ÇOMÜ Zir. Fak. Derg. (COMU J. Agric. Fac.)
2022: 10 (1): 119–129
ISSN: 2147–8384 / e-ISSN: 2564–6826
doi: 10.33202/comuagri.1073522

Araştırma Makalesi/Reserach Article

The Effect of Deficit Irrigation on Yield and Quality of Second Crop Sesame (*Sesamum indicum* L.)

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Received Date: 15.02.2022
Accepted Date: 12.04.2022

Abstract

This study was carried out in Bursa, Turkey which has a sub-humid climate, in order to examine the water-yield relationships and responses of yield and quality components under deficit irrigation of second crop sesame plant (*Sesamum indicum* L.) irrigated with drip irrigation method. Experimental treatments were application of 100% (S1), 75% (S2), 50% (S3), 25% (S4) and 0% (S5) of soil water depleted at effective rooting depth at 7-day intervals. The experiment was applied in 3 replicates according to the completely randomized blocks experimental design. According to the study results, the total amounts of irrigation water applied were between 127.0-354.7 mm. Crop evapotranspiration values varied between 246.0-449.5 mm. While the effects of deficit irrigation on seed yield and yield components in the second crop sesame were significant at the $P<0.01$ level, its effects on oil content and protein content were not statistically significant. Seed yield, oil content and protein content were obtained as between 76.3-189.2 kg da^{-1}, 56.3-62.6% and 18.6-20.4%, respectively. In the study, the seasonal yield response factor (k_y) was determined as 1.28. Water use efficiency (WUE) of the sesame plant was found between 0.31-0.43 kg m^{-3}. Irrigation water use efficiency (IWUE) varied between 0.50-0.57 kg m^{-3}. As a result, irrigation treatment S1 can be suggested as an irrigation schedule in order to reach the highest seed yield (189.2 kg da^{-1}) in the second crop sesame plant.
Keywords: Second crop sesame, Drip irrigation, Deficit irrigation, Yield, Quality

İkinci Ürün Susamda (*Sesamum indicum* L.) Kısıntılı Sulamanın Verim ve Kalite Özellikleri Üzerine Etkisi

Öz

Bu çalışma, ikinci ürün susam bitkisinin (*Sesamum indicum* L.) damla sulama yöntemi ile uygulanan kısıntılı sulama altında su-verim ilişkilerini ve verim ve kalite bileşenlerinin tepkilerini incelemek amacıyla, yarı-nemli iklime sahip Bursa'da yapılmıştır. Deneme konuları, etkili kök derinliğindeki nem düzeyi her 7 günde bir takip edilerek topraktaki mevcut nemi tarla kapasitesine ulaştırmak için gerekli suyun %100 (S1), %75 (S2), %50 (S3), %25 (S4) ve %0 (S5)'ının uygulanması şeklinde programlanmıştır. Deneme, tesadüf blokları deneme desenine göre 3 tekrarlamalı olarak yürütülmüştür. Araştırma sonuçlarına göre, sulama konuları dikkate alınarak uygulanan sulama suyu miktarları 127.0-354.7 mm arasında gerçekleşmiştir. Bitki su tüketimi değerleri ise 246.0-449.5 mm arasında bulunmuştur. Kısıntılı sulamanın tohum verimi ve verim bileşenleri üzerine etkileri $P<0.01$ düzeyinde önemli bulunurken, yağ ve protein oranları üzerine etkileri ise istatistiksel açıdan önemsiz olmuştur. Tane verimi 76.3-189.2 kg da^{-1}, yağ oranı %56.3-62.6 ve protein oranı %18.6-20.4 olarak elde edilmiştir. Araştırmada mevsimlik verim tepki etmeni (k_y) 1.28 olarak belirlenmiştir. Susam bitkisinin su kullanım etkinliği (WUE) 0.31-0.43 kg m^{-3} arasında bulunmuştur. Sulama suyu kullanım etkinliği (IWUE) ise 0.50-0.57 kg m^{-3} arasında değişmiştir. Sonuç olarak, ikinci ürün olarak yetiştirilen susam bitkisinde en yüksek tane verimine (189.2 kg da^{-1}) ulaşmak için S1 sulama konusu sulama programı olarak önerilebilir.
Anahtar Kelimeler: İkinci ürün susam, Damla sulama, Kısıntılı sulama, Verim, Kalite

Introduction

Sesame seeds contain approximately 50-60% oil and 25% protein. Since the use of sesame oil as vegetable oil is not economical in our country, its consumption has been limited. Sesame is mainly used in the production of tahini halva, pastry industry, bagels and bakery products, cosmetics industry, soap production and several products in Turkey (Tan, 2015). According to data of 2018, Sudan, Myanmar, India, Nigeria, Tanzania and China are in the first six places in terms of sesame production in the world, while Turkey is in 32nd place with 17437 tons (FAO, 2018). Sesame cultivation is carried

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out in the regions, Thrace, Mediterranean, Marmara, Aegean and Southeastern Anatolia in Turkey (Onurlubaş and Kızılaslan, 2007). According to data of 2019, 14 tons of sesame production was realized in Bursa, Turkey (TÜİK, 2019). Bursa Province has suitable ecological conditions for the cultivation and production of oil crops (sunflower, canola, sesame, safflower, etc.) and the fact that the region has a vegetable oil industry provides an extra advantage (Anonymous, 2021).

Water is an indispensable need for living things to survive. At the same time, water is a living space in itself. As a result of global warming, climate change, increasing and developing population, the water demand is increasing (Bayramoğlu et al., 2013). Given that the primary use of water is agricultural irrigation, a reduction in water supply will require more efficient water use with deficit irrigation, which is a way of maximizing water use efficiency (WUE) and achieving higher yields per unit of irrigation water applied. Plants are exposed to some degree of water stress during a given period or growing season, with the expectation that any reduction in yield will be negligible compared to the benefits obtained by diverting the water saved with deficit irrigation to other plants (Kırda, 2002).

The number of studies on the determination of crop water consumption (ET_c) and deficit irrigation in the second crop sesame plant is extremely limited. Derviş (1986) found the seasonal ET_c of the second crop sesame to be 464.6 mm and the grain yield as 166.8 kg da^{-1} in his study in Çukurova. Bastuğ et al. (2016) investigated the effects of deficit irrigation on ET_c, yield and quality characteristics of 2 different varieties (Muganlı-57 and Birkan) sesame plants grown as a secondary crop in Antalya conditions. They determined that the values of ET_c, yield, WUE, oil content and protein content varied between 164.9-537.9 mm, 30.3-216.0 kg da^{-1}, 0.18-0.41 kg m^{-3}, 44.70-52.96% and 17.16-24.80%, respectively, and found the yield response factor (k_y) as 1.2. In another study conducted by Anğın and Çatalkaya (2019) in Çukurova conditions, the ET_c, yield, protein and oil ratios for the second crop sesame were determined between 146.3-628.3 mm, 135-253 kg da^{-1}, 24.3-27.7% and 53.1-55.9%, respectively. It is seen that the studies, the results of which are summarized above, are carried out in regions where the Mediterranean climate prevails.

In this study, it was aimed to determine the effects of deficit irrigation practices on yield, yield components, quality characteristics and WUE in the second crop sesame plant irrigated by drip irrigation method in Bursa, Turkey which is located in the sub-humid climate zone.

Materials and Methods

The study was carried out in the Faculty of Agriculture, Bursa Uludağ University in Turkey in 2018 (Figure 1). The average altitude of the study area is 112 m and it is located at 40^o 13' 33" latitude (N), 28^o 51' 34" east longitude (E). Bursa is located in the southeast of the Marmara Region. It has a hot and dry climate in summer and a cold and rainy climate in winter. The meteorological data of the trial area for long-term years were obtained from the Bursa Meteorology Station affiliated to the Turkish State Meteorological Service (1960-2019). According to the climate data of long-term years, the annual average temperature is 16 ^{o}C, the coldest month is January with 5.3 ^{o}C in monthly averages, and the hottest month is July with an average of 24.4 ^{o}C. The annual total precipitation is 705.5 mm. The highest precipitation value was 108.5 mm in December. The annual average relative humidity is 71.2%. The value of the annual average wind speed at 2 m height is 2.0 m s^{-1}. The soils of the study area have a clayey texture. Based on the effective rooting depth, the average bulk density for the 0-60 cm soil profile was 1.36 g cm^{-1}. Field capacity and wilting point values are 317.8 mm and 219.9 mm in depth, respectively. Total available moisture (TAM) is 97.9 mm. The irrigation water used in the research was obtained from Uludağ University Yolçatı (Göbelye) Pond and it included in the C_2S_1 water quality class.

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Figure 1. Experimental area

In the study, completely randomized blocks experimental design was used and it was carried out in three replications (Figure 2). The plot dimensions were 2.8 m x 6.0 m = 16.8 m^2 at planting and 1.4 m x 5.0 m = 7.0 m^2 at harvest. Experimental treatments were application of 100% (full irrigation S1), 75% (S2), 50% (S3), 25% of the water depleted at a soil depth of 60 cm every 7 days to the plots (S4) and non-irrigated (excluding germination and emergence) (S5). For S1 full irrigation treatment, the available moisture measured at 7-day intervals reached to field capacity level.

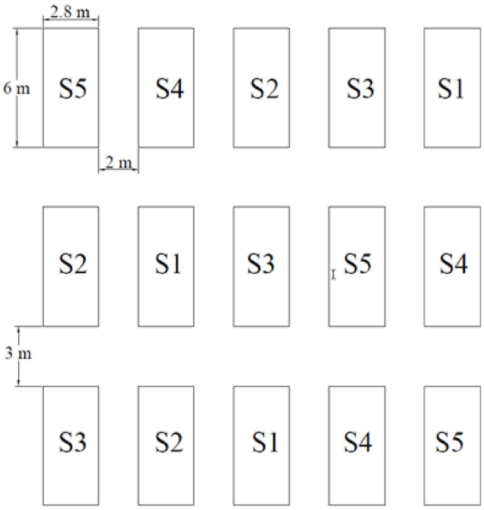

Figure 2. Field experiment plot layout

“Muganlı 57” sesame variety was used as plant material in the research. After the harvest of canola in the field, the trial area was made ready for planting. There were four rows in each plot. In the plots, the row spacing was taken as 0.70 m, the spacing between plants in each row was taken as 0.10 m and planting was done on July 13, 2018 at a soil depth of 3 cm. At the time of planting, 5 kg da^{-1} NPK (15-15-15) compound fertilizer was applied to the trial plots by hand. Afterwards, emergence and germination water were given with the drip irrigation system installed. A polyethylene lateral pipe with a length of 6 m and an outer diameter of 16 mm was laid on the rows of plants. Lateral pipes had in-line drippers with pressure-regulated. The flow rate of the drippers at 1 atm pressure was 2 L h^{-1}, and the distance between the drippers was 33 cm.

For 60 cm, the effective rooting depth of the sesame plant, soil samples were taken with a soil auger from 0-30 and 30-60 cm soil depths every 7 days before irrigation. After, the irrigation water depth was calculated to reach the available moisture determined by the gravimetric method to the field capacity. Crop evapotranspiration (ET_c) was calculated using the soil-water balance equation (Equation 1) (Garrity et al., 1982; James 1988):

$$ET_c = I + P \pm \Delta S - D - R \qquad (1)$$

where; I is amount of irrigation water applied (mm), P is rainfall (mm), ΔS is difference between two soil moisture measurements (mm 60 cm^{-1}), D is amount of drainage (mm), R is expressed as the amount of runoff (mm). In this study, since the irrigation water to be applied in each irrigation is applied with the drip irrigation method and will not exceed the field capacity value of the soil, the R value has been neglected. In addition, it was observed whether there was an increase in moisture at 60-90 cm soil depth for the possibility of drainage.

The second crop sesame plants were harvested on November 9, 2018 and the growing period lasted 119 days. By taking the average of the values determined from 10 randomly selected plants from each plot at the harvest time, plant height, number of branches per plant, first capsule height, number of capsules per plant and number of seeds per capsule, and 1000-seeds weight and seed yield were determined after the harvest process (Bürkük, 2019). The oil content of the seed samples obtained from the plots was determined based on the Soxhlet extraction technique (Pomeranz and Clifton, 1994), and the protein content was determined with the help of the Kjeldahl method (Ivanov, 1974).

Models have been developed to determine water-yield relationships. The most widely used one is the Stewart equation (Stewart et al., 1976; Doorenbos and Kassam, 1979). In this model, the relationship between relative yield decreases and relative evapotranspiration deficit is examined. The yield response factor (k_y) representing this relationship was calculated with Equation 2:

$$\left(1-\frac{Y_a}{Y_m}\right)=k_y\left(1-\frac{ET_a}{ET_m}\right) \quad (2)$$

where; Y_a is actual yield under water deficit (kg da^{-1}), Y_m is highest yield under full irrigation (kg da^{-1}), ET_a is actual seasonal evapotranspiration under water deficit (mm), ET_m is highest seasonal evapotranspiration under full irrigation (mm).

In the study, water use efficiency was used to evaluate the efficiency of different irrigation issues. Water use efficiency (WUE, kg m^{-3}) and irrigation water use efficiency (IWUE, kg m^{-3}) according to different irrigation treatments were calculated using Equation 3 and Equation 4, respectively (Sinclair et al., 1984; Yazar et al., 1999; Howell, 2001):

$$WUE=\frac{GY_i}{ET_i} \quad (3)$$

$$IWUE=\frac{GY_i-GY_0}{I_i-I_0} \quad (4)$$

where; GY_i is the grain yield obtained from the experimental treatment (kg da^{-1}), GY_0 is the grain yield obtained from the treatment without irrigation except for the germination and emergence period (kg da^{-1}), ET_i is the seasonal crop evapotranspiration (mm) obtained from the experimental treatment, I_i is the irrigation water applied according to the experimental treatment (mm) and I_0 is the irrigation water applied to the treatment that is not irrigated except for the germination and emergence period (mm).

In the study, variance analyzes were applied to seed yield, yield components and quality data obtained from the treatments according to the randomized blocks experimental design, and the Least Significant Difference (LSD) test was used to determine the statistically different groups. In the analysis of variance, 0.01 and 0.05 significance levels were considered and 0.05 significance levels to identify different groups.

Results and Discussion

The amounts of irrigation water applied in S1 full irrigation and S5 treatments were 354.7 mm and 127.0 mm, respectively (Table 1). Bastug et al. (2016) reported that the total amount of irrigation water applied was 380.0 mm for furrow irrigation and 410.5 mm for drip irrigation in the study where they used lysimeter in the second crop sesame plant in Antalya conditions. In Çukurova conditions, Anğın and Çatalkaya (2019) investigated the effects of irrigations applied in different development periods of the second crop sesame on yield and oil quality and reported that irrigation water applied during the growing period varied between 43-482 mm. The amounts of irrigation water applied in this study were different from the values applied by Anğın and Çatalkaya (2019). This difference can be basically attributed to climatic conditions.

While the ET_c of sesame was 449.5 mm in full irrigation condition (S1), it was found as 246.0 mm in S5 treatment (Table 1). Derviş (1986) found the seasonal water consumption of the second crop sesame in Çukurova to be 464.6 mm. Bastuğ et al. (2016) determined that the seasonal water consumption for the second crop sesame varied between 164.9-527.5 mm for drip irrigation in Antalya conditions. The ET_c values calculated in this study are in agreement with values from the above studies. Derviş (1981) determined the seasonal water consumption of the sesame plant as 396.4 mm in another study conducted in Çukurova. Anğın and Çatalkaya (2019) reported thatthe seasonal water consumption values of the second crop sesame ranged from 146.3 mm to 628.3 mm in Çukurova conditions. The differences between the results obtained in those above studies and current study can be mainly attributed to the differences in climate factors and irrigation programs.

Table 1. The total irrigation water (I) and seasonal ET_c values of the treatments.

Treatment	I (mm)	P (mm)	ET_c (mm)
S1	354.7		449.5
S2	297.7		392.6
S3	240.8	127.7	349.9
S4	183.9		301.9
S5	127.0		246.0

The effects of deficit irrigations on plant height, number of branches per plant, first capsule height, number of capsules per plant, number of seeds per capsule, 1000-seeds weight and seed yield values were found significant at the $P<0.01$ level. The lowest average values for those parameters were obtained from the non-irrigated treatment (S5) and the average values increased as the amount of irrigation water applied increased. The effects of applied different amounts of irrigation water on oil and protein contents were not statistically significant (Table 2).

In the experiment, the highest plant height was determined with 140.8 cm in full-irrigated S1 treatment, while the lowest plant height was obtained from S5 treatment (non-irrigated) with 91.0 cm (Table 2). El-Lattief (2015) reported that plant height varied between 118.7-144.1 cm under three different irrigation regimes in Egypt. The plant height values obtained in this study are in agreement with the values obtained in the previous study. Anğın and Çatalkaya (2019) irrigated the second crop sesame in different growth periods in Çukurova conditions and determined the plant height values of sesame between 127-184 cm. Nadeem et al. (2015) found the plant heights as between 83.78-103.33 cm in four different irrigation methods in soils with a clay-loam texture in Pakistan. Bastuğ et al. (2016) stated that the plant height of the second crop sesame under limited irrigation in Antalya conditions varied between 108.5-218.3 cm. Gerçek et al. (2004) compared the sprinkler and drip irrigation methods for different row spacings in Şanlıurfa and stated that the plant height values varied between 100-112 cm. Differences in plant height can be attributed to plant variety, climatic factors and differences in irrigation schedules.

According to the data obtained from the treatments, the highest number of branches per plant was obtained from the full irrigation (S1) with 3.6, while the lowest value was determined from the non-irrigated treatment (S5) with 1.2 (Table 2). The number of branches per plant increased in direct proportion to the increase in irrigation level. Anğın and Çatalkaya (2019) determined the number of branches of second crop sesame in Çukurova between 3.03-5.43. El-Lattief (2015) measured the number of branches between 1.82-2.35 for three different irrigation intervals in Egypt. Gerçek et al. (2004) reported that the number of branches varied between 4.06-4.75 in Şanlıurfa. The reason for the differences may be the variety of sesame plant, climatic factors, differences in irrigation programs and growing sesame as a second crop.

According to Table 2, the first capsule height changed from 43.7 cm for S5 treatment to 60.9 cm for the S1 treatment. It was observed that the first capsule height decreased as the irrigation level decreased. In a study conducted with sesame plants in Egypt, the first capsule height obtained for three different irrigation regimes and two cultivar ranged between 56.0-69.1 cm (El-Lattief 2015). The first capsule height values obtained under the full irrigation in our study were similar to those determined in the previous study. Anğın and Çatalkaya (2019) found the first capsule height for the second crop

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sesame in Çukurova between 33.7-42.1 cm. The differences in the first capsule height can be attributed to the sesame plant variety, climatic factors and the differences in irrigation programs.

In the experiment, the highest number of capsules per plant was 59.3 in S1 full irrigation treatment, while the lowest number of capsules was 40.3 in S5 treatment (Table 2). Irrigation levels significantly affected capsule number values. El-Lattief (2015) stated that the number of capsules per plant for three different irrigation regimes in Egypt varied between 52.0-64.2. The values presented are in line with the values found in the previous study. Anğın and Çatalkaya (2019) determined the number of capsules in the second crop sesame in Çukurova between 128-295. In another study carried out on sesame in Şanlıurfa, it was found that the capsule number per plant ranged between 89-108 (Gerçek et al., 2004). It can be said that the differences are caused by the differences in cultivars, climatic factors and irrigation programs.

As a result of the research, it was determined that the number of seeds per capsule increased significantly as the amount of irrigation water applied increased. The number of seeds per capsule changed from 47.3 (S5) to 61.3 (S1) (Table 2). Bürkük (2019) examined the agricultural quality and characteristics of some sesame varieties in Diyarbakır conditions, and found the number of seeds per capsule of sesame varieties grown in the region as 81.66 in Cumhuriyet-99 and 66.24 in Hatipoğlu variety. While the seed number of Hatipoğlu cultivar was close to the values in this study, the value obtained in Cumhuriyet-99 cultivar was different. This difference can be mainly attributed to the sesame plant variety and climatic factors and the cultivation of sesame as a second crop.

According to Table 2, the highest 1000-seeds weight value was obtained from the S1 irrigation treatment with 3.87 g, while the lowest value was found in the S5 treatment with 2.97 g. It was observed that the 1000-seeds weight decreased as the irrigation levels decreased. Anğın and Çatalkaya (2019) found the 1000-seeds weight values between 3.59-4.03 g in another study conducted in Çukurova on second crop sesame. El-Lattief (2015) found that 1000-seeds weight values varied between 2.840-3.405 g at three different irrigation intervals. El Naim et al. (2010) determined 1000-seeds weight values between 2.9-3.6 g in Sudan. Eskandari et al. (2009) reported 1000-seeds weight values for sesame in Iran as between 2.55-3.55 g. Ebrahimian et al. (2019) stated 1000-seeds weight values as between 2.1-3.2 g in a study on sesame in Azerbaijan. The values in this study are in agreement with the values obtained in the previous studies.

While the highest sesame seed yield was obtained from the S1 treatment with 189.2 kg da^{-1}, the lowest seed yield value was determined from the non-irrigated treatment (S5) with 76.3 kg da^{-1} (Table 2). According to these results, it can be said that as the irrigation level decreases, the seed yield decreases significantly. Derviş (1986) found the seed yield of the second crop sesame in Çukurova to be 166.8 kg da^{-1}. Bastuğ et al. (2016) investigated the seed yield for drip irrigation treatments, furrow irrigation and rainfed treatments for the second crop sesame in Antalya, researchers determined the seed yields as 75.7-207 kg da^{-1}, 216 kg da^{-1} and 40.7 kg da^{-1}, respectively, for "Muganlı-57" variety and as 64.7-201.3 kg da^{-1}, 206.4 kg da^{-1} and 30.3 kg da^{-1}, respectively, for "Birkan" variety. Ebrahimian et al. (2019), in the study conducted in Azerbaijan, found the seed yield values as 127.5-164.1 kg da^{-1} by using class A pan. The results obtained in our study are in line with those obtained in the above studies. Anğın and Çatalkaya (2019) found the seed yield in the second crop sesame in Çukurova in the range of 112-253 kg da^{-1}. Derviş (1981) stated the seed yield of sesame plant in Çukurova as 164 kg da^{-1}. El Naim et al. (2010) found the seed yield as 89.0-418.8 kg da^{-1} in a semi-arid and clayey soil structure in Sudan. Eskandari et al. (2009) found the highest seed yield with 163.9 kg da^{-1} in the irrigated treatment when 100 mm of water evaporated from a class A pan in Iran, and determined the lowest seed yield as 58.8 kg da^{-1}. El-Lattief (2015), in a study conducted on sandy soils in Southern Egypt, achieved the highest seed yield with 154.1 kg da^{-1} in irrigation performed at 7-day intervals, while the author determined the lowest seed yield as 109.1 kg da^{-1} in irrigation performed at 11-day intervals. Tantawy et al. (2007) reported the highest seed yield as 155 kg da^{-1} in Shandaweel 3 variety, while they found the lowest seed yield in Giza 32 variety as 102 kg da^{-1} in the study conducted in Egypt. In another study on sesame in Ethiopia, seed yield values were reported between 116.4-139.2 kg da-1 (Hailu et al., 2018). The differences between the results obtained in previous studies and the current results can be attributed to climatic factors, differences in irrigation programs and the cultivation of sesame as a second crop.

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According to the results of the study, the highest oil content was obtained from the S4 treatment with 62.6%, while the lowest value was determined from the S5 treatment with 56.3% (Table 2). Anğın and Çatalkaya (2019) determined the oil content in the second crop sesame in Çukurova as 53.1-55.9% and reported that the effect of irrigation applied according to the development periods on the oil content was not statistically significant. The results obtained in the previous study are in agreement with the results presented. El-Lattief (2015) found the highest oil content as 51.2% at 11-day irrigation intervals for three different irrigation regimes (irrigation with 7, 9 and 11-day intervals) in Egypt, while the researcher determined the lowest value as 50.9% at 9-day irrigation intervals. Eskandari et al. (2009) obtained the highest oil content with 54.92% from the irrigations made when 150 mm of water evaporated from class A pan in Iran, while the lowest oil content was obtained as 38.03% from the irrigations made when 300 mm of water evaporated. Bastuğ et al. (2016) reported the highest oil content of second crop sesame as 52.87% in the full irrigation treatment for the drip irrigation method under lysimeter conditions in Antalya, while the lowest oil content was obtained from rain-fed treatment the as 44.76%. Ebrahimian et al. (2019) used class A pan to determine the amount of irrigation water to be applied in Azerbaijan and reported the oil content of sesame between 34.2-35.6%. Differences in oil content can be mainly attributed to differences in sesame plant variety and irrigation program, and the cultivation of sesame as a second crop.

According to the results of the analysis, the highest protein content was determined with 20.4% from S5 irrigation, while the lowest value was determined from S2 irrigation with 18.6% (Table 2). According to these results, it can be said that as the water restriction level increases, the protein content of the second crop sesame increases. El-Lattief (2015) reported that according to the protein content results obtained in three different irrigation regimes in Egypt, there were no significant differences between the treatments and the protein content values were between 20.0-20.9%. The protein content results obtained in our study are in agreement with those found in the previous study. Bastug et al. (2016) obtained the highest protein content of the second crop sesame as 24.23% in the treatment with 25% water reduction under the drip irrigation method, while they reported the lowest protein content as 17.47% in the full irrigation method. Anğın and Çatalkaya (2019) determined the protein content in the second crop sesame in Çukurova between 24.3% and 27.7%, and reported that irrigation treatments applied according to the development periods did not have a significant effect on the protein content. The statistical results obtained in the previous studies showed parallelism with the results obtained in our study. Eskandari et al. (2009) found the highest protein content in Iran as 28.89% for irrigation applied when 200 mm of water evaporates from class A pan, and the lowest protein content was 18.86% for irrigation applied when 150 mm of water evaporates from class A pan. Differences in sesame variety and irrigation programs and planting as a second crop can be shown as the reason for the differences in protein content values.

Table 2. The effects of irrigation treatments on yield and yield components in the second crop sesame

Treatments	Plant height (cm)	No. of branches per plant	First capsule height (cm)	No. of capsules per plant	No. of seeds per capsule	1000-seeds weight (g)	Seed yield (kg da^{-1})	Oil content (%)	Protein content (%)
S1	140.8 a[1]	3.6 a	60.9 a	59.3 a	61.3 a	3.87 a	189.2 a	58.3	19.0
S2	130.8 b	2.9 b	56.4 ab	57.7 a	58.7 ab	3.67 ab	169.0 b	60.2	18.6
S3	118.3 c	2.6 bc	52.2 bc	53.3 b	56.0 bc	3.43 bc	138.1 c	61.4	18.7
S4	109.6 d	2.2 c	48.0 cd	47.0 c	53.7 c	3.23 cd	109.0 d	62.6	19.3
S5	91.0 e	1.2 d	43.7 d	40.3 d	47.3 d	2.97 d	76.3 e	56.3	20.4
$LSD_{0.05}$	6.534	0.444	4.862	3.905	4.182	0.386	19.982	-	-
F-test	**	**	**	**	**	**	**	ns	ns

[1] Indicate significant differences at P<0.05 using least significant difference (LSD) test.
** Significant at 1% probability level (P<0.01) ns: Non-significant.

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ISSN: 2147–8384 / e-ISSN: 2564–6826
doi: 10.33202/comuagri.1073522

In the study, it was determined that the linear relations between applied irrigation water and ET_c and seed yield were significant at the $p<0.01$ level (Figure 3). In this condition, the seasonal yield response factor (k_y) showing the effect of water deficiency on the yield in crop production was found to be 1.28 for the second crop sesame plant (Figure 4). Bastug et al. (2016) found the yield response factor as 1.2 for the second crop sesame in Antalya conditions. Simsek et al. (2003) determined the yield response factor of sesame seeds between 0.45-1.22 in Şanlıurfa conditions. The current yield response factor is in agreement with the values determined in previous studies.

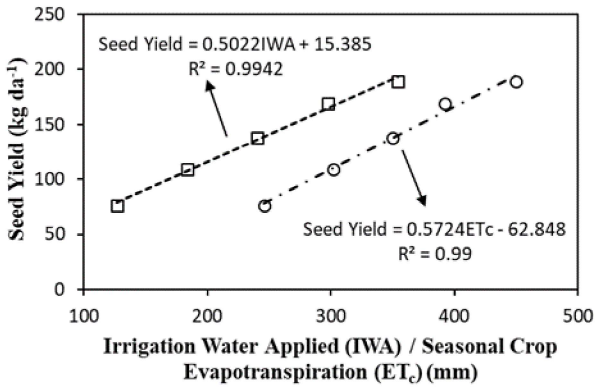

Figure 3. Relationships of seed yield with applied irrigation water and crop evapotranspiration

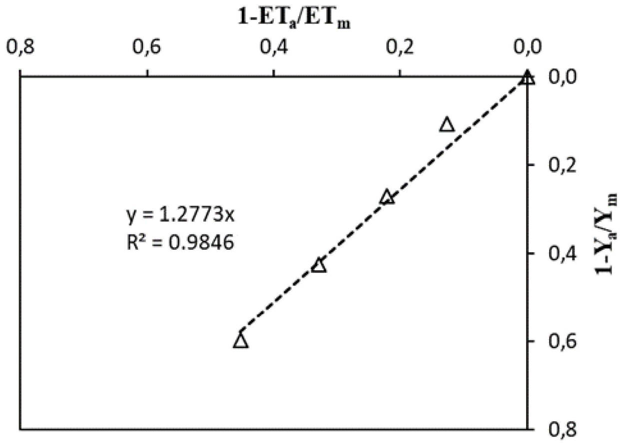

Figure 4. Relationships between relative seed yield reduction and relative crop evapotranspiration deficit

The WUE and IWUE values for the second crop sesame plant grown in sub-humid climatic conditions changed in the ranges of 0.31-0.43 kg m^{-3} and 0.50-0.57 kg m^{-3}, respectively (Table 3). Bastuğ et al. (2016) reported WUE values of the second crop sesame in Antalya between 0.18-0.41 kg m^{-3}. The current findings on WUE are in line with the results of the previous study. Şimsek et al. (2003) found WUE values as between 0.119-0.282 kg m^{-3} in Şanlıurfa. Kassab et al. (2005) used the drip method for irrigation of sesame plants in Egypt and determined the WUE values as between 0.93-0.546 kg m^{-3}. Hailu et al. (2018) investigated water deficiency and different water application techniques for sesame in irrigated agriculture in Ethiopia and found WUE values between 0.0994-0.1654 kg m^{-3}. The differences between the WUE values obtained in our study and the values determined in the previous studies can be attributed to the plant variety, climatic factors, and irrigation program differences. El-Lattief (2015) irrigated sesame plants in Egypt at 7-day, 9-day and 11-day intervals and found IWUE values as 0.156, 0.170 and 0.135 kg m^{-3}, respectively. The IWUE values of previous studies differed from the values presented. The reason may be mainly climatic factors, differences in irrigation programs and growing sesame as a second crop.

Table 3. Results of WUE and IWUE

Treatments	WUE (kg m^{-3})	IWUE (kg m^{-3})
S1	0.42	0.50
S2	0.43	0.54
S3	0.39	0.54
S4	0.36	0.57
S5	0.31	-

Conclusions

During the experiment, the irrigation water applied to the second crop sesame plants varied between 127.0-354.7 mm according to the irrigation treatments. Seasonal evapotranspiration was determined between 246.0-449.5 mm. Compared to S1, which is the treatment of full irrigation, S2, S3, S4 and S5 treatments plots received 16.0%, 32.1%, 48.1% and 64.2% less water, respectively.

While the effects of deficit irrigations on plant height, number of branches per plant, first capsule height, number of capsules per plant, number of seeds per capsule, 1000-seeds weight and seed yield in the second crop sesame were significant at the $P<0.01$ level, its effects on oil content and protein content were not statistically significant. The highest seed yield was obtained from the S1 full irrigation treatment (189.2 kg da^{-1}), the lowest grain yield was determined for the S5 non-irrigated treatment (76.3 kg da^{-1}). Seed yield increased significantly as the irrigation level increased. In terms of quality, the highest oil content was obtained from the S4 treatment (62.6%), and the lowest oil content was obtained from the non-irrigated treatment (56.3%). The highest value for the protein content, which is another quality parameter, was obtained from the non-irrigated treatment (20.4%), while the lowest protein content was found in the S2 treatment (18.6%).

As a result of the study, linear relationships between applied irrigation water and ET_c and seed yield were statistically significant ($p<0.01$), and the equations of the linear relationships could be used to predict seed yield. The seasonal yield response factor (ky) for the second crop sesame was found to be 1.28. The lowest WUE value was obtained from S5 treatment (0.31 kg m^{-3}), while the highest WUE value was obtained from S2 treatment (0.43 kg m^{-3}). IWUE in sesame ranged from 0.50 kg m^{-1} (S1) to 0.57 kg m^{-1} (S4).

As a result, in order to achieve the highest seed yield in the second crop sesame plant, the full irrigation treatment (S1) can be recommended as an irrigation schedule. In case of limited water resources, considering the WUE and IWUE values, the S2 irrigation schedule (25% water deficit) can be preferred in terms of water savings. However, in this condition, it should be taken into account that there may be a statisticaly significant decrease of about 10.7% in seed yield. In Bursa conditions, it can be said that a possible deficit irrigation management of second crop sesame should be planned very carefully since the k_y value obtained in the study is greater than 1 and deficit irrigation will significantly decrease seed yield and yield components.

Acknowledgements

This article was produced from the MSc dissertation of Emir Doğan Kumraltekin. Many thanks to Prof. Dr. Mehmet Sincik from Bursa Uludağ University, Faculty of Agriculture, Department of Field Crops for conveyance of the knowledge and experiences about sesame cultivation throughout the study.

Authors' Contributions

The authors contributed together to the article prepared from the MSc dissertation.

Conflicts of Interest Statement

The authors declare that they have no conflict of interest.

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