IRRIGATION SCHEDULING FOR WATERMELON WITH CROP WATER STRESS INDEX (CWSI)

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ABSTRACT

This study was designed to evaluate different threshold values of crop water stress index (CWSI) to schedule irrigation for watermelon (Citrullus vulgaris) grown with drip irrigation Irrigations were started when CWSI values reached to 0.2, 0.4, 0.6, 0.8 and 1.0 (non-irrigation). The CWSI values were computed from measurements of canopy temperature, air temperature and vapor pressure deficit. The total irrigations amount of 342, 280, 248 and 193 mm were applied to the 0.2, 0.4, 0.6 and 0.8 CWSI treatments, respectively. The maximum seasonal evapotranspiration (ET) as 412 mm was measured from 0.2 CWSI treatment. Irrigation levels significantly affected fruit yield. Although the highest fruit yield (76.3 t ha^{-1}) was obtained from the 0.2 CWSI treatment, the 0.4 and 0.6 of CWSI treatments were statistically in the same letter group with this treatment. Also, maximum water use efficiency (WUE) and irrigation water use efficiency (IWUE) were obtained from 0.6 of CWSI treatment as 22.1 and 13.3 kg m^{-3}, respectively. Therefore, based on these results, 0.6 of CWSI value should be used for irrigation time of watermelon under Tekirdag, Turkey conditions.

KEYWORDS: Watermelon; Crop water stress index (CWSI); Irrigation scheduling, Drip irrigation

1.INTRODUCTION

Irrigation scheduling is commonly defined as determining when to irrigate and how much water to apply. Successful irrigation depends upon understanding and utilizing irrigation scheduling principles to develop a management plan. Scheduling provides information managers can use to develop irrigation strategies for each field on the farm. Irrigation scheduling methods are based on two approaches: a) soil measurements, and b) crop monitoring (Hoffman et al., 1990). Irrigation scheduling based upon crop water status should be more advantageous since crops respond to both the soil and aerial environmental (Yazar et al., 1999).

The crop water stress index (CWSI), derived from canopy-air temperature differences (T_c-T_a) versus the air vapor pressure deficit (AVPD), was found to be a promising tool for quantifying crop water stress (Jackson et al., 1981; Idso and Reginato, 1982; Jackson, 1982). The calculation of CWSI based on Idso definition relies on two baselines: the non water stressed baseline (lower limit), which represents a fully watered crop, and the maximum stressed baseline (upper limit), which correspond to a non-transpiring crop (stomata fully closed) (Yuan et.al., 2004). The lower limit in the CWSI will change as a function of vapour pressure because at lower VPDs, moisture is removed from the crop at a lower rate, thus the magnitude of cooling is decreased. Idso (1982) demonstrated that the lower limit of the CWSI is a linear function of VPD for a number of crops and location (http://www.uswcl.ars.ag.gov/epd).

Many studies have been done on the determination of CWSI for different crops and locations (Jackson, 1982; Stark and Wright, 1985, Ben-Asher et al., 1992; Stegman and Soderlund, 1992; Fangmeir et al., 1989; Hutmacher et al., 1991; Nielsen, 1987, 1990, 1994; Gençoğlan and Yazar, 1999; Ödemiş and Baştuğ, 1999; Yazar et al., 1999; Irmak et al., 2000; Alderfasi and Nielsen, 2001; Orta et al., 2002; Colaizzi et al., 2003; Yuan et al., 2004). But, all these researchers and Orta et al. (2003) reported that the CWSI values could be used to measure crop water status and to improve irrigation scheduling. Orta et al. (2003), also defined the non-water stressed baseline equation (T_c-T_a =-1.2042 VPD + 0.4716) and stressed baseline value (3.4^{0}C) for watermelon in Tekirdag, Turkey condition and they reported that, based on these results, an average CWSI of about 0.41 before irrigation will produce maximum yield. However, they suggest that this CWSI value should not be used unless irrigation scheduling using several threshold CWSI values for watermelon is test.

The objectives of this study were to determine:

(1)If the CWSI can be used to schedule irrigations in watermelon,

(2)Water application variations and fruit yield with different threshold values of CWSI,

(3)Determine correlations between CWSI, available water in the active root zone and watermelon fruit yield,

(4)Evaluate water use and water use efficiency of watermelon in relation to the CWSI.

2. MATERIALS AND METHODS

This study was conducted during the 2003 growing season at the research field of the Viticultural Research Institute of Tekirdag, Turkey (40^{0}59`latitude, 27$^0$29` longitude and 4 m above sea level). The climate in this region is classified as semi–arid and the averages of annual temperature, relative humidity, wind speed, sunshine duration per day and total annual precipitation are 13.8^{0}C, 76%, 3.1 m/s, 6.5 h, 575.4 mm, respectively (Anonymous, 1974). The soil type in the plot area is clay–loam and the available water holding capacity within 0.90 m of the soil is about 175 mm. The electrical conductivity (EC) of irrigation water was 0.42 dS m^{-1} and the sodium absorption rate was 2.7. Additionally, some climatic factors in 2003 during the growing season are listed in Table 1.

Watermelon (Citrullus vulgaris, c.v. Crimson Sweet) was transplanted on the 14th May 2003 (DOY 134) and harvested during the 5th – 12th August 2003 (DOY 217 – 224).The experiment was arranged in a randomized block design with three replications. Each experimental plot took up an area of 24.0 m^2 (6.00 x 4.00 m) and included 20 plants with 1.20 x 1.00 m spacing. There was a gap of 3 m wide between the plots. The plots were irrigated by pressure compensating drippers. The dripper discharge was 4 l h^{-1} and dripper spacing was 0.50 m. The percentage of wetted area (P) that relates dripper spacing to lateral spacing was determined as 42 % according to the principles of Keller and Karmeli (1975).

The experiment included 5 treatments and crop water stress index (CWSI) value was used to initiate irrigation. In treatments S_1, S_2, S_3, S_4 and S_5, irrigation was approximately applied when the CWSI reached values of 0.2, 0.4, 0.6, 0.8 and 1.0 (non-irrigation), respectively. When the CWSI value for each treatment reached the treatment CWSI value, soil water level was brought to field capacity. The canopy temperature (T_c) was determined using a hand-held infrared thermometer (Raynger ST8 model, Raytek Corporation, Santa Cruz, CA) with a 3^0 field view and equipped with a 7–18 µm spectral band-pass filter. The infrared thermometer was operated with the emissivity adjustment set at 0.95. The IRT data collection was initiated on the 28th June (DOY 179) when

Table 1. Some climatic factors of region for the experimental year

Month	Average temperature (^{0}C)	Average relative humidity (%)	Average wind speed (m s^{-1})	Average sunshine duration (h)
May	17.9	76	2.0	9.5
June	23.0	70	2.3	10.9
July	24.8	70	2.6	10.7
August	25.2	69	2.6	11.0

Table 2. The irrigation and rainfall amounts (mm)

		Irrigation dates (DOY)											
Treatment		Before the CWSI measurements					After the CWSI measurements						
		139	148	163	170	178	182	184	185	190	196	201	Total
S_1		32	31	33	35	30	32	38	-	34	37	40	342
S_2		32	31	33	35	30	-	42	-	-	37	40	280
S_3		32	31	33	35	30	-	37	-	-	-	50	248
S_4		32	31	33	35	30	-	-	32	-	-	-	193
S_5		-	-	-	-	-	-	-	-	-	-	-	-
		Rainfall dates (DOY)											
141	145	146	147	155	163	176	186	187	217	219	220	221	Total
0.2	2.6	0.8	1.4	0.6	0.2	0.6	9.0	6.8	0.2	0.2	1.0	0.6	26.2

Table 3. The total amount of irrigation water, seasonal evapotranspiration, fruit yield, IWUE and WUE

Treatment	CWSI level	Irrigation water applied (mm)	Seasonal evapotranspiration (mm)	Fruit yield (t ha^{-1})	IWUE (kg m^{-3})	WUE (kg m^{-3})
S_1	0.2	342	412	76.3 a**	11.9 ^{ns}	18.5 ^{ns}
S_2	0.4	280	353	71.7 a	12.9	20.3
S_3	0.6	248	310	68.5 a	13.3	22.1
S_4	0.8	193	254	52.0 ab	8.5	20.5
S_5	1.0	-	167	35.5 b	-	21.3

** : Numbers followed by different letters indicate statistically significant differences between CWSI levels at the level of 1 % (Duncan's Multiple Range Test).
ns : Non- statistically significant

the percentage of plant cover was approximately 80 – 85% and crop water stress treatments were started. Before this date, irrigation was applied when approximately 50% of the available soil moisture was consumed in the 90 cm root zone. The foliage temperature was measured on four plants from four directions (east, west, north, south) at 0.50 m from the crop with oblique measurements at 20-30 degrees from the horizon to minimize soil background in the field of view and then averaged. The T_c measurements were made from 1100 to 1400 at hourly intervals under clear skies. The dry and wet bulb temperatures were measured with an aspirated psychrometer at a height of 2.0 m in the open area adjacent to the experimental plots. The mean T_a was determined from the average of the dry–bulb temperature readings during the measurement period. The mean VPD was computed as the average of the calculated instantaneous VPD using the corresponding instantaneous wet and dry–bulb temperatures and the standard pyschrometer equation (Allen et al., 1998) using a mean barometric pressure of 101.25 kPa .

The crop water stress index (CWSI) values were calculated using the procedures of Idso et al. (1981). Using the upper and lower limit estimates, a crop water stress index (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 is the air temperature (^{0}C), ll is the non- water stressed baseline (lower baseline) and ul is the non – transpiring upper baseline. The baseline equations for watermelon in the same climatic condition were defined by Orta et al., (2003) (Fig. 1). The upper limit (3.4^{0}C) and the lower baseline equation (T_c-T_a =-1.2042 VPD + 0.4716, R^2 = 0.52, S_{yx} = 0.57^{0}C, $P < 0.01$) in this figure were used for determination of the CWSI for each treatment.

Soil water level was monitored in each plot by neutron probe (CPN, 503 DR Hydroprobe) in each 0.30 m soil layer during the whole growing season. To do this, aluminum access tubes were installed to 120 cm soil depth. Although calibration equations were obtained for every 15 cm soil layers at the beginning of the growing season, one equation was used, because there were not statistically significant differences between them. The calibration equation for the neutron probe was PW = 76.506 CR – 25.969 ($R^2 = 0.85^{**}$, PW = volumetric soil water content, CR = count ratio) (Evett et al., 1993). Soil moisture content of the first 30 cm was measured by the gravimetric method since it was not possible to monitor by neutron probe. The amount of soil moisture in 0.90 m depth was used to initiate irrigation and the values within 1.20 m depth were used to obtain the evapotranspiration of the crop. Evapotranspiration was calculated using the soil water balance method (Heerman, 1985). The equation can be written as;

$$\mathrm{ET} = \mathrm{R} + \mathrm{I} - \mathrm{D} \pm \Delta\mathrm{W}$$

Where R is the amount of precipitation (mm), I is the irrigation water applied (mm), D is the drainage (mm) and ΔW is the 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, drainage was neglected.

Watermelon fruits were harvested at marketable maturity and were then counted, individually weighed and harvest plot yields calculated. The harvest area was 7.20 m^2 (3.60 x 2.00 m). Also, the parameters of fruit morphology (size, height and rind thickness) were measured. Two fruits were selected randomly for quality analysis from each replicate plot for all treatments on every harvest date. Those fruits were cut in half and a piece of the core was used for soluble solids determinations with a hand-held refractometer. Total sugar in watermelon juice was determined by the Lane-Eynon method and pH was determined with a pH meter (Anonymous 1989). Data were analyzed by analysis of variance.

Water use efficiency (WUE) for each treatment was calculated as total yield divided by seasonal evapotranspiration (ET). Irrigation water use efficiency (IWUE) was determined as (Zhang et.al., 1999);

$$\mathrm{IWUE} = \frac{(\mathrm{Y}_1 - \mathrm{Y}_{NI})}{\mathrm{I}}$$

Where, Y_1 is the total yield of irrigation treatments (t ha^{-1}), Y_{NI} is the total yield of non-irrigation treatment (t ha^{-1}) and I is the amount of irrigation water (mm).

3. RESULTS AND DISCUSSION

The irrigation dates, rainfall dates and the amount of irrigation water for each treatment are listed in Table 2. The same irrigation water amount was applied to stress treatments (except non-irrigation treatment) until beginning of the CWSI measurements. Irrigation application was finished on 20th July (DOY 201) in order not to reduce sugar content of the fruit in the ripening period. Irrigating with a higher CWSI resulted in lower seasonal irrigation and lower seasonal evapotranspiration (ET). The total irrigation numbers ranged from 6 to 10 according to stress treatment (Table 2). The amount of total irrigation water was 342, 280, 248 and 193 mm for the S_1, S_2, S_3 and S_4 treatments, respectively. The highest total irrigation water was applied to the lowest CWSI value treatment (S_1) with 10 irrigation applications. During the

Table 4. Yield, yield component and quality parameter analysis for watermelon with irrigation scheduled by CWSI

Treatment	CWSI level	Fruit weight (kg)	Fruit size (cm)	Fruit height (cm)	Rind thickness (cm)	Total soluble solids (%)	Total sugar (%)	pH
S_1	0.2	6.7 ns	71.0 ns	38.2 ns	1.9 ns	10.7 ns	10.5 ns	5.3 b **
S_2	0.4	6.0	72.4	37.8	2.0	10.8	10.6	5.5 a
S_3	0.6	6.3	70.2	37.3	2.2	10.8	10.6	5.4 ab
S_4	0.8	4.8	63.9	33.2	1.7	11.6	11.1	5.5 a
S_5	1.0	5.6	71.7	36.7	1.9	10.6	10.4	5.4 ab

** : Numbers followed by different letters indicate statistically significant differences between CWSI levels at the level of 1 % (Duncan's Multiple Range Test).
ns : Non- statistically significant

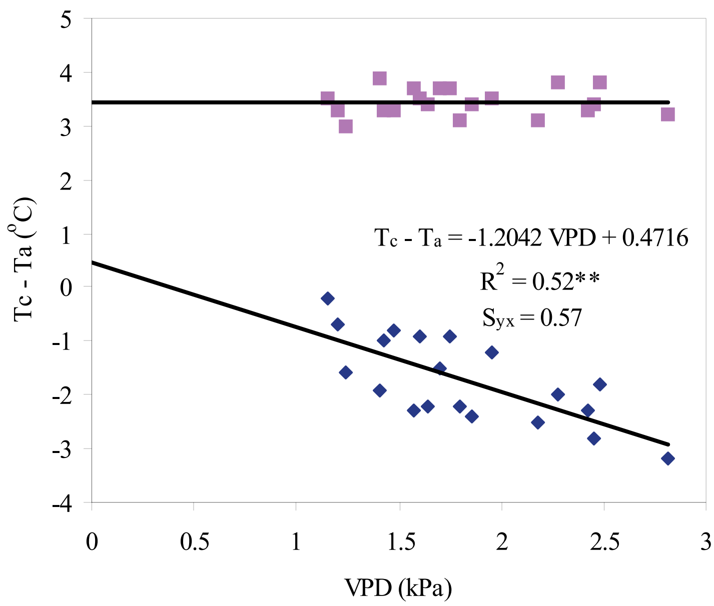

Figure 1. The upper and lower baselines for watermelon (Orta et.al., 2003)

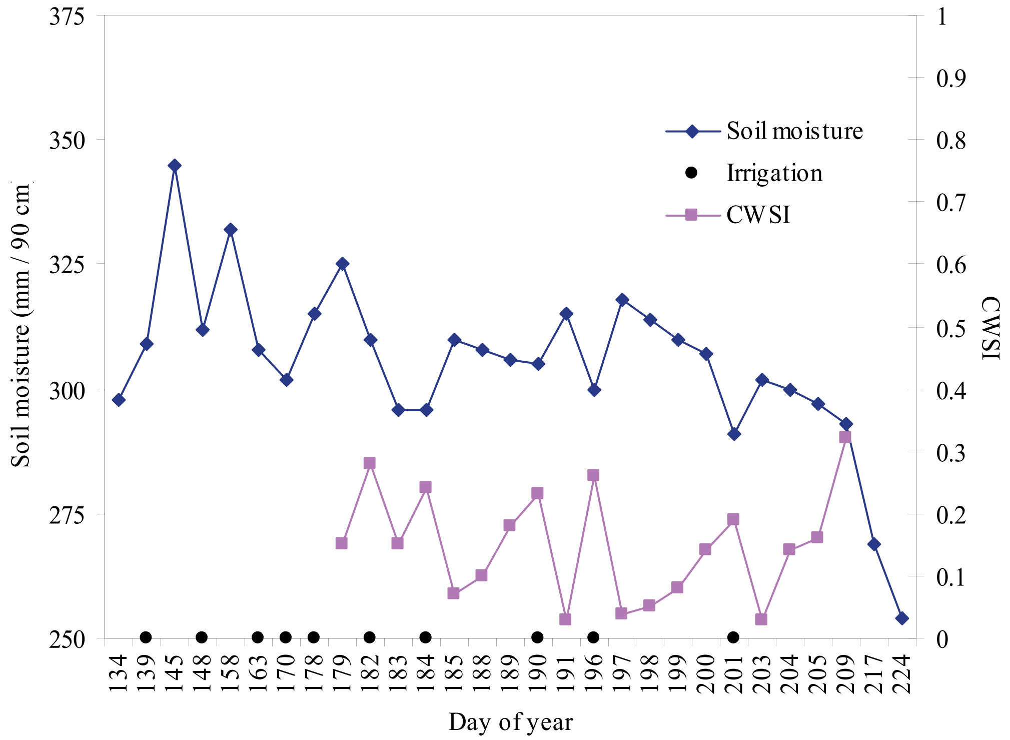

Figure 2. Seasonal trend of CWSI, soil moisture and times of irrigation for CWSI = 0.2

growing period, only 26.2 mm rainfall dropped and the experiment year can be classified as drought year. As seen in Table 3, S_1 treatment had the highest total ET, 412 mm and the other treatments underwent water deficits. The lowest ET occurred in treatment S_5 (non-irrigation treatment). Erdem and Yuksel (2003), also measured the seasonal ET as 363 mm in 1998 and 400 mm in 1999 for watermelon in Tekirdag, Turkey conditions.

The soil water content and CWSI values for each treatment are graphed in Figure 2 – 6. The T_c measurements were made from 1100 to 1400 at hourly intervals under clear skies. The CWSI values were calculated according to average of these temperatures and extreme values were eliminated. The graphs show that CWSI values increased with decreasing soil water content and these values decreased after irrigation. The CWSI values were generally between 0 and 1.0, with 0 being no water stress and value approaching 1.0 being water stress. For non- irrigation treatment (S_5), the CWSI values ranged from 0.48 to 0.85 during the measurement period and not increased to 1.0. This result can be explained that the crop adapted to water stress early under non-irrigation conditions. The CWSI value in the S_4 treatment only increased to 0.83 on DOY 185 and ranged from 0.16 to 0.72 for the other measurement times. When CWSI value of 0.6 was used (S_3), two irrigations were applied as 37 mm on DOY 184 and 50 mm on DOY 201 after CWSI measurements. For S_3 treatment, the CWSI values dropped to approximately 0.4 on DOY 184, 196 and 201 and generally CWSI value ranged from 0.02 to 0.44. Five irrigations were applied when CWSI value increased to 0.2 (S_1) and CWSI value decreased below this value. The soil water contents for each treatment were consistent with the CWSI values in that the highest stress level (non-irrigation treatment) had the largest soil water depletion levels and CWSI values, while lowest stress level (S_1) had the smallest soil water depletion and CWSI values. Soil water content within 90 cm depth gradually decreased towards the end of the growing season for each treatment. It remained higher in the lower stress treatment (S_1, S_2, S_3) than in the higher stress treatment (S_4 and S_5). The higher stress treatments resulted in soil water contents near the wilting point towards the end of the growing season.

Total fruit yields and quality parameters; namely, fruit

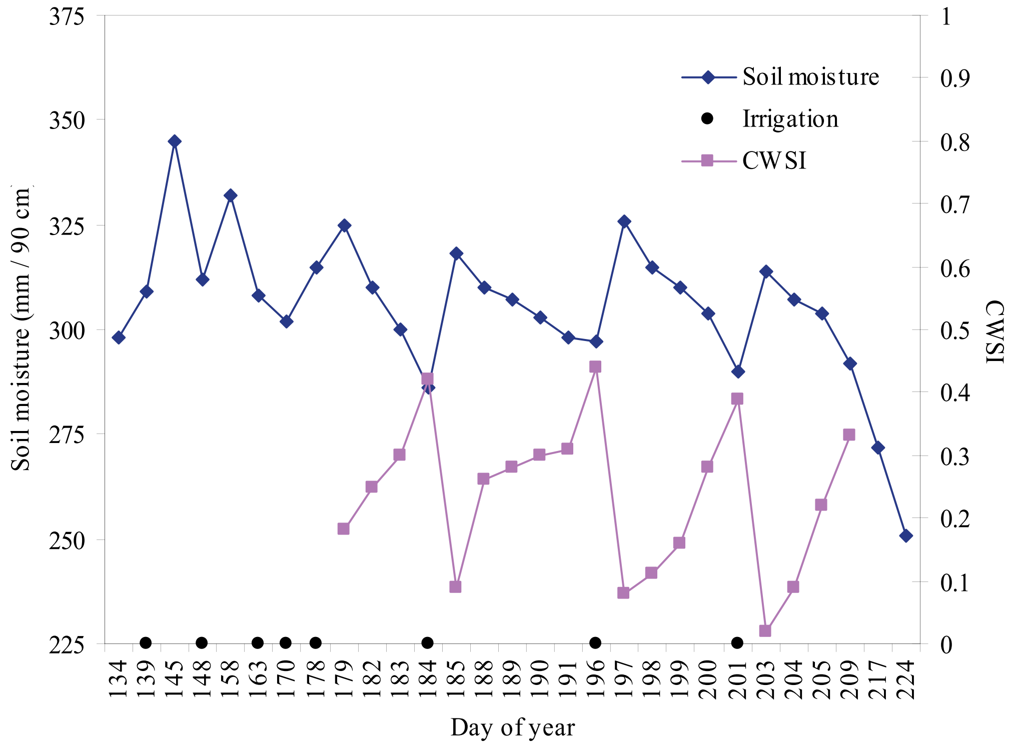

Figure 3. Seasonal trend of CWSI, soil moisture and times of irrigation for CWSI = 0.4

weight, fruit size, fruit height, rind thickness, total soluble solids, total sugar and pH obtained from each treatment are summarized in Table 3 and 4. The water stress level significantly affected fruit yield at the 0.01 confidence level according to an analysis of variance and the fruit yield ranged from 35.5 t ha^{-1} to 76.3 t ha^{-1}. The highest fruit yield was measured in the S_1 treatment with CWSI value of 0.2 while the lowest yield was obtained from S_5 treatment with no irrigation. As the amount of irrigation water decreased with increasing CWSI values, fruit yield decreased. Significant relationships were found between the fruit yield and irrigation water by the equation, $Y = -0.0012 I^2 + 0.8146 I - 59.371$ (R^2= 0.99, n=4 S_{yx}=1.19 t ha^{-1}, P <0.01) and between yield and water use by the equation, $Y = -0.0004 ET^2 + 0.4151 ET - 23.057$ (R^2= 0.99, n= 5 S_{yx}=2.75 t ha^{-1}, P <0.01) (Fig 7 and 8). The fruit yield decreased 6%, 10%, 32% and 53% for S_2, S_3, S_4 and S_5 treatments according to S_1, respectively. It was observed that ration of decreases in fruit yield for each percent of crop water stress was not constant. The highest watermelon yield in previous studies was also obtained when the irrigations were frequently (Srinivas et al., 1989, 1991; Lee et al., 1995; Pier and Doerge, 1995; Clark and Maynard, 1996; Senyigit, 1998, Erdem et al., 2001, Erdem and Yuksel, 2003). The other fruit and quality characteristics were not generally affected by water stress treatments while the influence of water stress on pH was significant at the 0.01 confidence level (Table 4).

Water use efficiency (WUE) and irrigation water use efficiency (IWUE) for each treatment are listed in Table 3. The effect of water stress on WUE and IWUE was not significantly differences. The highest WUE, averaging 22.1 kg m^{-3} was obtained from treatment of S_3 while the lowest WUE, averaging 18.5 kg m^{-3} was obtained from the lowest water stress treatment (S_1). IWUE ranged from 8.5 to 13.3 kg m^{-3} and it was highest for S_3 treatment same as WUE. The higher WUE and IWUE at the S_3 treatment can be explained that the fruit yield was obtained from this treatment very high and was statistically in the highest letter group (Table 2).

CONCLUSIONS

Researchers and producers using CWSI to quantify water

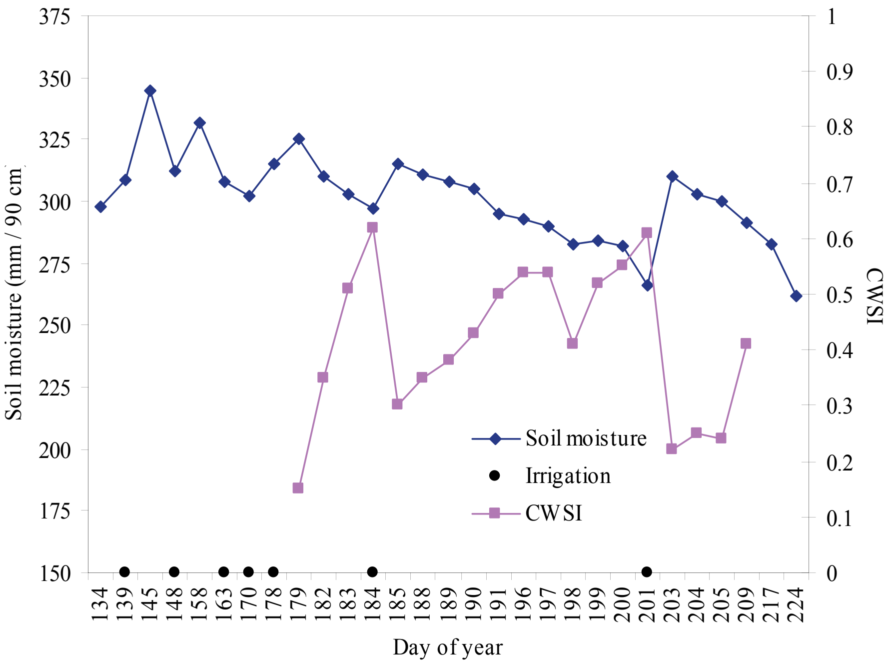

Figure 4. Seasonal trend of CWSI, soil moisture and times of irrigation for CWSI = 0.6

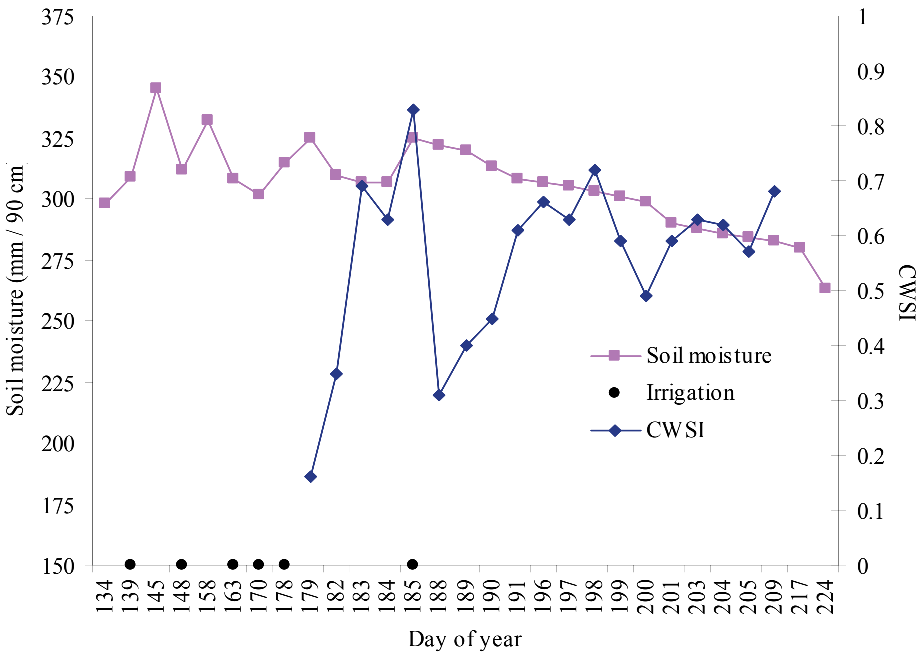

Figure 5. Seasonal trend of CWSI, soil moisture and times of irrigation for CWSI = 0.8

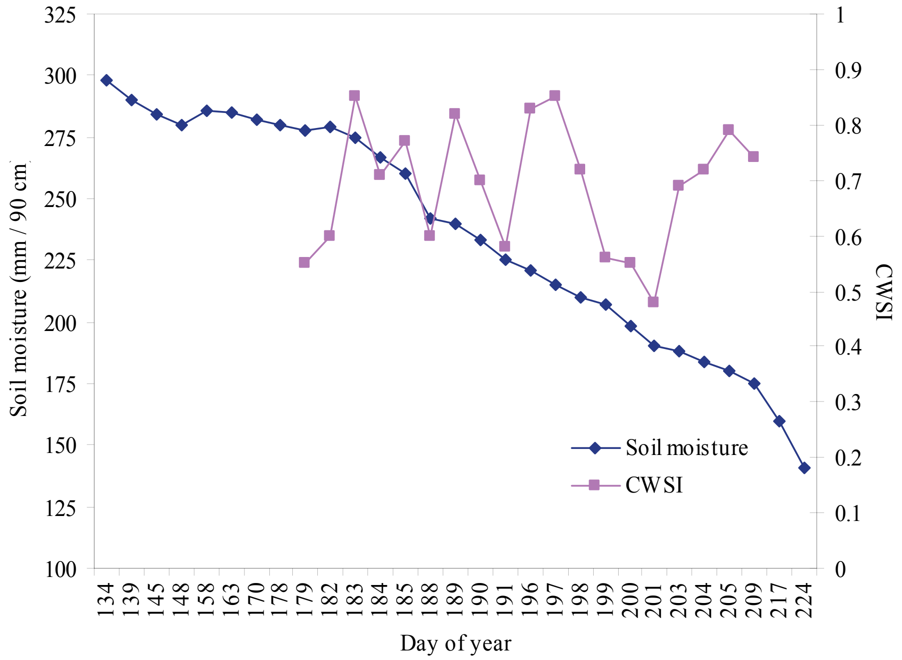

Figure 6. Seasonal trend of CWSI, soil moisture and times of irrigation for CWSI = 1.0 (non-irrigation treatment)

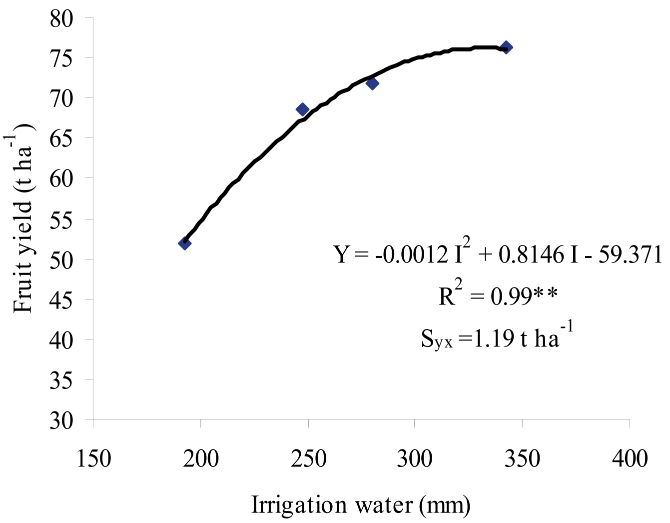

Figure 7. The relationship between fruit yield and irrigation water

stress and schedule irrigations should use preliminary studies to determine an appropriate non water-stressed baseline equation (Nielsen, 1990). In this research, the non-water stressed baseline determined as T_c-T_a =-1.2042 VPD + 0.4716 by Orta et al., (2003) for the same region and climatic conditions was used. Irrigations were applied when CWSI reached threshold values of 0.2, 0.4, 0.6 and 0.8. The CWSI values are only used for determining of irrigation time, but how much irrigation water to apply is not calculated. For this reason, soil water contents for each treatment was observed for calculating of irrigation water amount. Irrigation significantly increased crop water use and therefore fruit yield. The fruit yield was also directly correlated with CWSI values. The highest fruit yield (76.3 t ha^{-1}) was obtained from the lowest CWSI values (0.2). But, 0.4 and 0.6 CWSI treatments were statistically same letter group with 0.2 of CWSI. The differences for WUE and IWUE for were not statistically significant although 0.6 of CWSI treatment gave higher result. Therefore, based on this research, 0.6 of CWSI value should be used for irrigation time of watermelon under Tekirdag conditions. The fruit characteristics were not highly affected by irrigation treatments. This study has shown that the CWSI could be used to measure crop water status and to improve irrigation scheduling for watermelon.

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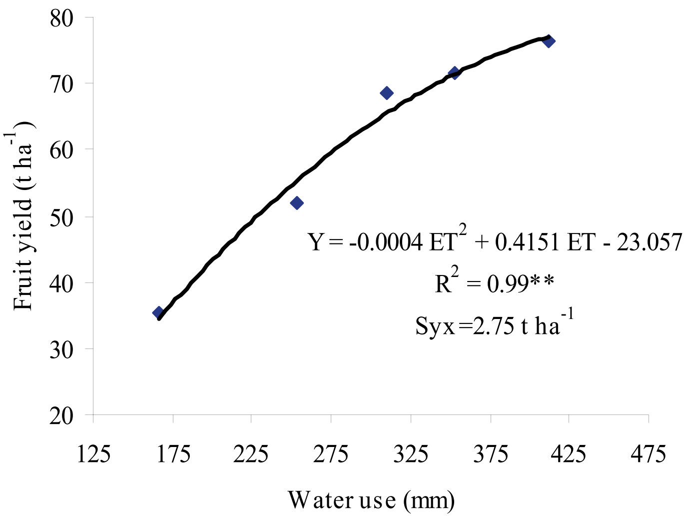

Figure 8. The relationship between fruit yield and seasonal water use

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