

Original Research Article

Use of Crop Water Stress Index for Irrigation Scheduling of Soybean

ABSTRACT

Canopy temperature measured with infrared thermometers is an important tool for detecting crop water stress. The crop water stress index (CWSI) is the most often used index which is based on differential of canopy temperature and vapor pressure deficit to detect crop water stress and to schedule irrigation for field crops. The aim of this study is to determine the relationship between the canopy-air temperature difference and the vapor pressure gradient (VPD) to calculate the CWSI value in soybean plants. The study is carried out in randomized complete block design in six different irrigation treatments in three replications. Plots were irrigated when the cumulative evaporation in Class A pan is 25 ± 5 mm using drip irrigation system based on the pan coefficient (k_{pc}) of 0, 0.25, 0.50, 0.75, 1.00, and 1.25. Before and after each irrigation, canopy temperature was measured with a hand-held infrared thermometer in all treatments between 11.00 and 14.00. Throughout the season, before irrigation, soil moisture content was measured. The CWSI values were determined using empirical approach. When using this technique in Antalya conditions, it is suggested to keep the seasonal mean CWSI value approximately 0.26 and index value of 0.40 can be used to start irrigations. Additionally, it is suggested that the amount of irrigation can be determined as much as the amount of evaporation measured until the index value reach 0.40. According to the results obtained, it is concluded that infrared thermometer can be used for irrigation scheduling of the soybean plant in Antalya conditions.

Keywords: Deficit Irrigation, Infrared thermometer, VPD, CWSI

1. INTRODUCTION

Soybean (*Glycine max* (L.) Merr.) is considered one of the most important legumes because it contains a good percentage of protein and improves soil characters through its ability to produce root nodule [1]. Soybean contributes the agriculture from significant point of view due to the presence of Rhizobium Japonicum bacteria, which can bind free nitrogen in their roots, both to meet its own nutritional needs and to make the land ready for the next product crop. It is produced in our country as both main crop and second crop. Soybean seeds, which are important in human and animal nutrition, contain 40-45% protein, 18-24% fat and 26% carbohydrates.

At the beginning of 1960's, the result of increasing biodiesel production, which could be an alternative to decreasing energy sources, world soybean production which 24 million hectares planted and about 24 million tons, reached 118 million ha and 308 million tons in production in 2014 [2]. In our country, soybean production started for the first time in the Karadeniz Region. At the beginning of 1960's, while 20 thousand hectares are planted and 50 thousand tons are being produced, in 2015, the planting area reached 36 thousand hectares and production reached 161 thousand tons [3].

All over the world, the reduction in the amount of water which is used for irrigation and environmental concerns make necessary to reach the highest benefit from the unit of water. The most important factor limiting plant growth and yield in arid and semi-arid regions, which our country is in, is considered to be water. Irrigation scheduling, which is defined as the determination of irrigation time and the amount of water to be applied, also affects water use efficiency.

Generally, irrigation scheduling methods fall into three categories: soil based, plant based, and meteorologically based. Irrigation scheduling based upon crop water status should be more

advantageous since crops respond to both the soil and aerial environment. Therefore, irrigation scheduling based on plant monitoring is increasingly used in recent years. The water stress of the plant can be detected using the measurements based on the plant and as a result, the irrigation time can be determined [4].

It is possible to obtain useful information about the water status by using the canopy temperature measurements. Plant surface temperature is directly related to its transpiration rate. Based on the assumption that water becomes limiting, transpiration is reduced and crop temperature will be higher than air temperature because of the absorbed radiation. When a plant is under stress due to lack of water, it tends to close the stomata to decrease transpiration leading to an increase in leaf temperature. The energy balance of a leaf shows that this change in leaf temperature also depends on ambient conditions (relative humidity, wind speed, and ambient temperature) and radiation incident on the canopy surface ([5], [6]).

Infrared thermometers which sense canopy temperatures remotely without making direct physical contact are the fast and reliable tools that are becoming increasingly widespread today. Using infrared thermometers, canopy temperature can be remotely detected and this value can be used in irrigation programming and to predict crop yield ([7], [8]).

Many researchers have reported that the plant water stress index (CWSI) value obtained through the use of plant surface temperature is a good indicator of plant stress and that using this value for irrigation scheduling, the targeted efficiency, quality and water savings can be achieved ([9], [10], [11], [12], [13]).

There are three methods to quantify crop water stress: the energy balance method developed by Jackson et al. (1981) [14], an empirical approach developed by Idso et al. (1981) [10], and a wet-bulb temperature method developed by Alves and Pereira (2000) [15]. Idso et al. (1981) [10] developed the crop water stress index (CWSI) to quantify crop water stress. These authors utilized the relationships between the air and canopy surface temperature difference ($T_c - T_a$) and the vapor pressure deficit (VPD) under non-water-stressed and fully water-stressed conditions. The lower limit ($T_c - T_a$) versus VPD represents the measured temperature difference when the crop is well watered (minimal stress). The upper limit ($T_c - T_a$) represents the temperature difference occurring when the crop transpiration rate approaches zero (maximum stress).

The CWSI method developed by Idso et al. (1981) [10] has been used as a method to monitor crop water status and to schedule irrigations of various plants by many previous researchers including Nielsen and Gardner (1987) [16], Yazar et al. (1999) [17], Irmak et al. (2000) [18], Bastug and Irmak (1996) [19] in corn; Nielsen and Halvorson (1991) [20], Alderfasi and Nielsen (2001) [9], Yuan et al. (2004) [21], Gontia and Tiwari (2008) [22] in wheat; Orta et al. (2003) [23] in watermelon; Koksai (2006) [24] in sugar beet; Emekli et al. (2007) [25] in bermudagrass; Nielsen (1994) [26] and Taghvaeian vd. (2014) [27] in sunflower; Köksal (2008) [28] in green bean; Ödemis and Bastug (1999) [13] in cotton in semi-arid and humid conditions. However, CWSI used less for the irrigation scheduling of soybean. For example, Nielsen (1990) [29] evaluated the irrigation scheduling of soybeans using various threshold CWSI values under a semi-arid climate. They reported that the higher the threshold value of CWSI used to signal the need for irrigation, the lower the amount of total seasonal water applied, and the lower the final grain yield obtained. Candogan et al. (2013) [30], evaluated yield, quality and crop water stress index relationships for deficit-irrigated soybean in sub-humid climatic conditions. They concluded that the CWSI could be used to evaluate crop water stress and improve irrigation scheduling for soybeans under sub-humid climatic conditions. More research is needed on the irrigation schedule generated by the calculation of the CWSI value under different environmental conditions.

In this study, it is aimed to evaluate crop water stress index using infrared thermometer technique and to determine the possibilities of use in irrigation schedule in soybean under Antalya conditions.

2. MATERIAL AND METHODS

The study was conducted between July and October 2015 at the Batı Akdeniz Agricultural Research Institute (BAARI), Antalya, Turkey. The research station was located at a latitude of 36° 52'N, a longitude

of 30°50'E, and an altitude of 28 m. The physical and chemical properties of soil are shown in Table 1 and long-term average monthly climatic parameters together with the climatic parameters recorded in the year in which the study was conducted are given in Table 2.

The salinity and pH of the irrigation water used in the irrigation is 0.561 dS m⁻¹ and 7.3, respectively. ATAEM-7 cultivar is used as the plant material in the study.

The experimental design was a completely randomized block design with three replications. Soybean seeds were planted 70 cm apart along, 10 cm rows at a depth of 5 cm on 15 May 2015. The length of the parcels is 30 m and each parcel has 4 rows of soybean plants. A lateral drip line was designed for each row. The diameter of the lateral pipes was 16 mm with 4 Lh⁻¹ in-line dripper spaced at 20 cm.

Table 1. Physical and chemical properties of the soil

Soil depth	Texture class	Field capacity (%)	Permanent wilting point (%)	Bulk density (gcm ⁻³)	pH	EC (dSm ⁻¹)	Organic matter (%)	CaCO ₃ (%)
0-30	CL	24.0	12.80	1.35	8.00	0.18	1.70	29.90
30-60	CL	23.5	12.80	1.30	8.10	0.13	0.80	32.10
60-90	L	21.6	11.30	1.32	8.10	0.16	0.70	33.70

Table 2. Average climatic parameters during 2015 and long-term measurements (1954-2013) in Antalya

Year	Months	Air temperature (°C)	Rainfall (mm)	Evaporation (mm)	Wind speed (ms ⁻¹)	Relative humidity (%)
1954-2013	May	20.5	31.8	142.7	2.0	65.0
	June	25.4	7.9	176.9	1.9	59.0
	July	28.4	3.0	195.3	1.9	56.0
	August	28.2	2.4	172.2	1.7	60.0
	September	24.7	13.7	133.6	1.8	60.0
	October	20.0	78.8	96.0	1.8	60.0
2015	May	21.1	43.0	120.9	2.1	62.0
	June	26.5	5.0	126.0	1.9	65.0
	July	28.0	0.0	164.3	1.7	62.0
	August	28.6	0.0	155.0	1.7	62.0
	September	25.4	33.3	123.0	1.5	68.0
	October	21.0	97.0	102.3	1.4	59.0

Irrigation treatments were based on the evaporation data (E_{pan} , mm) obtained from a Class A pan located next to the plots and six different irrigation treatments were selected to examine the effectiveness of irrigation scheduling, ($K_{pc1}=0$ (unirrigated); $K_{pc2}=0.25$; $K_{pc3}=0.50$; $K_{pc4}=0.75$ $K_{pc5}=1.00$; $K_{pc6}=1.25$). Irrigation was applied when the cumulative amount of evaporation in the Class A pan was 25 ± 5 mm. The following equation (equation 1) is used to calculate the amount of irrigation water:

$$I = AxExK_{pc}P \quad (1)$$

Where, A is parcel area (m²); K_{pc} is pan coefficient; P is wetted area ratio (%); I is the depth of irrigation water (lt); E_p is the cumulative amount of Class A Pan evaporation in the irrigation interval (mm). P value is taken as 100%.

Climatic parameters such as relative humidity, barometric pressure, solar radiation and dew point temperature were taken from the TIGEM Meteorology Station which was installed near the test area

(about 250 m distance). The vapor pressure deficit is calculated from the difference between the saturated vapor pressure at the measured air temperature and the actual vapor pressure at the dew point temperature.

The canopy temperature was measured daily using an infrared thermometry (Spectrum Technologies Inc.) between day of year (DOY) 182 and 257 to determine CWSI of soybean. The infrared thermometry measurements were taken with a field of view of 45°. The measurements were carried out at 11:00, 12:00, 13:00, and 14:00 o'clock, from four directions (east, west, north, and south) in each plot. Mean daily average CWSI of irrigation treatments was computed from total of 48 replications of each treatment. Soil moisture was determined by gravimetric method before every irrigation.

CWSI was calculated according to Idso et al. (1981) [10] by using measured $T_c - T_a$ and VPD. The non-water-stressed baseline for soybeans was determined from the data collected after irrigation in K_{pc5} (control treatment), in which the crop was irrigated well. The data set was obtained from data collected from 09:00 to 18:00 o'clock at 1-h intervals on different days. The upper baseline was determined using the canopy temperatures measured before irrigation from fully stressed plants (in the K_{pc1} treatment) at 13:00 h and 14:00 o'clock on different days. The empirical CWSI was calculated as;

$$CWSI = \frac{(T_c - T_a)_m - (T_c - T_a)_{ll}}{(T_c - T_a)_{ul} - (T_c - T_a)_{ll}} \quad (2)$$

where $(T_c - T_a)_m$, $(T_c - T_a)_{ll}$, and $(T_c - T_a)_{ul}$ are the measured canopy-air temperature difference (°C) at the moment, the lower and upper limit values of the canopy-air temperature difference (°C) for a given VPD, respectively. The air temperature and relative humidity measurements were used to calculate the VPD of the air as [31]:

$$e_s = 0.6108 \exp[17.27T/(T + 237.3)] \quad (3)$$

$$e_a = e_s \times (RH/100) \quad (4)$$

$$VPD = e_s - e_a \quad (5)$$

where e_s is the saturation vapor pressure (kPa), T is the mean air temperature (°C), RH is the relative humidity of the air (%), and VPD is the vapor pressure deficit (kPa).

3. RESULTS AND DISCUSSION

The amount of seasonal irrigation water applied, soil water depleted, rainfall and seasonal water use are presented in Table 3. Irrigation water applied in K_{pc1} , K_{pc2} , K_{pc3} , K_{pc4} , K_{pc5} , K_{pc6} treatments were 55.0, 202.0, 338.0, 495.0, 620.0, and 789.0 mm, respectively. The seasonal crop water use in treatment K_{pc5} and K_{pc6} was the highest, suggesting that the irrigation water applied was adequate to meet the full crop water requirements. Other treatments underwent water deficits and gave lower seasonal ET. The amount of seasonal water use in K_{pc1} , K_{pc2} , K_{pc3} , K_{pc4} , K_{pc5} , K_{pc6} treatments were found to be 218.4, 361.4, 472.2, 616.1, 737.6, and 877.5 mm, respectively. Soil water depletion in K_{pc1} , K_{pc2} , K_{pc3} , K_{pc4} , K_{pc5} , and K_{pc6} treatments were found to be 82.1, 78.1, 52.9, 39.8, 36.3, 7.2 mm, respectively. It can be said that the amount of water used from the soil increases when the amount of applied irrigation water decreases. Payero and Irmak (2006) [32] reported that seasonal amount of irrigation of the treatments ranged from 19 to 162 mm for soybean at North Platte, Nebraska. Candogan et al. (2013) [30] reported that seasonal evapotranspiration values varied between 394 and 802 mm in 2005 and between 351 and 841 mm in 2006 for soybean in Bursa.

Table 3. Total amount of irrigation water, soil water depletion, rainfall and seasonal water use of the soybean

Treatment	Irrigation water applied (mm)	Rainfall (mm)	Soil water depletion (mm)	Crop water use (mm)
K _{pc1}	55.0	81.3	82.1	218.4
K _{pc2}	202.0	81.3	78.1	361.4
K _{pc3}	338.0	81.3	52.9	472.2
K _{pc4}	495.0	81.3	39.8	616.1
K _{pc5}	620.0	81.3	36.3	737.6
K _{pc6}	789.0	81.3	7.2	877.5

The upper and lower limit baselines for calculating CWSI is plotted in Figure 1. The upper limit baselines value of $(T_c - T_a)_{ul}$ was calculated as 4°C. The lower limit baselines was defined as $(T_c - T_a)_{ll} = -2.162VPD - 2.051$ (figure 2). The equation determined by Nielsen (1990) [29] for non-water stressed soybean crops was $(T_c - T_a)_{ll} = -2.02VPD + 2.51$. Payero and Irmak (2006) [32] suggest $(T_c - T_a)_{ul} = 2.77$ °C for the upper baseline and $(T_c - T_a)_{ll} = 1.87 - 1.95VPD$ for the lower baseline. Candogan et al. (2013) [30] reported $(T_c - T_a)_{ul} = 3.20$ °C for the upper baseline and $(T_c - T_a)_{ll} = -1.85VPD + 0.64$ for the lower baseline. The differences between equations can vary depending on the climatic conditions in which the experiments are conducted, as well as the varieties [33].

The course of CWSI during the growing season is depicted in Figure 2. CWSI values decreased depending on the increasing amount of irrigation water applied. Higher values of CWSI were obtained in K_{pc1} and K_{pc2} treatment as compared to the other treatments and the effects of irrigation applications on the CWSI were more pronounced in these treatments. This can be explained by the fact that water stress occurred as a result of less amount of water applied. K_{pc5} and K_{pc6} had lower values than the other treatments and showed a tendency to be very close to each other. Daily CWSI values ranged between 0.21-0.98, 0.14-0.90, 0.11-0.82, 0.05-0.73, 0.0-0.64, and 0.0-0.59 for K_{pc1}, K_{pc2}, K_{pc3}, K_{pc4}, K_{pc5} and K_{pc6} treatments, respectively. Generally, it can be said that there is a linear relationship between the amount of water applied and the CWSI values (figure. 2).

The change in soil water content before irrigation is given in Figure 3. Evaluating Figure 2 and 3 together, it can be seen that the amount of soil moisture content was found to be consistent with the CWSI values. K_{pc6}, K_{pc5} treatments which have the highest soil moisture content and shows a trend at the closest value to field capacity, also had the lowest CWSI values while K_{pc1} and K_{pc2} treatments which have the least soil moisture content and showed a trend the nearest wilting point, have the lowest CWSI values.

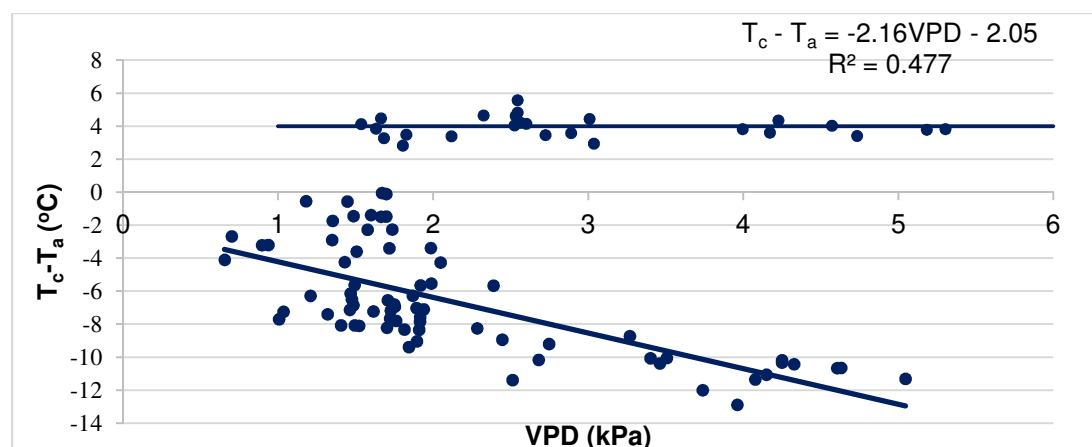


Fig. 1. Upper and lower base for soybean (stressed and non-stressed baselines for CWSI calculation of soybean)

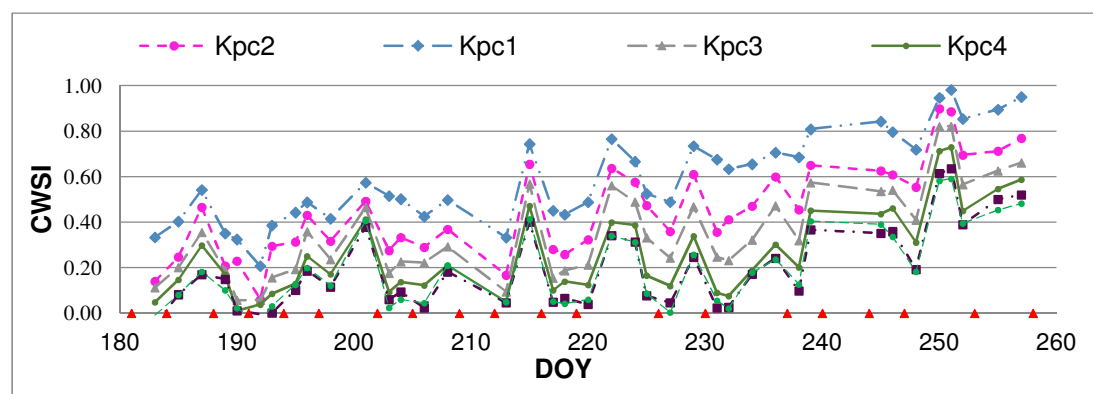


Fig. 2. Variations of the crop water stress index (CWSI) for each irrigation treatment during the experiment.

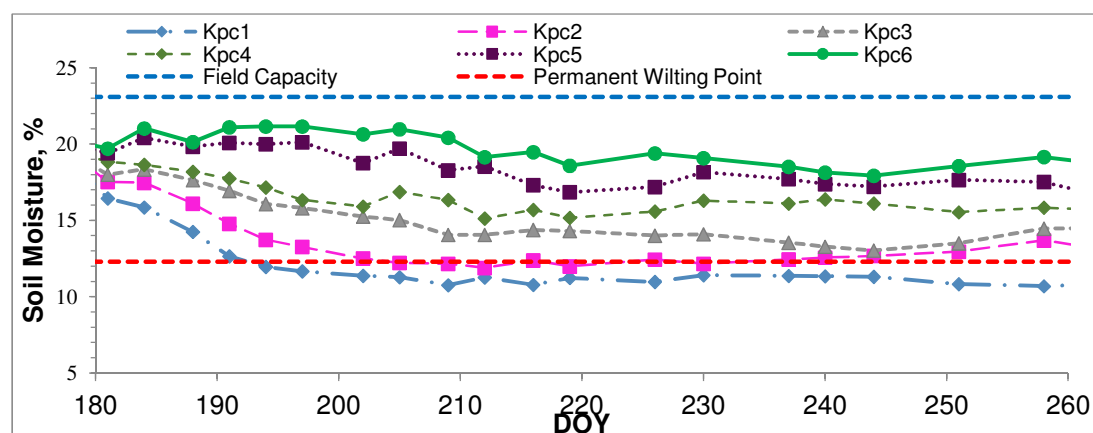


Fig. 3. Variations of the soil moisture for each irrigation treatment during the experiment.

Table 4 shows a summary of the comparison statistical relationship between the mean CWSI values and soybean yield. All relationships were significant at the 0.01 probability level. The highest seasonal average CWSI value calculated for K_{pc1} (0.59). Although there is no statistical difference between K_{pc4} , K_{pc5} and K_{pc6} , CWSI values are the lowest. When the yield values are considered, there are no statistically significant differences between K_{pc4} , K_{pc5} and K_{pc6} , nevertheless, the highest yield was obtained from these treatments. When the CWSI values and yield are examined together, it is seen that K_{pc4} , K_{pc5} and K_{pc6} have both the lowest CWSI value and the highest yield. According to these results applying water as much as 75% of the cumulative evaporation is enough to get optimum yield. When using this technique in Antalya conditions, it is suggested to keep the seasonal mean CWSI value approximately 0.26 and the index value of 0.40 can be used to start the irrigation. Additionally, it is suggested that the amount of irrigation can be determined as much as the amount of evaporation measured until the index value reach 0.40. Nielsen (1990) [29] used four threshold values of CWSI (i.e., CWSI = 0.2, 0.3, 0.4 and 0.5) to initiate irrigations and determined that the threshold CWSI value of 0.2 resulted in the highest yield of drip-irrigated soybean in Akron, CO, USA. The highest yield obtained in this study also corresponds to the seasonal average CWSI value of 0.20. Candogan et al. (2013) [30] reported that if the seasonal mean CWSI exceeds 0.17 then the soybean seed, protein and oil yields would decrease. However, the authors expressed that the highest water use efficiency was obtained when seasonal mean CWSI was 0.60. Results obtained in this study are consistent with already published values.

Table 4. The average soybean yields (kg da⁻¹) and seasonal average CWSI values

Treatment	K _{pc1}	K _{pc2}	K _{pc3}	K _{pc4}	K _{pc5}	K _{pc6}
CWSI**	0.59a	0.44b	0.35bc	0.26cd	0.20d	0.20d
Yield (kg da ⁻¹)**	0 d	260.94c	323.88bc	359.11abc	410.63ab	475.90a

** : Significant at the 1% probability level (P < 0.05). Numbers followed by different letters indicate statistically significant differences at the level of 5% (Duncan's Multiple Range Test).

4. CONCLUSION

This study has demonstrated that the CWSI values can be used for irrigation scheduling of soybean in Antalya conditions. In this research, the lower (non-stressed) and upper (stressed) baselines were determined empirically from measurements of Tc, Ta, and VPD values, and the CWSI was calculated for each irrigation treatment. The seasonal average CWSI value was calculated to be 0.26. The average potential soybean yield observed with this treatment averaged 359.11 kg da⁻¹. It is suggested to keep the seasonal mean CWSI value approximately 0.26 and index value of 0.40 can be used to start irrigations. Additionally, it is concluded that the amount of irrigation can be determined as much as the amount of evaporation measured until the index value reach 0.40. According to the results obtained, it is concluded that infrared thermometer can be used for irrigation scheduling of the soybean plant in Antalya conditions.

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