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Determination of Crop Water Stress Index for *Kharif* Pearl Millet in Semi-Arid Environment

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ABSTRACT

Achieving high grain yield depends on the ability to avoid water stress by continuous monitoring the crop during the growing season. This study investigates the use of infrared thermometry for monitoring water stress. A field experiment was conducted during *kharif* season of 2018 on pearl millet crop under rainfed condition. The experiment involved nine treatments composed of three dates of sowing (at onset of monsoon, after 10 d of onset of monsoon and after 20 d of onset of monsoon) and three cultivars (GHB 538, GHB 558 and GHB 744). Canopy temperature (T_c) was measured using infrared radiometer-IS 131 (Apogee instrument, USA) on daily basis in the afternoon hours (1400 h to 1430 h) along with psychrometric observations. Soil temperature, soil moisture, dry biomass, plant water content and plant height were also measured regularly. Pearl millet is drought tolerance crop but water stress condition during critical growth stage led to yield reduction. In CWSI, Upper base line (dT_u) was $dT_u = 2.9°C$ which was relatively independent of vapour pressure deficit (VPD) and lower baseline was $dT_l = -3.0468 (VPD) + 2.6409$. Throughout season CWSI value remain between -1.47 to 1.26. A strong and negative correlation was observed between CWSI and soil moisture up to 30 cm depth in all treatments. The results revealed that pearl millet crop in similar climate and soil condition, should be irrigated at CWSI values 0.52 to avoid water stress. The relationship between percent available soil moisture (PASM) and CWSI was linear and useful to farmers for irrigation scheduling.

Key Words: Infrared Thermometry, Pearl Millet, Rainfed, Soil depth, Water, Stress.

INTRODUCTION

Water is a critical input into agriculture in nearly all its aspects having a considerable effect on the eventual yield. Owing to poor water resource management system and climate change, India faces a persistent water shortage. Most of cultivated land in India is dependent on rainfall. Some of the predicted consequences of climate change such as the change in rainfall pattern and prolonged droughts indicate that decision makers will be faced with even more challenging and perhaps less studied issues in the near future. In such environment, the most promising approach towards a sustainable management of agricultural water resources seem to be through improving agricultural water productivity.

Scheduling irrigation can be based on two approaches: a) soil measurements, and b) crop stress monitoring. Irrigation scheduling based upon crop water status should be more preferable since crops respond to both the soil and aerial environmental. Idso *et al* (1981) developed an empirical approach with Crop Water Stress Index (CWSI) for determine water stress. This method is dependent on the determination of non-water-stressed baselines which facilitate normalising changes in canopy temperature for environmental conditions. These baselines are, however, crop-specific and still influenced by climate somewhat. The CWSI could be used to measure crop water status and to improve irrigation scheduling (Erdem *et al*, 2005; Alderfasia and Nielsen, 2001). CWSI increase with increase

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in soil water deficit (Erdem *et al*, 2006). Krista and Bradley (2020) reported that utilizing a daily CWSI threshold for irrigation scheduling reduced the irrigation amount without compromising the yield and remotely provided automated decision support for managing water stress severity.

Pearl millet is an important rainfed crop in arid and semi-arid regions (received rainfall below potential evapotranspiration) of India during monsoon period (June-September) (Serba *et al,* 2020). Pearl millet production in India is 8.61 million tons and in Gujarat is 961t (Directorate of Millets Development, 2020). One of the major limitations in crop production is matching the crop growth period with the available soil moisture (Rao and Saxton, 1995). In rainfed condition, dry spells and terminal drought conditions are the main factors responsible for water stress and limit the production. In Gujarat, most regions fall under the monsoon seasonality with dry periods is prone to soil moisture stress for rainfed farming or crops which totally depend on rainfall (Tow *et al*, 2011). In such scenario, optimal water supply and scheduling is crucial to sustain crop production with limited irrigation facility. This study is aimed to develop upper and lower base line for CWSI and determine its threshold. CWSI for moisture stress monitoring in rainfed pearl millet can supply decision to water management during *kharif* season.

MATERIALS AND METHODS

An experiment was conducted at Agronomy Farm, near agrometeorological observatory, B. A. College of Agriculture, Anand Agricultural University, Anand (semi-arid tropical climate), Gujarat at 22.58˚ N, 72.92˚ E, 45.1 m above mean sea level during *kharif* season from June to October, 2018. The soil of the experimental site is popularly known as "*Goradu*" soil. These soils are of alluvial origin and are classified as "loamy sand" and belong to Entisols order (type: ustorthents) with field capacity 18%, permeant wilting point 5% and bulk density 1.5%.

The experiment was laid out in split plot design with 4 replications. Gross plot size was 3.60 m × 6.00 m with net plot area 2.70 m × 5.00 m. The nine treatments composed of three dates of sowing and three cultivars were studied. Three cultivars namely, GHB 538, GHB 558 and GHB 744 were sown at onset of monsoon, after 10 d of onset of monsoon and after 20 d of onset of monsoon. Irrigation was applied to each plot at 8 August, at the time of thinning and gap filling because without irrigation it was difficult to do thinning and gap filling manually.

Soil moisture estimation was done by gravimetric method from each plot on daily basis during morning hours. Therefore, the soil moisture percentage by gravimetric method was calculated as,

$$=\frac{W2 - W3}{W3 - W1} \times 100 \frac{W2 - W3}{W3 - W1} \times 100$$

Where, W1 = weight of the empty cup, W2 = weight with the soil sample before

drying and W3 = weight with soil sample after drying

Per cent available soil moisture (PASM) was calculated as,

$$\frac{\text{Soil moisture content on weight basiss (\%)} - \text{Peremanent wilting point (PWP)}}{\text{Field capacity (FC)} - \text{PWP}}$$

X 100

Where,

PWP of the soil is 5% and FC is 18%.

Dry bulb and wet bulb temperature were measured using Assmann psychrometer to calculate the vapour pressure above the crop canopy on daily basis during 1400 h to 1430 h. Vapour pressure and relative humidity were calculated by hygrometer equations (WMO, 2010).

Canopy temperature (T_c) was measured using infrared radiometer-IS 131 (Apogee instrument, USA) on daily basis in the afternoon hours (1400 h to 1430 h) along with psychrometric observations.

Canopy temperature was recorded by taking an average of three observations from each treatment. Infrared radiometer-IS 131 was connected with data logger CR 800 (Campbell Scientific, Inc.). Appropriate correction for surface emissivity is required for accurate surface temperature measurements. The emissivity (Ɛ) value of pearl millet crop was considered as 0.96 (Pandya *et al*, 2013). Canopy temperature (T_c) which was measured with IRT was corrected as,

Corrected T_c = $T_c \times \varepsilon\, T_c \times \varepsilon$

Such corrected canopy temperature was used for the calculation of CWSI for all treatments. Calculation of the CWSI initially requires development of an upper and lower baseline. Baselines were determined from non-stressed and stressed condition observations. The lower limit represents dT as measured with a well-watered, non-stressed plant at a given humidity level, while the upper limit represents dT as measured with a severely stressed, non-transpiring plant at a given humidity level.

Using the lower and upper limit estimates, a CWSI is expressed as:

$$CWSI = \frac{dT - dT_l \;\; dT - dT_l}{dT_u - dT_l\, dT_u - dT_l}$$

Where,

dT is the measured difference between crop canopy and air temperature, dT_u is the upper limit of canopy minus air temperature (non-transpiring crop), dT_l is the lower limit of canopy minus air temperature (well-watered crop).

RESULTS AND DISCCUSION

Upper and lower base lines were developed for calculation of CWSI. The upper and lower baselines shown in Fig. 1 were developed based on field data. From entire season, only the days with less than 4 Octa cloud condition were considered for determination of base-lines as well as CWSI. It is apparent from the Fig. 1 that the dT_l is a linear function of VPD and is referred to as the non-stressed baseline. Linear fitting of canopy-air temperature difference with vapour pressure deficit resulted to the function dT_l = -3.0468 VPD + 2.6409, Whereas, the upper baseline dT_u is relatively independent of VPD. It was dT_u=2.9°C. Canopy-air temperature differential was varying linearly and inversely with the air VPD, which is an indicator of atmospheric evaporative demand.

Upper base-line dT_u = 2.9°C and the lower baseline as an equation dT_l = -3.0468 VPD + 2.6409 were used for determination of the CWSI. The regression of canopy-air temperature on VPD is often termed as non-stressed baseline. The data points which did not coincide with the lower baseline but lay above it, were considered stressed. As the soil water is depleted from the rooting volume, at some point, the crop will no longer be able to transpire at the potential rate hence the deviation from the non-stressed baseline.

CWSI and rainfall

CWSI influenced by rainfall distribution during growing season as it effects the soil moisture. The close scrutiny of the Fig. 2 revealed that the value of CWSI increased during period of dry spell and decreased after rainfall in all varietal treatments. Seasonal mean of CWSI of timely sown (onset of monsoon), late (10 d after onset of monsoon), and very late (20 d after onset of monsoon date of sowing) were 0.22, 0.23 and 0.26, respectively. The CWSI also found to decrease after application of irrigation (one essential irrigation applied on 8 August, 2018) as it also improves the soil moisture status. Besides, rainfall events which are also associated with high humidity condition and checks the transpirational cooling led to low CWSI value during clear sky days close to the rainy days. In crop cultivar sown late or very late revealed stress condition during last week of September, though the week was followed just after a good rainfall (39.2 mm on 23rd September and 18.0 mm on 24th September). This might be because of low transpiration efficiency of crop at senescence.

Table 1. Effect of date of sowing on grain yield, straw yield and biomass.

Sr. No.	Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Biomass (kg ha^{-1})
D_1	Onset of monsoon	3268	7209	10478
D_2	10 days after onset of monsoon	2833	6586	9419
D_3	20 days after onset of monsoon	2690	6222	8912
	SEm ±	114.0	210.3	141.5
	CD at 5%	394.7	727.9	489.6
	CV%	13.5	10.9	5.1

CWSI and soil moisture

Association between per cent available soil moisture (PASM up to 30 cm depth) and CWSI for different dates of sowing are depicted as scattered plot in Fig. 3. The CWSI values were calculated according to the base line obtained from this research and a few outliers were eliminated. Fig. 1 shows that many observations fell below the lower baseline and above the upper base-line, made the CWSI a negative value and value above 1, respectively. This finding is also in accordance with those reported by other researchers. (Gallardo, 1992; Emkeli *et al,* 2007; Feldhake *et al,* 2010)). They found that observations fell below the non stressed base-line made a CWSI a negative value.

The CWSI values were in the range of -1.47 to 1.26. In this study, a strong and negative correlation was observed between CWSI and PASM up to 30 cm depth. As PASM decreased, the stomata closed, transpiration rates declined, so that leaf temperature increased and CWSI increased. Erdem *et al* (2005) and Junzeng *et al* (2015) also reported that CWSI values increased with decreasing soil water content.

Thus, in all three cultivars strong negative associations revealed between CWSI and soil moisture. As the soil moisture directly controls transpirational cooling of the canopy, these correlations prove the utility of canopy temperature based CWSI for water stress monitoring and assessment in pearl millet crop.

Results revealed that pearl millet crop for this particular climate and soil condition, should be irrigated at CWSI values 0.54, 0.50, 0.52 for D_1 (onset of monsoon), D_2 (10 d after onset of monsoon) and D_3 (20 d after onset of monsoon date of sowing) to avoid water stress and good quality yield, respectively (based on 50% PASM).

The relationship between PASM and CWSI value (Fig. 4) was primarily linear: PASM = -48.821 CWSI + 73.803** (r = -0.67, R^2 = 0.45). This relation needs to be strengthened with further experimentation to use it for operational estimate of PASM value using CWSI.

Effect of date of sowing on grain yield, straw yield and Biomass

Grain yield, straw yield and biomass in the kg/ha as influenced by the different dates of sowing are given in Table 1. An appraisal of data in the table indicated that grain yield, straw yield and biomass were affected significantly by different date of

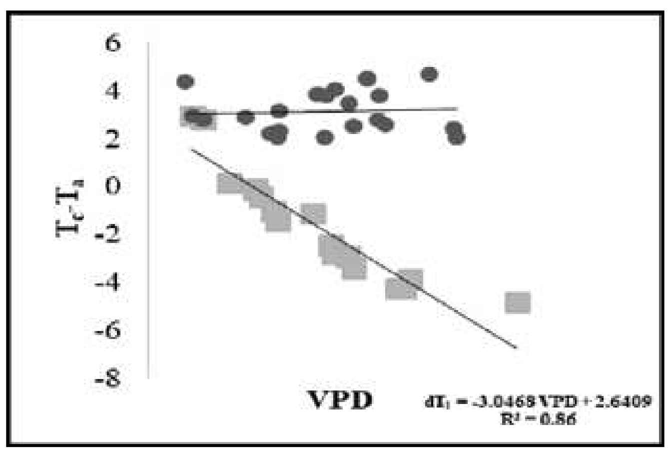

Fig. 1. The upper and lower base lines of CWSI for *kharif* pearl millet

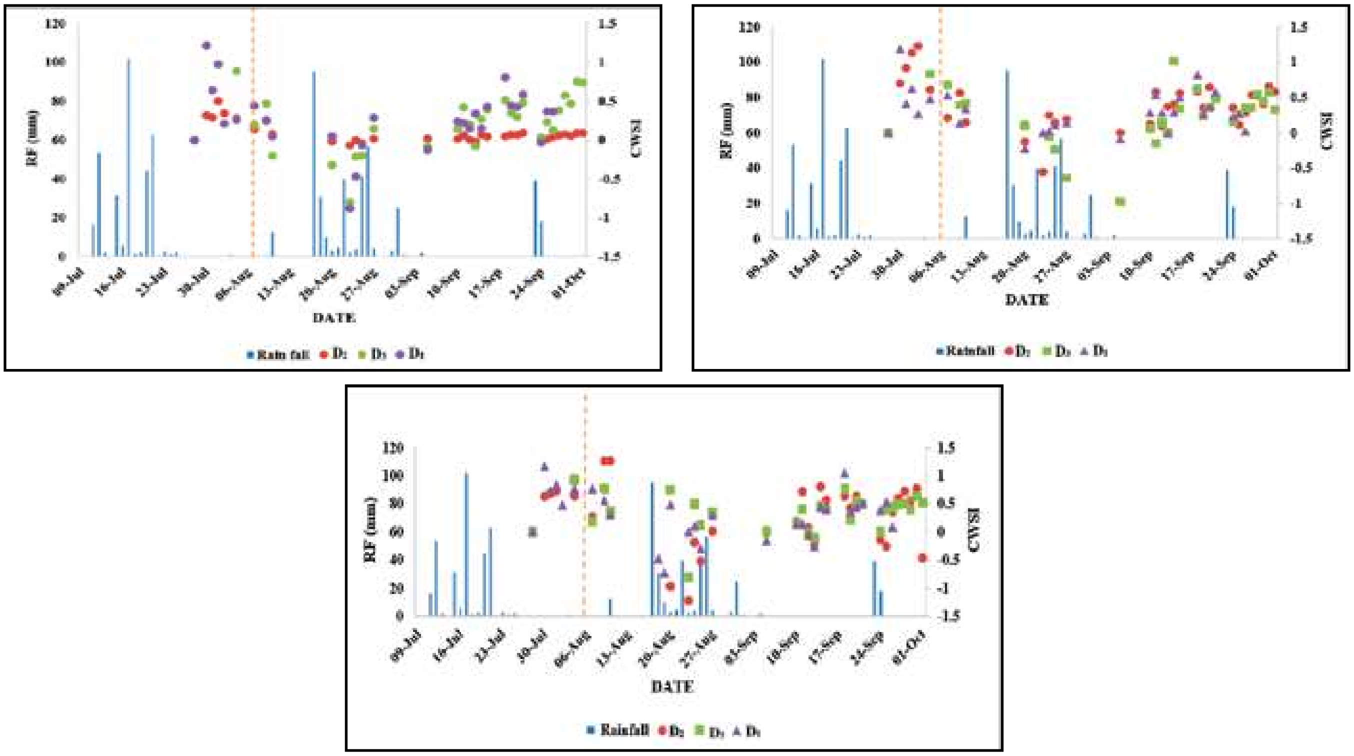

Fig. 2. Seasonal trend of rainfall and CWSI of variety (a) Variety GHB 538, (b) variety GHB 558, (c) varietyGHB 744, (June-October, 2018). Vertical dash-line is time of irrigation.

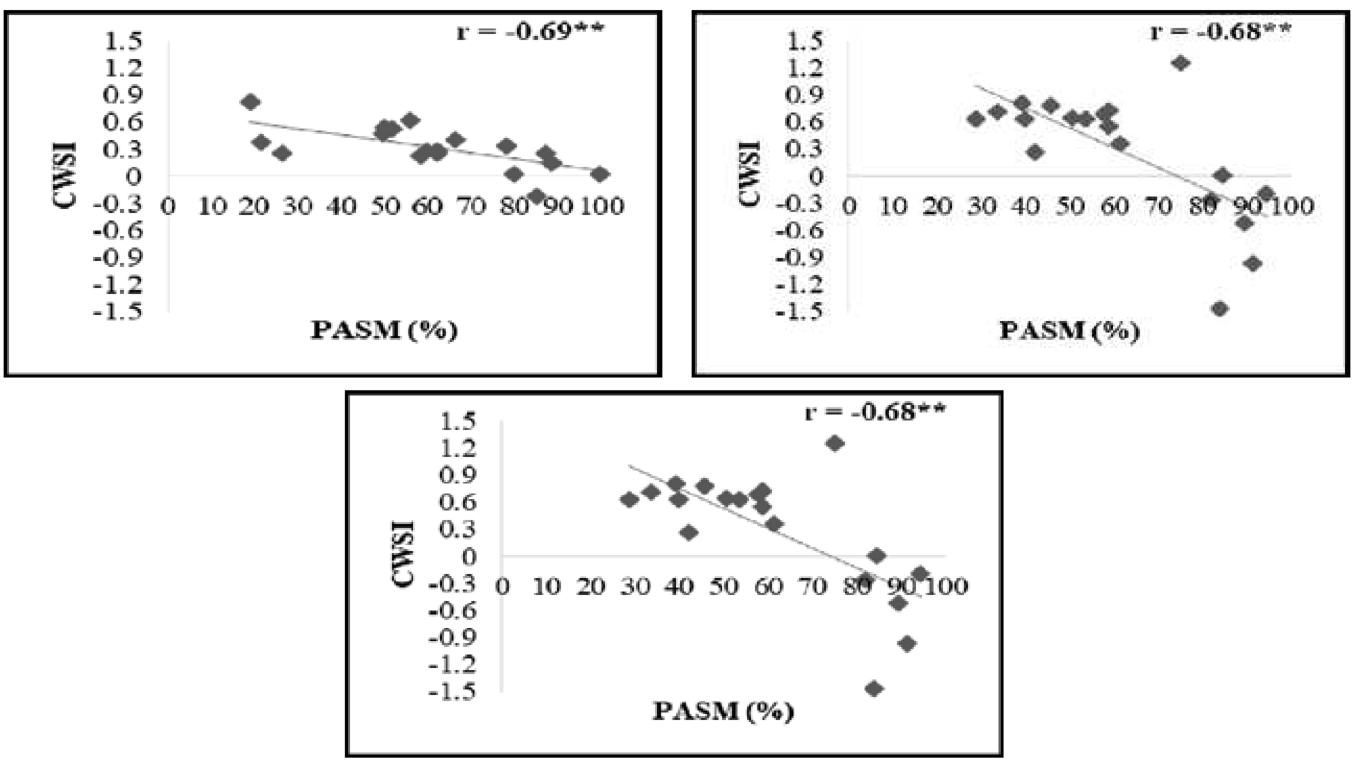

Fig. 3. Correlation between CWSI and PASM (30 cm depth) in (a) sowing on onset, (b) sowing after 10 days of onset, (c) sowing after 20 days of onset, (June- October, 2018)

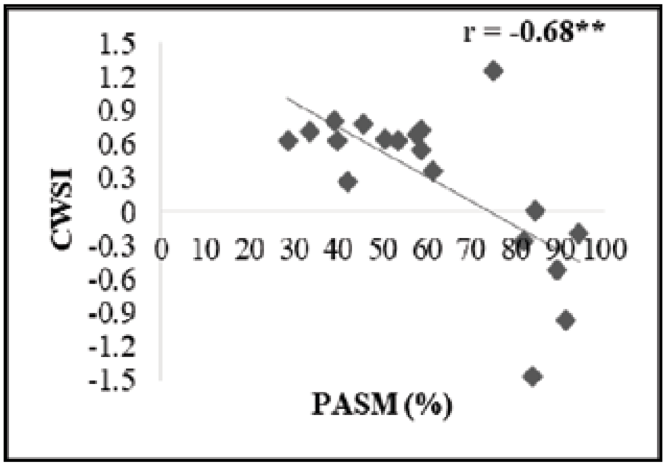

Fig. 4. Correlation between CWSI and PASM (30 cm depth) in *kharif*pearl millet (June-October, 2018)

sowing. Total biomass at the time of harvesting was estimated by summation of straw yield and grain yield. Among the sowing dates D_1 (onset of monsoon) produced significantly high grain yield (3268 kg/ha), straw yield (7209 kg/ha) and biomass (10478 kg/ha). Yield of pearl millet was decreased in delayed sowing. The late sown crop (D_3) recorded reduction in yield by over timely sown crop (D_1). Grain yield produced under treatment D_3 (20 d after onset of monsoon) was at par with D_2 (10 d after onset of monsoon).

Fig. 5 shows that PASM value remains low during flowering and goes below 40% during grain filling stage under treatment D_3 whereas under treatment D_1 (onset of monsoon) PASM value never goes below 50 per cent. In all treatments strong negative correlation observed between PASM and CWSI. CWSI value remain high throughout season under treatment D_3 followed by D_2. Negative CWSI value observed during flowering and grain filling stage under treatment D_3 whereas, throughout season CWSI value remains more than 0.2 under treatment D_3. It is well known that pearl millet is drought tolerance crop but if water stress condition observed during critical growth stages *i.e.,* flowering and grain filling stage its directly affect on yield. That's why higher yield was observed under treatment D_1 (onset of monsoon) with low CWSI value and high PASM value throughout growing season. Mahalaxmi *et al* (2009) reported that in pearl millet water stress during flowering and grain filling reduced grain yields of both main shoot and tillers.

CONCLUSION

The CWSI baselines, namely, upper (dT_u = 2.9 °C) and lower (dT_l= -3.0468 VPD + 2.6409) can be used to compute CWSI of pearl millet for irrigation scheduling in *kharif* season. Pearl millet crop under similar climate and soil condition can be irrigated at about CWSI 0.52 to avoid water stress (based on 50% PASM). However, validation of this threshold value and relationship should be done to use findings for irrigation scheduling in rainfed pearl millet in *Kharif* season. Yield parameter adversely affected if CWSI value remain high during flowering and grain filling growth stages.

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