Tarım Bilimleri Dergisi
Tar. Bil. Der.
Dergi web sayfası:
www.agri.ankara.edu.tr/dergi

Journal of Agricultural Sciences
Journal homepage:
www.agri.ankara.edu.tr/journal

# Effect of Irrigation Strategies on Yield of Drip Irrigated Sunflower Oil and Fatty Acid Composition and its Economic Returns

**Semih Metin SEZEN[a], Servet TEKİN[b], Dilşat BOZDOĞAN KONUŞKAN[c]**

[a] *Çukurova University, Faculty of Agriculture, Department of Agricultural Structures and Irrigation, Adana, TURKEY*

[b] *Kahramanmaraş Sütçü İmam University, Faculty of Agriculture, Department of Biosystems Engineering, Kahramanmaraş, TURKEY*

[c] *Mustafa Kemal University, Faculty of Agriculture, Department of Food Engineering, Hatay, TURKEY*

**ARTICLE INFO**
Research Article DOI: 10.15832/ankutbd.382617
Corresponding Author: Semih Metin SEZEN, E-mail: smsezen@hotmail.com Tel: +90 (322) 338 60 60
Received: 23 January 2018, Received in Revised Form: 16 April 2018, Accepted: 18 April 2018

**ABSTRACT**

A field trial was conducted to observe the effects of different irrigation strategies on the yield and the water use, oil content and marginal return of sunflower which was irrigated by means of a drip system during 2010 and 2011 under Çukurova condition of Turkey. The irrigation strategies include three irrigation intervals ($A_1$: 25 mm; $A_2$: 50 mm; $A_3$: 75 mm of cumulative pan evaporation) and six water levels (WL) based upon the percentages of cumulative pan evaporation ($WL_1$= 0.50, $WL_2$= 0.75, $WL_3$= 1.00 and $WL_4$= 1.25). In addition, $WL_5$= PRD50 and $WL_6$= PRD75 treatments were evaluated. They obtained water from alternative laterals 50% and 75% of the $WL_3$ treatment. Additionally, a non-irrigated treatment (NI) was included as control plot in the experiment. In each of the experimental years, the largest and the smallest average yields were acquired from the $A_2WL_4$ and NI treatments, respectively. The oil content and fatty acid composition were significantly affected by irrigation strategies. The oil content increased with the increasing amount of irrigation. Among all irrigation intervals, PRD-50 ($WL_5$) treatment provided the largest water use efficiency (WUE) and irrigation water use efficiency (IWUE) values in both growing seasons. In order to attain higher yields and a generated the marginal return, $A_2WL_4$ irrigation regime is suggested for sunflower production in the Mediterranean region. $A_2WL_3$ water strategy is proposed for an acceptable marginal return in case of water shortage.

Keywords: Reduced irrigation; Sunflower; Irrigation scheduling; Oil and fatty acid; Marginal return



## 1. Introduction

Sunflower is an important agricultural crop in most of the sunflower growing countries. In the world, 11% of crude vegetable oil production is supplied by sunflower. In Turkey, 47% of the crude vegetable oil production is supplied by the sunflower. The total production of sunflower is 1.670.716 tons in Turkey. The average yield of sunflower was 4100 kg $ha^{-1}$ in 2016, despite changes in the regions. Turkey which has 4% ratio of sunflower production is in the first ten countries in the world (Konyalı 2017). The Mediterranean region in Turkey is defined as a semi-arid zone where most of the limited annual precipitation and uneven distribution occurs from October to May during the principal growing season. Water deficiency in this region is one of the

TARIM BİLİMLERİ DERGİSİ — JOURNAL OF AGRICULTURAL SCIENCES 25 (2019) 163-173

most important factors affecting crop yield. Thus, irrigation is required during the growing season to maintain and enhance crop growth and yield. In the study conducted by Akcay & Dagdelen (2016), reported that, so as to save water and maximize the yield obtained, water saving irrigation systems should be followed; therefore, a proper irrigation scheduling is required for maximizing the yield and efficient water use. According to Asbaghy et al (2009) sunflower is not only tolerant to water stress caused by deficit irrigation (DI), but it is also high-yielding correspondingly to irrigation inputs. Numerous studies have been conducted to analyze the effect of DI in the response of crops in various areas worldwide. Recent literature revisions agree to conclude that DI is a highly convenient medium in stabilizing yields and increasing the productivity of water in water-scarce areas (Steduto et al 2012). Given the fact that irrigation water supply is scarce, DI becomes a favorable agronomic medium because water productivity is to be the goal instead of maximizing the yield per area unit. Being studied extensively in many parts of the world, deficit irrigation (DI) and partial root drying (PRD) are water-saving irrigation methods. DI is a method, by which the entire root zone is irrigated with an amount of water less than the evapotranspiration potential and the resulting minor stress has minimal effects on the yield, which consequently increases Water Use Efficiency (WUE). Finite water sources should be managed in a way that synthesizes the meeting irrigation requirements for crops and the improvement of WUE. Therefore the main goals of this research were to (a) detecting the effect of different deficit irrigation strategies on water use, seed, oil yields and oil yield-response factor of the sunflower and (b) evaluating the WUE and IWUE subject to different irrigation treatments and (c) estimating marginal return created by drip irrigated sunflower grown in the Çukurova region of Turkey.

## 2. Material and Methods

The field experiments of drip irrigated sunflower were conducted between April and August of two consecutive years, 2010 and 2011, at the Tarsus Location of Alata Horticultural Research Institute in Mersin, Turkey, (37º 01´ N latitude, 35º 01´ E longitude and 30 m altitude). The area is prevailed by typical Mediterranean climate and the soil of the field is identified as silty-clay-loam (SiCL) that has relatively high water-holding capacity. The available soil water in the upper 90 cm of the soil depth is 198 mm. The field capacity is 0.429 $cm^3\ cm^{-3}$ and permanent wilting point of soil is 0.207 $cm^3\ cm^{-3}$, while the mean bulk density ranged between 1.39 and 1.44 g $cm^{-3}$. The sunflower (cv. Oleko) seeds were planted in April 2$^{nd}$, 2010 and May 5$^{th}$, 2011 in rows that are 0.70 m apart. The seeding date was assigned as "0" Days After Sowing (DAS). After the crop establishment, final plant densities were calculated as 5.7 plants $m^{-2}$ in 2010 and as 5.9 plants $m^{-2}$ in 2011. The fertilizer treatments were performed according to soil analysis suggestions, in which equal amount of total fertilizer was provided for all treatment plots. Prior to planting on April 2$^{nd}$, 2010 and on May 5$^{th}$, 2011, a compose fertilizer with 15-15-15 (N, P, K) was administered at 40 N kg $ha^{-1}$ rate; the rest of the N was administered to the experimental plots as $NH_4NO_3$ (33% N) at 30 kg $ha^{-1}$ rate in May 10$^{th}$, 2010 and in May 31$^{st}$, 2011. In the study area, the water used was taken from channel having 7.8 pH value and 0.54 dS $m^{-1}$ average electrical conductivity. The experiment was conducted with a split-plot design, including four replications, in which each subplot was arranged as 5 rows (8.0 m long and 3.5 m wide). The irrigation intervals were assigned as the main plot. The irrigation was applied by dripping on the main plot as soon as three different cumulative evaporation amounts, including $A_1$: 25 mm, $A_2$: 50 mm, and $A_3$: 75 mm, are reached. Among all irrigation intervals ($A_1$, $A_2$, and $A_3$), six irrigation levels were studied according to the percentages of cumulative pan evaporation ($WL_1$: 0.50, $WL_2$: 0.75, $WL_3$: 1.00 and $WL_4$: 1.25) in addition to considering $WL_5$ and $WL_6$ treatments. In $WL_5$ and $WL_6$, while one-half of the root left to dry, 50% and 75% of $WL_3$ was administered to the other half. Afterwards, irrigation was moved to the dry part, throughout the following irrigation. The laterals in drip irrigated plots were placed in each plant row having 70 cm distance in-between for $WL_1$, $WL_2$, $WL_3$ and $WL_4$ treatments, and in-line emitters with a discharge rate of 4.0 L $h^{-1}$ were placed in the lateral line with 25 cm intervals (Betaplast Corp., Adana, Turkey). Two of the drip laterals were placed 20 cm away from the plant row in the $WL_5$: PRD-50 and $WL_6$: PRD-75 treatment plots. During the growing season, the system was run at a pressure of 100 kPa. As the control of these experiments, a non-irrigated treatment (NI) was also applied. A neutron probe (503 DR) was employed to measure the soil water content prior to irrigations during the growing season by using increments ranging from 30 cm to 90 cm. The neutron probes were installed on the plant row to monitor soil water throughout the growing seasons, while a Class-A pan was placed at the meteorological station next to the experimental plots. According to the physiological maturity of the plants, the yield was specified by hand harvesting three adjacent center rows with 6m sections in each plot. The seed yield and oil percentage values were noted subsequent to the harvest. The evapotranspiration (ET) value was calculated by using the water balance Equation (ET= I+R±ΔS-Dp-Rf), where ET is equal to evapotranspiration (mm), I amount of irrigation water applied (mm); ΔS change in soil water content (mm); Dp to deep percolation (mm); and Rf to runoff (Allen et al 1998). WUE and IWUE values were estimated as sunflower yield divided by seasonal ET and total seasonal irrigation water applied according to Howell (2001). The raw oil percentage was calculated by using the extraction method (Luque de Castro & García-Ayuso 1998), while the oil yield was calculated by using a function of seed yield and crude oil percentage. The fatty acid composition was analyzed by Erdemoglu et al (2003). The results obtained were presented as a relative area percentage of total fatty acid methyl esters (IOOC 2001). In order to assess the relationships between ET and the seed and oil yields attain from total ET, and the seed and oil yield data derived from the experiment, the regression analysis method was used. Within the scope of economic analysis, the irrigation cost and marginal return, in which the marginal yield was calculated as the difference between yield from irrigated treatment and non-irrigated treatment, were compared and all calculations were performed based on a unit area of 1 ha (Sezen et al 2011b). The sunflower production costs and sale prices were obtained from the Mersin Chamber of Commerce. Various expenses, including fertilizer, seed, soil cultivation, plant protection as well as land rental, labor cost for irrigation, harvesting and transportation costs constitute the production costs of sunflower. Therefore, the sum of crop production costs, yearly cost of the irrigation system, irrigation labor and water cost were evaluated in order to calculate the total cost for annual sunflower production.

All parameters were subjected to analysis of variance (ANOVA), and means were compared using Duncan test. All statistical analyses were performed using SPSS 11.5 for Windows.

## 3. Results and Discussion

### *3.1. Water use characteristics and soil water variation*

The experimental area is prevailed by typical Mediterranean climate. As a result of the data analysis regarding climate, the temperatures measured during the growing seasons of 2010 and 2011 were found to be parallel to the typical long-term temperature mean of Tarsus. Table 1 summarizes the monthly climatic data compared with the long term mean climatic data for experimental area. Meteorological data were obtained from a nearby weather station. Since the rainfall distribution were unequal during the growing seasons, both experimental years (2010-2011) varied. In the first growing season (from April to July 2010), the depth of received rainfall was 112 mm, a little less than the long-term mean rainfall of 142 mm, while during the growing season of the second year, 2011, it was determined as 184 mm which was greater than that of the long-term mean rainfall as well as the first year (Table 1). The data for seasonal irrigation, crop water use (ET), WUE, IWUE and relative irrigation percentage in each treatment are given in Table 2. The first irrigation treatment was applied in May 18$^{th}$, 2010 (DAS 47) and in June 7$^{th}$, 2011 (DAS 33). On the other hand, the last irrigation application was performed in July 28th, 2010 (DAS 117) and on August 29th, 2011 (DAS 116). Total irrigation numbers ($A_1$, $A_2$ and $A_3$) were measured as 17, 8, 5 and 19, 9, 6 for 2010 and 2011, respectively. While the amounts of the applied irrigation water ranged between 199 and 603 mm based on the treatment in the 2010 growing season, non-irrigated treatment received no water. However, the irrigation water amounts ranged from 220 to 578 mm in 2011 (Table 2). Sunflower total ET varied between 268 mm for NI and 607 mm for $A_2WL_4$ treatment in 2010; and between 243 mm and 611 mm for NI and $A_1WL_4$ in 2011, respectively. Sezen et al (2011a) reported that ET values remained with the increasing amount of irrigation water and that the total ET for sunflower grown in the Eastern part of Mediterranean ranged between 269-689 mm under none-irrigated and full irrigation in 2006, and 2007.

**Table 1- Historical monthly mean and growing season climatic data of the experimental area**

| *Year* | *Climatic parameters* | *Months* | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *I* | *II* | *III* | *IV* | *V* | *VI* | *VII* | *VIII* | *IX* | *X* | *XI* | *XII* |
| 2010 | $T_{mean}$ (°C) | 10.9 | 11.8 | 14.5 | 18.5 | 21.1 | 24.4 | 27.2 | 29.1 | 26.9 | 21.4 | 18.1 | 14.5 |
| | $T_{max}$ (°C) | 14.6 | 16.7 | 21.0 | 24.3 | 26.9 | 29.9 | 32.1 | 35.1 | 33.3 | 28.6 | 37.2 | 21.0 |
| | $T_{min}$ (°C) | 7.2 | 7.3 | 8.8 | 11.4 | 15.7 | 19.2 | 22.7 | 23.1 | 21.3 | 15.6 | 10.5 | 8.8 |
| | P (mm) | 108.0 | 105.0 | 19.0 | 37.0 | 71.0 | 4.0 | 0.0 | 5.0 | 15.1 | 33.5 | 0.2 | 251.5 |
| | E (mm) | 34.5 | 43.5 | 83.4 | 118.2 | 152.9 | 175.5 | 202.0 | 222.0 | 184.8 | 113.6 | 78.9 | 83.4 |
| | RH (%) | 74.2 | 70.4 | 65.5 | 74.0 | 74.2 | 75.2 | 76.6 | 72.2 | 67.5 | 64.7 | 49.0 | 65.5 |
| 2011 | $T_{mean}$ (°C) | 9.8 | 10.7 | 13.5 | 16.3 | 20.3 | 24.1 | 27.2 | 28.0 | 25.9 | 20.0 | 12.1 | 13.5 |
| | $T_{max}$ (°C) | 15.3 | 17.3 | 19.8 | 22.0 | 26.2 | 28.6 | 31.0 | 33.4 | 32.1 | 27.6 | 18.7 | 19.8 |
| | $T_{min}$ (°C) | 5.0 | 5.7 | 7.9 | 11.2 | 15.0 | 17.8 | 19.3 | 21.7 | 18.7 | 11.1 | 6.4 | 7.9 |
| | P (mm) | 71.0 | 36.0 | 77.0 | 89.0 | 70.0 | 25.0 | 0.0 | 0.0 | 8.0 | 19.4 | 27.0 | 183.9 |
| | E (mm) | 34.8 | 40.5 | 77.5 | 85.8 | 121.6 | 135.3 | 164.0 | 182.5 | 147.5 | 102.6 | 64.5 | 77.5 |
| | RH (%) | 68.0 | 67.0 | 70.2 | 69.1 | 70.4 | 75.2 | 77.1 | 70.8 | 66.8 | 52.0 | 60.2 | 70.2 |
| Long term | $T_{mean}$ (°C) | 8.9 | 9.8 | 13.5 | 17.5 | 22.0 | 26.0 | 28.5 | 29.0 | 26.3 | 22.0 | 15.2 | 13.5 |
| | $T_{max}$ (°C) | 19.5 | 21.0 | 26.2 | 31.9 | 35.7 | 37.3 | 37.6 | 39.2 | 38.2 | 36.0 | 28.7 | 26.2 |
| | $T_{min}$ (°C) | -1.9 | -1.7 | 2.8 | 6.2 | 11.3 | 16.2 | 20.5 | 21.0 | 16.1 | 11.3 | 4.5 | 2.8 |
| | P (mm) | 111.8 | 79.0 | 55.4 | 55.1 | 45.7 | 18.0 | 12.3 | 12.3 | 17.8 | 37.1 | 87.9 | 55.4 |
| | E (mm) | 45.2 | 55.6 | 90.2 | 118.0 | 167.9 | 222.1 | 240.1 | 229.9 | 181.7 | 130.2 | 72.2 | 90.2 |
| | RH (%) | 70.9 | 71.4 | 66.5 | 67.7 | 67.1 | 68.2 | 73.2 | 72.4 | 66.3 | 62.2 | 65.3 | 66.5 |

$T_{mean}$, mean air temperature; $T_{max}$, maximum air temperature; $T_{min}$, minimum air temperature; P, rainfall; RH, relative humidity; E, evaporation

The course of soil water storage during the 2010 and 2011 growing seasons of sunflower for each irrigation frequency ($A_1$, $A_2$ and $A_3$) are shown in Figure 1a-f, respectively. In the $A_1$ and $A_2$ irrigation frequencies, soil water contents of treatment plots remained fairly high as compared to $A_3$ irrigation treatments. Soil water remained higher in the WL3 and $WL_4$ plots (in $A_1$ and $A_2$ irrigation intervals) than in the deficit treatments ($WL_1$, $WL_2$, $WL_5$ and $WL_6$) considered. Available soil water in $WL_3$ and $WL_4$ treatment plots remained above 50% throughout the growing season except the $WL_3$ irrigation interval. The soil water storage within the 90 cm depth gradually decreased towards the end of the season in heavy stress treatment (NI) in both experimental years and resulted in soil water contents below wilting point towards the end of the growing season of sunflower.

### *3.2. Growth stages for sunflower*

The time spent on harvesting and on the various phenological growth stages (Steduto et al 2012)

**Table 2- Amount of irrigation water, ET, seed yield, relative yield, oil content, oil yield, WUE and IWUE and fatty acid composition (palmitic, stearic, oleic, linoleic) values for different treatments in 2010-2011 periods**

| *Years* | *Treatments* | *Irrigation (mm)* | *ET (mm)* | *Seed yield (kg ha$^{-1}$)*$^{**}$ | *1000 Seed weights (g)*$^{**}$ | *Oil content (%)*$^{**}$ | *Oil yield (kg ha$^{-1}$)* | *WUE (kg m$^{-3}$)* | *IWUE (kg m$^{-3}$)* | *Fatty acids (%)* Palmitic (C16:0)$^{*}$ | Stearic (C18:0)$^{**}$ | Oleic (C18:1)$^{**}$ | Linoleic (C18:2)$^{**}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2010 | $A_1WL_1$ | 225 | 354 | 2908 cd | 75.50 bc | 34.40 ef | 1000 | 0.82 | 1.29 | 4.03 | 2.50 abc | 87.73 a | 3.23 f |
| | $A_1WL_2$ | 338 | 471 | 3295 bcd | 82.20 abc | 36.30 cdef | 1196 | 0.70 | 0.97 | 4.43 | 2.30 bcde | 87.33 abc | 3.50 ef |
| | $A_1WL_3$ | 450 | 542 | 3793 b | 83.10 abc | 42.80 abc | 1623 | 0.70 | 0.84 | 5.67 | 1.87 hijk | 85.83 hi | 4.83 b |
| | $A_1WL_4$ | 563 | 597 | 4075 ab | 89.10 a | 43.50 ab | 1777 | 0.68 | 0.72 | 6.07 | 1.73 jk | 85.50 ij | 4.97 ab |
| | $A_1WL_5$ | 225 | 359 | 3650 bc | 84.00 abc | 38.80 bcdef | 1420 | 1.02 | 1.62 | 5.47 | 2.20 cdefg | 86.50 defg | 4.53 c |
| | $A_1WL_6$ | 338 | 460 | 3345 bcd | 83.12 abc | 42.10 abcd | 1408 | 0.73 | 0.99 | 5.30 | 2.00 efghij | 86.30 fgh | 4.37 cd |
| | $A_2WL_1$ | 212 | 339 | 2703 d | 75.00 bc | 35.30 def | 954 | 0.80 | 1.28 | 4.67 | 2.37 abcd | 87.07 bcd | 3.33 f |
| | $A_2WL_2$ | 318 | 446 | 3558 bc | 83.00 abc | 37.50 bcdef | 1334 | 0.80 | 1.12 | 4.97 | 2.33 abcd | 86.87 cdef | 3.73 e |
| | $A_2WL_3$ | 424 | 516 | 4030 ab | 84.20 abc | 44.00 ab | 1777 | 0.78 | 0.95 | 6.07 | 1.80 ijk | 84.57 k | 5.00 ab |
| | $A_2WL_4$ | 530 | 607 | 4758 a | 85.30 ab | 48.30 a | 2298 | 0.78 | 0.90 | 6.63 | 1.60 k | 84.13 k | 5.17 a |
| | $A_2WL_5$ | 212 | 349 | 3993 ab | 80.40 abc | 40.70 bcdef | 1625 | 1.14 | 1.88 | 5.47 | 2.17 defgh | 86.07 ghi | 4.53 c |
| | $A_2WL_6$ | 318 | 436 | 3813 b | 83.70 abc | 43.20 ab | 1647 | 0.87 | 1.20 | 5.90 | 1.90 ghijk | 85.20 j | 4.90 ab |
| | $A_3WL_1$ | 199 | 360 | 2675 d | 72.60 c | 34.10 f | 912 | 0.74 | 1.34 | 3.90 | 2.63 a | 87.73 a | 2.57 g |
| | $A_2WL_2$ | 298 | 425 | 2943 cd | 74.20 bc | 35.50 def | 1045 | 0.69 | 0.99 | 4.00 | 2.57 ab | 87.53 ab | 2.73 g |
| | $A_3WL_3$ | 397 | 514 | 3740 bc | 80.70 abc | 40.80 bcde | 1530 | 0.73 | 0.94 | 5.17 | 1.97 fghij | 86.37 efgh | 4.83 b |
| | $A_3WL_4$ | 603 | 603 | 4080 ab | 82.20 abc | 42.60 abc | 1734 | 0.68 | 0.68 | 5.50 | 1.83 ijk | 86.20 gh | 4.87 ab |
| | $A_3WL_5$ | 199 | 356 | 3633 bc | 84.80 abc | 36.40 cdef | 1319 | 1.02 | 1.83 | 4.27 | 2.23 cdef | 86.50 defg | 4.20 d |
| | $A_3WL_6$ | 298 | 426 | 3440 bcd | 82.70 abc | 39.50 bcdef | 1355 | 0.81 | 1.15 | 4.80 | 2.07 defghi | 86.93 bcde | 4.37 cd |
| | NI | 0 | 268 | 1670 | 65.10 | 33.60 | 563 | 0.62 | - | 3.73 | 2.90 | 88.50 | 2.20 |
| 2011 | $A_1WL_1$ | 236 | 396 | 2855 i | 78.50 cdef | 39.70 ij | 1138 | 0.72 | 1.21 | 3.93 hi | 1.90 cd | 88.67 a | 4.00 gh |
| | $A_1WL_2$ | 348 | 452 | 3335 h | 82.00 bcd | 40.80 ghi | 1366 | 0.74 | 0.96 | 4.67 efg | 1.90 cd | 87.67 cdef | 4.43 ef |
| | $A_1WL_3$ | 461 | 513 | 3940 de | 84.00 bc | 43.70 de | 1726 | 0.77 | 0.85 | 5.23 bcd | 1.60 fg | 86.13 i | 5.03 abc |
| | $A_1WL_4$ | 578 | 611 | 4560 b | 90.50 a | 46.60 b | 2116 | 0.75 | 0.79 | 5.47 bc | 1.53 gh | 85.93 ij | 5.17 ab |
| | $A_1WL_5$ | 236 | 385 | 3695 efg | 69.80 h | 41.80 fgh | 1550 | 0.96 | 1.57 | 5.10 cde | 1.63 efg | 86.97 fgh | 4.63 cdef |
| | $A_1WL_6$ | 348 | 443 | 4025 cd | 73.4 fgh | 42.60 efg | 1721 | 0.91 | 1.16 | 4.90 def | 1.77 de | 86.40 ghi | 4.87 bcd |
| | $A_2WL_1$ | 221 | 320 | 3430 gh | 75.10 efgh | 39.30 ij | 1351 | 1.07 | 1.55 | 4.73 ef | 1.77 de | 88.20 abc | 4.33 fg |
| | $A_2WL_2$ | 328 | 416 | 3700 efg | 76.50 defg | 40.10 hi | 1487 | 0.89 | 1.13 | 4.90 def | 1.70 ef | 87.87 bcd | 4.47 def |
| | $A_2WL_3$ | 436 | 491 | 4118 cd | 78.30 cdef | 46.80 b | 1934 | 0.84 | 0.94 | 5.63 ab | 1.53 gh | 85.33 jk | 5.17 ab |
| | $A_2WL_4$ | 546 | 595 | 4890 a | 80.20 bcde | 51.10 a | 2499 | 0.82 | 0.90 | 5.90 a | 1.40 h | 85.03 k | 5.40 a |
| | $A_2WL_5$ | 221 | 327 | 4115 cd | 69.40 h | 43.70 def | 1798 | 1.26 | 1.86 | 5.10 cde | 1.63 efg | 87.10 efg | 4.83 bcde |
| | $A_2WL_6$ | 328 | 400 | 4273 c | 71.00 gh | 45.60 bc | 1953 | 1.07 | 1.30 | 5.33 bcd | 1.57 fg | 86.20 i | 5.03 abc |
| | $A_3WL_1$ | 220 | 342 | 2375 j | 70.60 gh | 37.10 k | 885 | 0.69 | 1.08 | 3.43 j | 2.23 a | 88.57 ab | 2.60 i |
| | $A_2WL_2$ | 327 | 423 | 2805 i | 72.10 gh | 38.20 jk | 1076 | 0.66 | 0.86 | 3.63 ij | 2.13 ab | 88.20 abc | 2.93 i |
| | $A_3WL_3$ | 436 | 495 | 3635 fg | 83.30 bc | 42.60 efg | 1554 | 0.73 | 0.83 | 4.87 def | 1.70 ef | 86.43 ghi | 4.77 bcde |
| | $A_3WL_4$ | 546 | 605 | 4080 cd | 84.10 bc | 44.40 cd | 1817 | 0.67 | 0.75 | 5.10 cde | 1.67 ef | 86.33 hi | 4.93 bc |
| | $A_3WL_5$ | 220 | 329 | 3560 fgh | 85.20 ab | 40.20 hi | 1436 | 1.08 | 1.62 | 4.27 gh | 1.90 cd | 87.80 cde | 3.67 h |
| | $A_3WL_6$ | 327 | 400 | 3743 ef | 86.60 ab | 40.80 ghi | 1531 | 0.94 | 1.14 | 4.53 fg | 2.00 bc | 87.43 def | 4.63 cdef |
| | NI | 0 | 243 | 1700 | 63.50 | 36.10 | 614 | 0.70 | - | 3.30 | 2.40 | 89.20 | 1.70 |

Datas are emitted as a mean ± SD. $^{*}$, P<0.05 and $^{**}$, P<0.01

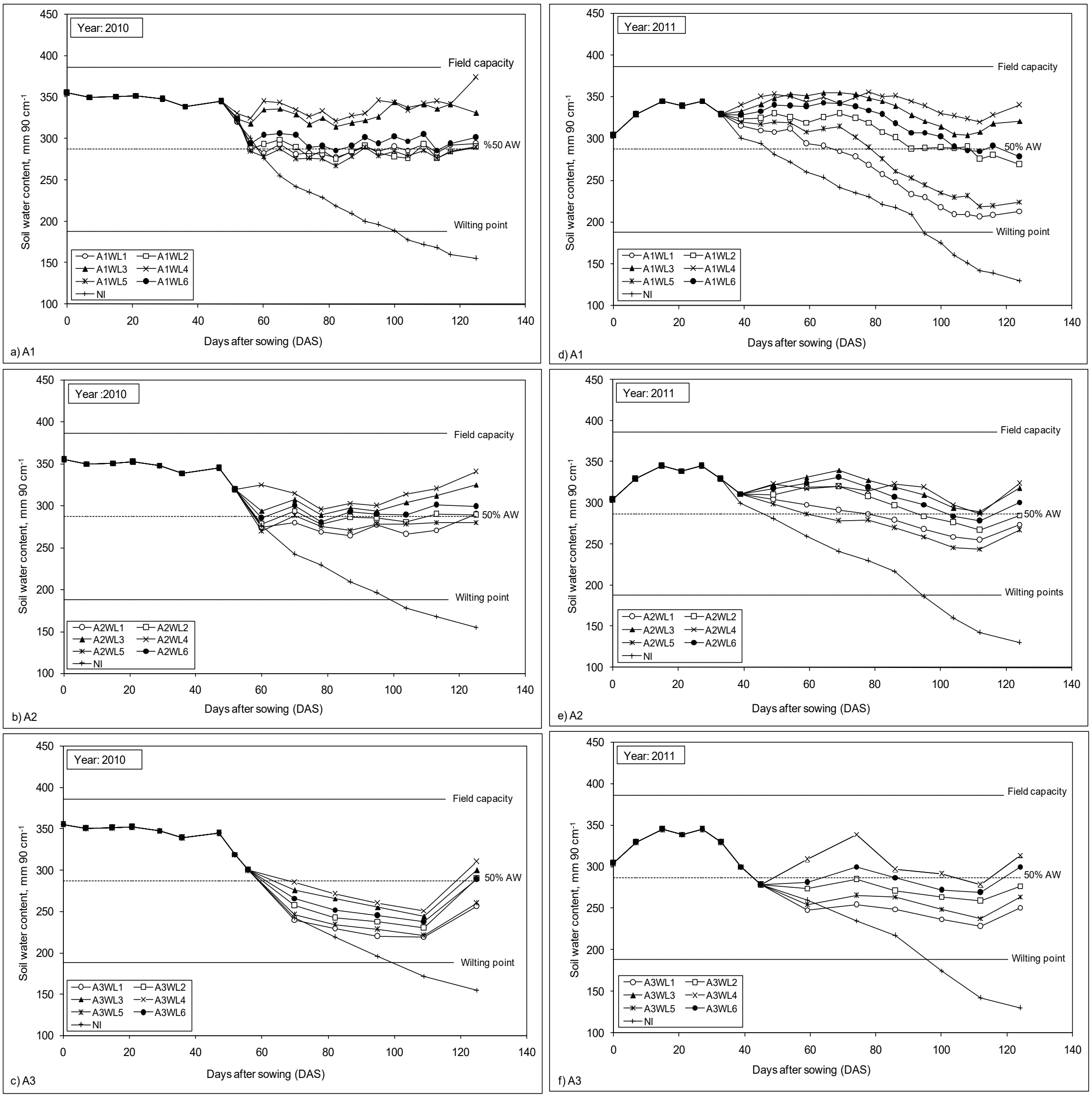


**Figure 1- Course of soil water storage during the 2010 (a, b, c) and 2011 (d, e, f) sunflower growing season in all treatments**

were noted as number of days after sowing (DAS). The total length of the growing season for sunflower was calculated as 125 days in 2010, while it was 124 days in 2011. Sezen et al (2011a) have reported growth stages of sunflower varying from 129 to 132 days in drip irrigation and varying from 121 to 132 days in sprinkler irrigation conditions in east Mediterranean part of Turkey.

### *3.3. Seed yield*

Sunflower seed yields and yield components at the 1% level were remarkably influenced by interaction of irrigation intervals (A) and irrigation levels (WL). Based on Duncan test (Table 2), $A_2WL_4$ treatment was placed in the first group ($P<0.01$) in the first experimental year. The minimum yield was found in the non-irrigated treatment as 1670 kg ha$^{-1}$ in 2010 and 1700 kg ha$^{-1}$ in 2011. Even though PRD-50 treatments ($WL_5$) of $A_1$, $A_2$, and $A_3$ intervals received about 50% less irrigation of the water that was administered to the $WL_3$ plots of $A_1$, $A_2$ and $A_3$ irrigation intervals, the reduction in seed yields of $WL_5$ at $A_1$, $A_2$, and $A_3$ treatments were only 3.8, 0.9 and 2.9% in 2010 and 6.2, 0.1, and 2.1% in 2011, respectively, as compared to $WL_3$ in both years (Table 2). It was found that seed yield decreased significantly when the amount of irrigation was lowered. Based on Duncan test (Table 2), $A_2WL_4$ treatment was situated in the first group ($P<0.01$) while $A_1WL_4$ treatment was fallen into the second group in 2011.

### *3.4. Water use efficiency (WUE) and irrigation water use efficiency (IWUE)*

It was observed that irrigation regimes affected WUE and IWUE values considerably (Table 2). WUE values varied between 0.62 kg m$^{-3}$ in NI treatment to 1.14 kg m$^{-3}$ in the $A_2WL_5$ for the first experimental year, while it varied between 0.66 kg m$^{-3}$ in $A_3WL_2$ and 1.26 kg m$^{-3}$ in the $A_2WL_5$ for the second year. The highest WUE values were measured in $A_2WL_5$ for both growing years. In the study carried out by Sezen et al (2011a), similar results were attained for sunflower grown under water stress conditions. Depending on the treatment applied, IWUE values varied between 0.68 and 1.88 kg m$^{-3}$ in 2010 and varied between 0.75 and 1.86 kg m$^{-3}$ in 2011. For both experimental years, the highest IWUE values were observed in $A_2WL_5$. In addition, Sezen et al (2011b) reported that the irrigation strategies in sprinkler and drip systems affected the IWUE values significantly. Akcay & Dagdelen (2016) reported that the WUE and IWUE values were affected by the irrigation intervals and levels. WUE varied from 0.70 kg m$^{-3}$ to 1.21 kg m$^{-3}$ among treatments in both years.

### *3.5. ET-seed yield and ET - oil yield relationships on sunflower*

Regression analysis showed that there was a linear relationship between seed and oil yield with total ET at the 0.05 level of significance for both years (Figure 2a-b). It was demonstrated that the oil content is strongly influenced by the figure of ET throughout the growing season.

### *3.6. Seed weight*

According to the analysis of variance administered to the results obtained in 2010 and 2011; sunflower seed weight at the 1% level were statistically

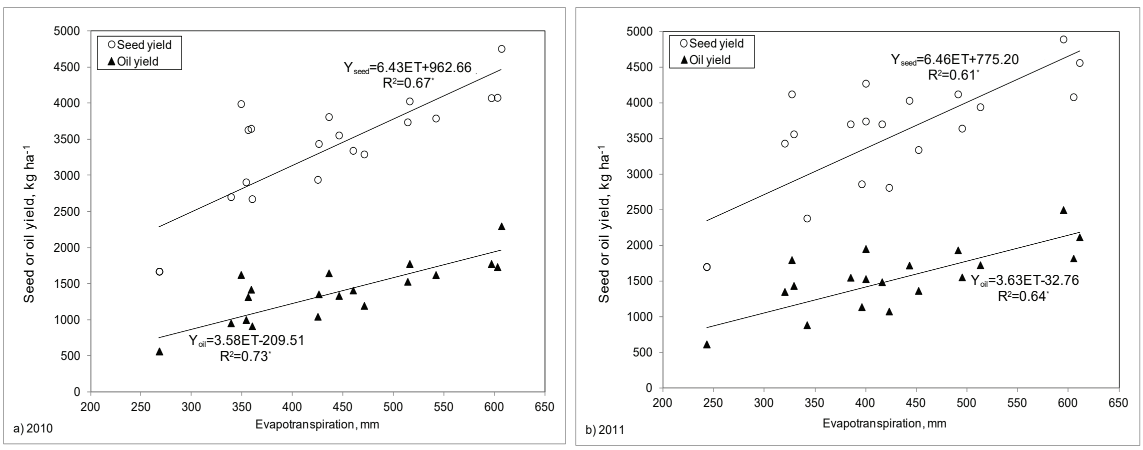


**Figure 2 a, b- Interaction between evapotranspiration (ET)-seed or oil yield in 2010(a) and 2011(b)**

influenced by interaction of irrigation intervals (A) and irrigation levels (WL). As for 1000 seed weights, it varied from 65.0 to 89.2 g in 2010 while the values were between 63.6 and 90.6 g in 2011. The lowest and the highest values in 1000 seed weights were obtained at NI and $A_1WL_4$ in 2010 and 2011, respectively (Table 2). Langeroodi et al (2014) reported that 1000 seed weight of the sunflower seeds varied between 54.3 and 68.0 g according to the treatments.

### *3.7. Oil yield, oil percentage and fatty acid compounds*

The oil yield and percentage was significantly influenced ($P<0.01$) by the irrigation intervals and irrigation levels in both years. The oil content increased with the increasing amounts of irrigation in the treatments, in which the greatest oil contents were attained from the $A_2WL_4$ (48.33 and 55.10%) treatment in both years (Table 2). NI yielded the least oil content (33.70 and 36.10%). Asbagh et al (2009) reported that the oil content of the sunflower seeds varied between 34.3% and 39.1% in non-irrigated conditions and between 38.5 and 42.7% in irrigated conditions in different varieties. In this study, the results which demonstrated the oil percentage correspond to those of Asbagh et al (2009) and Sezen et al (2011a), who suggested that the oil percentage increased with the increased use of irrigation water. Results showed that although stress did not affect the oil percentage, it reduced the oil yield via severe reduction in grain yield. Both the irrigation interval and irrigation levels had a significant effect on the sunflower oil yield in both growing seasons (Table 2), hence it reveals the increase in oil yield with the increasing amount of irrigation water. The maximum average oil yield was obtained in $A_2WL_4$, followed by $A_2WL_3$, and the minimum oil yield was obtained from the NI treatment. According to Essiari et al (2014), the fatty acid composition is an important parameter in identifying the quality of the oils. The major fatty acids were oleic acid (84.13- 89.20%), linoleic acid (1.70-5.17%) palmitic acid (3.30-6.07%) and stearic acid (1.40-2.90%) in sunflower oils (Table 2). It was determined that there is a negative correlation between oleic acid and linoleic acid. Baldini et al (2002) suggested that there is a positive correlation between the amount of oleic acid and ET during the vegetative period of the plant. However, Asbagh et al (2009) observed an increase in the amount of linoleic and palmitic acid and a decrease in the amount of stearic acid and oleic acid with irrigation. It was found that there are significant linear relationships between the oleic acid and linoleic acid contents compared to evapotranspiration for 2010 and 2011 growing seasons (Figure 3a-b). The water stress significantly affects the content of unsaturated

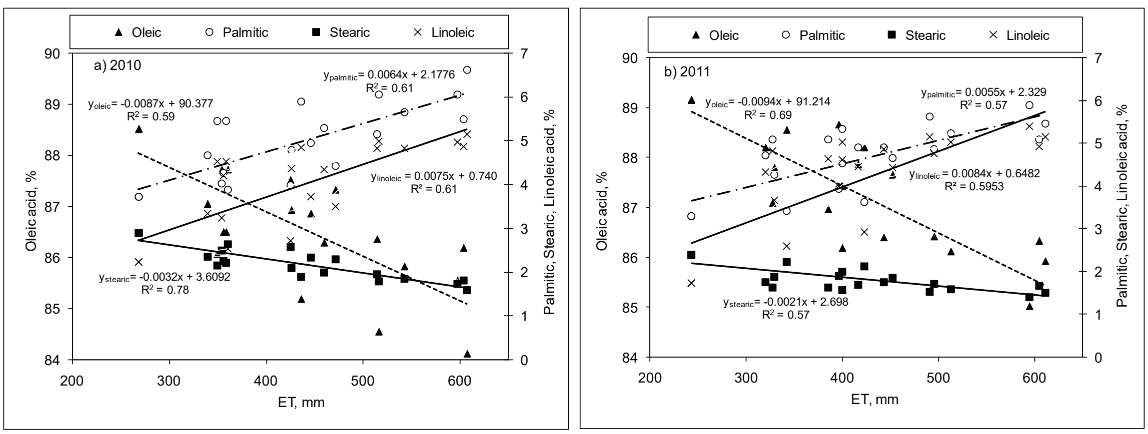


**Figure 3 a, b- The interaction between ET and oleic, palmitic, linoleic and stearic acid contents for all treatments in 2010(a)-2011(b)**

(oleic and linoleic acid) fatty acids. As ET increased oleic acid content decreased, while linoleic acid concentration increased in 2010 and 2011 growing seasons. In their study, Sezen et al (2011a) acquired similar results for sunflower grown under water stress conditions in Eastern Mediterranean part of Turkey.

*3.8. Economical evaluation*

In this study, the economical evaluation was performed by analyzing the results based on the means of the operation, investment and production costs for both years and the results are shown in Table 3. Within the scope of economical evaluation, the maximum return of 581 US$ ha$^{-1}$ was obtained from the $A_2WL_4$ treatment. It was observed that lower irrigation levels caused a decrease in marginal return per irrigation interval. In the context of marginal return, a significant difference was found between the irrigation intervals and irrigation levels. The marginal return was increased in all irrigation intervals as the water supply increased. In the economic analyses, the marginal return and irrigation costs were compared and for the evaluations the marginal yield was calculated, which is the difference between yield from irrigated treatment and non-irrigated treatment. The results indicated that $A_1WL_3$ and $A_1WL_4$ in $A_1$, $A_2WL_2$, $A_2WL_3$, $A_2WL_4$ and $A_2WL_5$ in $A_2$, and $A_3WL_3$ and $A_3WL_4$ in $A_3$ were the economical treatments since they generated higher income over the irrigation cost. Among them $A_2WL_4$ was the most economical treatment and recommended. It was found that $A_2WL_3$ treatment is a plausible alternative in areas where access to irrigation water is expensive or less than demanded.

## 4. Conclusions

In this study, the effects of different irrigation strategies on the seed and oil yield, water use, WUE and IWUE in Çukurova region of Turkey throughout the sunflower growing seasons of 2010 and 2011 were analyzed in terms of amount and frequency. $A_2WL_4$ treatment presented the highest yield as 4758 and 4890 kg ha$^{-1}$ respectively for both years. The oil contents were considerably affected depending on different irrigation intervals and levels. Furthermore, the results demonstrated that the WUE and IWUE values diminished depending on the increase in irrigation intervals. Lower WUE and IWUE were achieved by the means of the same irrigation level in $A_1$ and $A_3$ irrigation intervals compared to $A_2$ interval. It was determined that there is a significant linear relationship between sunflower seed and oil yield, and total ET, the oil content of sunflower as well as total ET in both of the experimental years. In the context of economic evaluation, the marginal return from the $A_2WL_4$ treatment under drip irrigation was determined to be logical in areas having no water scarcity. Under water scarcity conditions, however, it was determined that $A_2WL_3$ treatment may generate an acceptable marginal return. It has been thought that the results will help to adopt deficit irrigation method, by which net financial returns are enhanced.

In conclusion, it is suggested to apply $A_2WL_4$ treatment (cumulative pan evaporation: 50±5 mm, $WL_4$= 1.25) in drip irrigated sunflower production for the purpose of achieving a higher yield in Çukurova region of Turkey. For two consecutive experimental years, the total amount of irrigation water for suggested treatment ($A_2WL_4$) was found to be 530 mm and 546 mm, respectively, while the total amount of seasonal water use for $A_2WL_4$ was found to be 607 mm and 595 mm, respectively. The number of irrigation treatments varied from 8-9 in 2010, and 8-10 days in $A_2$ treatments.

## Acknowledgements

The authors would like to thank the General Directorate of Agricultural Research and Policies (TAGEM) for its financial support to the project of TAGEM-BB-090201C3. We also thank editors for their enthusiasm and dedication, and the reviewers for their critical and valuable comments on the manuscript.

**Table 3- The economical evaluation on sunflower for all treatments based on average of two years data**

| Treatments | (1) Irrigation water (mm) | (2) Irrigation water ($m^3$ $ha^{-1}$) | (3) Irrigation duration for the irrigation season (h) | (4) Labor cost for irrigation ($ $h^{-1}$) | (5) Total cost for irrigation labor ($) (3x4) | (6) Water price ($ $m^{-3}$) | (7) Water cost ($ $ha^{-1}$) (2x6) | (8) Irrigation system cost ($ $ha^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| $A_1WL_1$ | 231 | 2310 | 10.1 | 1.7 | 16.6 | 0.1 | 231 | 4446 |
| $A_1WL_2$ | 343 | 3430 | 15.0 | 1.7 | 24.8 | 0.1 | 343 | 4446 |
| $A_1WL_3$ | 456 | 4560 | 20.0 | 1.7 | 33.0 | 0.1 | 456 | 4446 |
| $A_1WL_4$ | 571 | 5710 | 25.0 | 1.7 | 41.3 | 0.1 | 571 | 4446 |
| $A_1WL_5$ | 231 | 2310 | 10.1 | 1.7 | 16.6 | 0.1 | 231 | 6983 |
| $A_1WL_6$ | 343 | 3430 | 15.0 | 1.7 | 24.8 | 0.1 | 343 | 6983 |
| $A_2WL_1$ | 217 | 2170 | 9.5 | 1.7 | 15.7 | 0.1 | 217 | 4446 |
| $A_2WL_2$ | 323 | 3230 | 14.2 | 1.7 | 23.4 | 0.1 | 323 | 4446 |
| $A_2WL_3$ | 430 | 4300 | 18.9 | 1.7 | 31.2 | 0.1 | 430 | 4446 |
| $A_2WL_4$ | 538 | 5380 | 23.6 | 1.7 | 39.0 | 0.1 | 538 | 4446 |
| $A_2WL_5$ | 217 | 2170 | 9.5 | 1.7 | 15.7 | 0.1 | 217 | 6983 |
| $A_2WL_6$ | 323 | 3230 | 14.2 | 1.7 | 23.4 | 0.1 | 323 | 6983 |
| $A_3WL_1$ | 210 | 2100 | 9.2 | 1.7 | 15.1 | 0.1 | 210 | 4446 |
| $A_2WL_2$ | 313 | 3130 | 13.7 | 1.7 | 22.6 | 0.1 | 313 | 4446 |
| $A_3WL_3$ | 417 | 4170 | 18.3 | 1.7 | 30.2 | 0.1 | 417 | 4446 |
| $A_3WL_4$ | 575 | 5750 | 25.2 | 1.7 | 41.6 | 0.1 | 575 | 4446 |
| $A_3WL_5$ | 210 | 2100 | 9.2 | 1.7 | 15.1 | 0.1 | 210 | 6983 |
| $A_3WL_6$ | 313 | 3130 | 13.7 | 1.7 | 22.6 | 0.1 | 313 | 6983 |
| NI | 0 | 0 | 0.0 | 1.7 | 0.0 | 0.1 | 0 | 0 |

| Treatments | (9) Irrigation system cost for 1 ha ($ $h^{-1}$) (8/6 years) | (10) Yearly cost for the irrigation system ($ $ha^{-1}$) (5+7+9) | (11) Yield (kg $ha^{-1}$) | (12) Marginal yield (kg $ha^{-1}$) | (13) Sunflower sales price ($ $kg^{-1}$) | (14) Marginal return ($ $ha^{-1}$ $year^{-1}$) (12x13) | (15) Return ($ $ha^{-1}$ $year^{-1}$) (14-10) |
|---|---|---|---|---|---|---|---|
| $A_1WL_1$ | 741 | 989 | 2882 | 1197 | 0.6 | 724 | -265 |
| $A_1WL_2$ | 741 | 1109 | 3315 | 1630 | 0.6 | 986 | -123 |
| $A_1WL_3$ | 741 | 1230 | 3867 | 2182 | 0.6 | 1320 | 90 |
| $A_1WL_4$ | 741 | 1353 | 4318 | 2633 | 0.6 | 1593 | 239 |
| $A_1WL_5$ | 1164 | 1411 | 3673 | 1988 | 0.6 | 1202 | -209 |
| $A_1WL_6$ | 1164 | 1532 | 3685 | 2000 | 0.6 | 1210 | -322 |
| $A_2WL_1$ | 741 | 974 | 3067 | 1382 | 0.6 | 836 | -138 |
| $A_2WL_2$ | 741 | 1087 | 3629 | 1944 | 0.6 | 1176 | 89 |
| $A_2WL_3$ | 741 | 1202 | 4074 | 2389 | 0.6 | 1445 | 243 |
| $A_2WL_4$ | 741 | 1318 | 4824 | 3139 | 0.6 | 1899 | 581 |
| $A_2WL_5$ | 1164 | 1397 | 4054 | 2369 | 0.6 | 1433 | 37 |
| $A_2WL_6$ | 1164 | 1510 | 4043 | 2358 | 0.6 | 1427 | -84 |
| $A_3WL_1$ | 741 | 966 | 2525 | 840 | 0.6 | 508 | -458 |
| $A_2WL_2$ | 741 | 1077 | 2874 | 1189 | 0.6 | 719 | -357 |
| $A_3WL_3$ | 741 | 1188 | 3688 | 2003 | 0.6 | 1212 | 23 |
| $A_3WL_4$ | 741 | 1358 | 4080 | 2395 | 0.6 | 1449 | 91 |
| $A_3WL_5$ | 1164 | 1389 | 3597 | 1912 | 0.6 | 1156 | -233 |
| $A_3WL_6$ | 1164 | 1499 | 3592 | 1907 | 0.6 | 1153 | -346 |
| NI | 0 | 0 | 1685 | 0 | 0.6 | 0 | 0 |

## References

Akcay S & Dagdelen N (2016). Water use effıciency, yield and yield components of second crop sunflower under deficit irrigation. *Turkish Journal of Field Crops* 21(2): 190-199

Allen R G, Pereira L S, Raes D & Smith M (1998). Crop evapotranspiration: guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56, FAO, Rome, 300 pp

Asbagh F T, Moghddam A F & Gorttapeh A H (2009). Influence of water stress and sowing date on sunflower yield and oil percentage. *Research Journal of Biological Sciences* 4(4): 487-489

Baldini M, Giovanardi R, Enferadi S T & Vannozzi G P (2002). Effects of water regime on fatty acid accumulation and final fatty acid composition in the oil of standard and high oleic sunflower hibrids. *Italian Journal of Agronomy* 6(2): 119-126

Erdemoglu N, Kusmenoglu S & Yenice N (2003). Effect of irrigation on the oil content and fatty acid composition of some sunflower seeds. *Chemistry of Natural Compounds* 39(1): 1-4

Essiari M, Zouhair R & Chimi H (2014). Contribution to the study of the typical characteristics of the virgin olive oils produced in the region of Sais (Morocco). *Official Journal of the International Olive Council* 119: 8-21

Howell T A (2001). Enhancing water use efficiency in irrigated agriculture. *Agronomy Journal* 93(2): 281-289

IOOC (2001). International Olive Oil Council. Preparation of the fatty acid methyl esters from olive oil and olive pomace olive oil. Madrid, Spain, COI/T.20/Doc. no. 24

Konyalı S (2017). Sunflower production, consumption, foreign trade and agricultural policies in Turkey. *Social Sciences Research Journal* 6(4): 11-19

Langeroodi A R S, Kamkar B, Silva J A T & Ataei M (2014). Response of sunflower cultivars to deficit irrigation. *Helia* 37(60): 37-58

Luque de Castro M D & García-Ayuso L E (1998). Soxhlet extraction of solid materials: an outdated technique with a promising innovative future. *Analytica Chimica Acta* 369(1-2): 1-10

Sezen S M, Yazar A, Kapur B & Tekin S (2011a). Comparison of drip and sprinkler irrigation strategies on sunflower seed and oil yield and quality under Mediterranean climatic conditions. *Agricultural Water Management* 98(7): 1153-1161

Sezen S M, Yazar A, Tekin S, Eker S & Kapur B (2011b). Yield and quality response of drip-irrigated pepper under mediterranean climatic conditions to various water regimes. *African Journal of Biotechnology* 10(8): 1329-1339

Steduto P, Hsiao T C, Fereres E & Raes D (2012). Crop yield response to water. FAO Irrigation and Drainage Paper 66, FAO, Rome 505 pp