THE EFFECT OF DEFICIT IRRIGATION APPLIED IN DIFFERENT PHENOLOGICAL PERIODS ON SAFFLOWER YIELD AND QUALITY

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Abstract. A field study was carried out to investigate the effect of deficit irrigation applied in the different phenological periods of safflowers (*Carthamus tinctorius* L.) at the Central Anatolian region in Turkey between 2007 and 2009. A randomized split block design in fourteen subjects with three replications was used. According to the results, the highest yield was obtained from the issue when there was no water stress during the growing period. It was found that there was a decrease in yield from the subjects when periodic water deficit was applied at various rates. At the end of the research, the most effective periods for yield were determined as flowering, vegetation, and yield formation. The average seasonal water consumption was between 234 and 591 mm; the highest and the lowest grain yield was 5.10 t ha^{-1} and 2.48 t ha^{-1}, respectively. Irrigation water usage efficiency (IWUE) ranged between 7.3 kg ha^{-1} mm^{-1} and 11 kg ha^{-1} mm^{-1}. The amount of irrigation water applied had no effect on oil ratios ranging from 28.89% to 30.66%. The effect of irrigation water applied was observed only on stearic and linoleic fatty acids. The coefficient of determination (r^2) of water-yield relationships during the experiment was obtained as 0.44, 0.71, and 0.68, respectively.
Keywords: *water use efficiency, evapotranspiration, water–yield relationship, fatty acids, oil content*

Introduction

The effects of global warming, which has increased markedly since 1980, are much more noticeable in arid and semi-arid climates (Pankova and Konyushkova, 2014; Cook et al., 2014). Due to the increasing temperatures, drought in agricultural areas makes the management of soil water in agricultural lands more and more important (Diogo, 2018; Shkolnik et al., 2019). Drought forecasts suggest that it will be more effective in the Mediterranean basin, including the Central Anatolia region (Hertig and Tramblay, 2017; Lionello et al., 2017). The main effects of drought on agricultural areas are the decrease in rainfall, the increase in recurring periods of aridity, and the lowering of groundwater due to excessive irrigation and low penetration (Gouveia et al., 2017; Caloiero et al., 2018).

Management of soil moisture in the root area is vital for plants, determination of critical and water-sensitive periods and possible drought scenarios (Pan et al., 2018; Grecksch, 2019). The main objective of water management is to maximize yield by determining the periods during which the plant is most susceptible to water shortages and the levels of sensitivity during these periods. Thanks to the development of water management strategies in plant breeding, the main objective of productive agricultural management on a watershed basis are to irrigate more land with existing water and improve the efficiency of water use (Bacelar et al., 2013; Choudhury and Singh, 2016). The development of water-saving deficit irrigation programs is also a way of ensuring food safety (Ward and Pulido-Velazquez, 2008; Shammout et al., 2018).

In Turkey, production of oilseeds (sunflower, cotton, soybean, rapeseed and safflower seeds) ranges from 2.3 to 2.7 million tonnes annually. Oilseed production distribution in

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Turkey consists of sunflower (46%), cottonseed (41%), soybean (6%), canola (5%), and safflower 2% (TUIK, 2018). Although safflower is a widely recommended plant in arid conditions such as exists in Central Anatolia, some preliminary studies have shown that the plant will produce very positive results from irrigable conditions. Many studies have been carried out on plant water consumption, water use efficiency, yield, and quality under limited irrigation conditions of the safflower in Turkey (İstanbulluoğlu, 2009; İstanbulluoğlu et al., 2009; Öztürk et al., 2009). However, the research on growing safflower in arid and semi-arid conditions as in Central Anatolia has not been sufficient. This study aims to investigate the yield, some physical characteristics (grain weight, fat ratio) and changes in the fatty acid composition at various irrigation levels during the phenological periods of safflower plants in an arid and semi-arid climate.

Material And Method

Site Description

The experimental area is located at the Soil and Water Resources Research Institute in the Alpu plain, east of Eskişehir province in Central Anatolia, Turkey. The trial site coordinates are 39° 46' north latitude and 30° 36' east longitude, and the elevation is 780 m above sea level.

Climate

The climate characteristics of the research area are continental and fall under the influence of the Central Western Anatolia climate. In general, summers are hot and dry, and winters are cold and snowy. The average annual temperature is 10.7^{0}C, the first frost is on average October 18, the last frost is on average April 20, the lowest temperature is -26.7^{0}C, the average annual rainfall is 343.2 mm, the evaporation value is 975.7 mm and the annual average relative humidity is 62% (SWRI, 2011). The monthly average temperature, rainfall and relative humidity values of the years when the trial period was carried out are given in *Table 1*.

Table 1. *Some climatic values of the experimental area during the study*

Month	Temperature, °C				Rainfall, mm				Relative Humidity, %			
	2007	2008	2009	Mean	2007	2008	2009	Mean*	2007	2008	2009	Mean*
I	0.0	-3.5	0.9	-0.2	42.2	13.1	66.3	36.1	74.1	72.2	71.2	74.8
II	1.5	0.0	3.1	1.3	14.2	2.7	74	26.7	68.1	59.4	66.6	70.3
III	5.4	8.4	4.6	5.0	24.0	29.9	39.8	35.6	63.0	56.1	60.5	63.5
IV	7.5	11.5	10.0	10.1	25.0	38.1	26.0	42.4	54.7	61.6	55.7	59.8
V	17.8	14.3	14.8	14.8	65.6	14.4	28.9	42.7	49.1	49.5	50.7	57.9
VI	20.8	20.2	20.4	18.6	58.6	2.8	7.9	31.2	47.9	40.9	41.0	54.6
VII	23.8	21.9	22.2	21.4	-	0.8	11.4	10.5	40.0	40.2	42.9	51.1
VIII	23.9	23.4	21.0	21.0	1.9	4.7	2.0	9.1	43.5	40.9	42.2	53.0
IX	17.7	17.0	16.5	16.9	-	30.9	7.2	13.4	44.9	54.7	52.8	54.8
X	12.6	11.7	14.5	11.7	19.1	8.1	18.3	25.6	57.7	59.0	52.1	61.1
XI	4.9	6.8	6.0	6.0	91.7	50.5	29.3	27.6	73.9	65.5	68.0	68.5
XII	0.6	1.5	4.6	2.1	46.1	34.7	69.7	42.3	73.3	68.5	69.7	75.7
Mean/Total	11.4	11.1	11.6	10.7	388.4	230.7	380.8	343.2	56.0	54.2	56.1	62.1

*Mean (1957–2011)

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Soil

Soil analysis tests, including physical (structure, volume weight) and chemical (pH, total salt, lime, phosphorus, potassium, organic matter) as well as infiltration tests were performed on the soils taken up to a depth of 120 cm at the research area (Tüzüner, 1990). The soil of the test area has a clay structure, consisting of slightly alkaline alluvial soils with pH values ranging between 7.50 and 8.03, and salt values varying between 0.102% and 0.187%. Although heavily structured, it is generally classified as too calcic. The soil of the test sites is defined as having high phosphorus, sufficient potassium, and low organic matter.

Irrigation water quality

The pH value of the irrigation water samples taken from the deep well in the research area was 6.8, the EC value was 0.747, the SAR value was 1.10, and no boron problem was detected (Boyacı and Karas, 2011).

Safflower variety

The safflower plant variety, Dincer, which was used in the experiment, was registered in 1977 by the Eskişehir Anatolian Agricultural Research Institute. Plant height is around 90–110 cm, the flower color is orange, the grain color is white and the plant has a thorny structure. The plant usually lasts from 127–130 days in the growing season (Boyacı and Karas, 2011).

Experimental design and field work

The experiment was conducted with a randomized split block design with 14 subjects and 3 replications (see *Table 2*). Irrigation subjects were arranged considering three different phenological periods (vegetative [V], flowering [F], yield formation [Y]) during the growing period. The plot areas were mouldboard ploughed in the fall and cultivated twice in the spring.

Table 2. *Trial subjects*

Subjects	**Application**	**Stage of development**		
		Vegetative (V)	**Flowering (F)**	**Yield formation (Y)**
S_1	VFY	I	I	I
S_2	VFY_0	I	I	0
S_3	VF_0Y	I	0	I
S_4	V_0FY	0	I	I
S_5	VF_0Y_0	I	0	0
S_6	V_0FY_0	0	I	0
S_7	V_0F_0Y	0	0	I
S_8	$V_{60}FY$	I_1	I	I
S_9	$V_{40}FY$	I_2	I	I
S_{10}	$VF_{60}Y$	I	I_1	I
S_{11}	$VF_{40}Y$	I	I_2	I
S_{12}	VFY_{60}	I	I	I_1
S_{13}	VFY_{40}	I	I	I_2
S_{14}	$V_0F_0Y_0$	0	0	0

Description of symbols: S_1-Full irrigated, I_1-0.6×S_1, I_2- 0.40×S_1, 0- No irrigation

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In the research, no water stress occurred in the subjects of irrigation (VFY) during the growing period of the plant. On the other hand, there was a certain amount of water stress in all other subjects and at least one period. For example, in VFY_0, no water stress occurred during vegetative and flowering periods and irrigation water was applied to meet plant water consumption needs during these periods; however, no irrigation was applied during the yield formation period. The index value in any period indicates the rate of application of irrigation water in that period. For example, the application of $V_{60}FY$, which is given as the subject of S_8 in *Table 2*, shows that 60% of plant water consumption is given in the vegetative period and full irrigation is performed during flowering and yield formation periods.

The plots were arranged in October (4.5 m x 6.0 m = 27 m^2), planted at the beginning of April and harvested (3.9 m x 5.0 m = 19.5 m^2) at the beginning of September. In the experiment, safflower was planted in 30 cm plant-row spacing and 10 cm plant-on-plant row. Fertilization was carried out according to soil analysis results. Base fertilization was applied to the soil by mixing before planting. All the phosphorus fertilizer and half of the nitrogen fertilizer were given up to planting depth of 4–6 cm with planting. During the second fertilization period, the remaining nitrogen was applied under the soil. The fertilizer requirement of the plant was realized according to the research results proposed by Yıldırım (2005); all parcels were based on 16 kg N, 8 kg P_2O_5 as a pure substance. 20-20-0 compound fertilizer with planting, Ammonium nitrate (33%) fertilizer was used as the top fertilizer.

Irrigation treatments, water use, and soil moisture measurements

In the experiment, the V, F and Y phenological periods were selected for the determination of irrigation periods in the experiment. Also taken into consideration were the principles specified by Doorenbos and Kassam (1979). Irrigation applications were carried out considering the effective root depth of 90 cm. Irrigation water was given to test plots utilizing a furrow method with plastic pipes and measured with a water meter. Soil moisture measurements were taken weekly from 0–30, 30–60 and 60–90 cm depths and determined by the gravimetric method.

Water budget equality was used to calculate plant water consumption.

$$ET_a = I + P - R - DP + CR \pm \Delta\ SF \pm \Delta\ SW \qquad \text{(Eq.1)}$$

where ETa: Actual evapotranspiration (mm), I: irrigation water (mm), P: precipitation (mm), R: surface runoff (mm), DP: deep percolation (mm), CR: capillary rise, ΔSF: subsurface flow (mm), ΔSW: change in soil water content (mm).

In the experiment, rainfall and irrigation water are directly measured values. Since the amount of water given at the effective root depth is as much as the field capacity, it is assumed that there is no deep percolation.

The agricultural operations and observations including irrigation made during the trial years are given in *Table 3*.

Seed Oil Content

The seeds were dried in the oven for 4 hours at 40°C and then ground using a blender. 4 grams of dried safflower seeds were extracted with petroleum ether for 6 hours in a Soxhlet system according to the AOCS method (AOCS, 1993). The n-hexane and oil mixture obtained after extraction was filtered and separated under vacuum using a rotary

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evaporator (Heidolph® brand Laborota 4000 Efficient) at 45°C. The crude oil ratio was calculated by weighing the obtained safflower oil weight.

Table 3. *Agricultural operations and observations in the experimental years*

Agricultural applications and observations	2007	2008	2009
Fallow	10/15	10/10	17/10
Tillage	04/08	03/28	04/02
Seeding	04/12	04/02	04/02
Germination	04/28	04/11	04/24
Emergence	05/02	04/20	04/30
Rosette	05/20	05/05	05/30
Fertilizing	05/30	06/02	05/25
First irrigation	06/12	06/05	06/10
Flowering (%5)	06/28	06/27	06/28
Second irrigation	07/04	07/02	07/02
Flowering (%100)	07/18	07/06	07/16
The beginning of maturidy period	07/26	07/25	07/26
Third irrigation	07/28	08/01	08/01
Harvest	09/01	08/28	08/28

Fatty Acid Composition

The fatty acid composition of the safflower oils was analyzed by gas chromatography according to the AOCS standard method. The oil samples were diluted with hexane and converted into methyl esters by esterification. Fatty acid methyl esters were analyzed by Agilent 7890A model gas chromatography using a Supelco 2380 capillary column (60 m x 0.25 mm x 0.20 µm) and flame ionization detector (FID). Helium was used as carrier gas at a flow rate of 20 cm s^{-1}. Injection, furnace and detector temperatures are 250, 185 and 260°C, respectively. 1 µL of methyl ester sample was injected into the device with a split ratio of 1/100. Fatty acid methyl esters were determined by comparing retention times with reference standards. The amounts of fatty acid methyl esters were determined by using internal standard (Methyl nonadecanoate). The contents of palmitic (16:0), stearic (18:0), oleic (18:1), and linoleic (18:2) acids were determined using a computing integrator. The effects of the independent variables on oil content and palmitic, stearic, oleic, and linoleic acid concentrations of the oil were analyzed on a percentage basis.

Statistical Analysis

Statistical analysis of the data obtained from the research was carried out following the procedure proposed by Yurtsever (1984). All data were subjected to ANOVA based on general linear models for factorial arrangement of treatments in a completely randomised design using the Statview statistical package (SAS Institute, 1998). Multiple comparisons with Duncan were used to determine the effects of treatment.

Water Use Efficiency

Water Use Efficiency (WUE) is defined as the amount of carbon assimilated as biomass or grain (Yield, Y kg ha^{-1}) produced per unit (ET, mm) of water used by the crop (kg $ha^{-1}mm^{-1}$).

$$WUE = \frac{Y}{ET} \quad \text{(Eq.2)}$$

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Irrigation Water Use Efficiency (IWUE): It takes into account the amount of irrigation water (IW, mm) applied during the trial period (kg ha^{-1}mm^{-1}).

$$IWUE = \frac{Y}{IW} \quad \text{(Eq.3)}$$

Water use–yield relationship

The data obtained from the study were used linear regression to obtain the relationship between seasonal ET and yield. Seasonal yield response factor (ky) for each year was determined using the Stewart model (Stewart et al., 1977).

$$(1 - \frac{Ya}{Ym}) = ky(1 - \frac{ETa}{ETm}) \quad \text{(Eq.4)}$$

where, Ya, actual yield (kg ha^{-1}); Ym, maximum yield (kg ha^{-1}); ETa, actual evapotranspiration (mm), ETm, maximum evapotranspiration (mm); ky, yield response factor

The ETa and ETm values in the Stewart equation are the actual ET and maximum ET values during the study. The ETa / ETm value in the equation is considered to be 1.00 for the absence of plant water stress; It is calculated by comparing the ETa value measured for other subjects where water stress occurs to the ETa value measured for the subject without water stress. The meaning of the Ky value can be interpreted as follows considering the results obtained:

Ky >1: crop response is very sensitive to water deficit with proportional larger yield reductions when water use is reduced because of stress.

Ky<1: crop is more tolerant to water deficit, and recovers partially from stress, exhibiting less than proportional reductions in yield with reduced water use.

Ky =1: yield reduction is directly proportional to reduced water use.

Results and Discussion

The effect of water stress on grain yield

The statistical results obtained during the study are given in *Table 4*, *Table 5* and *Figure 1*. Seed yield ranged between 2.48 and 5.10 t ha. The highest yield was obtained from full irrigation (S_1) application and the lowest yield was obtained from the non-irrigation (S_{14}) subject. Seed yield showed significant fluctuations between years according to water applications. In the second and third years of the experiment, higher yields were recorded in the parcels where full water was applied, whereas no significant differences were observed between the years in S_{10} application. In other applications, different reactions have occurred. This has led to significant interactions of the year x application. The combined analysis of the results have shown that seed yield was higher in the second year of the experiment compared to the other experimental years. While the highest seed yield was obtained from full irrigation application, the lowest yield was obtained from the rainfed conditions in the experiment. In general, decreasing irrigation water causes a reduction in seed yield. In the experiment, the flowering period was the most sensitive to yield loss, followed by the vegetation and yield-formation periods, respectively. The graph of the yield in the experiment carried out is given in *Figure 1-A*.

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Table 4. *The effect of irrigation treatment on trial subjects*

Subjects	Treatment	Yield (t ha^{-1})	1000 Seed weight (g)	IWUE kg ha^{-1}mm^{-1}	Oil rate (%)	Fatty Acid				
						Myristic (%)	Palmitic (%)	Stearic (%)	Oleic (%)	Linoleic (%)
S_1	VFY	5.10 ^{a}	48.96 ^{a}	8.8 ^{c}	27.83	0.11	6.17	2.14 ^{abc}	11.67	75.52 ^{a}
S_2	VFY_0	4.14 ^{b}	47.67 ^{bc}	9.1 ^{c}	28.85	0.12	6.07	2.04 ^{bc}	11.53	71.62 ^{c}
S_3	VF_0Y	3.56 ^{ef}	47.64 ^{bc}	8.1 ^{d}	27.88	0.11	6.11	2.10 ^{bc}	11.41	73.32 ^{b}
S_4	V_0FY	3.84 ^{cd}	48.58 ^{ab}	8.0 ^{d}	28.77	0.13	6.37	2.10 ^{bc}	11.85	71.97 ^{c}
S_5	VF_0Y_0	3.24 ^{g}	48.22 ^{abc}	10.2 ^{ab}	28.95	0.12	6.24	2.15 ^{abc}	11.32	71.49 ^{c}
S_6	V_0FY_0	3.56 ^{ef}	48.58 ^{ab}	9.9 ^{b}	28.01	0.13	6.30	2.05 ^{bc}	11.35	73.28 ^{b}
S_7	V_0F_0Y	3.52 ^{ef}	48.62 ^{ab}	10.6 ^{a}	28.34	0.12	6.13	2.05 ^{bc}	11.04	73.84 ^{b}
S_8	$V_{60}FY$	4.25 ^{b}	47.96 ^{abc}	8.0 ^{d}	28.55	0.12	6.03	2.22 ^{ab}	11.37	73.77 ^{b}
S_9	$V_{40}FY$	4.04 ^{bcd}	48.18 ^{abc}	7.9 ^{d}	28.46	0.12	6.09	2.10 ^{bc}	11.48	73.98 ^{b}
S_{10}	$VF_{60}Y$	4.13 ^{b}	47.41 ^{cd}	7.7 ^{d}	28.55	0.11	6.03	2.06 ^{bc}	11.53	73.14 ^{b}
S_{11}	$VF_{40}Y$	3.78 ^{de}	48.39 ^{abc}	7.9 ^{d}	28.08	0.11	6.02	2.06 ^{bc}	11.63	73.37 ^{b}
S_{12}	VFY_{60}	4.07 ^{bc}	46.59 ^{d}	7.8 ^{d}	28.12	0.12	6.13	2.05 ^{bc}	11.43	73.97 ^{b}
S_{13}	VFY_{40}	3.85 ^{cd}	48.09 ^{abc}	7.8 ^{d}	27.60	0.13	5.59	1.94 ^{c}	11.46	69.32 ^{d}
S_{14}	$V_0F_0Y_0$	2.48 ^{h}	48.26 ^{abc}	10.8 ^{a}	28.57	0.12	6.42	2.34 ^{a}	11.82	71.28 ^{c}
Mean		3.82	48.08	8.8	28.3	0.12	6.12	2.10	11.49	72.85
Year										
2007		3.65 ^{b}	47.46 ^{b}	6.9 ^{c}	26.79 ^{c}	0.13	6.32 ^{a}	2.27 ^{a}	13.17 ^{a}	73.34 ^{a}
2008		4.07 ^{a}	47.29 ^{b}	10.6 ^{a}	28.60 ^{b}	0.12	6.20 ^{a}	2.11 ^{b}	11.44 ^{b}	73.59 ^{a}
2009		3.73 ^{b}	49.50 ^{a}	8.8 ^{b}	29.51 ^{a}	0.11	5.84 ^{b}	1.92 ^{c}	9.87 ^{c}	71.62 ^{b}
Average		3.82	48.08	8.8	28.3	0.12	6.12	2.10	11.49	72.85
R		**	**	**	ns	ns	ns	**	ns	**
Y		**	**	**	**	ns	**	**	**	**
R X Y		**	**	**	ns	ns	ns	*	**	**

**Means within columns but not followed by the same letter are significantly different at the p<0.01 level by Duncan's multiple range test. ns: Not significant

Table 5. *Evapotranspiration, irrigation, seasonal irrigation water quantities, saving, water use efficiencies and yield of safflower for the treatments*

Subjects	Application	ET (mm)	Irrigation (mm)	Number of irrigation	Irrigation water saving (%)	WUE kg ha^{-1}mm^{-1}	IWUE kg ha^{-1}mm^{-1}
S_1	VFY	591	428	3	-	8.8 ^{c}	11.92
S_2	VFY_0	459	266	2	37.9	9.1 ^{c}	15.58
S_3	VF_0Y	451	272	2	36.4	8.1 ^{d}	13.10
S_4	V_0FY	510	317	2	25.9	8.0 ^{d}	12.13
S_5	VF_0Y_0	322	111	1	74.1	10.2 ^{ab}	29.28
S_6	V_0FY_0	364	155	1	63.8	9.9 ^{b}	22.68
S_7	V_0F_0Y	335	161	1	62.4	10.6 ^{a}	21.32
S_8	$V_{60}FY$	553	383	3	10.5	8.0 ^{d}	11.11
S_9	$V_{40}FY$	536	361	3	15.7	7.9 ^{d}	11.20
S_{10}	$VF_{60}Y$	554	365	3	14.7	7.7 ^{d}	11.32
S_{11}	$VF_{40}Y$	499	334	3	22.0	7.9 ^{d}	11.31
S_{12}	VFY_{60}	544	363	3	15.2	7.8 ^{d}	11.23
S_{13}	VFY_{40}	513	331	3	22.7	7.8 ^{d}	11.65
S_{14}	$V_0F_0Y_0$	234	0	0	100	10.8 ^{a}	-

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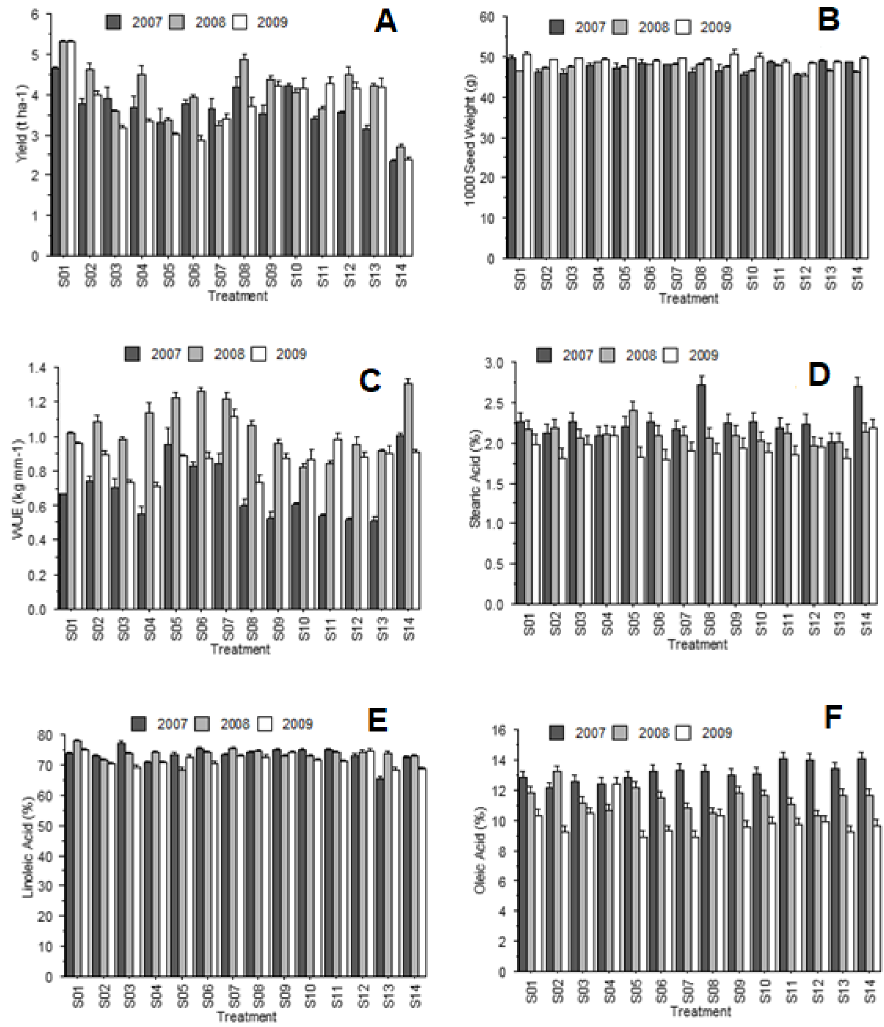

Figure 1. *Duncan grouped data in the experiment. A, yield (t ha^{-1}); B, 1000 Seed weight (g); C, WUE, kg mm^{-1}; D, stearic acid (%); E, Linoleic acid (%); F, Oleic acid (%)*

While Leonard and French (1968) obtained the highest yield as 3.68 t ha^{-1} with irrigation until the end of flowering, the lowest yield was obtained as 0.8 t ha^{-1} from irrigated subject applied until the beginning of flowering. Albel (1976) stated that the flowering period reached the maximum value of plant water consumption and that termination of irrigation during this period caused significant losses in yield. Hang and Evans (1985) indicated that water stress causes shortening in plant height, early flowering, early ripening and decrease in seed yield. Dashora and Sharma (2006) received the highest seed yield from the subject that was irrigated twice during flowering and yield formation periods. Nabipour et al. (2007) obtained the highest yield from the subject of full irrigation, whereas the lowest yield was obtained from the subject without irrigation during the flowering period. Istanbulluoglu et al. (2009) said that the effect of pre-flowering water deficit on winter safflower cultivation had more effect on the yield. Ghamarnia et al. (2010) mentioned that seed yield depends on the amount of water available in the soil. Sharrifmoghaddasi and Omidi (2010) point out that the effect on yield components of stopping irrigation after the flowering period is weak. Jabbari et al. (2010) reported that water limitation before flowering causes drastic effects. Omidi et al.

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(2012) stated that drought stress before flowering importantly influenced seed yield per plant and the number of buds per plant. The reduction rate of grain yield of safflower changed from about 10% to 38%, considering the decrease of soil moisture level. Santos et al. (2018) specified that deficit irrigation in phenological stages remarkably impacted plant height, diameter, length, fresh weight, dry weight and number of stems. They pointed out the benefit of irrigation during the vegetation period but stated that irrigation during the flowering period was more effective.

Seed Weight

The highest 1000 seed weight is achieved in full irrigation, while there is a significant reduction in limited irrigation issues. The 1000 seed weights obtained in the third year of the experiment are higher than in the first two years. While the S_5, S_8, S_9, S_{11}, S_{13} and S_{14} subjects are in the same group statistically, the data of the S_4, S_6 and S_7 subjects are listed after the statistics of full irrigation. The effect of full watering during the vegetative period led to a higher seed weight of 1000 compared to the flowering and yield formation periods. The graph of the 1000 seed weight in the experiment carried out is given in *Figure 1-B*.

Irrigation Water Use Efficiency (IWUE)

The highest IWUE value was obtained from the S_{14} subjects where no irrigation was applied and from the S_7 subjects where irrigation was performed only during the yield formation period. Full irrigation did not give the highest IWUE value. The lowest IWUE values were observed in S_3, S_4, S_8, S_9, S_{10}, S_{11}, S_{12} and $S_{13,}$ in which 40% and 60% of deficit water were applied in the vegetative, flowering and yield formation periods. Subject S_1 and subject S_2 were statistically in the same group. In the annual assessment, all trial years were in different groups, while in 2008 group A, which received the least rainfall during the irrigation period, in Group B in 2009 and in 2007, in which the highest rainfall occurred in the vegetative period were in the (c) group. The graph of the IWUE in the experiment is given in *Figure 1-C*.

Low irrigation water applications generally resulted in higher IWUE values. Our results are in agreement with Lovelli et al. (2007), Istanbulluoglu (2009) and Singh et al. (2016). Conversely, Kar et al. (2007) indicated an increase in the water use of the additional irrigation number. As the irrigation number increased, the IWUE value increased. In a two-year study, the IWUE value was 1.23 kg ha^{-1} mm^{-1} with one irrigation and 2.11 kg ha^{-1} mm^{-1} with a 71% increase with two irrigations. The highest IWUE was achieved with the mean value being 2.96 kg ha^{-1} mm^{-1} with three supplemental irrigations. Abd El-Lattief (2013) obtained the highest IWUE value for irrigation when there was a 50% reduction in soil moisture levels with 20 plants per square meter.

Oil Rate and Fatty Acid Composition

The irrigation subjects applied did not have any effect on the oil ratio of the safflower. The results of this study are also confirmed by Albel (1976), Hang and Evans (1985), Hamrouni et al. (2007) and Omidi et al. (2012). Conversely, while Amini et al. (2013) determined an 8.8% reduction of the mean oil content due to water-deficit stress, Hasanvandi et al. (2014), observed an increase in oil content under irrigation conditions.

When the results of the fatty acid composition were taken into account, no effect of restricted irrigation practices on fatty acids other than stearic and linoleic acid could be

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determined. In the stearic acid composition, where four different groups were formed, the subject S_{14}, where irrigation water was never applied, formed group (a). The graphs of the stearic, oleic and linoleic acid composition are given in *Figures 1-D, 1-E and 1-F*, respectively. Similar findings were found by Cosge et al. (2007). Hamrouni et al. (2007) indicated that excessive water stress led to a decrease in linoleic acid ratios, while moderate stress increased all the fatty acids proportionately. Ashrafi and Razmjo (2010) found that stearic, oleic and linoleic fatty acids in the safflower plant decreased by 5 to 14% depending on the degree of drought stress.

Irrigation water requirements and evapotranspiration

Table 5 summarizes the average evapotranspiration, irrigation water requirement, the number of irrigation treatments, conserved proportional irrigation water, WUE, IWUE and the yield values of applied irrigation water issues.

The amount of irrigation water applied to the experimental subjects and plant water consumption values differed due to variable climatic conditions and precipitation. The lowest ET value was naturally occurring at 234 mm from the subject S_{14} where no water was given, and the highest ET value was 591 mm from the subject S_1 where full irrigation was performed. Although the ET values of S_2 and S_3 subjects, which did not irrigate only during the flowering and yield formation periods, showed significant differences during the year, the values were very close to each other on a three-year average. In spite of this proximity in terms of average value of water consumed, the average yield values obtained for 3 years led to the yields per hectare being statistically different in terms of S_2 and S_3 yields of 4.14 and 3.56 tons, respectively. In this case, it can be said that the flowering period is more sensitive to water constraints than the yield formation period. In the vegetative period, the average ET value for the S_4, where irrigation was not performed, was 510 mm and the average yield was 3.84 tons ha^{-1}. When these three periods are compared with each other, flowering, vegetative and yield formation can be listed in terms of sensitivity to water stress. In this case, when limited irrigation needs to be implemented due to lack of water in the irrigation network, the restriction should be applied in other periods, excluding the flowering period.

For the subjects S_5, S_6, and S_7 only one irrigation was carried out during the growing period. In terms of ET value, the highest plant water consumption was in the flowering period (S_6) with an average of 364 mm, followed by yield formation (S_7) with 335 mm and vegetative (S_5) with 322 mm. Although the ET values of the S_6 and S_7 periods showed a 42 mm consumption difference on average, they were in the same group in terms of average yield with 3.56 and 3.52 t ha^{-1} yield, respectively. In this case, it can be said that there will not be any difference in the preference of one of the flowering or yield formation periods in irrigation networks where there is only one irrigation opportunity during the year.

The subjects S_8, S_{10}, and S_{12}, where 60% water is applied for a single period compared to full irrigation, represent subjects where irrigation is applied at 60% during the vegetation, flowering, and yield formation periods. This means that two of these three periods are fully irrigated and 60% of water is applied for the remaining period. The mean ET values of S_8 and S_{10} were 553 and 554 mm, respectively, and the yield values were 4.25 and 4.13 t ha^{-1}, respectively. While the S_8 and S_{10} issues are in the same group in terms of yield, their irrigation water needs are 383 and 365 mm, respectively. The ET value for S_{12} was 544 mm, the yield was 4.07 t ha^{-1} and the irrigation water requirement was 363 mm.

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The subjects S_9, S_{11}, and S_{13} represent subjects where 40% of total irrigation is provided during water application periods. These issues indicate that 40% of the full irrigation is given in the plant root zone and the other two periods are fully irrigated. The measured ET values for these subjects are 536 mm, 499 mm and 513 mm, respectively. The yield values obtained for these subjects, where irrigation water was applied three times, were 4.04, 3.78 and 3.85 tons per hectare, respectively, and each of them was statistically different. The water savings for the subjects were 15.7%, 22%, and 22.7%, respectively, whereas all three subjects were in the same group in terms of water application efficiency. The results of the yield–response factor are given in *Figure 2*.

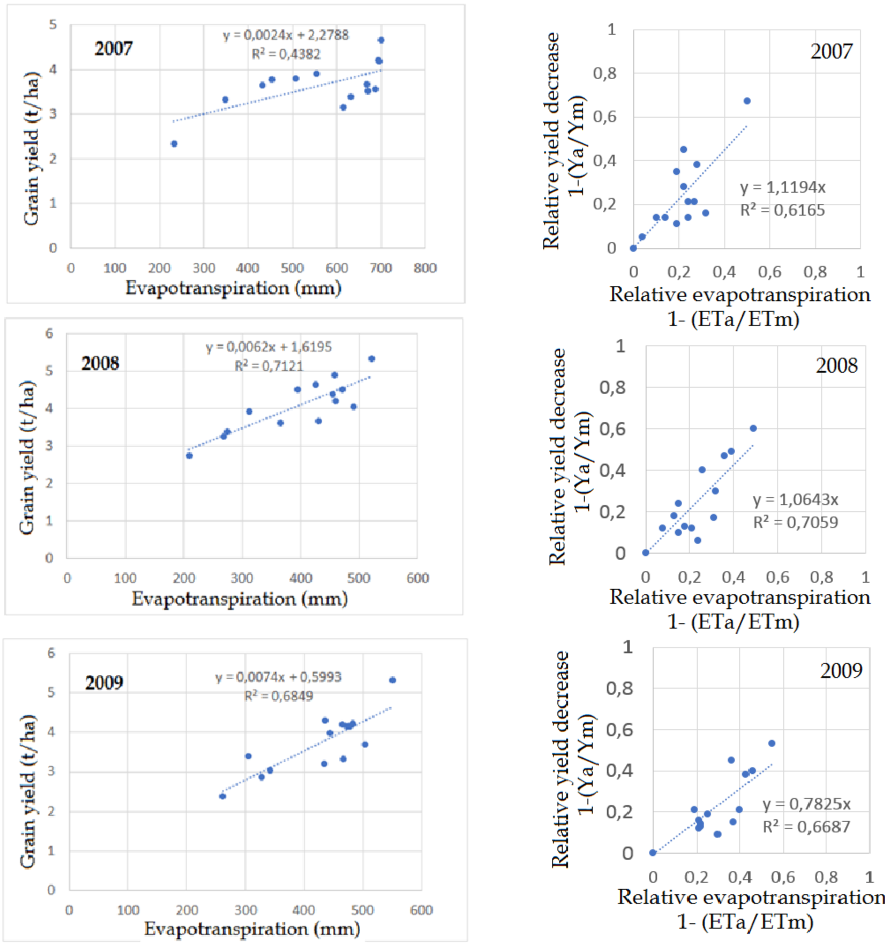

***Figure 2.** Relationship between grain yield and evapotranspiration (left side), Relationship between relative evapotranspiration deficit $1 - (ET_a/ET_m)$ and relative yield decrease $1 - (Y_a/Y_m)$ (confidence level $p<0.01$) (right side)*

Water–yield relationships and yield response factor (k_y)

Irrigation water and plant water consumption and yields of the subjects were evaluated mutually and water–yield relationships were obtained during the experiment. Since yields obtained from plant water consumption values vary from year to year, water–yield relationship graphs are given separately for the years in which the experiment is

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conducted. Since the maximum amount of irrigation water applied does not exceed the field capacity, the water yield relation is indicated by a linear equation.

The k_y values for the experimental years of 2007, 2008 and 2009 were 0.77, 0.84 and 1.15, respectively (mean = 0.92). The obtained k_y values for the whole growth period in this study were very close to the value of 0.80 proposed by Doorenbos and Kassam (1979), 0.93 by Lovelli et al. (2007) and 0.97 by Istanbulluoglu et al. (2009). The yield response factor (k_y) for each specific growth period proved to be an important criterion to decide which stage was the most sensitive to water. According to Lovelli et al. (2007), the k_y value, which is under 1 for safflower, indicates that the decrease in production is very low. It means that there is not much change in yield and that the plant is more resistant to water stress. Pourghasemin and Zahedi (2009) indicated that the effects of the decrease in soil moisture levels on plant growth vary according to the percentage of flowering. The decrease in soil moisture, plant height, leaf area index, plant dry matter, the number of trays per plant, bud seed weight and seed number per harvest index were not reduced at 50% of flowering. On the other hand, the decrease in soil moisture in the period when flowering is 100% leads to a decrease in these characteristics.

Phenological periods were evaluated separately by taking into consideration the values obtained during the three years of the study. The mean values obtained for the vegetation, flowering, and yield formation periods were 1.03, 1.18 and 1.00, respectively. In this case, the flowering period takes the first place in terms of its effect on yield, followed by the vegetative and yield formation periods. According to Istanbulluoglu et al. (2009), the safflower plant is most susceptible to water stress during the vegetative period, whereas Omidi et al. (2012) and Santos et al. (2018) stated that it was most susceptible during the flowering period.

Conclusions

The obtained results showed that for maximum yield in safflower cultivation, irrigation should be done without problems during all developmental stages of the plant. The flowering period is the most sensitive period for safflower productivity. Therefore, there is no compensation for the water deficit during the flowering period. The yield formation period was determined to be the second most sensitive period for soil moisture in terms of irrigation. Irrigation during this period increases the weight of 1000 grains, with especially the hectoliter weight being higher. When the k_y values obtained are evaluated together with the yield, the effect of water stress that may occur during the yield formation is seen. In this study, the effects of the safflower plant on the fat content and the fatty acid composition were investigated. The results showed that water deficit had no effect on the fat ratio, but it was found that water deficit did affect the stearic and linoleic acid ratios in the fatty acid compositions.

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