Relationship between spectral vegetation indices and crop parameters of maize under nitrogen and water stress

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ABSTRACT

Field experiments were conducted at the Tamil Nadu Agricultural University, Coimbatore, Tamilnadu, India during *kharif* and *rabi* season of 2014 with maize crop (TNAU maize hybrid Co 6). To ensure the stressed environment, the crop was subjected to two irrigation levels (IW/CPE: 0.80 and 0.50) and five staggered nitrogen levels (0, 50, 75, 100 and 125 per cent of recommended dose of nitrogen (RDN). The experiment was laid out in randomized blocks design RBD (Factorial) with three replications. A higher value of spectral vegetation indices *viz.,* NDVI, GNDVI, RVI, LCI, IR-RED and SR were recorded with irrigation at IW/CPE ratio 0.80 either with 100 or 125 per cent RDN (unstressed) applied to maize crop. Maize under stressed environment recorded reduced values of spectral vegetation indices when the crop was irrigated at 0.50 IW/CPE ratio with no nitrogen. All the spectral vegetation indices expressed positive correlation (highly significant at 1 per cent probability level) with crop parameters. The overall best fit was linear with a regression coefficient between vegetation indices (GNDVI, NDVI) and with crop parameters, and actual grain yield and predicted yield (0.81 to 0.85) of maize. The ability of spectral vegetation indices to quantify the combined effect of nitrogen and water stress on maize too early through remote sensing paves the way for large scale application of satellite remote sensing.

Key words: Nitrogen, water, stress, spectral vegetation indices, maize.

Stress come from a range of factors that limit the potential growth of canopies. Evaluation of the stress level to which plants are subjected to is, therefore, vital both for the quantification of consequences on production and for taking action for their mitigation. Remote sensing is a good tool to detect and quantify the impact of plant stress compared to visual techniques because a vegetative unit can be repeated, objectively, and non-destructively examined in a fast, robust, accurate, and inexpensive manner (Mirik *et al.,* 2012). The launch of new hyperspectral remote sensing satellites, the focus of current research has been shifted to investigate the possibilities of hyperspectral remote sensing in crop monitoring. Hyperspectral remote sensing techniques allow the early detection of vegetation stress, before the appearance of visible symptoms (Panigada *et al.,* 2010).

Using absorption and spectral reflection characteristics of vegetation researchers have defined many vegetation indices for monitoring vegetation parameters. Spectral vegetation indices were designed to evaluate vegetation condition, foliage, cover, phenology, and processes, in addition, to be used for land cover classification, climate and land use detection, drought monitoring, and habitat loss (Padilla *et al.,* 2011).

The advent of spectral mapping and identification of vegetation by remote sensing methods, assumes importance to study crop stress using remote sensing techniques in maize under stressed conditions. Keeping this in view an experiment was planned for earlier determination of nitrogen and water stress with hyperspectral reflectance and vegetation indices on maize with the objectives, to quantify the relationship between vegetation indices and crop parameters of maize and to study the effect of nitrogen and water stress on maize using spectral vegetation indices.

MATERIALS AND METHODS

Study area

A field experiment was conducted at Tamil Nadu Agricultural University, Coimbatore, Tamilnadu, India during *kharif* and *rabi* 2014 with maize crop (TNAU maize hybrid Co 6). The site of the experiment is located at N11°0'33.4" E76°56'25.7" and 430.5 MSL in a subtropical belt. The soil is sandy clay loam in texture and the soil is alkaline in reaction with a pH of 8.41. The soil was medium in organic carbon (0.62 %), Low available nitrogen (186 kg ha^{-1}),

Table 1: Spectral indices and ratio of spectral wavebands used to differentiate nitrogen and water stress in maize

Index	Abbreviation	Formula	Reference
Normalized difference vegetation index	NDVI	$(R_{850}-R_{670})/(R_{850}+R_{670})$	Rouse et al., (1973)
Green NDVI	GNDVI	$(R_{780}-R_{550})/(R_{780}+R_{550})$	Aparicio et al., (2000)
Ratio vegetation index	RVI	(R_{927}/R_{687})	Thenkabail et al., (2000)
Leaf chlorophyll index	LCI	$(R_{850}-R_{710})/(R_{850}+R_{680})$	
Infrared-red index	IR-RED	(R_{789}/R_{663})	Genc et al., (2011)
Simple ratio	SR	(R_{900}/R_{680})	Gitelson and Merzlyak, (1996)

medium available phosphorus (13 kg ha^{-1}) and high available potassium (367 kg ha^{-1}). The soil moisture retention is 24.3 % at 0.33 bars and 10.2 % at 15 bars.

Experimental design

To ensure the stressed environments, the crop was subjected to two irrigation levels and five staggered nitrogen levels. The experiment was laid out in RBD (Factorial) with three replications and the details of the treatments are as follows. The irrigation regimes were W$_1$ (IW/CPE: 0.80) and W$_2$ (IW/CPE: 0.50) (IW = 5 cm) and the nitrogen levels were N$_0$: No nitrogen, N$_1$: 50 % RDN, N$_2$: 75 % RDN, N$_3$: 100 % RDN and N$_4$: 125 % RDN (RDN: Recommended dose of nitrogen). The generally recommended dose of fertilizers for hybrid maize is 250:75:75 NPK kg ha^{-1} as per the package of practice suggested by the Department of Agriculture, Government of Tamilnadu and Tamil Nadu Agricultural University, Coimbatore.

Spectral reflectance measurements

Hyperspectral data were collected from plant canopy by using GER 1500 portable spectroradiometer which has 512 channels ranging from 350-1050 nm with 1.5-3.2 nm bandwidths. The reflectance measurements were made on sunny days. Calibration of the radiometer was done with the help of barium sulfate coated plate in the field before and after taking canopy reflectance measurement. The canopy reflectance was computed as the ratio of canopy radiances to the radiance from the white reference plate. The spectral characteristics of the crop were measured at 60 and 90 days after sowing.

Spectral vegetation indices

Spectral reflectance indices viz., NDVI, GNDVI, RVI, LCI, IR-RED and SR (Table 1) were calculated, where R and subscript number indicate the reflectance at the specific wavelength. The reflectance data were transformed into vegetation indices and used to distinguish nitrogen and water stress severity in maize. The correlation studies were done by using SPSS (16.0).

## RESULTS AND DISCUSSION

Spectral signature

Measured spectral reflectance curve of maize exhibited a broad low intensity peak centered in the green region at 550 nm and a sharp rise starting at about 675 nm to a plateau in the vicinity of 762 nm. Spectral reflectance of maize varied from different irrigation regimes and changed with nitrogen levels. Irrigation at IW/CPE ratio 0.80 with 100 % RDN (unstressed) of maize showed that low reflectance in visible region (400 to 700 nm) and high in near infra red (NIR) region (700 to 900). Under stressed condition the reflectance was high in visible region and low in NIR region at IW/CPE ratio 0.50 with no nitrogen compare to unstressed maize at 60 DAS (Fig. 1). Similar reflectance pattern of maize crop was observed at 90 DAS.

Spectral signature from different nitrogen levels within the irrigation regimes also varied. While similar reflectance pattern of maize was observed under nitrogen levels, the percent of reflectance was high in visible region and low in NIR region with no nitrogen as compare to all other nitrogen levels within irrigation regimes (Fig. 2 and 3). Whereas the spectral signature slightly decreased in visible spectrum and increased in NIR region when nitrogen dose was increased to 50, 75 and 100 % RDN of maize crop. As in line with the trend, spectral reflectance of maize crop at 125 % RDN was found that to be very low in visible region and very high in NIR region. Similar reflectance pattern of maize crop was observed at 60 and 90 DAS.

Among different irrigation regimes of 0.50 and 0.80 IW/CPE radio, water stressed maize crop (IW/CPE: 0.50) had higher reflectance than unstressed maize (IW/CPE: 0.80) in the visible spectrum in contrast to much higher reflectance from unstressed plants when compared to lower
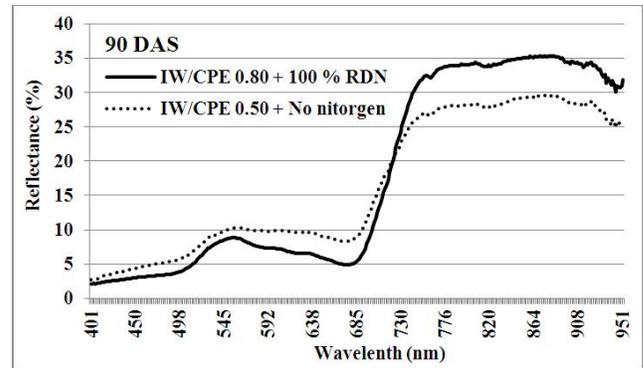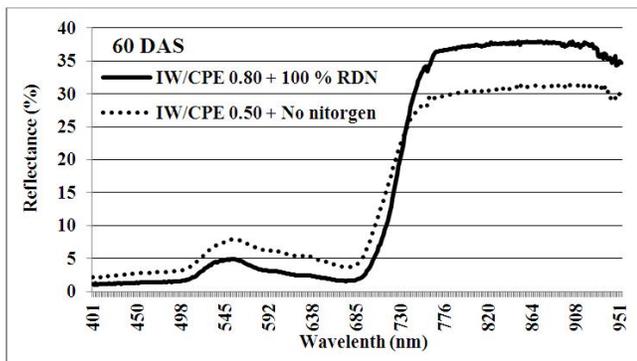
Fig. 1: Spectral signature characters of unstressed (IW/CPE ration: 0.80 + 100 % RDN) and stressed (IW/CPE ratio: 0.50 + No nitrogen) maize crop at 60 and 90 DAS.
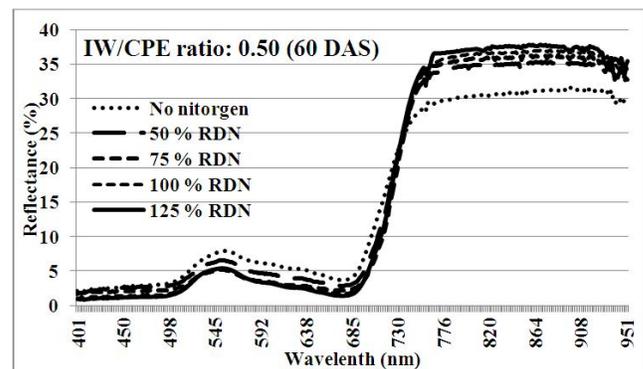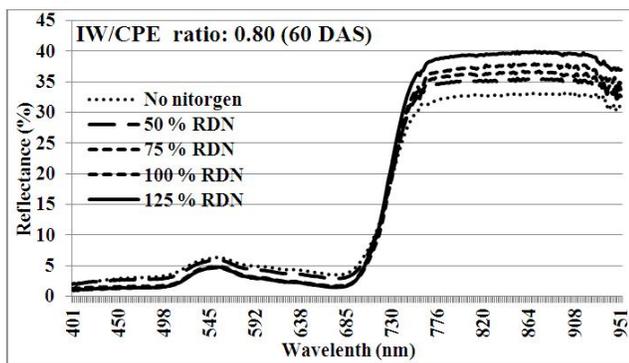
Fig. 2: Spectral signature characters of maize crop with irrigation at IW/CPE ration: 0.80, 0.50 and different nitrogen levels *viz.,* No nitrogen, 50 % RDN, 75 % RDN, 100 % RDN and 125 % RDN at 60 DAS.
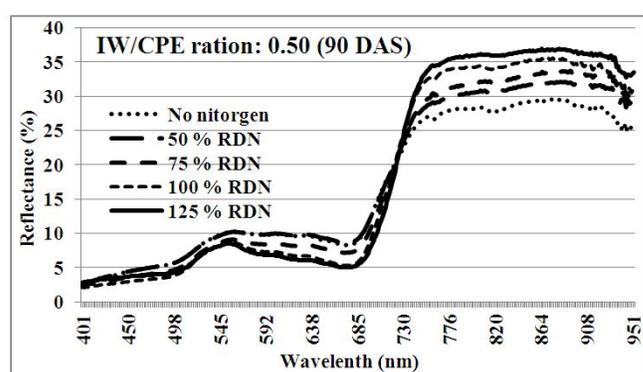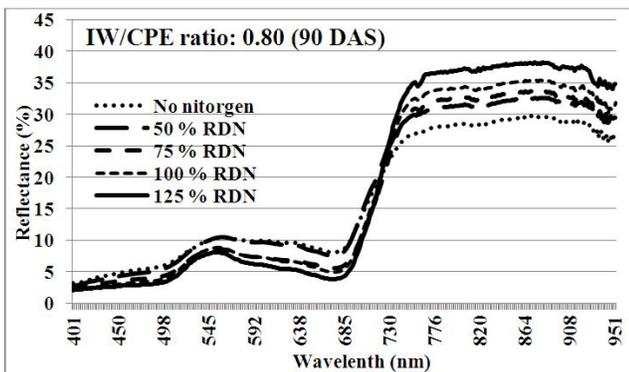
Fig. 3: Spectral signature characters of maize crop with irrigation at IW/CPE ration: 0.80, 0.50 and different nitrogen levels *viz.,* No nitrogen, 50 % RDN, 75 % RDN, 100 % RDN and 125 % RDN at 90 DAS.

reflectance from stressed plants in the NIR spectrum at 60 and 90 DAS (Fig. 2 and 3).

Spectral vegetation indices

A higher value of spectral vegetation indices *viz.,* NDVI, GNDVI, RVI, LCI, IR-RED and SR were recorded with irrigation at IW/CPE ratio 0.80 either with 100 or 125 per cent RDN (unstressed) applied to maize crop. Maize under

stressed environment recorded low values of spectral vegetation indices values when the crop was irrigated at 0.50 IW/CPE ratio with no nitrogen (stressed). The value of vegetation indices increased with increased nitrogen levels of 50, 75, 100, 125 percent of RDN. However the lowest values of spectral vegetation indices were recorded under nitrogen stressed condition compard to all other nitrogen levels. Among the irrigation regimes, irrigation at 0.80 IW/

Table 2: Effect of irrigation and nitrogen levels on spectral vegetation indices of maize (*Pooled data*)

Treatments	NDVI		GNDVI		RVI		LCI		IR-RED		SR	
	W_1	W_2	W_1	W_2	W_1	W_2	W_1	W_2	W_1	W_2	W_1	W_2
60 DAS												
N_0	0.7888	0.7408	0.6584	0.6094	7.65	6.07	0.6745	0.6192	28.08	25.47	8.36	6.46
N_1	0.8288	0.7973	0.7047	0.6725	9.53	7.88	0.7128	0.6810	30.08	28.80	10.40	8.51
N_2	0.8610	0.8396	0.7317	0.7186	11.98	10.42	0.7476	0.7276	31.59	30.49	13.28	11.30
N_3	0.8993	0.8682	0.7876	0.7703	16.95	13.19	0.7972	0.7785	35.66	34.18	18.83	14.38
N_4	0.9286	0.9039	0.8415	0.8181	23.55	17.67	0.8428	0.8139	39.01	37.59	26.38	19.39
90 DAS												
N_0	0.5714	0.5567	0.4730	0.4630	3.40	3.17	0.3859	0.3684	20.08	19.55	3.67	3.47
N_1	0.6272	0.5833	0.5127	0.5051	4.00	3.60	0.4214	0.4178	23.42	21.78	4.38	3.84
N_2	0.7080	0.6500	0.5814	0.5570	5.35	4.47	0.5376	0.4772	26.43	24.31	5.82	4.78
N_3	0.7475	0.7238	0.6066	0.5982	6.37	5.72	0.5611	0.5463	28.82	28.26	7.01	6.23
N_4	0.8116	0.7577	0.6628	0.6343	9.04	6.86	0.6339	0.6072	32.67	30.45	9.92	7.40

W_1 (IW/CPE: 0.80) and W_2 (IW/CPE: 0.50) and N_0: No nitrogen, N_1: 50, N_2: 75, N_3: 100 and N_4: 125 % RDN

Table 3: Pearson correlation coefficients between spectral vegetation indices and crop parameters of maize under irrigation and nitrogen levels (as per pooled data)

	60 DAS				90 DAS			
	LAI	Total chlorophyll	Proline	Yield	LAI	Total chlorophyll	Proline	Yield
NDVI	.950**	.963**	-.774**	.923**	.941**	.939**	-.737*	.902**
GNDVI	.919**	.933**	-.710*	.877**	.913**	.909**	-.665*	.870**
RVI	.906**	.915**	-.723*	.847**	.898**	.902**	-.695*	.837**
LCI	.928**	.943**	-.736*	.895**	.904**	.900**	-.665*	.857**
IR-RED	.903**	.917**	-.695*	.854**	.929**	.926**	-.693*	.882**
SR	.908**	.916**	-.730*	.850**	.900**	.905**	-.704*	.841**

*. Correlation is significant at the 0.05 level **. Correlation is significant at the 0.01 level

CPE ratio recorded higher values of the spectral vegetation indices. Irrigation at 0.5 IW/CPE and subsequent water stress resulted into reduction in values of these spectral indices at 60 and 90 DAS (Table 2).

It is quite clear that the vegetation indices value for the stressed plants is much less than the healthy plants due to decreased reflectance in NIR region and increased reflectance in the visible region.

Relationship between spectral vegetation indices and crop parameters

The Pearson correlation coefficients between spectral vegetation indices and crop parameters *viz.,* leaf area index, total chlorophyll content, proline content and grain yield at different plant growth stages of 60 and 90 DAS were significantly influenced by nitrogen levels and irrigation regimes as per pooled data over the two seasons (Table 3).

The relationship between vegetation indices *viz.,* NDVI, GNDVI, RVI, LCI, IR-RED and SR had better correlation with crop growth parameters. Especially all the spectral vegetation indices expressed high or positive correlation with significance at the 0.01 level with LAI, total chlorophyll content and yield with a correlation coefficient of >0.80 and Proline > -0.70 both at 60 and 90 DAS for the pooled data over the two seasons. All these spectral vegetation indices had high positive inter-correlation with values of > 0.90.
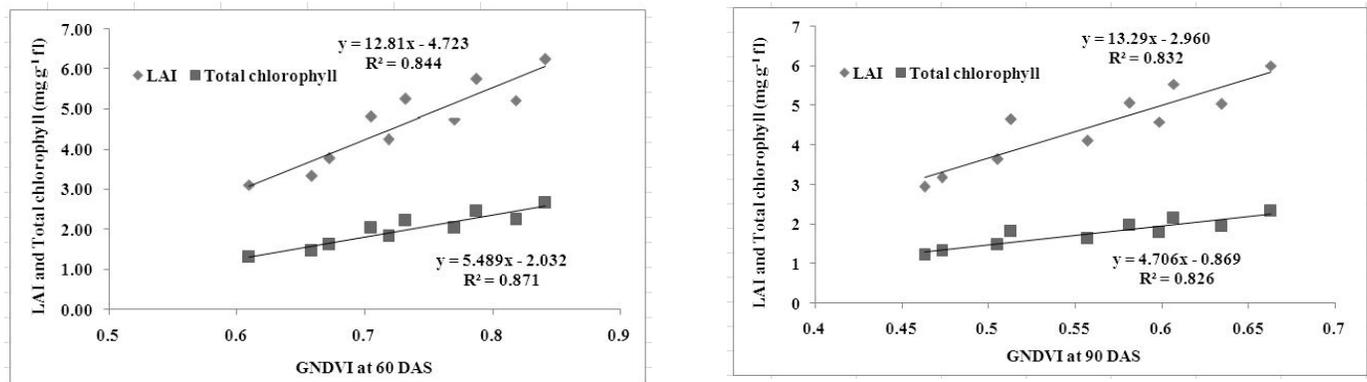
Fig. 4: Relationship between GNDVI *Vs* LAI and total chlorophyll content (as per pooled data)
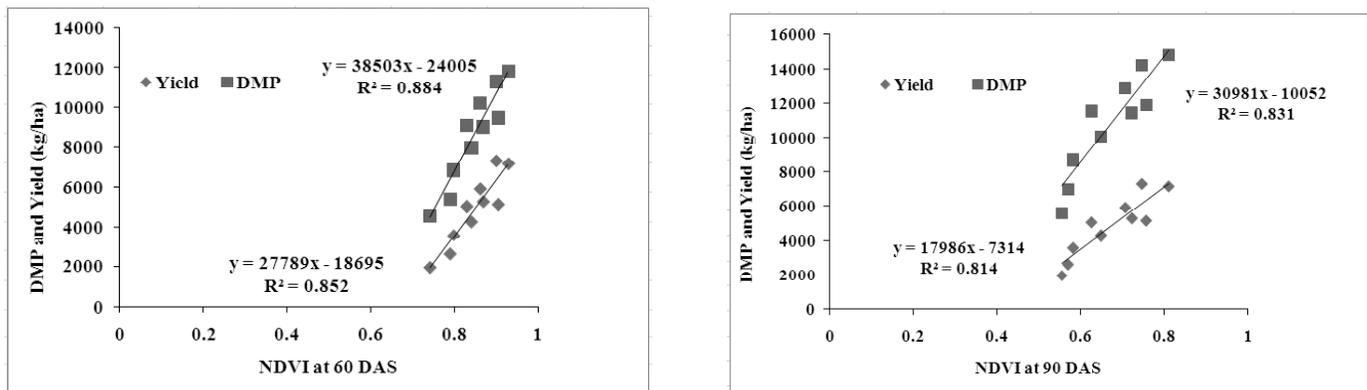

**Fig. 5:** Relationship between NDVI *Vs* DMP and yield of maize (as per pooled data)
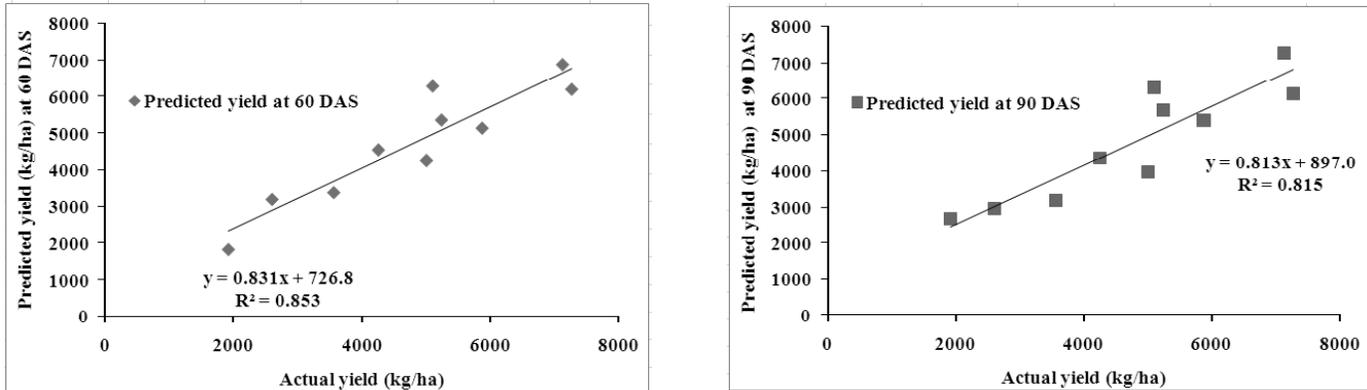
Fig. 6: Relationship between actual yield and predicted yield of maize (as per pooled data)

The relationship between NDVI and LAI for pooled data over the two years, the overall best fit was exponential with a coefficient of determination (0.85) as reported by Jayasree *et al.* (2013). An exponential relationship between LAI and NDVI was observed for soybean, beans, peas, corn and wheat by Haboudane *et al.* (2004). The study by Pradhan *et al.* (2013) revealed the significance of GNDVI correlating yield and stress in wheat.

Regression coefficient

The regression coefficients between spectral vegetation indices (NDVI, GNDVI) and crop parameters *viz.,* leaf area index, total chlorophyll content, DMP and grain yield at different plant growth stages of 60 and 90 DAS were significantly influenced by nitrogen levels and irrigation regimes as per pooled data over the two seasons.

Prediction equations were developed between the GNDVI with measured LAI and measured total chlorophyll content. The overall best fit was linear with a regression coefficient of determination of R^2 value from 0.83 to 0.84 and 0.82 to 0.87 per cent, respectively (Fig. 4).

Prediction equations were developed between the NDVI with measured dry matter production (DMP) and measured grain yield. The overall best fit was linear with coefficient of determination (R^2) values from 0.83 to 0.88 and 0.81 to 0.85 per cent respectively (Fig. 5).

Prediction equations were developed between the predicted maize grain yield (based on NDVI derived data) and observed grain yield. It indicated that there was a good agreement between the predicted and observed grain yield (Fig. 6). The results clearly indicated that the grain yield could be estimated and quantified at the large scale through NDVI derived from the satellite driven remote sensing data over a large area. Similar observation was made by Wiegand and Richardson (1990) with respect to spectral vegetation indices.

CONCLUSION

Remote sensing techniques to assess the combined effect of nitrogen and water stress in maize using hyperspectral reflectance spectra transformed into spectral vegetation indices. The spectral indices *viz.,* NDVI, GNDVI, RVI, LCI, IR-RED and SR recorded higher value on unstressed maize crop and plants under stress caused a reduction in value of these indices at 60 and 90 DAS in both the seasons. All the spectral vegetation indices expressed significant positive correlation with crop parameters.

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