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EFFECTS OF DEFICIT IRRIGATION REGIMES ON YIELD AND GROWTH COMPONENTS OF WINTER SAFFLOWER (*CARTHAMUS TINCTORIUS* L.)

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ABSTRACT

A field study was carried out in order to determine the effect of deficit irrigation regimes on grain yield, seasonal evapotranspiration and plant growth components of safflower (*Carthamus tinctorius* L.) in Thrace Region of Turkey. The field trials were conducted on a clay loam Entisol soil, on Dincer, the most popular variety in the research area. A randomised complete block design with three replications was used. Combination of three well-known growth stages of the plant, namely vegetative (V), flowering (F) and yield formation (Y) were considered to form a total of 8 (including rain fed) irrigation treatments. The effect of irrigation and water stress at any stage of development on grain yield per hectare, thousand grains weight, and plant growth components were evaluated. Results showed that safflower was significantly affected by water stress during the sensitive vegetative stage. The highest yield was obtained in VFY treatment. Seasonal irrigation water use and evapotranspiration were 367 and 857 mm, respectively, for the non-stressed treatment. Safflower grain yield of this treatment was 3.68 t ha^{-1} and weight of thousand grains was 46 g. The seasonal yield-water response factor value was 0.94. The total water use eff iciency was 4.3 kg ha^{-1} mm^{-1}.

Key words: evapotranspiration, deficit irrigation, safflower, yield response factor, plant growth components.

INTRODUCTION

Presently, effect of global climate change, whose impact is increasingly experienced year by year, is forecasted to be felt more and more in Turkey as well in its Thrace Region placed in Mediterranean Basin (Anonymous, 2007). Probable agricultural drought due to this global climate change necessitates inevitably that water should be used effectively in irrigated agriculture to increase and sustain productivity. Deficit irrigation is a way of using water effectively.

In crop production, instead of achieving maximum yield from a unit area by full irrigation, optimum irrigation number or amount of irrigation water may be limited by allowing small yield decreases from a unit area but more area is irrigated with the same amount of irrigation water and water productivity can be optimised within the concept of deficit irrigation (Allen et al., 1998; Fereres and Soriano, 2006).

Due to growing population, increasing food requirement and limited water resources in Turkey, deficit irrigation merits consideration. Safflower, subsidised by the government in order to cover the cooking-oil shortage, has therefore become an increasingly popular part of the crop rotation of the Thrace Region. Therefore, knowledge on the irrigation schedule and water use efficiency of safflower under deficit irrigation condition becomes more important. This is because many field crops are more sensitive to water deficit at one or more phenological stages than at the other stages. For example, these sensitive stages are during flowering and boll formation stages in cotton, vegetative growth of soybean, flowering and grain filling stages of wheat, vegetative and yield forming stages of sunflower and sugar beet (Kirda, 2002).

Although limited regional and global research is available on safflower production under irrigated conditions, safflower is known to be sensitive to water deficit (Quiroga et al., 2001; Bassil and Kaffka, 2002a) and moderately tolerant to salinity (Bassil and Kaffka, 2002b). Kar et al. (2007) investigated the total water use efficiency of safflower in a study which also included other oil crops such

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as linseed and mustard in Eastern India, while Lovelli et al. (2007) and Istanbulluoglu et al. (2009) calculated yield response factor to water (k_y) and water use efficiency of safflower under deficit irrigation treatments.

The purpose of the present study is to investigate the seasonal evapotranspiration, irrigation water requirement, water use-production functions and the response of safflower yield to water deficit during vegetative, flowering and yield formation stages, with a view to reducing irrigation applied with a minimum of yield loss under Mediterranean climatic conditions.

MATERIAL AND METHODS

Site description

Field experiments were conducted at the Agricultural Faculty of Tekirdag Province located at Thrace Region in Turkey (40°59' N latitude, 27°35' E longitude) during the years 2012 and 2013. The experimental area was 500 m from Marmara Sea with an altitude of 30 m.

Conditions of climate

The climate of Tekirdag is Mediterranean type with mild and rainy winters and hot and dry summers at the coast while continental type prevails inland. The long-term (1975-2013) averages of annual temperature, relative humidity, wind speed, sunshine duration and total annual precipitation are 13.8°C, 75%, 2.8 m s^{-1}, 5.83 h and 579.7 mm, respectively (Anonymous, 2013). Daily climatic parameters were measured at a weather station located adjacent to the experimental site in 2012-2013. Monthly temperature, relative humidity, wind speed, precipitation and sunshine duration amounts during the experimental years are given in Table 1.

Table 1. Some climate parameters during the 2012-2013 in the experimental area

Months	Climatic parameter									
	Temperature (ºC)		Humidity (%)		Wind speed (m s^{-1})		Precipitation (mm)		Sunshine (h)	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
January	8.2	3.6	90.7	78.5	2.9	3.0	18.4	20.2	4.9	4.2
February	7.2	4.9	92.9	77.3	2.8	2.5	33.2	18.5	2.9	4.5
March	9.1	10.9	92.1	74.0	2.6	2.8	42.8	56.2	4.4	5.8
April	11.5	14.0	85.0	74.2	2.2	2.3	17.4	20.1	8.3	5.4
May	18.4	17.3	88.3	69.4	2.0	2.2	45.9	18.9	8.1	9.6
June	24.2	22.4	78.4	68.8	2.5	2.4	9.1	9.8	10.0	9.8
July	26.0	24.4	68.1	62.1	2.6	2.9	–	12.0	10.9	10.1
August	25.5	25.3	76.4	64.6	2.6	2.6	3.1	1.2	8.1	8.9
September	19.1	20.1	84.5	70.5	3.1	2.7	33.1	29.5	6.7	7.1
October	17.0	16.2	90.5	75.7	2.7	2.7	41.3	55.1	4.5	6.1
November	10.2	12.4	84.4	80.2	2.7	3.1	242.0	39.5	3.2	3.9
December	5.8	7.9	77.9	79.9	1.4	2.7	60.2	23.2	3.5	–
Annual	15.2	15.0	84.1	72.9	2.5	2.7	546.5	304.2	6.3	6.3

Experimental design

Soil of the experimental field is clay–loam (46% sand, 22% silt and 32% clay as the average of 0-90 cm soil profile) textured placed in the Entisol order, which prevalent in the region (Anonymous, 2012). Soil moisture characteristics such as field capacity, permanent wilting point, bulk density, available water holding capacity and some important soil chemical properties of the experimental field were determined. The area does not have boron, salt, sodium and drainage problems. Irrigation water quality has no restriction in terms of salinity and slight to moderate restriction in terms of infiltration due to the combination of low ECw (electrical conductivity is 0.5 dS m^{-1}) and moderate SAR (sodium adsorption ratio is 7.0) according to Ayers and Westcot (1994).

Dincer, the most popular variety in the research area (Esendal, 2001), was sown in the plots on 17 October 2012 and 16 October

2013. Each experimental plot was designed as 2.1 m wide x 5.0 m long (6 rows per plot) at sowing and thinned to a spacing of 0.35 m (row width) x 0.10 m (Gecgel et al., 2005). Nitrogen and phosphorus fertilizer at 100 kg N ha^{-1} and 100 kg P_2O_5 ha^{-1} was applied before sowing each year. Since the soil analysis results pointed out for the sufficient level of the potassium in the soil, no additional fertilization was applied on the experimental site. Winter wheat had been growing in the experimental site before the experiment.

Irrigation treatments and water use

In the selection of irrigation treatments, three different growth stages of safflower were considered; vegetative (V, up to 211-214 days from sowing, corresponding to heading stage), flowering (F, up to 235-240 days from sowing, approximately when 50% of flowering is completed) and yield formation (Y, up to 250-258 days from sowing, when the seed filling is completed). Crop growth stages were determined according to Doorenbos and Kassam (1979). The treatments were as follows: rain fed (non-irrigation), irrigation at vegetative stage (V), irrigation at flowering stage (F), irrigation at yield formation stage (Y), irrigations at vegetative and flowering (VF), irrigations at vegetative and yield formation (VY), irrigations at flowering and yield formation (FY), irrigations at vegetative, flowering and yield formation (VFY). The treatment of VFY was the control. Field trials were laid out in a randomized complete block design, with three replications.

All the experimental treatments were irrigated at fixed turn as the fully irrigated VFY treatment, being watered at each time with the amount of irrigation water required to fill the 0-90 cm soil depth to field capacity. One irrigation per stage was given. Individual treatments were treated similarly except for omitting the irrigation application at a specific growth stage. Weekly soil moisture content of the plots was determined gravimetrically in the soil layers 0-30, 30-60 and 60-90 cm during the whole growing season (from sowing to harvest). Water applied to each experimental plot was measured using a flowmeter connected to an irrigation pipe. The plots were irrigated by furrow irrigation method. Irrigation water amounts applied to each experimental treatment as well as data concerning the application date are presented in Table 2.

Table 2. Irrigation water quantities applied to safflower at different stages of the experimental years

Years	Water application	Stage of development			Total stage
		Vegetative (V)	Flowering (F)	Yield formation (Y)	
2012	Application day[a]	214	235	250	288
	Irrigation water (mm)	104	118	143	
2013	Application day[a]	211	240	258	289
	Irrigation water (mm)	92	123	154	
Average	Application day[a]	211-214	235-240	250-258	288-289
	Irrigation water (mm)	92-104	118-123	143-154	

[a]Days after sowing.

Evapotranspiration (ET) from each plot was determined using the soil water balance equation: $ET = P + I + R + SD + D$, where P is the precipitation (mm), I is the irrigation water amount (mm), R is the runoff/runon (mm), SD is the soil water depletion (mm) and D is the drainage (mm) below the root zone. Runoff/runon was considered zero because the experimental plots were surrounded with dikes. Soil water depletion was calculated as the difference between soil water content values at the beginning and end of each period for a soil depth of 90 cm. Drainage below the root zone was assumed to be zero, since water applied with each irrigation was equal to water deficit in the 0–90 cm soil profile of the fully irrigated treatment (VFY).

All the experimental treatments were harvested at the same time as the VFY treatment, on 31 July 2012 and 2013. The grains of approximately 0.25 kg per plot were weighed, then oven-dried to constant weight at 65°C to determine the water content. The yields were converted to a standard grain water content of 10%. Total grain yield and 1000 grains weight were measured. Plant growth components of safflower were measured at the harvest time.

Data were subjected to an ANOVA and regression analysis using the procedure given by Yurtsever (1984) and Duncan mean separation test procedure was applied. First ANOVA and application of Duncan tests were done on the data for the treatments of each year separately.

Then, the same procedure was repeated for both trial years together after the homogeneity test showing that there was no statistically significant difference between them. Linear regression was used to evaluate water use – yield relationships using seasonal evapotranspiration and grain yield data obtained from the experiment. Seasonal values of the yield response factor (k_y) for each experimental year was determined using the Stewart model (Stewart et al., 1977).

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

where Y_a is the actual harvested yield (obtained from all the treatments), Y_m is the maximum harvested yield (obtained from fully irrigated control), k_y is the yield response factor, ET_a is the actual evapotranspiration and ET_m is the maximum evapotranspiration. In this study, ET of fully irrigated control treatment (VFY) was taken as ET_m whereas ET from the other treatments was defined as ET_a. While total water use efficiency (TWUE) was calculated from ratio of grain yield and total water use. Irrigation water use efficiency (IWUE) was calculated from ratio of grain yield and irrigation water use (Fereres and Soriano, 2006; Lovelli et al., 2007).

RESULTS AND DISCUSSION

The effect of water stress on grain and oil yield

Average of years yield values of each treatment and their Duncan test classes were given in Table 3. ANOVA and Duncan classification tests were also done for the average of the two years because the homogeneity test was positive, which meant that both years could be evaluated as a whole.

Table 3. The effect of irrigation treatment on grain and oil yield with 1000-grains weight

Experimental treatments	Grain yield ($t\ ha^{-1}$)	Grain yield decrease (%)	Thousand grain weight ($g\ 1000^{-1}$)	Rate of oil (%)	Oil yield ($t\ ha^{-1}$)
VFY	3.68 a	–	46 a	27.9	1.03
VF	3.44 a	6.7	44 ab	27.8	0.96
VY	3.27 ab	11.1	44 ab	28.0	0.92
FY	3.07 abc	16.6	43 ab	27.1	0.83
V	2.79 bcd	24.3	43 ab	27.4	0.77
F	2.61 cde	29.3	42 bc	27.7	0.72
Y	2.35 de	36.1	42 bc	27.5	0.65
Rain fed	2.15 e	41.6	40 c	27.2	0.59
x (overall mean)	2.92		43.0	27.6	
Sx	0.54		0.81	0.33	
Sd	0.19		0.64	0.12	
Cv	6.51		1.49	0.42	
Year	**		ns	ns	
Year * treatment	**		ns	ns	

**Means within columns not followed by the same letter are significantly different at the p<0.01 level by Duncan's multiple range test. ns: No significant.

Data obtained from the 2-year study showed that grain yield was significantly ($p<0.01$) affected by soil water deficits. On the other hand, yields of specific treatments were closely dependent on precipitation and its distribution during the crop cycle. As is evident, water stress in vegetative stage resulted in serious grain yield reduction. The yield of any treatment exposed to water stress at one or two growth stage was significantly lower than the fully irrigated (VFY) control treatment during two experimental years. The maximum yield, 3.68 t ha^{-1}, was obtained with the VFY treatment, which was significantly greater than the yield of other treatments. This was followed by VF treatment with 3.44 t ha^{-1} that was classified as the first group together. Vegetative (V) and flowering (F) periods proved to be the most important periods to determine the yield in relation to water deficit. Because (V) and (F) treatments produced highest yield under the conditions, one time irrigation was applied.

The 1000 grain weight values of the treatments for average of the years and their Duncan test classes are given in Table 3. These show that average parameters was significantly ($p<0.01$) affected by water deficits in the soil profile. The highest average weight of 1000 grains was recorded in the fully irrigated (VFY) control treatment. This was followed by the treatment containing vegetative (V) stage. The lowest average weight was recorded in the rain fed treatment. In addition, although weights of 1000 grain values were compatible among the treatments, it was lower in 2012 than in 2013, which could also be attributed to the high temperature in 2012.

As seen in Table 3, grain oil contents of the treatments are similar and no statistically significant differences were found among them. In general, increase in the number of irrigations decreased the oil content.

Seasonal irrigation water requirements and evapotranspiration

Irrigation water amounts applied to the experimental treatments and seasonal water consumption values for average of the years are presented in Table 4.

Total irrigation water applied to irrigation treatments was strongly affected by the amount and distribution of precipitation during the experiment years. The differences among the treatments irrigated once were the proof for this. The highest amount of irrigation water was applied to the treatment of yield formation stage (Y) and this was followed by flowering stage (F) and vegetative stage (V), whose soil moisture was partially sufficient. There were no significant differences between years in amount of applied water, for each specific irrigation were not different.

Table 4. Seasonal irrigation water quantities, saving, use efficiencies and evapotranspiration of safflower for the treatments

Experimental treatments	Irrigation number	Irrigation (mm)	Irrigation water saving (%)	Irrigation water use efficiencies (kg ha^{-1} mm^{-1})	Total water use efficiencies (kg ha^{-1} mm^{-1})	ET (mm)
VFY	3	367	–	10.0	4.3	857
VF	2	219	40.3	15.7	4.9	708
VY	2	247	33.0	13.3	4.4	737
FY	2	269	26.7	11.4	4.1	760
V	1	98	73.3	28.4	4.7	588
F	1	121	67.0	21.5	4.3	611
Y	1	149	59.7	15.9	3.7	639
Rain fed	–	–	100.0	–	4.4	490

Treatments whose irrigation application started in May changed the evapotranspiration that was the same until this period. The lowest ET was obtained in no irrigation treatment with average 490 mm, which was followed by V, F and Y treatments irrigated once. The highest ET was recorded in the VFY treatment, irrigated three times, with 857 mm water application. There was no statistically significant difference in ET values of the treatments between years.

The highest monthly ET values of the treatments occurred in different months: it was in April for the rain fed treatment, in May for the V treatment, in June for the F, VF, FY and VFY treatments, in July for the Y and VY treatments. The lowest and the highest monthly ET were 80 and 237 mm for the rain fed and VFY treatments, respectively. In addition, for both years, the biggest saving in irrigation water was realized in the treatments irrigated only once at vegetative (V) stage while the lowest was in yield formation (Y) stage. The soil water content in the profile at the time of irrigation determined the magnitude of water saved.

The irrigation and total water use efficiency of safflower

The irrigation water use efficiencies (IWUE) and the total water use efficiencies (TWUE) of the treatments for the average of years are presented in Table 4.

The IWUE of the treatments in the experiments were higher than the TWUE. The reason for this is that the amount of total water use was greater than the amount of irrigation water. Using average values, the highest TWUE was obtained from VF treatment with 4.9 kg ha^{-1} mm^{-1}, while the lowest TWUE was observed in Y treatment with 3.7 kg/ha/mm. As for the IWUE, the highest and lowest rates were recorded as 28.4 kg ha^{-1} mm^{-1} in V treatment and 10.0 kg ha^{-1} mm^{-1} in VFY treatment, respectively. This shows that, as stated by Fereres and Soriano (2006) and Lovelli et al. (2007), after a certain amount of irrigation water and soil water level, crop production cannot be increased and safflower does not equally benefits from the water during all growth stages.

The water use function and yield response factor for safflower

The relationship between seasonal ET and grain yield of safflower for all treatments was reported in Figure 1. There was a positive linear relationship between ET and grain yield (Ygrain) such that Ygrain = 0.0041 ET (R^2=0.94**). Using this relationship, grain yield of safflower in this region can be predicted from ET. But, when using the produced equation, the upper limit of the independent variable should not be exceeded.

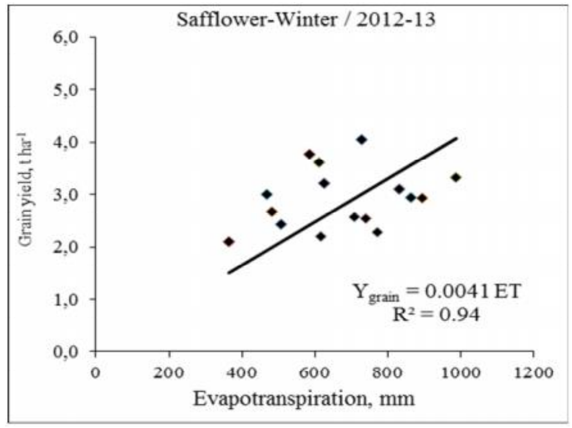

Figure 1. Relationship between seasonal evapotranspiration and grain yield (confidence level p<0.01)

Using seasonal ET and grain yield of the treatments, the yield response factor (k_y), which explains the relationship between the relative ET deficit and relative yield decrease, was calculated as explained by Stewart et al. (1977).

The slope of the fitted regressions represents the yield response factor (k_y), being 0.94 (R^2=0.77**) in Figure 2.

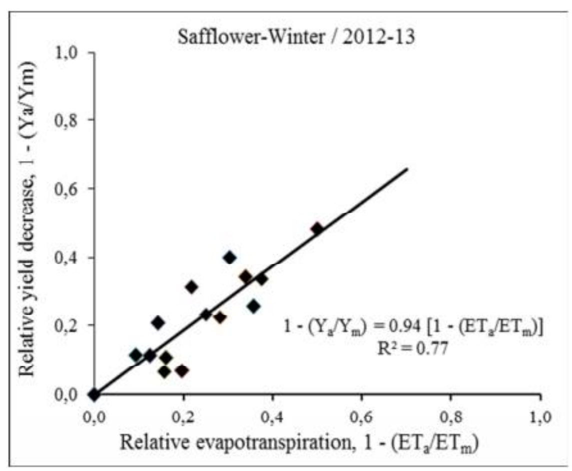

Figure 2. Relationship between relative evapotranspiration deficit $1 - (ET_a/ET_m)$ and relative yield decrease $1 - (Y_a/Y_m)$ (confidence level p<0.01)

The k_y values for the experimental years of 2012 and 2013 were 0.94 and 0.93, respectively. The obtained ky values of 0.93

and 0.94 for 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). 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. The k_y values of the growth stages were 1.05, 0.96 and 0.86, respectively for V, F and Y stages. This figures show that the most critical period of safflower to water is V stage.

The plant growth components of safflower

The plant growth components of the treatments for the average of years are presented in Table 5.

Table 5. The effect of irrigation treatments on plant growth components of safflower

Experimental treatments	Plant height (cm)	First branch height (cm)	Number of branches per plant	Number of heads per plant	Number of grains per head
VFY	118 a	74	10	16	38 a
VF	115 a	73	9	15	35 ab
VY	112 ab	70	9	14	33 abc
FY	111 ab	70	9	14	33 abc
V	110 ab	68	9	13	32 abc
F	109 ab	66	9	13	31 abc
Y	108 ab	65	8	13	29 bc
Rain fed	101 b	61	8	12	26 c
x (overall mean)	110.5	68.4	8.9	13.8	32.1
Sx	5.04	4.31	0.64	1.28	3.64
Sd	1.78	1.52	0.23	0.45	1.29
Cv	1.61	2.23	2.55	3.29	4.01
Year	**	ns	ns	ns	**
Year*treatment	**	ns	ns	ns	**

**Means within columns not followed by the same letter are significantly different at the $p<0.01$ level by Duncan's multiple range test. ns: No significant.

The statistical analysis were performed during experimental and after harvest. The results showed that statistically significant ($p<0.01$) among the irrigation treatments. Evapotranspiration of safflower increased with the number of irrigations and the amount of irrigation water. Using average values, the highest and the lowest plant height 118 and 101 cm; first of branch height 74 and 61 cm; number of branches per plant 10 and 8; number of head per plant 16 and 12; number of grain per head 38 and 26 were obtained from VFY and rain fed treatments, respectively.

CONCLUSIONS

According to the results obtained, the fully irrigated VFY treatment might be practiced to realize the highest yield. Irrigation schedule of this treatment may be as follows: The first irrigation is at the vegetative stage, when after 211-214 days from sowing/heading stage, that is in the middle of May; the second irrigation is at the flowering stage, approximately 50% level, that is the first half of June; and the third irrigation is at the yield formation stage, seed filling, that is the last week of June.

Evapotranspiration of safflower increased with the number of irrigations and the amount of irrigation water. The highest seasonal ET was calculated in the VFY control treatment as 857 mm, peak monthly ET was 237 mm in June. Safflower grain yield of this treatment was 3.68 t $ha^{-1.}$

The effect of irrigation or water stress at any stage of development on grain yield per hectare and 1000 grains weight, were evaluated. Results of this study showed that safflower was significantly affected by water shortage in the soil profile due to omitted irrigation during the sensitive vegetative stage.

The relationship between seasonal ET and grain yield was statistically significant ($p<0.01$) and it could be defined by the equation of Ygrain = 0.0041 ET (R^2=0.94**).

The yield response factor (k_y) which explain the relationship between the relative ET deficit and relative yield decrease was calculated 0.94. The k_y values for the experimental years of 2012 and 2013 were 0.94 and 0.93, respectively. This was 1.05 for vegetative (V) stage at which the crop is most sensitive to water. Using average values, the highest TWUE was obtained in VF treatment with 4.9 kg ha^{-1} mm^{-1} while the lowest TWUE was observed in Y treatment with 3.7 kg ha^{-1} mm^{-1}.

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