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Effect of water stress on 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 irrigation, water stress imposed at different development stages on seed yield, seasonal evapotranspiration (ET), crop-water relationships, oil yield and plant growth components of safflower (*Carthamus tinctorius L.*) for winter sowing at Thrace Region in Turkey. The field trials were conducted on a loam Entisol soil, using cv. Dincer, the most popular variety in the region. A randomised complete block design with three replications was used. Three known growth stages of the plant were considered and a total of 8 (including rain fed) irrigation treatments were applied. Results of this study show that safflower is significantly affected by water shortage in the soil profile due to omitted irrigation during the sensitive vegetative stage. Highest yields were observed in the fully irrigated control. An evapotranspiration of 728 mm were calculated for non-stressed production for winter sowing. Safflower seed yield of this treatment was 4.05 ton per hectare.

Keywords: Safflower - deficit irrigation – evapotranspiration - oil yield - plant growth components

Introduction
It is estimated that climate change, whose effect is being increasingly felt, will be more serious in Turkey, located in the Mediterranean basin, especially in the Thrace region of Turkey (Anonymous, 2007). Drought, one of the expected results of the climate change in the region, necessitates a much more effective water use in irrigated areas. One way of increasing the water use efficiency is the practice of deficit irrigation.

Due to rapid population growth, increasing food requirement and limited water resources in Turkey, deficit irrigation is inevitable. Safflower, which is subsidised by the government in order to gap the cooking oil shortages both in the region and in Turkey, has been increasingly used in crop rotation in 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 all field crops respond differently in different phenological stages to changing water status of the soil under deficit irrigation, which means that plants are more sensitive to water deficit at some stages than at other stages. For example, these sensitive stages are flowering and boll formation in cotton, vegetative growth in soybean, flowering and seed filling stages in wheat, vegetative and yielding stages in sunflower and sugar beet (Kirda, 2002).

The purpose of the present study was to investigate the seasonal evapotranspiration, irrigation water requirement, time and number of irrigations, water use-production functions and the response of safflower yield to water deficit in the soil profile during vegetative, flowering and yield formation stages, with a view to reducing irrigation with a minimum yield loss in winter sowing.

Materials and method
Field experiment was conducted on field of the Agricultural Faculty of Tekirdag Province located at Thrace Region in Turkey for the winter sowing in 2007. The experiment area, at a distance of

300 m from Marmara Sea and at an altitude of 20 m, is located at 40°59' N latitude, 27°35' E longitude.

The climate of Tekirdag is characterized by Mediterranean type with mild and wet winters and hot and dry summers at the coast while continental type prevails in the inland parts of the province. The long-term 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 580.8 mm, respectively (Anonymous, 2008). Daily climatic parameters were measured at a weather station located very close to the experimental sites.

Cv. Dincer, the most popular variety in the region (Esendal, 2001; Gecgel, 2004), were sown on October 17th, 2006. Each experimental plot was designed as 2.1 m wide x 5.0 m long (6 rows per plot) at sowing. Row spacing was 0.35 m and plant spacing was 0.10 m (Gecgel et al., 2005). Nitrogen and phosphorus fertiliser at 100 kg N ha^{-1} was applied before sowing. Since the soil analysis results pointed out for the sufficient level of the potassium in the soil, no additional K fertilisation was applied on the experimental sites.

In the selection of irrigation treatments, three different growth stages of safflower, vegetative (V, heading stage), flowering (F, approximately 50 % level) and yield formation (Y, grain filling) were considered. Water application stages were determined according to Doorenbos and Kassam (1979) and Allen et al., (2004). The treatments were as follows: non-irrigation (rainfed), one irrigation at vegetative stage (V), one irrigation at flowering stage (F), one irrigation at yield formation stage (Y), two irrigations at vegetative and flowering (VF), two irrigations at vegetative and yield formation (VY), two irrigations at flowering and yield formation (FY), and three irrigations at vegetative, flowering and yield formation (VFY). VFY treatment was the control. Field trials were laid out in a randomised complete block design, with three replications.

All experimental treatments were irrigated at the same time as the VFY treatment, watered at each growth period with the amount of irrigation water required to saturate the 0-90 cm soil depth to field capacity. The plots were irrigated by furrow irrigation method. Evapotranspirasyon (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 (Allen et al., 2004).

All the experimental treatments were harvested at the same time as the VFY treatment, on July 31st, 2007. The grains of approximately 0.25 kg per plot were oven-dried to constant weight at 65 °C and re-weighed to determine the moisture content. The seed yields were adjusted to a standard grain water content of 10 %. Total seed yield and 1000 seed-weight were measured. Plant growth components of safflower were measured at the harvest time.

Data were subjected to variance and regression analyses. Duncan multiple range test was used to compare treatment means. Regression was used to evaluate water use-yield relationships using seasonal evapotranspiration and seed yield data obtained from the experiment.

Results and discussion

The seed yield, 1000 kernel weight and oil yield values of each treatment and their Duncan groupings are given in Table 1. Data obtained from the study showed that seed yield was significantly ($p<0.01$) affected by soil water deficits. On the other hand, yields of experimental treatments were dependent on precipitation and its distribution during the growing period.

The highest yield was obtained from VFY treatment as 4.05 t ha^{-1}. It was followed by VF with 3.77 t ha^{-1} seed yield. V treatment (irrigation at vegetative period) was the highest yield among single irrigation treatments and had a yield loss of about 25 % (3.01 t ha^{-1}) compared to VFY. The lowest seed yield was obtained from no irrigation treatment.

There is no safflower irrigation trial conducted in the region and in Turkey, and therefore no regional data is available on the subject. FAO reports that good rainfed yields are in the range of 1.0 to 2.5 t ha^{-1} while in the range of 2.0 to 4.0 t ha^{-1} under irrigation conditions (Doorenbos and Kassam, 1979). Safflower yield data in different areas under rainfed and irrigated conditions are also available. For instance, seed yields from 1.0 to 3.3 t ha^{-1} were obtained in Sacramento Valley of California, USA (Cavero et al., 1999), in the Ariana of Tunisia (Hamrouni et al., 2001), in the Pampas region of Argentina (Quiroga et al., 2001), in the Potenza of Italy (Lovelli et al., 2007), in the Orissa of India (Kar et al., 2007). The yield obtained in the present study is higher than the above presented values. Applied irrigation treatment is one of the most important reasons for this.

Table 1. The effect of irrigation treatments on seed and oil yield of safflower

Experimental treatments	Seed yield (t ha^{-1})	Thousand seed weight (gr 1000^{-1})	Oil content of seed (%)	Oil yield (t ha^{-1})
VFY	4.05 a	46 a	27.53 ab	1.12 a
VF	3.77 ab	43 ab	27.11 ab	1.08 a
VY	3.61 ab	44 ab	28.30 a	1.02 a
FY	3.21 abc	42 ab	26.21 b	0.84 ab
V	3.01 bc	43 ab	26.92 ab	0.81 abc
F	2.67 cd	41 b	27.27 ab	0.73 bc
Y	2.43 cd	41 b	26.89 ab	0.65 bc
Rainfed	2.10 d	40 b	27.03 ab	0.57 c
Mean	3.11	42.4	27.16	0.85
C.V.	4.5**	1.0**	3.4 NS	19.2**

NS, non-significant; ** means with the same letter within a column are not significantly different at $p < 0.01$ level based on Duncan's multiple range test.

The highest average thousand-seed weight was recorded in the fully irrigated control (VFY). All V treatments, i.e. the treatments in which one irrigation was made at the vegetative stage, had higher thousand seed weight than others. This was followed by treatments with F (irrigation at flowering stage) and F (irrigation at yield formation stage). The lowest values for this variable were obtained from non-irrigated (rainfed) treatment.

Irrigation water amounts applied to the treatments and seasonal water consumption values of the treatments are presented in Table 2.

Table 2. The effect of irrigation treatments on water quantities, irrigation water saved and evapotraspiration of safflower (mm).

Experimental treatments	Total amount of Irrigation	Irrigation water Saved.	Evapotraspiration	Number of irrigation
VFY	365	-	728	3
VF	222	39.2	585	2
VY	247	32.3	611	2
FY	261	28.5	625	2
V	104	71.5	468	1
F	118	67.7	482	1
Y	143	60.8	507	1
Rainfed	-	100.0	364	-

Total irrigation water applied to irrigation treatments was strongly affected by the amount and distribution of precipitation during the trial season. Evidence for this is the differences in amounts of irrigation water applied in single irrigation treatments. Treatments with the highest amount of applied irrigation water are yield formation (Y) and flowering (F) stages. The lowest amount of irrigation water was applied in vegetative stage when the effect of winter precipitation still continues and the soil moisture is partly enough.

Seasonal plant water consumption was calculated for each treatment using soil water content, irrigation water applied and precipitation. Seasonal plant water use increases with the increasing amount of irrigation water. The lowest plant water consumption was realized in non-irrigated treatment as 364 mm, followed one irrigation treatments of V, F and Y. The highest water consumption was at VFY treatment as 728 mm.

The highest monthly ET values of treatments were in different months: it was in May for the V treatment, in June for the rainfed, F, FY, VF, and VFY treatments, and in July for the Y and VY treatments. The highest monthly water consumption was in VFY treatment in June as 245 mm. The highest consumption was in flowering stage of the development. Daily water consumption in this stage was 7.9 mm. Water consumption values recorded in the present study is in accordance with the ones reported by Doorenbos and Kassam (1979), Lovelli et al., (2007), and Kar et al., (2007). Results from different climate and soil conditions, different sowing periods and cultivars showed that safflower has a seasonal water consumption of 200–1000 mm (Doorenbos and Kassam, 1979).

Table 3. The effect of irrigation treatments on plant growth components of safflower

Experimental treatments	Plant height (cm)	Number of branch per plant	Number of head per plant	Number of seed of head per plant
VFY	137.43	12.77	20.77	28.60 bc
VF	135.40	11.63	20.23	32.30 abc
VY	136.77	13.13	20.07	32.13 abc
FY	137.50	11.57	23.57	32.70 abc
V	140.97	12.60	20.63	38.57 a
F	135.37	13.37	21.50	34.97 ab
Y	139.07	11.80	22.27	30.20 bc
Rainfed	132.43	11.70	18.03	27.60 c
Mean	136.9 NS	12.32 NS	20.88 NS	32.14*
C.V.	4.0	13.8	13.7	13.7

NS, non-significant; *, means with the same letters within a column are not significantly different at $p < 0.05$ level based on Duncan's multiple range test.

The water use function obtained using seasonal evapotranspiration and seed yield of safflower presented in Fig. 1. There was a positive linear relationship between ET and seed yield (Y) such that Y = 0.0054 ET + 0.1634 (R^2 = 0.80**) for winter sowing. Using this relationship, seed 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.

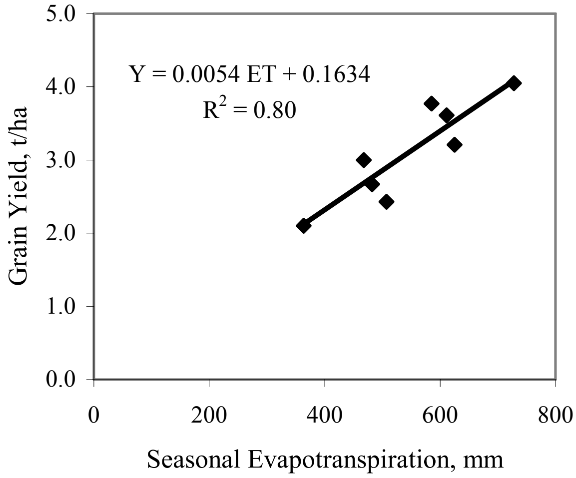

Figure 1. Relationship between seasonal evapotranspiration and seed yield for winter sowing. $p < 0.01$ level

Conclusions

According to the results obtained, three-irrigation treatment resulted in the highest seed yield as expected. This treatment almost doubled the safflower seed yields compared to non-irrigated treatment. However, yields from all of the two-irrigation treatments were not different from three-irrigation treatments and some of them (VF) had yield losses of as low as 7 %. If the irrigation period is selected carefully, e.g. in vegetative period, even one irrigation can provide about 75 % of the yield achieved by three irrigations. Thus, water, one of the most valuable resources of earth, can be saved and used for irrigation of other farmlands.

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