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Spectral Response of Rice Plant Canopy

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ABSTRACT

Irrigated rice crop is practised in an area of about 21 million ha. which is about 49% of the country's rice producing area and contributing above 70% to the country's rice production. Due to expansion of irrigation, it has become possible to cultivate rice in dry areas and in dry season.

Increase in the yield of rice crop grown in Punjab, Haryana and Western Uttar Pradesh largely because of assured and regulated water supply. The inherently congenial climatic environment for traditional rice culture in the eastern region is relatively less congenial for modern rice culture involving the use of high yielding varieties and high levels of fertilizers and pesticides.

The main objective of this study was to establish the relationship between spectral reflectance of rice canopy and crop growth. Taking account of the goals of the study and of the rice cover density variation, two fields were chosen for radiometric and agronomic measurements during the period August to November 1997.

A hand held Radiometer (model 100 BX) was used to measure spectral reflectance with four bands corresponding to band 4, 5, 6 and 7 of the Multi Spectral Scanner on board Landsat 1-5. Radiometer with 2π steradian diffuser cap was set upward to measure direct (sun) and diffuse (sky) irradiance with a 15° field of view viewed the canopy with a zenith angle of 57.5°.

Relations among spectral reflectance, and crop growth stages of rice plants grown on irrigated light textured soil in a semi arid region are presented. There was a linear relation

between spectral reflectance and rice plant height (r=0.97), for band 1 (0.45-0.52 μm) reflectance values. On the other hand, in bands 2 (0.52-0.60 μm) and 3 (0.63-0.69 μm), reflectance values decreased until 70 days after planting (DAP) and then increased during the reproductive phase of the crop. This suggests that band 2 is affected by the greenness of the plant. The near infrared band 4 (0.76-0.90 μm) showed maximum reflectance at 59 DAP (panicle initiation stage) and a decline in reflectance thereafter through maturity.

1.0 INTRODUCTION

The production of rice in India has increased over the year keeping pace with the food demand of the country. The growth in production has come largely from the application of scientific knowledge and technologies related to biotechnology and production resource management. The irrigation and water use has been a crucial factor in bringing about the enhancement in rice production and yield. The country has developed large irrigation potential, the efficiency of irrigation and water use is generally low and poor in case of rice, causing concerns with respect to productivity. The rain water in high rainfall plains where rain-fed rice is mostly concentrated is not efficiently utilized.

The irrigated rice growing areas, constitute about 30 % of the gross irrigated area and consumes about 66% of total irrigation water with very low water productivity. The rain-fed rice producing areas have also poor productivity. Rice is a staple food crop, its production has to be enhanced to meet the food requirement of the growing population. It is known that the rice crop requires relatively high water regime for optimal growth and has a limited ability to grow under water-deficient condition, it has to sustain under the looming scarcity of fresh water resource. The constraint of water scarcity and the dire need of enhancing rice productivity enjoin efficient management of on farm water resources and improvement in water-use efficiency.

Rice is a staple food crop of the country and a major diet of the people living in the eastern and southern region of India. The rice area has increased over the years from 30.52 M ha. in 1949-50. reaching about 42 M ha. in 1995 around which it seems to be stablising. It account for 34% of the area planted to food grain crops. The increase in rice area has been accompanied with a proportional increase in coverage under irrigation. Almost the entire irrigated rice area is covered by IR 8 and Jaya. The modern cultivers are responsive to high levels of fertilizers and hence the quantity of fertilizer application has also increased to realise their yield potential. Such a progress in rice production has imparted food security, but in respect of rice producing Asian countries, India is still behind (table 1a). In national scenario of growth of rice production, there is a wide inter and intra regional disparity (table 1 b).

The northern region states have shown a spectacular progress in rice production and productivity as mediated through a rapid increase in rice area and concentration of vital production inputs such as quality seeds, fertilizers and water. The rice crop, fitting in the rice-wheat cropping pattern, has emerged as the dominant kharif crop in the tract, where just three decades back it used to be a minor crop. The key factor is the water supply that has brought about this transformation. Both surface and ground water resources have been developed adequately. The ground water resources, mostly developed under private sector, are amenable to demand driven regulation by farmers. The canal irrigation system developed under public sector have supply driven regulation but a well structured "Warabandi" system has enabled controlled water delivery. With conjunctive utilisation of the two resources, demand based water availability has been ensured to a great extent causing convergence of various production inputs. How assured water availability through

Table 1 a. Area and productivity of paddy in some Asian countries during 1995

Country	Area (M ha)	Productivity (t/ha)
Bangladesh	9.95	2.478
China	31.11	6.017
India	42.81	2.774
Indonesia	11.48	4.343
Japan	2.10	6.012
Myanmar	6.48	3.106
Pakistan	2.09	2.733
Vietnam	6.60	3.636

Source: Agriculture statistics at a glance 1997.

Table 1 b. Area and productivity of rice in various states of India, during 1994-95

Country	Area (M ha)	Productivity (t/ha)
Assam	2.45 (33.8)	1.350
West Bengal	5.77 (24.6)	2.120
Orissa	4.46 (35.5)	1.426
Bihar	4.86 (37.5)	1.297
Madhya Pradesh	5.35 (22.9)	1.208
Uttar Pradesh	5.58 (58.0)	1.859
Jammu & Kashmir	0.27 (90.8)	2.157
Punjab	2.28 (99.2)	3.383
Haryana	0.80 (99.6)	2.801
Gujrat	0.61 (90.8)	1.543
Maharashtra	1.54 (33.8)	1.568
Andhra Pradesh	3.64 (95.0)	2.550
Karnataka	1.30 (99.6)	2.445
Tamil Nadu	2.23 (92.7)	3.394
Kerala	0.50 (53.3)	1.937
Other	1.17	1.658
All India	42.81 (48.6)	1.911

Figures in parentheses show percent coverage under irrigation (1993-94)

Source: Agriculture statistics at a glance 1997.

conjunctive utilisation makes a difference is well exemplified by the differential agricultural development in the western and the eastern Uttar Pradesh.

Compared to the northern region states, those in the other region have shown slower progress, particularly the eastern region states where rice is traditionally and predominantly grown. The ground water resources are not adequately developed. The water delivery from the canal system is not properly controlled in absence of a structured delivery system like "Warabandi" and that delivered to the forms flows field to field instead of through field channels. These conditions portend poor water management and limit the adoption of high input agriculture.

The country has a good endowment of rain water resource and a large proportion (51%) of the rice areas is rain-fed with upland and lowland rice culture. Because of variability of rainfall, the upland rice often suffers from drought during dry spells while the lowland rice suffers both water deficiency during dry spell and flooding due to excessive rainfall and runoff from the upperlying sloping lands. Except in areas of high rainfall with least probability of dry spells and drought, the use of input in the drought/flood prone rice areas is minimal which results in low productivity. However in high rainfall areas, a substantial amount of rain water is wasted before the crop gets established by transplanting.

Remote sensing techniques have the potential to provide information on agricultural crops quantitatively, instantaneously and above all, nondestructive over large areas. In the past decade, knowledge about optical remote sensing techniques and their application to fields such as agriculture has improved considerably. Knowledge of how solar radiation interact with vegetation is necessary to interpret and process remotely sensed data of agricultural and other natural resources.

A lot of research has been devoted to land cover classification and acreage estimation with considerable success. Another field of interest in agriculture is yield estimation.

The accurate estimation of the area planted paddy fields is important in the design of a food supply plan and cultivation programme. It is also expected to be an issue in remote sensing technology in order to calculate the supply and expenditure of the greenhouse effect gases, methane and carbon di oxide, because paddy fields are both a source and sink from the viewpoint of global warning studies. In India, paddy fields are flooded during the rice planting season and occupy large areas.

Research on this topic, however has indicated that remote sensing alone is generally not capable to produce accurate yield estimations. This has prompted scientists to look for other techniques that can be combined with remote sensing data to give better results. One such techniques is crop growth modeling.

2.0 REVIEW

In India, estimates of crop production at national and regional levels are needed early in the growing season to aid agricultural planning. Monitoring the growth of the crop during the growing season can improves the yield estimation (Clevers and vanLeeuwen, 1996). Such monitoring can be a significant task since about 40% of the irrigated land of India is devoted to rice, which is grown under a range of soil and climatic conditions (Michael, 1983),.

Rice is the biggest consumer of water. In large irrigation systems, about 4000-5000 litre of water are required to produce one kilogram of rice under current rice production practices. Irrigated rice occupy about 31% of the gross irrigated areas, consumes about 66% of the total water used in irrigation. In contrast, wheat occupying similar area consumes only 14% water. Although the consumptive use of water by rice may be only a little more than that by nonrice crops, an enormous loss of water occurs in percolation. Excessive percolation loss of water has environmental repercussions by way of rise in water table and waterlogging. In semi-arid and arid areas with low rainfall and high evaporative demands, this process leads to soil salinisation. Irrigation efficiency in irrigated rice production is dismally poor and it needs to be improved to effect conservation of irrigation water.

Remote sensing techniques have proven useful for assessing vegetation distribution and estimating crop yield and total biomass production (Tucker et al 1986., Daughtry, et al, 1992., Delecolle et al 1992). The reflectance spectra of plants in the visible region of the spectrum (0.4-0.7 μm) was the manifestation of the light absorption maxima of different plant constituents (Chappelle et al., 1992). It is essential to understand the correspondence between crop radiance and field parameters such as species, chlorophyll concentration and growth stage to utilize remote observations of crops.

A plant leaf typically has a generally low reflectance in the visible spectral region with a low peak in the visible green at about 0.55 μm because of strong absorption by chlorophylls and other plant pigments which is greatest in blue and red regions (Fig. 1). The reflectance in the near infrared is much higher because of internal leaf scattering and almost no absorption. The transmittance spectrum has the same shape as the reflectance spectrum. The absorption is strong in visible and in the shortwave infrared beyond 1.3 μm, but is nearly zero in the NIR from 0.7 to 1.3 μm.

Leaf spectra generally have the shape and average order of magnitude shown in Fig. 1, leaves of different species of crop demonstrate significantly different spectral signatures. The spectral signature of a crop canopy, as an assemblage of leaves, is a complex result of multiple scattering within the canopy. In recent years, the relationship between canopy radiance and properties of individual leaves, has been studied using canopy models (Cooper et al 1982). However, despite these efforts there is much to learn about the reflectance of crop in the field.

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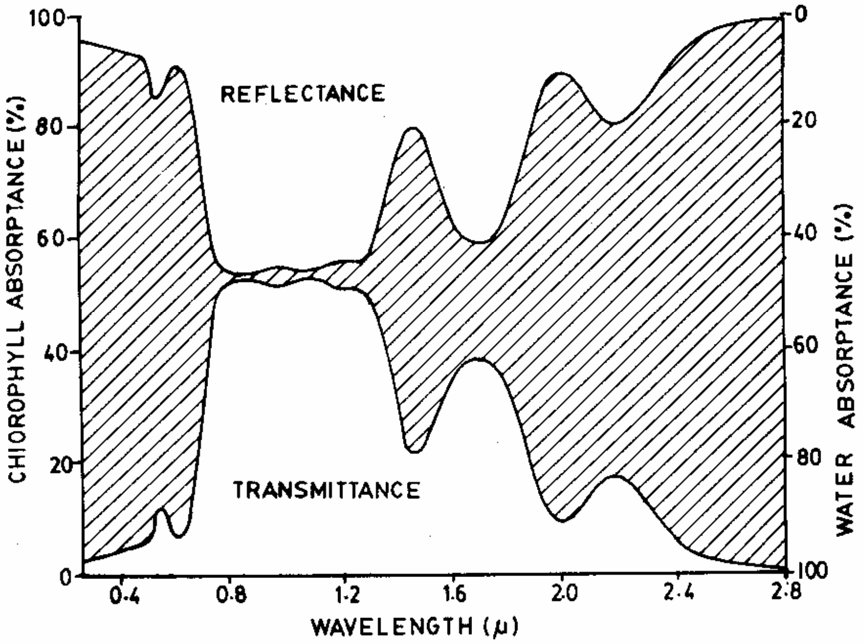


Fig. 1 Reflectance, absorptance and transmittance spectra of a plant leaf (Knipling, 1970)

crops in the field.

Crop growth models are develop to formalize and synthesize knowledge on the processes that govern crop growth. When applied to operational uses such as yield estimation, these models often appear to fail when growing conditions are nonoptimal. Optimal remote sensing can provide such information.

Crop growth models describe the relationship between physiological processes in plants and environmental factors such as solar irradiation, temperature and water and nutrient availability. The main driving force for crop growth in the models as developed is absorbed solar radiation and a lot of emphasis is given to modeling of solar radiation budget in the canopy.

The green pigment chlorophyll is usually an indicator of photosynthetic capacity and productivity (Pinar and Curran, 1996) and could be used to estimate crop yield (Munden et al., 1994). Investigators have demonstrated influence of chlorophyll and water on leaf reflectance (Jacquemoud and Baret,1990., Jacquemoud et al., 1995).

The leaf area index during the growing season is an important state variable in crop growth modelling. Moreover the LAI is a major factor determining crop reflectance and is often used in crop reflectance modelling (Verhoef 1984). The estimation of LAI from remote sensing measurements has received much attention.

Prospective application of remotely sensed data in irrigated agriculture needs spectral-plant parametric relations of crops. The present investigation was carried out to establish the relationships between reflectance of rice plant canopy and crop growth on light textured Indian soils.

3.0 STATEMENT OF PROBLEM

The irrigation and water use has been a crucial factor in bringing about the enhancement in rice production and yield. The country has developed large irrigation potential, the efficiency of irrigation and water use is generally low and poor in case of rice, causing concerns with respect to productivity. The rain water in high rainfall plains where rain-fed rice is mostly concentrated is not efficiently utilised.

The rain-fed rice producing areas have also poor productivity. The irrigated rice growing areas, constitute about 30 % of the gross irrigated area and consumes about 66% of total irrigation water with very low water productivity. It is known that the rice crop requires relatively high water regime for optimal growth and has a limited ability to grow under water deficient condition, it has to sustain under the looming scarcity of fresh water resource.

Remote sensing techniques have proven useful for assessing vegetation distribution and estimating crop yield and total biomass production. Knowledge of how solar radiation interacts with vegetation is necessary to interpret and process remotely sensed data of agricultural and other natural resources. It is essential to understand the correspondence between crop radiance and field parameters and growth stage to utilize remote observations of crops. This study is an attempt to establish the relationships between, the spectral reflectance of rice plant canopy and crop growth in controlled field condition by radiometer.

4.0 STUDY AREA

The field experiment was conducted with rice (CV Pant-4) during kharif season (June-October, 1995) on sandy loam soil at the experimental plot (25 m X 27 m) of the University of Roorkee, India. The plot lies at 268 m above MSL, latitude 29° 52' N and longitude 77° 54' E. The annual rainfall of 1050 mm, is received mainly from July to September. During the experimental period (July to October) air temperature ranged from 18° to 36°C and the ground water level varied from 2.5 m to 4.5 m. The light textured soil of the site has high seepage and percolation rate (60 to 80 mm/ day) (Godkhindi, 1995). The plot was devided into site A and B. The physio-chemical properties and texture of the soil are presented in Table 2.

Table 2.

Physico-chemical properties and soil profile description of experimental site.

Depth (cm)	pH	EC (dS/m)	K mm/day	Textural analysis Sand(%)	Silt(%)	Clay(%)	USDA Class
00-30	7.7	0.12	0.39	66.0	11.0	23.0	Sandy loam
30-60	7.6	0.12	1.01	72.2	12.5	15.3	Sandy loam
60-75	7.5	0.11	1.25	85.2	4.5	10.5	Loamy sand
75-105	7.4	0.10	1.20	94.1	1.7	4.2	Sand
105-120	7.2	0.10	0.20	62.1	1.7	36.2	Sandy clay
120-150	7.1	0.10	--	77.2	12.3	10.5	Loamy sand

EC= Electrical conductivity, K= Hydraulic conductivity

5.0 METHODOLOGY

5.1 MODEL 100BX HAND HELD RADIOMETER

The model 100BX radiometer is a four channel instrument designed for use in the field environment. The unit is battery operated and has a built-in analog meter. The radiometer is supplied with adopters for each channel for 1 degree, 15 degree and a 180 degree field of view. All the four independent channels have separate gain controls. This feature aids in measurement accuracy in cases where there is a large difference in radiance in the four spectral bands. The model has removable optical filters.

The spectral response of each channel is determined by the filters installed and the spectral response of the silicon photodetectors. The optical elements are stamped with the codes which identify each element. Letters or numbers identify the type of filter i.e., M=MSS, T=TM etc. and dots identify the channel number (1 dot = CH A, 2 dot = CH B, 3 dot = CH C and 4 dosts = CH D). All channel outputs are available simultaneously on specified output pins of this connector. Channel outputs are independent of position of the function switch except that the switch must not be in the off position.

5.2 FIELD EXPERIMENTS

The rice crop (rice CV Pant 4) was transplanted randomly 15 cm apart and the plant density was 45 plants/m2 in sites A and B (Chandra and Manna 1989). In addition to rain, the plot was irrigated with good quality water. For uniform distribution of water, irrigation water was applied to the plot for 24 to 26 hours at 20 day intervals. The water use and ponding depth were measured on the reference pegs fixed in the site A and B. The evapotranspiration was estimated by penman method, considering temperature, sunshine hours, humidity, wind speed and solar radiation. The periodical (20 day period) evapotranspiration varied about 80 mm. The depth of water used (irrigation and rain) for the season by crop was 1185 mm (Godkhindi, 1995).

An Exotech Radiometer (model 100 BX Exotech Inc. Gaithersburg, Maryland, USA) with a 15° field of view was used to obtain canopy reflected radiance values in four spectral bands similar to the Landsat TM and Indian Remote Sensing Satellite - Linear Imaging Self Scanner (IRS-LISS) bands (i.e. band 1 (0.45-0.52 μm), band 2 (0.52-0.60 μm), band 3 (0.63-0.69 μm) and band 4 (0.76-0.90 μm)). Radiometer with 2π steradian diffuser cap was set upward to measure direct (sun) and diffuse (sky) irradiance with a 15° field of view viewed the canopy with a zenith angle of 57.5° and was employed to measure the radiance of the rice canopy and a standard panel. The data were collected at + and - 90 azimuth to the sun so that it shows from left and right and the results averaged. This ensured greater consistency in the results and decreased data independence on leaf angle variation and asymmetry between leaf transmittance and reflectance.

The radiometer was held 1 m above the rice canopy centered over the plant row and levelled for a nadir view. Four readings at different points in both sites A and B were taken to minimize errors due to small field of view (Daughtry et al 1992). Measurements were taken under clear skies around 10:30 am. A canopy reflectance factor was calculated as the ratio of the radiance reflected from the crop canopy with that reflected from a reference panel of barium sulfate maintained in a horizontal position above the canopies. The spectral measurements did not start until the plant canopies were substantially developed, i.e., 59 DAP (Days After Planting) to avoid spectral contribution from the soil and water background (Tucker, 1979). Very little soil surface could be seen through fully developed plant canopy.

Crop development, irrigation and hydrometeorological data were recorded concurrently (Table 3). Plant height was measured in the field at 10 days interval.

Table 3.

	Days after planting			
	0-20	20-40	40-60	60-80
Water use (mm)	218.4	359.7	266.2	285.0
Cum. ET (mm)	92.4	79.4	83.7	85.1
Cum rain (mm)	168.4	259.7	266.2	--
Cum irrg. (mm)	50.0	100.0	--	285.0
Plant height (cm)	50.2	79.2	83.9	93.0
Tillers (per plant)	11.8	13.5	14.0	12.0
Rooting depth (cm)	50.2	52.9	55.2	53.9

(Source: Godkhindi, 1995)

6.0 RESULTS AND DISCUSSIONS

6.1 GROWTH PHASES AND DURATION:

The life cycle of a rice plant, beginning with germination of seeds and seedling emergence, passes through:

1. Vegetative phase involving seedling, tillering and stem elongation stages.
2. Reproductive phase involving panicle initiation and development, booting i.e. swelling of the flag leaf sheath towards the later part of the panicle development, heading i.e. emergence of the panicle out of the flag leaf sheath and flowering.
3. Ripening phase which involves grain development and maturation passing through milk, dough and mature grain stages. While the time ranges depend upon weather condition, especially temperature and also the type of cultivers (early, medium and late maturing), the following time frame may be applicable for rice cultivars (Table. 4).

Table: 4

Rice plant growth stages and their duration.

Growth stage	Duration
Germination to seedling emergence	About a week
Seedling stage	3 to 4 weeks
Tillering stage	4 to 5 weeks
Panicle initiation to flowering	4 to 5 weeks
Grain development to maturation	4 to 5 weeks

The traditional photo-period sensitive rice varieties take long duration (160-170 days) to mature. In general, they are tall with harvest index around 0.3 and are highly susceptible to lodging, particularly when nitrogen application exceeds 40 kg/ha. Semi-dwarf varieties, which mature in 125-140 days, were developed to improve resistance to lodging with high N application. Dwarfness improved not only lodging resistance but also the rate of partitioning of photosynthate to grain, obtaining a harvest index of 0.4 or more. Short duration varieties maturing in 110-125 days and very short duration varieties maturing in less than 110 days have been developed and are being adopted to increase cropping intensity. These varieties accumulate relatively lower biomass as they receive less solar energy.

In the tropics, where temperature is favorable for year around rice culture, there appears to be an optimum growth duration for high grain yields. The growth period of short duration cultivars (of less than 110 days maturity) grown under normal field conditions usually does not permit the production of sufficient leaf area to result in production of larger number of panicles with well filled spikelets. The varieties that mature in 130 days or longer seem to have optimum growth duration from the stand point of biomass accumulation. With increased emphasis on crop intensification in both irrigated and rain-fed areas, there would be a need for rice with growth duration around 110 days. Even with the use of short duration varieties, it can be possible to raise productivity by denser planting and higher N application.

6.2 PLANT FEATURES AND WATER NEED

Rice plant, endowed with an efficient mechanism for conducting oxygen through above ground plant parts to roots for respiration, has an intrinsic characteristic to grow under high water regime and is recognised to be semiaquatic. It has a limited adoptability to grow under water deficit conditions. The plant's water need, however, varies with growth stages.

The growth features that determine yield are tiller formation, development of plant height and leaf area, and flowering including fertilisation and grain development. While the tillers are the forerunners of the panicles, leaf area determines the quantity of intercepted radiation. The crop biomass is proportional to the intercepted solar radiation when nutrients, water supply, pests and diseases do not limit growth. It is known that the dry matter in vegetative organs produced upto flowering determines the sink potential of the grains which include panicle number, number of grain per panicle and grain size. Leaf area at flowering is also very important since 75-80% of the carbohydrates in the grains are photosynthesized after flowering. Therefore, the crop growth rate around heading is crucial. It is at this stage that the plants use maximum water, and sufficient water supply is more critical in this period than in others.

While water stress during the vegetative phase may reduce plant height, tiller number and leaf area, the plant can recover from the retarded growth if water is supplied to permit sufficient time for recovery before flowering. Major recovery of grain yield occurs through an increase in number of spikelets per panicle, sensitivity to water stress is most marked during reproductive phase. The most sensitive period for water deficit is from penicle initiation until completion of flowering. Severe water stress at this stage causes high percentage of sterility and drastic yield reduction. Since sterility is irreversible, adequate water supply later during growth is of no avail.

The water use and water stress effect vary at different growth stage of rice plants and inter-varietal difference exist in response to water stress at different growth stages. Therefore remotely sensed data could be used to monitor growth stages for efficient use of water, fertilizer.

6.3 WATER CONTENT AND LEAF TEMPERATURE

The rice crop was at tillering, booting, heading and dough stages in July, August, September and October respectively. Crop growth showed an increasing trend up to September and decreasing trend in October. The water requirement of rice in kharif season (June-October) in Roorkee is 1620 mm (Gupta and Bhattacharya 1963). The average daily consumption of water depends upon growing period and ranges between 5 and 10 mm (De Datta 1981).

The plants rapidly increased in height from 20 to 74 days after planting (DAP) and reached maximum plant height at 88 DAP (Fig. 2). Spectral reflectance was measured in rice canopies on 10 dates (between August and October, 1997) at approximately weekly intervals from early growth stages until maturation. The temporal changes in spectral response are attributed to crop growth.

Rice plants respond differently to solar radiation in the visible and infrared region. Radiation in visible light (0.4-0.7 µm) supports photosynthesis in green plants (Daughtry et al 1992) and hence scattering by green leaves is low. Site A and B (not

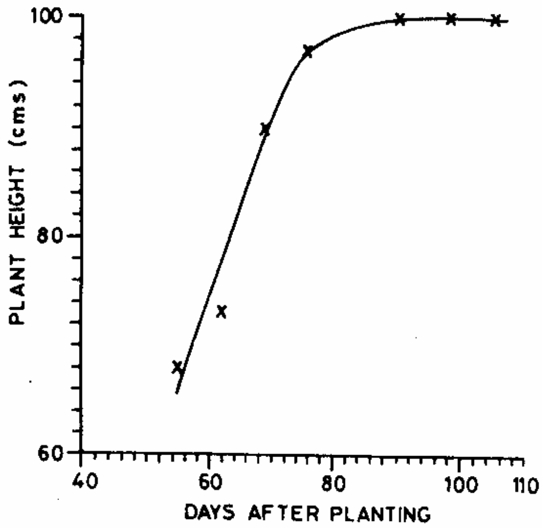


Fig. 2 Plant height versus time during the season expressed as days after planting (DAP).

shown separately) rice plant growth indicate a increasing trend in band 1 (0.45-0.52 μm) reflectance values during full crop cycle (Fig. 3 a). On the other hand bands 2 (0.52-0.60 μm) revealed a decreasing trend up to 68 DAP and then increased in reflectance values during senescence stage of rice crop (Fig. 3 b).

The decrease in reflectance values in band 3 (0.63-0.69 μm) could be due to rapid foliage development (up to 68 DAP) leading to high chlorophyll absorption of red radiance. The increase in red band reflectance beyond 68 DAP was associated with decreased greeness as a result of leaf senescence (Fig. 3 c). Peak reflectance was observed at 59 DAP (panicle initiation) in near infrared band 4 (0.76-0.90 μm). Thereafter, there was a negative relationship of band 4 reflectance with crop growth (flowering and maturity) (Fig. 3 d).

IR/R increased with advanced growth, was maximum at panicle stage (62 DAP) and declined gradually with crop senescence (Fig. 4 a). IR/R ratio depends on the reflectance contrast between the near IR and visible bands. The area of IR/R peak also has high correlation with different crop canopy characteristics e.g. wheat, pulses and soybean in India (Ajai et al, 1985., Patel et al, 1993 and Saxena et al 1991).

Normalized difference vegetation index (NDVI) was calculated as the difference between reflectance factor of a near infrared (0.76-0.90 μm) and visible (0.63-0.69 μm) red band 3, divided by the sum of these two bands. NDVI appear to respond primarily to green vegetation (Baret and Guyot, 1991). An inverse relationship ($r = -0.88$) was found between NDVI and DAP during the reproductive and maturity stages (Fig. 4 b).

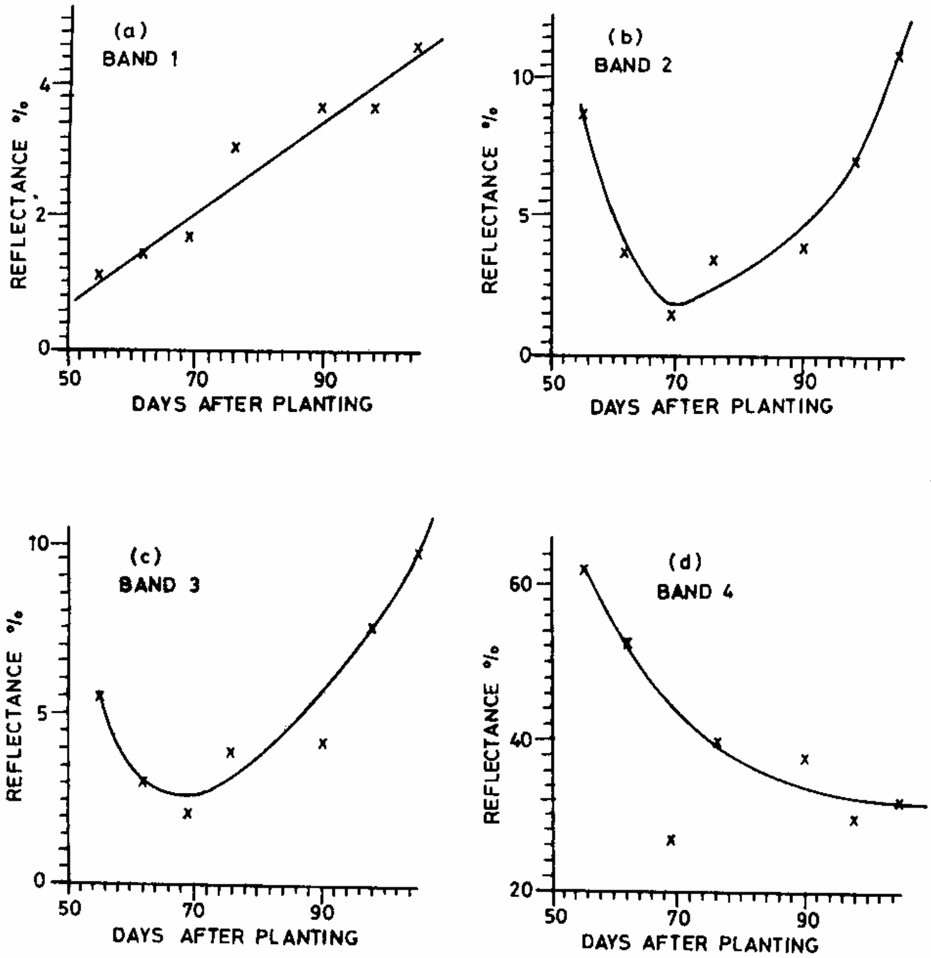
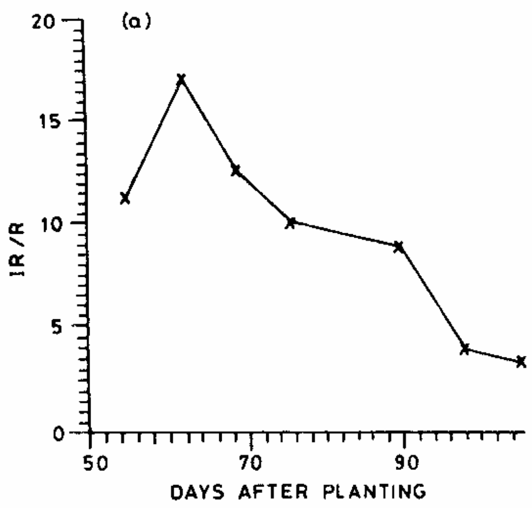


Fig. 3 Reflectance spectra of rice canopies versus days after planting (DAP) in blue (a), yellow (b), red (c) and near infrared (d) bands.



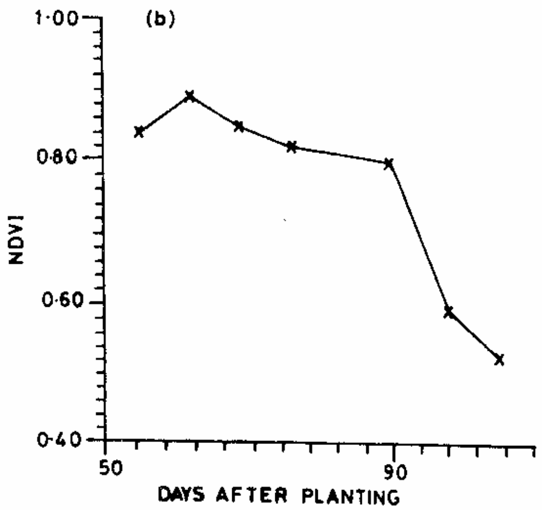


Fig. 4 Plot between IR/R ratio (a) and NDVI (b).

Significant relationship was developed between spectral indices and growth period. The coefficient of correlation for the relationship between crop growth period and reflectance spectra are given in table 5. The correlation coefficient (r) ranged from 0.41 to 0.97 for the plant growth stages and canopy reflectance in single band and ratio spectra.

Table 5. Correlation between plant growth (DAP) and bands 1, 2, 3, 4 and ratio spectra.

	Coefficient of correlation with						
	Band 1	Band 2	Band 3	Band 4	IR/R	NDVI	DAP
Days after planting	0.97	0.41	0.73	-0.71	-0.88	-0.88	1.00

CONCLUSIONS:

Based on the results obtained from the field spectral measurements of rice plant canopies, it can be concluded that, there was a positive linear relationship between band 1 reflectance and days after planting (DAP) throughout the measurement period (56 to 106 DAP). Band 2 and 3 reflectance values were negatively related to DAP until the flowering phase (68 DAP) and positively related to DAP during senescence of the crop. Infrared band 4 was inversely related to DAP after panicle stage.

It appears that the period between 66 to 70 DAP (heading stage) is most suitable for the assessment of rice crop yield based on spectral response. Obtained results indicate that when periodic spectral measurements are available, crop growth can be monitored well and a good estimate of rice yield is possible by using a calibrated crop growth model.

Future sensors having capability to monitor chlorophyll such as LISS-III (Linear Imaging Self Scanner) onboard IRS-1D (Indian Remote Sensing Satellite-1D) would be extremely useful for the regional assessment of crop yield.

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