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WATER USE EFFICIENCY, YIELD AND YIELD COMPONENTS OF SECOND CROP SUNFLOWER UNDER DEFICIT IRRIGATION

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ABSTRACT

This study was conducted to observe the effects of different irrigation treatments on yield and yield components of second crop sunflower (*Helianthus annuus* L.) grown in western Turkey in 2012 and 2013. Trials comprised of two irrigation intervals (4-day and 8-day) and six different water levels (125, 100, 75, 50, 25 and 00% of cumulative Class-A pan evaporation on a 4-day and 8-day interval basis) were investigated. Seasonal water use values varied between 191.1-662.6 mm in 2012 and 194.0-675.8 mm in 2013. Interactions between irrigation interval and irrigation levels were found to be significant for seed yield in both years. Maximum and minimum seed yield were obtained from the 8-day IL-100 and 8-day IL-00 treatments as averaging 5072.6 kg ha^{-1} and 2327.9 kg ha^{-1}, respectively. Significant curvilinear relationships between seed yield and crop water use were obtained for 2012 and 2013. Water use efficiency and irrigation water use efficiency values were influenced by the irrigation intervals and levels. Water use efficiency varied from 1.21 kg m^{-3} to 0.70 kg m^{-3} among treatments in both years. The yield response factor (*ky*) was determined to be 0.70 for 4-day irrigation interval and 0.69 for 8-day irrigation interval. Deficit and frequent irrigation caused a remarkable decline in all yield components (head diameter, stem diameter, plant height, 1000 seed weight and oil yield) investigated in both experimental years. The yield components decreased as irrigation levels decreased for each irrigation interval. The IL-100 treatment in 8-day irrigation interval could be proper for sunflower irrigated in semi-arid regions under no water shortage and the 8-day IL-75 treatment could be used as a good basis for reduced drip irrigation strategy development under water shortage.

Keywords: Deficit irrigation regimes, sunflower, water use efficiency, yield, yield components

INTRODUCTION

Biotic and abiotic stresses negatively affect the growth and development of plants. Thus, yield and seed quality of sunflower decrease due to biotic and abiotic stresses (Kaya et al., 2016). Water stress is a prominent abiotic stress factor. Deficit water conditions affect the yield and quality of sunflower particularly during the flowering, seed filling and seed maturity periods (Bajehbaj, 2010; Esmaeilian et al., 2012; Farahvash et al., 2011). Under drought conditions, it is important to have a better knowledge of the effects of water shortage at different stages of the growing period of any crop for obtaining higher yield and better quality (Omidi et al., 2012). Drought tolerant genotypes of a given crop respond better to water scarce conditions and preferring it will ensure sustainable crop growing in such water-short regions (Rad et al., 2014).

Turkey is among the top 10 sunflower producing countries in the world. According to the latest crop production reports; the area planted by sunflower is 685 317 ha, the total crop production is 1 680 700 tonnes and the average sunflower yield is about 2095 kg ha^{-1} in Turkey (TUIK, 2016).

All sunflower production areas of western Turkey receive inadequate amounts of rainfall in uneven distribution. Owing to the negative impact of global climate change on water resources, the irrigators started to find a way to allocate finite water resources to irrigation by deficit irrigation practices or by shifting their irrigation systems from surface to pressurized which save water substantially. Water saving irrigation systems should be followed in order to save water and maximize yield. Thus, appropriate irrigation scheduling is required for maximizing the yield and water use. Kuscu et al. (2013) stated that the need for water in water user sectors other than agriculture will give rise to deficit irrigation practices due to water scarcity. Sunflower is tolerant to water stress caused by deficit irrigation, but responds positively in aspect of yield and yield components to the irrigation water applied. Sunflower seed yield and quality response to different irrigation regimes has been previously studied and reported by many researchers (Karam et al. 2007; Todorovic et al. 2009; Bakht et al. 2010; Soleimanzadeh et al. 2010; Sezen et al. 2011a, 2011b; Alahdadi et al. 2011; Ghaffari et al. 2012; Mobasser and Tavassoli, 2013, Urrea et al. 2014).

The dependence of crop yields to water supply is a critical issue due to the limited water resources for irrigation in the Aegean region and its semi-arid climate. Implementing water saving and environmentally sound irrigation methods such as drip irrigation, creates the possibilities for continuous improvement in irrigation practices. It is believed that research work studying agricultural production under deficit irrigation conditions may help to develop irrigation programs for minimizing future yield reductions when water scarcity becomes widespread. However, little attempt has been made to develop deficit irrigation regimes for second crop sunflower under drip irrigation in the plains of Aegean region. Therefore, this research was undertaken to determine the effects of deficit irrigation on water use efficiency (WUE), seed and oil yield and yield components of drip irrigated second crop sunflower in the Soke Plain of western Turkey.

MATERIALS AND METHODS

Experimental site

Field experiment was carried out in Agricultural Research Station located in Soke-Aydın region of western Turkey (37° 71’ N latitude, 27° 38’ E longitude, altitude 10 m) during the 2012 and 2013 growing seasons. Climate in this region is semi-arid with total annual precipitation of 657 mm, with 90% of the rain occurring between November and March. Typical Mediterranean climate prevails in the experimental area. The growing season temperatures were in parallel with long-term means (1975-2013) for Soke located in the western Aegean region of Turkey. Meteorological data (air temperature, relative humidity, evaporation, rainfall) of the study area were given in Table 1. Evaporation data was collected on a daily basis from the Class-A pan located in the study site.

Table 1. Weather conditions prevailed during the experiments compared to the long-run at the experimental site

Months	**Temperature (ºC)**			**Rainfall (mm)**			**Relative Humidity (%)**			**Evaporation (mm)**		
	2012	**2013**	**Long-term***	**2012**	**2013**	**Long-term***	**2012**	**2013**	**Long-term***	**2012**	**2013**	**Long-term***
May	20.6	21.5	20.9	56.1	58.2	36.1	62.7	63.5	57.1	129.0	145.7	161.1
June	27.5	25.6	26.1	45.1	7.0	14.7	48.8	45.7	49.4	204.0	205.2	223.2
July	30.4	28.2	28.6	-	-	3.1	43.3	51.0	49.1	255.1	258.8	259.8
Aug	29.2	28.7	27.5	-	-	2.2	37.4	57.7	53.7	241.8	241.2	233.4
Sept	24.6	23.9	23.4	-	0.8	11.1	52.6	53.5	56.6	147.0	141.5	163.6

* Long-term average (1975-2013)

The soil of the experimental site is classified as Entisols and Fluvisols-Regosols in silty-clay-loam texture (Soil Survey Staff, 1999; FAO-UNESCO, 1989). The experiment area was flat with a deep and well-drained soil profile with high water holding capacity. Mean bulk density, field capacity and wilting point were measured in laboratory conditions with disturbed and undisturbed soil samples. Mean bulk density varies from 1.30 to 1.35 g cm^{-3}, field capacity varied from 27 to 32% and wilting point varied from 12 to 16% on dry weight basis. The available water holding capacity within 90 cm of the soil profile is 178 mm.

Experimental design

The Tunca sunflower variety was planted on 13 June 2012 and 6 June 2013, with 0.70 × 0.20 m spacing after winter wheat harvesting. A compound fertilizer (each included 15 % composite) was applied at a rate of 30 kg ha^{-1} pure N, P and K at planting.

A randomized complete block design was used with three replications. There were 3 m separations between each plot in order to minimize water movement among treatments. Each experimental plot had eight sunflower rows at 0.7 m spacing and 6 m in length. In the study, two irrigation intervals (II-1: 4-days and II-2: 8-days) and six irrigation levels (IL-125, IL-100, IL-75, IL-50, IL-25 and IL-00-rainfed). Irrigation water was applied based on cumulative Class-A pan evaporation within the irrigation intervals. IL-100 treatment designated to receive 100 % of cumulative Class-A pan evaporation on a 4 and 8-day basis, respectively. Five irrigation treatments received 125, 75, 50, 25 and 0% (rainfed) of the IL-100 on a 4 and 8-day basis for each level. A drip irrigation system was designated for the experiment. Irrigation water was used from a deep well located near the experimental site. Quality of irrigation water was suitable for irrigation and its electrical conductivity (EC) value (0.72 ds m^{-1}) was far below the salinity tolerance level of sunflower. The control unit consisted of screen filter with 10 L s^{-1} capacity, control valves, manometers mounted on the inlet and outlet of each unit. Distribution lines consisted of PVC pipe manifolds for each plot. The diameters of the laterals were 16 mm PE and each lateral irrigated one plant row. The inline emitters were used with a discharge rate of 4 L h^{-1} above 10 m operating pressure. In the system, emitter and the lateral spacing were chosen as 0.20 and 0.70 m, respectively.

Evapotranspiration and yield response factor calculations

Crop evapotranspiration (ET) of sunflower plants under varying irrigation amounts was calculated with the water balance equation (Doorenbos and Kassam, 1986).

$$ET = I \pm P \pm \Delta S - D_P - R_f$$

In the equation; crop evapotranspiration is notated with ET (mm), the amount of irrigation water applied with I (mm), rainfall with P (mm), variations in the soil profile water content with ΔS (mm), deep percolation with D_p (mm), and the runoff with R_f (mm). Runoff was neglected in the 0-90 cm soil depth due to favorable soil and water table characteristics and deep percolation was also neglected since the excess water contributed to the root zone either by rainfall and/or irrigation is assumed to be over the field capacity and drained from the soil profile. The difference between the inputs and the outputs of the water balance model within the soil profile was used in ET calculation procedure (Karam et al., 2007; Todorovic et al., 2009).

The equation used to calculate the amount of irrigation water is given below;

$$I = P \times A \times E_{pan} \times IR$$

In the equation; I is defined as the volume of irrigation water (L), P is defined as wetting percentage (which was regarded as 100% for row crops), A is defined as plot area (m^2), E_{pan} is defined as the amount of total evaporation between two irrigation intervals (mm) and IR defines the irrigation levels (IL-125, IL-100, IL-75, IL-50, IL-25 and IL-00).

Water use efficiency (WUE) was calculated by dividing the yield (kg ha^{-1}) by seasonal evapotranspiration (mm), irrigation water use efficiency (IWUE) was determined by dividing the yield (kg ha^{-1}) by per unit irrigation water applied (mm) (Howell et al., 1990).

The effect of water stress during the growing season on yield was investigated with Stewart's model which is commonly used. Water production functions are obtained by a regression analysis as a result of the relationships between yield and evapotranspiration and irrigation water or transpiration using Stewart's model. Seasonal values of the yield response factor (*ky*), which indicates the relationship between relative yield reduction and relative evapotranspiration deficit were determined using the below given equation (Doorenbos and Kassam, 1986).

$$1-\left(\frac{Y_a}{Y_m}\right) = k_y\left[1-\left(\frac{ET_a}{ET_m}\right)\right]$$

Here; Y_a is the actual harvested seed yield and Y_m is the maximum harvested seed yield in kg ha^{-1}, *ky* is the yield response factor, ET_a is the actual evapotranspiration and ET_m is the maximum evapotranspiration in mm. Relative seed yield decrease is expressed as $1-(Y_a/Y_m)$ is the and the relative evapotranspiration deficit is expressed as $1-(ET_a/ET_m)$ and those given above enables us to calculate the *ky*.

Yield and yield parameters

Yield was determined by hand harvesting in each plot on 3 October 2012 and on 7 October 2013. After harvesting; seed yield, plant height, stem diameter, 1000 seed weight, and head diameter were measured immediately. Soxhlet extraction technique given by Pomeranz and Clifton (1994) was used in determining the crude oil content (%) of the samples. Oil yield was calculated by using the seed yield obtained from the field experiment and crude oil percentage (%) determined in the laboratory.

Statistical evaluation

Analysis of variances (ANOVA) of data for each attribute was conducted to evaluate the effects of the treatments on seed sunflower yield, plant height, stem diameter, 1000 seed weight, diameter of head and oil yield by using SPSS software (version 12.0). The Least Significant Differences (LSD) test was used for comparing and ranking the treatments means if needed. Differences were declared significant at $p<0.05$.

RESULTS AND DISCUSSION

Crop water use and yield

The climatic conditions of the area showed similarity to the long-run meteorological data (Table 1). Only the rainfall pattern showed uneven distribution compared to the long-term rainfall data. Particularly the total rainfall (45.1 mm) recorded on June 2012 deviated remarkably from the long-run data of June (14.7 mm).

The total irrigation water amounts applied, seasonal water use, water use efficiency and irrigation water use efficiency values (WUE, IWUE) were presented in Table 2. The irrigation was initiated on July 31 and it was terminated on Sep 1, in 2012. In 2013, first irrigation and last irrigation were applied on July 25 and Aug 26, respectively. Total number of treatment irrigations varied from 5 in the lowest frequency (8-day) plots to 10 in the high frequency treatment (4-day) in both years. Seasonal amount of irrigation water applied for different drip treatments ranged from 468.8 to 93.8 mm in 2012 and from 507.5 to 101.5 mm in 2013 depending on the irrigation levels (Table 2).

Table 2. Sunflower seed yield and water use efficiency values as influenced by irrigation interval and irrigation levels

Year/Irrigation Intervals	Irrigation Levels	Seed yield (kg ha^{-1})	Irrigation water applied (mm)	Water use (mm)	Water use efficiency (kg m^{-3})	Irrigation water use efficiency (kg m^{-3})
2012 4-day	IL-125	4652.3	468.8	658.6	0.70	0.99
	IL-100	4856.4	375.0	567.4	0.86	1.29
	IL-75	4442.0	281.2	473.4	0.94	1.57
	IL-50	4155.6	187.5	379.6	1.09	2.21
	IL-25	3214.2	93.8	284.8	1.12	3.42
	IL-00	2325.1	-	191.1	1.21	-
2012 8-day	IL-125	4732.9	468.8	662.6	0.71	1.00
	IL-100	4954.7	375.0	566.9	0.87	1.32
	IL-75	4685.2	281.2	474.2	0.99	1.66
	IL-50	4384.1	187.5	378.5	1.15	2.33
	IL-25	3455.6	93.8	292.2	1.18	3.68
	IL-00	2304.2	-	194.3	1.19	-
2013 4-day	IL-125	4702.6	507.5	670.8	0.70	0.93
	IL-100	4974.3	406.0	573.4	0.87	1.22
	IL-75	4645.9	304.5	485.6	0.96	1.52
	IL-50	4273.6	203.0	385.5	1.10	2.10
	IL-25	3335.8	101.5	293.4	1.14	3.28
	IL-00	2332.1	-	194.0	1.20	-
2013 8-day	IL-125	4795.3	507.5	675.8	0.71	0.94
	IL-100	5190.2	406.0	585.6	0.89	1.28
	IL-75	4764.5	304.5	493.8	0.96	1.56
	IL-50	4502.6	203.0	397.4	1.13	2.22
	IL-25	3558.7	101.5	299.5	1.18	3.50
	IL-00	2351.3	-	195.4	1.20	-
Mean	IL-125	4720.8	488.2	667.0	0.71	0.97
	IL-100	4993.9	390.5	573.3	0.87	1.28
	IL-75	4634.4	292.9	481.8	0.96	1.58
	IL-50	4329.0	195.3	385.3	1.12	2.22
	IL-25	3991.1	72.3	292.5	1.16	3.47
	IL-00	2328.2	-	193.7	1.20	-

Seasonal water use values increased with increasing irrigation levels in each irrigation interval. Water use varied from 662.6 mm in 8-day IL-125 treatment to 191.1 mm in 4-day IL-00 treatment plots in the 2012 growing season; and 675.8 mm in 8-day IL-125 treatment to 194.0 mm in 4-day IL-00 treatment plots in the 2013 growing season (Table 2). This was followed by IL-100 4-day treatment with 570.4 mm and IL-100 8-day treatment with 576.3 mm over two years. This variation in water use between the years can be attributed to the climatic factors, particularly in rainfall and temperature. Seasonal water use in the full irrigation treatment, IL-100, was in agreement with results obtained as 563.0 mm by Sullu and Dagdelen (2015) in the Soke plain by drip irrigation. Urrea et al. (2014) reported the sunflower water use as 619 mm in 2009 and 576 mm in 2011 under drip irrigation system. Soriano et al. (2004) used the soil water balance method to estimate sunflower water use between 527 and 572 mm for early planting. Demir et al. (2006) determined the response of sunflower to 14 different irrigation schedules in sub-humid climatic conditions. The average sunflower ET was 652 mm for fully irrigation treatments in two study years. In both years of this study, ET increased until flowering and at the milk ripening stage it remarkably decreased, but the highest decrement was observed after milk ripening stage. Tolk and Howell (2012) measured the sunflower water requirements in a semi-arid environment using small lysimeters with several soil textures. They reported water requirements for sunflower ranging from 581 to 698 mm under full irrigation. Under drip irrigation applications, seasonal water use of sunflower was obtained by Sezen et al. (2011a) as 647-689 mm for full irrigated treatments in Cukurova conditions.

The response of sunflower seed yield to different irrigation regimes are given in Table 3. Data obtained from the two year study showed that seed yield was affected by irrigation intervals and irrigation levels. Interactions between irrigation interval (II) and irrigation levels (IL) were found to be significant for seed yield in both years. However, regardless of irrigation intervals, the highest seed yield was obtained from full irrigated treatment (IL-100) and the lowest yield was obtained as expected from rainfed conditions (IL-00) in both years (Table 3). The 8-day irrigation interval resulted in higher yield than the 4-day interval revealing that the seed yield was enhanced with less frequent irrigation. Sunflower seed yield was found to increase with irrigation water applied. The highest seed yield was obtained from IL-100 treatment as averaging 4905.5 kg ha^{-1}, followed by IL-125 treatment as averaging 4692.4 kg ha^{-1} in 2012. The lowest yield was obtained from IL-00 treatment as averaging 2314.9 kg ha^{-1}. For 2013, the highest seed yield was obtained from IL-100 treatment as averaging 5082.8 kg ha^{-1} and the lowest from IL-00 treatment. The reduction rate was 53 % between the highest and lowest seed yield. When the amount of applied water through drip irrigation was reduced 25 % (IL-75) the decrease in yield was about 7 % in both years. However, as the irrigation water applied was reduced to 50 % (IL-50), it resulted in 13 % lower seed yield than full irrigation in both years (IL-100). Sezen et al. (2011a) mentioned that seed yield is a reliable indicator of the water stress that sunflower was exposed to during the growing season. Seed and oil yield were severely affected by the water stress that the crop was exposed to after flowering stage and the differences in seed yield among treatments were dependent to the levels of water stress (Sezen et al., 2011a). A slight decline in seed yield under deficit irrigation treatment is reported in many previous researches. Yield results of this study agreed with 4916 kg ha^{-1} yield reported by Sullu and Dagdelen (2015) for drip irrigated sunflower at the same region. Similar results were determined by Goksoy et al. (2004) as 4056 kg ha^{-1} sub-humid climatic conditions. Sezen et al. (2011a) obtained, maximum yield of 5029.5 kg ha^{-1} from well irrigated drip plots in Cukurova plain - Turkey conditions. Also, in Bursa-Turkey conditions Demir et al. (2006) determined highest yield (3950 kg ha^{-1}) from the fully irrigated treatments at three different phenological stages. Water deficit that the plant is being exposed to after flowering is more adversely effective on seed and oil yield than the water stress before flowering. If the water content of the soil profile declines below the 60% of the readily available water, differences between the seed yield of deficit irrigated plots become more evident (Sezen et al., 2011a). Gradual decrease in the soil water content that creates more severe stress conditions that may lead to reduced photosynthesis and improper hormone activity and metabological processes in the whole plant. Under stress conditions ABA hormone (Abscisic acid) activity increases which restrains the activity of Cytokinins (CK) and Indole-3-acetic acid (IAA) that commences the cell division. Under circumstances in which the plant cannot use the available water in the root-zone, turgidity and cell division decreases that causes decrease in the plant growth (Tabatabaei et al., 2012).

Table 3. Mean seed yield at different irrigation intervals and irrigation levels in 2012 and 2013

Factor		**2012**		**2013**	
		Irrigation Intervals (II)		**Irrigation Intervals (II)**	
		4-day	**8-day**	**4-day**	**8-day**
Irrigation Levels (IL)	IL-125	4652.1 b[1] B[2]	4732.6 b A	4702.1 b B	4795.6 b A
	IL-100	4856.6 a B	4954.4 a A	4974.7 a B	5190.8 a A
	IL-75	4442.8 c B	4685.7 b A	4645.6 c B	4764.4 b A
	IL-50	4155.0 d B	4384.5 c A	4273.4 d B	4502.3 c A
	IL-25	3214.8 e B	3455.3 d A	3335.3 e B	3558.7 d A
	IL-00	2325.4 f A	2304.3 e A	2332.7 f A	2351.6 e A
Analysis within years	II	**	**	**	**
	IL	**	**	**	**
	II x IL	**	**	**	**
LSD$_{0.05}$		5.66		5.28	

[1] The same lower-case letter within a column indicates no significant difference between irrigation level mean values ($p < 0.05$)

[2] The same upper-case letter within a column indicates no significant difference between irrigation interval mean values ($p < 0.05$)

In order to evaluate the effects of water use on seed yield, a regression analysis was conducted. Second order polynomial relationships were found between seasonal water use and seed yield in 4-day and 8-day irrigation treatments, respectively (Fig 1). The fairly high correlation coefficient (0.99) between the seasonal water use and seed yield reveals that the seed yield is adversely influenced by deficit irrigation levels and irrigation intervals during the growing season. Polynomial relationships of water use and seed yield for drip irrigated sunflower were reported by Demir et al. (2006); Sezen et al. (2011b) and Sullu and Dagdelen (2015).

The *ky* factor which is defined by the slope of the relationship between relative ET and relative yield, was determined to be 0.70 (Fig 2) for the combined data from both years using the method of Doorenbos and Kassam (1986). When data from both years were combined, the seed yield response factor (*ky*) was determined to be 0.70 in the 4-day irrigation interval and 0.69 in the 8-day irrigation interval, respectively. Doorenbos and Kassam (1986) determined that the *ky* factor of sunflower as 0.95. For drip irrigated sunflower, Sullu and Dagdelen (2015) found that the *ky* factor was 0.74 for the Soke plain. However, Sezen et al. (2011a) suggested *ky* factors of 1.06-1.19 for seed yield in the Cukurova conditions. Demir (2006) reported that seasonal *ky* factor was 0.83 in Bursa plain.

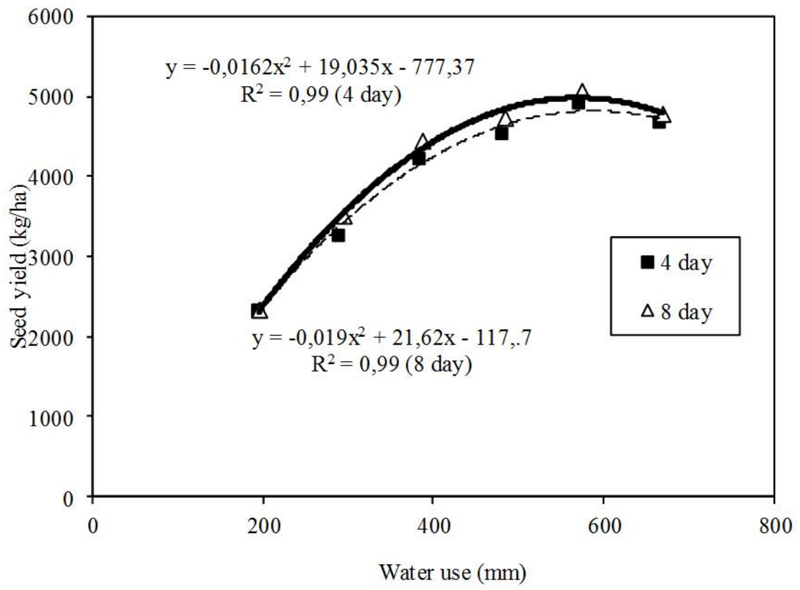

Figure 1. Seed yield as a function of water use

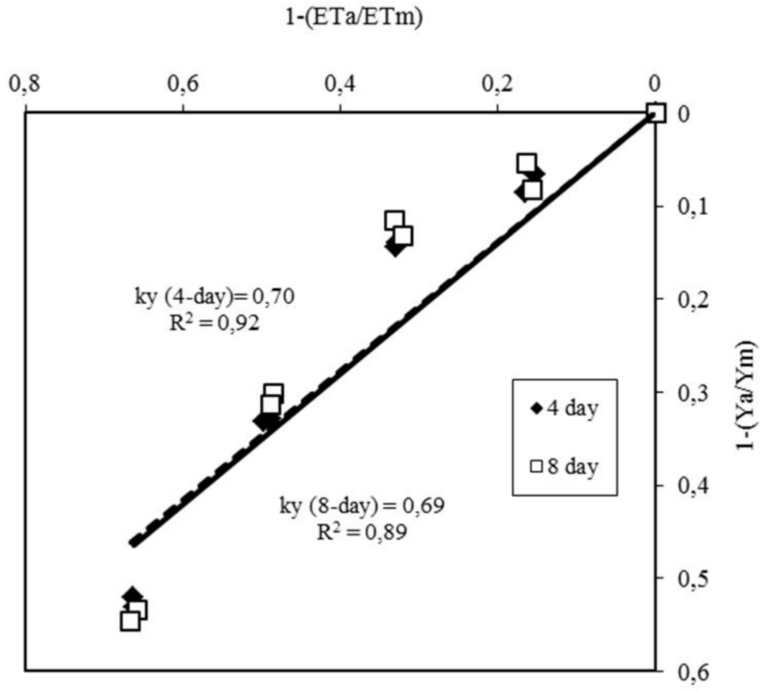

Figure 2. Yield response factor, *ky*, for sunflower

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

The term "water use efficiency" (WUE) refers to the amount of the obtained yield/biomass by each volumetric unit of consumed water by the crop. On the other hand, "irrigation water use efficiency" is a function of the amount of the obtained yield/biomass and each volumetric unit of irrigation water applied to the field. Water use and irrigation water use efficiencies (WUE, IWUE) values are listed in Table 2 for two years. In general, the IWUE values were higher than those of WUE in all treatments. This could be ascribed to water consumed from soil storage. Water use efficiency (WUE) varied from 1.21 kg m^{-3} to 0.70 kg m^{-3} among treatments in both years. The highest WUE averaging 1.21 kg m^{-3} was obtained in 4-day IL-00 treatment and the lowest as 0.70 kg m^{-3} from 4-day IL-125 treatment in 2012. In 2013 the highest WUE was observed both in 4-day and 8 day IL-00 treatments and the lowest WUE as 0.70 kg m^{-3} in 4-day IL-125 treatment. This was followed by IL-25 (1.16 kg m^{-3}); IL-50 (1.12 kg m^{-3}) and IL-75 (0.96 kg m^{-3}) treatments in both years. WUE values decreased with increasing water use. Sezen et al. (2011b) reported that WUE of sunflower under drip irrigation was 1.0 kg m^{-3} in the Cukurova conditions. Similar results were reported by Demir et al. (2006), Erdem et al. (2006), Karam et al. (2007) between 0.52-1.30 kg m^{-3}. WUE values of this study agreed with the 0.5-1.2 kg m^{-3} values reported by Sullu and Dagdelen (2015) for drip irrigated sunflower at the same place. According to Doorenbos and Kassam (1986), crop water consumption of sunflower in different phenelogical stages occurrs around 20% at vegetative period, 55% at the flowering period and 25% during the yield formation and ripening periods.

On the other hand, the IWUE values ranged from 0.93 to 3.68 kg m^{-3}. The average IWUE values measured from treatments were 3.47 to 0.97 kg m^{-3} over two years. In general, IWUE results obtained from the experiment were different from those of previous researchers in different regions. In Cukurova-Turkey conditions Sezen et al. (2011a) reported the IWUE of sunflower under drip irrigation ranged between 0.57-1.80. Demir et al. (2006) determined these values as 0.5-1.0 kg m^{-3} in Bursa-Turkey conditions. In deficit irrigated treatments, greater IWUE values were obtained as it was determined by different researchers (Karam et al., 2007; Sezen et al., 2001b). The main explanation for the higher IWUE values obtained from the study contrasting of those literatures cited above is the rainfall received in both growing seasons. Higher the rainfall is, higher the contribution of the total water supplied to the soil profile, which leads to higher IWUE values.

Yield components

The differences in head diameter, stem diameter, plant height, 1000 seed weight and oil yield under different treatments are presented in Table 4. Under drip irrigation, deficit irrigation practices caused a remarkable decline in all parameters investigated in both experimental years. Frequent irrigation also had adverse effect on yield components of sunflower.

Table 4. Yield components as influenced by irrigation interval and water levels

		Head diameter (cm)		**Stem diameter (cm)**		**Plant height (cm)**		**1000-seed weight (g)**		**Oil yield (kg/ha)**	
		2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Irrigation Intervals (II)	8-day	20.0	17.9a	2.15a	2.28a	155.6a	176.9a	66.96a	64.03a	1558.5a	1600.6a
	4-day	19.8	17.6b	2.07b	2.18b	152.7b	171.6b	64.04b	61.96b	1460.4b	1499.4b
Irrigation Levels (IL)	IL-125	20.2c	17.0d	2.08c	2.23bc	153.5c	176.8b	69.11ab	67.15b	1874.4b	1897.0b
	IL-100	22.6a	18.9a	2.39a	2.50a	164.0a	185.3a	71.60a	70.11a	2059.9a	2135.2a
	IL-75	21.0b	18.3b	2.24b	2.29b	158.5b	178.2b	67.01bc	65.25b	1761.7c	1816.5c
	IL-50	19.6c	17.9c	2.15c	2.20cd	154.5bc	172.7c	64.11cd	61.40c	1580.1d	1623.7d
	IL-25	18.8d	17.8c	1.93d	2.14d	150.5c	167.3d	62.46d	59.33c	1171.9e	1211.2e
	IL-00	17.0e	16.8d	1.88d	2.03e	144.0d	165.3d	58.70e	54.75d	609.0f	616.4f
Analysis within years	II	ns	**	**	**	*	**	**	**	**	**
	IL	**	**	**	**	**	**	**	**	**	**
	IIx IL	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

II, irrigation intervals; IL, irrigation levels; II x IL, irrigation intervals x irrigation levels

ns, not significant; *,**significant at $p< 0.05$ and $p< 0.01$

In a column values with a common letter are not significantly differ from one another using $LSD_{0.05}$

Observed values of the head diameter among the irrigation intervals (II) and irrigation levels (IL) have shown variations at p<0.01 for years 2012 and 2013. The highest head diameter (22.6 and 18.9 cm) were obtained from the IL-100 full irrigation treatment and occurred in the first group (a) for both years (Table 4). IL-100 full treatment resulted in highest diameter of head in the study and followed by IL-75 and IL-50 as shown in Table 4. More irrigation ratio with less frequent irrigation (II-8 day) resulted in higher diameter of head, while deficit irrigation with frequent irrigation interval (II-4 day) resulted in lower head diameter. Farahvash et al. (2011) stated that head diameter is an essential yield trait that is directly associated with other yield components such as seed number per head which implicitly affects seed yield and 1000-seed weight. They also stated selection of genotypes with greater head diameter should be among the objectives of sunflower breeding programs. Alahdadi et al. (2011) reported negative impacts of irrigation water deficit on head diameter which coincides with our results. The findings related to head diameter obtained in the study were similar to most of the previous research aimed to determine the effects of different irrigation methods on sunflower head diameter conducted by Erdem et al. (2001), Goksoy et al. (2004), Sezen et al. (2011b) and Urrea et al. (2014).

In both experimental years, the irrigation intervals (II) and irrigation levels (IL) resulted in variations among the stem diameter values (p<0.01). In the first and second year the highest stem diameter values (2.39 and 2.50 cm) were obtained from the IL-100 full irrigation treatment and took place in the first group (a). The lowest stem diameter values (1.88 and 2.03 cm) were obtained from the IL-00 non irrigated treatments in both years. Less frequent irrigation intervals resulted in thicker stem diameters (Table 4). Farahvash et al. (2011) determined decreased cell division that leads to thinner stem diameter of sunflower at mild to severe stress conditions. Hafez et al. (2002); Sezen et al. (2011b) and Sullu and Dagdelen

(2015) reported that the stem diameter was positively influenced by the increasing water ratio.

In the first and second research year, the plant height values among the irrigation intervals (II) and irrigation levels (IL) were found to be different ($p<0.01$). The highest plant heights (164.0 and 185.3 cm) were obtained from the IL-100 full irrigation levels and occurred in the first group (Table 4). Deficit irrigation treatments resulted in plant height decreases of 3.6 % in IL-75 and 6.3 % in IL-50 as compared to full irrigation. Longer irrigation intervals (8-day) resulted in higher plant height values. Comparable results were given by Farahvash et al. (2011), Alahdadi et al. (2011) and Mobasser and Tavassoli (2013) indicating that the plant height is increased with the increments in irrigation water applied.

1000-seed weight is one of the major yield contributing attributes. Experimental results related to seed weight indicated a significant effect of irrigation intervals (II) and irrigation levels (IL) ($p<0.01$). Sezen et al. (2011b) emphasized that supplying adequate water to the plant in the growing season will improve sunflower seed size, shape and yield which addresses the role of the proper irrigation program. The highest 1000-seed weights (71.60 and 70.11 g) were obtained from the IL-100 full irrigation treatment and fell into the first group (a) (Table 4). These were followed by IL-75 and IL-50 as shown in Table 4. 8-day irrigation interval had better 1000-seed weight results as shown in Table 4. The findings of the study were found similar with those reported by Erdem et al. (2001); Goksoy et al. (2004) and Sezen et al. (2011b) who stated that 1000-seed weight decreased notably with the decrease in irrigation level. Water deficit conditions during flowering leads to reduced fertilization and seed-set due to dehydration of pollen grain that may result in reduced 1000-seed weight (Yagoub et al., 2010).

Irrigation intervals (II) and irrigation levels (IL) explicitly affected the oil yield at $p<0.01$ in the experimental years. The oil yield increased in parallel to the increasing amounts of irrigation in the treatments, where the highest oil yield was obtained from the IL-100 (2059.9 and 2135.2 kg ha^{-1}) treatments in both years (Table 4). The non-irrigated treatment IL-00 (609.0 and 616.4 kg ha^{-1}) yielded the lowest oil yield. Tan et al. (2000) and Flagella et al. (2002) reported that the oil content of sunflower seeds ranged between 34 and 39% in non-irrigated treatments in different varieties. Sezen et al. (2011a) reported oil yields as 744 kg ha^{-1} under rainfed conditions and as 2395 kg ha^{-1} under full irrigation. Demir et al. (2006) obtained highest oil yield as 1780 kg ha^{-1} from the full irrigated plots, while Bakht et al. (2010) reported a decrease in oil yield in treatments which were fully irrigated at three stages (heading; heading and flowering; heading and flowering and grain filling). Alahdadi et al. (2011) determined that the seed oil content of sunflower was notably decreased at the most-intense stress level than the mild-water stress. Mobasser and Tavassoli (2013) stated that average seed weight and oil content of the crop could only be increased by meeting the water requirements of the sunflower during vegetative, leaf development and grain filling stages. The results of the study were in accordance with those reporting that seed oil content exhibited increments with increasing irrigation levels (Tabatabaei et al., 2012; Sullu and Dagdelen, 2015).

For both experimental years, the correlations between the yield and yield traits were investigated regarding the irrigation intervals and irrigation levels. According to the correlation tests performed, it was determined that the yield and the investigated yield components have positive and statistically significant correlations ($p<0.01$).

In order to assess the effects of water use on oil yield, a regression analysis was conducted for determining the relationship between the oil yield and evapotranspiration (Figure 3). Notable second order polynomial relationships were found between seasonal water use and oil yield in 4-day and 8-day irrigation treatments, respectively. The similar relationship was reported by Sezen et al. (2011a).

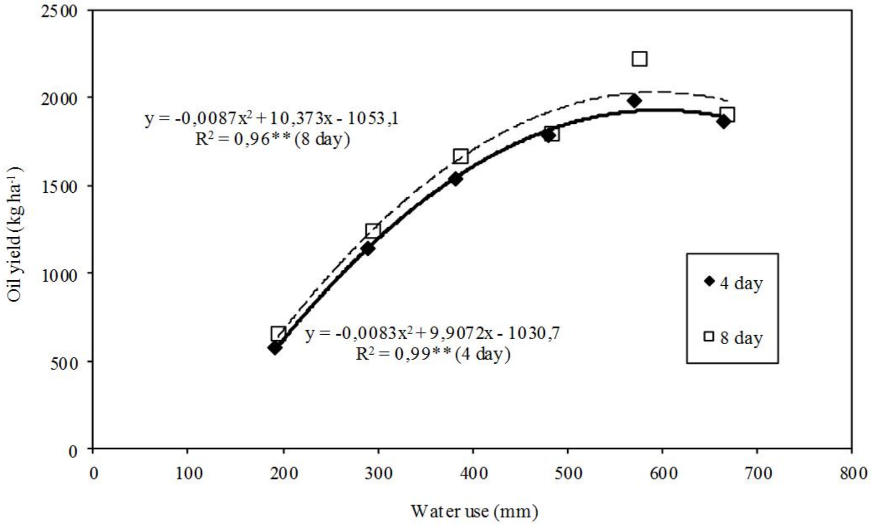

Figure 3. Oil yield as a function of water use

CONCLUSIONS

Results of the study significantly demonstrated that the effects of the amount of the irrigation water and interval are the major factors in obtaining higher yields and better quality in sunflower production under Aegean conditions. Irrigation intervals and levels had significant effects on the yield and yield components of sunflower. The maximum average yield was obtained from IL-100 treatment as averaging 4993.5 kg ha^{-1} of the two growing season with the highest water use. Moreover the 8-day IL-100 treatment yielded in better quality compared to the other treatments, due to the positive effects of the higher irrigation intervals (8-days).

The results indicated that the WUE and IWUE values decreased with the increasing irrigation interval. The higher WUE and IWUE were obtained at the lowest irrigation level of each irrigation interval. However, the lowest irrigation levels resulted in lower seed yields and lower oil content. Significant relationships between seed yield and the seasonal water use were found for each irrigation intervals in this study.

In conclusion, in a semi-arid region with water abundant conditions, the 8-day IL-100 treatment is recommended for drip irrigated sunflower for obtaining higher yield and better quality. The higher amounts of irrigation water use and plant water consumption positively affects sunflower yield and quality parameters (head diameter, stem diameter, plant height, 1000-seed weight and oil yield). On the other hand, when the amount of applied water through drip irrigation was reduced 25 % (IL-75), the observed decrease in yield was about 7 % in both years. Thus, the results obtained from the 8-day IL-75 treatment could be used as a good basis for reduced drip irrigation strategy development in semi-arid regions under water shortage.

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