

Use of Crop Water Stress Index for Irrigation Scheduling of Soybean

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 in six different irrigation treatments in three replications between July and October 2015 at the Batı Akdeniz Agricultural Research Institute (BAARI), Antalya, Turkey. Plots were irrigated when the cumulative evaporation 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 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 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 to produce root nodule [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 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 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].

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 Turkey is in, is considered to be 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 as soil, plant, and meteorologically based. 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 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. 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 threefold: a) the energy balance method developed by Jackson et al. (1981) [14], b) the empirical approach developed by Idso et al. (1981) [10], and c) the wet-bulb temperature method developed by Alves and Pereira (2000) [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. (1981) [10] has been used widely to observe crop water status and to schedule irrigations of different plants by many 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; Koksall (2006) [24] in sugar beet; Emekli et al. (2007) [25] in bermuda grass; Nielsen (1994) [26] and Taghvaeian et al. (2014) [27] in sunflower; Köksall (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. 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. MATERIAL AND METHODS

The study was carried out 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 characteristics of soil are presented 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. In the study, ATAEM-7 cultivar developed by BAARI is used as the plant material.

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.

Table 1. Physical and chemical characteristics of the soil

Soil depth (cm)	Texture class	Field capacity (%)	Permanent wilting point (%)	Bulk density (g cm ⁻³)	pH	EC (dS m ⁻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 (m s ⁻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

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 (Figure 1). The following equation (equation 1) is used to calculate the amount of irrigation water:

$$I = Ax E_p x K_{pc} x P \quad (1)$$

Where, A is parcel area (m²); 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%.

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 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.

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 45°. 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 [25]. 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 every irrigation.

The empirical method developed by Idso et al. (1981) [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 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 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} 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 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

The upper (water stressed) and lower limit (non-water stressed) baselines to calculate CWSI is plotted in Figure 1. The upper limit baselines value of $(T_c - T_a)_{ul}$ was found to be constant at 4°C. A linear relationship for 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 plant 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. 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 (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.

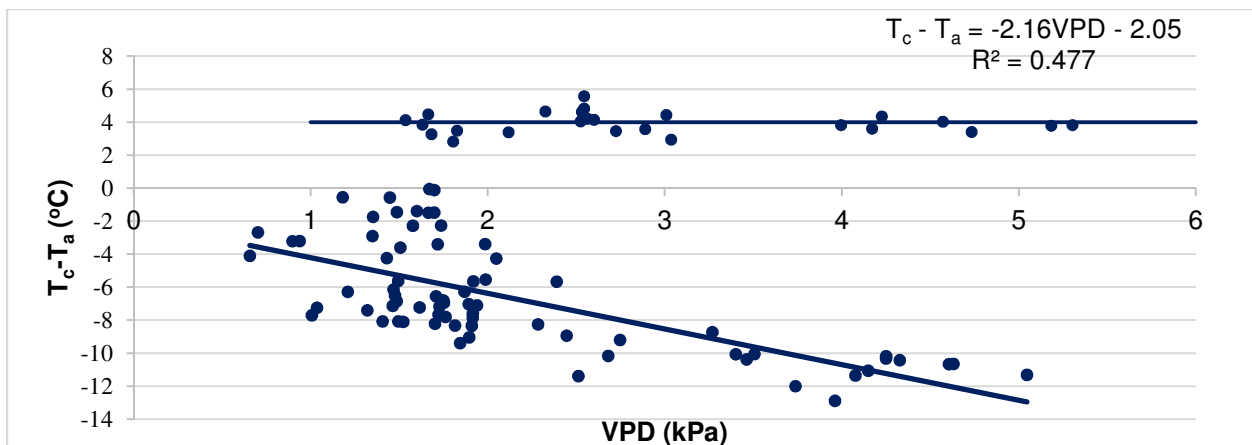


Fig. 1. Upper and lower baselines for soybean.

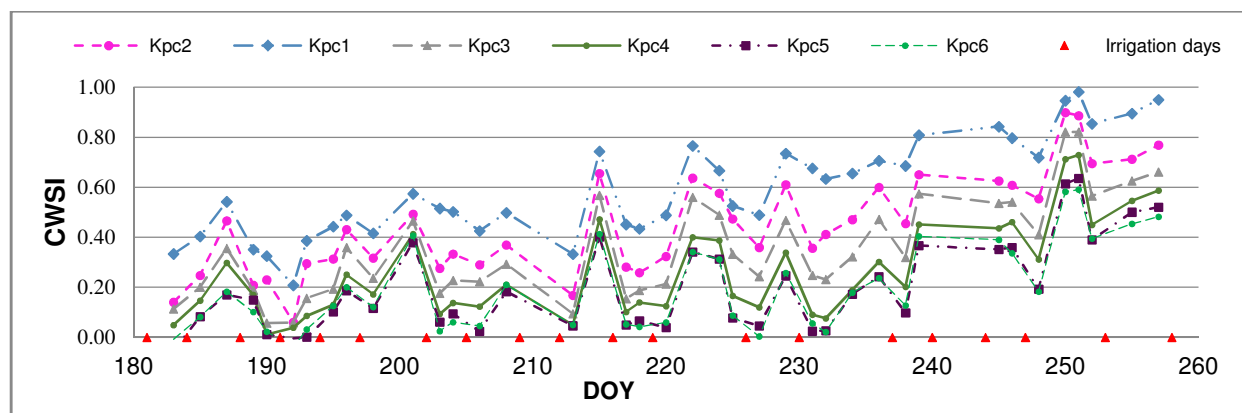


Fig. 2. The crop water stress index (CWSI) for each irrigation treatment.

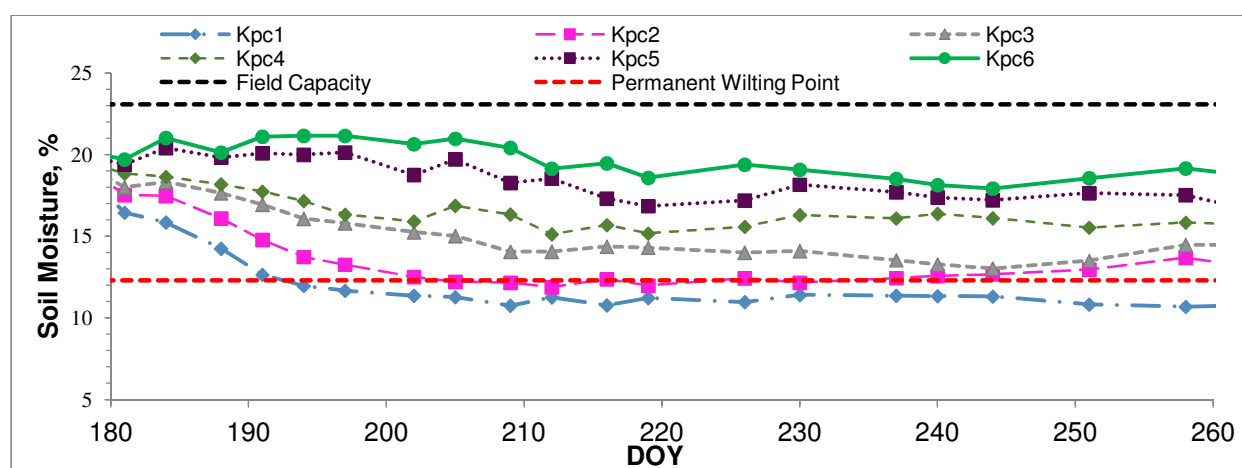


Fig. 3. Soil moisture content before irrigation.

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 (1990) [29] 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. (2013) [30] 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.

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).

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 ([34], [35], [36]). 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 T_c, T_a, and VPD values, and the CWSI was calculated for each irrigation treatment. The seasonal average CWSI value in K_{pc4} treatment 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 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.

REFERENCES

1. Jabbar A, Saud HM. Effects of phosphorus on biological nitrogen fixation in soybean under irrigation using saline water, Global Journals Inc. (US) Guidelines Handbook, 2011;12(1):65-67.
2. FAOSTAT. Crops Productions. [Online]. Accessed on 26 April 2016. Available: <http://faostat3.fao.org/download/Q/QC/E>.
3. TUIK. Crop production statistics. Turkish statistical institute, Accessed 04 April 2016 Available: http://www.tuik.gov.tr/PreTablo.do?alt_id=1001.
4. Grimes DW, Yamada H, Hughes SW. Climate normalized cotton leaf water potentials for irrigation scheduling. Agric. Water Manage., 1987;12:293-304.
5. Jackson RD. Canopy temperature and crop water stress index. Advances in Irrigation, 1982;1:43-85.
6. Clawson KL, Jackson RD, Pinter PJ. Evaluating plant water stress with canopy temperature differences. Agronomy J., 1989;81:858-863.
7. Pinter PJ, Reginato RJ. Thermal infrared technique for monitoring cotton water stress and scheduling irrigations. Transaction of the ASAE, 1982;25(6):1651-1655.
8. O'toole JC, Turner NC, Namuco OP, Dingkuhn M, Gomez KA. Comparison of some crop water stress measurement methods. Crop Science, 1984;24(6):1121-1128.

- 267 9. Alderfasi AA, Neilsen DC. Use of crop water stress index for monitoring water status and scheduling
268 irrigation in wheat. *agricultural water management*, 2001;47(1):69-75.
- 269 10. Idso SB, Jackson RD, Pinter PJ, Reginato RJ, Hatfield JL. Normalizing the stress-degree-day
270 parameter for environmental variability. *Agric. Meteorol.*, 1981;24:45-55.
- 271 11. Reginato RJ. Field quantification of crop water stress. *Transaction of the ASAE*, 1983;26(3):772-781.
- 272 12. Gencoglan C, Yazar A. Çukurova koşullarında yetiştirilen ı. ürün mısır bitkisinde infrared termometre
273 değerlerinde yararlanılarak bitki su stresi indeksi (CWSI) ve sulama zamanının belirlenmesi. *Turkish*
274 *Journal of Agriculture and Forestry*, 1999;23(2):87-95.
- 275 13. Ödemis B, Bastug R. Infrared termometre tekniği kullanılarak pamukta bitki su stresinin
276 değerlendirilmesi ve sulamaların programlanması. *Turkish Journal of Agriculture and Forestry*,
277 1999;23(1):31-37.
- 278 14. Jackson RD, Idso RB, Reginato RJ, Pinter PJ. Canopy temperature as a crop water stress indicator.
279 *Water Resour. Res.*, 1981;17:1133-1138.
- 280 15. Alves I, Pereira LS. Non-Water-stressed baselines for irrigation scheduling with infrared
281 thermometers: a new approach. *Irrig. Sci.*, 2000;19:101-106.
- 282 16. Nielsen DC, Gardner BR. Scheduling irrigations for corn with the crop water stress index (CWSI).
283 *Applied Agricultural Research*, 1987;2:295-300.
- 284 17. Yazar A, Howell TA, Dusek DA, Copeland KS. Evaluation of crop water stress index for lepa irrigated
285 corn. *Irrigation Science*, 1999;18:171-180.
- 286 18. Irmak S, Haman ZH, Bastug R. Determination of crop water stress index for irrigation timing and
287 yield estimation of corn. *Agronomy Journal*, 2000;92:1221-1227.
- 288 19. Bastug R, Irmak S. Toprak suyu potansiyeli ve bitki su stresi indeksi (CWSI) değerlerinin mısır
289 sulanmasında kullanılması. *Akdeniz Üniversitesi Ziraat Fakültesi Dergisi*, 1996;9(1):241-255.
- 290 20. Nielsen DC, Halvorson AD. Nitrogen fertility influence on water stress and yield of winter wheat.
291 *Agronomy Journal* 1991;83:1065-1070.
- 292 21. Yuan G, Luo Y, Sun X, Tang D. Evaluation of a crop water stress index for detecting water stress in
293 winter wheat in the north china plain. *Agricultural Water Management*, 2004;64:29-40.
- 294 22. Gontia NK, Tiwari KN. Development of crop water stress index of wheat crop for scheduling irrigation
295 using infrared thermometry. *Agricultural Water Management*, 2008;95:1144-1152.
- 296 23. Orta AH, Erdem Y, Erdem T. Crop water stress index for watermelon. *Scientia Horticulturae*,
297 2003;98,121-130.
- 298 24. Köksal ES. Sulama suyu düzeylerinin şekerpancarının verim, kalite ve fizyolojik özellikleri üzerindeki
299 etkisinin, infrared termometre ve spektoradyometre ile belirlenmesi. *Doktora Tezi. Ankara*
300 *Universitesi, Fen Bilimleri Enstitüsü, Tarımsal Yapılar ve Sulama Anabilim Dalı, Ankara*, 2006;101.
- 301 25. Emekli Y, Bastug R, Buyuktas D, Emekli NY. Evaluation of a crop water stress index for irrigation
302 scheduling of bermudagrass. *Agricultural Water Management*, 2007;90:205-212.
- 303 26. Nielsen DC. Non-water-stressed baselines for sunflowers. *Agricultural Water Management*,
304 1994;26:265-276.
- 305 27. Taghvaeian S, Comas L, Dejonge KC, Trout TJ. Conventional and simplified canopy temperature
306 indices predict water stress in sunflower. *Agricultural Water Management*, 2014;144:69-80.
- 307 28. Köksal ES. Irrigation water management with water deficit index calculated based on oblique viewed
308 surface temperature. *Irrigation Science*, 2008;27:41-56.
- 309 29. Nielsen DC. Scheduling irrigations for soybeans with the crop water stress index (CWSI). *Field*
310 *Crops Research*, 1990;23:103-116.
- 311 30. Candogan BN, Sincik M, Buyukcangaz H, Demirtas C, Goksoy AT, Yazgan S. Yield, quality and crop
312 water stress index relationships for deficit-irrigated soybean [*Glycine max (L.) Merr.*] in sub-humid
313 climatic conditions. *Agricultural Water Management*, 2013;118:113-121.
- 314 31. Allen RG, Pereira LS, Raes D, Smith M. Crop evapotranspiration guidelines for computing crop
315 water requirements. *FAO Irrigation and Drainage Paper No. 56. Rome, Italy: FAO*, 1998;300.
- 316 32. Payero J, Irmak S. Variable upper and lower crop water stress index baselines for corn and soybean.
317 *Irrigation Science*, 2006;25(1):21-32.
- 318 33. Tekelioglu B, Büyüktas D, Aydınsakir K, Dinç N, Bastug R, Karaca C. Soya fasulyesinde taç örtüsü
319 sıcaklığı ve bitki su stresi indeksi (cwsı) değerlerinin çeşitlere bağlı olarak değişiminin irdelenmesi.
320 13. Ulusal Kültürteknik Kongresi, 2016;302-309.

- 321 34. Yazar A, Howell AT, Dusek DA, Copeland KS. Evaluation of Crop Water Stress Index for LEPA
322 Irrigated Corn. Irrig. Sci., 1999;18:171-180.
- 323 35. Sezen SM, Yazar A, Daşgan Y, Yücel S, Akyıldız A, Tekin S, Akhoundnejad Y. Evaluation of Crop
324 Water Stress Index (CWSI) for Red Pepper with Drip and Furrow Irrigation under Varying Irrigation
325 Regimes. Agric. Water Manage. 2014;143:59-70.
- 326 36. Erdem Y, Arin L, Erdem T, Polat S, Deveci M, Okursoy H, Gültas H. Crop Water Stress Index For
327 Assessing Irrigation Scheduling of Drip Irrigated Broccoli (*Brassica oleracea* L. var. *italica*). Agric.
328 Water Manage. 2010;98(1):148-156.