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İ Ç İ N D E K İ L E R / C O N T E N T S

Variations of Non-Water Stressed Baselines for Dwarf Cherry Trees Under Different Irrigation Regimes

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The experiment aimed at determining the non-water stressed baselines for dwarf cherry trees to quantify crop water stress index (CWSI). The trees were irrigated by drip irrigation and subjected to two irrigation regimes which irrigation was applied when 40 and 60% of the available water holding capacity was consumed, and five irrigation levels (100, 75, 50, 25 and 0% replenishment of soil water depleted). The non-water stressed baselines and stressed baselines were determined empirically from measurements of canopy temperatures, ambient air temperatures and vapor pressure deficit values and the crop water stress index (CWSI) was calculated. A small difference was found in the non-water stresses baselines. Trends in CWSI values were consistent with the soil water contents induced by the deficit irrigations. The seasonal mean CWSI values changed as 0,13 and 0,10 under full irrigation in 40% irrigation regime and also 0,17 and 0,10 in 60% irrigation regime for 2005 and 2006, respectively. The seasonal CWSI and mean CWSI values before irrigation were close to each irrigation regime.

Keywords: Crop water stress index (CWSI), drip irrigation, canopy temperature, vapor pressure deficit.

Farklı Sulama Programları Altında Bodur Kiraz Ağaçlarının Stressiz Temel Grafiklerinin Değişimleri

Araştırmada, bodur kiraz ağaçları için bitki su stres indeksinin (CWSI) hesaplanmasına kullanılacak stressiz koşullar için belirlenen alt baz eşitliklerinin eldesi amaçlanmıştır. Damla sulama yönteminin kullanıldığı araştırmada, deneme konuları; kullanılabilir su tutma kapasitesinin % 40 ve % 60' ı tüketildiğinde sulanmaya başlanması şeklinde iki farklı sulama programı ve bu koşullarda hesaplanan miktarının % 0, 25, 50, 75 ve 100' ünün uygulandığı beş farklı sulama seviyesinden oluşturulmuştur. Araştırmada, bitki sıcaklığı, hava sıcaklığı ve buhar basıncı açığı ölçümlerine göre elde edilen alt ve üst baz eşitliklerine göre bitki su stres indeksi değerleri hesaplanmıştır. Farklı deneme konuları ve yıllara göre elde edilen alt baz eşitliklerinde küçük farklılıklar elde edilmiştir. Ayrıca, CWSI değerlerinin değişimi toprak nem içeriğinin azalması ile paralellik göstermiştir. Mevsimlik CWSI değerleri, kullanılabilir su tutma kapasitesinin % 40' ı tüketildiğinde sulanmaya başlandığı deneme konusu için 2005 ve 2006 yılları için 0,13 ve 0,10 olarak elde edilirken, % 60 deneme konusu için sırasıyla 0,17 ve 0,10 olarak elde edilmiştir. Diğer yandan, her bir sulama seviye si için mevsimlik CWSI ile sulama öncesi CWSI değerleri paralellik göstermiştir.

Anahtar Kelimeler: Bitki su stres indeksi (CWSI), damla sulama, bitki tacı sıcaklığı, buhar basıncı açığı

Introduction

Irrigation scheduling methods are generally based on measurement of soil water content or meteorological parameters for modeling or computing evapotranspiration. 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). Most methods used to quantify crop stress under field conditions have relied on point measurements. In the last 15 years, researches using portable infrared thermometers to monitor water stress in the crops are becoming more popular (Erdem et al., 2010).

Plant stress associated with water deficits under field conditions has been quantified by using the crop water stress index (CWSI), defined by Idso et al. (1981), who developed empirical linear relationships for canopy-air temperature difference (T_c–T_a) versus vapor pressure deficit (VPD) of the atmosphere for a crop transpiring at its potential rate. The lower limit (T_c–T_a) versus VPD represents the measured temperature difference when the crop is well watered (no stress) and it is defined as non–water stressed baseline (NWSB). The upper limit (T_c–T_a) represents the temperature difference occurring when the crop transpiration rate approaches zero (maximum stress) (Jackson, 1982; Reginato, 1983; Stegman and Soderlund, 1992; Stockle and Dugas, 1992; Nielsen, 1994). Also, many studies have been done on the determination of CWSI for different crops and locations (Gardner et al., 1992; Hutmacher et al., 1991; Nielsen, 1994; Yazar et al., 1999; Irmak et al., 2000; Alderfasi and Nielsen, 2001; Orta et al., 2002, 2003; Colaizzi et al., 2003; Yuan et al., 2004; Erdem et al., 2005, 2006a, 2006b, 2010; Payero and Irmak, 2006; Emekli et al., 2007; Kar and Kumar, 2007, 2010; Gontia and Tiwari, 2008; Kırnak and Doğan, 2009).

A range of empirical studies also reported by Idso (1982) have shown that there may be different non—water stressed baselines for different crops and that ideally these need to be determined for each agro climatic zone in which crop is being grown. Nielsen (1994) reported that the effective use of CWSI to quantify water stress requires knowledge of non—water stressed baseline and the crop situations greatly affects the measured canopy temperature. Nielsen (1994) explained that non-water stressed baselines for sunflowers based on canopy temperature measurements were found to be affected by plant population only when leaf area index was less than about 2.0. Testi et al. (2008) undersigned that the non-water stressed baseline for pistachio trees showed a marked diurnal variation in the intercept, mainly explained by the variation in solar radiation. The NWSB was determined empirically for potato under three irrigation levels (irrigation was applied when 30, 50 and 70 % of the available water holding capacity was consumed) by Erdem et al. (2006a) and they explained that NWSB was affected by irrigation application time.

In recent years, both in Turkey and the world has begun to be able to see rapid development of fruit cultivation. This is because as a dwarf and semi-dwarf fruit trees other than trees to be taken early production and higher efficiency can be explained. Turkey cherry production has taken a very important role in the world production. The cherry production capacity is about 1.9 million t from 385000 ha in the world while Turkey's production is about 0.35 million t from 40000 ha (www.fao.org). The cherry trees are generally irrigated by pressurized irrigation system and irrigation schedule is important for cultivation under global warming conditions. This study was planned to develop baseline equations that can be used to calculate CWSI and to determine the variation in CWSI of dwarf cherry trees grown under different irrigation regimes.

Table 1. Some climatic data for the experimental years

Year	Month	T* ^{0}C	RH %	W m s^{-1}	n h	R mm
2005	March	7,0	78	2,9	4,2	57,4
	April	11,7	76	2,3	5,8	40,9
	May	16,6	75	2,2	7,6	38,2
	June	21,0	71	2,3	9,0	38,5
	July	23,5	68	2,6	9,8	22,6
	August	23,4	68	2,9	8,9	13,4
	September	19,8	72	2,7	7,5	30,5
	October	15,3	77	2,8	5,0	54,3
2006	March	8,0	87	2,5	4,9	101,6
	April	12,0	83	2,0	6,8	9,5
	May	17,3	81	2,2	9,3	14,1
	June	21,7	78	2,1	9,5	29,0
	July	24,0	75	3,0	10,0	4,0
	August	25,8	77	2,4	10,0	10,6
	September	20,3	84	2,5	6,5	108,9
	October	15,9	89	2,6	3,6	42,0
Long term	March	7,3	81	2,8	4,7	54,0
	April	11,7	76	2,3	5,8	40,9
	May	16,6	75	2,2	7,6	38,2
	June	21,0	71	2,3	9,1	38,5
	July	23,6	71	2,7	10,0	26,6
	August	23,4	72	2,6	9,3	20,2
	September	19,8	72	2,7	7,5	30,5
	October	15,3	77	2,8	5,1	54,3

* T: average temperature; RH: average relative humidity; W: average wind speed at 2 m; n: sunshine duration; E_p: class-A pan evaporation; R: rainfall.

Table 2. Some soil properties of the experimental site

Soil depth	pH	EC	Organic matter	Texture class	Field capacity	Wilting point	Bulk density
cm		ds m^{-1}	%		m^3m^{-3}	m^3m^{-3}	g cm^{-3}
0-30	7,8	0,7	1,87	CL	0,428	0,238	1,48
30-60	7,8	0,8	1,24	CL	0,433	0,245	1,51
60-90	7,8	0,6	1,45	CL	0,447	0,248	1,55

Materials and methods

Field experiments were conducted in 2005 and 2006 at the research field of the Viticultural Research Institute of Tekirdag in Turkey, (northwestern part of Turkey) at $40^0$59'N latitude, $27^0$29'E longitude and 10 m altitude. The research field is situated in a semi-arid climatic region. The averages of annual temperature, relative humidity, wind speed, sunshine duration and total precipitation are 13,8^{0}C, 75%, 2,8 m s^{-1}, 6,5 h and 580 mm, respectively. Additionally, the climatic factors for experimental periods recorded by an automatic weather station (Model "WS-STD 1, Delta- T. Devices, England) are given in Table 1.

The upper 90 cm soil profile could be classified as clay-loam. The bulk density varies from 1,48 to 1,55 g cm^{-3}. The available water holding capacity within 60 cm of the soil profile is 113 mm. There are no salinity and alkalinity problems. Some physical and chemical properties of the experimental field soil related to irrigation are shown in Table 2. Irrigation water quality is classified as C_2S_1 with 2,7 sodium absorption ratio (SAR) and 0,4 dS m^{-1} electrical conductivity (EC).

Trees of the cultivar 'Ziraat 900' on Mazzard root stock were planted in 2003 at spacing of 5,0 m x 2,5 m (800 trees/ha) in 2,5 ha field size. The experiment was arranged in randomized block design with three replications. The irrigation treatments were based on soil water replenishment. The experiments consisted of two irrigation regimes in the first years and five irrigation levels were added for second year. Irrigation was applied when 40 and 60% of available soil moisture was consumed in the 0,60 m root zone, and each irrigation regime was consisted of five irrigation levels, applied at a rate of 0, 25, 50, 75 and 100 of the soil water depletion. These treatments are summarized in Table 3.

The plots were irrigated by drip irrigation and irrigation water was taken by a pump from deep-well near the experiment site. The dripper discharge rate as 4 L h^{-1} and dripper spacing as 0,60 m were selected according to soil texture and infiltration rate (8,7 mm h^{-1}). The diameters of the PE lateral were 20 mm and each row trees was irrigated by two lateral lines. Thus, the percentage of the wetted area (P) that relates dripper spacing to row spacing was determined as 31% by the methods described by Yıldırım (2003) given below:

$$P = \mathrm{k}\frac{S_d}{S_S} \qquad 1$$

where P is the percentage of the wetted area (%), k is the coefficient (1,3 for heavy soil), S_d is the dripper spacing (m) and S_s is the row spacing (m).

Soil water was monitored in each plot using a neutron probe (CPN, 503 DR Hydroprobe, ICT International, Australia) for each 0,30 m soil layer during the whole growing season. The soil moisture content in the first 30 cm layer was measured by gravimetrically since it was not possible to monitor it with the neutron probe method (Evett et al., 1993).

The amount of soil water in the 0,60 m layer was used to initiate irrigation. Evapotranspiration (ET) for 10 day periods was calculated applying the water balance method to the upper 0,90 m soil layer (Allen et al., 1998). The equation can be written as:

$$ET = \mathrm{I} + \mathrm{P} - \mathrm{DP} - \mathrm{RO} \mp \Delta\mathrm{SW} \qquad 2$$

Table 3. The treatments applied for the experiment

Irrigation regimes (%)	Irrigation levels (%)				
	100	75	50	25	0
40	I_1	I_3	I_4	I_5	NI
60	I_2	I_6	I_7	I_8	NI

*Non-irrigated treatment.

where ET is the evapotranspiration (mm), I is the irrigation water (mm), P is the precipitation (mm), ΔSW is the change in the soil water storage in the 0,60 cm soil profile (mm), DP is the deep percolation (mm) and RO is the amount of runoff (mm). Since the amount of irrigation water was controlled, run off was assumed to be zero.

The canopy temperature (T_c) was determined using a hand-held infrared thermometer (Raynger ST8 model, Raytek Corporation, Santa Cruz, CA) with a 3° field of view and equipped with a 7–18 µm spectral band-pass filter. The infrared thermometer was operated with the emissivity adjustment set at 0,98. The IRT data collection was initiated on June 8 (DOY (Day of the year) 159) in 2005 and on May 27 (DOY 147) in 2006 and was finished on July 19 (DOY 200) in 2005 and on August 3 (DOY 215) in 2006. The canopy temperature was measured on four trees 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 the readings averaged. The T_c measurements were made from 11:00 to 14:00 h 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 were 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 for Tekirdağ.

The crop water stress index (CWSI) values were calculated using the procedures of Idso et al. (1981). In this approach, the measured crop canopy temperatures were scaled relative to the minimum canopy temperature expected under no water stress and the maximum temperature under severe water stress. The non-stressed baselines for the canopy-air temperature difference (T_c-T_a) versus VPD relationship were determined using data collected only in control treatments for I_1 and I_2 treatments. Infrared thermometer measurements were made one day after irrigation. The upper (fully stressed) baseline was computed according to the procedures explained by Idso et al. (1981). To verify the upper baselines, the canopy temperatures of the fully stressed plants (NI treatment) were determined on several occasions' times.

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

$$\text{CWSI} = \frac{\left[(T_c - T_a) - (T_c - T_a)_{ll}\right]}{\left[(T_c - T_a)_{ul} - (T_c - T_a)_{ll}\right]} \qquad 3$$

Where T_c is the canopy temperature (°C), T_a the air temperature (°C), ll is the non-water stressed baseline (lower baseline) and ul is the non – transpiring upper baseline.

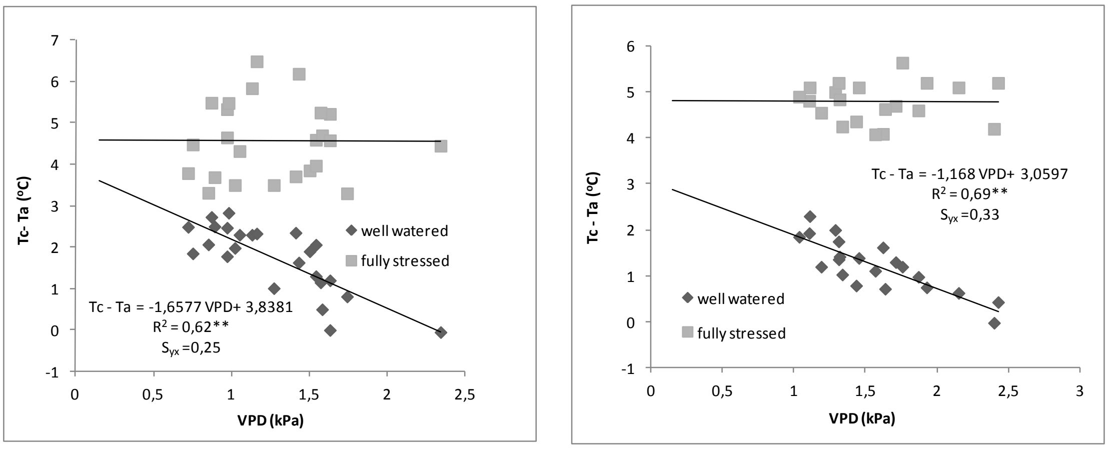
Results and discussions

The soil water measurements and irrigation applications were conducted from the June 6 (DOY 157) to the July 19 (DOY 200) in 2005 and from the May 27 (DOY 147) to the August 3 (DOY 215) in 2006. The 65 mm and 82 mm irrigation water with four applications was applied to I1 and I2 treatments in 2005 and the evapotranspiration was determines as 106 mm in I1, 135 mm in I2 and 68 mm in NI treatment for measurement interval. According to irrigation level degree, between 33 and 134 mm irrigation water with seven applications was applied and between 135 and 216 mm evapotranspiration was measured in 2006.

The fully stressed and non water stressed baselines shown in Figure 1 and 2 were derived from measurements for dwarf cherry trees for 2005 and 2006 years. The CWSI values were calculated between upper and lower baselines relating the difference between canopy (Tc) and air (Ta) temperatures (°C) to vapour pressure deficit (kPa) as given by Idso et al. (1981) and Irmak et al. (2000). Several factors such as errors in determining relative humidity, IRT calibration, IRT aiming or field of view and microclimate (like clouds or wind) can affect the baseline relation. The crop canopy temperature measurements were obtained from non-irrigated (NI) treatment for the fully stressed baselines. The average values of canopy temperatures obtained from these plots were computed and subtracted from the average air temperature values (Ta) and graphed against vapour pressure deficit (VPD). The Tc–Ta values for upper baseline were obtained as 4,6 0C (n=24) for 2005 and as 4,8 0C (n=21) for 2006. The non-water stressed treatments were used to determine lower baselines. The canopy temperatures (Tc) and vapour pressure deficits (VPD) were selected when days were clear; then, the differences between Tc- Ta were linearly correlated with VPD (Figure 1-2). The non-water stressed baselines were described by linear equations as Tc-Ta = -1,6577 VPD + 3,8381 (R2=0,62, n=24, Syx=0,25, p<0,01) for 2005 year and Tc-Ta = -1,168 VPD + 3,0597 (R2=0,69, n=24, Syx=0,33, p<0,01) for 2006 year under the 40% irrigation regime. Although, this baselines were determined as Tc-Ta = -1,4807 VPD + 3,814 (R2=0,73, n=21, Syx=0,30, p<0,01) for 2005 year and Tc-Ta = -0,8978 VPD + 2,5011 (R2=0,79, n=21, Syx=0,19, p<0,01) for 2006 year under the 60 % irrigation regime. There was a small difference in the non-water stressed baselines slope and intercept between the irrigation regimes.

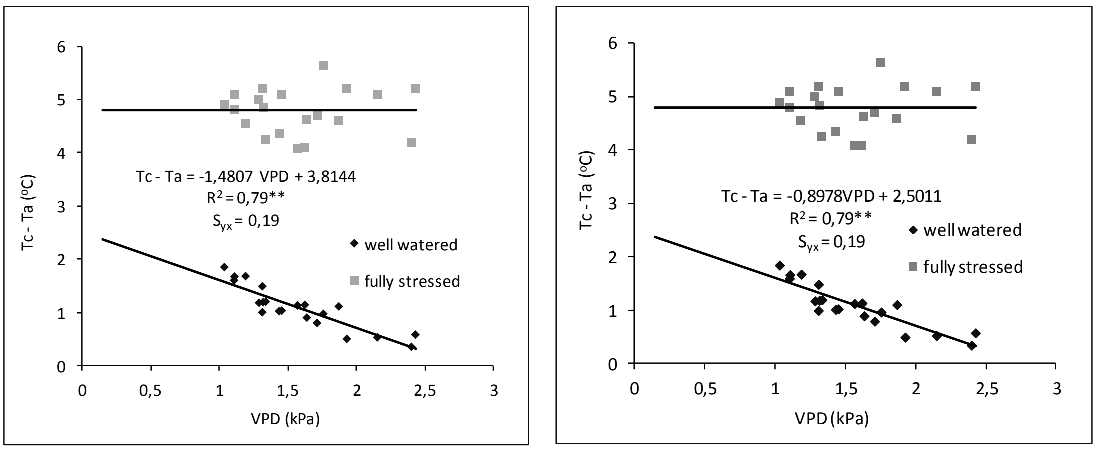
The variations in crop water stress index (CWSI) based on the Idso empricial model (Idso et al., 1981) under two different irrigation regimes for two years are shown in Figures 3 and 5.

Because of the inadequate water resources in 2005, two different irrigation treatments were only created for 2005 year. Otherwise, in the 2006 years, the CWSI variations were evaluated under different five irrigation levels. Generally, the values of CWSI increased with increasing water stress. Following irrigation, water stress was usually relieved and CWSI declined accordingly, 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. Idso et al. (1981) and Gardner and Shock (1989) reported that the CWSI values theoretically change between 0 and 1.



a)2005 b)2006

Figure 1. Canopy –air temperature (Tc-Ta) versus air vapour pressure deficit (VPD) for well watered and fully stressed dwarf cherry trees irrigated with 40% irrigation regime



a)2005 b)2006

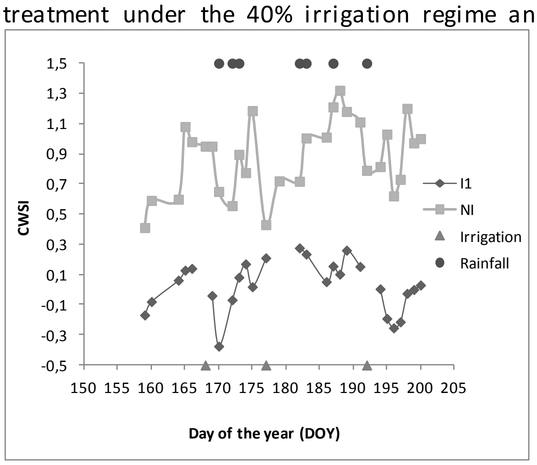
Figure 2. Canopy –air temperature (T_c-T_a) versus air vapour pressure deficit (VPD) for well watered and fully stressed dwarf cherry trees irrigated with 60% irrigation regime

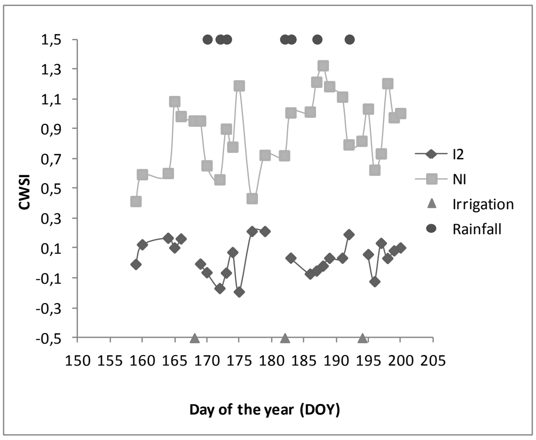
Table 4. Seasonal mean CWSI, mean CWSI before irrigation times for different irrigation treatments

Year	Treatment	Seasonal CWSI	Mean CWSI before irrigation times
2005	I_1	0,13	0,17
	I_2	0,11	0,19
	NI	0,74	-
2006	I_1	0,10	0,11
	I_2	0,10	0,12
	I_3	0,20	0,23
	I_4	0,27	0,28
	I_5	0,30	0,38
	I_6	0,16	0,17
	I_7	0,22	0,26
	I_8	0,25	0,28
	NI	0,87	-

On the other hand, Alderfasi and Nielsen (2001) underlined that obtained values might be out of this ranges in practice because of the measurement and calculation errors. For this reason, the seasonal CWSI values were evaluated in the range of 0-1 while the figures were graphed according to measurement values in this study. The CWSI values ranged from 0,41 to 1,32 in NI treatment, from – 0,38 to 0,28 in I1 treatment and from -0,20 to 0,21 in I2 treatment for 2005, from 0,75 to 1,19 in NI treatment, from – 0,14 to 0,14 in I1 treatment, from -0,05 to 0,10 in I2 treatment, from – 0,13 to 0,39 in I3 treatment, from -0,11 to 0,47 in I4 treatment, from – 0,02 to 0,59 in I5 treatment, from -0,04 to 0,29 in I6 treatment, from –0,12 to 0,45 in I7 treatment and from 0 to 0,54 in I8 treatment for 2006. The seasonal CWSI values for each irrigation level, calculated as the average of all measurement periods, were 0,13 in I1 and 0,74 in NI treatment under the 40% irrigation regime, 0,17 in I2 and 0,74 in NI treatments under the 60% irrigation regime for 2005. Also, these values were 0,10 in I1, 0,20 in I3, 0,27 in I4, 0,30 in I5 and 0,87 in NI treatment under the 40% irrigation regime and 0,10 in I2, 0,16 in I6, 0,22 in I7, 0,25 in I8 and 0,.87 in NI treatment under the 60% irrigation regime for 2006. As seen, the lower CWSI values were observed with non-deficit irrigation treatments (I1 and I2). The CWSI values before irrigation applications were measured as an average of 0,17 in I1, 0,19 in I2 for 2005 and 0,11 in I1, 0,12 in I2, 0,23 in I3, 0,28 in I4, 0,38 in I5, 0,17 in I6, 0,26 in I7 and 0,28 in I8 for 2006 (Table 4). The seasonal CWSI and mean CWSI values before irrigation were close to each irrigation regime.

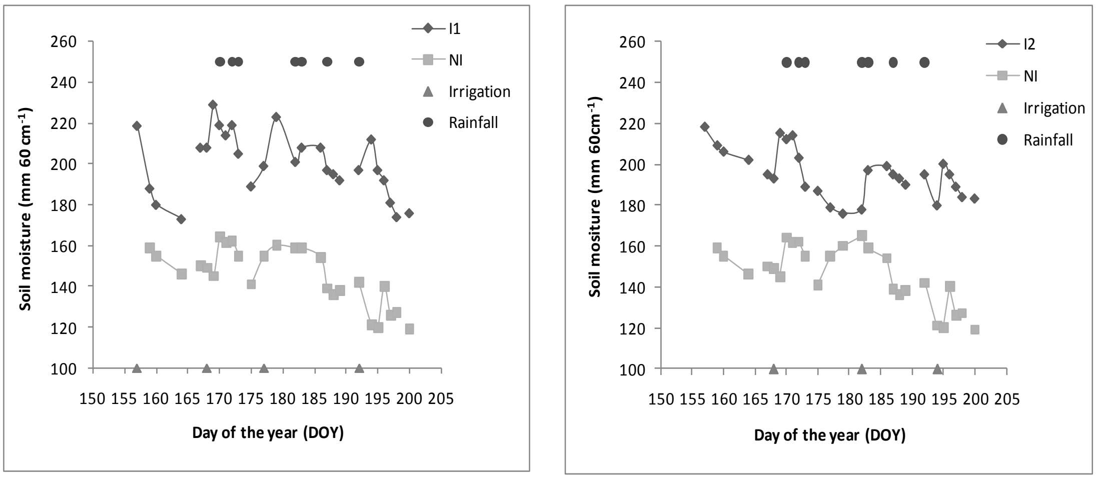
The variations in soil water content are shown in Figures 4–6. The soil water content was consistent with the CWSI values in that the lowest irrigation level (non-irrigation treatment) had the largest soil water depletion levels and CWSI values, while higher irrigation levels had the smallest soil water depletion levels and CWSI values. The optimum yield was not obtained from cherry trees since they were under the age of 3 years. For this reason, in this research, the relationships between yield and CWSI were not evaluated.





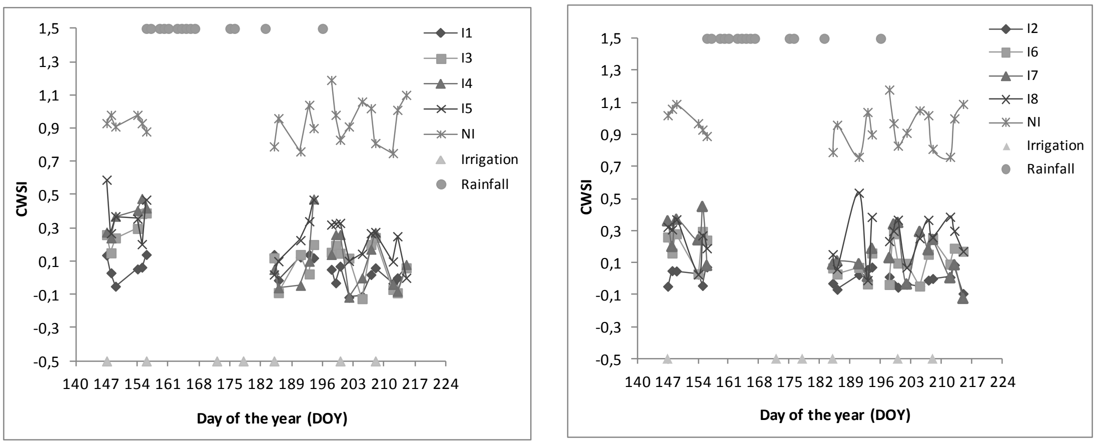
40% irrigation regime b) 60% irrigation regime

Figure 3. Variation of crop water stress index (CWSI) for treatment, 2005



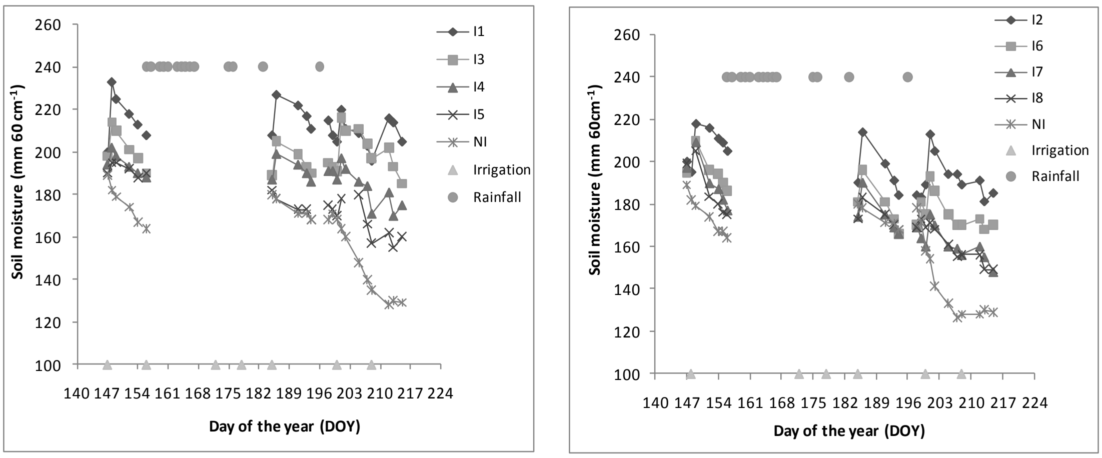
40% irrigation regime b) 60% irrigation regime

Figure 4. Variation of soil moisture for treatment, 2005



40% irrigation regime b) 60% irrigation regime

Figure 5. Variation of crop water stress index (CWSI) for treatment, 2006



40% irrigation regime b) 60% irrigation regime

Figure 6. Variation of soil moisture for treatment, 2006

Conclusions

Infrared thermometry and the CWSI are valuable tools for monitoring and quantifying water stress and irrigation scheduling. The non-water stressed baselines and CWSI values determined during this study in the years of 2005 and 2006 under different irrigation regimes were slightly different. Therefore, different non-water stressed baselines should be used for dwarf cherry trees under different irrigation regimes. The seasonal CWSI values were generally changed as between 0,10 and 0,30 except non-irrigation treatment. However, we can not conclude that this CWSI values should be used for timing of irrigation for dwarf cherry trees since we did not determine CWSI-yield relation.

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