



Identification of Water and Nitrogen Stress Indicative Spectral Bands Using Hyperspectral Remote Sensing in Maize During Post-Monsoon Season

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Abstract

Realization of agricultural crop condition through field survey is quite expensive, time consuming and sometimes not practical for remote locations. Optical remote sensing techniques can provide information on real condition of the crops by observing spectral reflectance at different crop growth phases and is less expensive and less time consuming. Hyperspectral remote sensing provides a unique opportunity for non-destructive, timely and accurate estimation of crop biophysical and biochemical properties. In this study, a field experiment was conducted to identify the water and nitrogen stress indicative spectral bands using ground-based hyperspectral data and to assess the predictive capability of selective bands on yield of maize under water and nitrogen stress environment. The experiment comprised of three irrigation scheduling treatments based on IW/CPE ratio of 0.6, 0.8 and 1.2 and three nitrogen level treatments, i.e., 100, 200 and 300 kg of N ha⁻¹, respectively, with three replications in a split plot design. The spectral reflectance was measured before irrigation at tasseling and dough stage of the maize crop using portable field spectroradiometer. The results of stepwise multiple linear regression indicated the highest predicting capability of spectral bands 540 nm, 780 nm and 860 nm for leaf nitrogen and 700 nm, 740 nm and 860 nm for leaf water content. The derived biophysical parameters based on spectral reflectance viz. relative leaf water content (%), leaf area index and leaf nitrogen contentment (%) at tasseling stage of maize crop accounted for 80%, 61% and 66% variation in grain yield, respectively.

Keywords Remote sensing · Maize · Spectral reflectance · Relative leaf water content · Leaf nitrogen · Leaf area index

Introduction

Remote sensing is obtaining information from an object of interest without being in physical contact with it and whose temperature is above the obsolete zero having property of

absorption, reflectance and transmission of electromagnetic waves. Application of optical remote sensing technique in agriculture gaining lot of importance during recent past as it can able to provide information on real situation of the crops by observing spectral reflectance at different crop

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growth phases even from remote area and is less expensive, in time otherwise it is very difficult through expensive field surveys. The incident radiation influences the physical and physiological properties of crop plants and acts as a key element to understand the crop growth and its interaction with surrounding environment. From recent past, remote sensing is being used as a successful technology for continuous monitoring crop growth on spatiotemporal scale as a decision support system in agriculture. Monitoring crop growth response to water and nutrients availability at farm level and regional scale are essential for crop yield assessment. Early detection of stress prior to expression of visible symptom by the crop using hyperspectral remote sensing was reported by Panigada et al. (2010) and increased the interest of several researchers to investigate on different crops.

Maize is most important cereal crop grown worldwide with production of 1.09 BMT (US statistics, 2018–2019). More than 35.87% world maize crop production is being contributed from the USA and is largest producer of the world with a productivity of 10.57 t ha⁻¹ which is almost double over world average productivity of 4.92 t ha⁻¹. In India, maize is cultivated over an area of 9.2 m ha with production of 28.7 million tonnes and productivity of 3115 kg ha⁻¹ in 2016–2017 (FAOSTAT 2017), and it is considered as 3rd most important crop among the cereals after rice and wheat. The productivity of maize crop is affected by various abiotic (water and nutrients) and biotic (pests and diseases) stresses. Among the abiotic factors, water and nitrogen are considered as more critical elements in deciding maize productivity (Gheysari et al. 2009). Inappropriate management of these two crucial factors causes reduction in yield as both the factors have positive correlation with maize productivity (Di Paolo and Rinaldi 2008). The application of remote sensing technology in detection of water and nutrient stress in maize on temporal scales allows accurate and precise documentation of information and is very difficult and time consuming with traditional way of field survey and sampling.

In this paper, an attempt was made to identify the water and nitrogen stress indicative spectral bands using hyperspectral remote sensing and assessed the predictive capability of selective bands on growth and yield of maize under water and nitrogen stress environment during post-monsoon season.

Materials and Methods

A field experiment was conducted at Agro Climate Research Centre, P.J.T.S Agricultural University, Hyderabad, India during *rabi* (winter) season of 2018–2019 with maize crop (maize hybrid Cargill 900 M). The site of

experiment is located at N 17° 32", E 78° 39" and 542.3 MSL in the Southern Telangana Agro-Climatic Zone in Telangana State. 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. The experiment was laid out in split plot design replicated thrice. The treatments comprises of three irrigation levels viz. IW/CPE (irrigation Water/ Cumulative Pan Evaporation) ratio of 0.6, 0.8 and 1.2 and three nitrogen levels viz. 100, 200 and 300 kg of nitrogen ha⁻¹. The crop was sowed on 16 October, 2018 and harvested at harvest maturity. The nitrogen fertilizers was applied in 3 equal splits each at basal (in the form of DAP and 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 (P₂O₅) in the form of Di-ammonium phosphate applied as basal and 40 kg potassium (K₂O) in the form of muriate of potash (MOP) 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 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.

Relative Leaf Water Content (%)

The relative leaf water content (RLWC) was measured before irrigation by collecting leaf samples from each treatment and estimated by using the formula suggested by Barrs and Weatherley (1962) as expressed below.

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

Leaf Nitrogen Content (%)

The exposed leaf for spectral reflectance study was collected for estimation of nitrogen content. The leaf samples at tasseling and dough stages were collected oven-dried at 65 °C powdered for analysis using Microkjeldahl method (Piper 1966).

Leaf Area Index

Leaf area was estimated on two plants in each plot at tasseling and dough stages. The area of total leaves was measured with digital leaf area meter (LI-3100) and

expressed in cm^{-2} . Leaf area index was calculated by using the formula as proposed by Watson (1952).

$$\text{LAI} = \frac{\text{Leaf area per plant}}{\text{Land area per plant}} = \frac{A}{P}$$

Spectral Reflectance Measurements and Data Analysis

Non-destructive *in situ* spectral data were collected using Spectroradiometer (PS-100) at nadir position with 25° Field of view (FOV) placed at 10–15 cm above the canopy. The spectral reflectance measurements were performed during bright sunny day between 11.30 am to 2.30 pm (Darvishzadeh et al. 2008). The spectral resolution (Full width half maxima, FWHM) of PS 100 spectroradiometer was 1.6 nm. The collected spectra were resampled to 0.5 nm. The specifications of PS 100 spectroradiometer are mentioned in Table 1.

Target radiance was normalized by recording the radiance of a white standard panel of known reflectivity (barium sulphate coated plate) before each observation. Ten measurements of reflectance were collected within each sub-plot. The reflectance data were pre-processed for outlier removal and averaged thereafter.

Selection of Effective Spectral Bands

Multiple linear regression analysis was performed using backward elimination stepwise method and best combinations of bands were selected based on highest coefficient of determination for biophysical parameters viz. leaf nitrogen (%), relative leaf water content (%) and leaf area index. In this study, the values of biophysical parameters viz., leaf nitrogen content (%), relative leaf water content (%) and leaf area index dataset (Y) were used as the dependent variables, and full bands spectra and sensitive wavelengths from 400 to 1000 nm averaged to 10 nm interval dataset (X) were used as the independent variables. The P value of an F -statistic was computed to test models with and without a potential variable at each step. The maximum

P values for a spectral band to be included or removed were defined as 0.05 and 0.01, respectively.

Results and Discussion

Selective Spectral Bands in Prediction of Biophysical Parameters

The leaf nitrogen content (%), relative leaf water content (%) and leaf area index of maize crop were derived from reflectance of selective spectral bands and are presented in Table 1. The variation in leaf nitrogen concentration at tasseling and dough stage ranged from 1.33 to 1.82% as a result of differential nitrogen levels of 100 (N_1), 200 (N_2) and 300 (N_3) kg N ha^{-1} (Fig. 1) was explained by reflectance at green (540 nm) and NIR (780 nm and 860 nm) bands with coefficient of determination (R^2) of 78% (Table 2). The spectral bands in red (700 nm and 740 nm) and NIR (860 nm) regions were found effective with coefficient of determination (R^2) of 77% (Table 2) for predicting relative leaf water content ranged from 66.6% to 81.1% under varied moisture regime created with scheduling irrigation at IW/CPE ratio of 0.6 (I_1), 0.8 (I_2) and 1.2(I_3) at tasseling and dough stage (Fig. 2). The variation in leaf area index in response to varied nitrogen levels (N_1 , N_2 and N_3) ranged from 3.07 to 5.30 and irrigation scheduling (I_1 , I_2 and I_3) ranged from 2.73 to 5.35 was explained by spectral band at yellow (580 nm), orange (600 nm) red (660 nm) and NIR (800 nm) regions with coefficient of determination (R^2) of 98% (Table 2). This investigation culled out the potential of remote sensing for estimating biophysical parameters viz leaf nitrogen (%), relative leaf water content (%) and leaf area index which are sensitive to environment and contributes to growth and yield of maize. These results in line with the findings of Blackmer et al. (1994, 1996) who reported that the reflectance around 550 nm or 610 nm in green region of spectrum has close correlation with nitrogen content in maize leaf. Different researchers have used reflectance at red and INR wavelengths in detection of nitrogen stress in maize crop (Walburg et al. 1982; Blackmer et al. 1996;

Table 1 The properties and specifications of spectroradiometer used in hyperspectral remote sensing in maize

Properties	Specifications
Spectral range	350 nm to 1000 nm
Linear range	0 to 1.2 absorption units (< 0.5%)
Wavelength stability	< 0.001 nm per C
Base unit size	$15.5 \times 9.5 \times 4$ cm
Signal-to-noise ratio	Up to 1000:1
Wavelength resolution	1.6 nm
Detector	2048 pixel; 14 by 200 nm microelement array

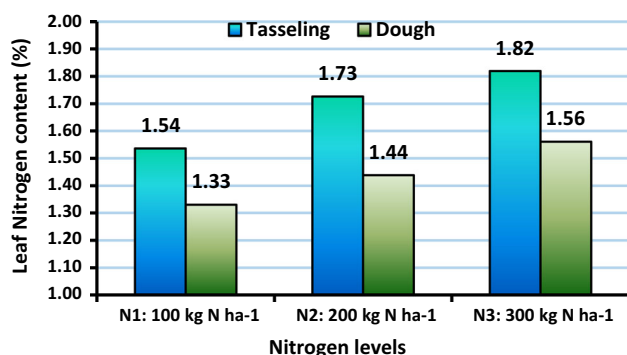


Fig. 1 Leaf nitrogen content (%) of maize at tasseling and dough stages as influenced by nitrogen levels

Stone et al. 1996). Zhang and Zhou (2015) demonstrated that the canopy water information at the red edge of 680 nm–780 nm. For prediction of leaf area index Zhao et al. (2007), used red edge bands (690 nm–710 nm and 750 nm–900 nm), Stagakis et al. (2010) combined green (580 nm), red edge (700 nm and 710 nm), and near infrared wavelengths (1003 nm); Haboudane et al. (2003) also combined green (550 nm), red (670 nm) and near infrared (800 nm) wavelengths (Table 2).

Sensitivity of Spectral Reflectance to Age of the Crop

The spectral reflectance pattern at different wavelengths was influenced by the age of the crop (Fig. 4). It was higher at tasseling stage when compared to dough stage. This evidences the relationships between reflectance in different spectral bands and phenological stages of the crop. A gradual decrease in NIR reflectance during the early reproductive stage and rapid drop toward senescence in corn was also reported by Nguy-Robertson et al. (2013). According to Liang (2004), in the visible part of the spectrum, absorption is due to pigments such as chlorophyll *a* + *b* and carotenoids, while the near-IR and middle-IR absorption by water is more important in the variation of reflectance (Figs. 3 and 4).

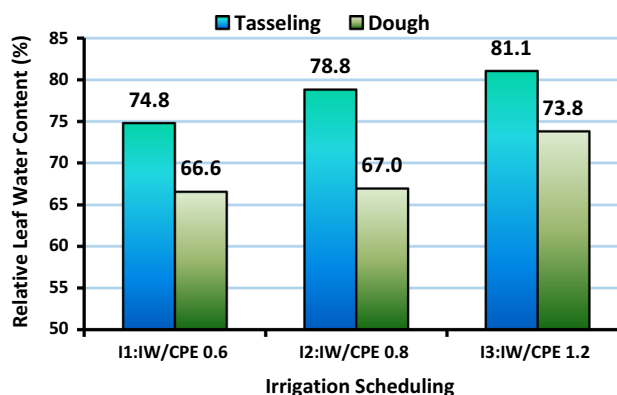


Fig. 2 Relative leaf later content (%) of maize as influenced by irrigation scheduling at tasseling and dough stage

Reflectance Pattern of Different Biophysical Parameters Indicative Spectral Bands

a) Leaf Nitrogen (%)

At tasseling and dough stage of the crop, the spectral bands in NIR region (780 nm and 860 nm) and visible green region (540 nm) were found sensitive to leaf nitrogen content (Fig. 5a, b). The spectral reflectance of selected bands in NIR region and absorption in visible region was more at tasseling stage and decreased at dough stage of the crop. The higher reflectance in NIR region and more absorption in visible region represent the healthiness of the canopy. The crop nurtured with 300 kg N ha⁻¹ (N₃) appears healthier with higher leaf nitrogen content of 1.82% and 1.56% at tasseling and dough stages, respectively, when compared to medium (N₂) and low (N₁) nitrogen level canopy (Fig. 1). Therefore, N₃ treatment exhibited more reflection of 60.9% and 51.1% at 780 nm wavelength and 57.8% and 41.7% at 860 nm wavelengths in NIR and more absorption of 13.1% and 14.6% at 540 nm in visible region at tasseling and dough stages, respectively, and these effects were reduced with decreasing the nitrogen dose from N₂ (200 kg N ha⁻¹) to N₁ (100 kg N ha⁻¹) level. Similar results were also reported by Min et al. (2006) and Xie et al. (2018) who demonstrated that 555 nm wavelength was the nitrogen

Table 2 Stepwise regression models for prediction of leaf nitrogen (%), relative leaf water content (%) and leaf area index in corn using spectral reflectance of identified bands in maize

Parameters	Regression model	R ²
Leaf nitrogen (%)	$Y = 0.444176 + 0.007781 \times R_{540} + 0.009907 \times R_{780} + 0.011622 \times R_{860}$	0.78
Relative leaf water content (%)	$Y = 28.75174 + 0.74338 \times R_{700} + 0.39956 \times R_{740} + 0.39321 \times R_{860}$	0.77
Leaf area index	$Y = 0.422930 - 0.069871 \times R_{580} + 0.131964 \times R_{600} - 0.067401 \times R_{660} + 0.022995 \times R_{800}$	0.98

Fig. 3 Leaf area index (LAI) of maize as influenced by irrigation scheduling and nitrogen levels at tasseling and dough stage

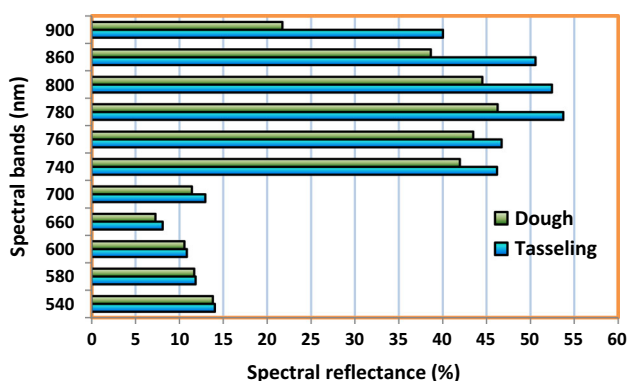
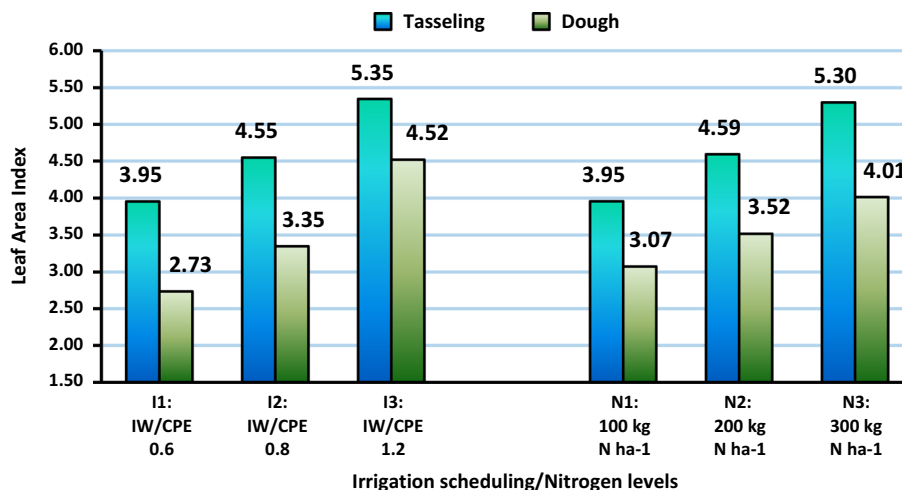


Fig. 4 Difference in spectral reflectance (%) at tasseling and dough stage in maize

absorption band which correlates to absorbed light by nitrogen within the crop tissue.

b) Relative Leaf Water Content (%)

The differential relative leaf water content of maize leaf as a result of varied degrees of water stress imposed through irrigation scheduling influenced the reflectance pattern of selective wave bands at tasseling and dough stage of the crop (Fig. 6a, b). Under optimum irrigation scheduled at IW/CPE of 1.2 (I₃), the spectral reflectance of 50.0% and 47.2% at 700 nm and 56.5% and 39.1% at 860 nm in NIR region and 14.4% and 13.9% in visible green region at tasseling and dough stages, respectively, were more and decreased with increasing interval between two successive irrigations scheduled at I₂ (IW/CPE of 0.8) and I₁ (IW/CPE of 0.6) treatments. The more relative leaf water content under I₃ treatment allowed the crop to stay healthy at silking and dough stage of the crop growth (Fig. 2). The spectral region from 840 to 870 nm is sensitive to plant water stress in full canopy condition (DeTar et al. 2006; Govender et al. 2009). The higher reflectance from non-water stressed crop than the stresses crop in NIR spectrum was also reported by Elmetwalli et al. (2012) and Weber

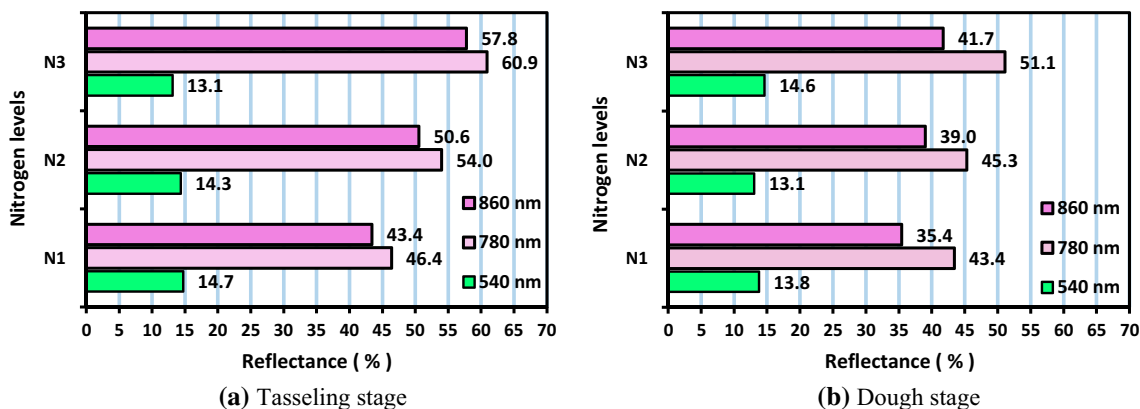


Fig. 5 a and b Spectral reflectance of leaf nitrogen content indicative wave bands at tasseling and dough stage of maize as influenced by nitrogen levels

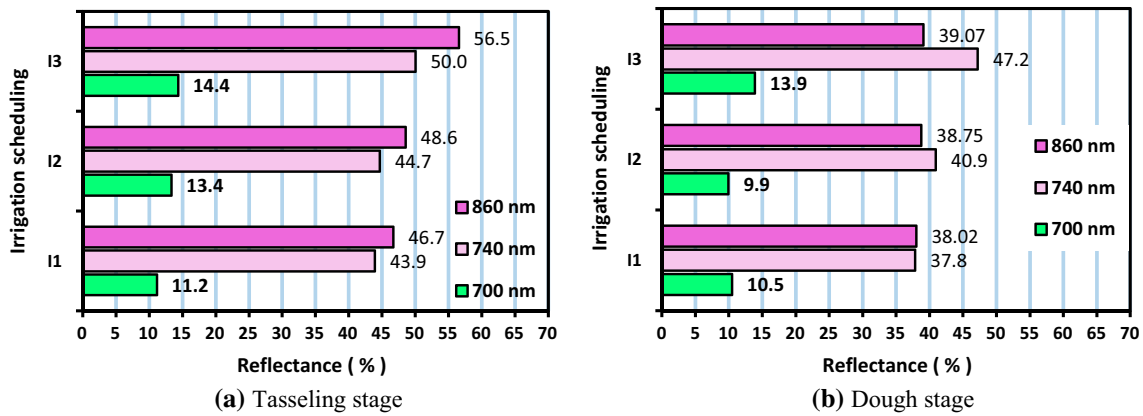
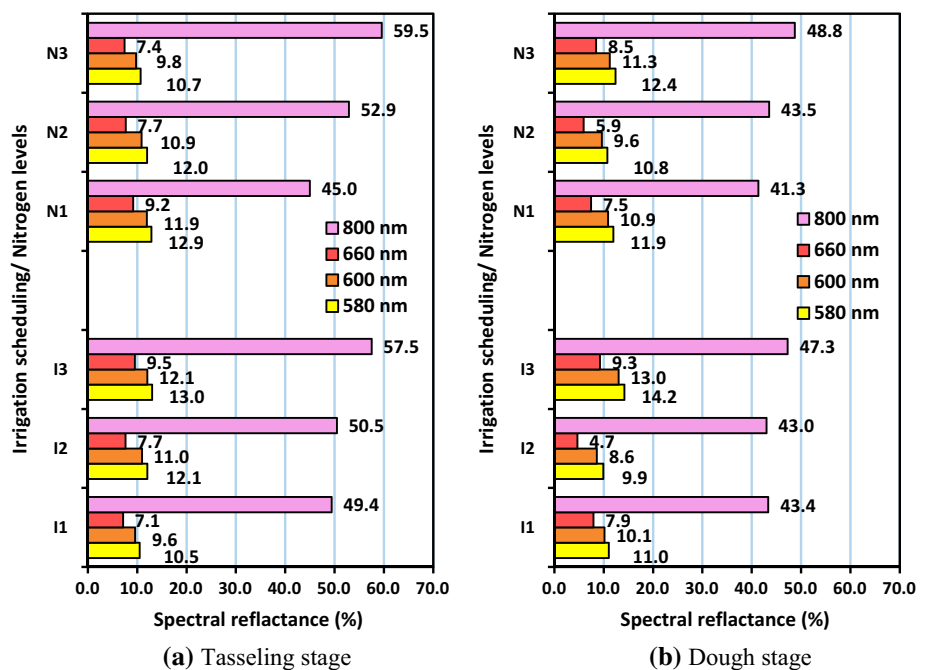


Fig. 6 a and b Spectral reflectance of Relative leaf water content indicative wave bands at tasseling and dough stage of maize as influenced by irrigation scheduling

Fig. 7 a and b Spectral reflectance of leaf area index indicative wave bands at tasseling and dough stage of maize as influenced by irrigation scheduling and nitrogen levels



et al. (2012) in maize crop. The more reflectance in green region under I₃ treatment as compared to I₂ and I₁ treatments might be due to increase in biomass with increasing frequency between two successive irrigations resulted in dilution effect of mineral N concentration in different plant parts. Increased dry-weight accumulation accompanied by decreased shoot mineral concentration has been defined as a dilution effect (Jarrell and Beverly 1981). Greenwood et al. (1990) were also demonstrated that, the plant N% decreases with increasing crop biomass.

c) Leaf Area Index (LAI)

The reflectance pattern of leaf area index indicative selected spectral bands at tasseling and dough stage is depicted in Fig. 7a, b, respectively. The leaf area index of the maize increased with decreasing interval between two subsequent irrigation (I₁ to I₃) and increasing the nitrogen dose from N₁ to N₃ (Fig. 3). Higher leaf area index (LAI) is indicative of healthiness of the canopy. The reflectance at 800 nm in NIR region was higher at I₃ (57.5% and 47.3%) and N₃ (59.5% and 48.8%) levels at tasseling and dough stages, respectively, where maximum LAI was observed. The higher reflectance in yellow (580 nm), orange

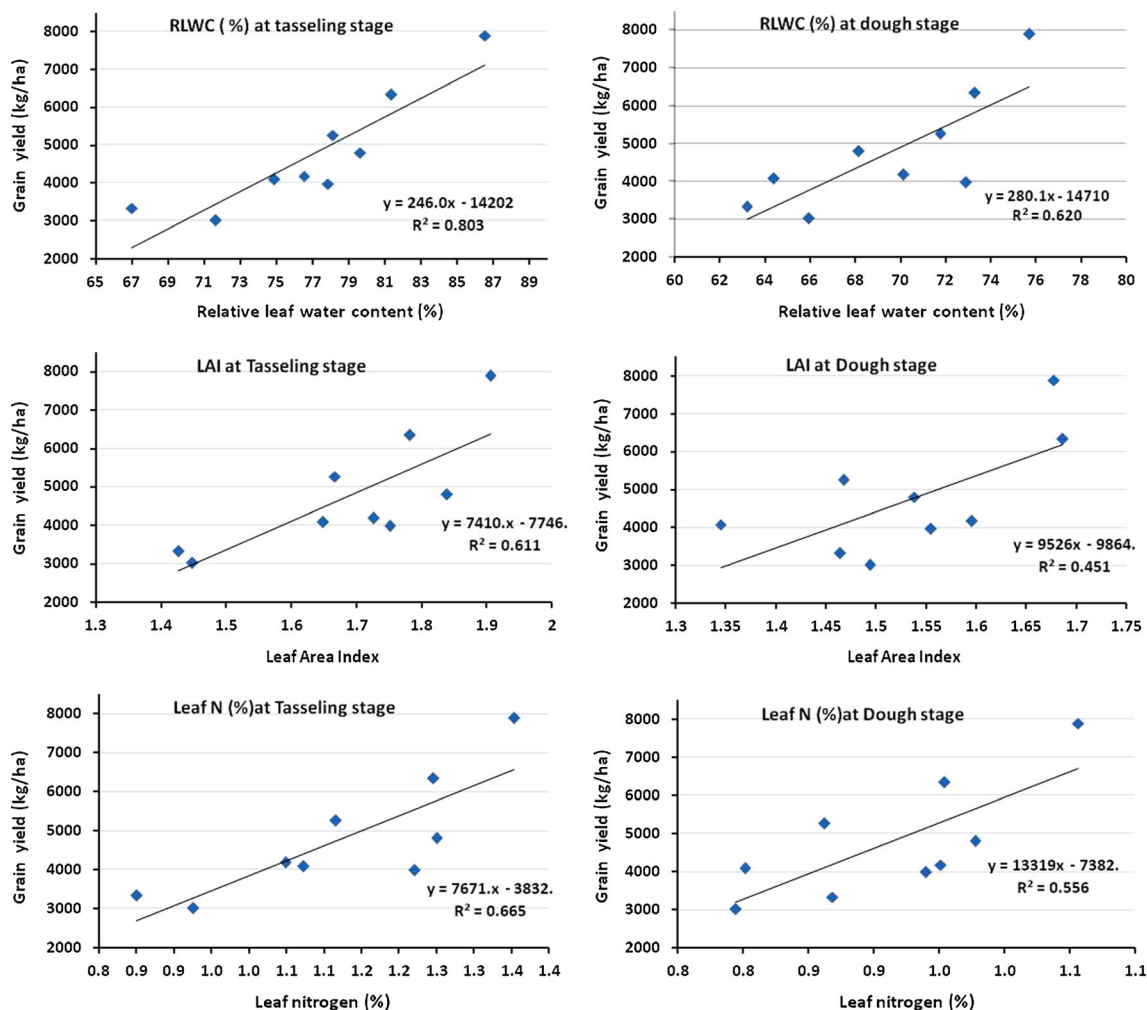


Fig. 8 Regression equations for prediction of grain yield (kg/ha) based on derived biophysical parameters (relative leaf water content (RLWC %), leaf area index (LAI) and leaf nitrogen contentment (N

%) using reflectance (%) from selective spectral bands at tasseling and dough stages of maize crop

(600 nm) and red (660 nm) in visible range under deficit irrigation scheduled at IW/CPE of 0.6 (I_1) and deficit nitrogen level of 100 kg N ha⁻¹ (N_1) treatment are the indicative of water stress and nitrogen stress resulted in reduction in LAI at tasseling and dough stages of the crop. These results clearly demonstrate that, the spectral bands viz. 580 nm, 600 nm, 660 nm and 800 nm were more sensitive to detect the effect water and nitrogen stress on leaf area index at tasseling and dough stages of maize crop.

Prediction of Grain Yield Based on Spectral Reflectance-Derived Biophysical Parameters

The regression equations for prediction of grain yield (kg/ha) based on derived biophysical parameters viz. relative leaf water content (RLWC %), leaf area index (LAI) and leaf nitrogen contentment (N %) using multiple regression equations (Table 1) which was developed based on

reflectance (%) from selective spectral bands at tasseling and dough stages of maize crop is presented in Fig. 8. The results indicated that the derived biophysical parameters viz. relative leaf water content (RLWC %), leaf area index (LAI) and leaf nitrogen contentment (N %) at tasseling stage of maize crop accounted for 80%, 61% and 66% variation in grain yield, respectively. The predictive capabilities of these biophysical parameters for grain yield were comparatively low at dough stage of the crop. These results indicated that the biophysical parameters derived at tasseling stage based on regression equation developed from reflectance of selective wave bands were more sensitive for prediction of grain yield in maize crop. At dough stage (90 days after sowing), the maximum translocation of photosynthates/food material from source (leaves and stem) to sink (cob) occurs. The translocation of food material depends upon availability of soil moisture; active root mass, root shoot ratio, transpiration gradient from root

to stomata, photosynthesis rate, stomatal conductance etc. These physiological activities tend to decrease from active growth phase (tasseling) to maturity stage. The reduction in these entire parameters become complex and thus increase the complexity in spectral reflectance pattern as the crop tends to approach toward physiological maturity stage. Therefore, the yield predictive capability of spectral reflectance at dough stage might be low as compared to tasseling stage.

Conclusions

The potential for hyper-spectral remote sensing to detect water and nitrogen stress in irrigated maize was illustrated this investigation. Multiple linear regression analysis was performed using backward elimination stepwise method, and best combinations of bands were selected based on highest coefficient of determination for biophysical parameters viz. Leaf nitrogen (%), relative leaf water content and leaf area index. The sensitiveness of spectral reflectance pattern at different wavelengths as influenced by water and nitrogen stress was illustrated. The sensitivity of spectral reflectance to age of the crop was established. The grain yield predictive capability of derived biophysical parameters viz. relative leaf water content (RLWC %), leaf area index (LAI) and leaf nitrogen contentment (N %) using multiple regression equations which was developed based on reflectance (%) from selective spectral bands at tasseling stage of maize crop was tested and found effective. This investigation culled out the most effective spectral bands in visible and infrared region for detection of water and nitrogen stress in maize crop. The outcome of this study may be useful for choosing effective spectral bands for multispectral remote sensing for assessing maize crop condition at spatiotemporal scale on real-time basis.

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