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Canopy reflectance spectra of wheat as related to crop yield, grain protein under different management practices

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ABSTRACT

A field experiment was conducted during the winter season of 2010-2011 in a sandy loam soil at the Research Farm of the Indian Agricultural Research Institute, New Delhi, India to study the relationship of canopy reflectance with the yield and protein content of wheat as infuenced by different irrigation and nitrogen levels. Three spectral reflectance indices (SRI) related to canopy photosynthetic area were calculated using spectral reflectance values viz., Red normalized difference vegetation index (RNDVI), Green normalized difference vegetation index (GNDVI) and Simple ratio (SR). The RNDVI, GNDVI and SR increased from Crown Root Initiation (CRI) to booting stage and there after decreased progressively till maturity. Among the three SRIs, GNDVI at milking stage was most closely related to grain yield (r=0.97**) and biomass yield (r= 0.93**) of wheat and at booting stage it was most closely related to the protein content (r=0.90**). The GNDVI was the best index for prediction of grain yield, biomass yield and grain protein percentage in wheat.

Keywords: Yield, grain protein, RNDVI, GNDVI, SR, canopy reflectance

Wheat is one of the most important cereal crops in India which contributes nearly one-third of the total food grain production. Among the various inputs, water and fertilizer (nutrients) are two most important inputs which contribute to wheat productivity (Lenka *et al*., 2009). Wheat crop is highly responsive to nitrogen fertilizer and its response to nitrogen depends on the availability of soil water (Hati *et al*., 2001). The advantage of remote sensing technologies over traditional methods based on field survey is the potential to provide quantitative and timely information on agricultural crops over large areas (Clevers, 1997). Crop yield can be predicted at an early stage of crop growth using various kinds of crop growth models. However, under non-optimal growing conditions, it has been seen that estimates of crop growth and thus yield prediction are inaccurate (Clevers, 1997). In order to get best result in estimation or prediction of crop yield, the growth of crops has to be monitored through out the growing season. Remote sensing can provide information on the actual status of agricultural crops on a regular basis.

Canopy spectral reflectance is used for predicting grain, final biomass and grain protein content in various crops. The more commonly used spectral reflectance indices (SRI) for morphophysiological study of crop plants are simple ratio (SR) and normalized difference vegetation index (NDVI) (Araus *et al*., 2002). The NDVI has also been reported to predict grain yield in winter wheat (Raun *et al*., 2001), and in durum wheat (*Triticum turgidum* L.), (Aparicio *et al*. 2000), Shanahan *et al*. (2001) reported the green normalized difference vegetation index (GNDVI) collected during midgrain filling stage of corn was highly correlated with the yield.

MATERIALS AND METHODS

Study area

Field experiments were conducted during *rabi* (winter) 2010-2011 at the Research Farm of the Indian Agricultural Research Institute, New Delhi, India (77°89'N, 28°37'E, 228.7m asl) with wheat (*T. aestivum,* L.) as the test crop. The climate is semi-arid with warm summer and mild winter. Summers are long (April–August) with the monsoon setting in between (July–September). The soil is sandy loam (Typic Haplustept) with medium to angular blocky structure, non-calcareous and slightly alkaline in reaction (pH= 7.6).

Experimental design

The experiment was laid out in a split plot design with irrigation levels as the main plot and nitrogen sources as subplot factors, replicated three times. The

Table 1: Grain yield, above ground biomass and grain protein content of wheat under different irrigation and nitrogen treatments.

Treatment	Grain yield (kg ha^{-1})	Biomass yield (kg ha^{-1})	Grain protein content (%)
Effect of Irrigation levels			
0.4 IW/CPE	3336b*	9361d	11.39
0.6 IW/CPE	3276b	10764c	11.87
0.8 IW/CPE	3916a	11506b	12.21
1.0 IW/CPE	3969a	11992a	11.62
Effect of Nitrogen sources			
Urea	4458a	13615a	13.07a
Urea+FYM	3751b	11123b	11.58b
FYM	2663c	7979c	10.68c

* Numbers followed by same numbers are not significantly different at pd” 0.05 as per Duncan’s Multiple Range Test

subplot size was 3.5 m´ 5.5 m. Wheat (cv. PBW-502) was grown during the winter season (2010-11). The irrigation levels were I_1 (IW/CPE: 0.4, IW = 6 cm), I_2 (IW/CPE: 0.6), I_3 (IW/CPE: 0.8) and I_4 (IW/CPE: 1.0). The nitrogen sources consisted of N_1: 100 % nitrogen from urea, N_2: 50 % nitrogen from urea and 50 % nitrogen from farmyard manure (FYM) and N_3: 100 % nitrogen from FYM. Nitrogen was applied in split: 50% at sowing, 25% at CRI stage (21 days after sowing) and the rest 25% maximum tillering stage (75 days after sowing). The whole amount of FYM, P and K fertilizers was applied as basal application. The recommended dose of fertilizers for wheat (120:60:60 kg N, P, Kha^{-1}) as per the package of practice suggested by the Division of Agronomy, Indian Agricultural research Institute, India was applied.

Reflectance measurements

The canopy reflectances were measured in the spectral range of 350-2500 nm with 1nm bandwidth with the help of hand held ASD FieldSpec Spectroradiometer (Analytical Spectral Devices Inc., Boulder, CO, USA).The reflectance measurements were made on sunny days between 11.00 and 13.00 hours. The field of view (FOV) was 25° and the distance between the optical head of the Spectroradiometer and the top of the plant was kept at 1 m for all observations. For optimization of ASD instrument, a Spectralon (Labsphere, Inc., Sutton, NH, USA) white panel was used to obtain reference signal prior to canopy reflectance measurement. The canopy reflectances were computed as the ratio of canopy radiances to the radiance from the white reference panel.

Spectral signatures of the wheat crop were recorded at seven phenostages, viz., crown root initiation (CRI), tillering, booting, flowering, milking, soft dough and harvesting stage.

Spectral reflectance indices were calculated as follows, Red normalized difference vegetation index (RNDVI) = $(R_{780}-R_{670}) / (R_{780}+R_{670})$ (Raun *et al.*, 2001), Green normalized difference vegetation index (GNDVI) = $(R_{780}-R_{550}) / (R_{780}+R_{550})$ (Aparicio *et al.*, 2000) and Simple ratio (SR) = (R_{900}/R_{680}) (Gitelson *et al.*, 1996), where R and the subscript numbers indicate the light reflectance at the specific wavelength (in nm). All the above mentioned vegetation based indices (i.e., RNDVI, GNDVI and SR) are related to canopy photosynthetic area.

RESULTS AND DISCUSSION

Grain yield, biomass yield and grain protein content

The grain yield was significantly influenced by irrigation levels (Table 1). The grain yeilds were significantly higher for I_3 (IW/CPE: 0.8) and I_4 (IW/CPE: 1.0) treatments than I_1 (IW/CPE: 0.4) and I_2 (IW/CPE: 0.6) treatments. There was no significant difference in the grain yield of wheat due to I_3 and I_4 treatments and I_1 and I_2 treatments. It indicated that I_3 irrigation level was sufficient enough for wheat under the present condition. Grain yield was also significantly different in the three different nutrient management practices, the highest being in N_1 (100 % N from urea) treatment and lowest in N_3 (100 % N from FYM) treatment. The biomass yield was significantly influenced by levels of irrigation supply, the

Table 2: Variation of RNDI, GNDVI, SR during wheat growth

Treatment	CRI	Tillering	Booting	Flowering	Milking	Dough	Harvesting
Red Normalized Difference Index (RNDI)							
Effect of Irrigation levels							
0.4 IW/CPE	0.296	0.592	0.842	0.809c	0.700	0.541	0.115
0.6 IW/CPE	0.259	0.497	0.874	0.870b	0.667	0.538	0.120
0.8 IW/CPE	0.258	0.490	0.899	0.886ab	0.737	0.631	0.147
1.0 IW/CPE	0.319	0.601	0.885	0.889a	0.747	0.584	0.128
Effect of Nitrogen sources							
Urea	0.338	0.599a	0.924a	0.904a	0.809a	0.660a	0.133
Urea+FYM	0.249	0.608a	0.902a	0.885a	0.745a	0.599a	0.124
FYM	0.262	0.428b	0.799b	0.801b	0.583b	0.462b	0.125
Green normalized difference vegetation index (GNDVI)							
Effect of Irrigation levels							
0.4 IW/CPE	0.370	0.531a	0.716	0.682c	0.604	0.504	0.298
0.6 IW/CPE	0.327	0.467b	0.748	0.726b	0.580	0.490	0.301
0.8 IW/CPE	0.328	0.470b	0.767	0.744a	0.642	0.555	0.338
1.0 IW/CPE	0.375	0.532a	0.747	0.736ab	0.625	0.517	0.303
Effect of Nitrogen sources							
Urea	0.392	0.541a	0.809a	0.773a	0.695a	0.587a	0.333
Urea+FYM	0.334	0.533a	0.762b	0.733b	0.632a	0.521b	0.309
FYM	0.324	0.425b	0.663c	0.661c	0.511b	0.441c	0.288
Simple ratio (SR)							
Effect of Irrigation levels							
0.4 IW/CPE	1.927	4.157	13.750b	11.986b	6.921	3.985	1.342
0.6 IW/CPE	1.785	3.249	18.900ab	16.407ab	5.651	3.780	1.356
0.8 IW/CPE	1.788	3.279	25.378a	18.266a	9.613	5.298	1.441
1.0 IW/CPE	2.050	4.141	22.137a	19.024a	8.769	4.300	1.379
Effect of Nitrogen sources							
Urea	2.102	4.202a	29.546a	21.837a	10.985a	5.576a	1.412
Urea+FYM	1.752	4.271a	20.742b	17.177a	7.537b	4.490b	1.364
FYM	1.809	2.646b	9.836c	10.249b	4.694c	2.955c	1.362

*Numbers followed by same letter in a column are not significantly different at p<0.01 as per DMRT.

highest being in I_4 treatment and lowest in I_1 treatment (Table 1). The biomass yield was also significantly influenced by sources of nitrogen supply. The biomass yield followed the trend similar to grain yield with respect to sources of nitrogen supply. The grain protein content was not significantly influenced by the irrigation levels. However, nitrogen sources had significant effect on grain protein content. The highest grain protein content was observed in N_1 treatment and the lowest in N_3 treatment.

Temporal variation of spectral indices (RNDVI, GNDVI and SR)

The variation of RNDVI, GNDVI and SR during crop growth period are presented in Table 2. The RNDVI, GNDVI and SR increased from CRI to booting stage and there after decreased progressively till maturity. The decrease in RNDVI, GNDVI and SR from booting to grain filling stage has also been reported by Prasad *et al.* (2007). The primary reason for the decreasing trend of

Table 3: Correlation coefficients (r) between grain yield, final biomass and grain protein content with three vegetation indices at different growth stages.

Parameters	Indices	CRI	Tillering	Booting	Flowering	Milking	Dough	Harvesting	Cumulative Indices
Grain Yield(kg/ha)	RNDVI	0.449	0.676*	0.873**	0.734**	0.954**	0.894**	0.444	0.924**
	GNDVI	0.549	0.734**	0.896**	0.819**	0.967**	0.917**	0.793**	0.954**
	SR	0.450	0.685*	0.848**	0.838**	0.927**	0.918**	0.565	0.910**
Biomass (kg/ha)	RNDVI	0.454	0.585*	0.894**	0.790**	0.908**	0.869**	0.407	0.888**
	GNDVI	0.507	0.642*	0.924**	0.886**	0.930**	0.894**	0.782**	0.930**
	SR	0.458	0.583*	0.862**	0.906**	0.885**	0.873**	0.545	0.921**
Protein Content (%)	RNDVI	0.437	0.425	0.845**	0.746**	0.822**	0.765**	0.502	0.776**
	GNDVI	0.484	0.499	0.902**	0.870**	0.877**	0.814**	0.869**	0.860**
	SR	0.422	0.457	0.857**	0.845**	0.834**	0.800**	0.652*	0.885**

*indicate significant at p d”0.05, ** indicate significant at pd”0.01

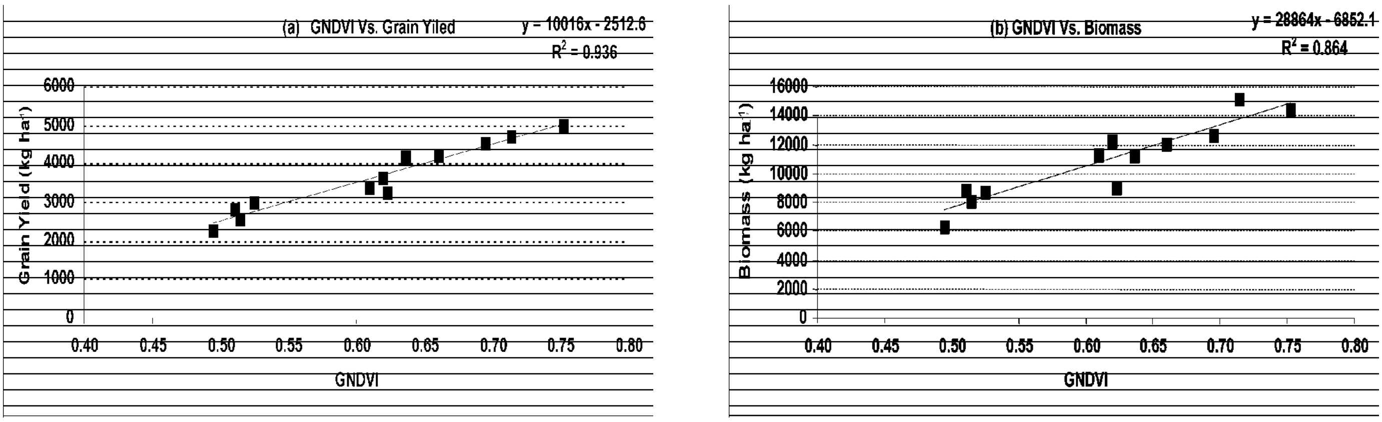

Fig. 1 : Relationship between (a) grain yield (b) biomass yield at milking stage.

RNDVI, GNDVI and SR from booting to maturity is the reduced reflectance in the NIR region and increased reflectance in the visible region due to loss of green tissue with advancement of plant growth (Aparicio *et al.*, 2000 and Prasad *et al.*, 2007). The highest value of RNDVI, GNDVI and SR at booting stage may be attributed to the highest amount of green leaf area and the highest leaf area index observed at this stage.

There was no significant variation in RNDVI, GNDVI, and SR values among irrigation treatments at all stages except at flowering stage for RNDVI, tillering and flowering stage for GNDVI, and booting and flowering stage for SR value. Besides the CRI and harvesting stage, the RNDVI, GNDVI and SR values were significantly influenced by different nitrogen sources. The highest value was observed in N_1 treatment and the lowest in N_3 treatment. The release of nitrogen from FYM was relatively slower in the dry season, which might resulted in poor crop stand and less green leaf area in FYM treatments leading to lower values of RNDVI, GNDVI and SR.

Correlation of spectral reflectance indices with grain yield, biomass and protein content

The correlation coefficient between grain yield and spectral reflectance indices (RNDVI, GNDVI, SR) from CRI stage to maturity stage are presented in Table 3. Significant and positive correlations between grain yield and spectral reflectance indices (SRI) are observed for all stages except at CRI stage and maturity stage, indicating that yield could be estimated well in advance of harvest. The correlation coefficients were highest for the spectral reflectance indices measured at milking stage. Among the three spectral reflectance indices, GNDVI was having highest correlation coefficient with wheat grain yield. This indicated that the green band was better yield predictors than the red band. Aparicio *et al.* (2000) reported that SR was more strongly correlated with yield compared with RNDVI; however, this study showed that RNDVI is better correlated with yield than SR. Cumulative SRI value from CRI to maturity didn't show any improvement in correlation coefficient compared to the correlation coefficient obtained at milking stage. The grain yield was significantly correlated with the GNDVI at milking stage (r=0.97) (Fig. 1). About 94% variation in grain yield of wheat can be accounted for by GNDVI at milking stage. Hence, for early prediction of wheat grain yield, GNDVI at milking stage can be used more successfully.

Significant and positive correlations between biomass yield and SRI was observed for all stages except at CRI stage and maturity stage, indicating that biomass yield could be estimated well in advance of harvest. Similar results have been reported by Verma *et al.* (2010) for wheat. Regression between biomass yield and GNDVI of wheat crop at milking stage showed that 86.4% variation in biomass yield can be explained by GNDVI measured at milking stage (Fig.1).

Significant and positive relationship was observed between grain protein content and SRI at booting, flowering, milking, dough and harvesting stage. Freeman *et al.* (2003) also observed a positive correlation between grain protein content and vegetation indices after jointing. It indicated that the grain protein content can be predicted well in advance. We observed highest correlation coefficient (r= 0.845** for RNDVI; r= 0.902** for GNDVI and r= 0.845** for SR) between grain protein content and SRI at booting stage. (Table 2).

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