EFFECTS OF DEFICIT IRRIGATION TREATMENTS ON SEED YIELD, OIL RATIO AND WATER USE EFFICIENCY OF SUNFLOWER (Helianthus annuus L.)

Ali Beyhan Ucak¹*, M Cuneyt Bagdattr¹²

¹Siirt University, Faculty of Agriculture, Department of Biosystem Engineering, Siirt /Turkey
²University of Nevsehir Hacı Bektaş Veli, Faculty of Engineering and Architecture, Department of Biosystem Engineering, Nevsehir/Turkey

ABSTRACT

The present study was conducted as a field research to investigate the effects of different water deficit levels applied throughout growing season on seed yield, oil ratio and water use efficiency (WUE) of main crop sunflower plants under semi-arid climate conditions of Siirt and Nevsehir provinces in 2015. Irrigation treatments were set as full irrigation (I₁₀₀) in which water depletion in 0-90 cm soil profile was fully supplied every week, 25% water deficit (I₇₅) in which 75% of full irrigation was supplied and 50% water deficit (I₅₀) in which 50% of full irrigation was supplied. A total of 6 irrigations were performed in both locations and respectively 400.6 and 373.7 mm irrigation water was applied to I₁₀₀ (control) treatment. Plant water consumption of control treatment was measured as 551.0 mm in Siirt and 493.3 mm in Nevsehir location. Seed yields in I₁₀₀ treatment of relevant locations were respectively observed as 405.7 and 422.2 kg da⁻¹, oil ratios respectively as 48.2 and 47.8%. The seed yield obtained from I₇₅ treatment was placed in the same group (A) with I₁₀₀ treatment in Siirt province and placed in subsequent group (B) in Nevsehir province. In both locations, oil ratio of I₇₅ treatment was placed in the same group (A) with I₁₀₀ treatment. Water deficits over 25% resulted in significant decreases in seed yield and oil ratio of sunflower plants. A significant linear relationship (p<0.01) was observed between plant water consumption (ETₘ) values and seed yields. Average yield response factor (kₛ) was calculated as 0.62, water use efficiency (WUE) as between 0.72-0.96 kg da⁻¹ mm⁻¹ and irrigation water use efficiency (IWUE) as between 1.01-1.31 kg da⁻¹ mm⁻¹.

KEYWORDS:
Deficit irrigation, seed yield, oil ratio, drip irrigation, sunflower, Turkey

INTRODUCTION

Sunflower has a strategic significance in human nutrition worldwide. Annual sunflower oil consumption of Turkey is around 650 thousand tons. However, annual production is about 400-450 thousand tons. The deficit is met through imports [1].

Insufficient precipitations for plant growth in arid and semi-arid regions and irregular distribution of precipitations in these regions create great risks for sunflower farming. Irrigation is the most significant yield factor in these regions. However, global warming and climate change gradually reduce available water resources for irrigation in various parts of the world. Increasing domestic and industrial water demands are also reducing available water resources for irrigation. The places where this research was carried out are located within arid climate zone. High temperature, radiation and low relative humidity of research sites increase plant water consumption through evapotranspiration. The amount of precipitation received throughout growing season is not also sufficient for optimum yield levels. In relevant regions, sufficient amount of water should be supplied to plant at proper periods for optimum yields. However, water resources are quite insufficient in arid and semi-arid regions. Therefore, irrigations should be so planned as to have optimum water use efficiency. A well-designed irrigation program is needed for optimum water use efficiency. With a well-designed irrigation program, water, energy and fertilizer-like inputs are used efficiently. Such a program also allows the together implementation of irrigation, fertigation and chemigation. In this way, it is possible to get a yield increase with reduced input costs, thus to get relatively more profitable production. In this sense, the studies on irrigation programs for sunflower farming in semi-arid climates are not sufficient.

Two approaches are commonly used as creation for irrigation programs: full irrigation and deficit irrigation. While full irrigation is preferred in places with sufficient water resources, deficit irrigation is recommended for the regions with insufficient water resources. In deficit irrigation, water is saved by applying less water than plant requirement and the saved amount is used to irrigate more fields, in other words to open new fields for irrigation. “Irrigation water is reduced to a point over the production function in which reduction in
income is equal to production costs. Since less water is applied to plants than their actual water requirement, a certain amount of yield loss is evident. However, water saving with deficit irrigation may sometimes reach to significant levels or a certain amount of yield loss is allowed in deficit irrigation. In a study carried out with sunflower under Cukurova conditions (Turkey), 15% decrease was observed in yield with 36% deficit in irrigation water [2].

Deficit irrigation is known as the application of water at levels below full crop water requirements and it is one of the new strategies designed to improve water savings in agriculture [3]. The main purpose of deficit irrigation is to raise the water use efficiency (WUE) and to obtain the highest yield per unit water [4]. In arid, semi-arid regions and the regions with similar climate conditions, scarcity of water coupled with an ever increasing water demand has resulted in undesirable deficit irrigation situations [5]. Kazemeini et al. [6] stated that deficit irrigation influenced sunflower crop yield and such influences could be less significant if water stress was applied to the crop during specific growth stages that are less sensitive to moisture deficiency. Erdem et al. [7] performed a field research on irrigation scheduling for sunflower in Tekirdag province of Turkey with an average annual rainfall of 584 mm. They found that the water use efficiencies were 0.54, 0.52, 0.58, 0.60, and 0.93 kgda⁻¹mm⁻¹ at 679, 584, 470, 227, and 0.0 mm of water applied, respectively. Genotypes are very important improvement material in crop production, and different genotypes of sunflower have different responses to water stress [8].

In places with water deficits, efficient water use should be ensured through innovative and sustainable approaches [9]. The research sites are located in semi-arid climate zone with insufficient water resources for irrigation. Therefore, the present study was conducted under semi-arid climate conditions to investigate the effects of deficit irrigation treatments (I₁₀₀, I₇₅, I₅₀) through drip irrigation on seed and oil ratio (%) and water use efficiency of sunflower.

**MATERIALS AND METHODS**

This study was conducted as a field research in Siirt and Nevsehir provinces (Turkey) in 2015. Siirt is located at 37° 58' 7.37" N and 41° 51' 3.87" E coordinates with 894 m altitude and Nevsehir is located at 38° 44' 17.52" N -34° 46' 20.00" E coordinates with an altitude of 1045 m. P63F73 genotype with oleic acid content was used as the plant material of the study.

Siirt has terrestrial climate with cold and rainy winters, hot and dry summers. Annual summer temperature is 29.6 °C and minimum winter temperature is 2.7 °C, long-term average maximum relative humidity is 70.2% in January and minimum relative humidity is 29.6% in August. Annual average relative humidity is 50.41%. Long-term annual average precipitation is 669.2 mm and monthly precipitation varies between 1.3-103.6 mm [10]. Long-term average annual precipitation of Nevsehir is 421 mm. Precipitation is 30.3 mm in June, 9.5 mm in July, 4.3 mm is August and 13.1 mm in September. Average temperature is 0.8°C in winter, 10°C in spring, 20.9 °C in summer and 11.7 °C in autumn [11].

Experimental soils in Siirt location have low electrical conductivity without a salinity problem. Lime content was not creating any problem for plant culture. Soil texture was clay with low phosphorus, high potassium and medium organic matter content. Field capacity (FC) was 35.38% (for 0-90 cm), permanent wilting point (PWP) was 25.57% and soil bulk density was 1.40 g cm⁻³. In Nevsehir location, field capacity was 22.74%, permanent wilting point was 10.01% and soil bulk density was 1.48 g cm⁻³. Irrigation water quality class was CₓSₓ in Siirt and C₄S₂ in Nevsehir location. Irrigation water was of high quality with an electrical conductivity of 0.34 dSm⁻¹ and 0.27 dSm⁻¹ and a pH of 7.21 and 7.53 in Siirt and Nevsehir provinces, respectively. Experiments were conducted in in randomized blocks design with 3 replications.

**Irrigation Treatments** Irrigation treatments were set as “full irrigation” (I₁₀₀, control treatment) in which 100% of water depletion in 90 cm soil profile was supplied, “25% deficit” (I₇₅) in which 75% of full irrigation was applied and “50% deficit” (I₅₀) in which 50% of full irrigation was applied. Irrigation scheduling was set as to have one irrigation weekly.

For water conveyance and distribution into plots, PE pipes with 63 mm outer diameter and 10 atm operational pressure were used. In drip irrigation, a lateral line was installed for each plant row (70 cm). Water distribution within the plots was carried out through soft PE pipe lines with 20 mm outer diameter and 4 atm operational pressure. Experimental soils have heavy texture with an infiltration rate of 7 mm h⁻¹. Dripper spacing was 0.30 m, dripper discharge rate was 4 L h⁻¹. In-line pressure regulated drippers work at 1 atm operational pressure. Seed bed was prepared as to have planting over the ridges. Each plot had 4 rows 70 cm apart and on-row plant spacing was 30 cm. Styles were 6 m long and 2.8 m wide (16.8 m²). Sowing was performed with a 4-row pneumatic single seed planter and seeds were dropped at 4.5 cm depth. Buffer zones of 2 m were placed to prevent interactions between the plots and replications.

All of phosphorus fertilizer (9 kg da⁻¹ as pure P₂O₅) and one-third of nitrogenous fertilizer (28 kg da⁻¹ N) were applied at sowing and the remaining
two-third of nitrogen was applied in two doses when the plants reached to a height of 40-50 cm [12]. Following the emergence, thinning was performed among close plants when the plants reached to a height of 15-20 cm, hoeing and earthing up were performed when the plants had 8-9 leaves. Herbicides were not used since an intense weed invasion was not observed; only mechanical weed control was preferred. Before each irrigation, moisture content at efficient root depth (90 cm) was determined with gravimetric method. The amount of irrigation water to be applied in each irrigation was determined based on full irrigation treatment (I100) as to bring the deficit moisture in 90 cm soil profile into the field capacity. Therefore, before each irrigation of all irrigation treatments, soil samples were taken from 0-30, 30-60 and 60-90 cm layers of 90 cm soil profile and moisture content was determined in dry-weight base (%). Then the dry-weight-based moisture contents for each layer were converted into moisture depths by using the Equation 1: (Eq. (1))

\[ d = \frac{(FC-Pw) \times A \times D}{100} \]  

Where; \( d \): soil moisture content in depth (mm), \( FC \): Field Capacity (%), \( Pw \): dry weight-based moisture content of each layer (%), \( A_s \): soil bulk density (gcm\(^{-3}\)) and \( D \): depth of layer (mm). Then, the moisture depths calculated for each layer are summed up to get total moisture content in depth (\( d_T \)) for efficient root depth (Eq. (2)).

\[ d_T = d_{30} + d_{60} + d_{90} \]  

Volume of water to be applied to each plot was calculated with Equation 3 by multiplying plot size, deficit ratio (1.0, 0.75, 0.50) and cover ratio (Eq. (3)):

\[ V = d_T \times A \times U_o \times P \]  

Where; \( V \): Volume of water to be applied (L), \( A \): plot size (m\(^2\)), \( U_o \): deficit ratio (%) and \( P \): cover ratio (%). Cover ratio was calculated through dividing plant canopy width by plant row spacing. Cover ratio (CR) was taken as 0.30 until 30% cover, as the calculated value until 80% cover and fixed at 80% at further values. Water applications were performed in a controlled manner through water meters and continuous dripper discharge checks. Monthly and seasonal evapotranspiration values were calculated with water balance method by using weekly soil moisture measurements (90 cm) throughout the growing season, at the beginning and end of harvest [13].

\[ ET_a = P + I - R_f - D_p \pm \Delta S \]  

Where; \( ET_a \): Evapotranspiration (mm), \( P \): precipitation (mm), \( I \): amount of irrigation water (mm); \( R_f \): runoff (mm); \( D_p \): deep percolation (mm) and \( \pm \Delta S \): change in soil water storage in root zone. Since the discharge of selected drippers was lower than soil infiltration rate, runoff was not encountered. Since a certain amount of water was applied to bring the current moisture levels into field capacity, deep percolation was not also observed.

The equations provided in Howell [14] were used to calculate irrigation water use efficiency (IWUE) and water use efficiency (WUE) values (Eq. (5, 6)).

\[ \text{IWUE} = \frac{Y}{I} \]  

(5) \text{WUE} = \frac{Y}{ET_a} \]  

(6) \text{IWUE: Total irrigation water use efficiency (kgda}^{-1} \text{mm}^{-1})

\text{WUE: Total water use efficiency (kgda}^{-1} \text{mm}^{-1})

Where; \( Y \): Yields of irrigation treatments

The relationship between relative evapotranspiration reduction (1-\( Et_a/ET_m \)) and relative yield reduction (1-\( Y_a/Y_{a,m} \)) was determined during the method given by Doorenbos and Kassam [15]. The equations are as follows Eq. (7)).

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

(7)

Where, \( Y_a \) is actual harvested yield, \( Y_m \) is maximum harvested yield, \( k_Y \) is yield response factor, \( ET_a \) is actual evapotranspiration, \( ET_m \) is maximum evapotranspiration.

Following the entire measurements over the experimental plots, harvest was performed. Side rows were omitted and 0.5 m from top and bottom of the rows was not also considered, thus harvest was made from 5 m sections of inner rows.

Seed yield per decare (kgda\(^{-1}\)): Seed yield was converted into yield per decare based on harvested plot size. Crude oil ratio (%): Some of harvested seeds (about 5 g) were grinded in a hand mill. Then, 1 g sample was taken from this grinded portion and crude oil contents were determined in an oil analysis device. All the data acquired through these methods have been subjected to Analysis of Variance (ANOVA) in randomized blocks design. Based on the results obtained from the analysis of variance, significant treatments were compared through LSD (Least Significant difference) and Tukey multiple comparison tests, accordingly [16].

**RESULTS AND DISCUSSION**

Right after sowing on 9 May 2015 in Siirt and 10 May 2015 in Nevsehir, irrigation water was supplied through drip irrigation to bring the soil moisture in 0-90 cm soil profile to field capacity (41 mm in Siirt and 54 mm in Nevsehir), thus to provide a homogenous emergence. Lower irrigation water
supply in Siirt than Nevsehir was because 60.6 mm precipitation was observed in May in which sowing was performed. Irrigation treatments were initiated together with earsing up (when the plants had 6-8 leaves) on 20.06.2015 (41 days after sowing) when 50% of available moisture was depleted [14] and treatments were terminated at physiological ripening stage on 26.08.2015 (100 days after sowing). A total of 7 irrigations were performed through drip irrigation. Harvest was performed on 8 September 2015 (120 days after sowing) in Siirt and on 13 September 2015 (125 days after sowing) in Nevsehir. Harvest was performed 5 days earlier in Siirt than in Nevsehir since higher temperatures of Siirt let the plants reach to ripening maturity earlier. Similarly, effects of air temperature during the crop development stages were not observed but the higher temperature during the flowering and seed filling might have accelerated the physiological maturity [17].

Amount of irrigation water applied in different locations (Siirt and Nevsehir) and plant water consumptions under semi-arid climate conditions of the present study and relevant statistical analysis results (LSD groups) are provided in Table 1. Weekly amount of irrigation water applied in irrigation treatments varied between 53-61 mm. While daily water requirement varied between 4-5 mm/day in early vegetative period, the value reached to maximum level (9.5 mm/day) in pre-blooming, blooming and head formation periods. In full irrigation treatment (I100), the amount of irrigation water applied in Siirt and Nevsehir locations was respectively measured as 400.6 and 373.7 mm. Seasonal plant water consumption (ETa) values of full irrigation (I100) varied between 551 and 493.3 mm and the values in excessive water deficit treatment (I30) varied between 375.7 and 368.1 mm. The plant water consumptions in the other irrigation treatment (I75) were between the values of the other two treatments. Plant water consumption of I100 treatment in Siirt location was 57.7 mm higher. The reason for this higher value was high temperature, radiation and low relative humidity, thus higher plant water consumption of the location.

In previous studies carried out about water-yield relationships in sunflower plants, the amount of irrigation water applied in full irrigation treatments in which soil moisture depletion was fully met varied between 563-769 mm. Sezen [2] reported values in experimental years respectively as 563 and 611 mm, Erdem et al. [7] as 679 mm, Kaya and Kolsarci [18] as 578 mm in full irrigation (I100) treatment of hybrid Sanbro cultivar, 580 mm for Tarsan-1018 cultivar and 726 mm for Ozdemirbey cultivar in the first year, as 769 mm for Sanbro cultivar, 726 mm for Tarsan-1018 and again 726 mm for Ozdemirbey cultivar in the second year of experiments. Current values were lower than the values reported by Kaya and Kolsarci [18] and Erdem et al.[7], but comply with the values of Sezen et al. [2]. Such different results were mainly because of cultivars, different soil, climate and environmental conditions, irrigation programs and cultural practices.

In previous studies, Sezen et al. [2 ] reported seasonal water consumption of sunflower as between 268-607 mm in the first year and between 243-611 mm in the second year; Orta et al. [19] and Erdem and Delibaş [20] reported the water consumption of the plant under conditions where soil moisture content was maintained at a sufficient level throughout the entire growing season as 781 mm. The values reported in those previous studies carried out in different climate zones were generally higher than the present values. Sullu and Dagdelen [21] reported water consumption of sunflower in full

<table>
<thead>
<tr>
<th>Irrigation treatments</th>
<th>Mean Irrigation (mm)</th>
<th>Mean ETa (mm)</th>
<th>Seed yield (kg da⁻¹)**</th>
<th>WUE (kg da⁻¹ mm⁻¹)*</th>
<th>IWUE (kg da⁻¹ mm⁻¹)**</th>
<th>Oil yield (%)**</th>
<th>CWSI**</th>
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<tr>
<td>Siirt location</td>
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<tr>
<td>I100</td>
<td>400.6</td>
<td>551.0</td>
<td>405.7a</td>
<td>0.74b</td>
<td>1.01c</td>
<td>48.2a</td>
<td>0.30c</td>
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<td>I75</td>
<td>344.3</td>
<td>473.3</td>
<td>398.3a</td>
<td>0.84a</td>
<td>1.15a</td>
<td>48.0a</td>
<td>0.39b</td>
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<td>I50</td>
<td>261.0</td>
<td>375.7</td>
<td>267.4b</td>
<td>0.72b</td>
<td>1.03b</td>
<td>42.3b</td>
<td>0.51a</td>
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<tr>
<td>LSD (0.05)</td>
<td>6.05</td>
<td>0.034</td>
<td>0.01</td>
<td>3.96</td>
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<td>Nevsehir location</td>
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<tr>
<td>I100</td>
<td>373.7</td>
<td>493.3</td>
<td>422.2a</td>
<td>0.85b</td>
<td>1.13c</td>
<td>47.8a</td>
<td>0.28c</td>
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<td>I75</td>
<td>315.6</td>
<td>432.6</td>
<td>414.9b</td>
<td>0.96a</td>
<td>1.31a</td>
<td>47.0a</td>
<td>0.37b</td>
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<tr>
<td>I50</td>
<td>242.0</td>
<td>368.1</td>
<td>305.2c</td>
<td>0.83c</td>
<td>1.26b</td>
<td>42.7b</td>
<td>0.50a</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>4.70</td>
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<td>0.046</td>
<td>4.50</td>
<td>0.086</td>
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*p ≤ 0.05, **p ≤ 0.01 It is significant within the error limits, ns: not significant
irrigation treatment (I100) as between 563.3-564.9 mm and reported water consumption in 40% water deficit (I35) as between 405.1-417.2 mm. These earlier values were similar to current values.

Seasonal water consumption of the same cultivar may differ in different climates and regions. It may even be different within the same region. Such differences may be resulted from differences in climate, plant, soil characteristics, irrigation programs and methods and other cultural practices. In other words, it can be stated that there were several factors effecting sunflower plant water consumption from sowing to harvest. Among these factors, the time to reach harvest maturity (ripening days), short (early) or long (late) is the most significant one. While early cultivars have low water consumption, late cultivars have higher consumption values. Abiotic stress factors (temperature, relative humidity, wind) in blooming period may significantly decrease seed formation and increase evapotranspiration rates.

Seed yield. The seed yields of irrigation treatments are provided in Table 1. In both locations, the greatest seed yield and oil ratio were obtained from full irrigation treatment and the lowest values were seen in I50 treatments (Table 1). Seed yield and oil ratio of the other treatment were in between these two treatments. Seed yields and oil contents increased with increasing amount of applied irrigation water quantities. Deficit irrigations significantly affected seed yields and oil ratios and irrigation treatments were placed in different LSD groups. Similar findings were also reported by previous researchers [30] [31] [32]. Kaya and Kolsarici [18] under arid conditions, reported applied irrigation water quantities as between 578-726 mm, seed yield as 2769 kg ha\(^{-1}\) in dry conditions and as 4340 kg ha\(^{-1}\) in full irrigation. Kazemeini et al. [6] also reported the greatest seed yield and oil ratio in full irrigation treatment and the lowest values in severe water deficits and recommended not to have water deficits in sensitive growth stages of sunflower. Current findings quite comply with those earlier findings. Variance analyses revealed significant differences in seed yields and oil ratios of irrigation treatments in both locations (p < 0.01) (Table 1). LSD grouping revealed 2 groups for seed yields with 95% confidence in Siirt and 3 groups in Nevsehir location. Current findings revealed that water deficits after a certain level resulted in decreases in seed yield and oil ratio and different LSD groups. The yield from I75 treatment of Siirt location (3983 kg ha\(^{-1}\)) and full irrigation (I100) (4057 kg ha\(^{-1}\)) were placed in group (A); the seed yield in I35 treatment of Nevsehir location (4149 kg ha\(^{-1}\)) and full irrigation (I100) (4222 kg ha\(^{-1}\)) were placed in subsequent group (B).

The oil ratio obtained from I75 treatments of Siirt location (48%) and oil ratio of I100 treatment (48.2%) were placed in the same group (A); similarly the oil ratio obtained from I35 treatment of Nevsehir location (47%) and I100 treatment (47.8%) were also placed in the same group (A). Therefore, I35 treatment may be recommended for optimum water use efficiency in semi-arid climates. As it was expected, the lowest seed yields were obtained from I50 treatments in both locations (2674 kg ha\(^{-1}\) and 3052 kg ha\(^{-1}\)). Relatively higher seed yield of Nevsehir location was because of cool climate of the province and 41.6 mm precipitation in June in which sunflower is quite sensitive soil moisture deficits. Compared to full irrigation, yield decreased by 2 and 34% with I35 and I50 treatments in Siirt province and by 2 and 26.4% in Nevsehir province. Deficit irrigations resulted in small head and thus less number of seeds per head. Such a case then resulted in less yield and less oil ratio in deficit irrigations [2]; [22]. Timing and plant growth stages in which deficit irrigations are applied significantly influence seed yield and oil ratio. Deficit irrigations applied in vegetative period have less effects in yield losses, the effects are higher when applied in germination, blooming and seed formation periods. Mohammed et al. [23] indicated that water stress during the flowering stage causes considerable reduction in seed yield of sunflower. Therefore, plant growth stages should be taken into consideration and irrigation programs should accordingly be created to have optimum water use efficiency in semi-arid climates.

In previous studies about water-yield relationships in sunflower with different irrigation intervals, seed yields were reported as between 2080-3140 kg ha\(^{-1}\) in full irrigation treatments and oil ratios as between 37-42%. The irrigation interval of seven days (W) gave the highest seed yield (3130, 3140 and 3100 kg ha\(^{-1}\)) and 20 days interval after the flowering stage (F3) gave the lowest seed yield (2080, 2130 and 2260 kg ha\(^{-1}\)) in the first, second and third seasons, respectively. The high oil content (42%) was recorded under weekly irrigation and the lowest percentage was (37%) under the irrigation interval of 20 days after flowering (F3) [24]. Sullu and Dagdelen [21] reported sunflower oil ratio as between 38.87-43.41%. Current findings were also similar with earlier results [24][25][6][2].
FIGURE 1

Plant water consumption – seed yield relationship of irrigation treatments

When the differences in seed yields of full and deficit irrigation are associated to photosynthesis metabolism, it can be stated that cells should have optimum moisture levels for plants to have desired photosynthesis rates and for photosystem reactions of chlorophylls to operate at optimum levels [26]. In this case, with the aid of solar energy adsorbed by chlorophyll pigments, photolysis of water molecules takes place.

Then with the photolysis of water, electrons and protons effective in organic matter formation through Calvin cycle of photosynthesis take place. Ultimately, increase in seed yields in full irrigation (I\(_{100}\)) may be resulted from increased organic matter contents of the plants [27].

The relationship between plant water consumption and yield of irrigation treatments (I\(_{50}\), I\(_{75}\) and I\(_{100}\)) were respectively identified as Y=2.023 ET\(_{a}\)+2005.0 (r\(^2\)=0.968**), Y=4.399 ET\(_{a}\)+1412.0 (r\(^2\)=0.973**), Y=3.891 ET\(_{a}\)+1778.0 (r\(^2\)=0.997**) in Siirt location and as Y= 3.175 ET\(_{a}\)+ 1558.0 (r\(^2\)=0.984**), Y=4.596 ET\(_{a}\)+ 1363.0 (r\(^2\)=0.957**), Y=4.083 ET\(_{a}\)+ 1720.0 (r\(^2\)=0.994**) in Nevsehir location (Figure 1). Seed yield linearly increased with increasing irrigation water quantities and ET\(_{a}\) ratios. A linear relationship was reported between corn grain yield and evapotranspiration [21][2][30][31][32].

Yield response factor (k\(_{y}\)) have recently be used to consider critical threshold water stress level of plants. In this way, possible yield losses due to water stress and water losses due to untimely irrigations can be prevented. In other words, it is possible to estimate yield loss ratio with water deficits applied in any growth stage. However, the yield loss ratio with deficit irrigation in a growth stage is related to plant sensitivity against water deficits in relevant growth stage. In general, plants are more sensitive to water deficits in germination, blooming and grain formation stages than vegetative growth stages. The yield response factor (k\(_{y}\)) was calculated as 0.60 in Siirt and 0.64 in Nevsehir location. Pejić et al. [28] reported yield response factor (k\(_{y}\)) as 0.20 for total growth period and as 0.27, 0.31 and 0.48 respectively for the vegetative, flowering and yield formation stages. Similarly, Sullu and Dagdelen [21] reported k\(_{y}\) factor as 0.74 for entire growth season. Current k\(_{y}\)
The relationship between evapotranspiration reduction and relative yield reduction

Factors were different (higher) from some previous ones and similar with the others. Slight differences in yield response factors were mainly because of differences in climate parameters, plant water consumptions, cultivars, soil conditions, irrigation programs and other cultural practices [30]. Average yield response factor was calculated as 0.62 in this study. It is possible to estimate yield loss in sunflower plant by using \( (1 - \frac{Y_a}{Y_m}) = 0.62 \left(1 - \frac{ET_a}{ET_m}\right) \) value to improve water use efficiency in drip irrigation under semi-arid climate conditions (Figure 2).

Water use efficiency (WUE) and irrigation water use efficiency (IWUE) values indicating seed yield in response to seasonal plant water consumption are provided in Table 1 for different irrigation treatments. WUE and IWUE values varied with irrigation treatments and applied irrigation water quantities. The lowest WUE value in Siirt and Nevşehir locations were observed in I75 treatments respectively with 0.72 and 0.83 kg da⁻¹ mm⁻¹, the highest values were observed in I100 treatments respectively with 0.84 and 0.96 kg da⁻¹ mm⁻¹. The lowest IWUE values in Siirt and Nevşehir locations were obtained from I100 treatments respectively with 1.01 and 1.13 kg da⁻¹ mm⁻¹ and the greatest values were seen in I75 treatments respectively with 1.15 and 1.35 kg da⁻¹ mm⁻¹. The values of the other treatment were in between these two treatments. WUE and IWUE values were quite close to each other. Except for I50 irrigation treatment, there were slight differences between WUE values of treatments. Since applied irrigation water quantities, water consumptions and seed yields were close to each other, similar WUE values were observed. These slight differences were mainly because of similar water deficits applied throughout the growing season. WUE values increased with increasing water consumptions (I100). Similarly, Sezen et al. [2] indicated increased WUE values with increasing applied irrigation water quantities and reported WUE values as between 0.62-1.14 kg da⁻¹ mm⁻¹, IWUE values as between 0.68-1.88 kg da⁻¹ mm⁻¹. Sullu and Dageden [21] reported water use efficiency values as between 0.71-1.22 kg da⁻¹ mm⁻¹. Current WUE and IWUE values were complying with the values reported by Sezen et al. [2].

Considering the research locations together, it was observed that I100 treatment yielded lower IWUE values than I50 and I100 treatments. It can be stated that IWUE values decreased with increasing irrigation water quantities. Similarly, Kang and Zhang [29] reported increased IWUE values with decreasing irrigation water quantities.

CONCLUSION AND RECOMMENDATIONS

Deficit irrigation can be considered as an alternative strategy in regions with deficit water resources. With deficit irrigations, a significant water saving can be achieved and larger areas are served with the available water. Plants may exhibit quite high response to water deficits, but the losses observed in yield and quality most of the time stay within allowable limits. An efficient water use can be provided and higher yields can be obtained from unit water in deficit irrigations. The greatest water use efficiency value (0.90 kg da⁻¹ mm⁻¹) was observed in I75 treatment of both locations. High water use efficiency does not make any sense alone. However, when associated with yields, it was observed that I75 treatment was the best treatment converting irrigation water into yield with an optimum efficiency. In addition, the seed yield obtained from I5 treatment was placed in the same group (A) with I100 treatment in Siirt province and placed in subsequent group (B) in Nevşehir province. In both locations, oil ratio of I75 treatment was placed in the same group with I100 treatment. Water deficits over
25% significantly reduced seed yield and oil ratio of sunflower plants. Therefore, 10% treatment can be recommended for drip irrigation of sunflower plants in regions with semi-arid climate and deficit water resources. On the other hand, in places with sufficient water resources, 10% treatment with 7% higher seed yields can be recommended. Crop water stress index (CWSI) increased inversely with applied irrigation water quantities. Average yield response factor was calculated as 0.62. Possible yield losses can be estimated by using (1 - Ys / Ym) = 0.62 (1 -ETa / ETm) value in drip irrigation planning of sunflower plants under semi-arid climate conditions.

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CORRESPONDING AUTHOR
Asst. Prof. Dr. Ali Beyhan Ucak
Siirt University, Faculty of Agriculture
Department of Biosystem Engineering
50300, Siirt/Turkey
E-mail:alibeyhanucak@gmail.com