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Interactive effects of mulching and deficit irrigation on yield, oil content and water use efficiency of Sesame in a semiarid environment

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ABSTRACT

To increase food and nutritional demands of the growing population, a significant part of agricultural research should focus on improving water use efficiency. Few studies have involved the simultaneous use of mulch and deficit irrigation in the semiarid environment to conserve water without yield penalties. Accordingly, a field experiment was conducted over a silty clay soil at the outskirt of Sulaimani, Iraqi Kurdistan region during the summer season of 2021 to evaluate the impact of deficit irrigation levels [(100%, 80%, 60 and 40% of full irrigation (FI)] and straw mulch (with and without) on seed yield, quality traits of sesame, *Sesamum indicum* L. besides its water use efficiency. The results indicated that there was a steady decrease in sesame with a decrease in the amount of applied water with and without mulch. The water use efficiency increased by water deficit level from 100 to 60% of FI and declined at 40% of FI with and without mulch. Mulch offered a better performance compared to no mulch in terms of crop yield, water use efficiency and oil content. The crop response factor (ky) values were 0.849 and 0.785 with no- and with- mulch respectively. Based on these findings, it is recommended to apply deficit irrigation in combination with mulching practice as an approach of water savaging for agriculture in regions with limited water resources.

Keywords: Sesame, Deficit irrigation, Water use efficiency, Crop response factor, Mulching.
Article type: Research Article.

INTRODUCTION

In regions where irrigation is the only source for growing crops, the success of farming depends completely on the capability of farmers to manage limited water resources for agriculture (Suleiman *et al.* 2021). Thus, to attain maximum yield and income profit per unit area, the available water should be used professionally (Ucan *et al.* 2007). Irrigation for crop production is the biggest consumer of high-quality water resources globally, accounting for about 70% of total withdrawals (FAO 2017) and water scarcity is a major constraint for sustainable agriculture and economic development (IPCC 2014). The practice of limiting water applications to drought sensitive growth stages aim at maximizing water productivity and stabilizing, rather than maximizing, yields (Oweis 1994). To cope with these conditions, different options are available, including reduction of the irrigated areas, planting short season crops, and practicing deficit irrigation (Shammout *et al.* 2018). The potential of deficit irrigation practices in conserving scarce water resources and increasing farm productivity has been recognized (Kirdra & Kanber 2000). Under this agronomic measure, the growing crop is exposed to certain levels of water stress during either a certain growth period or the whole growing season, without significant reduction in yields. The resulting yield reduction may be small compared to the benefits achieved through redirecting the saved water to irrigate other planted areas. Research data has highlighted that deficit is successful in elevating water productivity for different crops without causing substantial crop yield reduction (Geerts & Raes 2009; Vahdati *et al.* 2021; Abdal-Mnam Hassan *et al.* 2022; Ameer Abbas 2022). This can be achieved by introducing advanced methods of irrigation and improved water management practices (Zaman *et al.* 2001). Few studies have involved the

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simultaneous application of mulch and irrigation-management practices in arid and semiarid regions to achieve a relatively good level of performance. It was observed that the crop water use efficiency was generally elevated by irrigation amount, however declined at the highest irrigation level. Additionally, it was noticed that water use efficiency upraised linearly as irrigation water applied raised by deficit irrigation level and dropped by excessive irrigation level (Abd El-Mageed & Semida 2015). Understanding the relationship between the plant and water consumption as well as developing different management systems based on this knowledge may help maximize the yield (Ucan *et al.* 2006). Ramalan *et al.* (2010) revealed that merging irrigation deficit by employing a mulch covers, particularly straw mulch, which is in abundance with farmers, presents a sustainable approach for crop production in the semi-arid areas of Ethiopia. The advantages of using mulch encompass reduced evaporation, reduced fertilizer leaching, cleaner product and reduced weed problems. On the other hand, higher initial cost and management are some of its demerits (Allen *et al.* 1998). Sesame, *Sesamum indicum* L. is considered as one of the promising crops to cover the increasing demands for edible oils due to its high oil content (47-52%), good oil quality and adaptability to the arid and semiarid environmental conditions (Elshamly *et al.* 2013). It is an important summer crop with drought-resistant characteristics and suitable for farming in semiarid areas than other crops. Its grain filling period is of great importance in determining productivity and environmental stresses such as drought can cause yield loss (Frederick *et al.* 1991). The findings of Hailu *et al.* (2018) indicated the possibilities of substantial saving of water by sesame without any decline in grain yield, and 0.99 kg ha^{-1} mm^{-1} water use efficiency was achieved by irrigating with 75% ETC under the fixed furrow method. Therefore, it is crucial to evaluate the impact of deficit strategies with multi-years open field experiments, before generalizing the most appropriate irrigations scheduling method to be adapted in a specific location for a given crop (Igbadun *et al.* 2008). As water requirements of sesame have not been investigated adequately so far, irrigation water planning and management need to be studied. Accordingly, an experiment was conducted to evaluate the impact of deficit irrigation levels and straw mulch (with and without) on seed yield and quality traits of sesame grown under the semiarid condition of Sulaimani, Iraqi Kurdistan region.

MATERIALS AND METHODS

The field experiment was conducted at the farm of Directorate of Sulaimani Agricultural Research, located in the outskirt of Sulaimani City. The field is adjacent to the Qaragol bridge within the administrative border of Arbat County. It is located about 20 km northeast of the Sulaimani City centre and about 2 km to the south of Arbat county. The geoposition of the experimental site is 35º 44′ 05″ N and is 44º 30′ 25″ E, lying 760 m a.s.l. Fig. 1 illustrates the location of the experimental site. Typical Mediterranean climatic conditions with intensive storms in spring and dry spells in summer are prevalent in most of the areas surrounding Sulaimani City. Mean annual precipitation (1985 – 2018) across the study ranges between 500 and 900 mm distributed over rainy months. It has a unimodal distribution with an average value of 700 mm. Further, the annual distribution shows a dry season lasting from June to September and a wet season from October to April. Temperature is the lowest during December and January with mean minimum of 5 ºC, while the highest during July and August with mean maximum of 38 ºC. On the basis of aridity index defined as the ratio of mean annual precipitation to potential evapotranspiration, the climate regime can be classified as semiarid (0.2 > AI < 0.5; UNESCO 1979). The aridity index according this scheme is 0.23. Further, it can be classified as a temperate, dry summer, hot summer (Csa).

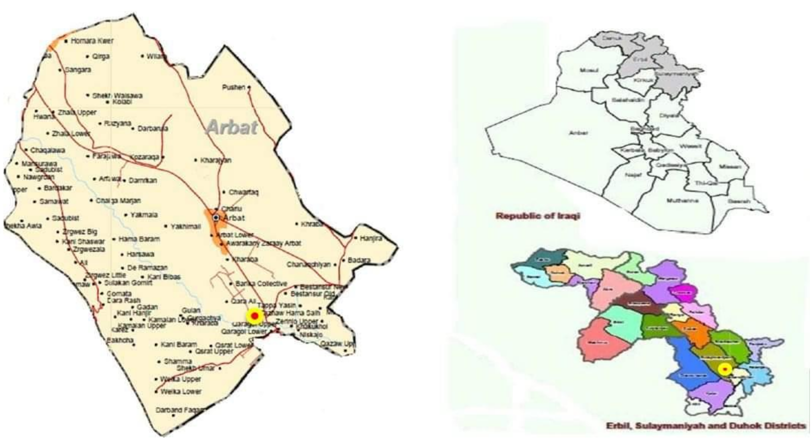

Fig. 1. Location of the experimental site.

The field experiments were conducted over a silty clay soil. It can be categorized as: Fine clay, Active, Mixed, Thermic, Typic Chromoxerets. The soil of the site is nearly free of rocks. Table 1 displays some selected physical and chemical properties of the investigated soil. A local variety of sesame seeds was sown manually by hand with row spacing of 40 cm and plant spacing of 10 cm. The size of each plot was 2 m × 1.6 m. The blocks were bounded with buffer zone (2 m in width) to avoid the interaction between treatments. The crop received a basal application of 25 kg N and 225 kg P in form of urea and single superphosphate, respectively. The layout of the experiment was a 2 × 4 factorial experiments in randomized completely block design using three replicates.
The first factor is mulching with two levels:
Mo = without mulching
M1 = Covering the soil surface entirely with wheat straw at a rate of 0.6 kgm^{-2}
The second factor is deficit irrigation with four levels:
I_1 = Full irrigation
I_2 = 80 % of FI
I_3 = 60 % of FI
I_4 = 40% of FI
For the first 2 weeks after planting, irrigation was uniformly applied to all treatments based on 100% replacement readily available water, and, afterwards, variable amounts of water (EC = 0.817 – 0.910 dS m^{-1} and pH = 7.6- 8.1) were applied according the level of deficit irrigation. The irrigation schedule at full irrigation was initiated on the basis of soil moisture depletion monitoring by gravimetric method. The crop was irrigated when 60% of available water was depleted (Allen *et al.* 1998). The plants in two inner rows were used to determine the seed yield. The irrigation water use efficiency (kg/ha.mm) was calculated as the ratio of grain yield to used irrigation water:

$$\mathrm{IWUE} = \frac{\mathrm{Y}}{\mathrm{IW}} x10$$

where IWUE is the irrigation water use efficiency (kg/ha-mm), *Y* is the yield (kg ha^{-1}), and IW is the applied irrigation water (mm). Crude oil percentage was determined by the Soxhlet extraction technique (Dalaly & Al-Hakim 1987).
The formula proposed by Dooenbos & Kassam (1986) was employed to compute the yield response factor. It represents the ratio of relative decrease in evapotranspiration to relative decrease in yield:

$$\mathbf{K_y} = \frac{\left(\mathbf{1} - \frac{\mathbf{Y}}{\mathbf{Ym}}\right)}{\left(\mathbf{1} - \frac{\mathbf{ETa}}{\mathbf{ETm}}\right)}$$

where Y and Ym are actual and maximum yields (ton ha^{-1}) respectively, and also ET and ETm are actual and maximum evapotranspiration (mm) respectively.

Table1. Some selected physical and chemical properties for the soil at the site of the field experiments.

Property		Unit	Average value
Particle size distribution	Clay	g kg^{-1}	40.51
	Silt	g kg^{-1}	52.62
	Sand	g kg^{-1}	6.88
	Textural Name	-	Silty Clay
Soil bulk Density		mg m^{-3}	1.43
Water retention at	-33 kPa	%	25.42
	-1500 kPa	%	15.28
pH		-	7.53
ECe		dSm^{-1}	0.57
Organic Matter		g kg^{-1}	0.733
Calcium carbonate equivalent		g kg^{-1}	142.67
Major nutrient content	N	%	0.115
	P	ppm	3.5
	K	nmol L^{-1}	0.09

RESULTS AND DISCUSSION

Total Depth of Applied Water

Table 2 depicts the quantity of applied water. It varied from 425.91 mm under 40% of FI with mulching (I_4 M_1) to as high as 1153.85 mm under 40%of FI with no mulching (I_4 M_o). The water applied was calculated as the cumulative depth divided by 65%, corresponding to the irrigation efficiency of the surface irrigation system. The net depth of applied water with no mulch amounted to 750 mm. The low irrigation application efficiency was due to considerable deep percolation through the cracks of investigated soils. The percentage of the linear shrinkage of this was about 12%. Apart from the net depth of applied water falls within the range cited in literature (Elshamly *et al.* 2013; Pereira *et al.* 2017). It is commendable to mention that the relatively high net depth of net irrigation depth can be attributed to elevated air temperature during the growing season, particularly, during July and August. Given the effect of mulching on this parameter, it was noticed that the total depth of applied water under no mulching was 1.08 times as much as that under mulching.

Sesame yield

The highest sesame yield was obtained at full irrigation level with and without mulching (Table 2). Conversely, the lowest yield was obtained under deficit irrigation of I4 (40% of full irrigation). The sesame yield decreased progressively with a decrease in the amount of applied water with and without mulch. This implies that the magnitude of yield reduction upraised by elevating water deficit. At 40% of full irrigation (FI), the no mulch had the least value with 690.6 kg ha^{-1}. Similarly, this level of water deficit offered the least sesame yield of 1097.4 kg ha^{-1} under wheat straw mulching treatment. Overall, we found 8.9, 21.2 and 62.1 % reduction in sesame yield under I_2, I_3 and I_4 respectively without mulch (Table 3). One the other hand, the reduction rate under mulching were 14.3, 24.5 and 52.2%. One plausible explanation is that water stress under the deficit irrigation treatment can lessen crop yield by reducing CO_2 assimilation area, besides its negative effect on number and area of leaves and yield attributes (Golombek & Al-Ramamneh 2002). However, relatively smaller yield reductions under low to moderate water deficit levels (80% and 60% of FI) can be tolerated in areas with limited water resources, especially for crops like sesame, which can produce nearly similar yield as FI under low water deficits.

Table 2. Effect of interaction between deficit irrigation and mulching on sesame water use efficiency.

Treatment	Total water applied		Seed yield (kg ha^{-1})	IWUE (kg ha^{-1} mm^{-1})
	mm	m^3 ha^{-1}		
I_1 M_o	1153.85	11538.462	1822.5	1.58
I_2 M_o	923.08	9230.769	1660.5	1.80
I_3 M_o	692.31	6923.077	1435.5	2.07
I_4 M_o	461.54	4615.385	690.6	1.50
I_1 M_1	1064.78	10647.812	2295	2.16
I_2 M_1	851.82	8518.249	1966.5	2.31
I_3 M_1	638.87	6388.687	1732.5	2.71
I_4 M_1	425.91	4259.125	1097.4	2.58

Table 3. Effect of interaction between deficit irrigation and mulching on yield reduction and water saving.

Treatment	Seed yield (kg m^{-3})	Yield reduction (%)	Water saving (%)
I_1 M_o	1822.5	0.0	0.00
I_2 M_o	1660.5	8.9	20.00
I_3 M_o	1435.5	21.2	40.00
I_4 M_o	690.6	62.1	60.00
I_1 M_1	2295	0.0	0.00
I_2 M_1	1966.5	14.3	20.00
I_3 M_1	1732.5	24.5	40.00
I_4 M_1	1097.4	52.2	60.00

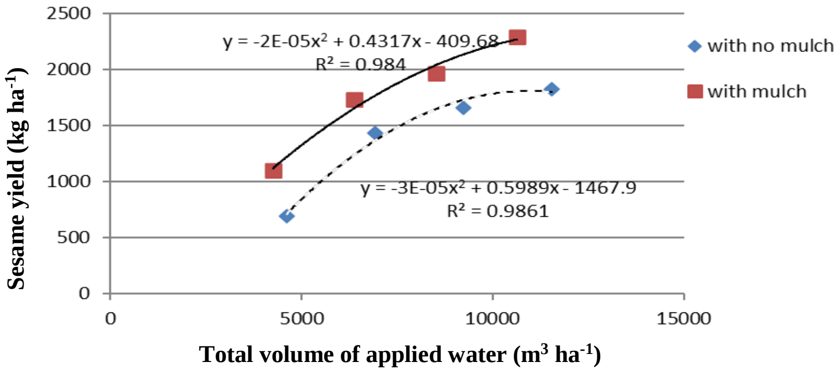

Fig. 2. Plot of semsame yield versus total amount of applied water as influencing by mulching treatments.

Further, the results indicated that a given level of deficit irrigation, the sesame yield under mulching was superior to that under no mulching. The result is in line with the findings of Seyfi & Rashidi (2007), which highlighted that mulching markedly increased crop yield. Mulching treatment is not only important to suppress weed growth, but also, it improves the soil micro-environment (Dickerson 1996), which indicated that organic mulches help to moderate the soil temperature and conserve soil water. Additionally mulching return valuable nutrients to the soil through decomposition. Results from current study addresses that combining irrigation deficit using straw mulch covers, which is in abundance with farmers, afford a sustainable strategy for sesame production in the areas under study. The quadratic formula attributed 98.4% and 98.4% of variation in yield to variation in the applied water under no mulch and mulching with wheat straw respectively (Fig. 2). The analysis of variance indicated that the crop yield was affected by deficit irrigation, mulching and their interactions very high significantly (Table 4).

Irrigation water use efficiency (IWUS)

Irrigation water use efficiency (IWUE) was calculated as the ratio between the sesame yield harvested (kg ha^{-1}) and the total volume of water applied (m^3 ha^{-1} mm^{-1}) during the growing season (Table 2). As indicated in Table 1, there is no a steady increase in IWUE with an elevation in the total amount of irrigation water. The IWUE tended to increase by a decline in depth of applied water up to application of 60% of FI, beyond which the parameter tended to drop under both mulching and non-mulching treatments. Similar studies on water use efficiency showed that the highest water use efficiency was recorded at 75% replacement of soil moisture depleted compared to 100% and 50% replacement of soil moisture depleted (Suleiman *et al.* 2021). The highest IWUE were 2.07 and 2.71 kg ha^{-1} mm^{-1} with 60% of FI under both no mulch and mulching respectively. At this moderate water stress level, a decline in transpiration (lower leaf expansion, stomata closure) can be noticed, but not in photosynthesis (leaf is rarely responsive to moderate water stress), as reported by Taiz & Zeiger (2009). In contrast, the lowest IWUE were 1.50 and 2.16 kg ha^{-1} mm^{-1} with 40% of FI without mulch and with 100% of FI under wheat straw mulching respectively.

Table 4. ANOVA test depicting the effect of mulching, deficit irrigation efficiency and their interactions on sesame yield.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	150247586.960[a]	9	16694176.3	1054.186	0
Intercept	1447158392	1	1447158392	91383.612	0
Mulching	2332201.76	1	2332201.76	147.271	0
Deficit	147668463	3	49222821	3108.27	0
Rep	8927.163	2	4463.582	0.282	0.759
Mulching * Deficit	237995.041	3	79331.68	5.01	0.014
Error	221705.15	14	15836.082		
Total	1597627684	24			
Corrected Total	150469292.1	23			

The obtained results from the current study was not in line with the findings of Pereira *et al.* (2017), who observed that the water use efficiency (WUE) declined by elevated irrigation (T_1, 305; T_2, 436; T_3, 567 and T_4, 698 mm), resulting in higher efficiency (0.34 kg m^{-3}) with the lower applied depth (305 mm). Moreover, it is evident from Table 1, as expected, the irrigation water use efficiency at all levels of deficit irrigation under straw mulch showed superiority over those under no mulch treatment. Overall, these findings show that the sesame plant was very insensitive to a lack of available soil water throughout the entire growing season over a wide range of deficit irrigation from 60% FI to 100% FI). Like sesame yield, the ANOVA test revealed that IWUS was affected by deficit irrigation, mulching and their interactions were very high significantly (Table 5).

Table 5. ANOVA test showing the effect of mulching, deficit irrigation efficiency and their interactions on sesame water use efficiency.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4.13	9	0.459	206.967	0
Intercept	104.667	1	104.667	47205.64	0
Mulching	2.954	1	2.954	1332.281	0
Deficit	0.864	3	0.288	129.91	0
Rep	0.009	2	0.004	1.93	0.182
Mulching * Deficit	0.303	3	0.101	45.609	0
Error	0.031	14	0.002		
Total	108.828	24			
Corrected Total	4.161	23			

Crop response factor

The yield response factor (ky), which represents the slopes of the relationship between relative sesame yield reduction and relative evapotranspiration deficit was determined under no mulch and with wheat straw mulch from the plots of Figs. 3-4 respectively. The ky values with no mulch and with mulch were 0.849 and 0.785 respectively. Under both treatments, the obtained Ky value was less than 1 indicating that sesame is tolerant to water stress (Pereira *et al.* 2017). Furthermore, it is in agreement with statements of Bezerra *et al.* (2010), who highlighted that the plant has a quite high stomata resistance, mechanism used to reduce evapotranspiration and save water for more critical periods in the future of its cycle. In this sense, there are reductions of 0.849 and 0.785

units in yield for each decrease in unit in the applied water. This reflects the insensitivity of the crop to water deficit with proportionally smaller yield reduction when deficit was implemented at this stage.

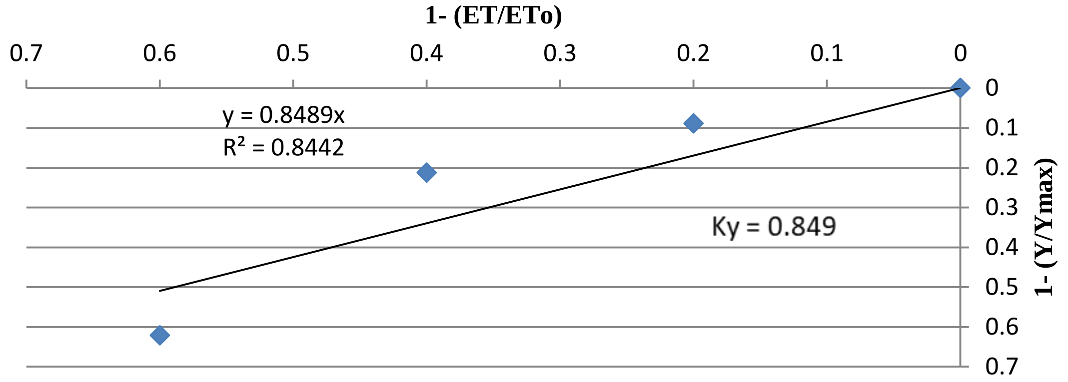

Fig. 3. The relationship between relative sesame yield reduction and relative evapotranspiration deficit without mulching.

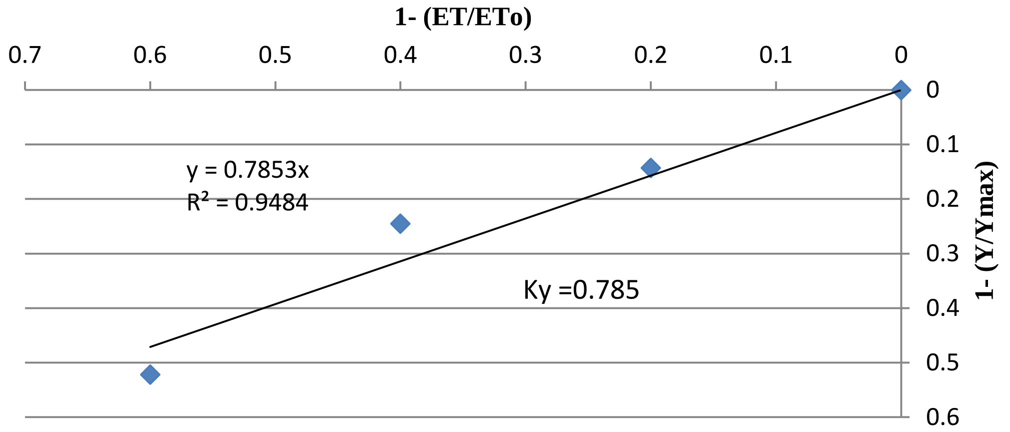

Fig. 4. The relationship between relative sesame yield reduction and relative evapotranspiration deficit with mulching.

The sesame yield response factor (Ky) was determined as 1.01 in 2003 and 0.54 in 2004 with an average of 0.65 by Ucan *et al.* (2007) and 0.77 by Pereira *et al.* (2017). Some differences are due to the extent of deficit irrigation, applied, climatic change, irrigation techniques and cultural practices (Ucan *et al.* 2007; Smith & Steduto 2012).

Overall, mulching led to some improvement in crop response factor in favour of drought combating. Mulching resulted in about 8% lower Ky compared to no mulch treatment. Albeit mulching did not give rise to a considerable reduction in the amount of applied water, it is recommended to apply deficit irrigation in combination with mulching practice as an approach of water saving for agriculture in regions with limited water resources such as the investigated area and similar areas. Based on the scheme of FAO Bulletins 33 (Doorenbos & kassam 1979), the crop can be categorized under low- intermediate sensitivity class (0.85 < ky < 1.00) without mulching and under low sensitivity class (Ky < 0.85) with mulching.

Sesame oil content

Table 6 depicts the crude oil content of sesame affected by irrigation deficit and mulching, exhibiting the crude oil ranged from as low as 50% under 100% FI with no mulch to as high as 60% under 40% FI with mulch. At a given water deficit level, mulching offered a better performance compared to no mulch treatment. Moreover, the results elucidated that there was a steady decrease in crude oil content with an elevation in available soil moisture with and without mulch. The obtained results do not confirm the findings of Elshamly *et al.* (2013), who observed that the sesame oil content (%) was substantially upraised by an elevation in available soil moisture during two growing seasons.

Table 6. Effect of interaction between deficit irrigation and mulching on sesame oil content.

Treatment	Sesame oil content (%)
I_1 M_o	41
I_2 M_o	43
I_3 M_o	45
I_4 M_o	46.5
I_1 M_1	42.5
I_2 M_1	44.5
I_3 M_1	47.5
I_4 M_1	49

CONCLUSION

The obtained results from the current study confirm the previous results found in literature in that sesame is insensitive to a lack of available soil water during the entire growing season from 60% to 100% full irrigation. Further improvement in water use efficiency of sesame can be achieved upon combining mulching with irrigation deficit

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