Journal of Agrometeorology 17 (2) : 213-218 (December 2015)

Determination of nitrogen and water stress with hyper spectral reflectance on maize using classification tree (CT) analysis

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ABSTRACT

Field experiments were conducted at the Tamil Nadu Agricultural University, Coimbatore, Tamilnadu, India during *rabi* (winter) season of 2013-14 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 % of recommended dose of nitrogen (RDN). The experiment was laid out in factorial randomized blocks design RBD (Factorial) with three replications. Hyper spectral observations were made with spectroradiometer GER 1500 at 60 and 90 days after sowing (DAS). 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 under unstressed environment created with irrigation at 0.80 IW/CPE ratio and fertilizer application at 100 % RDN. Significant differences in reflectance were established for nitrogen and water stress at green and NIR region. The results of Classification tree analysis revealed that nitrogen and water stress can be assessed and differentiated using reflectance data when transformed into spectral vegetation indices *viz.*, NDVI, GNDVI, RVI, LCI, IR-RED and SR. Further the Classification tree algorithm could determine that NDVI was the most effective index to assess the combined effect of nitrogen and water stress in maize crop.

Key words: Classification tree, spectral vegetation indices, nitrogen and water stress, maize

Remote sensing is a better method to detect and quantify the impact of plant stress compared to visual techniques because a vegetative unit can be repeatedly, objectively, and nondestructively examined in a fast, robust, accurate, and inexpensive way (Mirik *et al.,* 2012). Stresses come from a range of factors that limit the potential growth of canopies. Evaluation of the stress level to which plants are subjected is therefore critical information required both for the quantification of consequences on production and for taking action for their mitigation (Baret *et al.,* 2007). Many stresses are caused directly or indirectly by water shortages or insufficient satisfaction of canopy mineral requirements, particularly nitrogen.

Hyper spectral remote sensing techniques allow the early detection of vegetation stress, before the appearance of visible symptoms (Panigada *et al.,* 2010). Using that absorption and spectral reflection characteristics of vegetation researchers has 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). More recently, Mirik *et al.* (2012) discussed that spectral vegetation indices are mathematical expressions involving reflectance values from different part of the electromagnetic spectrum, aimed to optimize information and normalize measurements made across varied environmental conditions.

In addition to vegetation indices, many statistical and mathematical models such as principle component analysis (Genc, 2003), random forest, support vector machine, artificial neural network, and other classification procedures have been developed to extract optimal information from remotely sensed data. Classification tree (CT) was developed to investigate the relationship between the categorical data and determine the variables affecting other independent variables (Yohannes and Hoddinott, 1999). Researchers observed that the CT was a very useful model to analyze complex data sets by providing visual results (Camdeviren *et al.,* 2005). Recently, Genc *et al.* (2013) to investigate the most effective vegetation index to

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})	Heute, (1988)

determine water stress using classification tree (CT) model. Keeping these in view an experiment was planned to determination of nitrogen and water stress with hyper spectral reflectance on maize using classification tree (CT) analysis.

MATERIALS AND METHODS

Study area

A field experiment was conducted at Tamil Nadu Agricultural University, Coimbatore, Tamilnadu, India during *rabi* (winter) season of 2013-14 with maize crop (TNAU maize hybrid Co 6). The site of 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}), 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 replication 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 general 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, Govt. of Tamilnadu, Chennai and Tamil Nadu Agricultural University, Coimbatore.

Spectral reflectance measurements

Hyper spectral 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. The field of view (FOV) was 25° and the distance between the optical head of the spectroadiometer and the top of the plant was kept at 1 m for the all observations. Calibration of the radiometer was done with the help of barium sulphat coated plate in the field before and after taking canopy reflectance measurement. The canopy reflectances were 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 were calculated, where R and subscript number indicate the light reflectance at specific wavelength (in nm) Table 1. The reflectance data were transformed in to vegetation indices and used to distinguish nitrogen and water stress severity in maize. These indices to analysis the Classification Tree models in SPSS 16.0 var.

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. Chlorophyll a and b absorb light in the red (around 670 nm) and blue (around 450 nm) portions of the spectrum (Gates *et al.,* 1965; Lawlor, 2001). 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

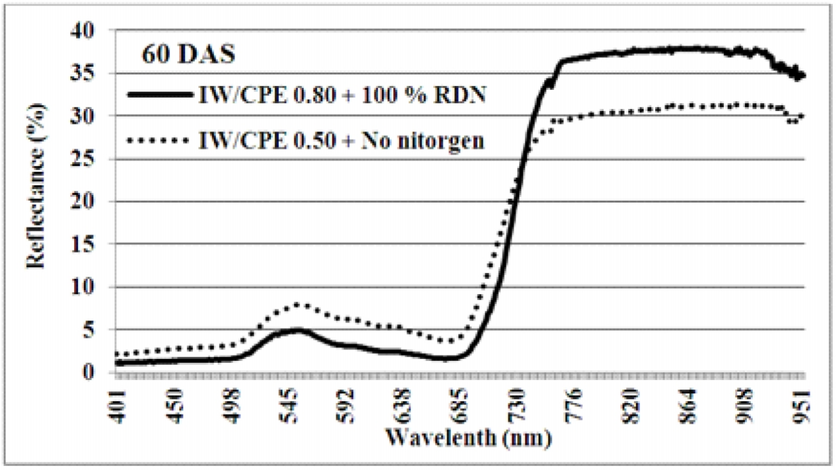

Fig. 1: Spectral signature characters of unstressed (IW/CPE ration: 0.80 + 100 % RDN) and stressed (IW/CPE ratio: 0.50 + No nitrogen) maize crop at 60 DAS

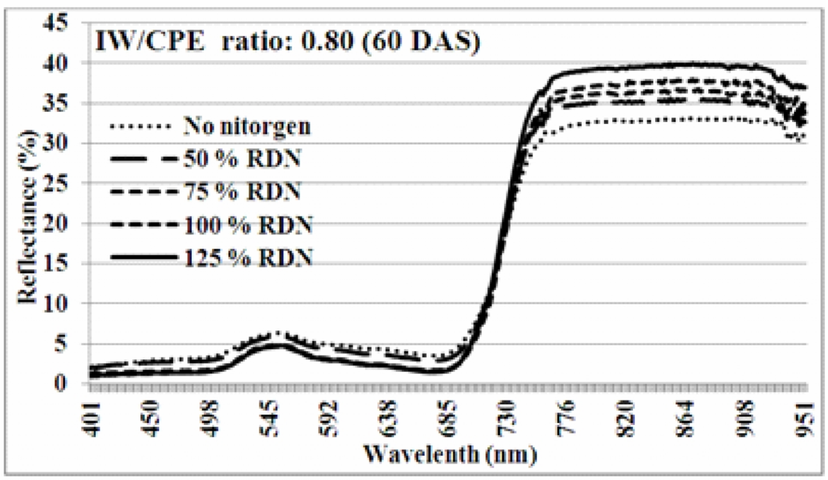

Fig. 2: Spectral signature characters of maize crop with irrigation at IW/CPE ration: 0.80 and different nitrogen levels.

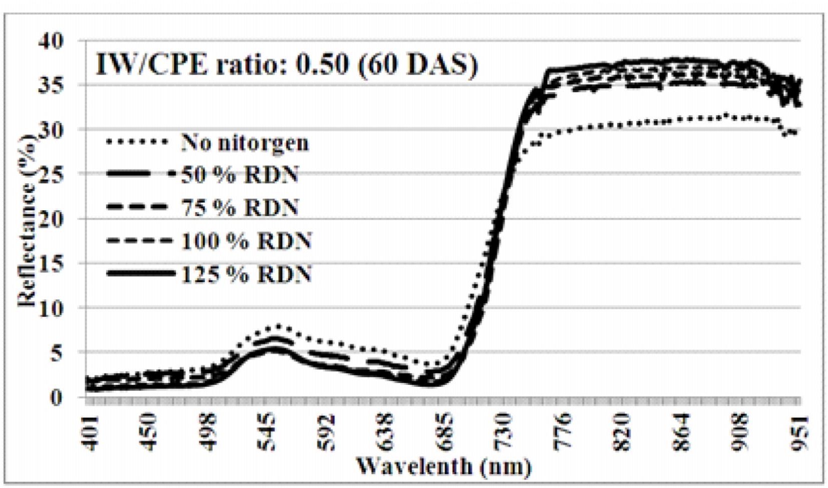

Fig. 3: Spectral signature characters of maize crop with irrigation at IW/CPE ration: 0.50 and different nitrogen levels.

Table 2 : Classification accuracy between observed and predicted values for maize grown under two irrigation regimes and five nitrogen levels at 60 DAS.

Observed	Predicted											
	IW/CPE ratio: 0.80					Percent	IW/CPE ratio: 0.50					Percent
	N_0	N_1	N_2	N_3	N_4	correct	N_0	N_1	N_2	N_3	N_4	correct
N_0	3	0	0	0	0	100	1	0	0	0	0	100
N_1	0	3	0	0	0	100	0	1	0	0	0	100
N_2	0	0	4	0	0	100	0	0	3	0	0	100
N_3	0	0	0	1	0	100	0	0	0	1	0	100
N_4	0	0	0	0	2	100	0	0	0	0	3	100
Overall Percentage	23.1	23.1	30.8	7.7	15.4	100	11.1	11.1	33.3	11.1	33.3	100

Note: N_0 = No nitrogen, N_1 = 50 % RDN, N_2 = 75 % RDN, N_3 = 100 % RDN and N_4 = 125 % RDN

with no nitrogen compare to unstressed maize (Fig. 1). Similar reflectance pattern of maize crop was observed at 60 and 90 DAS. Plant stress that causes reduction in chlorophyll leads to an increase in light reflected in the visible range (400-700nm). Conversely, percent reflection in the NIR region (740-1100nm) is reduced as internal leaf structure degenerates. This scattering occurs deep within the leaf tissue, and hence percentage light reflected in the NIR region may provide on the physiological condition of plant under stress (Nilsson, 1995; Hatfield and Pinter, 1993).

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. Light reflected by vegetation in the visible region of the spectrum is predominantly influenced by the presence of chlorophyll pigments in the leaf tissues, which have been found to relate to the concentration of leaf N (Haboudane *et al.,* 2002). Increase in nitrogen dose, the chlorophyll content increased significantly (Pradhan *et al.,* 2013). The spectral region between the red absorption feature and high NIR reflectance, termed the ''red edge'', changes shape and position when the plant undergoes stress, such as nitrogen deficiency (Barnes *et al.,* 2000).

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 reflectance from stressed plants in the NIR spectrum at 60 and 90 DAS as also reported by Elmetwalli *et al.* (2012). The increase of moisture stress in plant caused an increase in red band reflection and decrease in the near infrared spectral band. The increase in reflectance in the red region is caused by the reduced activity of chlorophyll leading to decrease in absorption. While in the near infrared region, the decline in reflectance is due to the reduced turgidity of spongy - mesophyll layer in rainfed crop compared to the turgidity levels of fully irrigated crop (Jayasree *et al.,* 2013).

Classification tree analysis

In order to determine the combined effect of nitrogen and water stress severity in two irrigation regimes (IW/CPE: 0.80 and 0.50) with five nitrogen levels (no nitrogen, 50, 75, 100 and 125 % RDN), NDVI, GNDVI, RVI, LCI, IR-RED and SR were analysed using CT paths. The results of the analysis revealed that classification accuracy for both the irrigation regimes was 100 % at 60 DAS (Table 2).

Among the indices, CT algorithm selected NDVI as a starter index to predict combined effect of nitrogen and water stress at 60 DAS. It was calculated that, there was no effect of nitrogen and water stress in 100 per cent of the plants when NDVI was $\leq$ 0.92 and GNDVI was $\geq$ 77 when irrigated at IW/CPE: 0.80 and applied either with 125 or 100

% RDN respectively. Sever nitrogen and water stress could be expected in all the plants at IW/CPE: 0.80 with no nitrogen when GNDVI reading was ≤ 0.68. In contrast, nitrogen and water stress was not expected at 50 % RDN if GNDVI reading was ≥ 0.68 in IW/CPE: 0.80.

At IW/CPE ratio of 0.50 when applied with 125 % RDN, there was no effect of nitrogen and water stress in 100 % of the plants recording a NDVI value of < 0.92. Considering GNDVI value of > 0.74 no stress was observed at 100 % RDN. Sever nitrogen and water stress could be expected in 100 % of plants at IW/CPE: 0.50 with no nitrogen if GNDVI reading was ≤ 0.59. In contrast, nitrogen and water stress was not expected at 50 % RDN if GNDVI reading was ≥ 0.59 in IW/CPE: 0.50.

Among the indices, CT model selected NDVI as a starter index to predict the combine effect of nitrogen and water stress at 90 DAS. It was calculated that, at IW/CPE ratio of 0.80 there was no effect nitrogen and water stress in 100 % of the plants when NDVI was ≤ 0.78 and GNDVI was ≥ 58 with 125 and 100 % RDN respectively. In the same irrigation regime sever nitrogen and water stress could be expected in 100 % of plants when no nitrogen was applied indicated by GNDVI reading of < 0.47. In contrast, nitrogen and water stress was not expected at 50 % RDN if GNDVI reading was ≥ 0.47.

At irrigation regime with 0.50 IW/CPE ratio, there was no effect of nitrogen and water stress in 100 % of the plants when NDVI was ≤ 0.75 and GNDVI was ≥ 56 with 125 and 100 % RDN respectively. Sever nitrogen and water stress could be expected in 100 % of plant at IW/CPE: 0.50 when no nitrogen was applied recording a GNDVI reading of ≤ 0.47. In contrast, nitrogen and water stress was not expected at 50 % RDN if GNDVI reading was ≥ 0.47.

The Classification tree analysis revealed that water stress can be assessed and differentiated using chlorophyll readings and reflectance data when transformed into spectral vegetation indices (Genc *et al.,* 2013). In our study, spectral vegetation indices derived from hyperspectral reflectance spectra were used in CT to assess water stress in corn plants. Overall success rate of classification accuracy between predicted and measured values of stressed corn indicated that NDVI has potential to determine combine effect of nitrogen and water stress of maize. The advantage of tree-based classification includes that it does not require the assumption of probability distribution, specific interactions can be detected without previous inclusion in the model, nonhomogeneity can be taken into account, mixed data types can be used and dimension reduction of hyperspectral datasets is facilitated (Delalieux *et al.,* 2007).

CONCLUSION

We tested the ability of classification tree algorithm to assess combined effect of nitrogen and water stress in maize using hyper spectral reflectance spectra transformed into spectral vegetation indices. The results of this study demonstrated that nitrogen and water stress in maize is detectable through spectral reflectance analysis. Two water regimes and five nitrogen levels applied in this study clearly caused variation in the spectral reflectance. It was found that the most effective index to determine combined effect of nitrogen and water stress using classification tree (CT) model was normalized difference vegetation index (NDVI) for maize crop.

ACKNOWLEDGEMENT

This work has been undertaken with financially support from UGC, New Delhi under Major research projects scheme.

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Received : November 2014 ; Accepted : July 2015