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Effect of rainfed and irrigated conditions on yield and quality traits of new-improved sunflower (*Helianthus annuus*) hybrids in a sub-humid climate

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ABSTRACT

The study was carried out to compare the effects of a rainfed (non-irrigated) and irrigated conditions on yield, certain yield components and quality traits of new-improved sunflower (*Helianthus annuus* L.) hybrids in southern Marmara Region, Turkey having a sub-humid climate. Over two years (2006 and 2007), significant differences for all characters except plant height and crude oil per-cent were found between irrigation regimes (irrigated and non-irrigated conditions) while genotypes showed significant differences for all characters investigated. Also, genotype × irrigation regime interaction was highly significant for all traits except crude oil percent. In addition, year × irrigation regime, year × genotype and year × genotype × irrigation regime interactions were statistically significant for head diameter, 1 000 seed weight, seed yield and crude oil yield. The seed yield and crude oil yield increased highly with irrigations. The seed yield increases for irrigated treatment compared with non-irrigated treatment were 58.3 % in 2006 and 101.4 % in 2007. Compared with non-irrigated treatment, crude oil yield increases for irrigated treatments were 56.9 % in 2006 and 99.4 % in 2007. Differences between genotypes in seed yield and crude oil yield significantly varied according to irrigated and non-irrigated conditions. The control variety, Sanay and experimental hybrid, C 10 × R 10 produced more seed yield and crude oil yield than those of others in irrigated conditions, whereas highest seed yield and crude oil yield was obtained from the control variety, Muson in non-irrigated condition and differences among other hybrids were not statistically significant under rainfed condition.

Key words: Irrigated, Non-Irrigated, Quality, Sunflower and Yield

Sunflower (*Helianthus annuus* L.) is an important oilseed crop for Turkey. Oil crops were grown only at about 9.1 % of the total cropped area, which was 21.5 million hectare (TUIK 2008). Sunflower has the largest planting area with proportion of 49.4 % in annual oilseed crops in Turkey. Generally, sunflower is grown as a dryland in many countries of the world. However, water is a primary limiting factor, especially for summer crops such as sunflower in Turkey. Therefore, the low yield is usually obtained from sunflower grown under dryland conditions. It is likely that the low yield is mainly due to water stress depending upon low precipitation during the summer. The water stress resulted in less evapotranspiration (ET) by closure of the stoma, reduced assimilation of carbon and decrased biomass production (Demir *et al.* 2006).

Sunflower is generally considered moderately resistant to drought and is often grown in hot, semi-arid climatic regions (Hatim and Abbasi 1994, Fick and Miller, 1997), but the water requirement of this crop is higher than other crops (Hatim and Abbasi 1994). At any stage of plant development, a soil moisture deficit will have a negative impact on sunflower yield, but the severity of drought effect depends on the developmental stage of sunflower plants. The greatest yield reductions resulting from drought occur at flowering up until seed maturation (Skoric 2009). The critical period for seed yield in drought tolerance starts about 20 days before and ends about 20 days after flowering (Robelin 1967, Robinson 1973).

There are differences between sunflower cultivars in drought tolerance. Early maturity is an important vehicle for drought escape, suitable for environments subjected to late-season drought stress (Singh 2000). In addition, Merrien and Champolivier (1996) reported that the escape from water deficit (i e sowing date, earliness, etc.) could provide yield benefits higher than those coming from the genetic effect (more than 1 tonne/ha, versus 0.1 to 0.2 tonne/ha for the genetic gain). Fick and Miller (1997) noted that one approach in breeding for drought resistance is to develop high-yielding

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cultivars that flower and mature before soil water conditions become limiting.

In the Marmara region, the largest sunflower production center of Turkey, there is sufficient moisture in soil at sowing time and during early spring season for the crop to germinate, emerge and grow. Water stress starts at the flowering period of sunflower plants in this region. Schneiter *et al*. (1988) found that approximately 75 to 80 % of the seasonal water is used by the time the plants had reached the flower anthesis stage. Therefore, sunflower is usually grown as a dryland crop in the arid and semi-arid region of Turkey and also in the Marmara region having a sub-humid climate. However, the highest seed yield and oil content are achieved with early plantings in the arid, semi-arid, and sub-humid regions, because plants escape from water stress with the early plantings under dry conditions in these climates. Also, it is likely that higher seed yield and oil content are obtained by using of early-flowering cultivars. But, sunflower yield decreases in years of low rainfall under dry conditions of these regions. In the last 20 years, seed production of sunflower in Turkey has greatly increased in areas where high yielding and adapted hybrid cultivars have been planted (Oz *et al*. 2009) because of their resistance to drought.

Sunflower responds to irrigation and yield increments exceeding 100 % are common on soil of low water holding capacity (Robinson 1971). Especially, hybrid cultivars having high seed-cost give the highest yield only when irrigated (Unger 1982 and Flagella *et al*. 2002).

The aim of this research was to compare the effects of irrigated and non-irrigated conditions on yield, certain yield components and quality traits of the new-improved sunflower hybrids in the southern Marmara region having a sub-humid climate.

MATERIALS AND METHODS

Field trials were conducted for two consecutive summer seasons (2006 and 2007) at the Research and Training Field of the Mustafakemalpasa Vocational School, Bursa, Turkey (40°02'N, 28°23'E, 22 m above sea level) on a clayey loam (23.6 % sand, 43.6 % silt and 32.8 % clay content) soil having 0.15 % total nitrogen content (Kjeldahl Method), 0.79 kg/ha phosphorus (Olsen Method, P_2O_5), 6.1 kg/ha exchangeable potassium (Ammonium Acetate Method, K_2O), 1.8 % organic matter (Walchey-Black Method), and a bulk density of 1.44, 1.36 and 1.44 g cm^3 in 0-30.0, 0.30-0.60 and 0.60-0.90 m profile, respectively. The soil pH was 7.8. The water holding capacity (WC) of the experimental site was observed as 186 mm in a 0.90 m soil profile. WC was determined by the difference between the water content at field capacity (FC) and at permanent wilting point (PWP). Waterlogging is not observed in the area as the water table of soil is deeper than 100 cm in early spring. Average annual rainfall was 679 mm and 14.2 °C mean monthly temperature. Total monthly precipitation and mean air temperature data during the sunflower growing period are presented in Table 1. Total rainfall from March to August were 147.4, 164.4 and 217.9 mm in 2006, 2007 and 1975 to 2007, respectively. This correspond to 32 % of the annual precipitation. It is insufficient for sunflower production as expected.

Table 1 Mean air temperature and total monthly precipitation during the sunflower growing period in 2006, 2007 and between 1975 to 2007 at Mustafakemalpasa, Bursa.

Month	Temperature (°C)			Precipitation (mm)		
	2006	2007	1975-2007	2006	2007	1975-2007
March	9.6	9.5	8.4	57.0	57.9	64.9
April	14.2	11.4	12.9	13.0	32.8	57.9
May	18.9	19.9	17.2	9.3	12.1	42.9
June	22.4	24.6	21.6	62.8	47.2	23.4
July	24.2	26.2	23.6	2.0	13.4	13.9
August	26.8	26.4	23.3	3.3	1.0	14.9
Total				147.4	164.4	217.9

Thirteen sunflower genotypes (two restorer lines and three cytoplasmic male sterile lines, as parental and their six experimental hybrids and commercial hybrid varieties as check) were evaluated under irrigation and dryland conditions for their seed yield, certain agronomical and quality characteristics in this study. Six experimental hybrids were produced by factorial cross of three cytoplasmic male sterile lines; C 1, C 10 and C 23 and two restorer lines; R 3 and R 10. These parental materials were selected from different origins and representing the elite varieties commonly grown in the world by the Field Crops Department, Faculty of Agriculture, Uludag University in Bursa, Turkey. In addition, two hybrid varieties, Sanay (Syngenta Seed Company) and Muson (MAY Seed Company) were used as check varieties.

Three growth periods of sunflower which were suggested by Doorenbos and Kassam (1979): heading (H), flowering (F) and milking (M), sensitive to water stress, were considered at irrigated plots. Drip irrigation was scheduled on the basis of the periods. Date of irrigations and amounts of irrigation water are shown in Table 2. Irrigation water was applied to all plots to reach 100 % of the total available water. A watermeter was used to measure the amount of water applied by the drip irrigation system. Rainfall was measured also.

In the experiment, individual subplot size was 9.75 m^2 (5 m × 1.95 m). The row-to-row and plant-to-plant spacings

Table 2 Irrigation schedules and amonuts of supplied water

Growth period	Irrigation date (day/month)		Supplied water (mm)	
	2006	2007	2006	2007
Heading	23/06	21/06	120	117
Flowering	05/07	06/07	106	98
Milking	26/07	23/07	125	111
Total			351	326

were 0.65 and 0.25 m, respectively. Plantings were done on 19 April 2006 and 17 April 2007. Sixty kilograms of nitrogen per hectare (as ammonium nitrate) was applied prior to sowing and a further 60 kg N/ha (as urea) was added when the plants were 30-40 cm in height. After planting, Linuron was sprayed at a rate of 0.20 cm^3/m for weed control.

Twenty plants were randomly selected from each plot (at maturity period of plants) for measurement of plant height, head diameter. After plots were harvested, seed yield, 1 000 seed weight, crude oil percentage and crude oil yield were recorded. Crude oil percentage was determined by the Soxhlet extraction technique (Pomeranz and Clifton 1994). Crude oil yield was calculated as a function of seed yield and crude oil percentage. Thirteen sunflower genotypes and two different irrigation regimes (dryland and irrigation conditions) were tested in a randomized split plot design with three replications. Irrigation regimes were main plots and genotypes subplot. All data were subjected to analysis of variance for each character using MSTAT-C (version 2.1, Michigan State University, 1991) and MINITAB (University of Texas at Austin) software.

RESULTS AND DISCUSSION

Effects of years, genotypes and irrigation regime (rainfed and irrigated environments) on yield and other agronomical characteristics are presented in Table 3. The analysis of variance showed that during two-years of research there were significant differences for several characteristics in terms of effects of years, genotypes and irrigation regimes. According to the data combined over two years, differences between effects of years were not statistically significant for all characters except plant height, head diameter and 1 000 seed weight. Genotypes showed significant differences for all characters. In addition, significant differences for all characters except plant height and crude oil percent were found between irrigation regimes. Genotype × irrigation regime interaction was also highly significant for all traits except crude oil percent. On the other hand, year × irrigation regime, year × genotype, and year × genotype × irrigation regime interactions significantly affected head diameter, 1 000 seed weight, seed yield and crude oil yield.

Differences between genotypes were significant for all characters observed in each individual experimental year, except for crude oil percent in 2007. The effects of irrigation regimes were significant for 1 000 seed weight, seed yield and crude oil yield in both 2006 and 2007; for head diameter in 2007. On the other hand, G × IR interaction showed significant differences for plant height in 2006; for head diameter in 2007; for 1 000 seed weight, seed yield and crude oil yield in both 2006 and 2007.

The mean values of all characters measured in different irrigation regimes, genotypes and G × IR interactions are summarized in Table 4. There were no significant differences in plant height between irrigated and non-irrigated conditions. Differences between genotypes were highly significant in plant height. Check hybrid varieties, Sanay and Muson

Table 3 Variance analysis

Source	Degree of freedom		Plant height			Head diameter			1000 seed weight		
	(1)	(2)	2006	2007	2006-07	2006	2007	2006-07	2006	2007	2006-07
Years (Y)		1			**			**			**
Blocks	2	4	ns	ns	ns	ns	ns	ns	ns	ns	ns
Irrýgation regime (IR)	1	1	ns	ns	ns	ns	**	**	**	*	**
Y × IR		1			ns			**			**
Error (a)	2	4									
Genotypes (G)	12	12	**	**	**	**	**	**	**	**	**
IR × G	12	12	*	ns	**	ns	**	**	**	**	**
Y × G		12			ns			**			**
Y × IR × G		12			ns			**			**
Error (b)	48	96									
			Seed yield			*Crude oil percent*			*Crude oil yield*		
			2006	*2007*	*2006-07*	*2006*	*2007*	*2006-07*	*2006*	*2007*	*2006-07*
Years (Y)		1			ns			ns			ns
Blocks	2	4	ns	ns	ns	ns	ns	ns	ns	ns	ns
Irrýgation regime (IR)	1	1	**	**	**	ns	ns	ns	**	**	**
Y × IR		1			**			ns			**
Error (a)	2	4									
Genotypes (G)	12	12	**	**	**	**	ns	**	**	**	**
IR × G	12	12	**	**	**	ns	ns	ns	**	**	**
Y × G		12			**			ns			**
Y × IR × G		12			**			ns			**
Error (b)	48	96									

Table 4 Effects of years, genotypes, irrigation regimes and its interactions on plant height and head diameter of sunflower

Treatment	Plant height (cm)			Head diameter (cm)		
	2006	2007	2006-2007	2006	2007	2006-2007
			Years			
2006	192.2 a			18.2 a		
2007	181.6 b			16.4 b		
LSD (0.05)	4.4			0.7		
			Irrigation regimes			
Irrigated	194.3	183.7	188.9	18.3	19.3 a	18.8 b
Non-irrigated	190.2	179.5	184.8	18.1	13.5 b	15.8 a
LSD (0.05)	ns	ns	ns	ns	2.0	0.7
			Genotypes			
C 01	213.0 b	207.6 b	210.3 b	19.8 bc	17.0 e	18.4 b-d
C 10	189.3 c-e	178.6 d	183.9 de	20.7 ab	17.5 c-e	19.1 a-c
C 23	180.3 e	175.3 d	177.8 e	18.5 c	19.1 a-c	17.9 d
R 03	148.8 f	126.8 f	137.8 f	9.6 d	8.4 f	9.0 e
R 10	148.2 f	142.6 e	145.3 f	7.9 e	8.3 f	8.1 e
C 01 × R 03	195.3 c	192.5 c	193.9 c	19.8 bc	17.3 de	18.5 b-d
C 10 × R 03	191.3 cd	178.1 d	184.7 de	19.6 bc	16.9 e	18.2 cd
C 23 × R 03	185.3 de	180.6 cd	182.9 de	19.7 bc	18.9 ab	19.3 ab
C 01 × R 10	193.5 cd	182.8 cd	188.2 cd	21.1 ab	17.5 c-e	19.3 ab
C 10 × R 10	189.2 c-e	177.2 d	183.2 de	21.6 a	18.7 a-c	20.1 a
C 23 × R 10	189.8 c-e	174.2 d	182.0 de	19.1 c	19.8 a	19.4 ab
Sanjay	235.2 a	216.7 ab	225.9 a	19.9 bc	18.4 b-d	19.1 a-c
Muson	239.7 a	227.6 a	233.6 a	18.9 c	17.8 b-e	18.4 b-d
LSD (0.05)	9.6	13.8	8.3	1.5	1.3	1.0
			Irrigation regimes × Genotypes			
Irrigated						
C 01	227.7 c	215.2	221.4 b	19.7	19.6 d	19.6 c-e
C 10	192.7 de	184.9	188.8 cd	20.9	20.0 cd	20.5 bc
C 23	176.2 f	173.1	174.6 f	18.0	19.5 d	18.7 d-f
R 03	145.7 g	130.9	138.3 g	9.7	9.3 g	9.5 j
R 10	146.3 g	150.6	148.5 g	8.8	8.7 g	8.7 jk
C 01 × R 03	196.3 de	202.2	199.2 c	19.6	20.2 cd	19.9 cd
C 10 × R 03	197.0 de	181.0	188.9 cd	19.8	21.0 cd	20.4 bc
C 23 × R 03	184.7 ef	175.9	180.3 d-f	20.2	22.9 ab	21.5 ab
C 01 × R 10	194.0 de	182.8	188.4 cd	20.5	21.1 b-d	20.8 a-c
C 10 × R 10	189.3 d-f	175.2	182.3 d-f	22.3	21.6 bc	21.9 a
C 23 × R 10	187.3 d-f	165.0	176.2 ef	19.7	24.5 a	22.1 a
Sanjay	241.3 ab	221.4	231.3 ab	19.6	21.7 bc	20.7 a-c
Muson	247 a	229.7	238.4 a	19.0	21.2 b-d	20.1 b-d
Non-irrigated						
C 01	198.3 d	200.0	199.2 c	19.9	14.4 ef	17.2
C 10	186.0 d-f	172.3	179.1 d-f	20.4	15.0 e	17.7 f-h
C 23	184.7 ef	177.4	181.0 d-f	19.1	14.9 e	17.0 g-ý\
R 03	152.0 g	122.7	137.3 g	9.5	7.5 g	8.5 jk
R 10	150.0 g	134.5	142.2 g	7.0	7.8 g	7.4 k
C 01 × R 03	194.3 de	182.8	188.6 cd	20.0	14.4 ef	17.2 g-ý
C 10 × R 03	185.6 d-f	175.2	180.4 d-f	19.4	12.8 f	16.1 ý
C 23 × R 03	186.0 d-f	185.4	185.7 d-f	19.2	14.9 e	17.1 g-ý
C 01 × R 10	193.0 de	182.9	188.0 cd	21.7	13.9 ef	17.8 f-h
C 10 × R 10	189.0 d-f	179.2	184.1 d-f	20.9	15.7 e	18.3 e-g
C 23 × R 10	192.3 bc	183.5	187.9 c-e	18.5	15.1 e	16.8 hý
Sanjay	229.0 bc	212.1	220.5 b	20.1	15.1 e	17.6 f-h
Muson	232.3 bc	225.4	228.8 ab	18.7	14.5 ef	16.6 hý
LSD (0.05)	13.5	ns	11.7	ns	1.8	1.4

produced the tallest plants (225.9 and 233.6 cm) while the shortest plants (137.8 and 145.3 cm) were obtained from restorer lines (R 03 and R 10).

Significant G × IR interaction indicated that differences between genotypes in plant height varied with respect to irrigated and non-irrigated conditions. Generally, experimental hybrids showed a little difference in plant height under non-irrigated conditions, compared with the irrigated conditions while check hybrid varieties resulted in tallest plants in both irrigated and non-irrigated conditions (Table 4). Our findings do not correspond to those of Beg *et al*. (2007) who reported that there were highly significant differences in plant height due to water level and year × water level interaction. Similarly, Khaliq and Cheema (2005) reported that plant height varied with irrigation treatments. Since plant height is determined by several environmental factors (climatic factors and soil fertility, etc.) as well as genotypical structure, it is likely that differences between results of the researches are mainly due to environmental conditions.

There were significant differences in head diameter between irrigation regimes. The mean of two-year data indicated that irrigated conditions produced higher head diameter compared with the non-irrigated treatment. Results of the second experimental year were also similiar to two-year combined data. Contrary to those, head diameter was not significantly influenced by the irrigation regimes in the first experimental year. Meo and Baig (1999) reported that when the water stress period was increased, the head diameter (8.25 cm) was observed in S_o (zero stress) and maximum significant decrease was observed in S_1 (stress after 20 days of sowing). Khaliq and Cheema (2005) found that head diameter increased with irrigation treatments. Our findings were compatible with those experiments given above. The Y × IR interaction was found significantly due to differences between irrigation regimes with respect to the experimental years. Similar results were reported by Beg *et al*. (2007). The genotypes were significantly different in terms of head diameter. The highest head diameter means (19.1-20.1 cm) were obtained from experimental hybrids; C 10 × R 10, C 23 × R 03, C 01 × R 10, C 23 × R 10, inbred line; C 10 and check variety, Sanay; whereas restorer lines gave the least head diameter values. Differences between genotypes varied a little with respect to the experimental years. It is likely that the G × Y interaction was highly significant due to the differences in the experimental conditions. In addition, differences between genotypes also showed variation with respect to irrigated and non-irrigated conditions. There were slightly differences between the hybrid genotypes under non-irrigated conditions, while the hybrids, C 23 × R 10, C 10 × R 10, C 23 × R 03, C 01 × R 10 and check variety, Sanay had significantly higher head diameter than the others under irrigated conditions. The effect of the years on the head diameter was statistically significant. The first experimental year (18.2 cm) produced higher mean head diameter than the second experimental year (16.4 cm).

The 1 000 seed weight significantly increased under irrigated conditions (57.3 g) compared with non-irrigated conditions (48.5 g). Among the genotypes, experimental hybrids; C 01 × R 03 (66.5 g), C 01 × R 10 (65.3 g), C 23 × R 10 (65.3 g) and check varieties, Sanay (68.0 g) and Muson (65.9 g) had more 1 000 seed weight than those of the other genotypes. Results indicated that the 1 000 seed weight of genotypes significantly varied according to irrigation regimes and years. The highest 1 000 seed weight values were obtained from the hybrids, Sanay (72.4 g), C 01 × R 10 (70.5 g), C 01 × R 03 (70.1 g), C 10 × R 10 (68.6 g) and Muson (68.4 g) and the lowest from the hybrid, C 23 × R 03 (59.7 g) under irrigated conditions, whereas there were slight differences between hybrid genotypes due to unfavourable environmental conditions in non-irrigated treatment. In 2006, the highest 1000 seed weight values were obtained from the hybrids, C 01 × R 03 (80.0 g), C 01 × R 10 (74.1 g), Muson (72.1 g) and Sanay (70.8 g), but the lowest mean values from these hybrids except Sanay in 2007 (Table 5).

The average 1 000 seed weight was more value in 2006 (56.4 g) compared with 2007 experimental year (49.3 g). Our findings are in agreement with those of Chaudhary *et al.* (1998), Baksh *et al*. (1999), Khaliq and Cheema (2005) and Göksoy *et al*. (2004) who reported that the 1 000 seed weight increased as the amount of irrigation water or number of irrigation increased compared with non-irrigated treatment. In addition, our results on irrigation regime × genotype interaction for 1000 seed weight are supported by Khani *et al.* (2005) who reported that cultivars significantly varied for 1 000 seed weight under drought stress and no-stress conditions.

Our results clearly indicate that seed yield highly increased with irrigations. Irrigated treatment (3368.7 kg/ha) produced 78.2 % higher seed yield than the non-irrigated treatment (1 890.0 kg/ha). Significant Y × R interaction showed that differences between irrigated and non-irrigated treatments in terms of seed yield were greater in 2007 than that in 2006.

The seed yield increases for irrigated treatment compared with non-irrigated treatment were 58.3 % in 2006 and 101.4 % in 2007. Over the two years, the highest seed yields were obtained from check varieties. Sanay (3 568.8 kg/ha) and Muson (3 498.6 kg/ha), followed by experimental hybrids, C 10 × R 10 (3 393.0 kg/ha), C 23 × R 10 (3 337.6 kg/ha), C 23 × R 03 (3 225.1 kg/ha) and C 01 × R 10 (3 314.9 kg/ha) while the lowest by restorer lines, R 03 (537.8 kg/ha) and R 10 (438.5 kg/ha). Significant G × Y interaction revealed that differences between genotypes in seed yield highly varied according to the experimental years. Results of the first experimental year were similiar to the data combined over two-years. Whereas in the second experimental year, the highest seed yields were obtained from experimental hybrids, C 01 × R 10, C 10 × R 10 and C 23 × R 10 and check

Table 5 Effects of years, genotypes, irrigation regimes and its interactions on 1 000 seed weight and seed yield of sunflower

Treatment	1 000 seed weight (g)			Seed yield (kg/ha)		
	2006	2007	2006-2007	2006	2007	2006-2007
			Years			
2006	56.4 a			2626.7		
2007	49.3 b			2631.9		
LSD (0.05)	2.1			ns		
			Irrigation regimes			
Irrigated	58.9 a	55.6 a	57.3 a	3219.8 a	3517.5 a	3368.7 a
Non-irrigated	53.9 b	43.0 b	48.5 b	2033.6 b	1746.4 b	1890.0 b
LSD (0.05)	2.0	6.3	2.1	126.1	128.4	58.3
			Genotypes			
C 01	48.2 e	44.4 d	46.3 e	2172.0 c	2387.5 a	2279.7 g
C 10	49.7 e	42.0 d	45.8 e	2079.2 e	2273.2 c	2176.2 gh
C 23	49.0 e	41.3 d	45.2 e	1998.7 e	2206.8 c	2102.8 h
R 03	14.3 f	20.7 e	17.5 f	413.2 f	662.5 d	537.8 ý
R 10	17.3 f	19.9 e	18.6 f	363.3 f	513.7 d	438.5 ý
C 01 × R 03	75.9 a	56.9 bc	66.5 ab	3122.5 d	3136.5 b	3129.5 f
C 10 × R 03	64.7 cd	56.7 bc	60.7 cd	3391.0 bc	2967.0 b	3179.0 ef
C 23 × R 03	62.5 d	53.9 c	58.2 d	3405.7 bc	3044.5 b	3225.1 d-f
C 01 × R 10	73.3 ab	57.4 bc	65.3 ab	3269.2 cd	3360.7 a	3324.9 c-e\
C 10 × R 10	64.6 cd	63.2 a	63.9 bc	3370.3 bc	3415.7 a	3393.0 bc
C 23 × R 10	72.8 ab	57.8 b	65.3 ab	3314.2 cd	3361.0 a	3337.6 cd
Sanjay	71.7 ab	64.3 a	68.0 a	3679.7 a	3457.8 a	3568.8 a
Muson	69.4 bc	62.4 a	65.9 ab	3568.7 ab	3428.5 a	3498.6 a
LSD (0.05)	6.2	3.6	3.5	229.3	18.5	145.2
			Irrigation regimes × Genotypes			
Irrigated						
C 01	54.5 h	51.7 f-h	53.1 j	2565.3 e-g	3193.0 d	2879.2 f
C 10	58.2 f-h	50.3 gh	54.3 ýj	2466.9 fg	3183.0 d	2824.5 f
C 23	57.1 gh	48.5 h	52.8 j	2485.0 fg	3065.7 d	2775.8 f
R 03	13.4 k	25.9 j	19.6 lm	671.0 j	946.3 l	809.7 k
R 10	22.4 j	21.6 jk	22.0 l	562.0 j	748.7 l	655.8 k
C 01 × R 03	80.0 a	60.2 de	70.1 ab	3746.0 c	4226.0 bc	3986.0 e
C 10 × R 03	69.1 b-d	63.5 cd	66.3 b-e	3840.0 c	4173.7 bc	4006.3 de
C 23 × R 03	59.2 e-h	60.3 de	59.7 f-h	4336.0 b	4087.6 c	4211.3 b-d
C 01 × R 10	74.1 a-c	66.9 bc	70.5 ab	3889.7 c	4516.0 a	4202.3 b-d
C 10 × R 10	67.5 c-e	69.8 ab	68.6 a-c	4234.7 b	4558.4 a	4396.7 ab
C 23 × R 10	67.9 c-e	65.8 bc	66.9 b-e	4248.0 b	4380.3 ab	4314.2 bc
Sanjay	70.8 bc	73.9 a	72.4 a	4630.3 a	4571.0 a	4600.5 a
Muson	72.1 a-c	64.7 cd	68.4 a-d	4186.0 b	4083.3 c	4135.7 c-e
Non-irrigated						
C 01	41.9 ý	37.1 ý	39.5 k	1778.7 h	1582.0 k	1680.3 ý
C 10	41.2 ý	33.7 ý	37.4 k	1692.3 hý	1363.3 k	1527.8 ýj
C 23	41.0 ý	34.2 ý	37.6 k	1512.3 ý	1349.0 k	1430. 7 j
R 03	15.2 jk	15.5 l	15.4 m	155.3 k	378.7 m	267.0 l
R 10	12.2 k	18.2 kl	15.2 m	164.7 k	297.7 m	222.2 l
C 01 × R 03	71.9 a-c	53.8 fg	62.8 ef	2499.0 fg	2047.0 gh	2273.0 h
C 10 × R 03	60.4 d-h	49.7 gh	55.1 h-j	2942.0 d	1761.3 ýj	2351.7 gh
C 23 × R 03	65.9 c-g	47.6 h	56.7 g-j	2475.3 fg	2002.3 hý	2238.8 h
C 01 × R 10	72.5 a-c	47.9 h	60.2 fg	2649.7 ef	2205.3 f-h	2427.5 gh
C 10 × R 10	61.7 d-h	56.6 ef	59.2 f-ý	2507.0 e-g	2273.7 fg	2390.3 gh
C 23 × R 10	77.7 ab	49.9 gh	63.8 c-f	2380.3 g	2341.7 f	2361.0 gh
Sanjay	72.7 a-c	54.6 fg	63.6 c-f	2729.0 de	2345.0 f	2537.0 g
Muson	66.8 c-f	60.2 de	63.5 d-f	2951.3 d	2773.7 e	2862.5 f
LSD (0.05)	8.8	5.1	5.0	229.3	262.4	205.1

varieties, Sanay and Muson. On the other hand, differences between genotypes for seed yield significantly varied according to the irrigated and non-irrigated conditions, as well. Among the hybrids, Sanay (4 600.5 kg/ha) and C 10 × R 10 (4 396.7 kg/ha) had more seed yield than those of the others in irrigated treatment while the highest seed yield was obtained from Muson (2 862.5 kg/ha) and differences between the other hybrids were not statistically significant in non-irrigated treatment. Our findings revealed that Sanay and C 10 × R 10 were promising hybrids for irrigated conditions and check varitey Muson for non-irrigated conditions. However, significant Y × IR × G interaction indicated that the promising hybrids determined irrigated and non-irrigated conditions changed with respect to the years (Table 5). Thakuria *et al.* (2003) and Beg *et al*. (2007), reported that seed yield obtained under rainfed conditions was significantly lower than those obtained under supplementary irrigation, with both lower and higher quantity of irrigation water. Unger (1982) suggested that seed yield was the highest with irrigation treatment with no water stress, followed by irrigation treatment applied at flowering and at the end of flowering. Similarly, Baksh *et al*. (1999) found that seed yield was the lowest in non-irrigated treatments, whereas it was the highest in six irrigation treatments. Similar findings were also reported by Chaudhary *et al.* (1998), Meo and Baig (1999), Sur and Sharma (1999), Ghani *et al*. (2000), Goksoy *et al.* (2004), Khaliq and Cheema (2005). Our results are in close agreement with those experiments given above.

In addition, our results on G × Y, IR × G and IR × G × Y interactions do not correspond to that Beg *et al*. (2007) who found that the year × cultivar, water level × cultivar and year × cultivar × water level interactions were not statistically significant. It is likely that different results were due to differences between experiments, genotypes and environment conditions. On the other hand, Esmaeili and Golchin (2005) found that the main effect of irrigation and interaction of irrigation and cultivar on seed yield were statistically significant.

Crude oil percent, an important quality component in sunflower, was not affected by irrigation regimes. Mean crude oil percent for irrigated and non-irrigated treatments were 36.8 % and 37.2 %, respectively. Similar results were obtainbed at individual experimental years, also. All the experimental hybrids had higher crude oil percent, varied from 36.8 % to 37.6 % compared with check varieties (36.3 % to 36.6 %). Differences between genotypes in crude oil percent significantly varied according to the years even though the G × Y interaction was not significant. Crude oil percent of all genotypes was similar (36.5 %) and 37.8 % in 2007 while there were significant differences between genotypes in 2006. The highest crude oil percent means were obtained from experimental hybrids, C 01 × R 03, C 10 × R 03, C 23 × R 03 and C 10 × R 10. The IR × G interaction indicated that crude oil percents of genotyes did not change according to the irrigated and non-irrigated conditions. Mean crude oil percents varied from 36.1 % to 37.7 % for all genotypes according to the both irrigated and non-irrigated conditions (Table 6). Our findings are in agreement with those of Goksoy *et al.* (2004), Karaata (1991), and Mendez-Natera *et al*. (2007) who reported that oil percentage in sunflower was not affected by irrigation treatments. However, in many previous studies, it was also reported that oil percentage increased with irrigation (Jana *et al*. 1982), Tan *et al*. 2000, Unger, 1982, Flagella *et al*. 2002 and Chaudhary *et al.* 1998). It is likely that differences between results are mainly due to environmental conditions and genotypic structure. In additon, Mendez-Natera *et al*. (2007) reported that there were no significant differences for cultivars, irrigation intervals and and irrigation intervals × cultivar interaction for seed oil content. Our findings were similiar to that results given above.

In contrast to the crude oil percent, crude oil yield was affected by the irrigation treatments because of the different seed yields. In our study, irrigated treatment resulted in 83.7% more crude oil yield (1 240 kg/ha), comparing with non-irrigated treatment 675 kg/ha). Increases in crude oil yield with irrigated treatment varied according to experimental years. Compared with non-irrigated treatment, the crude oil yield increases for irrigated treatment were 56.9 % in 2006 and 99.4 % in 2007. Over the two-year means, the highest crude oil yields were obtained from check varieties, Sanay (1 304.7 kg/ha) and Muson (1 267.4 kg/ha) and experiment hybrid, C 10 × R 10 (1 248.7 kg/ha). G × Y interaction revealed that genotypes affected the crude oil yield differently, according to the years. In 2006, the highest crude oil yields were obtained from experimental hybrids, C 10 × R 03 and C 23 × R 03 and both check varieties, whereas the lowest from the same experimental hybrids in 2007. In addition, differences between genotypes varied according to the irrigated and non-irrigated conditions, also. The highest crude oil yield produced Sanay with 1 676.5 kg/ha and C 10 × R 10 with 1 610.0 kg/ha in irrigated treatment, whereas Muson with 1 043.5 kg/ha produced more crude oil yield than the other hybrid genotypes due to its higher seed yield and the other hybrids were not different for crude oil yield in non-irrigated treatment (Table 6). These results indicated that Sanay and C 10 × R 10 could be recommended for irrigated conditions and check variety Muson for non-irrigated conditions because of their higher crude oil yields. Osman and Talha (1975), Jana *et al*. (1982), Browne (1977), Kadayýfçý and Yýldýrým (2000), Goksoy *et al*. (2004) and Kumar and Rao (2006) reported that oil yield increased as the amount of irrigation water increased, compared with non-irrigated treatment.

CONCLUSION

Over the two-years period in the southern Marmara Region of the Turkey, having a sub-humid climate, the

Table 6 Effects of years, genotypes, irrigation regimes and its interactions on crude oil percent and crude oil yield of sunflower

Treatment	Crude oil percent (%)			Crude oil yield (kg/ha)		
	2006	2007	2006-2007	2006	2007	2006-2007
			Years			
2006	36.7			963.6		
2007	37.3			978.4		
LSD (0.05)	ns			ns		
			Irrigation regimes			
Irrigated	36.6	37.1	36.8	1177.0 a	1303.0 a	1124.0 a
Non-irrigated	36.9	37.4	37.2 ns	750.3 b	653.3 b	675.3 b
LSD (0.05)	ns	ns		53.1	54.2	23.0
			Genotypes			
C 01	36.4 de	37.7	37.1 a-d	792.7 d	900.4 d	846.4 e
C 10	37.3 a	37.6	37.5 ab	775.5 d	853.9 de	814.7 ef
C 23	36.0 e	36.6	36.3 de	718.7 d	805.3 e	762.0 f
R 03	36.5 c-e	37.1	36.7 b-e	150.0 e	245.4 f	197.6 g
R 10	37.4 a	37.6	37.5 ab	135.2 e	192.7 f	164.0 g
C 01 × R 03	37.0 a-d	37.2	37.1 a-d	1154.3 c	1162.9 bc	1158.6 d
C 10 × R 03	37.1 a-c	37.7	37.4 a-c	1258.0 ab	1116.1 c	1187.0 cd
C 23 × R 03	37.3 a	37.8	37.6 a	1269.0 ab	1149.4 c	1209.2 b-d
C 01 × R 10	37.2 ab	37.5	37.4 a-c	1216.2 bc	1258.9 a	1237.6 bc
C 10 × R 10	36.6 b-e	37.1	36.8 a-e	1232.9 bc	1264.5 a	1248.7 ab
C 23 × R 10	36.5 c-e	37.1	36.8 a-e	1207.4 bc	1243.2 ab	1225.3 bc
Sanjay	36.3 e	36.9	36.6 c-e	1334.0 a	1275.5 a	1304.7 a
Muson	35.9 e	36.5	36.3 e	1283.7 ab	1251.2 a	1267.4 ab
LSD (0.05)	0.7	ns	0.8	88.4	82.5	59.5
			Irrigation regimes × Genotypes			
Irrigated						
C 01	36.8	37.6	37.2	946.1 hý	1202.0 f	1074.0 f
C 10	37.2	37.5	37.3	917.2 hý	1194.3 f	1055.5 f
C 23	35.7	36.4	36.1	888.3 ý	1115.7 fg	1001.5 fg
R 03	36.2	36.9	36.6	243.0 l	349.7 l	296.3 l
R 10	37.1	37.5	37.3	208.3 l	279.7 l	244.0 l
C 01 × R 03	36.7	36.9	36.8	1376.0 e	1562.7 c-e	1469.4 e
C 10 × R 03	36.9	37.5	37.2	1418.3 de	1566.2 b-e	1492.0 c-e
C 23 × R 03	37.1	37.6	37.4	1610.0 ab	1538.7 de	1574.8 b-d
C 01 × R 10	37.0	37.3	37.1	1439.0 de	1685.0 a	1562.0 b-d
C 10 × R 10	36.4	36.8	36.6	1543.0 bc	1677.0 a-c	1610.0 ab
C 23 × R 10	36.2	36.8	36.5	1539.0 bc	1613.3 a-d	1576.2 bc
Sanjay	36.1	36.7	36.4	1672.3 a	1681.4 ab	1676.5 a
Muson	35.8	36.3	36.1	1502.5 cd	1481.0 e	1491.3 de
Non-irrigated						
C 01	35.9	37.8	36.9	693.3 d	1582.0 jk	619.0 j
C 10	37.5	37.7	37.6	634.4 d-k	1363.3 k	574.0 jk
C 23	36.3	36.8	36.5	549.1 k	1349.0 k	533.5 k
R 03	36.7	37.2	36.9	57.0 m	378.7 m	98.9 m
R 10	37.7	37.8	37.7	62.1 m	105.7 m	83.9 m
C 01 × R 03	37.3	37.3	37.3	932.6 hý	764.2 hý	848.4 ý
C 10 × R 03	37.3	37.8	37.5	1097.7 f	666.4 ýj	882.1 hý
C 23 × R 03	37.5	38.0	37.7	927.9 hý	761.1 hý	844.5 ý
C 01 × R 10	37.5	37.7	37.6	993.5 gh	832.8 h	913.2 hý
C 10 × R 10	36.8	37.4	37.1	922.8 hý	852.0 h	887.4 hý
C 23 x R 10	36.8	37.3	37.1	875.9 ý	873.1 h	874.5 hý
Sanjay	36.5	37.1	36.8	996.3 gh	869.7 h	933.0 gh
Muson	36.1	36.8	36.5	1065.7 fg	1021.4 g	1943.5 f
LSD (0.05)	ns	ns	ns	88.1	117.3	84.2

irrigated treatment produced 58.3-101.4 % higher seed yield and 56.9-99.4 % higher crude oil yield than the non-irrigated treatment. The seed and crude oil yields of the genotypes significantly varied with respect to the irrigated and non-irrigated conditions. In non-irrigated condition, the highest seed yield and crude oil yield were obtained from check variety, Muson and differences between yield values of the other hybrids were not statistically significant. On the other hand, check variety, Sanay and experimental hybrids, C 10 x R 10 produced more seed yield and crude oil yield than those of the others in irrigated conditions.

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