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Hyperspectral Remote Sensing for Determining Water and Nitrogen Stress in Maize during *Rabi* Season

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Authors' contributions

This work was carried out in collaboration among all authors. Author HRN designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors BBN and GS managed the analyses of the study. Author AK managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims/Objectives: Is to examine the use of spectral reflectance characteristics and explore the effectiveness of spectral indices under water and nitrogen stress environment.
Study Design: Split-plot.
Place and Duration of Study: Agro Climate Research Center, A.R.I., P.J.T.S. Agricultural University, Rajendranagar, Hyderabad, India in 2018-19.
Methodology: Fixed amount of 5 cm depth of water was applied to each plot when the ratio of irrigation water and cumulative pan evaporation (IW/CPE) arrives at pre-determined levels of 0.6,

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0.8 & 1.2 as main-plot and 3 nitrogen levels *viz.* 100, 200 & 300 kg N ha^{-1} as a subplot to create water and nitrogen stress environment. Spectral reflectance from each treatment was measured using Spectroradiometer and analyzed using statistical software package SPSS 17, SAS and trial version of UNSCRABLER.

Results: At tasseling and dough stages, the reflectance pattern of maize was found to be higher in visible light spectrum of 400 to700 nm whereas lower in near-infrared region (700 to 900) in both underwater (IW/CPE ratio of 0.6) and nitrogen stress (100 kg N ha^{-1}) environment as compared to moderate and no stress irrigation (IW/CPE ratio of 0.8 & 1.2) and nitrogen (200 and 300 kg N ha^{-1}) treatments. The discriminant analysis of NDVI, GNDVI, WBI and SR indicated that 72.2% and 66.7% of the original grouped cases and 55.6% and 38.9% of the cross-validated grouped cases under irrigation and nitrogen levels, respectively were correctly classified.

Conclusion: Hyperspectral remote sensing can be used as a tool to detect and quantify the water and nitrogen stress in maize non-destructively. Spectral vegetation indices *viz.* Normalized Difference Vegetation Index (NDVI) and Green Normalized Difference Vegetation Index (GNDVI) were found effective to distinguish water and nitrogen stress severity in maize.

Keywords: Water and nitrogen stress; spectral reflectance; vegetation indices; maize.

1. INTRODUCTION

Remote sensing is the science of collecting information from a target, an object or phenomenon without any physical contact with it. This can be achieved by acquiring reflected or emitted energy from the target and analyzing and applying the processed information in real conditions [1]. A visible/NIR spectroscopy is a powerful instrument, used in the detection of reflectance from the crop canopy which is a fast and non-destructive technique that is increasingly used for measuring a large number of chemical and physical properties of agricultural products [2]. In agriculture, this technology has much practical management of land and water resources, crop production forecasting and disaster assessment such as flood, drought and epidemics etc. which seriously affect the agriculture [3]. Compared to visual techniques it is a better method to detect and quantify the impact of plant stress because a vegetative unit can be repeatedly, objectively, and non-destructively examined in a fast, robust, accurate, and inexpensive way [4,5,6]. The spectral reflectance from a plant canopy provides a wide range of information depends on the interaction of electromagnetic radiation with the biophysical and physiological parameters. Hyperspectral remote sensing is based on the examination of many contiguous narrowly defined spectral channels [7] and is superior to conventional broadband remote sensing in spectral information. However, these data being voluminous and widely varying in different wavelengths, it should be compressed into spectral indices for useful applications. To better understand the spectral reflectance characteristics of plants, several vegetation indices (VI) have been developed by remote sensing researchers. Some spectral indices like Normalized Difference Vegetation Index (NDVI), Green Normalized Difference Vegetation Index (GNDVI) Water Band Index (WBI), Simple Rate Index (SR) and the Infrared-Red Index (IR-RED) was used by [8] to characterize the spectral reflectance by the crop canopy.

Maize (*Zea mays L.*) is one of the most important cereal crops having wider adaptability under varied agro-climatic conditions. It is the third most important cereal after rice and wheat as human food, contributing almost nine per cent to India's food basket and five per cent to the world's dietary energy supply. It is used as food for human and feed for livestock, especially in the poultry industry. Maize crop growth is affected by different stresses viz., water, pest, weed, nutrients, etc., which reduce productivity. Among these, management of irrigation water and nitrogen is crucial to improve maize productivity [9] as both of these factors had a positive correlation with maize productivity and can induce yield loss if applied in an inappropriate way [10]. The application of remote sensing technology in the detection of water and nutrient stress in maize provide accurate and up to date information in a different range of spatial and temporal scales which is difficult and time-consuming when done by traditional methods such as field survey and sampling questionnaires. The objective of this investigation is to examine the use of spectral reflectance characteristics and explore the effectiveness of spectral indices under water and nitrogen stress environment.

2. MATERIALS AND METHODS

2.1 Experimental Area Design and Management

The experiment was carried out in the research farm of Agro Climate Research Centre, Agricultural Research Institute, P.J.T.S. Agricultural University, Rajendranagar, Hyderabad in India. It is situated at 17°32'N latitude, 78°39'E longitude and an altitude of 542.3 m above mean sea level in the Southern Telangana Agro-Climatic Zone in Telangana State. According to troll's classification, it falls under semi-arid tropics (Troll, 1965). The soil is sandy loam in texture and neutral in reaction with a pH of 7.43. The soil was low in organic carbon (0.22%) and available nitrogen (186 kg ha^{-1}) and high in available phosphorus (35.3 kg ha^{-1}) and potassium (383 kg ha^{-1}). The soil moisture-holding capacity was 13.8% (w/w) at -0.1 M Pa and 5.25% (w/w) at -1.5 M Pa. To ensure the water and nitrogen stressed, the crop was subjected to three irrigation (IW/CPE: 0.60, 0.8 and 1.2) and three nitrogen levels (100, 200 and 300 kg of nitrogen ha^{-1}). The experiment was laid out in split-plot design replicated thrice. The fixed amount of 5 cm depth of water was applied to each plot when the ratio of irrigation water and cumulative pan evaporation (IW/CPE) arrives at pre-determined levels as per the treatments. The crop was sowed on 16 October 2018 and harvested at harvesting maturity. The nitrogen fertilizers were applied in 3 equal splits each at basal (in the form of DAP & urea), 6 leaf stage (in the form urea) and tasseling stage (in the form urea) of the crop. The recommended entire dose of phosphorus @ 60 kg (P_2O_5) in the form of Di-ammonium Phosphate applied as basal and 40 kg potassium (K_2O) in the form of muriatic of potash was applied in 2 equal splits each at basal and tasseling stage. The field was laid out in ridges and furrows at 60 cm apart. The plant to plant spacing adopted within the row was 20 cm. all the treatments were uniformly irrigated initially up to 15 days after sowing to ensure the better establishment of the crop. The other standard management practices as recommended by the P.J.T.S. Agricultural University for the state of Telangana were followed. Nitrogen content in the leaf sample was estimated by the Microkjeldahl method [11] and the Relative Water Content (RWC) was estimated according to [12] and calculated by using the following formula and expressed as per cent.

$$\text{Relative Leaf Water Content} = \frac{\text{Fresh weight (g)} - \text{dry weight (g)}}{\text{Turgid weight (g)} - \text{dry weight (g)}} \text{ x } 100$$

2.2 Spectral Reflectance Measurements and Data Analysis

Spectral data were collected by using Spectrora-diometer PS-100 ranging from 350- 1000 nm with 0.5 nm bandwidths. The reflectance measurements were made on sunny days. The field of view (FOV) was 30° and the distance between the optical head of the Spectrora-diometer and the top of the plant leaf was kept depends on the size of the leaf. Calibration of the Spectroradiometer was done with the help of standard reference (barium sulphate coated plate) in the field before taking reflectance measurement. The Spectrora-diometer data were analyzed with the statistical software package SPSS 17, SAS and trial version of UNSCRABLER software.

2.3 Spectral Vegetation Indices

The spectral reflectance indices viz., NDVI, GNDVI, WBI and SR were calculated, where R and subscript number indicate the light reflectance at a specific wavelength (in nm) presented in Table 2. The reflectance data were transformed into vegetation indices and used to distinguish nitrogen and water stress severity in maize.

3. RESULTS AND DISCUSSION

3.1 Spectral Signature

3.1.1 Effect of irrigation

The spectral reflectance pattern of the maize leaf differed before ((blue line) and after an irrigation (red line) in visible and NIR regions and also with levels of irrigation at tasseling and dough stages of the crop (Fig. 1a-f). Before irrigation, the spectral reflectance in the visible region was more and in the NIR region was less when compared to after irrigation. The higher reflectance in the NIR region and more absorption in the visible region are indicative of healthiness of the crop canopy. The spectral reflectance in the NIR region decreased with increasing the water stress levels through irrigation scheduling from IW/ CPE ratio of 1.2 (I_3) to 0.6 (I_1) at tasseling and dough stage. These results are in line with the findings of [13] who reported that in the visible region the water-stressed maize had higher reflectance than unstressed maize in contrast to much higher reflectance from unstressed plants when compared to lower reflectance from stressed plants in the NIR spectrum. Similar response of water-stressed maize was also observed by [14].

Table 1. The reflectance data

Index	Abbreviation	Formula	Reference
Normalized Difference Vegetation Index	NDVI	$(R_{850}-R_{670})/(R_{850}+R_{670})$	Rouse et al. [15]
Green NDVI	GNDVI	$(R_{780}-R_{550})/(R_{780}+R_{550})$	Aparicio et al. [16]
Water Band Index	WBI	(R_{900}/R_{970})	Peñuelas [17]
Simple ratio	SR	(R_{900}/R_{680})	Gitelson and Merzlyak [18]

3.1.2 Effect of nitrogen

The spectral reflectance pattern of maize leaf influenced by graded levels of nitrogen under optimum moisture condition (IW/CPE 1.2) treatment (Fig 2. a- d). The spectral reflectance from leaf was low in the visible spectrum and high in NIR region with every successive 100 kg increment in nitrogen dose from 100 kg N ha^{-1} to 300 kg N ha^{-1} at tasseling and dough stage of the crop. Nitrogen-stressed plants had significantly lower levels of plant nitrogen and chlorophyll, higher starch content and greater leaf thickness and they reflected more light in the visible region due to lower chlorophyll content and less reflectance in the near-infrared region. Increase in nitrogen dose, the chlorophyll content increased significantly, the crop reflectance higher in the NIR region and lower in the visible region. Similar findings conformity with [19,20] and [21]. The per cent spectral reflectance was less in at dough stage as compared to tasseling stage may be due to decrease in the greenness of leaves as a result of translocation of nitrogen reserves from source (leaf) to sink (cob).

3.2 Spectral Vegetation Indices

Spectral vegetation indices are mathematical expressions involving reflectance values from different part of the electromagnetic spectrum, aimed to optimize the information and normalize measurements made across varied environmental conditions. The vegetation indices *viz.* Normalized Difference Vegetation Index (NDVI), Green Normalized Difference Vegetation Index (GNDVI), Water Band Index (WBI) and Simple ratio (SR) and used to distinguish nitrogen and water stress severity in maize at tasseling and dough stage (Table 2).

3.2.1 Effect of irrigation

Among the different irrigation scheduling treatments, irrigation scheduled at IW/CPE ratio of 1.2 recorded higher NDVI values of 0.89 and 0.82, GNDVI values of 0.69 and 0.60 and these values were decreased with increasing the water stress level through irrigation scheduling at IW/CPE ratio of 0.8 to 0.6 at tasseling and dough stages of the crop, respectively. This trend was also observed with SR at the tasseling stage. At dough stage, the crop irrigated at IW/CPE ratio of 0.8 recorded higher SR (4.51) followed by IW/CPE ratio of 1.2 (4.40) and stressed plot (IW/CPE ratio of 0.6) recorded lowest SR of 2.64.

3.2.2 Effect of nitrogen

Among the different nitrogen levels, application of 300 kg N ha^{-1} recorded higher NDVI values of 0.85 and 0.77and GNDVI values of 0.69 and these values were decreased with increasing the nitrogen stress through reducing the dose from 200 kg N ha^{-1} to 100 kg N ha^{-1} at tasseling and dough stages of the crop, respectively. This trend was also observed with SR at the tasseling stage.

The vegetation indices higher at tasseling stage and declined at dough stage of the crop in all the treatments. Plant senescence affected the reflectance properties of plants and hence vegetation indices decreased after tasseling stage. The higher reflectance from unstressed plants when compared to lower reflectance from stressed plants in the NIR spectrum at 60 and 90 DAS as also reported by [22] so that vegetation indices values were higher in unstressed plants as compared to stressed plants. Similar findings reported by [23] and [24]. In the present investigation, it was quite clear that the vegetation indices *viz.,* NDVI, GNDVI, SR computed to capture the information on water and nitrogen stress is highly useful. These indices explained the crop condition under water and nitrogen stress environment could be useful for quantification of possible crop growth and yield.

The water index (WBI) values computed were not useful for assessment of crop condition due to limitation in instrument useful for radiation reflectance study. Though the instrument used for reflectance study have spectral range 350 nm to 1000 nm, the quality of the data not was good enough with high noise from 350 nm to 440 nm and 880 nm to 1000 nm. Hence WBI derived might not be useful for assessment of crop condition.

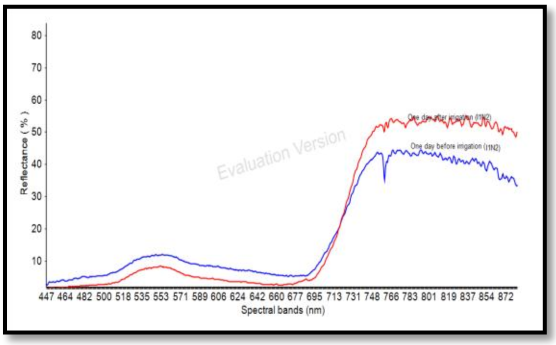

Fig. 1(a). Spectral reflectance before (blue line) and after an irrigation (red line) from I_1N_2 at tasseling stage of maize

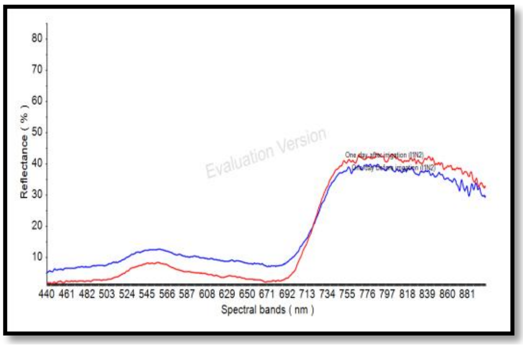

Fig. 1(d). Spectral reflectance before and after irrigation from I_1N_2 at dough stage of maize

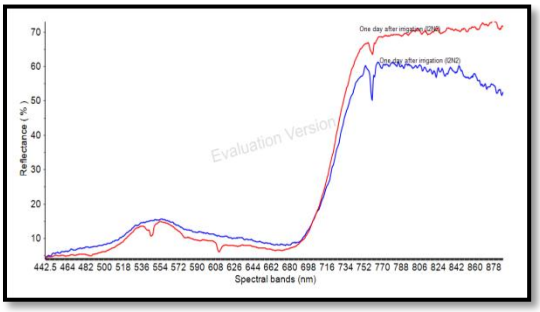

Fig. 1(b). Spectral reflectance before and after irrigation from I_2N_2 at tasseling stage of maize

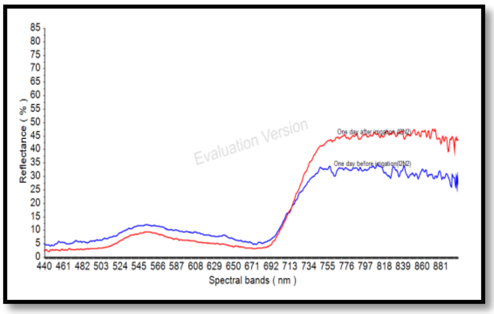

Fig. 1 (e). Spectral reflectance before and after irrigation from I_2N_2 at dough stage of maize

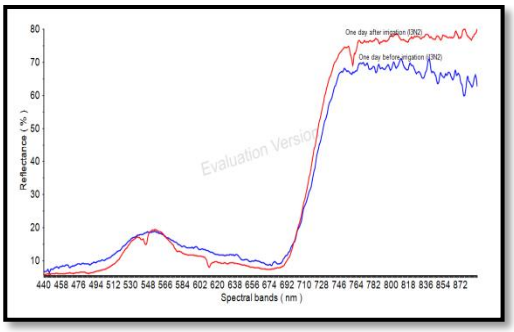

Fig. 1(c). Spectral reflectance before and after irrigation from I_3N_2 at tasseling stage of maize

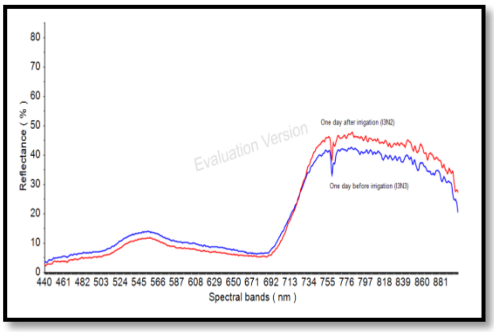

Fig. 1(f). Spectral reflectance before and after irrigation from I_3N_2 at dough stage of maize

3.3 Classification of Spectral Vegetation Indices by Discriminant Analysis

To determine the water and nitrogen stress severity, Normalized Difference Vegetation Index (NDVI), Green Normalized Difference Vegetation Index (GNDVI), Water Band Index (WBI) and Simple Ratio (SR) were investigated using discriminant analysis function for water (Table 3) and nitrogen (Table 4) separately.

3.3.1 Effect of irrigation

The results in Table 3 indicated that 72.2% of the original grouped cases correctly classified and 55.6% of the cross-validated grouped cases correctly classified under differential water stress environment in maize. The test of the quality of group means showed that NDVI was highly significant (at p=0.001) in discrimination of water stress effect on maize crop. There was no water stress in plants when NDVI calculated > 0.86 and 0.82 at tasseling and dough stages, respectively when the crop irrigation scheduled at IW/ CPE ratio of 1.2 (I_3). The crops experienced severe water stress when NDVI calculated < 0.77 and < 0.65 and at tasseling and dough stages, respectively in IW/ CPE ratio of 0.6 treatment (Table 2). These results are in line with the findings of [24] who reported that NDVI is the most effective index to determine the combined effect of nitrogen and water stress using classification tree (CT) model in maize crop. The GNDVI and SR were also found significant with the test of quality of group means (at p= 0.05) in terms of prediction of water stress in maize. There was no water stress in plants when GNDVI calculated > 0.69 and 0.60 and SR calculated > 11.34 and 4.40 at tasseling and dough stages, respectively when the crop irrigation scheduled at IW/ CPE ratio of 1.2. The crop experienced severe water stress when GNDVI calculated < 0.59 and < 0.45 and SR calculated < 5.18 and 2.64 at tasseling and dough stages, respectively when it was irrigated at IW/ CPE ratio of 0.6 (I_1) (Table 2). These results are in agreement with the findings of [25] who also reported that GNDVI was the better predictors of spectral indices in maize crop under varies water stress environment. The Water Band Index computed did not show any significant effect in the prediction of water stress in Maize crop due to some limitations with the instrument used (spectroradiometer) for reflectance studies.

3.3.2 Effect of nitrogen levels

The result in Table 4 showed that 66.7% of the original grouped cases correctly classified and 38.9% of the cross-validated grouped cases correctly classified under graded levels of nitrogen in maize. The quality test of group means of different spectral indices showed that none of the indices found significant in discrimination of stress inducted under graded levels of nitrogen in maize crop. The crop with NDVI calculated > 0.80 and 0.70 under 300 kg N ha^{-1} (N_3) treatment at tasseling and dough stages respectively were healthier than when it was nurtured with lower levels of nitrogen viz. 200 kg and 100 kg ha^{-1} (Table 2).

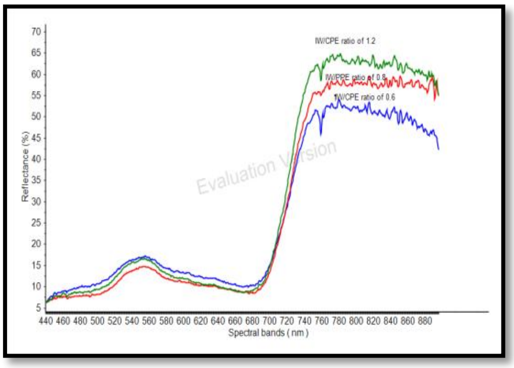

Fig. 2(a). Spectral reflectance under different irrigation scheduling at tasseling stage in maize

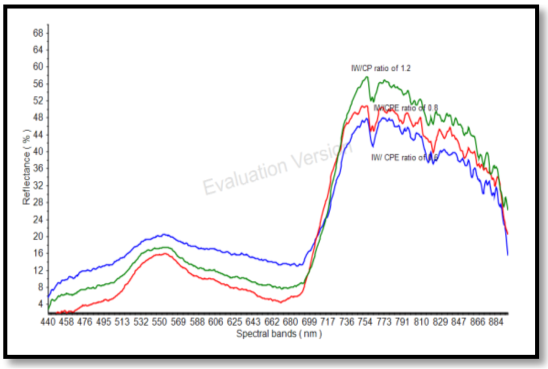

Fig. 2(c) Spectral reflectance under different irrigation scheduling at dough stage in maize

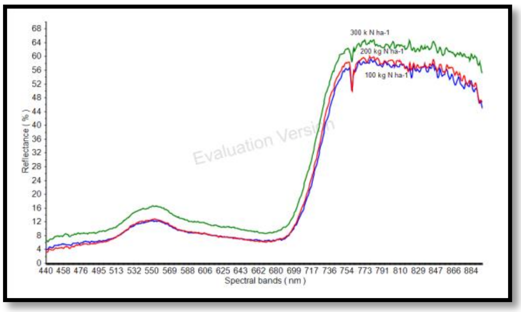

Fig. 2(b). Spectral reflectance under different nitrogen levels at tasseling stage in maize

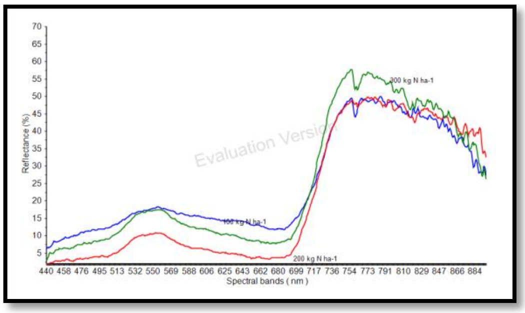

Fig. 2 (d) Spectral reflectance under different nitrogen levels at dough stage in maize

Table 2. Spectral vegetation indices of maize at different growth stages as influenced by irrigation scheduling and nitrogen levels

Treatments	Tasseling stage				Dough stage			
	NDVI	**GNDVI**	**WBI**	**SR**	**NDVI**	**GNDVI**	**WBI**	**SR**
The main plot - (Irrigation scheduling)								
I_1: IW/CPE 0.6	0.77	0.59	3.45	5.18	0.65	0.45	0.82	2.64
I_2: IW/CPE 0.8	0.81	0.64	-0.92	6.89	0.72	0.54	1.91	4.51
I_3: IW/CPE 1.2	0.89	0.69	2.57	13.38	0.82	0.60	-0.24	4.40
Subplot – (Nitrogen levels)								
N_1: 100 kg N ha^{-1}	0.80	0.63	0.99	7.58	0.70	0.51	0.76	3.81
N_2: 200 kg N ha^{-1}	0.82	0.63	1.38	8.07	0.73	0.53	0.99	3.04
N_3: 300 kg N ha^{-1}	0.85	0.66	2.73	9.80	0.77	0.54	0.73	4.70

Note: NDVI- Normalized Difference Vegetation Index; GNDVI -Green Normalized Difference Vegetation Index; SR – Simple Ratio; WBI – Water Band Index

Table 3. Classification accuracy between original and predicted values of maize under different irrigation scheduling treatments

Irrigation scheduling		Predicted group membership			Total	Correct (%)
		I_1	**I_2**	**I_3**		
Original (%)	I_1	83.3	16.7	0	100	83.3
	I_2	33.3	50.0	16.7	100	50.0
	I_3	0	16.7	83.3	100	83.3
Overall correct %		38.9	27.8	33.3	100	72.2
Cross-validated (%)	I_1	50.0	33.3	16.7	100	50.0
	I_2	33.3	50.0	16.7	100	50.0
	I_3	0	33.3	66.7	100	66.7
Overall correct %		27.8	38.9	33.4	100	55.6
Test of quality of group means						
Variables						**Sig**
NDVI						0.004
GNDVI						0.016
SR						0.049
WI						0.587

Note: NDVI- Normalized Difference Vegetation Index; GNDVI -Green Normalized Difference Vegetation Index; SR – Simple Ratio; WBI – Water Band Index

Table 4. Classification accuracy between original and predicted values of maize under different nitrogen level treatments

Nitrogen levels		Predicted group membership			Total	Correct (%)
		N_1	**N_2**	**N_3**		
Original (%)	**N_1**	**50.0**	**33.3**	**16.7**	**100**	**50.0**
	N_2	16.7	66.7	16.7	100	66.7
	N_3	0	16.7	83.3	100	83.3
Overall correct %		22.2	38.9	38.9	100	66.7
Cross-validated (%)	**N_1**	**33.3**	**50.0**	**16.7**	**100**	**33.3**
	N_2	66.7	16.7	16.7	100	16.7
	N_3	0	33.3	66.7	100	66.7
Overall correct%		33.3	33.3	33.3	100.0	38.9
Test of equality of group means						
Variables					**Sig**	
NDVI					0.820	
GNDVI					0.802	
SR					0.211	

Note: NDVI- Normalized Difference Vegetation Index; GNDVI -Green Normalized Difference Vegetation Index; SR – Simple Ratio; WBI – Water Band Index

4. CONCLUSION

Hyperspectral remote sensing can be used as a tool to detect and quantify the water and nitrogen stress in maize non-destructively. The higher reflectance in the NIR region and more absorption in the visible region are indicative of healthiness of the crop canopy. Spectral vegetation indices *viz.* Normalized Difference Vegetation Index (NDVI) and Green Normalized Difference Vegetation Index (GNDVI) were found effective to distinguish water and nitrogen stress severity in maize.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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