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Determination of Crop Water Stress Index (CWSI) of Second Crop Corn in a Semiarid Climate

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ABSTRACT

This study was carried out to determine the relationship between the canopy-air temperature differential and vapor pressure deficit (VPD), which can be used to quantify the crop water stress index (CWSI) under fully irrigated (100 %) and maximum water stress (0 %) conditions of furrow irrigated corn. The effects of five different irrigation levels (100, 70, 50, 30 and 0 % replenishment of soil water depleted from the 0.90 m soil profile depth) on corn yields and the resulting CWSI were investigated. The highest yield and total water use were obtained under fully irrigated corn plots (100 % replenishment of soil water depleted). The trends in CWSI values were consistent with the soil water content induced by deficit irrigation. CWSI increased with increased soil water deficit. An average CWSI of 0.22 before irrigation time provided the highest grain corn yield. The yield was directly correlated with seasonal mean CWSI values and a second order polynomial equation "$Y = 59258CWSI^2 - 72051CWSI + 24060$" can be used to predict the grain yield of corn as a second crop under the semiarid climate.

Keywords: crop water stress index (CWSI), canopy temperature, lower baseline, corn

INTRODUCTION

Corn (*Zea mays* L.) grown mostly under irrigated conditions is a major commercial crop in the Aegean semiarid region of Turkey. During recent years, irrigated corn production has expanded rapidly in the Aegean semiarid region of Turkey. Corn has become a widely grown feed grain crop particularly as a second crop after wheat or barley. Almost no second crop corn production areas of Turkey have enough rainfall to reach the potential grain yield. Therefore, irrigation is necessary during the growing season to maintain and enhance crop growth and yield (Anac et al., 1999). Under these conditions farmers have to understand the water-yield relationship of corn and how to choose the most water efficient methods of irrigation scheduling (Anac et al., 1999; Orta et al., 2002).

Irrigation management is generally based on the estimation or measurement of evapotranspiration by measuring soil water content in the effective root zone or measuring some meteorological parameters. However, irrigation scheduling based on crop water status should be more advantageous since crops respond to both the soil and aerial environment (Yazar et al., 1999). Plant stress measurement with hand-held infrared thermometers (IRT) has become increasingly popular after 1980. This technique is based on the fact that transpiration cools the leaf surface. As water becomes limiting, stomatal conductance and transpiration decrease and leaf temperature increases (Reginato, 1983). Idso et al. (1981) determined an empirical approach for quantifying plant stress by determining "non-water stressed baselines" for crops. Under field conditions, they developed linear relationships for canopy-air temperature difference (Tc-Ta) versus vapor pressure deficit (VPD) of the atmosphere for a crop transpiring at its potential rate. This line, (Tc-Ta) versus VPD, represents the measured temperature difference when the crop is fully irrigated (no water stress). The upper limit (Tc-Ta) represents the temperature difference occurring when the crop transpiration rate approaches zero (maximum water stress) (Reginato, 1983).

Productivity response to water stress is different for each crop and this response is expected to vary with climate. Therefore, the critical values of CWSI should be determined for a particular crop in different climates and soils for use in yield prediction and irrigation management. Predicting yield response to crop water stress is important in both developing strategies and decision-making concerning irrigation management under limited water conditions by farmers and their advisors, as well as researchers. A range of empirical studies have reported on the determination of CWSI for different crops. Gardner et al. (1992a) suggested that baselines are strongly location dependent and perhaps species and variety dependent. Idso (1982) developed non-water stressed baselines for various crops. Steele et al. (1994) obtained the highest yield in the fully irrigated treatment with an average CWSI value between 0.2 and 0.4 for corn. Gencoglan and Yazar (1999) and Irmak et al. (2000) showed that the CWSI values could be used to determine irrigation scheduling and that irrigation should be applied when the critical CWSI values were about 0.21 and 0.22 for corn in the Mediterranean conditions of Turkey. Howell et al. (1984) determined that irrigation should be applied when the CWSI value for cotton is in the range 0.30-0.50. Yazar et al. (1999) and Kırnak and Gencoglan (2001) found critical average CWSI values of 0.33 and 0.25 in the Texas and in the GAP (Southesatern Anotolia Project) conditions, respectively.

The purpose of this study was to develop a baseline equation that could be used to calculate CWSI for monitoring water status and yield prediction of second crop corn under Aegean semiarid conditions of Turkey.

MATERIALS and METHODS

The experiment was conducted at the Agricultural Research Station of Adnan Menderes University, Aydın- Turkey, at 37^{o} 51' N latitude, 27^{o} 51' E longitude and 56 m altitude during the 2003 and 2004 growing seasons. The climate in this region is classified as semiarid and the average values of air annual temperature, air relative humidity, wind speed, sunshine duration per day and total annual precipitation are 17.5 ^{0}C, 63 %, 1.6 m s^{-1}, 7.6 h and 657 mm, respectively (Anonymous, 2003). The soil texture in the plot area was loam and sandy loam and the available water holding capacity within 0.90 m of the soil is about 0.16 m. Pioneer brand 3394 corn hybrid, the most popular hybrid as a second crop corn in the research area, was planted in rows at 0.70 m spacing during the last week of June (Day of year (DOY):178 in 2003; DOY:182 in 2004) of each experimental year. Corn plants were thinned leaving a plant every 0.25 m in all treatments. Corn plots were fertilized with 75 kg ha^{-1} of N, P and K (15 15 15 composite) before sowing and an additional nitrogen dose of 115 kg ha^{-1} of N was applied as Ammonium nitrate 33 % when the plant reached 0.3- 0.4 m in height.

The plots were arranged in a complete randomized block design with three replications. Each plot was 8.0 m by 4.2 m (6 rows, 0.7 m row spacing, 0.25 m inter plant spacing). There were 3.0 m spaces between the experimental plots in order to minimize water movement among treatments. Five irrigation treatments, differing in irrigation rate were evaluated. Irrigation was applied when approximately 50% of the available soil moisture was consumed in the root zone of the control treatment (T_1). The measured soil moisture content at the T_1 treatment was used to initiate irrigation during the growing season. In treatments T_2, T_3, T_4 and T_5, irrigation was applied at the rates of 70, 50, 30 and 0 % of T_1 on the same day, respectively. Closed-end furrow irrigation method was used in all treatments and a flow meter was used to measure the amount of water applied. The soil water content was measured at 9:00 am daily in the control treatment (T_1) and, if necessary, the plots were irrigated.

A neutron probe method (CPN, 503 DR Hydroprobe, Campbell Pacific Nuclear International, Martinez, CA, USA) was used to measure daily soil moisture level at depths of 0.60 to 1.20 m throughout the whole growing season. The soil moisture content in the fist 30 cm layer was measured by the gravimetric method since it was not possible to monitor it with the neutron probe method (Evett et. al., 1993). The water use (evapotranspiration) was calculated applying the water balance method to the upper 0.90 m soil layer. Evapotranspiration (ET) was calculated using the soil water balance method (Heerman, 1985);

$$ET = P + I - D \pm \Delta W$$

where P is the rainfall (mm), I is the irrigation applied to individual plots (mm), D is the deep percolation and ΔW is variation in water content of the soil profile (mm). Since the amount of irrigation water was only sufficient to bring the water deficit to field capacity, deep percolation was neglected.

Canopy temperatures (Tc) were measured using a hand-held infrared thermometer (IRT), (Raynger ST60 model Raytek Corporation, Santa Cruz, CA, USA). The instrument has a field of view of 3^0 and a 7.0 to 18 μm spectral band-pass filter. The infrared thermometer was operated with the emissivity adjustment set at 0.98. The IRT data collection was performed from August 1th (day of year (DOY) 213), when the percentage of plant cover was approximately 80-85 % until September 15th (DOY 258) in 2003 and from July 30th (DOY 212) until September 14th (DOY 258) in 2004, respectively. Canopy temperature was measured on four plants from four directions per plot and then averaged. For each measurement the IRT was held above the plant (0.50 m) at an angle of $20\text{-}30^0$ below the horizontal so that soil background would not influence measurements.

The Tc, dry and wet bulb temperature measurements were made from 11:00 to 14:00 at hourly intervals under clear skies. Dry and wet bulb temperatures were measured with an aspirated pyschrometer at a height of 2.0 m in the open area adjacent to the experimental plots. The mean vapor pressure deficit (VPD) was computed using the corresponding instantaneous wet and dry bulb temperatures and the standard pyschrometer equation (Allen et al., 1998) using a mean barometric pressure of 101.7 kPa.

Using the upper and lower limit estimates, a CWSI can be defined as (Idso et al., 1981):

$$\mathrm{CWSI} = \frac{\left[(T_c - T_a) - (T_c - T_a)_{ll}\right]}{\left[(T_c - T_a)_{ul} - (T_c - T_a)_{ll}\right]}$$

where, T_c is the canopy temperature (^{0}C), T_a the air temperature (^{0}C), the subindex ll indicates the non-water stressed baseline (lower baseline) and the subindex ul indicates the non – transpiring upper baseline.

From the above equation, the non-stressed baselines for canopy-air temperature difference (Tc-Ta) versus VPD relationship were determined using data collected from the control (100 %) treatment (T_1) a day after irrigation. The upper (fully stressed) baseline was determined based on the procedures suggested by Idso et al. (1981). To obtain the upper baseline, the canopy temperatures of the fully stressed crops (in T_5 treatment) were measured several times during the growing season.

Corn ears were harvested by hand from 7.5 m section of the two adjacent center rows (60 plants) of each plot, on 11 November 2003 (DOY:315) and on 8 November 2004 (DOY:313). Grain yields were converted to a standard grain water content of 15.5 % wet basis (Yazar et al., 1999). The data were analyzed by analysis of variance. The differences among treatments were evaluated using an F test in the yield results and the means were compared using Duncan's Multiple Test Procedure.

RESULTS and DISCUSSION

The seasonal water use of the T_1 treatment was the highest in both years, suggesting that the water applied was enough to meet the full crop water requirements. Therefore, the T_1 treatment was used to determine the lower (non-stressed) CWSI baseline. The lowest water use occurred in treatment T_5 since there was no irrigation water applied and presumably the highest water deficit in the crop root zone occurred in this treatment. The T_5 treatment was used, therefore, to determine the upper (fully-stressed) baseline. During the growing seasons, the upper and lower baselines as outlined by Idso et al. (1981) were determined using data taken from the T_1 and T_5 treatments using linear regression of the differences between Tc and Ta against VPD (Figs. 1 and 2). The resulting baselines were described by the following linear equations;

Tc-Ta = 2.90-2.18VPD ($r^2 = 0.89$, $p<0.01$, $S_{yx} = 0.55$) in 2003

Tc-Ta = 3.22-2.51VPD ($r^2 = 0.96$, $p<0.01$, $S_{yx} = 0.47$) in 2004 ; where Tc-Ta is in ^{o}C and VPD is in kPa.

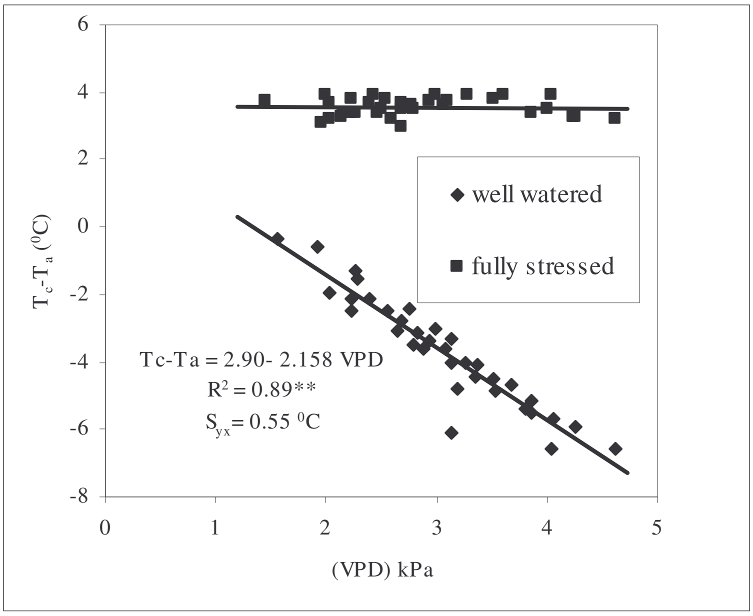

Figure 1. Canopy-air temperature differential (Tc-Ta) versus air vapor pressure deficit (VPD) for upper non-transpiring baseline and the lower non-water stressed baseline for corn in 2003.

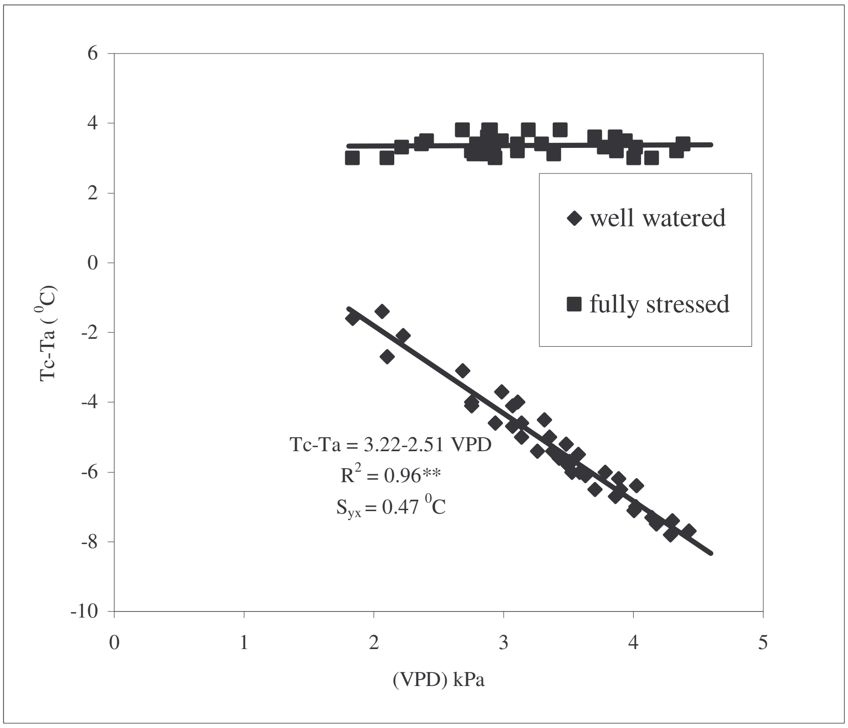

Figure 2. Canopy-air temperature differential (Tc-Ta) versus air vapor pressure deficit (VPD) for upper non-transpiring baseline and the lower non-water stressed baseline for corn in 2004.

These equations differ somewhat from those obtained for corn in previous studies. For example; Idso et al. (1982) found the equation Tc-Ta = 3.11-1.97 VPD in Arizona; Nielsen and Gardner (1987) obtained the equation Tc-Ta =2.67-2.059 VPD in Colorado; Steele et al. (1994) determined the lower limit equation of Tc-Ta= 2.14-1.97 VPD in Oakes. Yazar et al. (1999) reported the equation Tc-Ta = 1.06-2.56 VPD for the lower baseline for corn in Texas conditions. Gencoglan and Yazar (1999) determined the lower limit equations of Tc-Ta= 2.9-2.66 VPD and Tc-Ta= 2.41-2.045 in 1993 and 1994, respectively, under the Cukurova-Turkey conditions. Also Irmak et al. (2000) defined the lower limit equation of Tc-Ta= 1.39-0.86 VPD under Mediterranean conditions. Several factors such as the climate, soil type, IRT calibration and specific corn variety may have caused differences in the intercept and the slope of the lower baseline of this study.

Regarding to the upper baseline, the average value of (Tc-Ta) for the fully-stressed plants (treatment T_5) were 3.6 ^{0}C in 2003 and 3.3 ^{0}C in 2004. These values are similar to those reported in previous studies for corn. For example; Nielsen and Gardner (1987) reported an upper limit value of 3.0 ^{o}C, while Steele et al. (1994) reported a value of 5.0 ^{o}C. Howell et al. (1984) stated that the upper limit range was between 3 and 4 ^{o}C, and that the appropriate value depended on the intercept of the lower baseline and the air temperature of the region.

The seasonal course of CWSI values for the irrigation treatments studied in the years of 2003 and 2004 are shown in Figs. 3 and 4, respectively. In these figures, the arrows indicate the days of irrigation. The CWSI values in irrigated plots generally dropped following each irrigation application, and then increased steadily to a maximum value just prior to the next irrigation application as the soil water in the crop root zone was depleted. In 2003, the CWSI values ranged from 0.0 to maxima values of 0.78 (treatment T_1), 0.69 (treatment T_2), 0.77 (treatment T_3), 0.74 (treatment T_4), and 0.93 (treatment T_5). In 2004, these maxima values were 0.54 (treatment T_1), 0.54 (treatment T_2), 0.64 (treatment T_3), 0.67 (treatment T_4) and 0.92 (treatment T_5). Irrigations occurred when the CWSI on the previous day reached an average value of 0.44 and 0.45 (average 0.45) in T_1 treatment; 0.45 and 0.48 (average 0.47) in T_2 ; 0.50 and 0.55 (average 0.53) in T_3 ; 0.51 and 0.57 (average 0.54) in T_4 treatment, in the years of 2003 and 2004, respectively. The highest grain yield was attained in the T_1 treatment which had an average CWSI of 0.45 before irrigation. Gardner et al. (1992 b) stated that cotton, corn, and wheat crops tolerate increases of CWSI of 0.20 to 0.30 between irrigations without significant yield reductions. For the maximum water stressed (non irrigated) treatment, $T_{5,}$ the average CWSI values approached to 0.92 and stayed near this value.

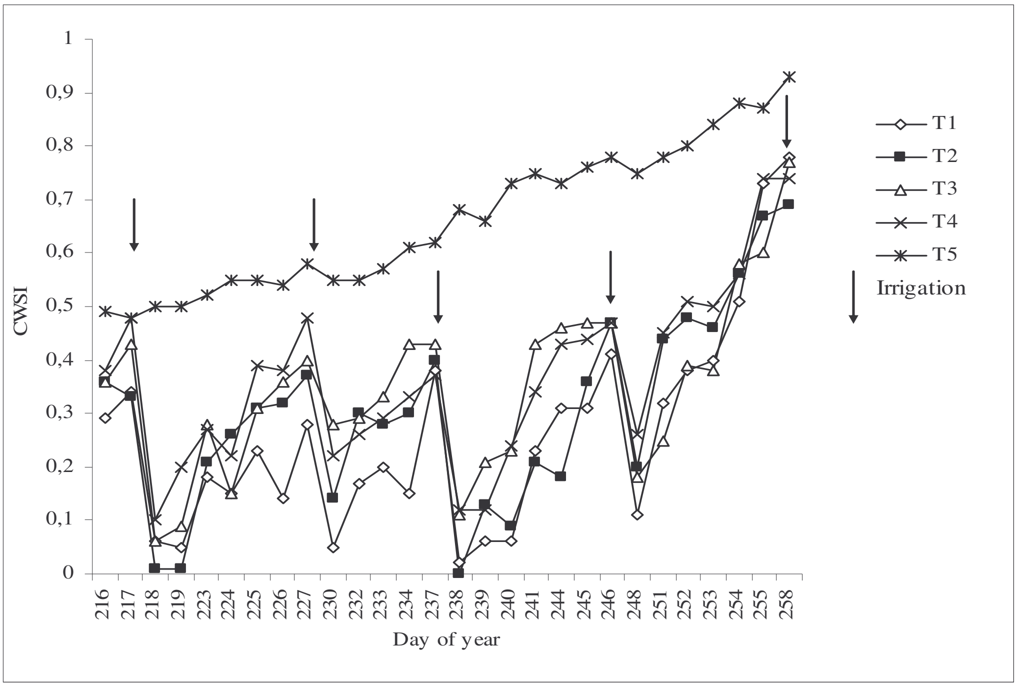

Figure 3. Seasonal variation of CWSI for each treatment in 2003.

The seasonal mean CWSI values for each treatment and the grain corn yields for the two studied years are presented in Table 3. Grain yield was significantly increased ($p<0.01$) by the irrigation level. The highest yield was measured for T_1 treatment in both years. The seasonal mean CWSI for treatment T_1 was 0.22 and 0.21 in 2003 and 2004, respectively. Results indicated that if the seasonal mean CWSI values were greater than the values mentioned above, grain corn yield would decrease. The relationship between yield and seasonal mean CWSI values was curvilinear within the range of mean CWSI for the two studied years (Fig. 5). This result agrees with many other studies for different crops (Reginato, 1983; Howell et al., 1984; Wanjura et al., 1990; Nielsen, 1994; Odemis and Bastug 1999; Yazar et al., 1999; Irmak et al., 2000).

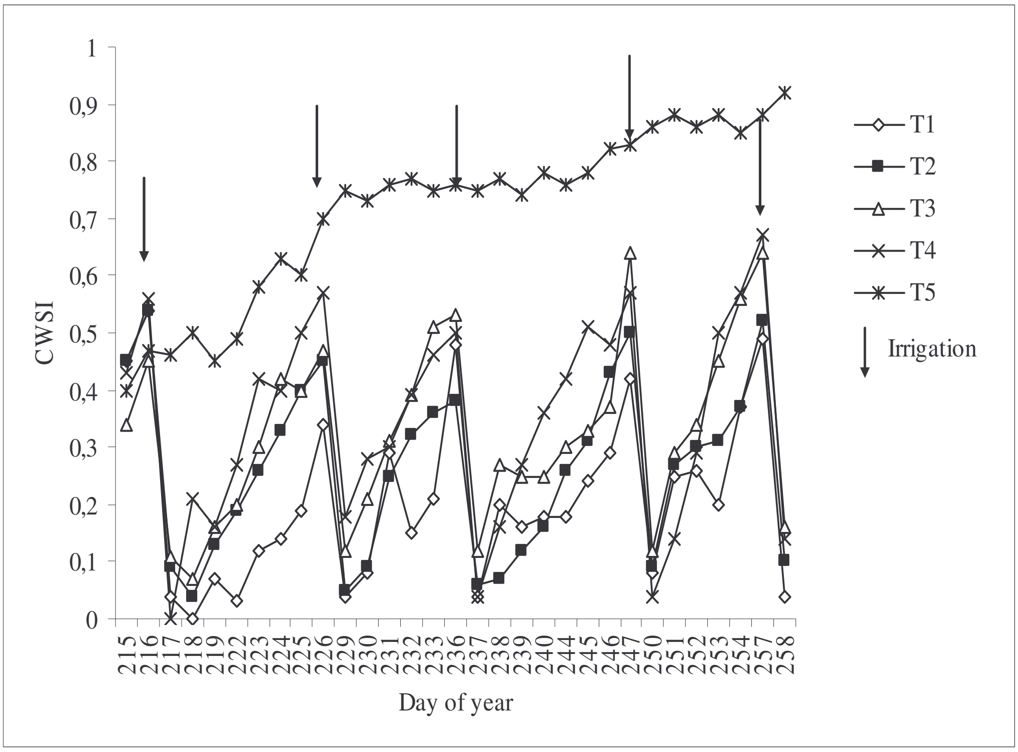

Figure 4. Seasonal variation of CWSI for each treatment in 2004.

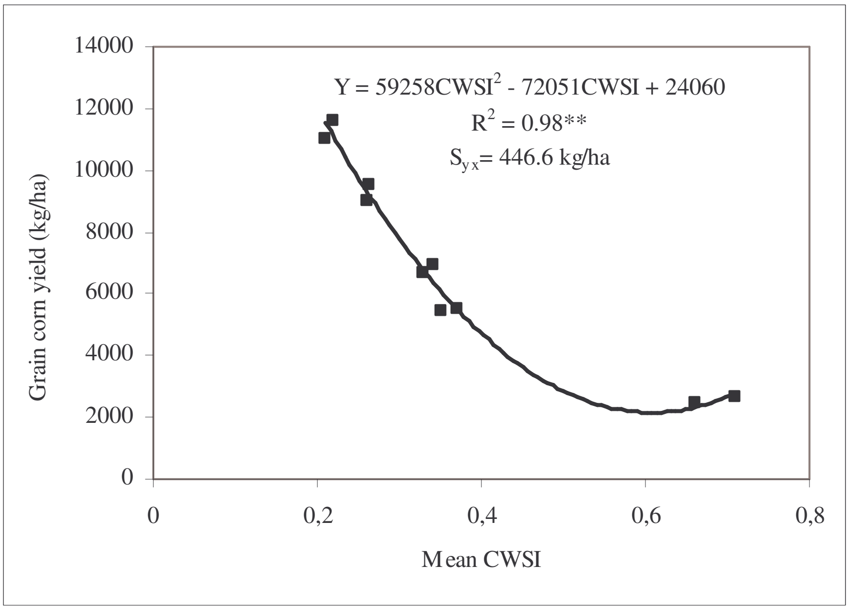

Figure 5. Relationship between corn grain yield and seasonal mean crop water stress index (CWSI).

Table 3. Corn grain yield and seasonal mean crop water stress index (CWSI) values for the different treatments of both growing seasons.

Year	Treatments	Grain corn yield (kg/ha)	Seasonal mean CWSI
2003	T_1	11630 a**	0.22
	T_2	10000 b	0.26
	T_3	7190 c	0.35
	T_4	5520 d	0.37
	T_5	3080 e	0.66
2004	T_1	11050 a**	0.21
	T_2	9000 b	0.26
	T_3	6670c	0.33
	T_4	4910 d	0.35
	T_5	2680 e	0.71

** Numbers followed by different letters indicate statistically significant differences at the 1 % level (Duncan's multiple range test).

CONCLUSIONS

In this research, the upper (water-stressed) and lower (non-water stressed) baselines and CWSI values determined empirically during this study in the years of 2003 and 2004 were slightly different. These differences can be due to several factors mentioned earlier. Based on these results the mean CWSI value before applying irrigation was 0.45 under non-water stress conditions. This CWSI value was consistent with the highest yield for corn in our study. However, we can not conclude that this CWSI value should be used for timing of irrigations for corn since we did not test irrigation scheduling using CWSI. Further studies are needed to reach such a conclusion. The critical value of CWSI that a farmer can use to determine when to irrigate corn in semiarid climate should be tested with long term experiments.

REFERENCES

Allen, R.G., L.S. Pereira, D. Raes and M. Smith. 1998. Crop evapotranspiration. FAO Irrigation and Drainage Paper 56, Rome, pp. 299.

Anac, S., M.A. Ul, D. Anac, I.H. Tuzel, H. Hakerlerler and B. Okur. 1999. Optimum irrigation scheduling for cotton under deficit irrigation conditions. In: Kırda, C., Moutonnet, P., Hera, C., Nielsen, D.R. (Eds.), Crop Yield Response to Deficit Irrigations , Kluwer Academic Publishers, Dordrecht, The Netherlands. p. 196-212.

Anonymous. 2003. Meteorological Station, Aydın, Turkey.

Evett, S. A.T. Howell, J.L. Steiner and L.L. Cresap. 1993. Management of Irrigation and Drainage, Div/ASCE, Utah.

Gardner, B.R., D.C. Nielsen and C.C. Shock. 1992a. Infrared thermometry and the crop water stress index. I. History, theory, and baselines. J. Prod. Agric. 5: 462-466.

Gardner, B.R., D.C. Nielsen and C.C. Shock. 1992b. Infrared thermometry and the crop water stress index. II. Sampling procedures and interpretation. J. Prod. Agric.5: 466-475.

Gencoglan, C. and A. Yazar. 1999. Determination of crop water stres index (CWSI) and irrigation timing by utilizing infrared thermometer values on the first corn grown under Çukurova conditions. Turkish J. Agr. For. 23: 87-95.

Heerman D.F. 1985. ET in irrigation management, In Proceedings of the National Conference on Advances in Evapotranspiration. ASAE Publication, p. 323-334.

Howell, T.A., J.L. Hatfield, H. Yamada and K.R. Davis. 1984. Evaluation of cotton canopy temperature to detect crop water stress. Trans. ASAE. 27: 84-88.

Idso, S.B., R.D. Jackson, P.J. Pinter, Jr. R.J. Reginato and J.L. Hatfield. 1981. Normalizing the stress-degree-day parameter for environmental variability. Agric. Meteorol. 24: 45-55.

Idso, S.B. 1982. Non-water-stressed baselines: A key to measuring and interpreting plant water stress. Agric. Meteorol. 27: 59-70.

Idso, S.B., R.J. Reginato and S.M. Farah. 1982. Soil and atmosphere induced plant water stress in cotton as inferred from foliage temperature. Water Resour Res. 18: 1143-1148.

Irmak, S., Z.H. Dorota and R. Bastug. 2000. Determination of crop water stress index for irrigation timing and yield estimation of corn. Agron. J. 92: 1221-1227.

Kırnak, H. and C. Gencoglan. 2001. Use of crop water stres index for scheduling irrigation in second crop corn. J. Agric. Fac. HR.U. 5: 67-75.

Nielsen, D.C. and B.R. Gardner. 1987. Scheduling irrigation for corn with the crop water stres index (CWSI). Appl. Agric. Res. 2: 295-300.

Nielsen, D.C. 1994. Non-water stressed baselines for sunflowers. Agric. Water Manag. 26:265-276

Orta, A.H., S. Sehirali, I. Baser, T. Erdem, Y. Erdem, O. Yorgancılar. 2002. Water-yield relation and water use efficiency of winter wheat in Western Turkey. Cer. Resear. Commun. 30**:** 367-374.

Odemıs, B. and R. Bastug. 1999. Assessing crop water stress and irrigation scheduling in cotton through use of infrared thermometry technique. Tr. J. of Agr. and Forestry. 23: 31-37.

Reginato, R.J. 1983. Field quantification of crop water stress. Trans. ASAE. 26: 772-775.

Steele, D.D., E.C. Stegman and B.L. Gregor. 1994. Field comparison of irrigation scheduling methods for corn. Trans. ASAE. 37**:** 1197-1203.

Wanjura, D.F., J.L. Hatfield and D.R. Upchurch. 1990. Crop water stress index relationship with crop productivity. Irrig. Sci. 11**:** 93-99.

Yazar, A., A.T. Howell, D.A. Dusek and K.S. Copeland. 1999. Evaluation of crop water stress index for LEPA irrigated corn. Irrig. Sci. 18: 171-180.