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SPECTRAL DATA BASED VEGETATION INDICES TO CHARACTERISE CROP GROWTH PARAMETERS AND RADIATION INTERCEPTION IN *BRASSICA*

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SUMMARY

Four spectral data based vegetation indices viz., infra-red/red (IR/R) ratio, normalized difference (N.D.), greenness index (GNI) and brightness index (BNI) were derived to characterise leaf area index, above ground biomass production and intercepted photosynthetically active radiation in *Brassica* oilseed crop. It was found from correlation study among different spectral indices, plant growth parameters and radiation interception that there was strong relationship between infrared/red and normalized difference with green area index for all the three *Brassica* cultivars whereas these spectral were not significantly correlated with above ground biomass. On the other hand, the brightness and greenness indices were closely correlated with above ground dry biomass as compared to infrared/red ratio and normalized difference. All the four spectral indices were correlated with interecepted photosyntheticaly active radiation (IPAR). The best fit equations relating them were derived, which can be incorporated in the algorithms of crop growth simulation model to estimate plant growth parameters and radiation interception using spectral indices.

***Key words*: *Brassica,* intercepted photosynthetically active radiation, spectral parameters, vegetation indices.**

INTRODUCTION

Of all the oilseed crops, *Brassica* crop occupies a leading place next in importance to groundnut both in area and production. An understanding of the crop response to different environmental conditions under various agro-ecological zones helps us to assess the crop growth and development which would enable us to predict the seed yield. In recent times considerable attention has been paid to relate the remotely sensed spectral data with the crop parameters. With the launching of Indian Remote Sensing Satellite, IRS-IA in March 1988, the use of Remote Sensing has become a proven technology for the assessment of vegetation resources including the crop condition and productivity. Wiegand *et al.* (1979) suggested that canopy spectral reflectance might serve as a tool in predicting photosynthetic capacity of standing canopies. Because the indices derived from the spectral data obtained through the satellites could respond to non-leaf photosynthetically active tissues such as heads, leaf sheaths of cereals and pods of oilseed crops, it can be said that these data could be used to characterise the crop environment apart from assessing the plant parameters. A few attempts were made to characterise crop growth (Wiegand and Richard 1984., Das and Chopra 1989., Smith *et al.* 1996) as well as intercepted photosynthetically active radiation (Subba Rao and Nagaraja Rao 1990 and Subba Rao and Sastry 1992) using spectral data based vegetation indices on different crops. However, no attempt has been made to correlate the spectral indices with the plant parameters which can enable one to assess the leaf area, biomass production and prediction of seed yield well in advance using the satellite data. Thus, keeping in view the lacuna of such data as well as proper regression model equations, the present study was carried out with

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an aim to generate the data and develop regression model equations to predict the seed yield in *Brassica* cultivars.

MATERIALS AND METHODS

A field experiment was conducted in the sandy loam soil at the farm of the Indian Agricultural Research Institute, New Delhi (lat. 28°35'N., long. 77°10'E. and altitude of 228.72 meters above mean sea level) during 1993-94 and 1994-95 *rabi* seasons. Three *Brassica* spp. viz., *Brassica napus* cv. B.O.54, *Brassica juncea* c.v. Pusa Bold and *Brassica campestris* c.v. Toria-T9 were sown on three dates at 14 days intervals starting from third week of October. The sowing dates for first, second and third sowing during 1993-94 were 23rd Oct, 3rd Nov. and 16th Nov. while in 1994-95 these dates were 15th Oct., 29th Oct and 12th Nov.

The experiment was laid out in randomized block design with three replicates and size of each plot was 8 x 5 m. The plant samples were collected at periodic intervals of ten to fifteen days to measure leaf area index, pod area index, above ground biomass and its partitioning. The leaf area was measured using the leaf area meter (Model LI-3100 Li-Cor, USA)

The surface area of pod was estimated by geometrical measurement of the dimension of the pods by assuming the pod shape to be nearly cylindrical. The length of the pod was measured by a scale and a vernier callipers was used to measure the diameter of the pod. Surface area of the pod was determined with the help of formula, π x length x diameter. The sum of leaf area and pod area index was considered as green area index, which was correlated with different spectral indices. A line quantum sensor (LI-19B) with integrator (LI-188B) was used to measure photosynthetically active radiation (400-700nm). Spectral reflectance on crop was measured at weekly intervals with the help of spectroradiometer by keeping the sensor inverted at 50 cm above the canopy. After every two observations, irradiance was recorded. The data on measured reflectance were used to calculate the four spectral indices for understanding the relationship of crop growth and yield with spectral characteristics as illustated below.

Infra-red/Red ratio (IR/R)

The ratio of near-infrared (800 to 1100 nm corresponding to band MSS7) to visible red (600 to 700 nm corresponding to band MSS5) radiation was calculated by dividing infra-red by red.

Normalized Difference (ND)

Normalized Difference is the ratio of difference between the near infra-red and red bands to their sum (Deering *et al.*, 1975).

ND = (IR-R)/(IR+R)

Greenness Vegetation Index (GNI)

GNI = b1 MSS4 + b2 MSS5 + b3 MSS6 +b4 MSS7

Where b1, b2, b3 and b4 are the weightages to be given to the four MSS bands for a particular crop. For *Brassica* spp., these values were found to be -0.283, -0.660, -0.577 and 0.388, respectively by Subba Rao (1987) and were used for the present study.

Soil Brightness Index (BNI)

BNI = al MSS4 + a2 MSS5 + a3 MSS6 + a4 MSS7

Where al, a2, a3 and a4 are derived (from bare soil) weightage coefficients and depend on the soil type. For sandy loam soils of I.A.R.I these values were found to be 0.332, 0.603, 0.675 and 0.262, respectively by Subba Rao (1987) and were used for the present study as the soils were the similar.

Intercepted Photosynthetically Active Radiation(IPAR)

The intercepted photosynthetically active radiation was computed using the following relationship:

IPAR (whole canopy)= Incident radiation on the canopy - reflected radiation by the canopy-transmitted radiation to the ground + reflected radiation from the ground.

To understand the relationships between plant parameters like green area index, dry biomass, radiation interception and different spectral indices, correlation matrix was computed from pooled data of both the seasons separately for all the cultivars using "Microsta" software program.

RESULTS AND DISCUSSION

The leaf area index (LAI), pod area index (PAI), above ground biomass and grain yield were highly affected by dates of sowing, delayed sowing resulting in lower peak values in all the cultivars in both seasons (Table 1). The reduction in crop growth parameters and yield in the late sown crop in both the seasons may be attributable to the fact that the late sown crop (third sowing) was exposed to relatively higher mean temperatures (3 to 4°C) and higher evaporative demand during the vegetative and reproductive phases of the crop growth as compared to the first and second sown crop. The higher temperatures might have enhanced the respiration rate during the seed filling stage and restricted the pod area development. The profound effect of the ambient environmental conditions on the seed yield is quite evident from Table 1. The reduction in the seed yield in the B.O. 54 cultivar was of the order of 5.1 and 4.4 q/ha from first sowing to the third (late) sowing amounting to 29 and 24 per cent in the first and second season, respectively. A similar decrease in the seed yields was observed in cultivar Pusa Bold in both the seasons wherein the reduction was found to be 23 and 17 per cent in the third sown crop as compared to the first sown crop in the first and second crop seasons, respectively. Interestingly, the reduction in the seed yield with the delayed sowings in the cultivar Toria T-9 was marginal and was of the order of 6 and 8 per cent in both the seasons, respectively. However, the yields were found to be lower as compared to the other two cultivars, obviously because Toria T-9 is recommended for the early sown for the Delhi region.

Table 1. Maximum leaf area index, pod area index and maximum biomass production in three cultivars as influenced by sowing dates.

Cultivars:	Leaf area index		Pod area index		Above ground biomass (g m^{-2})		Seed yield (q/ha^{-1})	
	I	II	I	II	I	II	I	II
B.O. 54								
1st sowing	6.9	7.1	2.1	2.3	1690	1852	17.3	18.3
2nd sowing	6.6	6.8	1.9	2.1	1635	1766	19.6	16.9
3rd sowing	5.6	5.9	1.6	1.7	1361	1473	12.2	13.9
Mean	6.48		1.95		1629.5		15.7	
S.E.	0.24		0.19		74.92		0.94	
Pusa Bold								
1st sowing	6.5	6.9	3.0	2.9	1815	1976	20.1	19.5
2nd sowing	5.8	6.1	2.5	2.7	1664	1696	17.5	18.0
3rd sowing	5.1	5.3	2.4	2.5	1460	1531	15.4	16.1
Mean	5.95		2.66		1690.1		17.6	
S.E.	0.28		0.10		76.66		0.76	
Toria-T9								
1st sowing	3.9	4.1	1.9	2.0	1206	1293	14.6	15.2
2nd sowing	3.4	3.7	1.6	1.9	1168	1275	14.5	14.9
3rd sowing	2.5	3.4	1.5	1.6	1165	1187	13.7	13.9
Mean	3.5		1.75		1215.6		14.4	
S.E.	0.23		0.09		22.55		0.24	
POOLED								
Mean	5.31		2.12		1511.8		15.9	
S.E.	0.35		0.11		61.5		0.56	

I : First crop year season (1993-94) **II : Second crop year season (1994-95)**

To understand the variation of spectral indices viz., infra-red/red ratio (IR/R), normalized difference (ND), greenness index (GNI) and brightness index (BNI) in relation to crop growth at different growth stages, the spectral reflectance was measured throughout the crop growth period at weekly intervals and the variation of diffeent spectral indices from the pooled data of the two seasons and the three sowing dates is depicted in Fig.1. It can be seen from the figure that there were two peaks of IR/R and ND, one before the canopy turned yellow due to flowers and the other during seed filling period when the canopy was full of green pods with no flowers. Obviously, due to the yellow crop canopy of flowers, there would be higher reflection as compared to the green canopy.

The greenness index followed the general pattern of growth. It increased as the plants grew and declined with crop canopy coverage. The depression due to flowering was not prominent in this index unlike the other two indices discussed earlier. Thus, in contrast to the IR/R and ND, the greenness index and the brightness index showed a reverse pattern i.e., these values decreased as the canopy developed and attained the lowest values during the period of maximum canopy coverage.

The green area index (leaf area + pod area), above ground dry biomass and intercepted photosynthetically active radiation (IPAR) undoubtedly, govern the crop growth and yield to a greater extent especially when the crop is grown under not short of water conditions as was the case in the present study. Since direct measurement of these parameters are time consuming, destructive and tedious, an attempt has been made to make the quantitative estimates of these parameters using different remotely sensed spectral indices. It is revealed from the correlation matrix (Table 2) that IR/R and ND had a positive relationship with the green area index (GNI) in all the cultivars whereas the brightness and greenness indices were closely correlated with the above ground biomass. But, all the four indices were significantly correlated with the intercepted photosynthetically active radiation (IPAR). Hence, interrelating different significant parameters and spectral indices in case of two cultivars B.O. 54 and Pusa Bold (as shown in Table 3) regression equations were derived.

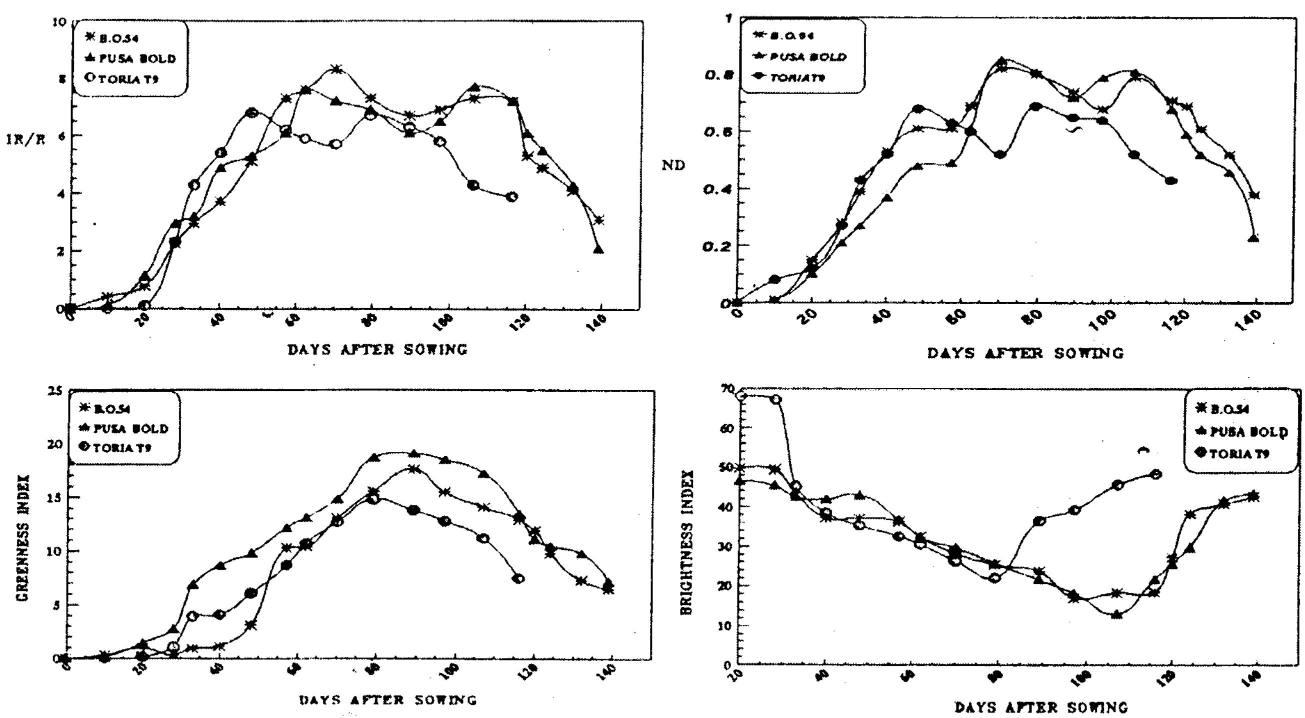

Fig. 1. Variation of spectral indices in three *Brassica* cultivars

Table 2. Correlation matrix of intercepted photosynthetically active radiation (IPAR), green area index (GAI), biomass and different spectral indices (IR/R,ND,GNI, & BNI).

	IPAR	GAI	Biomass	IR/R	ND	GNI
B.O. 54						
	IPAR	GAI	Biomass	IR/R	ND	GNI
GAI	0.578					
Biomass	0.658	0.237				
IR/R	0.638*	0.805*	0.216			
ND	0.717*	0.797*	0.183	0.913		
GNI	0.870*	0.487	0721*	0.724	0.668	
BNI	0.806*	-0.666*	0.728*	-0.729	-0.778	-0.679
Pusa Bold						
	IPAR	GAI	Biomass	IR/R	ND	GNI
GAI	0.544					
Biomass	0.698	0.241				
IR/R	0.670*	0.868*	0.287			
ND	0.650*	0.840*	0.472	0.907		
GNI	0.860*	0.678*	0.871*	0.725	0.867	
BNI	0.881*	-0.776*	0.616*	-0.775	-0.884	-0.909
Toria-T9						
	IPAR	GAI	Biomass	IR/R	ND	GNI
GAI	0.569					
Biomass	0.687	0.633				
IR/R	0.659*	0.693*	0.120			
ND	0.644*	0.887*	0.273	0.857		
GNI	0.790*	0.138	0.760*	0.487	0.297	
BNI	0.939	-0.487	-0.691*	-0.791	-0.779	-0.689

* Significant at 5% level of significance.

Table 3. Regression equations between green area index (GAI), above ground dry biomass, intercepted photosynthetically active radiation (IPAR) and different spectral indices (IR/R, ND, GNI, BNI).

Cultivar: B.O. 54									
(i)	GAI	=	$0.752-0.135\,(IR/R)^2$	N	=	36,	r	=	0.92
		=	$0.518 + 0.309\,(ND) - 0.97(ND)^2$	N	=	36,	r	=	0.91
(ii)	Biomass	=	$0.88^* \,Exp(-0.0016^* GN)$	N	=	36,	r	=	0.98
		=	$0.003 - 163.5(BNI) + 2.70(BNI)$	N	=	36,	r	=	0.64
(iii)	IPAR	=	$22.8+15.9(IR/R)-1.33(IR/R)^2$	N	=	36,	r	=	0.56
		=	$39.7^* \,Exp(0.885^* \,ND)$	N	=	36,	r	=	0.72
		=	$0.90 + 8.55\,(GNI)- 0.28(GNI)^2$	N	=	36,	r	=	0.76
		=	$104.3-1.49(BN)+0.0091(BNI)^2$	N	=	36,	r	=	0.68
Cultivar: Pusa Bold									
(i)	GAI	=	$0.834-0.125(IR/R)^2$	N	=	36,	r	=	0.87
		=	$0.712+0.803(ND)-0.847(ND)^2$	N	=	36,	r	=	0.85
(ii)	Biomass	=	$0.81^* \,Exp(-0.0071^* \,GN)$	N	=	36,	r	=	0.87
		=	$0.045 - 175.3(BNI) + 2.43(BNI)^2$	N	=	36,	r	=	0.72
(iii)	IPAR	=	$21.8+14.9(IR/R)-0.91\,(IR/R)^2$	N	=	36,	r	=	0.62
		=	$39.7^* \,Exp(0.753^* \,ND$	N	=	36,	r	=	0.63
		=	$0.79 + 9.63(GNI) - 0.35(GNI)^2$	N	=	36,	r	=	0.92
		=	$107.3-11.79(BNI)+0.0073(BNI)^2$	N	=	36,	r	=	0.69

The idea of devleoping these regression equations was to see whether one could use these spectral indices computed using remotely sensed spectral signatures to assess the GNI, biomass and IPAR which would eventually avoid the field measurements especially over a very large area of hundreds or thousands of hectares of cropped land. Interestingly, the regression equations were second-degree polynomials or exponential equations. But, these equations need to be further validated for different soil types since BNI is soil dependent index.

Similarly, an attempt has been made here to assess the seed yield using the peak values of IR/R and ND, which represent the spectral signature more or less of the maximum biomass produced (Table 4). The individual correlation coefficients were found to be of the order of 0.80 which were found to be significant at 5 per cent level. From these regressions, it can be envisaged that the seed yield could be predicted approximately, by obtaining one time spectral data from the satellite coinciding with the maximum biomass production in the farmers' fields. The accuracy may be improved if suitable models incorporating the harvest index were incorporated as input in the regression models provided the information on the varieties sown over different zones were available.

Thus, the above results clearly indicate the relationship of the spectral signatures with the plant growth and development. Also these studies indicate the possibility of using the spectral data from the remote sensing satellites to assess the leaf area index, biomass and the seed yield in *Brassica* crop. These studies if extended further, would enable us to use the spectral data over larger area of the entire country. Since the direct measurement of plant growth parameters are time consuming, tedious and destructive, the relationships betwen spectral indices, IPAR and plant growth parameters can be incorporated in the algorithms of dynamic crop simulation models to characterise radiation and crop growth parameters which would be useful in forecasting the yield well in advance with a geat accuracy.

Table 4. Regressin equations between peak values of infra-red/red radiation (IR/R) and normalised difference (ND) and grain yield (GY, q/ha) :

Seed yield (GY) and IR/R :										
(i)	B. O. 54	:	GY	=	3.11 (IR/R) -	4.82,	r	=	0.78	
(ii)	Pusa Bold	:	GY	=	3.81 (IR/R) -	3.81,	r	=	0.81	
(iii)	Toria-T0	:	GY	=	3.52 (IR/R) -	7.74,	r	=	0.79	
(iv)	POOLED	:	GY	=	3.48 (IR/R) -	4.25,	r	=	0.82	
Seed yield (GY) and ND :										
(i)	B. O. 54	:	GY	=	36.71 (IR/R) -	9.31,	r	=	0.72	
(ii)	Pusa Bold	:	GY	=	32.21 (IR/R) -	8.21,	r	=	0.84	
(iii)	Toria-T0	:	GY	=	28.71 (IR/R) -	4.12,	r	=	0.82	
(iv)	POOLED	:	GY	=	38.73 (IR/R) -	15.37,	r	=	0.79	

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