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Evaluation of Crop Water Stress Index (CWSI) for Eggplant under Varying Irrigation Regimes Using Surface and Subsurface Drip Systems

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Abstract

The main objective of this research is to evaluate crop water stress index (CWSI) on eggplant under various irrigation regimes applied with subsurface and surface drip systems in the Eastern Mediterranean Region of Turkey. The field experiments were carried out during the eggplant season of 2013, in the experimental fields of Soil and Water Resources Research Unit in Tarsus. In the study, two irrigation systems (surface drip (DI) and subsurface drip systems (SDI)) in main plots; two irrigation intervals in sub-plots (IF_3: 3-day; IF_6: 6-day) and four irrigation levels in sub-sub plots (Full irrigation, FI; deficit irrigation, DI-50; deficit irrigation, DI-75; and Partial Root-zone drying PRD-50% of full irrigation treatments) were tested in split-split plot design with four replications. Canopy temperatures were measured throughout the growing season with an infrared thermometer (IRT), and vapor deficit of air (VPD) was used for calculating empirical the CWSI. The effect of irrigation treatments on yield, crop growth and juice quality differed. Irrigation methods, irrigation intervals and irrigation levels resulted in significantly different yields. Surface drip performance was superior to subsurface drip considering yield and quality of eggplants. Full irrigation treatment with 3-day interval under the surface drip (IF_3 FI) produced the highest yield (78.7 t ha^{-1}), the lowest yield was obtained in subsurface drip IF_6 PRD-50 treatment plots (40.9 t ha^{-1}). The highest water use efficiency (WUE) was found in subsurface drip IF_6 DI-50 (21.9 kg m^{-3}) and the lowest in subsurface drip IF_6 PRD-50 (12.2 kg m^{-3}). The results revealed that eggplant should be irrigated at CWSI values between 0.18-0.20 for high and good quality yields. CWSI can be used for irrigation scheduling for eggplant.

Keywords: Eggplant, surface drip, subsurface drip, crop water stress index (CWSI), deficit irrigation.

1. Introduction

Rapid increase of world population, pollution of natural resources, global warming and climate change nowadays

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increases the pressure on limited water resources. Food and water demand also increase in parallel to world population increase. Therefore the efficient utilization of limited available fresh water resources in irrigated agriculture necessitates the use pressurized irrigation systems for increasing yield and quality. Surface drip (DI) and subsurface drip irrigation (SDI) is most effective way to convey directly water and nutrients to plants and not only, does it save water but it also increases yields of vegetable crops (Tiwari et al., 1998; Tiwari et al., 2003). A properly managed SDI system wets the root zone uniformly throughout the field, while maintaining a dry soil surface; water losses due to evaporation and consequent growth of weeds are therefore reduced and deep percolation eliminated. All these benefits can potentially contribute to increase water use efficiency, with important implications for the agricultural sustainability and for soil and water conservation (Provenzano, 2007; Douh and Boujelben, 2010). Deficit irrigation and partial root-zone drying (PRD), are the water management techniques in which applying less irrigation water than required allows larger irrigation areas with the available water resources. The effect of deficit irrigation on growth and yield of many vegetable and field crops are well documented (English, 1990; Pereira et al. 2002; Karam et al. 2006; Fereres and Soriano, 2007). Kırnak et al. (2002) and Chaves et al. (2003) reported reductions in eggplant fresh yield in response to water stress. Lovelli et al. (2007) demonstrated that the sensitivity to water stress of eggplants was expressed in high marketable yield decrements and a drop in water productivity.

Turkey is in the third place with 880 000 metric tons among the eggplant producing countries and produces 3% of the world production (TUİK, 2010). Although eggplant production is realized in all the geographical regions in Turkey, the most eggplant production with 392 000 tons is in the Mediterranean region, which provides 42% of total production.

Irrigation scheduling is 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 environment (evaporative demand) (Yazar et al. 1999). The behavior of plant canopy temperature (Tc) both under stress and non-stress conditions provides signs of crop water status and yield performance during drought conditions. This is based on the fact that transpirational cooling reduces leaf temperature relative to air temperature; the reduction being greater at relatively high vapor pressure deficit (VPD) values compared to low VPD values. Leaf temperature increases when the supply of water to a plant limits transpiration and when radiant energy is not dissipated via evaporation (Jackson et al. 1981; Idso, 1982). Canopy surface temperature measured with infrared thermometers (IRT) or other remote infrared sensors provides an important tool to detect water stress in a crop, which has been in practice for some decades. The crop water stress index (CWSI) is the most frequently used index to quantify crop water stress based on canopy surface temperature. Idso et al. (1981) presented an empirical approach to quantify stress by determining the “non-water-stressed baselines” for crops. They developed linear relationships for canopy–air temperature difference (Tc–Ta) versus VPD. Research has been conducted to evaluate the application of the CWSI in irrigation scheduling for different crops in different places (Alderfasi and Nielsen, 2001; Orta et al. 2002; Cremona et al. 2004; Erdem et al. 2006a,b, 2010; Yazar et al., 2010; Aladenola and Madramootoo, 2012; Sezen et al. 2014). However, little research has been done to evaluate the CWSI for horticultural crops in Turkey, especially the East Mediterranean part where crop water stress is frequent and pervasive.

The objectives of the present study were to: (i) evaluate CWSI for differentially irrigated eggplant (*Solanum melongema* L.) grown in the Mediterranean region of Turkey; (ii) determine the effect of water stress occurring during the growing season on yield and water use efficiency of field grown eggplant irrigated by a surface drip and subsurface drip irrigation system; (iii) compare deficit irrigation (DI) and partial root drying (PRD) for their effects on water relations, growth, yield of eggplant.

2. Material and Method

2.1. Experimental site and soil description

The field experiment was conducted at the Tarsus Soil and Water Resources Unit of Horticultural Research Station (36°53' N and 34°57' E, altitude 60.0 m above sea level), in Tarsus, Turkey. Long-term mean monthly (1950–2012) and 2013 growing season’ climatic data of the experimental area are presented in Table. 1. A typical Mediterranean climate prevails in the experimental area. The average annual rainfall is 616.3 mm but approximately 54% of total rainfall concentrated from November to May. Annual evaporation is 1487 mm, average annual temperature is 17.8°C and annual humidity is 70.6%. The rainfall received in the growing season (May through

August) was 88.6 mm, which was 14.4% of the long-term mean rainfall. The soil of the experimental site is classified as clayey-silt. Some physical and chemical properties of the experimental soil are given in Table 2. Available water in the upper 0.60 m of the soil profile depth is 88 mm. In the root zone, soil water contents at the field capacity and permanent wilting point are 245 and 157 mm, respectively. Mean bulk density varies from 1.30 to 1.45 g cm^{-3}. Water is obtained from an open well irrigation system in the experimental area, where pH was 7.98–8.18, and the average electrical conductivity values were 0.91-1.03 dS m^{-1} for the experimental year.

Table 1. Historical monthly and 2013 growing season climatic data of experimental area

Experimental years	Months	May	June	July	August
2013	Tmax (°C)	35.2	34.1	33.9	35.4
	Tmin (°C)	13.3	15.0	17.9	19.5
	Tmean(°C)	22.4	24.4	26.8	27.8
	Rainfall(mm)	60.0	0.6	28	0
	Evaporation (mm)	153.4	174.3	193.7	192.4
	RH (%)	70.0	70.7	69.9	69.0
Longterm (1950-2012)	Tmean(°C)	20.8	24.5	26.8	27.1
	Rainfall(mm)	29.6	10.7	3.3	2.1
	Evaporation (mm)	168.3	200.6	217.7	197.9
	RH (%)	71	71.9	75.5	75.3

Tmax: maximum air temperature; Tmin: minimum air temperature; Tmean: mean air temperature; RH: relative humidity

2.2. Experimental design

The experimental design was two irrigation systems (surface drip and subsurface drip systems) in main plots; two irrigation intervals in sub-plots (IF_3: 3-day; IF_6: 6-day) and four irrigation levels in sub-sub plots (Full irrigation, FI; deficit irrigation, DI-50; deficit irrigation, DI-75; and Partial Root-zone drying PRD-50% of full irrigation treatments) were tested in split-split plot design with four replications. Irrigation was applied at two irrigation intervals; soil water deficit in a 60 cm soil depth was refilled to field capacity in full irrigation treatment (FI); DI-50 and DI-75, respectively received 50 and 75% of water applied to (FI). In PRD-50 irrigated alternately and received 50% of water applied to (FI). Each subplot had a length of 10 m and 5.4 rows in width. A totalizing flow meter was installed at the control unit to measure total flow distributed to all replications in each treatment.

In drip irrigated plots, laterals were laid in each plant row for FI, DI-75, DI-50 treatments, and inline emitters with discharge rate of 1.6 l h^{-1} were spaced at 20 cm intervals on the lateral line (Betaplast Corp., Adana, Turkey). In the PRD-50 treatment plots, two drip laterals were laid out 45 cm away from the plant row. The system was operated at 100 kPa throughout the growing season. Subsurface drip irrigation system laterals were placed under 25 cm of the soil surface. In subsurface drip irrigated plots, inline emitters with discharge rate of 2.3 l h^{-1} spaced at 30 cm intervals on the lateral line were used.

The amount of irrigation water was calculated based on the pre-irrigation soil water content (SWC) in 60 cm soil depth according to the following equation (Eq. (1)):

$$I = (FC - SWC)\ A\ P \qquad (1)$$

Where I is the amount of irrigation water (l); FC is the soil water content at field capacity (mm); SWC is pre-irrigation soil water content (mm), P is the wetting percentage (%), and A is the surface area of the plot (m^2).

2.3. Agronomic Practices

Seedlings of 21 days old of Anamur Karası, a variety widely used in the region, were transplanted into the plots at a row spacing of 90 cm and in-row spacing of 70 on 6 May 2013. All plots received 50 N; 50 P_2O_5; and 50 kg ha^{-1} K as compound fertilizer at planting. Three weeks after transplanting, plots stated to receive N through fertigation at every 6-day irrigation interval (160 kg ha^{-1} N) throughout the growing season. To set constant fertilizer dose, a fertigation injection pump (Digital dose pump or dosing pump) was used.

2.4 Measurements

Soil water content was measured at 0.2 m increments down to 0.9 m, using a neutron probe (Model 503 DR, Campbell Pacific Nuclear, Martinez, CA) before irrigation throughout the growing season. The access tubes were installed in the center of the plant bed in the experimental sub-plots. The surface soil layer (0–20 cm) was sampled gravimetrically.

Crop water use or evapotranspiration (ET) was calculated with the water balance equation Eq. (2).

$$ET = I + P \pm \Delta SW - Dp - Roff \tag{2}$$

Where ET is evapotranspiration (mm); I, the amount of irrigation water applied (mm); P, the precipitation (mm); ΔSW, the change in the soil water content (mm); Dp, the deep percolation (mm); and Roff is amount of runoff (mm). Since the amount of irrigation water was controlled, Dp and Roff were assumed to be negligible.

Water use efficiency (WUE) and irrigation water use efficiency (IWUE) were calculated as fresh eggplant yield divided by seasonal ET and total seasonal irrigation water applied, respectively (Howell et al., 1990).

Canopy temperatures (Tc) were measured with a hand-held infrared thermometer (IRT) (Everest model 110), which has a field of view of 3^{o} and detects radiation in the 8–14 μ waveband. IRT readings were taken at a horizontal angle of 30–40^{o} in order to have only crop canopy in view area. Data collection for Tc was initiated at the middle of June in the experimental year when the plant cover percentage was nearly 85–90%. Canopy temperatures were measured from four different corners of the plots at 1 m distance from the canopy and averaged to determine the plot's canopy temperature. Tc measurements were made between 12:00 and 14:00 h (local standard time) under clear skies when the sun was unobscured by clouds. Dry and wet bulb temperatures were measured with an aspirated psychrometer (Assmann Psychrometer, Sato Keiryoki MFG. Co., Ltd, Japan) at a height of 1.5 m in the open area adjacent to the experimental plots. The mean VPD was computed as the average of the calculated instantaneous wet and dry bulb temperatures and the standard psychrometer equation (List, 1971) with a mean barometric pressure of 101.25 kPa. The CWSI was calculated based on empirical equation suggested by Idso et al. (1981) (Eq. (3)):

$$CWSI = \frac{(Tc-Ta)-(Tc-Ta)_{UL}}{(Tc-Ta)_{UL}-(Tc-Ta)_{LL}} \tag{3}$$

Where LL represents the non-water-stressed baseline (lower base-line) and UL represents the non-transpiring upper baseline; Tc = canopy temperature (^{o}C); Ta = air temperature (^{o}C). LL for the canopy–air temperature difference (Tc–Ta) versus the vapor pressure deficit (VPD) relationship was determined using data collected only from the unstressed treatments (FI). UL was computed according to the procedures explained by Idso et al. (1981). To verify the upper baseline, canopy temperatures of the fully stressed plants were determined several times during the growing season of eggplant.

Occurrence of the different growth stages and picking time were recorded as number of days after transplanting (DAT). Dates of occurrence of growth stages in FI treatment were given in Table 3. The total length of the growing season of eggplant was 91days growing season. There was no difference among the plants in each treatment until the vegetative stage. After the vegetative stage, the occurrence of flowering and first fruit set stages of eggplant were observed at a later date in the deficit irrigation treatments compared to unstressed treatments (FI).

Yield was determined by hand picking the 8 m sections of the four adjacent center rows in each plot depending on the physiological maturity of plants. The harvest area in each sub-plot was 28.8 m^{2} (four rows, each 8 m long). In order to determine total dry matter above the ground level, all plants within 2.1 m of a row section in each plot were cut from the ground level at 14-day intervals until harvest. All plant samples were dried at 65^{o}C until constant weight was achieved. Yield quality parameters, such as yields, yield per plant, fruit weight, length and width, and total soluble solid of fruit were determined in each picking period.

Leaf area index (LAI) measurements were made regularly throughout the growing season on five randomly selected plants per treatment using the "LAI-2000 Plant Canopy Analyzer" (Li-Cor 2000).

Table2. Physical and chemical properties of different soil layers of the experimental field

Soil depth	Sand	Silt	Clay	Texture class	FC* g g^{-1}	WP* g g^{-1}	BD* g cm^{-3}	EC dS m^{-1}	pH	$CaCO_3$ (%)	P_2O_5	K2O	OM*
0-20	20.2	41.9	37.9	C	29.92	19.14	1.30		7.91	21.78	1.9	134.32	1.80
20-40	15.9	42.0	42.1	SC	29.77	18.95	1.40	0.017	7.97	28.30	0.9	68.49	1.06
40-60	11.7	44.1	44.3	SC	29.64	19.09	1.42	0.015	8.08	24.80	0.5	43.01	0.77
60-90	11.1	42.2	46.7	SC	29.40	19.71	1.45	0.015	8.11	31.64	0.5	38.51	0.63

*FC: field capacity; *WP: permanent wilting point; *BD: bulk density; *OM: Organic matter

Table3. Growth stages of eggplant in the full irrigation treatments in the experimental year

Growth stages of eggplant	Experimental years (2013)			
	DI IF_3	DI IF_6	SDI IF_3	SDI IF_6
Transplanting	May 6	May 6	May 6	May 6
Vegetative	May 24	May 27	May 25	May 29
First flowering	June 3	June 5	June 3	June 7
Fruit setting	June 13	June 15	June 14	June 15
First picking	June 27	June 27	June 27	June 27
Last picking	Agust 5	Agust 5	Agust 5	Agust 5

3. Result and discussion

3.1. Fresh yield and quality

Data on the yield of eggplant and quality parameters such as yield per plant, total soluble solid, fruit length and width are presented in Table 4. The effect of irrigation treatments on yield, crop growth and juice quality differed. Irrigation methods, intervals and levels resulted in significantly different yields ($P < 0.01$). Surface drip performance was superior to subsurface drip considering yield of eggplants. Yield values ranged from 40880 kg ha^{-1} in SDI IF_6 PRD-50 to 78660 kg ha^{-1} in the DI IF_3 FI treatments. The FI treatments with 3-day irrigation intervals in both irrigation systems resulted in significantly higher yields. Water stress reduced eggplant yield significantly. In general, as the amount of irrigation water applied decreased, yield decreased. Irrigation levels had a significantly different effect on quality parameters in the treatments. Maximum yield per plant, fruit weight, length and width was obtained from the IF1FI surface drip system plots. Irrigation methods, intervals and levels resulted in significantly different yield per plant, fruit weight. Surface drip performance was superior to subsurface drip considering quality of eggplants.

There was difference in total soluble solid of fruit (TSS) among the treatments. Irrigation methods x irrigation intervals x irrigation levels interaction resulted in significantly different TSS of fruit ($P < 0.01$). The highest TSS values were obtained in deficit irrigation treatments.

Full irrigation treatment with 3-day interval under the surface drip (IF_3 FI) produced the highest above-ground total dry matter (6329 kg ha^{-1}), the lowest total dry matter was obtained in subsurface drip IF_6 PRD-50 treatment plots (3070 kg ha^{-1}) (Table 4). Irrigation methods, intervals, levels resulted in significantly different biomass yields ($P < 0.01$). In both irrigation methods with 3-day irrigation intervals resulted in maximum amount of dry matter yields. The significant reduction in dry matter for plants undergoing deficit irrigation at fruit ripening may be due to a consistent reduction in fruit dry matter yield, as reported in the works of Kırnak et al. (2002), Chaves et al. (2003), and Lovelli et al. (2007).

Table 4. Yield and quality parameters of eggplant in different treatments

Irrigations systems	Irrigations intervals	Treatments	Yields (kg ha^{-1})	Dry matter (kg ha^{-1})	Yield per plant (kg plant^{-1})	Mean fruit weight (g)	Fruit length (cm)	Fruit width (cm)	Total soluble solid (g100g^{-1})**
DI	IF3	FI	78660	6329	5.5	200.7	20.4	7.4	4.38 l
		DI-75	75270	5397	5.2	201.2	18.7	6.9	4.47 j
		DI-50	70430	4447	4.9	199.0	18.2	6.5	4.53 fg
		PRD-50	58110	4127	4.0	188.0	17.5	6.1	4.59 c
DI	IF6	FI	69840	5095	4.8	199.7	18.9	7.0	4.44 k
		DI-75	63400	4651	4.4	198.4	18.4	6.7	4.51 h
		DI-50	60780	3845	4.2	191.3	17.8	6.2	4.55 e
		PRD-50	48680	3393	3.4	178	17.2	5.8	4.63 b
SDI	IF3	FI	71920	5853	5.0	186.9	19.9	7.3	4.43 k
		DI-75	69340	4857	4.8	187.2	18.6	6.7	4.50 ı
		DI-50	66920	4365	4.6	186.6	18.1	6.3	4.54 ef
		PRD-50	53950	3571	3.7	174.0	17.2	5.9	4.60 c
SDI	IF6	FI	60730	4762	4.2	183.0	19.0	6.9	4.46 j
		DI-75	58100	4206	4.0	185.0	18.4	6.5	4.52 gh
		DI-50	56770	3750	3.9	179.4	17.5	6.1	4.57 d
		PRD-50	40880	3070	2.8	175.0	16.9	5.7	4.68 a

** LSD grouping at 1% level, * LSD grouping at 5 % level

3.2. Leaf area index of eggplant

The evolution of the leaf area index (LAI) with time under surface drip and subsurface drip irrigation during the growing season is presented in Fig 1a-b. Full irrigation treatment with 3-day interval under the surface drip (IF_3 FI) produced the highest LAI (4.13), the lowest was obtained in subsurface drip IF_6 PRD-50 treatment plots (2.60). Madramootoo and Rigby (1991) found that water stress resulted in a reduction of the leaf area of eggplants. Karam et al. (2011) reported maximum LAI of 6.6 m^2 m^{-2} in the control, while reductions of 44, 33 and 10% were observed in deficit-irrigated treatments.

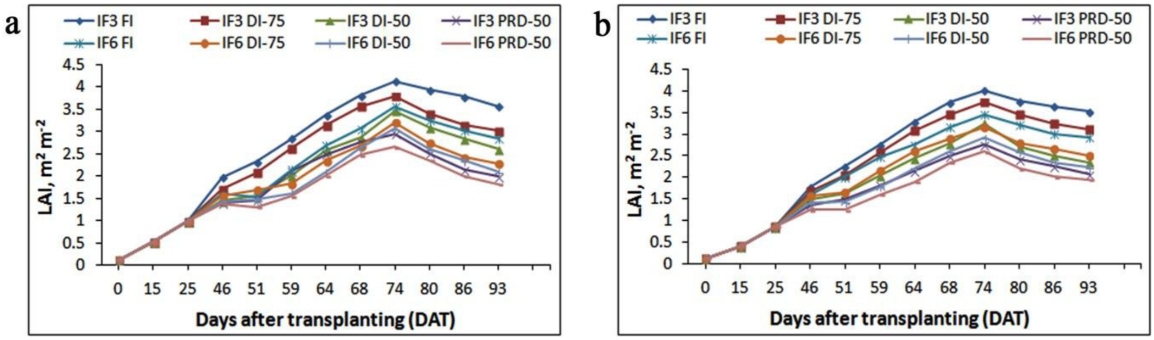

Fig 1. Leaf area index (LAI) variation during eggplant growing season in all treatments under surface (a) and subsurface (b) drip irrigation

3.3. Soil water content before irrigation

Profil soil water storage variations during the growing season for each irrigation interval and irrigation method are shown in Fig. 2a-d. In both irrigation methods with 3-day irrigation interval, available soil water in FI and DI-75 treatment plots remained above 50% throughout the growing season. On the other hand, in deficit irrigation treatments (DI-50 and PRD-50) SWC remained below the 50% available water. SWC in FI treatment plots remained over 50% available soil water throughout the growing season for both irrigation systems. In deficit irrigation treatments (DI-75, DI-50 and PRD-50) SWC remained between the 50% of available with the wilting point.

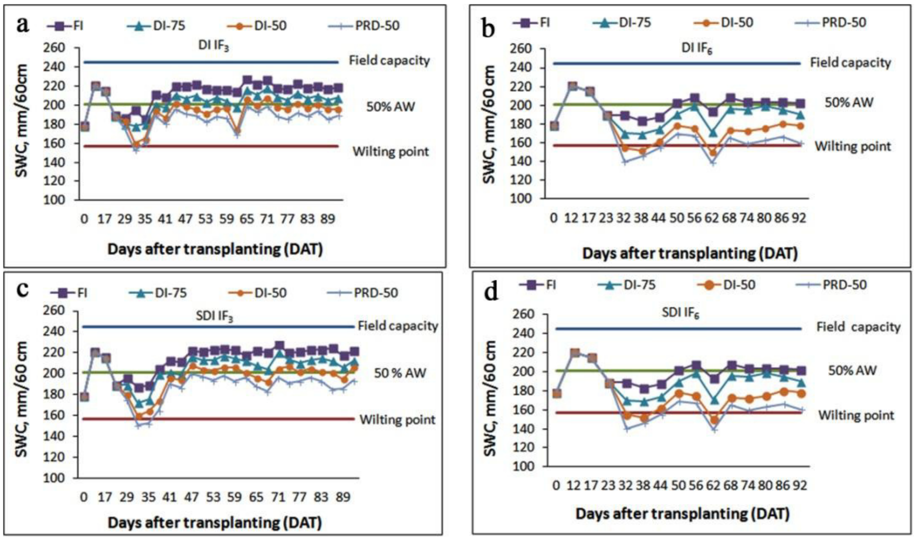

Fig.2. Soil water storage variation during the eggplant growing season in all treatments.

3.4. Applied irrigation water amount(I) and crop evapotranspiration (ET)

Water management of eggplant extremely important at all stages of plant development due to its influence on stand establishment, fruit set and quality. Table 5 presents the data on irrigation quantity and crop evapotranspiration for different treatments in the experimental year. To achieve a good stand, a total of 41 mm of irrigation water was applied equally to all treatment plots. The first treatment irrigation was applied on June 04, 2013 and final application was made on August 7, 2013. The total amount of irrigation water applied varied from 243 mm to 495 mm according to treatments with surface drip irrigation. In the subsurface drip plots, the total amount of irrigation water applied varied from 228 mm to 446 mm (Table 4). Subsurface drip received slightly less water than the surface drip plots due to reduced evaporation losses.

Eggplant evapotranspiration (ET) was highly dependent on the variation of soil water storage in growth season, irrigation amount and effective rainfall. In surface drip system treatments, ET varied from 339 mm in IF$_3$ DI-50 to 543 mm in IF$_3$ FI treatment plots. In subsurface drip system treatments, ET varied from 306 mm in IF$_3$ DI-50 to 495 mm in IF$_3$ FI treatment plots. The seasonal evapotranspiration (ET) increased with the increasing amount of irrigation under both surface and subsurface drip systems. DI-50 treatments in the two irrigation systems resulted in slightly lower ET than PRD-50 treatment despite receiving the same amount of water.

3.5. Water use efficiency (WUE) and irrigation water use efficiency (IWUE)

WUE values were significantly influenced by irrigation treatments (Table 5). WUE values ranged from 12.2 kg m^{-3} in SDI IF$_6$ PRD-50 to 21.9 kg m^{-3} in the SDI IF$_3$ DI-50. IWUE values ranged from 14.7 kg m^{-3} in SDI IF$_6$ FI to 27.3 in the SDI IF$_3$ DI-50 treatments. Karam et al. (2011) reported the highest WUE value in the deficit irrigation treatment as 5.6 kg m^{-3}. Lovelli et al. (2007) reported highest WUE as 10.3 kg m^{-3} for full irrigated eggplant in Southern Italy. Others researchers found increased WUE values under water stress conditions for red pepper (Sezen et al. 2014), eggplant (Kırnak et al., 2002). The higher WUE of plants under stress conditions is because stressed plants wilt far more than unstressed plants and wilting invariably occurs in times when the saturation deficit of the atmosphere is large. Therefore, the plant assimilates only when the saturation deficit is small and hence loses less water for every carbon molecule fixed (Bloch et al., 2006).

Table 5.The effect of different treatments on eggplant yield, irrigation, ET, WUE and IWUE.

Irrigations systems	Irrigations intervals	Treatments	Yield (kg ha^{-1})	Seasonal irrigation (mm)	ET (mm)	WUE (kg m^{-3})	IWUE (kg m^{-3})
DI	IF$_3$	FI	78660	495	543	14.5 h	15.9
		DI-75	75270	382	441	17.1 def	19.7
		DI-50	70430	268	339	20.8 b	26.3
		PRD-50	58110	268	346	16.8 f	21.7
DI	IF$_6$	FI	69840	446	517	13.5 ı	15.7
		DI-75	63400	344	425	14.9 g	18.4
		DI-50	60780	243	349	17.4 d	25.0
		PRD-50	48680	243	356	13.7 ı	20.0
SDI	IF$_3$	FI	71920	450	495	14.5 h	16.0
		DI-75	69340	348	403	17.2 de	19.9
		DI-50	66920	245	306	21.9 a	27.3
		PRD-50	53950	245	318	17.0 ef	22.0
SDI	IF$_6$	FI	60730	414	479	12.7 j	14.7
		DI-75	58100	321	398	14.6 gh	18.1
		DI-50	56770	228	317	17.9 c	24.9
		PRD-50	40880	228	335	12.2 k	17.9

** LSD grouping at 1% level, * LSD grouping at 5 % level

3.6. Crop water stress index (CWSI) and baseline equations

The variations in CWSI prior to irrigations under different treatments during the growing season are shown in Fig. 3a–b. The upper limit (UL) and lower limit (LL) equations were developed as follows: UL= 0.0349 VPD+ 4.088 and LL=-1.4502 VPD-1.352. The CWSI values increased with increasing water stress. In the surface drip irrigation treatments, CWSI values ranged between 0.20 and 0.53 and subsurface drip irrigation treatments ranged between 0.18 and 0.49 in the growing season.

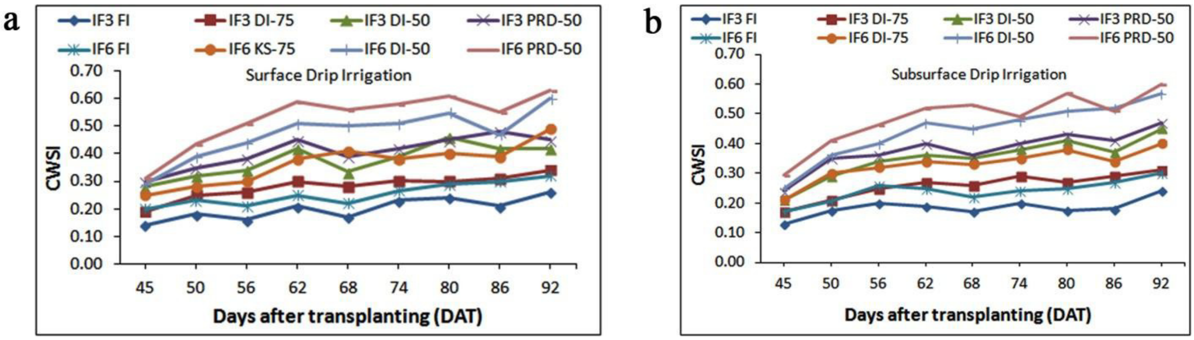

Fig.3. Variation of CWSI with time during the growing season of eggplant in all treatments under surface and subsurface drip irrigation.

The seasonal mean CWSI values for surface drip treatments IF_3FI, IF_3 DI-75, IF_3 DI-50, IF_3 PRD-50, IF_6FI, IF_6 DI-75, IF_6 DI-50 and IF_6 PRD-50 were 0.20, 0.28, 0.38, 0.41, 0.25, 0.36, 0.47 and 0.53 respectively, subsurface drip treatments IF_3FI, IF_3 DI-75, IF_3 DI-50, IF_3 PRD-50, IF_6 FI, IF_6 DI-75, IF_6 DI-50 and IF_6 PRD-50 were 0.18, 0.26, 0.35, 0.38, 0.24, 0.33, 0.45 and 0.49 respectively. Eggplant should be irrigated at CWSI values between 0.18-0.20 for high and good quality yields. The results revealed that CWSI can be used for irrigation scheduling for eggplant.

3.7. Relations between CWSI and yield

The relationship between yield and mean CWSI values for surface drip and subsurface drip irrigation treatments were presented in Fig. 4a,b. Significant linear equations were developed. 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. Thus, the CWSI values proved to be a good indicator of plant to available water for eggplant and it may be used to predict yield where the CWSI is known.

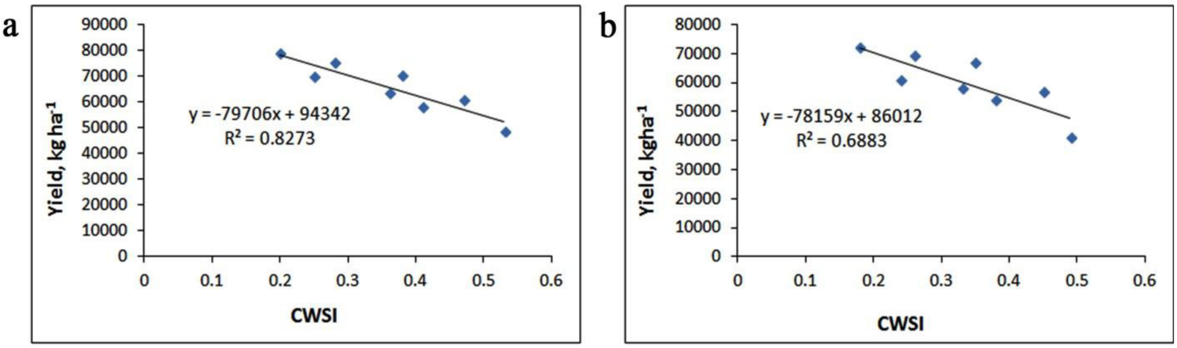

Fig.4. The relationship between crop water stress index (CWSI) and total yield in surface drip (a) and subsurface drip (b) irrigation

4. Conclusions

The results of the current study demonstrate that the effects of surface drip and subsurface drip irrigation methods, irrigation intervals and irrigation levels had significant effect on total yield of eggplant, and water use are significantly important in order to obtain higher yields of field grown eggplant under the Mediterranean climatic conditions in Turkey. Full irrigation treatment with 3-day interval under the surface drip (IF_3 FI) produced the highest yield (78.7 t ha^{-1}), the lowest yield was obtained in subsurface drip IF_6 PRD-50 treatment plots (40.9 t ha^{-1}). Surface drip performance was superior to subsurface drip considering yield and quality of eggplants. The highest total and first quality yield was obtained from the IF_3 FI treatment in surface drip plots in the growing season. Irrigation had a significantly different effect on quality parameters such as yield per plant, weight of the eggplant fruit, eggplant length and width, and total soluble solid of fruit in the different treatments. Although the DI-75 treatment received approximately 25% less water compared to the FI plot, total yield was reduced by an average of 4.3%. When it comes to water shortages deficit irrigation practices (DI-75) subject suggested. According to the issues referred to the full while saving irrigation watering eggplant can be a suitable irrigation strategy. The results revealed that surface drip irrigation IF_3 FI treatments in the 60 cm soil depth was used and brought to field capacity was recommended under field conditions in order to obtain higher and better quality eggplant yield in the Mediterranean region of Turkey.

The results revealed that CWSI can be used for irrigation scheduling for eggplant. Eggplant should be irrigated at CWSI values between 0.18-0.20 for high and good quality yields. Significant linear relations were found between the eggplant yield and CWSI for each irrigation method. The prediction of the yield response to crop water stress is important in developing strategies and decision making for use by farmers and their advisors, and researchers for irrigation management under limited water limited water conditions.

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