0.83*	0.84*
Chlorophyll content (g/m^2) (19)	0.06-1.88	−0.87*	0.75*	0.90*	0.86*
Leaf Dry biomass (g/m^2) (19)	9.4-102.5	−0.94*	0.90*	0.92*	0.95*

* Indicates significance at the 0.01 level of probability.

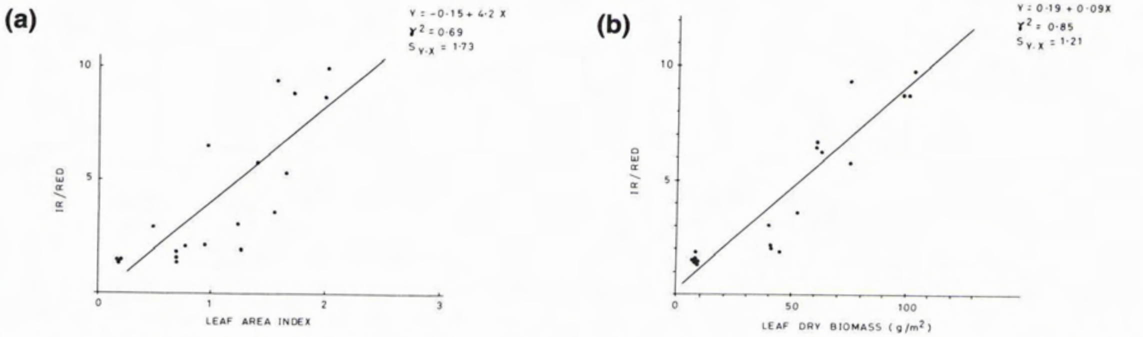

FIG. 5. The relationship between the IR/red reflectance ratio and (a) leaf area index and (b) leaf dry biomass.

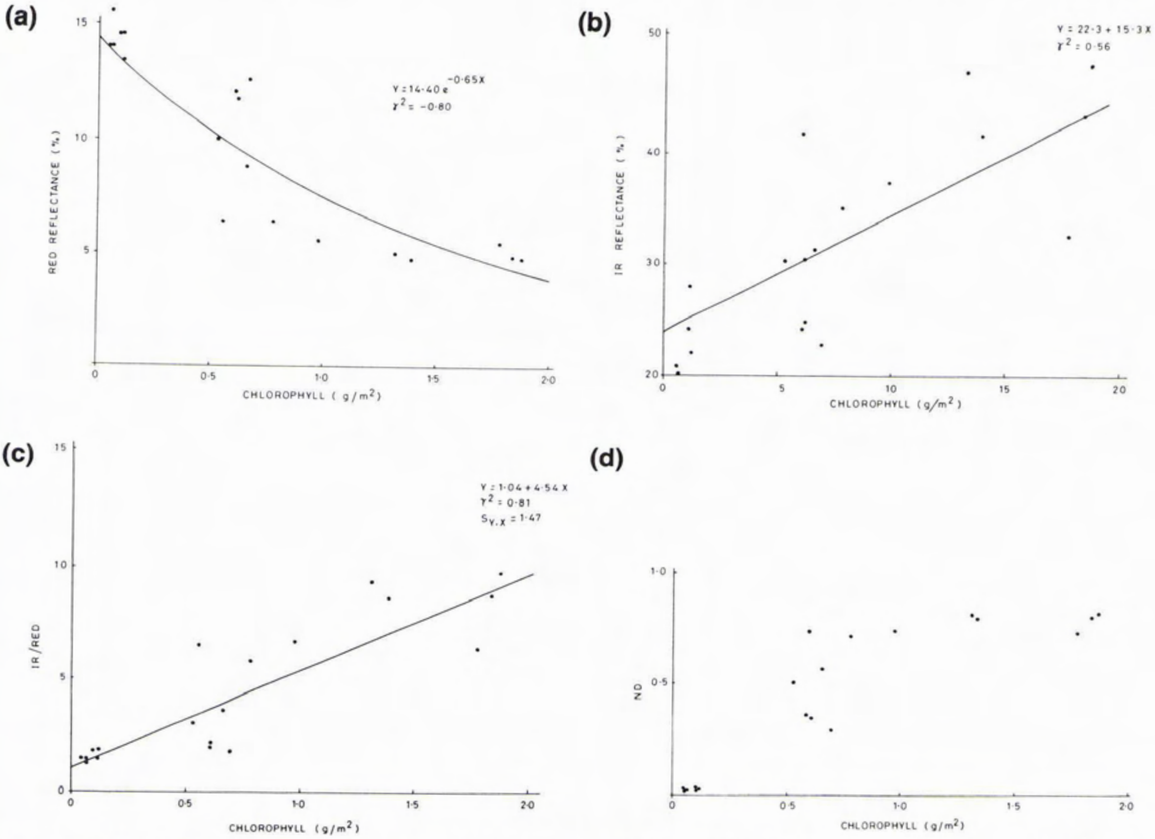

FIG. 6. (a) Red reflectance, (b) IR reflectance, (c) IR/red ratio, and (d) normalized difference (ND) measurements plotted against chlorophyll content in gm^{-2} of ground area. The red reflectance and ND saturates for higher values of chlorophyll. Note the superiority of the IR/red ratio for predicting the chlorophyll content.

the four spectral variables. The mechanism for this spectral manifestation of water stress on the plant canopy is due basically to a reduction in the chlorophyll concentration and leaf area index of the plants (Table 2). The differences in the IR/Red ratio and the ND for the irrigated and stressed chickpea crop is greatest during the 80 to 120 day period. Thus, spectral descriminability in irrigated and stressed plants is enhanced during this period. The maximum difference† in the IR/Red ratio for the stressed and normal crop is as high as 35 percent (Figure 3).

The spectral data were highly related to leaf area

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† The difference is significant at 0.01 level of probability.

index, leaf dry biomass, and chlorophyll content (Table 3, Figures 5 and 6). The ratio IR/red reflectance was the spectral variable most highly correlated with these three physiological parameters. Red reflectance was negatively correlated with leaf area index and dry biomass, whereas the IR reflectance, the IR/red, and the ND increased with increased value of these physiological parameters. Similar relationships between the spectral parameters and leaf area index and leaf biomass has been reported by Tucker *et al.* (1980a) for alfalfa and by Holben *et al.* (1980) for soybeans.

Red reflectance decreased as the chlorophyll content increased (Figure 6a) and saturated for high chlorophyll contents. IR reflectance was linearly correlated with the chlorophyll content (Figure 6b). The IR/red ratio shows a very good linear correlation with chlorophyll content (Figure 6c). The ND shows a nonlinear behavior with chlorophyll (Figure 6d). The saturation behavior of red reflectance and the ND for a high value of chlorophyll content restricts their utility.

The above discussion reveals that, out of the four remote sensing variables, the IR/red ratio has the most potential for assessing chlorophyll content, leaf area index, and leaf dry biomass.

In most instances leaf area index and its duration provide a measure of the net assimilation rate and accumulation of biomass. For a given variety, knowledge of the harvest index or partitioning coefficient between biomass and grain could be utilized for estimating grain yield. Remote sensing can thus supply information about plant growth and development, and potentially about grain yield.

CONCLUSIONS

Hand-held radiometer data were used to monitor chickpea (*Cicer-arietinum L*) canopy growth and development under irrigated and stressed conditions. Spectral parameters can be used to distinguish stressed and normal crop. The IR/red reflectance ratio was linearly and highly correlated to leaf area index, chlorophyll content, and leaf dry biomass. Red reflectance and normalized difference saturated for high values of chlorophyll content, which restricts the utility of these spectral parameters. Spectral monitoring of crop canopies could provide a significant and direct input to a terrestrial vegetation biomass and productivity model.

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Aerial Photography, Inc., a wholly-owned subsidiary, owns a Cessna Stationair 206 aircraft and a Zeiss RMK 15/23 precision aerial photography camera with two film magazines.

Fully-staffed photographic laboratory services are equipped with a Brown Commodore copy camera, two Keuffel and Esser horizontal enlargers and a Saltsman enlarger, vacuum frames and boards, processors, printers, print dryers, and other equipment.

Equipment for analytic triangulation includes a Dell Foster monocomparator, a Wild point transfer instrument, a DEC 1170 floating point processor, and all necessary computer software.

Stereoplotting instruments include six Santoni Simplex II-C and G-6 optical type stereo plotting instruments, a Santoni ortho-photo scope, and two automatic terrain plotting tables.

Interactive Computer Graphics System hardware includes a Synercom central processing unit, four work stations, alphanumeric printers, a Calcomp 960 plotter, and Texas Instruments and Lear-Ziegler mini-computer terminals; while software library includes Kenefick's RABAT, Schut's Block Analytical Triangulation, Synercom's INFORMAP and Synercom/Wild's WILDMAP; as well as terrain engineering programs for automated road design with cut and fill calculations derived directly from stereoplotter input.

The Firm's in-house programmers and analysts have developed software for digital terrain modelling, data base translation, facilities management, and boundary studies.

Woolpert Consultants has performed photogrammetric work for a host of public and private clients, and recent representative contracts include:

- aerial photography and mapping of 1,100 square miles in northern Florida preparing computer generated topographic maps for the Suwannee River Water Management District;
- computer modelling to locate long-lost boundary markers between the states of Ohio, Indiana, and Kentucky; and
- a digital data base/facilities management project for the Dayton Power and Light Co., digitizing the information contained on more than 7,000 construction drawings and developing 30 layers of geographic data with accompanying alphanumeric information.
