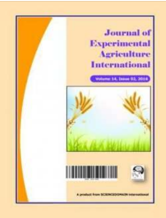

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Use of Crop Water Stress Index for Irrigation Scheduling of Soybean in Mediterranean Conditions

Begüm Tekelioğlu[1], Dursun Büyüktaş[1*], Ruhi Baştuğ[1], Cihan Karaca[1], Köksal Aydinşakir[2] and Nazmi Dinç[2]

[1]Department of Farm Structures and Irrigation, Faculty of Agriculture, The University of Akdeniz, Antalya, Turkey.
[2]Bati Akdeniz Agricultural Research Institute, Antalya, Turkey.

Authors' contributions

This work was carried out in collaboration between all authors. Authors BT, KA and CK designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors DB, RB and ND managed the analyses of the study, literature searches and overall planning and supervision of the experiment. All authors read and approved the final manuscript.

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ABSTRACT

Canopy temperature measured via infrared thermometers is an important parameter to determine crop water stress. The crop water stress index (CWSI) is the most often used index based on difference of canopy-air temperature and vapor pressure deficit (VPD) 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 deficit in order to calculate the CWSI value in soybean plants. The study is carried out in randomized complete block design with six different irrigation treatments and three replications at the Batı Akdeniz Agricultural Research Institute (BAARI), Antalya, Turkey. Plots were irrigated when the cumulative evaporation

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**Corresponding author: E-mail: dbuyuktas@akdeniz.edu.tr;*
E-mail: cihankaraca@akdeniz.edu.tr;

in Class A pan is 25±5 mm using drip irrigation system based on the plant-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 using a portable infrared thermometer in all treatments between 11.00 to14.00. 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 equal to 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 to schedule irrigation of the soybean plant under Mediterranean (Antalya) conditions of Turkey.

Keywords: Deficit irrigation; infrared thermometer; vapor pressure deficit; canopy temperature.

1. INTRODUCTION

Soybean (*Glycine max (L.) Merr.*) is deemed one of the most important legumes because it includes a high percentage of protein and enhances soil characteristics through its ability of root nodulation [1]. Soybean contributes the agriculture from a 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 Turkey as both main crop and second crop. Soybean seeds, which are important in human and animal nutrition, contain 35-45% protein, 18-24% fat, 30% carbohydrates and 5% mineral [2].

In Turkey, 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].

Water is considered as the most important factor limiting plant growth and yield in arid and semi-arid regions including Turkey. 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. Irrigation scheduling, which is defined to determine irrigation time and the amount of water to be applied, also affects water use efficiency.

Irrigation scheduling methods is usually categorized on soil, plant, and meteorological basis. Irrigation scheduling based upon crop water status can be more advantageous since crops react to both the soil and aerial environment. For that reason, plant-based scheduling of irrigation is used more and more in recent years. The irrigation time can be determined by detecting the water stress status of the plant [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. The assumption is that as water becomes limiting, transpiration is reduced and crop temperature will be higher than air temperature because of the absorbed radiation. If a plant is under stress due to lack of water, it has a tendency to close the stomata to lessen transpiration which causes an increase in leaf temperature. The leaf energy balance shows that this change in leaf temperature also depends on ambient conditions (relative humidity, wind speed, and ambient temperature) and radiation received by 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 the 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].

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

The method developed by Idso et al. [10] has been used widely to observe crop water status and to schedule irrigations of corn, wheat, watermelon, sugar beet, Bermuda grass, sunflower, green bean and cotton in semi-arid and humid conditions by many researchers. However, CWSI used less for the irrigation scheduling of soybean. For example, Nielsen [16] 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. [17], 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. Therefore, the aim of this study is to evaluate crop water stress index using infrared thermometer technique and to determine the possibilities of use in irrigation schedule in soybean plant under Mediterranean (Antalya) conditions of Turkey.

2. MATERIALS AND METHODS

2.1 Experimental Site

The study was carried out between May 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 characteristics of soil are presented in Table 1 and long-term average monthly meteorological data from 1954-2015 along with the record of study year 2015 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. In the study, ATAEM-7 cultivar developed by BAARI is used as the plant material.

2.2 Experimental Design

The experimental plots were comprised of 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 and harvested on 30 September 2015. The length of the parcels is 30 m and each parcel has 4 rows of soybean plants. A lateral drip line was placed for each row. The diameter of the lateral pipes was 16 mm having 4 L h^{-1} in-line dripper spaced at 20 cm.

The treatments were Irrigated based on the evaporation data (E_{pan}, mm) obtained from a Class A pan located near the plots and six different irrigation treatments were chosen to examine the efficiency of irrigation scheduling, depending on plant-pan coefficients of 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 first and last irrigation in the study was carried out on 15/06/2015 (181 DOY) and 15/09/2015 (258 DOY) respectively (Fig. 1). The following equation (equation 1) is used to calculate the amount of irrigation water:

$$I = AxE_pxK_{pc}xP \tag{1}$$

Where, A is parcel area (m^2); K_{pc} is plant-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%.

2.3 Canopy Temperature Measurements and Evaluations

Meteorological data was obtained from the TİGEM Meteorology Station which was installed near the experimental 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.

Table 1. Physical and chemical characteristics of the soil

Soil depth (cm)	Sand (%)	Clay (%)	Silt (%)	Texture class	Field capacity (%)	Permanent wilting point (%)	Bulk density (g cm^{-3})	pH	EC (dS m^{-1})	Organic matter (%)	CaCO$_3$ (%)
0-30	22.2	24.9	52.9	Clay Loam	24.0	12.80	1.35	8.00	0.18	1.70	29.90
30-60	25.1	22.6	52.3	Clay Loam	23.5	12.80	1.30	8.10	0.13	0.80	32.10
60-90	35.1	21.5	43.4	Loam	21.6	11.30	1.32	8.10	0.16	0.70	33.70

Table 2. Average meteorological data during 2015 and long-term measurements (1954-2015) in Antalya

Year	Months	Air temperature (℃)	Rainfall (mm)	Evaporation (mm)	Wind speed (m s^{-1})	Relative humidity (%)
1954-2015	May	20.4	29.3	172.9	2.6	66.6
	June	25.3	7.0	243.2	2.9	59.3
	July	28.3	2.6	280.3	2.8	57.1
	August	28.0	1.7	253.5	2.7	59.3
	September	24.6	12.1	203.4	2.8	59.1
	October	19.9	68.2	142.3	2.8	60.6
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

The canopy temperature measurements were taken daily using an Infrared Thermometer (Spectrum Technologies Inc.) between day of year (DOY) 182 and 257 to compute CWSI of soybean. The Infrared Thermometer measurements were taken at a field of view of 45º. The measurements were conducted at 11:00, 12:00, 13:00, and 14:00 o'clock, from four directions (East, West, North, and South) in each plot [18]. Mean daily average CWSI of irrigation treatments was computed from the total of 48 replications of each treatment. Soil water content was determined gravimetrically before each irrigation.

The empirical method developed by Idso et al. [10] was used to calculate CWSI based on the measured T_c-T_a and VPD. The non-water-stressed baseline (lower baseline) was determined using the data collected after irrigation in K_{pc5} (control treatment), where the plants were irrigated well. The data set was obtained from data measured 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 at fully stressed plants (in the K_{pc1} treatment) at 13:00 and 14:00 o'clock at different days. The empirical CWSI was calculated as;

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

where $(T_c\text{-}T_a)_m$, $(T_c\text{-}T_a)_{ll}$, and $(T_c\text{-}T_a)_{ul}$ are the measured canopy-air temperature difference (ºC) at the moment, the lower and upper limit values of the canopy-air temperature difference (ºC) for a given VPD, respectively. The air temperature and relative humidity measurements were used to calculate the VPD of the air as [19]:

$$e_s = 0.6108xexp[17.27T/(T + 237.3)] \tag{3}$$

$$e_a = e_s x(RH/100) \tag{4}$$

$$VPD = e_s - e_a \tag{5}$$

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

2.4 Statistical Analysis

The experimental data were statistically analyzed by the general linear model (GLM) using SAS software. Means are compared using Duncan's Multiple Range Test, if necessary, to separate the means of the data at 0.05 level of significance.

3. RESULTS AND DISCUSSION

3.1 Applied Water and Yield

The amount of seasonal applied irrigation water, depleted soil water, rainfall and seasonal water use are given in Table 3. Applied irrigation water 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} andK_{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}, andK_{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 [20] reported that seasonal amount of irrigation of the treatments ranged from19 to162 mm for soybean at North Platte, Nebraska. Candogan et al. [17] 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.

3.2 Crop Water Stress Index (CWSI)

The upper (water stressed) and lower limit (non-water stressed) baselines to calculate CWSI is plotted in Fig. 1. The upper limit baselines value of $(T_c\text{-}T_a)_{ul}$ was found to be constant at 4ºC. A linear relationship for the lower limit baselines was defined as $(T_c\text{-}T_a)_{ll}$= -2.162VPD-2.051 (Fig. 2). The equation determined by Nielsen [16] for non-water stressed soybean plant was $(T_c\text{-}T_a)_{ll}$ = −2.02VPD+2.51. Payero and Irmak [20] suggest $(T_c\text{-}T_a)_{ul}$= 2.77ºC for the upper baseline and $(T_c\text{-}T_a)_{ll}$= 1.87 - 1.95VPD for the lower baseline. Candogan et al. [17] reported $(T_c\text{-}T_a)_{ul}$= 3.20ºC for the upper baseline and $(T_c\text{-}T_a)_{ll}$= -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 [21].

The course of CWSI during the growing season is depicted in Fig. 2. As the amount of applied irrigation water increased CWSI values decreased. Comparing to the K_{pc3}- K_{pc6} treatments, higher values of CWSI were obtained in K_{pc1} and K_{pc2} treatments. Also, the effects of irrigation applications on the CWSI were more evident in these treatments. Less amount of applied water resulted in water stress. K_{pc5} and K_{pc6} had lower values than the other treatments and showed a tendency to be very close to each other. Daily values of CWSI 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 (Fig. 2).

The change in soil water content before irrigation is given in Fig. 3. Evaluating Figs. 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.

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

Treatment	Applied irrigation water (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

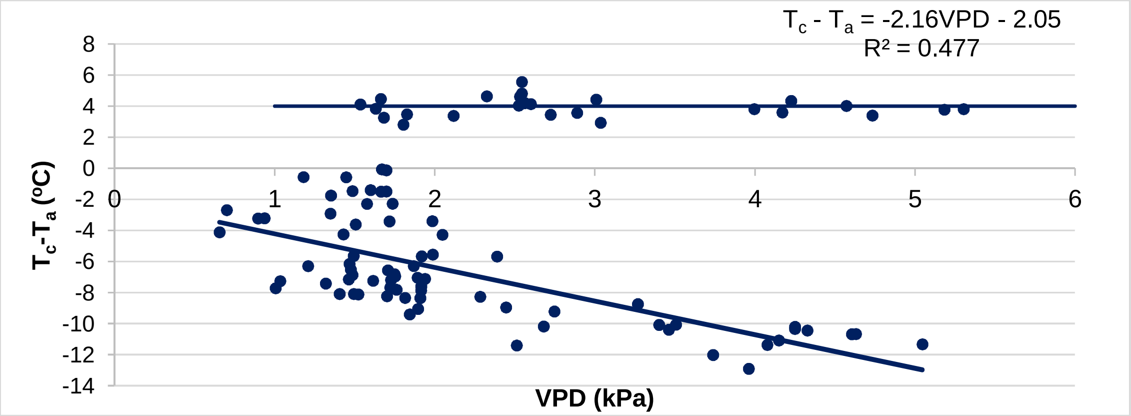

Fig. 1. Upper and lower baselines for soybean

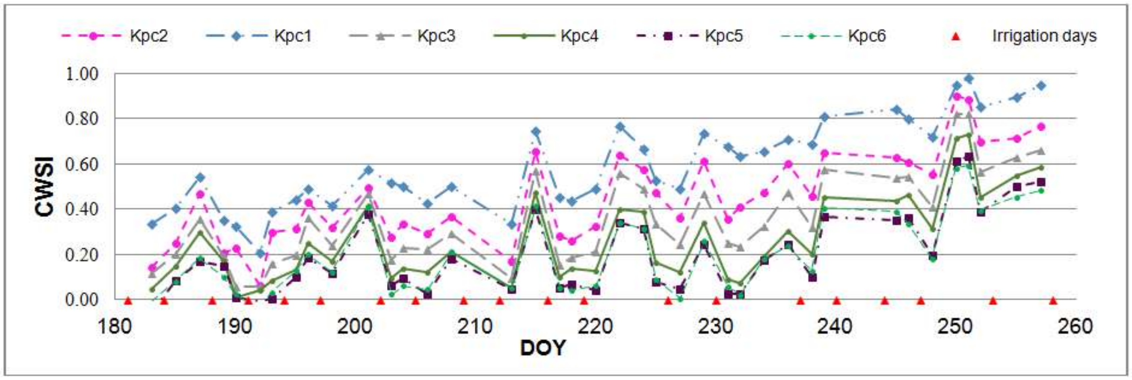

Fig. 2. The crop water stress index (CWSI) for each irrigation treatment

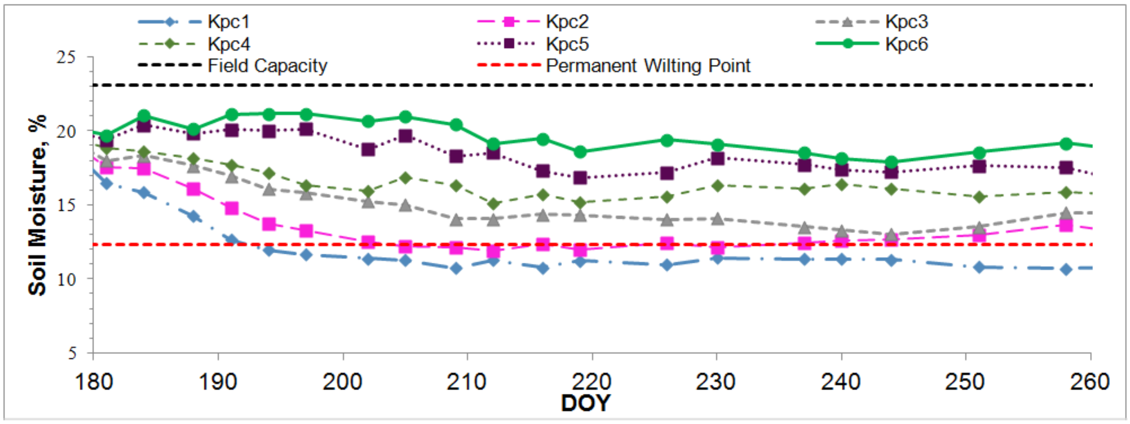

Fig. 3. Soil moisture content before irrigation

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 <0.01). Numbers followed by different letters indicate that differences are statistically significant at the level of 5% (Duncan's multiple range test)*

3.3 Yield and Seasonal Average CWSI

Table 4 shows statistical relationship between the mean CWSI values and soybean yield. The result regarding average CWSI and yield are statistically 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 under Mediterranean (Antalya) conditions of Turkey, 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 applied water can be equal to the amount of evaporation measured until the index value reach 0.40. In a study where four different threshold values of CWSI (i.e., CWSI = 0.2, 0.3, 0.4 and 0.5) are compared to initiate irrigations, Nielsen [16] 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. On the other hand, Candogan et al. [17] reported that the soybean seed, protein and oil yields would decrease when the seasonal mean CWSI exceeds 0.17. 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.

Significant linear equations were developed under CWSI experiments. A linear relationship between average CWSI and yield was established as (Yield = -1044.9CWSI+660.35, r^2=0.93*) when data given in Table 3 is graphed. As the amount of applied irrigation water decreased, the transpiration rates of the crop decreased, resulting in increased crop canopy temperatures and subsequent reductions in yield and growth. These results confirm many earlier studies on different crops [22,23,24]. Thus, the CWSI values proved to be a good indicator of the plant to available water for soybean and it may be used to predict yield where the CWSI is known.

4. CONCLUSION

This study has demonstrated that the CWSI values can be used to schedule irrigation of soybean under Mediterranean (Antalya) conditions of Turkey. 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 in K_{pc4}treatmentwas 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 equal to 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 under Mediterranean (Antalya) conditions of Turkey. It is also shown that CWSI values can be used to estimate yield of soybean using yield-CWSI equation established.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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