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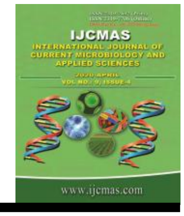

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Hyperspectral Remote Sensing Technique to Detect Water Stress in Groundnut

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A B S T R A C T

Groundnut is an important oil seed crop largely grown under rainfed conditions in India. Uneven distribution and or failure of monsoon rain affects the plant growth and reduces the productivity When crop is subjected to water stress it closes the stomata leading to reduced photosynthesis. Detection of plant water stress and assessing the possible effect on the growth and yield of crop is often difficult and challenging. To study the effect of water stress on the spectral reflectance properties of Groundnut and to assess the water stress using hyperspectral indices, a pot culture experiment with groundnut variety CO-7 was conducted during 2016-17. In order to induce water stress, varying soil moisture regimes were created by altering the irrigation intervals as well as the quantity of water applied. The spectral reflectance measurement (using Spectroradiometer) along with soil moisture content (using TDR probe) and plant sampling were made on 45 days after sowing (DAS), 60 DAS and 75 DAS. The results revealed that the treatments had significant effect in inducing soil moisture stress as evident from varying soil moisture content at various stages. The relative water content (RWC) during 45 DAS was higher for control(86.5 %) followed by moisture stress at 70 % moisture depletion (81.0 %) and 90 % moisture depletion (74.1%), similar trend was observed for the 60 DAS and 75 DAS also and also with plant water content. The spectral indices *viz*., chlorophyll red_edge and Transformed Chlorophyll Absorption in Reflectance Index (TCARI)were related with relative water content of the plant at various dates of observation. RWC relates well with chlorophyll red_edge with a R^2 value of 0.5072at 45 DAS and TCARI with a R^2 value of 0. 6379 and 0.7657 during 60 and 75 DAS. Thus, the present study indicated that the spectral reflectance data can be used to assess the water stress conditions of groundnut.

Introduction

Plant water status at various crop growth stages provides information that can be used to prevent crop water deficit (Koksal, 2008). The standard method of measuring the water content involves drying the plants in an oven are a very simple and reliable procedure but it is also slow and labour demanding process. Plant water status can also be assessed remotely by measuring canopy reflectance indices, since they change in response to crop water content (Penuelas *et al*., 1997; Ustin *et al*., 1998; Stimson *et al*., 2005).

The ability to accurately assess water stress symptoms in vegetation using spectral reflectance measurements is an important application of remote sensing (Jackson, 1986). Water stress is one of the most common limitations of primary productivity in both natural and cultivated plants (Boyer, 1982).

Penuelas *et al.,* (1993, 1996 and 1997) reported that reflectance in the near-infrared region at 950-970 nm corresponding to a weaker water absorption band has been proved to be useful for assessing the plant water stress. Several research evidences indicate that leaf reflectance is altered by stress more consistently at visible wavelength (400-720 nm) than in the remainder of the incident solar spectrum (Carter, 1993 &1994). The advancements in remote sensing sensor can help to assess the plant water status based on the canopy reflectance at certain wavelengths in the near-infrared band of the electromagnetic spectrum. Gaussman (1985) and Jackson (1986) findings states that reflectance of light varies as the water content in the leaf tissue varies. The potential of using leaf and canopy reflectance for measuring plant water stress has been demonstrated by several workers (Bowman, 1989; Penuelas *et al*., 1993, 1997; Pietro Ceccato *et al*., 2001; Carter and Knapp, 2001; Sims and Gamon, 2003). Penuelas *et al.*, (1997) reported that a simple radiometer measuring plant reflectance at 680, 900 and 970 nm could speed up the measurement of plant water content and be useful in drought assessment.

Approximately 70 % of the world's groundnut production comes from semi-arid regions and the semi-arid regions in India are characterized by extremes of moisture availability and temperature during the peak period of crop cultivation. Abiotic factors of prime importance include temperature extremes and drought stress and soil factors, in which water deficits at critical stages can reduce the pod yields by more than 70 per cent. Groundnut development stages close to flowering and post flowering (upto pod development) stages are sensitive to drought stress and it also affects the biological N fixation and nitrogen assimilation in plants.

With this background knowledge the present investigation was carried out to study the usefulness of hyperspectral remote sensing technique to assess and detect the water stress in Groundnut under controlled environment (pot culture experiment).

Materials and Methods

To study the effect of water stress on the spectral reflectance properties of Groundnut and to assess the water stress using hyperspectral indices, a pot culture experiment with groundnut variety CO-7 was conducted in the Department of Remote Sensing and GIS, TNAU, Coimbatore during 2016-17. In order to induce water stress, varying soil moisture regimes were created by altering the irrigation intervals (considering the available water capacity) as well as the quantity of water to be applied (ensured by regular monitoring of soil moisture through real time TDR probe). The treatment schedule consists of i) Irrigation at 50 % of soil moisture depletion, ii) Irrigation at 70 % of soil moisture depletion and iii) Irrigation at 90 % of soil moisture depletion these were replicated five times in a completely randomized block design. All other factors *viz*., nutrition and crop management practices were kept at optimum. Spectral reflectance from groundnut leaves were measured using Spectroradiometer (model: GER 1500; make: Spectra Vista Corporation, USA which can measure the reflectance between 350 and 1050 nm with 3 nm band width and record reflectance at 512 channels) at weekly intervals during bright sunshine hours (between 10 am and 12.00 noon). The spectral reflectance measurement along with soil moisture content (using TDR probe) was made on 45 days after sowing (DAS), 60 DAS and 75 DAS. Leaf samples were collected at the time of spectral measurement and analysed for relative water content (RWC) and Plant Water Content (PWC) in groundnut leaves and the data were analysed statistically.

Relative Water Content (RWC) was estimated using fresh and dry weight of fully opened leaf. The leaf samples were then soaked in distilled water for 8 hrs to record saturated leaf weight and consequently dried and dry weight was recorded.

RWC was calculated using the formula suggested byBarrs and Weatherly (1962).

$$RWC = \frac{(\mathrm{fW} - \mathrm{dW})}{(\mathrm{tW} - \mathrm{dW})} * 100$$

Where, fW is the sample fresh weight, tW is the sample turgid weight and dW is the sample dry weight.

Similarly, Plant Water Content **(**PWC) Analysis was also determined using the formula given below,

$$PWC = \frac{(\mathrm{fW} - \mathrm{dW})}{(\mathrm{fW})} * 100$$

Where, fW, fresh weight and dW, dry weight.

The spectral reflectance data were analysed using a customized tool *viz*., “Hyperanalyst” (Balajikannan *et al.,* 2015) to derive spectral indices. The following are the spectral indices developed and tested by many researchers which are useful for correlating crop water stress parameters and plant water content (Table 1).

Results and Discussion

Water stress parameters and groundnut yield

The results obtained from the experiment *viz.*, soil moisture, relative water content, plant water content and spectral reflectance measurement and their indices at various stages are presented and discussed in this chapter. The TDR soil moisture, relative water content and plant water content determined at 45, 60 and 75 DAS are presented in Table 2. The objective of creating water stress in the pot culture experiment was very well reflected in the soil moisture measurement.

The treatments had significant effect in inducing soil moisture stress as evident from varying soil moisture content at various stages significantly at 5 % level. The relative water content (RWC) during 45 DAS was higher for T1 (86.5) followed by T2 (81.0) and T3 (74.1), similar trend was observed for the 60 and 75 DAS also, however T1 is significantly different from T2 and T3 as the effect of irrigation at 70 % and 90 % moisture depletion were on par.In general, the RWC was decreased remarkably in response to declining soil water availability (Table 2 and Figure 1). The results are in accordance with Painawadee *et al.,* (2009) and Shinde and Laware (2014) who found significant difference in RWC between drought treatment and control treatment in peanut varieties. Leaf water status has been widely used as an indicator of crop water stress as reported by de Jong *et al.*, (2012). In the present study plant water content varied from 71.64 to 80.97 % and on 45 DAS PWC was higher for T1 (75.37) followed by T2 (74.41) and T3 (71.64), similar trend was observed for the 60 and 75 DAS and T1 is significantly different from T2 and T3 as the effect of irrigation at 70 % and 90 % moisture depletion were on par. The groundnut crop was harvested at maturity after 105 days of sowing and the yield and yield parameters were recorded. The pod weight, haulm weight, total dry matter production (DMP) and kernel yield are presented in Table 3. It is evident from the data presented in the table that varying soil moisture had a significant effect on the yield and yield parameters of the groundnut crop. The pod weight per pot (3 plants) highest for T1 (21.4 g) followed by T2 (17.2 g) and T3 (14.0 g), wherein the T1 is significantly higher than T2 and T3. Whereas the T2 (Irrigation at 70% moisture depletion) and T3 (Irrigation at 90% moisture depletion) were on par. In the case of haulm yield, total DMP and kernel weight, similar trend was observed for 60 and 75 DAS also. The haulm weight varied from 23.5 g (T3) to 32.5 (T1) and the haulm yield for T2 was 27.9 g and the total DMP varied from 37.5 g to 53.9 g. The kernel weight was higher for T1 (16.1 g), T2 (12.7 g) and T3 it was 10.4 g. In all the parameters T1 is significantly higher than T2 and T3 at 5 % level.

Water stress parameters and spectral data analysis

The spectral reflectance data (collected as reflectance percentage against wavelength) by the spectroradiometer were subjected to analysis for deriving spectral indices *viz.*, NDVI, Chlorophyll red edge, Transformed Chlorophyll Absorption in Reflectance Index (TCARI) and water index, besides other indices were also tried to establish relationship between the plant water stress parameters and spectral data. Among the different indices tried, the Normalized Difference Vegetation Index (NDVI), Chlorophyll_rededge and TCARI only influenced by the water stress. The NDVI (which is an important indicator of plant greenness or biomass), is sensitive to crop stress calculated from spectral data for different dates of observation for three treatments are presented in Figure 2. It is evident from the figure that, NDVI value for T3 (irrigation at 90% water depletion) was low, which varied from 0.66 to 0.8 followed by T2 (irrigation at 70% water depletion) and high for T1 (0.77 to 0.90 during various stage of crop growth. In general, NDVI value increases with increase in biomass and decreases during maturity and in the present study the low NDVI values for water stress treatments might be due to poor biomass and decline in leaf turgidity. In order to establish the relationship between water content and spectral indices, the relative water content was correlated with chlorophyll red edge and sensitive stress region. The Figure 3 relates RWC and chlorophyll_rededge on 45 DAS, the relative water content relates well with chlorophyll rededge with a R^2 value of 0.5072. Similarly, the RWC was related with Transformed Chlorophyll Absorption in Reflectance Index (TCARI) of the spectral data collected at60 and 75 DAS (Figure 4 and 5).

The TCARI, which is basically sensitive to variation in chlorophyll content correlate well with variation in relative water content with a R^2 of 0.6379 at 60 DAS and 0.7657, meaning that the plant water content could be predicted or estimated at different growth stages using the spectral index, TCARI. The present study is in accordance with Yoshio Inoue *et al.*, (1993) who obtained a positive correlation between relative water content and spectral index for groundnut. Yunseop Kim *et al.*, (2010) reported that Red Edge NDVI and NDVI are highly correlated to water stress. Zhang and Zhou (2019) reported difference in crop growth through the spectral indices *viz*., NRred edge, Cl_green, and Cl_red edge. Thus, the above results indicated that the spectral reflectance data can be used to assess the water stress conditions of groundnut as reported by Satpute *et al.*, (2018).

Table.1 List of spectral indices utilized in this study

Sl No	Spectral Index	Formula	Reference
1	Normalized Difference Vegetation index (NDVI)	$NDVI = \frac{Rnir - Rred}{Rnir + Rred}$	Rouse *et al.,* (1974)
2	Transformed Chlorophyll Absorption in Reflectance Index (TCARI)	$TCARI = 3(R_{700} - R_{670}) -0.2(R_{700} - R_{550}) * (R_{700}/R_{670})$	Haboundane *et al* (2002)
3	Water Index (WI)	$WI = \frac{R900}{R970}$	Penuelas *et al.,* (1993)
4	Chlorophyll Index _ Red Edge (Cl_red edge)	$Cl - red\ edge = \frac{R(770 - 800)}{R(720 - 730)}$	Gitelson *et al.,* (2006)

Table.2 Soil moisture (TDR probe) and leaf water content of groundnut leaves at various dates (DAS-days after sowing) of observation

Treatment#	**Soil moisture (%)**			**Relative Water Content**			**Plant Water Content (%)**		
	45	**60**	**75**	**45**	**60**	**75**	**45**	**60**	**75**
T1	14.37	22.57	30.79	86.5	87.6	88.4	75.35	77.35	80.97
T2	10.24	10.07	12.04	81.0	81.2	85.2	74.41	76.55	80.14
T3	8.88	6.85	4.82	74.1	79.5	80.3	71.64	75.65	79.31
SE (d)	*0.83*	*1.46*	*1.29*	*1.71*	*1.20*	*0.98*	*1.05*	*0.72*	*1.44*
CD (5%)	*1.81**	*3.19**	*2.81**	*3.72**	*2.62**	*2.13**	*2.29**	*1.57**	*3.14**

#T1: Irrigation at 50% moisture depletion; T2: Irrigation at 70% moisture depletion;
T3: Irrigation at 90% moisture depletion
*Significant at 5% level

Table.3 Yield of groundnut (weight in grams/ pot of 3 plants) at harvest

Treatment#	**Pod weight**	**Haulm weight**	**Total DMP**	**Kernel weight**
T1	21.4	32.5	53.9	16.1
T2	17.2	27.9	45.1	12.7
T3	14.0	23.5	37.5	10.4
SE (d)	*2.00*	*1.71*	*3.05*	*1.44*
CD (5%)	*4.35**	*3.73**	*6.65**	*3.14**

#T1: Irrigation at 50% moisture depletion; T2: Irrigation at 70% moisture depletion;
T3: Irrigation at 90% moisture depletion
*Significant at 5% level

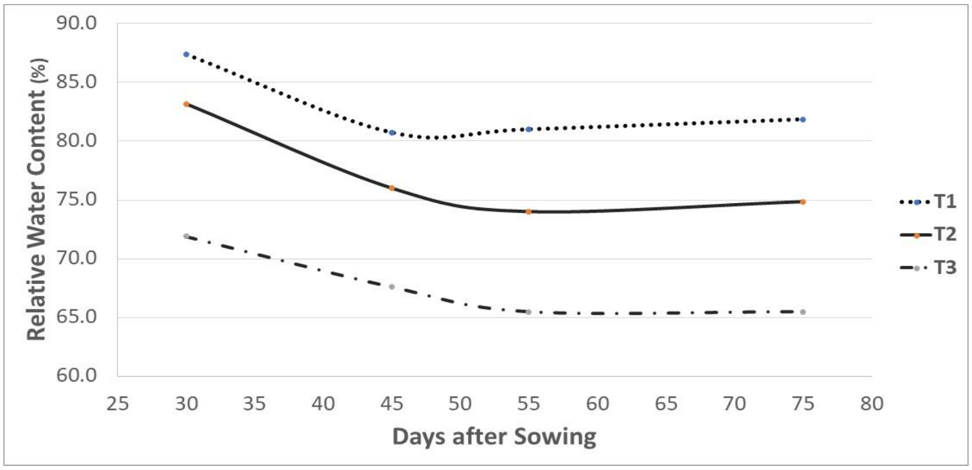

Fig.1 Relative water content in groundnut leaves at various dates of observation

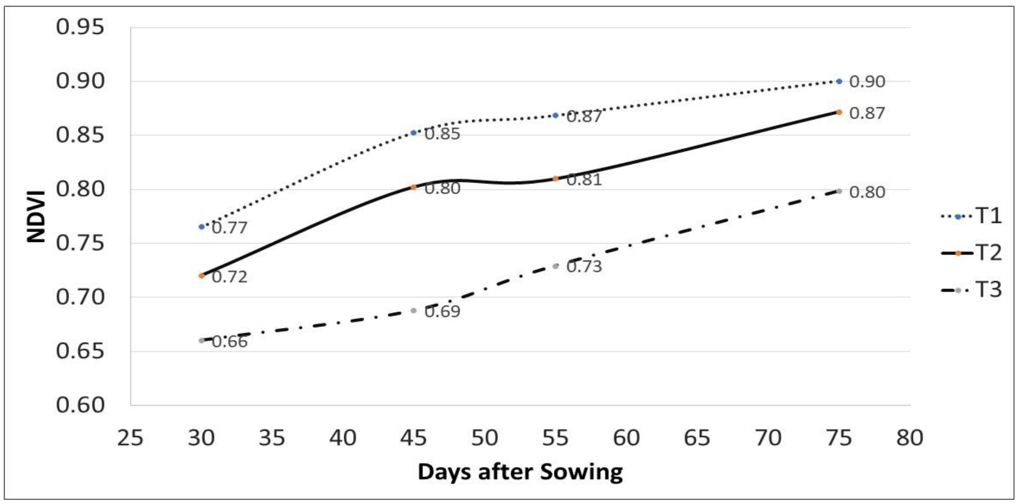

Fig.2 Normalized Difference Vegetation Index (NDVI) in groundnut at various stages

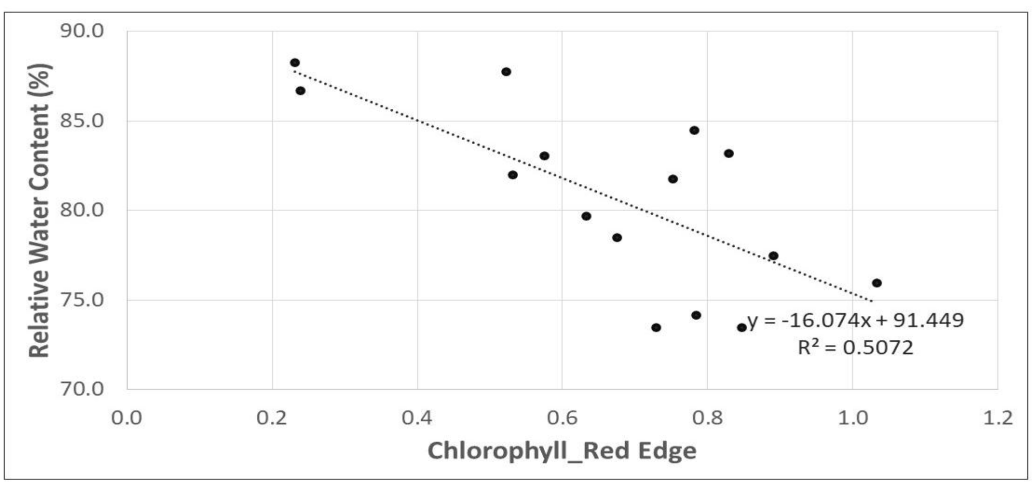

Fig.3 Relationship between Relative water content and chlorophyll red edge in groundnut at 45 DAS

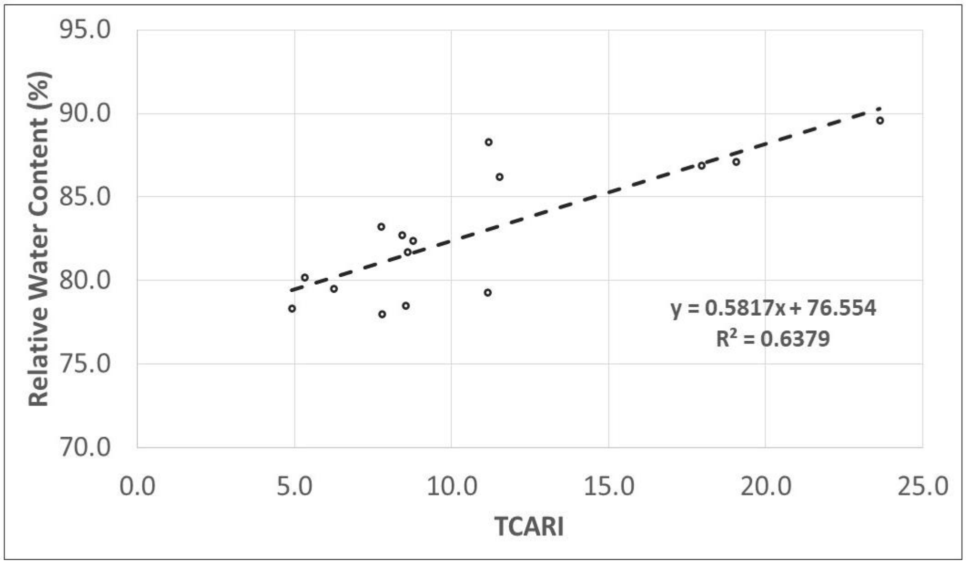

Fig.4 Relationship between Relative Water Content and Transformed Chlorophyll Absorption in Reflectance Index (TCARI) in groundnut at 60 DAS

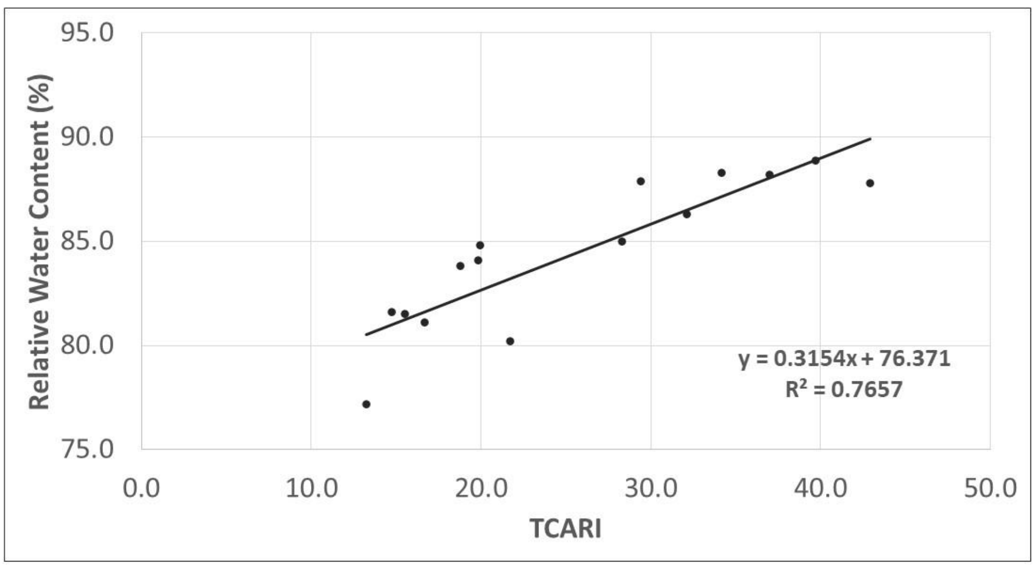

Fig.5 Relationship between Relative Water Content and Transformed Chlorophyll Absorption in Reflectance Index (TCARI) in groundnut at 75 DAS

The present investigation carried out to study the effect of induced crop water stress on the yield and spectral reflectance properties of groundnut, clearly indicates that varying levels of soil moisture aims at creating varying crop water stress significantly influenced the yield of groundnut crop. The relative water content of crop is significantly influenced by the treatments. The spectral data analysis and their derived indices (NDVI) varied with varying crop water stress and the indices *viz.*, chlorophyll red_edge and Transformed Chlorophyll Absorption in Reflectance Index (TCARI) correlate well with relative water content of the plant and this would help in predicting or estimating the plant water content at different growth stages.

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