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Characterization of water stress and prediction of yield of wheat using spectral indices under varied water and nitrogen management practices

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ABSTRACT

There is a need to characterize the water stress in wheat using suitable indices, which will help us to find out the water stress sensitive period for efficient use of irrigation water. Recently indices based on canopy spectral reflectance, which are non destructive, fast and reliable, are being used effectively to characterize the water stress. A field experiment was carried out during the year 2010–2012 in split plot design with four levels of irrigation (irrigation at 0.4 IW/CPE, 0.6 IW/CPE, 0.8 IW/CPE and 1.0 IW/CPE, IW = 6 cm) as main plot factors and three sources of nitrogen (100% N from urea, 50% N from urea and 50% N from farmyard manure (FYM) and 100% N from FYM) as subplot factors. The objective of the study was to find out the water stress indices best correlated with wheat grain and biomass yield, to determine the optimum growth stage for measurement of water stress indices and to predict the grain and biomass yield of wheat based on water stress indices. The canopy reflectance was measured in the spectral range of 350–2500 nm with 1 nm bandwidth with the help of hand held ASD FieldSpec Spectroradiometer at seven phenostages, *viz.*, crown root initiation (CRI), tillering, booting, flowering, milk, soft dough and harvesting stage. Then different water stress indices were computed as: water index (WI) = R_{970}/R_{900}, normalized water index-1 (NWI-1) = $(R_{970} - R_{900})/(R_{970} + R_{900})$, normalized water index-2 (NWI-2) = $(R_{970} - R_{850})/(R_{970} + R_{850})$, normalized water index-3 (NWI-3) = $(R_{970} - R_{920})/(R_{970} + R_{920})$, normalized water index-4 (NWI-4) = $(R_{970} - R_{880})/(R_{970} + R_{880})$, where R and the subscript numbers indicate the light reflectance at the specific wavelength (in nm). It was observed that spectral reflectance based water indices recorded at the milk stage, WI and NWI-1 were significantly negatively correlated with the grain yield and NWI-1 and NWI-3 were significantly negatively correlated with the biomass yield of wheat, having maximum correlation coefficients. Validation of regression model based on NWI-1 could account for the maximum 87.5% variation in the observed grain yield and the regression model based on WI could account for maximum 89.2% variation in the observed biomass yield of wheat with minimum root mean square errors. So the regression models based on NWI-1 and WI recorded at milk stage can be successfully used to predict the grain and biomass yield of wheat in advance.

1. Introduction

Wheat is an important staple food of more than 35% of the world population. In India wheat is the second most important cereal crop and plays an important role in the food and nutritional security of the country. Though there is quantum jump in the wheat production from 12.57 M tones in 1965–1966 to 84.27 M tones in 2010–2011 during the last five decades, with the current average productivity of 2938 kg/ha, there is a wide gap between the realized and the potential wheat production. Water and nitrogen are the key inputs, which must be used optimally to bridge this yield gap. Growth and yield in cereals is affected by soil moisture deficits, and the extent to which yields are affected is dependent on the stage of development at which the deficit occurs (Entz and Fowler, 1988). In wheat, growth is affected by water stress, which can reduce the final number of tillers per plant by reduced production and increased mortality of tillers (Fischer, 1973). Water stress in anthesis reduces pollination and thus less number of grains are formed per spike, which results in the reduction of grain yield (Ashraf, 1998). Water stress is known to reduce biomass, tillering ability, grains per spike

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and grain size at any stage when it occurs. So the overall effect of water stress depends on the intensity and length of stress (Bukhat, 2005). Water stress at later stage may additionally cause reduction in number of kernels/ear and kernel weight (Gupta et al., 2001; Dencic et al., 2000).

So there is a need to characterize the water stress in wheat using suitable indices. This will help us to find out the water stress sensitive period of wheat under different agroclimatic regions for efficient use of irrigation water. This will also help us to screen wheat genotypes susceptible to water stress in advance. Different approaches have been used to characterize water stress in wheat viz., phenotypic characteristics like plant height, leaf area, yield and yield attributes, physiological characteristics like relative leaf water content (Slatyer, 1967), stomatal conductance (Amani et al., 1996), plant water potential, membrane stability index, chlorophyll content, chlorophyll fluorescence etc. (Bukhat, 2005), thermal environment of wheat like canopy air temperature difference (Reynolds et al., 2007), vapour pressure deficit based crop water stress index (Idso et al., 1977) etc. However, determination of these indices is time consuming and cumbersome. Recently indices based on canopy spectral reflectance are being used effectively to characterize the water stress (Peñuelas et al., 1997; Ustin et al., 1998; Stimson et al., 2005). Canopy reflectance spectra has a number of advantages over the other methods as this involves nondestructive, reliable, easy and quick measurements, integration at canopy level and has facility to measure additional information using the canopy reflectance spectra.

The basic principle governing canopy reflectance spectra is that specific plant traits are associated with the absorption of specific wavelength of the spectrum (Reynolds et al., 1999). Wavelengths in the near infrared (NIR: 700–1300 nm) and in the short infrared (SWIR: 1300–2500 nm) regions have been employed for monitoring plant water status. Several water bands have been proposed in the electromagnetic spectrum at 970, 1240, 1400 and 2700 nm for this purpose (Tucker, 1980; Peñuelas et al., 1993; Gao, 1996; Zarco-Tejda and Ustin, 2001; Anderson et al., 2004; Stimson et al., 2005). The water index (WI, R_{970}/R_{900}) proposed by Peñuelas et al. (1993) has been used to estimate water status in *Phaseolus vulgaris*, *Capsicum annum* and *Gerbera jamesonii* and was associated relative water content (RWC) under water stressed condition (El-Shikha et al., 2007). Babar et al., 2006 proposed two normalized water indices (NWI-1 = $[R_{970} - R_{900}]/[R_{970} + R_{900}]$) and NWI-2 = $[R_{970} - R_{850}]/[R_{970} + R_{850}]$) based on the water index proposed by Peñuelas et al. (1993) for screening spring wheat genotypes for grain yield under well irrigated and water deficit condition. Prasad et al. (2007) proposed two more water indices (NWI-3 = $[R_{970} - R_{880}]/[R_{970} + R_{880}]$) and NWI-4 = $[R_{970} - R_{920}]/[R_{970} + R_{920}]$) for screening grain yield of advanced lines of winter wheat under rainfed conditions. These water indices are based on the hypothesis that electromagnetic radiation at NIR wavelengths (970 nm) penetrate deeper into the canopy and absorbed by the canopy water. Therefore they accurately estimate the water content (Babar et al., 2006; Prasad et al., 2007; Gutierrez et al., 2010). These five water indices (WI and four NWIs) have explained a large portion of grain yield variability and can serve as an alternative approach for selecting high yielding lines in wheat for diverse environments (Babar et al., 2006; Prasad et al., 2007).

These spectral indices need to be validated with the field data under diverse stress level (Sims and Gamon, 2003). With these backdrop, the objectives of the present investigation were, (i) to find out the water stress indices best correlated with wheat grain and biomass yield under diverse water and nitrogen management, (ii) to determine the optimum growth stage for measurement of water stress indices and (iii) to predict the grain and biomass yield of wheat based on these water stress indices.

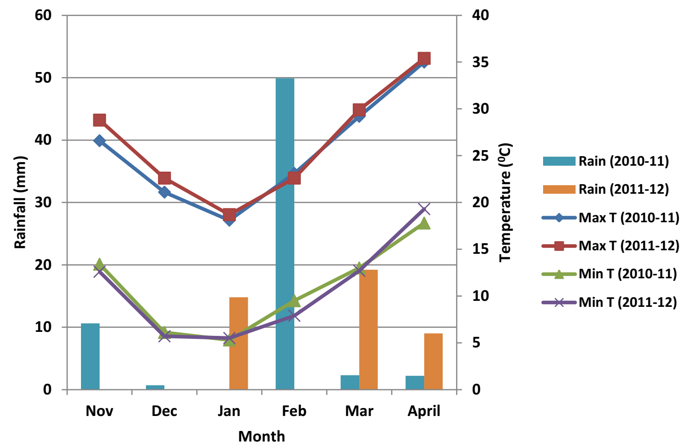

Fig. 1. Weather condition during wheat growth in the year 2010–2011 and 2011–2012.

2. Materials and methods

2.1. Soil and climate of the experimental site

The field experiment was carried out during the year 2010–2011 and 2011–2012 at the research farm of the Indian Agricultural Research Institute, New Delhi (28°37′ to 28°39′N latitude and 77°90′ to 77°11′E longitude and at an altitude of 228.7 m above mean sea level). This region is characterized by extreme temperatures, the annual maximum temperature goes as high as 45 °C in summer, whereas the minimum temperature dip to as low as 1 °C in winter. The mean summer and mean winter temperatures were 33.0 and 17.3 °C, respectively. The mean annual rainfall is around 750 mm, of which a substantial amount (85%) is received during July to September. The daily weather situation during wheat growth for both the years has been depicted in Fig. 1. The soil is sandy loam (Typic Haplustept) with medium to angular blocky structure, non-calcareous and slightly alkaline in reaction. The soil (0–30 cm) has bulk density 1.56 Mg m^{-3}; hydraulic conductivity (saturated) 1.05 cm h^{-1}, saturated water content (0.42 m^3 m^{-3}; pH (1:2.5 soil/water suspension), 7.4; EC, 0.34 dS m^{-1}; organic C, 3.0 g kg^{-1}; total N, 0.031%; available (Olsen) P, 6.9 kg ha^{-1}; available K, 279.0 kg ha^{-1}; sand, silt and clay, 64.0, 16.8 and 19.2%, respectively. The soil moisture at 0.033 MPa suction ranged from 25 to 28% and at 1.5 MPa suction ranged from 8 to 10% in different layers of 0–90 cm soil depth.

2.2. Crop culture

The experiment was laid out in a split plot design with four irrigation levels as the main plot and three nitrogen sources as subplot factors, replicated three times. The subplot size was 3.5 m × 5.5 m. Wheat (cv. PBW-502) was grown during the winter season (3rd week of November to 2nd week of April in 2010–2011 and 3rd week of November to 3rd week of April in 2011–2012). The irrigation levels were: irrigation at 0.4 IW/CPE, IW = 6 cm (I_1), 0.6 IW/CPE (I_2), 0.8 IW/CPE (I_3) and 1.0 IW/CPE (I_4), where IW is depth of irrigation water in cm and CPE is cumulative pan evaporation in cm. The amount of irrigation water applied under different treatments in the year 2010–2011 and 2011–2012 has been presented in Table 1. The nitrogen sources consisted of: 100% N from urea (N_1), 50% N from urea and 50% N from farmyard manure (FYM) (N_2) and 100% N from FYM (N_3). Nitrogen was applied in three splits: 50% at sowing, 25% at CRI stage (21 days after sowing) and the rest 25% maximum tillering stage (45 days after sowing). The whole amount of FYM, P and K fertilizers was applied as basal at