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Research Paper

Hyperspectral remote sensing for monitoring growth of rice (*Oryza sativa*) crop

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ABSTRACT

A field experiment was conducted with 3 cultivars of rice (*Oryza sativa* L.), viz. 'PR 114', 'PR 116' and 'PR 118', under 5 levels of nitrogen (0, 75, 125, 175 and 225 kg N/ha) during the rainy (*kharif*) seasons of 2010 and 2011 at Ludhiana, Punjab. Growth parameters like leaf-area index (LAI), chlorophyll content, number of tillers, chlorophyll-concentration index (CCI) and plant height were recorded. Spectral indices such as normalized difference vegetation index (NDVI), ratio-vegetation index (RVI), moisture-stress index (MSI), green index (GI), leaf-chlorophyll index (LCI) and plant-senescence reflectance index (PSRI), were computed using the multiband spectral data, recorded with Fieldspec®Pro 2000. The spectral indices at booting stage had the best correlations with the crop parameters and had 'R^2' values between 0.68 and 0.85. Spectral indices correlated well with grain yield (R^2 = 0.59–0.85) and 1,000-grain weight (0.64–0.84). But the best correlations were recorded with NDVI and R^2 = 0.82 for grain yield, R^2 = 0.81 for 1,000-grain weight, and with LCI, R^2 = 0.85 for grain yield, R^2 = 0.84 for 1,000-grain weight. The leaf colour index (LCI) and NDVI were found to be the best indices among the selected and can be used to predict plant-growth parameters and yield at the booting stage of rice crop.

***Key words*: Hyperspectral data, Plant growth parameters, Nitrogen, Rice, Spectral indices**

In India, rice is grown in about 45 m ha area with an annual production of 106.4 million tonnes and productivity of 2.2 tonnes/ha of rice. At the current rate of population growth (1.5%) in India, rice demand would increase to 125 million tonnes in the year 2025. This increase in production has to come from enhancement in productivity by effective crop-management practices, despite the declining factors like land, labour and water. Fertilizers especially nitrogen plays a vital role in increasing the productivity of rice. Research has shown that adoption of integrated nutrient-management practices, helps in mitigating the adverse effects of climate change by means of less emission of GHG's from rice fields (Chauhan *et al.*, 2014). In Punjab, during 2011–12, rice was grown on an area of 28.31 lakh hectares with total production and productivity of 108.37 lakh tonnes and 3.8 tonnes/ha respectively (PAU, Ludhiana, 2012).

Effective crop management and yield prediction over a large area would be possible by remote-sensing techniques, through operational models on crop growth and development. The operational models are based on the fact that each crop has a unique spectral signature. Spectral response of a crop canopy is influenced by leaf-area index, per cent ground cover, growth stages, difference in cultural practices, stress conditions, attack of insect-pests and diseases, canopy architecture etc. (Sompal, 1999). Spectral-reflectance properties in different wavelength bands are utilized in crop identification, forecasting the yield and crop-condition assessment. Spectral properties of the plant came into focus as a potential selection tool for grain yield in more recent years (Aparicio *et al*., 2000; Araus *et al.,* 2001; Royo *et al*., 2003; Babar *et al*., 2006). Recent studies have demonstrated the usefulness of optical indices from hyperspectral remote sensing in the assessment of vegetation biophysical variables in agriculture. These indices are, however, the combined response to variations of several vegetation and environmental properties, such as leaf-area index (LAI), leaf-chlorophyll content, canopy shadows and background of soil reflectance. Particular significance to precision agriculture is chlorophyll content, an indicator of photosynthesis activity, which is related to the nitrogen concentration in green vegetation and serves as a measure of the crop response to nitrogen application. The different hyperspectral indices can provide useful information on crop growth and can predict grain yield well in advance. The relationship between nitrogen and chlorophyll amount in vegetation needs to be further explored, because the remote sensing gathers spectral reflectance

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mainly being influenced by chlorophyll content, not directly nitrogen content. It is assumed that both are significantly correlated. Also it should be further investigated to which extent the correlations are crop and site specific and if the results from one location could be transferred to another location (Clevers and Kooistra, 2012). Simple ratio (SR) and normalized difference (ND) indices have been developed and are still widely used for many applications mainly owing to their simplicity. These indices are usually based on the contrast between 2 spectral bands. The challenge is to discover combination of 2 narrow bands providing essential information to the target parameters. Common approach is to calculate all possible combinations and to identify the combination that has highest coefficient of determination (R^2) with the target variable. In this approach the index is valid only for the specific dataset (Thenkabail, *et al*. 2002). Keeping these facts in view, an attempt was made to develop the hyperspectral indices from spectral reflectance and to correlate these indices with growth and yield parameters of rice crop.

MATERIALS AND METHODS

The field experiment was carried out to study the spectral characteristics of 3 varieties of rice under 5 nitrogen application rates during *kharif* (June–November) seasons of 2010 and 2011 at Research farm, Department of Farm Power and Machinery, Punjab Agricultural University, Ludhiana, Punjab. The soil was sandy loam, neutral in *p*H and electrical conductivity, and low in organic carbon, nitrogen and phosphorus and medium in available K. Recommended agronomic practices were followed for raising a healthy rice crop. The experiment was laid out in split-plot design with 3 rice cultivars, viz. 'PR 114', 'PR 116' and 'PR 118', in mainplot and 5 N-treatments, viz. 0, 75, 125, 175 and 225 kg/ha, in subplots, replicated thrice. Sowing of nursery was carried out on 21 and 22 May and transplanting was done on 19 and 21 June during 2010 and 2011 respectively, using seed rate of 20 kg/ha. Entire amount of P, K and one-third N fertilizer was broadcast before last puddling and remaining N was applied in 2 equal splits–3 weeks after transplanting and 3 weeks thereafter as top-dressing.

Data on plant height, leaf-area index (LAI), total chlorophyll, tiller number, etc were recorded at tillering and booting stages of crop, and at the same time, spectral reflectance data were also recorded. The LAI was measured with leaf-area meter LICOR 3100, starting from 25 days after transplanting. Photosynthetic pigments like chlorophyll *a* & *b* were estimated following Hiscox and Israel (1979) using dimethyl sulphoxide (DMSO). Chlorophyll-concentration index (CCI) was recorded using Apogee's CCM 200 instrument. Plant height was recorded by selecting 10 plants randomly from each plot and the values were averaged. Number of tillers were counted and presented as number/m^2.

Collection of spectral data

Spectral reflectance of rice crop was measured using a 512-channel spectro-radiometer (Fieldspec®Pro 2000) with a range of 325–2,500 nm. The instrument acquired hyperspectral data at spectral resolution of 3 nm, which was re-sampled at 1-nm interval after processing of the spectra. The target reflectance is the ratio of energy reflected off the crop to the energy incident on the target $BaSO_4$ plate as the reference panel. Reflectance measurements were taken at 1 m above the crop canopy with the sensor facing the crop and oriented normal to the plant with a 25° field of view (FOV). All data were collected on cloud-free days at near solar noon time. Spectral vegetation indices (VI's) were computed using the reflectance data as shown in Table 1.

Statistical analysis

Regression analysis was carried out between spectral indices and different crop growth and physiological parameters recorded at tillering and booting stage during the 2 years. Multiple-regression equations were developed using step-wise regression techniques using Un-scrambler Software (V.10).

RESULTS AND DISCUSSION

Growth, yield attributes and yield

An increase in plant height, number of tillers/m^2 and LAI was recorded with successive increase in N dose (Table 2). Similar results were also obtained by Abdalla (2012) in which they recorded maximum tillering, leaf-area index, chlorophyll content, number of tillers/m^2, 1,000 grain-weight, number of grains/panicle, panicle length (cm) and the highest grain yield (t/ha) with application of 220 kg N/ha. The yield attributes of rice and grain yield increased significantly with increasing N levels up to 175 kg/ha, but a decrease was noticed in yield and yield-contributing characters beyond this level (Table 2). The highest grain yield was recorded with 175 kg N/ha, followed by application of 125 kg N/ha. Both these N levels resulted in yields which were statistically at par, but significantly higher than the control (no N) and 75 kg N/ha. Bhowmick and Nayak (2000) and Boling *et al.* (2004), reported a increase in yield with increasing level of N from 110 to 156 kg/ha. Statistically non-significant differences were observed in grain yield, ear length and number of grains/spike except 1,000-grain weight, but highest grain yield, ear length, number of grains/spike and 1,000-grain were recorded in 'PR 116' amongst the 3 genotypes. Carotenoid content, chlorophyll concentration index (CCI) and total chlorophyll content recorded at 90 DAT were higher than that of 120 DAT because of crop senescence (Table 3) and differences were non-significant amongst the genotypes for carotenoid content, CCI and total chlorophyll content at 90 and 120 DAT.

Spectral variation

Hyperspectral data has the potential to measure the reflected radiation from many plants, thus making N assessment feasible at canopy level. Most widely used approaches for nitrogen and chlorophyll estimation are primarily based on regressive models. They relate *in-situ* measurements and vegetation indices (VIs). Hyperspectral vegetation indices (HVIs) have greater dynamic range and offer greater opportunity in finding the right index to predict certain biophysical or biochemical variable compared to multispectral data.

Trends in temporal variation of vegetation indices for rice genotypes were nearly identical. The indices derived from visible-near infrared (V-NIR) reflectance region like NDVI, GI, RVI and LCI increased in the early vegetative period, reached at peak during tillering or jointing stage, and declined towards maturity of crop. All these VI's are related with greenness or chlorophyll content of the crops. The trend was reverse in plant-senescence reflectance index (PSRI) and moisture-stress index (MSI), where reflectance decreased from seedling to tillering, remained constant between tillering and heading stage due to full supply of nitrogen and water to the plant and increased rapidly towards crop maturity and beginning of senescence (Table 4). The most visible symptom of plant senescence is yellowing of leaves due to decline in chlorophyll pigments.

Spectral indices and growth parameters

Linear-regression analysis between plant-growth parameters and spectral-vegetation indices at different growth stages indicates that spectral indices recorded at booting stage were correlated better with crop parameters than the tillering stage (Table 5). Results are in agreement

Table 1. Different spectral vegetation indices (VI) computed for the study

Spectral vegetation index	Abbreviation	Equation	Property	Reference
Normalized difference vegetation index	NDVI	$(R_{927}- R_{687}) /(R_{927} + R_{687})$	Green biomass	Thenkabail *et al.* (2000)
Ratio vegetation index	RVI	R_{927}/ R_{687}	Light use efficiency	Thenkabail *et al.* (2000)
Moisture stress index	MSI	R_{1662}/ R_{927}	Water content	Thenkabail *et al.* (2000)
Green index	GI	R_{554}/R_{677}	Green biomass	Zarco-Tejada *et al.* (1999)
Leaf chlorophyll index	LCI	$(R_{850}-R_{710})/ (R_{850}+R_{680})$	Chlorophyll presence	Thenkabail *et al.* (2000)
Plant senescence reflectance index	PSRI	$(R_{680}-R_{500})/R_{750}$	Carotenoid pigments	Sims and Gamon (2002)

R, Reflectance at different wavelengths

Table 2. Effect of varying levels of nitrogen on growth parameters, yield-contributing characters and yield of rice genotypes (mean of 2 years)

Treatment	Tillers/m^2 120 DAT*	Plant height (cm) 120 DAT	Leaf-area index at 90 DAT	Leaf-area index at 120 DAT	Grain yield (t/ha)	Ear length (cm)	Grains/ spike	1,000-grain weight (g)
N level (kg/ha)								
Control	245.2	84.8	2.07	2.74	3.86	23.0	125.0	22.7
75	252.0	89.5	3.13	2.42	4.35	24.4	130.0	23.4
125	278.7	91.6	4.02	2.90	4.74	24.8	137.2	23.8
175	271.1	96.0	4.59	2.96	4.94	25.0	142.2	23.2
225	277.4	93.8	4.74	3.17	4.61	24.5	134.3	23.0
SEm±	1.3	1.41	0.25	0.05	0.12	0.56	1.61	0.9
CD (P=0.05)	3.57	4.66	0.71	NS	0.38	1.65	4.90	0.25
Rice cultivar								
'PR 114'	264.8	92.3	3.85	2.94	4.69	24.8	134.1	22.5
'PR 116'	262.8	94.7	3.52	2.91	4.65	26.7	145.2	24.9
'PR 118'	267.0	86.4	3.76	2.66	4.21	24.5	129.4	22.4
SEm±	0.02	0.14	0.25	0.02	0.04	0.03	0.01	0.39
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	1.23

DAT, Days after transplanting

with Mahey *et al*. (1991) and Kaur *et al.* (2015), who reported that correlation between different plant parameters and vegetation indices were best at 75–105 days after sowing. This might be due to more ground coverage by the crop at this stage as compared to the other growth stages. In early stage, the exposure of soil to the sensor may lead to low correlation. All the spectral indices recorded at booting stage had very high correlation with crop parameters with R^2 values varied between 0.68 and 0.85. However, leaf-chlorophyll index (LCI) was the only vegetation index, exhibiting best correlation with plant height, leaf-area index (LAI), total chlorophyll and CCI. Canopy reflectance, in the visible and near-infrared, is strongly dependent on both structural (e.g. LAI) and biochemical properties (e.g. chlorophyll) of the canopy. Moreover, LAI and chlorophyll content have similar effects on canopy reflectance, particularly in the spectral region from the green (550 nm) to the red edge (750 nm). At the booting stage, total chlorophyll (Chl), plant height, leaf-area index (LAI) and CCI were correlated with LCI, with coefficient of determination (R^2) values of 0.79, 0.85, 0.71 and 0.67 respectively. Results indicated that total chlorophyll content in the rice canopy could be successfully estimated using LCI. Possible explanation could be the red-edge absorption waveband (670 nm) which is very sensitive to total Chlorophyll content (Vigneaua *et al.,* 2011). Previous studies also showed strong relationship between total Chlorophyll content and biomass, and biomass changes influenced the spectral reflectance in the near-infrared at 800 nm. Both red edge absorption and near-infrared waveband are involved in LCI calculation. Therefore, variations in chlorophyll content changes were eventually

Table 3. Effect of varying levels of nitrogen on carotenoids content, chlorophyll concentration index (CCI) and total chlorophyll in rice genotypes (mean data of 2 years)

Treatment	Carotenoids content (%)		Chlorophyll concentration index (CCI)		Total chlorophyll (Chl *a* + Chl *b*) content (%)	
	90 DAT	120 DAT	90 DAT	120 DAT	90 DAT	120 DAT
N level (kg/ha)						
Control	1.19	0.47	10.13	2.61	1.95	0.77
75	1.35	0.45	14.60	2.47	2.07	0.73
125	1.36	0.50	15.19	2.70	2.20	0.83
175	1.48	0.43	18.43	2.52	2.33	0.63
225	1.60	0.50	17.34	2.84	2.56	0.78
SEm±	0.034	0.001	1.01	0.002	0.06	0.003
CD (P=0.05)	0.12	NS	2.87	NS	0.20	NS
Rice cultivars						
‘PR 114’	1.38	0.52	14.97	2.84	2.19	0.88
‘PR 116’	1.32	0.48	14.99	2.91	2.16	0.77
‘PR 118’	1.49	0.41	15.46	2.14	2.32	0.60
SEm±	0.03	0.002	0.001	0.002	0.003	0.003
CD (P=0.05)	0.09	NS	NS	NS	NS	NS

DAT, Days after transplanting

Table 4. Coefficient of determination of linear-regression models between spectral indices, grain yield and 1000-grain weight at tillering and booting stage of rice crop

Vegetation indices	Tillering stage (R^2)		Booting stage (R^2)	
	Grain yield (t/ha)	1,000-grain weight (g)	Grain yield (t/ha)	1,000-grain weight (g)
NDVI	0.41	0.54	0.82	0.81
RVI	0.45	0.45	0.65	0.69
MSI	0.50	0.49	0.59	0.64
GI	0.45	0.42	0.66	0.69
LCI	0.51	0.65	0.85	0.84
PSRI	0.43	0.30	0.63	0.65

NDVI, Normalized difference vegetation index; RVI, ratio vegetation index; MSI, moisture-stress index; GI, green index; LCI, leaf-cholorphyll index; PSRI, plant-senescence reflectance index

Table 5. Coefficient of determination of regression models between plant growth parameters and spectral vegetation indices at tillering and booting stage

Vegetation indices	LAI (R^2)		Chlorophyll concentration index CCI (R^2)		Plant height (R^2)		Total chlorophyll (R^2)	
	Tillering	Booting	Tillering	Booting	Tillering	Booting	Tillering	Booting
NDVI	0.71	0.68	0.35	0.59	0.44	0.75	0.31	0.68
RVI	0.55	0.74	0.42	0.55	0.47	0.72	0.55	0.75
MSI	0.39	0.44	0.49	0.58	0.73	0.74	0.79	0.69
GI	0.51	0.69	0.57	0.71	0.44	0.76	0.51	0.76
LCI	0.72	0.71	0.63	0.67	0.74	0.85	0.61	0.79
PSRI	0.30	0.30	0.46	0.51	0.23	0.66	0.45	0.61

NDVI, Normalized difference vegetation index; RVI, ratio vegetation index; MSI, moisture-stress index; GI, green index; LCI, leaf-cholorphyll index; PSRI, plant-senescence reflectance index

detected by LCI. Our result are in conformity with Rodriguez-Moreno *et al.* (2014), and explains if leaf analyses are complemented with a few additional measures, instantaneous and with a minimal cost, it is possible to deduce the diagnosis using statistical and spatial analysis in the crop.

Spectral indices and yield-contributing parameters

Correlations at tillering stage varies as 0.41–0.51 for VI's and grain yield, and 0.30–0.65 for 1,000-grain weight, but all these spectral indices were best correlated at booting stage with grain yield as well as 1,000-grain weight of rice obtained R^2= 0.59–0.85 for grain yield and = 0.64–0.84 for 1,000-grain weight (Table 5). Amongst various indices studied, best correlation were obtained between NDVI and grain yield (R^2 = 0.82), NDVI and 1,000-grain weight (R^2 = 0.81), LCI and grain yield (R^2 = 0.85), LCI and 1,000-grain wt (R^2 = 0.84). The LCI and NDVI which exhibited best correlation with grain yield and 1,000-grain weight, can be used in decision support system for yield forecasting models.

All spectral indices recorded at booting stage were well correlated with crop-growth parameters (R^2 = 0.68–0.85), however leaf-chlorophyll index (LCI) showed better correlation. The spectral indices had strong correlations with grain yield and yield-contributing characters with R^2 0.59 - 0.85 for grain yield, and 0.64–0.84 for 1,000-grain weight. But, best correlations were noticed between NDVI and grain yield (R^2 = 0.82), NDVI and 1,000-grain weight (R^2 = 0.81), LCI and grain yield (R^2 = 0.85), LCI and 1,000-grain wt (R^2 = 0.84).

It can be concluded that either of NDVI or LCI may be used for estimation of plant-growth parameters and can be potentially used for yield forecasting in rice.

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