CS (AR)-26/98-99

SPECTRAL REFLECTANCE, PLANT GROWTH CHLOROPHYLL AND WATER USE RELATIONSHIPS FOR RICE CROP IN SEMI-ARID REGION OF INDIA

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ABSTRACT

The rice producing 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. 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.

The aim of the present study was to establish relationship between spectral reflectance of rice canopy and crop growth, chlorophyll concentrations and water use. Taking account of the goals of the study, two fields were chosen for radiometric and agronomic measurements over the period from flowering to maturity (August to November).

A hand held Radiometer (model 100 BX) was used to measure spectral reflectance with four bands corresponding to band 1, 2, 3 and 4 of the Multi-Spectral Scanner on board Landsat 4 & 5. A high value of spectral response is observed for crop at water level because of multiple scattering effect between crop canopy and smooth water surface and low response is observed when rice plant is high above water level.

There is a functional relationship between spectral reflectance and rice plant growth (r=84), which indicate increasing trend in band 1 (0.45-0.52 um) reflectance values as growth of rice plant till the crop achieve maturity stage i.e., 100 days after planting (DAP) and than decline trend in wilting stage may be due to water stress on the plant. On the other hand bands 2 and 3 revealed decreasing trend up to 68 DAP and than increase in reflectance values during maturity stage. The near infrared band 4 (0.76-0.90 um) showed maximum reflectance at 59 DAP (panicle initiation stage) and a decline in reflectance thereafter through maturity. The peak value of IR/R ratio observed was 16.39 at 62 DAP during growing season and thereafter it decline gradually with senescence of crop.

The rice plant canopies show high chlorophyll 'a' concentration during early growth (vegetative and early reproductive stages) and decreased during the flowering and maturity stages when plant attain its maximum height (92 cms). The rice plant canopy show high

chlorophyll 'a' concentration at 64 and 59 DAP for site A and B respectively. Chlorophyll 'a' concentration is higher in site A plant canopies, than the site B during entire crop cycle.

Negative correlation (r=0.91) has been found between chlorophyll 'a' and band 1. Band 2 and 3 radiance values show bi-phasic linear relationship with chlorophyll 'a' concentrations, negative for early growth and positive for flowering and maturity stages. Positive correlation (r=0.86) have been found between chlorophyll and near IR band 4. While IR/R ratio showed bi-linear relation (r=0.78), one for early growth period up to 62 DAP and another for senescence of crop and water stress.

In site A high water use efficiency causes high chlorophyll, which produces high yield (69.17 Q/ha) compare to low water use efficiency site B (59.53 Q/ha). Results indicate that the period between 66 to 70 DAP is most suitable for the assessment of rice crop yield based on chlorophyll 'a' concentration.

1.0 INTRODUCTION

Rice is a staple food crop, its production has to be enhanced to meet the food requirement of the growing population. 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 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 conjunctive utilisation makes a difference is well exemplified by the differential agricultural development in the western and the eastern Uttar Pradesh

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 rain-fed rice producing areas have also poor productivity. 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. The rain water in high rainfall plains where rain-fed rice is mostly concentrated is not efficiently utilised.

About 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 upper-lying 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.

In 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 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, fertilisers and water. Such a progress in rice production has imparted food security, but in respect of rice producing Asian countries, India is still behind. In national scenario of growth of rice production, there is a wide inter and intra regional disparity.

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

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.

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 modelling.

2.0 REVIEW

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. In large irrigation systems, about 4000-5000 litre of water are required to produce one kilogram of rice under current rice production practices. Although the consumptive use of water by rice may be only a little more than that by non rice 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.

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),.

The life cycle of a rice plant, beginning with germination of seeds and seedling emergence, passes through vegetative phase reproductive phase and ripening phase. Short duration varieties maturing in 110-125 days and very short duration varieties maturing in less than 110 days 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 favourable 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 bio-mass 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.

Remote sensing techniques have proven useful for assessing vegetation distribution and estimating crop yield and total bio-mass production (Tucker et al 1986., Daughtry, et al, 1992., Delecolle et al 1992). 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 modelling of solar radiation budget in the canopy.

Crop growth models are develop to formalise and synthesis 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 non-optimal. Optimal remote sensing can provide such information. In the recent past, several investigators have used regression analysis and modelling approaches for the estimation of vegetation properties through remote sensing considering leaf area index as a key parameter (Clevers, 1989). The regression analysis is based on the reflectance in the red wavelength region decreases whereas in the near infrared region increases when leaf area index increases. In order to establish a relationship between LAI and spectral measurement a large number of LAI measurement, vegetation type are needed at each vegetation site.

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. Significant results were obtained by monitoring biomass and leaf area index during growing season and calibrating the growth model (Choudhury, 1987., Bouman 1992., Curran et al 1992., Price 1993 and Cabot et al 1995).

Recent studies are based on correlation between chlorophyll concentration and reflected radiance in red wavelength (0.69 to 0.74 μm). The reflectance spectra of plants in the visible region of the spectrum (0.4-0.7 μm) is a manifestation of the light absorption maxima of different plant constituents (Chappelle et al., 1992). Therefore It is essential to understand the correspondence between crop radiance and field parameters such as species, chlorophyll concentration and growth stage to utilise remote observations of crops.

The spectral signature of a crop canopy, as an assemblage of leaves, is a complex result of multiple scattering within the canopy. Leaf spectra generally have the shape and average order of magnitude, leaves of different species of crop demonstrate significantly different spectral signatures. 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.

Plant leaf has generally low reflectance in the visible spectral region with a low peak in the visible green at about 0.55 um because of strong absorption by chlorophyll and other plant pigments which is greatest in blue and red regions 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 short-wave infrared beyond 1.3 um, but is nearly zero in the NIR from 0.7 to 1.3 um.

The 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).

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

Water being the vital requirement for the successful raising of the crop, its availability in optimum quantity in the root zone, particularly at the critical stages of the crop growth is essential. Such moisture requirement of crops can either be met from precipitation through rainfall. 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.

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 bio-mass 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 utilise remote observations of crops.

The main objective of the present study was to evaluate interrelationship between reflectance, chlorophyll concentration and water use for the rice plant growth in irrigated light textured soil in semi- arid region in controlled field condition by radiometer. The study area was part of the experimental plot of Water Resources Development Training Centre, University of Roorkee. In view of the goals of the study two fields were chosen for radiometric and agronomic measurements.

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 divided into site A and B. The physio-chemical properties and texture of the soil are presented in Table 1.

Table 1.

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 FIELD EXPERIMENTS

The rice crop (rice CV Pant 4) was transplanted on July 14, 1996 randomly 15 cm apart and the plant density was 45 plants/m^2 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. Crop development, irrigation and hydrometeorological data were recorded concurrently (Table 2). Plant height was measured in the field at 10 days interval.

The radiometer was held 1.25-1.45 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 minimise errors due to small field of view (Daughtry et al 1992). Bare soil reflectance also taken to interpolate data between emergence and first canopy reflectance measurements.

Table 2.

	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)

Measurements were taken under clear skies around10:30am. 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.

For the estimation of chlorophyll 'a', canopy samples were collected from the same portion of the leaves used for reflectance measurement sites. The samples were macerated in 80% acetone with 0.3 gms of sodium bicarbonate and homogenised. The absorption spectra of chlorophyll 'a' was determined using a double beam spectrophotometer. The concentrations of chlorophyll 'a' were calculated from absorbance values at 625 nm, 645 nm and 663 nm.

6.0 RESULTS AND DISCUSSIONS

6.1 PLANT FEATURES AND WATER NEED

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).

Rice plant, has an intrinsic characteristic to grow under high water regime and is recognised to be semi-aquatic. It has a limited adoptability to grow under water deficit conditions. The plant 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 bio-mass 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 up to 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 photosynthesised 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.

6.2 RELATIONSHIP BETWEEN PLANT GROWTH AND REFLECTANCE

The plants rapidly increased in height from 20 to 74 days after planting (DAP) and reached maximum plant height at 88 DAP (Fig. 1). Spectral reflectance was measured in rice canopies on 10 dates (between August and October, 1995) 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. Thomas and Gausman (1977), reported good correlation between reflectance at 0.55 um, where as multiple absorption maxima wavelength are 0.58 um, 0.63 um and 0.67 um for chlorophyll 'a' (Chappelle et al., 1992) and minimum absorption and increased reflectance beyond 0.75 um, primarily a function of leaf structure and scatter (Jacquemond et al., 1996). Site A and B (not shown separately) rice plant growth indicate a increasing trend in band 1 (0.45-0.52 μm) reflectance values during full crop cycle (Fig. 2 a). On the other hand band 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.2 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 green leaf area as a result of leaf senescence (Fig. 2 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. 2 d).

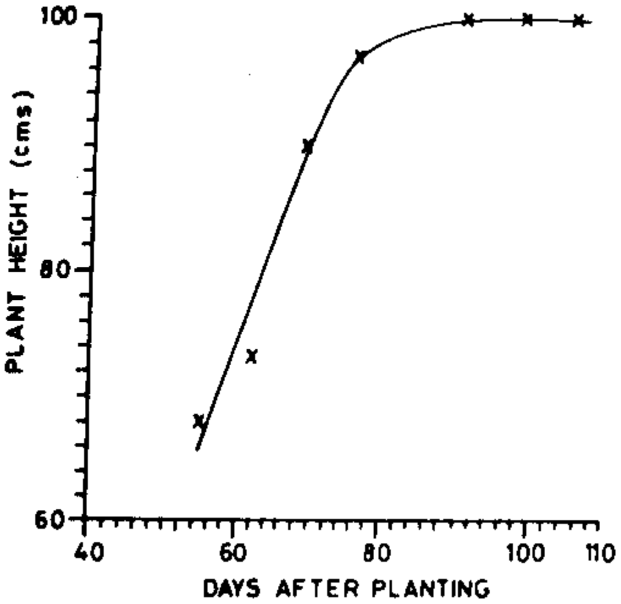

Fig. 1 Relationship between rice plant growth and plant height during season expressed as days after planting

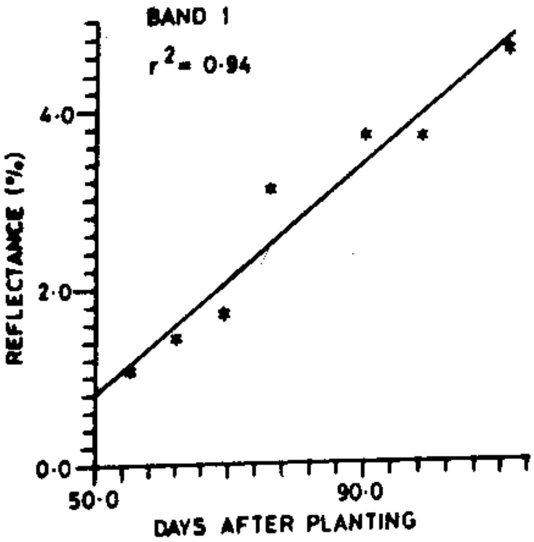

FIG. 2a

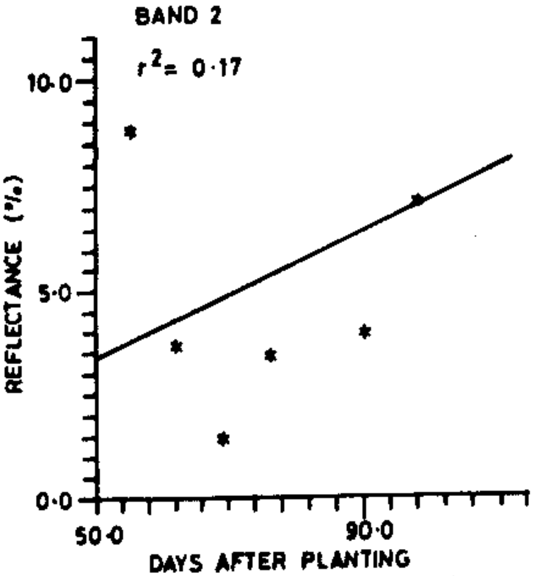

FIG. 2b

Fig. 2 a & b Reflectance spectra of rice canopies versus days after planting (DAP) in Band 1 (fig. a), Band 2 (fig.b)

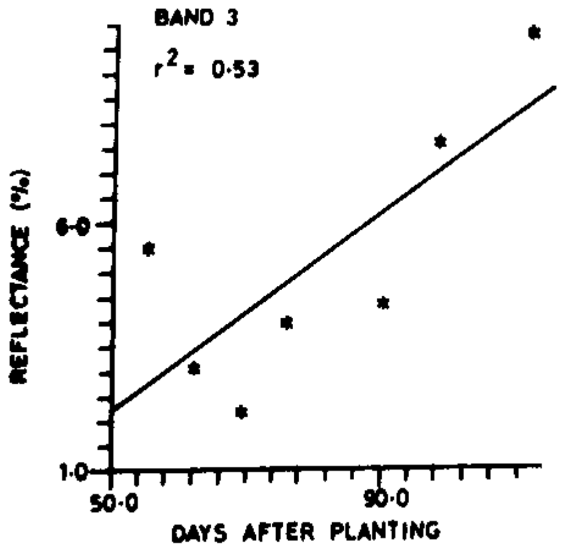

FIG. 2c

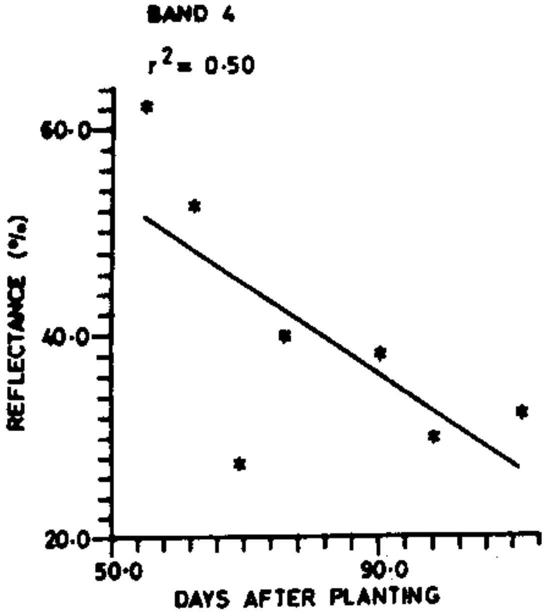

FIG. 2d

Fig. 2 c & d Reflectance spectra of rice canopies versus days after planting (DAP) in Band 3 (fig. c), Band 4 (fig. d).

IR/R increased with advanced growth, was maximum at panicle stage (62 DAP) and declined gradually with crop senescence (Fig. 3 a). IR/R ratio depends on the reflectance contrast between the near IR and visible bands; the IR/R ratio seemed to follow the chlorophyll concentration better than any of the individual bands (Fig. 2). 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).

Normalised difference vegetation index (NDVI) was calculated as the difference between reflectance factor of a near infrared (0.76-0.90 um) and visible (0.63-0.69 um) 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. 3 b). The NDVI was sensitive to vegetative growth early in the season. From about 54 DAP to about 62 DAP, the NDVI increased linearly with time. Above 62 DAP the sensitivity to vegetative change gradually decreased.

6.3 RELATIONSHIP BETWEEN CHLOROPHYLL, PLANT GROWTH AND REFLECTANCE

The chlorophyll 'a' concentration was highest for the first two measurement dates at both sites A and B, corresponding to 62 DAP (panicle stage) for site A and 70 DAP for site B (Fig. 4). It was also observed that 50% heading occurred on 62 and 70 DAP for site A and B respectively.

In general, plant leaf has low reflectance in the visible green at about 0.55 um because of strong absorption by chlorophyll and other plant pigments which is highest in blue and red regions (Fig. 5). The spectral response in the near infrared is higher due to internal leaf scattering and no absorption. The transmittance spectrum has the same shape as the reflectance spectrum. The absorption is strong in visible and in the short wave infrared beyond 1.3 um, but is nearly zero in the NIR from 0.7 to 1.3 um (Knipling, 1970).

Rice plant canopies with high chlorophyll 'a' concentration had a low reflectance in the visible and high reflectance in near infra red. High concentrations of chlorophyll 'a' resulted in the absorption of nearly all of the visible radiation (Curran et al 1991). The correlation between

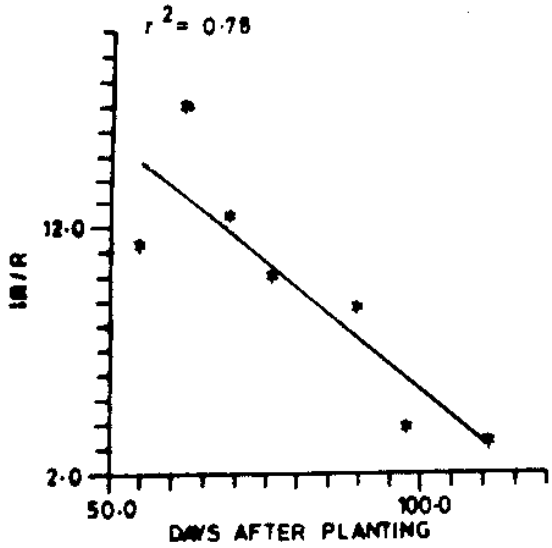

FIG. 3a

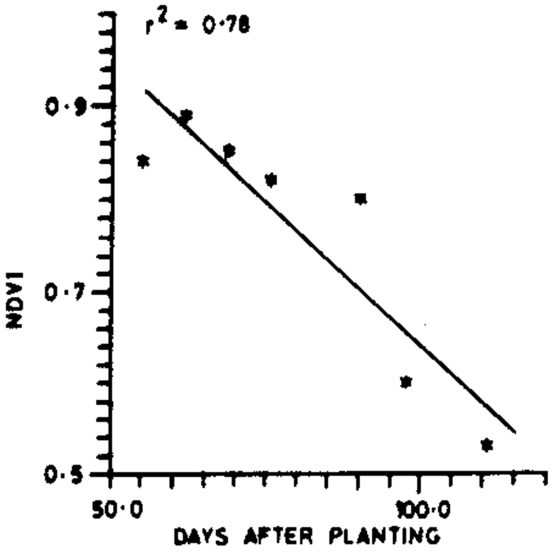

FIG. 3b

Fig. 3 a & b Plot between IR R ratio (a) NDVI (b) and plant growth (DAP).

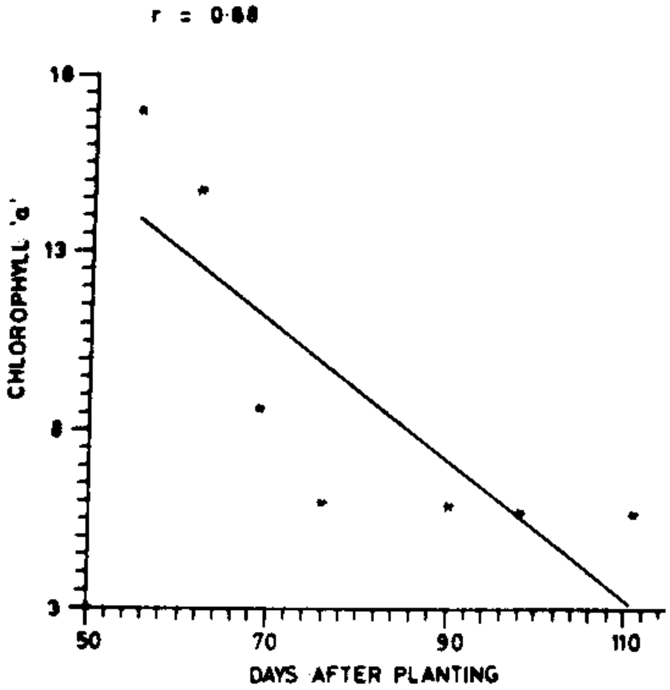

Fig. 4 Rice plant growth versus canopies chlorophyll 'a' concentration.

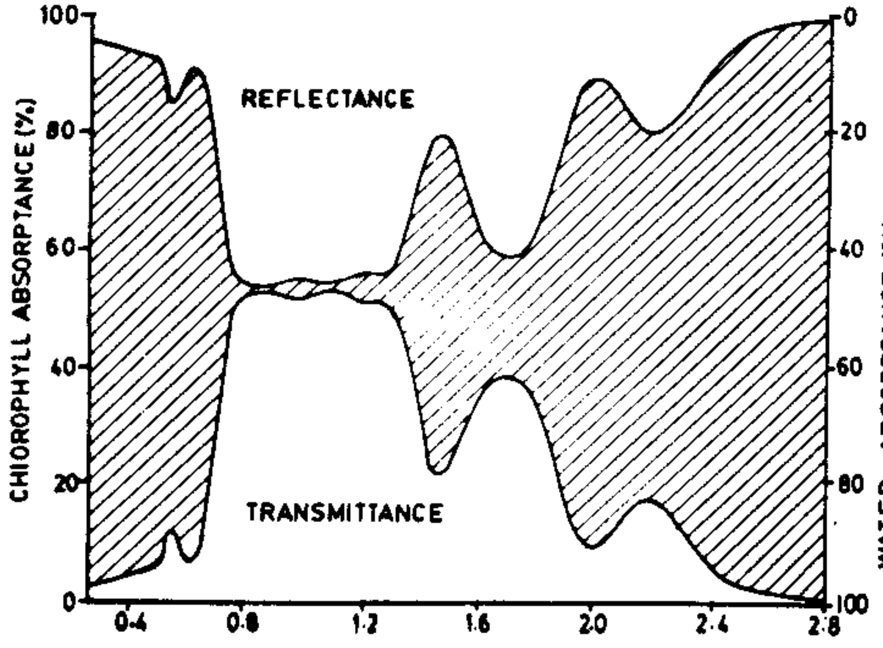

Fig. 5 Reflectance, absorptance and transmittance spectra of plant leaf.

chlorophyll 'a' and reflectance in three of the four bands is shown in Fig. 6 a, b, c and d. Chlorophyll 'a' has maximum absorption in the blue-violet and red wavelengths (Fogg, 1969).

Reflectance of radiation in the visible region by the plant canopies is dependent on the stage of development and chlorophyll 'a' concentration of the canopies. Reflectance decreases rapidly with an increase in chlorophyll 'a' concentration. Visible blue band 1 reflectance values are negatively correlated (r=0.91) with chlorophyll 'a' in all the concentration range (6 to 15.92 mg/l) (Fig. 6 a). The reason may be the high extinction coefficient of the chlorophyll results in a very low reflectance (< 5%) in the visible region (Chappelle et al 1992).

Yellow, red and near infra-red bands show positive relationship with chlorophyll 'a' concentrations, negative for early growth and positive for flowering and maturity stages. The canopy chlorophyll show low absorption in red band 3 (Fig. 6 c) and maximum reflectance in near infrared band 4. Near infrared band 4 reflectance values show positive correlation (r=0.81) with increase in canopies chlorophyll 'a' concentration for reproductive and maturity stages (Fig. 6 d).

The peak value of IR/R ratio was 16.39 at 62 DAP during early reproductive phase; thereafter, it declined gradually with maturity of crop. Chlorophyll 'a' concentration was high during early growth (vegetative and early reproductive stages) and decreased during the flowering and maturity stages. The rice plant canopy show high chlorophyll 'a' concentration at 64 and 59 DAP for site A and B respectively. Chlorophyll 'a' concentration is higher in site A plant canopies, than the site B during entire crop cycle. While IR/R ratio and normalised difference vegetation index (NDVI) showed linear relationship (r=0.78) with chlorophyll 'a' concentration during crop cycle.

The canopy NDVI was insensitive to chlorophyll 'a' concentrations about 7.0 mg/l. Fig. 7 a & b, show a linear relationship between the canopy chlorophyll 'a' concentration and IR/R ratio (r=0.78) and NDVI (r=0.65) respectively. Similar observations were made by Asrar et al (1984) for wheat crop.

Significant linear relationships were developed between spectral indices and chlorophyll 'a' and growth period. The coefficient of correlation for the relationship between crop growth

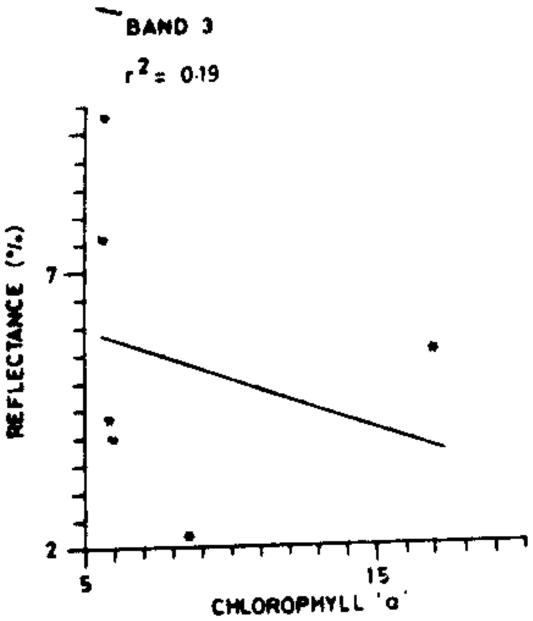

FIG. 6 c

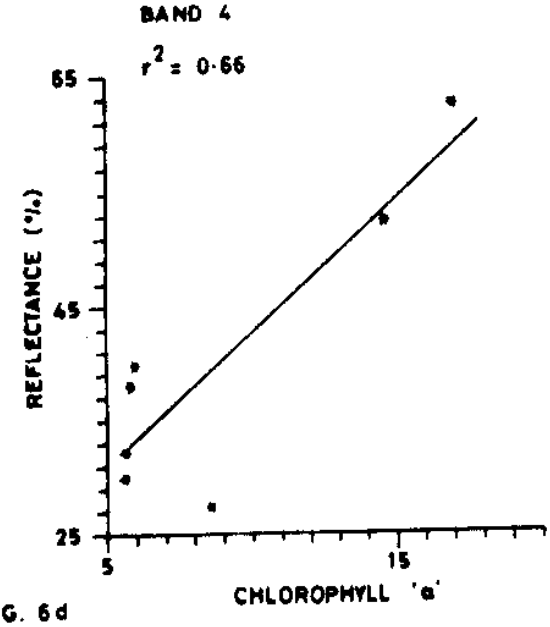

FIG. 6 d

Fig. 6 a & b Canopy reflectance relationship with chlorophyll 'a' in band 1 (fig. a), and band 2 (fig. b).

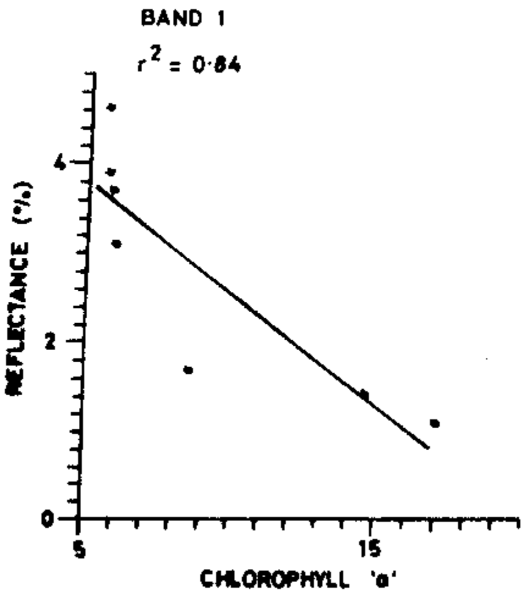

FIG. 6a

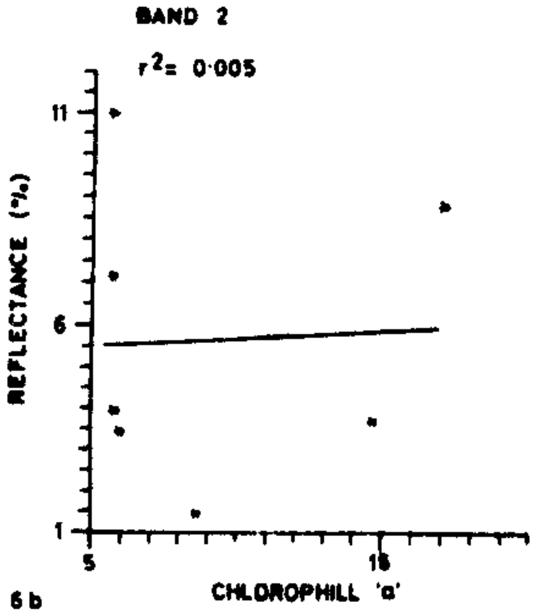

FIG. 6b

Fig. 6 c & d Canopy reflectance relationship with chlorophyll 'a' in band 3 (fig. c), and near infrared (fig. d).

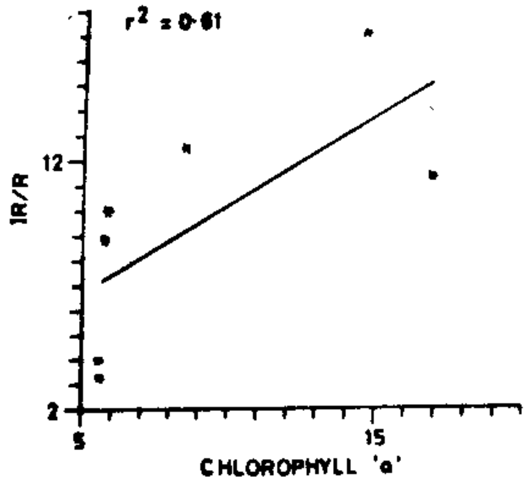

FIG. 7a

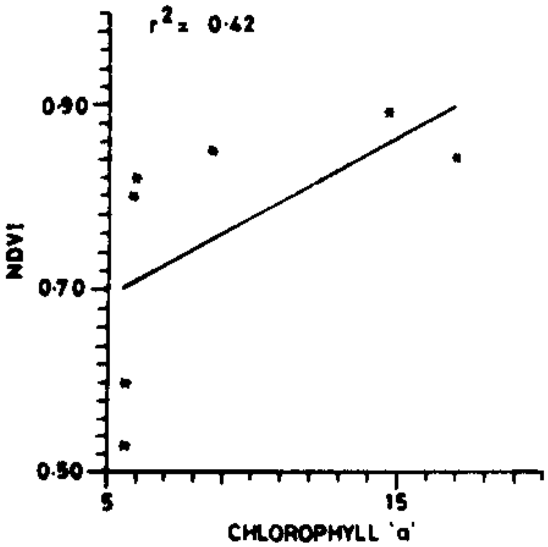

FIG. 7b

Fig. 7 a & b IR/R band ratio (fig. a), NDVI (fig. b) versus canopies chlorophyll 'a' concentration (mg/l).

period, reflectance spectra and chlorophyll 'a' for site A are given in table 3. Statistical summary for the linear relationship between plant growth (DAP) and reflectance spectra and relationship between and reflectance spectra and Chlorophyll 'a' concentration for the rice crop is tabulated in table 4 a and b respectively.

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. The correlation (r) ranged from 0.07 to 0.91 for chlorophyll 'a' concentration with bands and band ratios. There was no band or band ratio, which was significantly related to the level of chlorophyll 'a' (table 3). There may be other factor such as biochemical or leaf structure, which have an influence upon the reflectance.

Table 3. Correlation between plant growth (DAP), chlorophyll 'a' concentration and bands 1, 2, 3, 4 and ratio spectra.

	Coefficient of correlation								
							Site A	Site B	
	Band 1	Band 2	Band 3	Band 4	IR/R	NDVI	Chl 'a'	Chl 'a'	DAP
SiteA, Chlorophyll 'a'	-0.91	0.07	-0.43	0.81	0.78	0.65	1.00	0.98	0.88
Days after planting	0.97	0.41	0.73	-0.71	-0.88	-0.88	0.88	0.80	1.00

Chl = Chlorophyll 'a'

DAP = Days after planting

Photosynthesis and the water economy of a plant are intimately interrelated that water supply is one of the most important factors determining the concentration of chlorophyll in the plant (Fogg, 1969). The substance primarily responsible for light absorption is chlorophyll 'a'.

In site A, high water use efficiency (4.53 kg/ha-mm) produces high chlorophyll 'a' (15.92 mg/l) in rice plant canopies, thereby high yield (69.17 Quintal per hectare) compare with site

Table 4 a. Statistical summary for the linear relationship between plant growth (DAP) and reflectance spectra

	r^2	r
Y = - 0.42 + 0.06 x Band 1	0.94	0.97
Y = - 0.41 + 0.08 x Band 2	0.17	0.41
Y = - 2.75 + 0.10 x Band 3	0.53	0.73
Y = 75.71 + 0.44 x Band 4	0.50	0.71
Y = 3.22 + 0.70 x IR/R	0.78	0.88
Y = 0.61 + 0.02 x NDVI	0.78	0.88

Table 4 b. Statistical summary for the linear relationship between and reflectance spectra and Chlorophyll 'a' concentration for the rice crop.

	r^2	r
Y = 5.06 + 0.25 x Band 1	0.84	0.91
Y = 5.33 + 0.04 x Band 2	0.005	0.07
Y = 6.90 + - 0.19 x Band 3	0.19	0.43
Y = 19.35 + 2.33 x Band 4	0.66	0.81
Y = 26.32 + -0.21 x IR/R	0.61	0.78
Y = 1.25 + - 0.01 x NDVI	0.42	0.65

r^2 = Coefficient of determination

r = Coefficient of correlation

B plants having relatively low chlorophyll 'a' concentration at water use efficiency 3.62 kg/ha-mm, the yield was (59.53 Q/ha).

Dakshinamurthi et al, (1990) had reported that 3.7 kg/ha-mm of water is adequate for the optimum rice production. However results obtained in this study indicate that 4.53 kg/ha-mm is needed to increase chlorophyll 'a' concentration (15.92 mg/l), which may have significant impact on high crop yield (69.17 Q/ha) in site A (table 5). On the other hand, at site B, under low water use efficiency (3.62kg/ha-mm), chlorophyll 'a' concentration was less (14.65 mg/l), thereby lowering rice yield to 59.53 Q/ha (Godkhindi, 1995).

Table 5. Showing chlorophyll 'a' concentration, water use efficiency, yield and its attributes of Rice CV Pant 4.

Site	Chlorophyll 'a' (mg/l)	Water use efficiency (Kg/ha-mm)	50% ear heading	Grain per ear head	Ear head density/m²	Yield (Q/ha)
A	15.92	4.53	66.3	121	287	69.17
B	14.65	3.62	72.0	110	236	59.53

Q/ha = Quintal per hectare

7.0 CONCLUSIONS:

Obtained results indicate that when periodic spectral measurements are available throughout most of growing season, crop growth and chlorophyll can be monitored well and good prediction of yield can be made during heading stage (66 to 70 DAP).

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.

The rice plant canopies show high chlorophyll 'a' concentration during early growth (vegetative and early reproductive stages) and decreased during the flowering and maturity stages when plant attain its maximum height (92 cms). The rice plant canopy show high chlorophyll 'a' concentration at 64 and 59 DAP for site A and B respectively. Chlorophyll 'a' concentration is higher in site A plant canopies, than the site B during entire crop cycle.

Good inverse correlation (r=0.91) has been found between chlorophyll 'a' and band 1. Band 2 and 3 radiance values show bi-phasic linear relationship with chlorophyll 'a' concentrations, negative for early growth and positive for flowering and maturity stages. Good correlation (r=0.86) have been found between chlorophyll and near IR band 4. While IR/R ratio showed bi-linear relation, one for early growth period up to 62 DAP and another for senescence of crop and water stress (r=0.78), and could be useful for the assessment of rice plant chlorophyll concentration which is a best indicator of rice crop growth. Normalised difference vegetation index (NDVI) showed relationship (r=0.65) with chlorophyll 'a' concentration during crop cycle.

In site A, high water use efficiency causes high chlorophyll, which produces high yield (69.17 Q/ha) compare to low water use efficiency site B (59.53 Q/ha). Results indicate that the period between 66 to 70 DAP is most suitable for the assessment of rice crop yield based on chlorophyll 'a' concentration.

It appears that the period between 66 to 70 DAP (heading stage) is most suitable for the assessment of rice crop yield based on chlorophyll 'a' concentration. Obtained results indicate that when periodic spectral measurements are available, chlorophyll 'a' can be monitored well and a good estimate of rice yield is possible. Thus estimate of chlorophyll 'a' could be used to assess yield.

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.

ACKNOWLEDGEMENT:

Author is thankful to Professor S.K. Tripathi, WRDTC, University of Roorkee for giving permission to carry out this work. I am also thankful to Dr. Rani Choubey for her assistant in analysis work.

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