Optimizing water productivity and production of sunflower crop under arid land conditions

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ABSTRACT

A field experiment was carried-out during 2015/16 and 2016/17 seasons at the Agriculture Experimental Station of King Abdulaziz University to investigate the effect of stress and full irrigations with different plant densities on yield and yield attributes of sunflower and to determine water productivity under the investigated treatments. The design of the experiment was a split block with four replications. Main blokes contained full and stress irrigation water regimes while the sub mains comprised six plant densities of sunflower cultivar (*Helianthus annuus* L.). Results revealed that decreasing irrigation water regime to 65% of field capacity (FC) reduced daily and seasonal water supplies, yield, yield attributes and oil content of sunflower crop but increased water productivity. Increasing plant density reduced head diameter, seeds yield/plant and seed index. Combination of 50 cm row spacing with 15 cm inter row spacing under 100% FC and 60 cm row spacing with 15 cm inter row spacing under 65% FC produced the highest significant seeds yield and water productivity. In these combinations, using full irrigation requirement increased seeds yield by about 10% compared with the stressed one. However, the stress combination increased water productivity by about 38% compared with fully irrigation combination.

Key words | irrigation method, plant density, water stress, water use efficiency

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INTRODUCTION

Sunflower (*Helianthus annuus* L.) is one of the most important oil crops due to its high content of unsaturated fatty acids and low cholesterol level. It accounts about 14% of the world production of seed oils. Sunflower can perform well under wide spectrum of climatic and soil conditions. Generally, its maximum yields obtained when full irrigation is followed and nearly maximum yields obtained with practicing deficit irrigation when adequate water supply is followed during flowering and yield formation stages (Connor & Jones 1985; Bakhsh *et al.* 1999).

Ghani *et al.* (2000) reported that 60% of the depletion of available water is optimum for better sunflower production. Reducing water supply might increase water saving and decrease yield production, but yield reduction resulted from deficit irrigation is met by the benefits of reduced water use (Kirnak *et al.* 2002). Langeroodi *et al.* (2014) suggested that only the 0–50 cm soil profile might be considered for scheduling irrigation in sunflower because the plants extracted most of the soil moisture from this layer. They also reported that 60% moisture available deficit when considering the 0–50 cm as the target depth could be considered as a strategic scheme to save water, while maximum water use efficiency (WUE) is achieved. Bashir & Mohamed (2014) and Buriro *et al.* (2015) found that the maximum yield of sunflower grains was obtained with full irrigation. However, nearly maximum yields were obtained in spite of water deficit when adequate irrigation water was given during flowering stage. Practicing deficit irrigation except flowering stage saves more than 50% of irrigation water which can be utilized economically to produce more land with the objective of optimize yield (Mila *et al.* 2017).

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Gubbels (1989) said that sunflower is an adoptable crop for a wide range of densities by adjusting the size of head, seed size, and number of seeds in head. Plant biomass, head diameter, seed yield per plant, 100-seed weight, seed yield, harvest index, seed oil percentage and non-saturated fatty acids were decreased by increasing plant density while plant height was increased by increasing density (Allam *et al.* 2002; Barrosh *et al.* 2004; Ibrahim 2012). In order to obtain higher achene yield and oil contents, sunflower should be sown 60 cm apart between rows and 20 cm apart between plants (Ali *et al.* 2007). Beg *et al.* (2007) carried out a field experiment in two different locations to investigate the effect of plant density (38,000 to 100,000 pl/ha), two row spacing (50 and 75 cm) and four plant spacing (20, 25, 30, 35 cm) on agronomic traits of two sunflower cultivars. Results revealed that higher plant populations (from 80,000 to 100,000 plants) produced higher yield compared with lower populations in both locations. Plant spacing of 22.5 cm was observed as a suitable planting density for obtaining the maximum achene's yield (Ali *et al.* 2012). The highest seed yield was found when the sunflower was sown at 40 cm apart and irrigated every 10 days (Elsheikh *et al.* 2015). The highest yields were obtained at row spacing of 75 cm under favorable growing conditions (Ion *et al.* 2015). Biomass and achene yields, as well as oil content, were found significantly higher for planting geometry of 90 × 15.5 cm compared with that of 70 × 20 cm (Khan & Akmal 2016).

Plant density affects the birth and death rates of plant organs. So that the population per unit area determines the maximum above ground conditions that allow the plant to attain the essential growth factors that influence the productivity of dry matter and final yield. Therefore, the objectives of this study were to investigate the effect of stress and full irrigation water requirements with different plant densities on yield and yield attributes of sunflower and to determine water productivity (WP) under the investigated treatments.

MATERIALS AND METHODS

Experimental location, design and treatments

A field experiment was carried out for two consecutive seasons of 2015/16 and 2016/17 at the Agriculture Experimental Station of King Abdulaziz University located at Hada Al-Sham, 110 km northeast of Jeddah, KSA. The soil texture is classified as sandy loam. The climate of the area is arid, with high temperatures during the summer season. The design of the experiment was a split plot with four replications. The plot size was 6 m^2 (2 × 3 m). The main plots contained two irrigation water regimes. The first one was representing the full irrigation water requirement of sunflower crop (100% field capacity, FC) while the second water regime was representing only 65% of the first one as stress treatment. The sub main plots comprised six different plant densities (PD) of Giza-2 sunflower cultivar (*Helianthus annuus* L.). The plant density treatments were PD1, PD2, PD3, PD4, PD5 and PD6, respectively. The geometry distribution that represented these plant densities was practiced by investigating three rows spacing (40, 50 and 60 cm) with two inter row spacings (15 and 30 cm) for each, as follows: 40 × 15 cm, 50 × 15 cm, 60 × 15 cm, 40 × 30 cm, 50 × 30 cm, and 60 × 30 cm, respectively.

Irrigation system installation and water requirement calculation

Drip irrigation system was used in this research study. Dripper lines were installed on a soil surface at distance of 40, 50 and 60 cm apart and the distance between drippers was 30 cm along the dripper lines. The type of the dripper line was RAIN BIRD LD-06-12-1000 Landscape drip 0.6 G/h @12'. The main water source for drip irrigation network was from two containers always full of water via the main irrigation network installed in the location. Plants were cultivated every 15 or 30 cm distance alongside each dripper line of each row spacing to represent the investigated plant densities as indicated in plant geometry distribution.

Irrigation water supply during the growing seasons was based on a precise irrigation technique known as water electronic module (WEM). When the available soil moisture falls below a certain level (100% and 65% FC under the current study), WEM calls for irrigation to add the required amount of water. The added water brings soil moisture to the precise level. There is a relationship between soil moisture content and soil tension. Decreasing soil moisture increases soil tension. The WEM uses two watermark sensors placed at varying depths (15 and 45 cm below the soil surface) within the root zone. The total tension is measured and averaged to report the overall condition within the root zone. This device typically works in conjunction with a standard 24 VAC irrigation controller. The WEM is, in effect, a switch which interrupts the common ground connection between the control valves and the controller. The irrigation scheduler selects the appropriate moisture level on the dial of WEM, and at 7:00 a.m. every day the controller is allowed to run only the necessary irrigation cycles. Under the current study the FC was measured at 30 cm soil depth (average location between watermark sensors which installed at 15 and 45 cm soil depth) using pressure plate method in the laboratory. Tension of 10–20 kPa was used for maintaining the soil at FC and 40 kPa for maintaining at 65% FC. The WEM was programmed with these user-input soil water tension to run the irrigation system automatically and supplied the require amount of water based on the daily shortage of the measured soil moisture tension. In the treatment of (100% FC), the WEM was adjusted to keep soil moisture at FC level. In 65% FC, the WEM was adjusted to keep soil moisture at 65% of FC.

Cultural practices

Due to the warm weather conditions in the western region of Saudi Arabia, only one growing season for the majority of the field crops started in November and December can be cultivated. Therefore, the seeds of sunflowers were sown on 11th and 21th December 2015 and 2016 for the first and the second growing seasons, respectively. After complete germination, the plants of each row were thinned to represent the investigated rows and inter rows spacing (one plant in each hill). After thinning, the investigated irrigation level treatments were applied. The plants were fertilized by the recommended doses of N fertilizer (180 kg/ha N) in the form of urea 46% in 5 doses through fertigation. The first dose was after 20 days from sowing, then one dose every week for 4 continuous weeks. 120 kg/ha phosphorus in the form of triple superphosphate 46% and 100 kg/ha of potassium in form of potassium sulfate 50% were added in one dose during the soil preparation at the start of each growing season. Hand weeding was used to remove weeds during the growing seasons. The plants were harvested at the hard stage of the seeds.

Data recording procedure

The recorded data included daily and seasonal water supply, head diameter, seeds weight·plant^{-1}, seed index (100-seeds weight), seeds yield·ha^{-1}, oil % and WP. The seasonal water supply was obtained from the recorded accumulate daily water supply measured by flow meters installed in each treatment. For yield components, the data were recorded at harvesting by taking the average of 10 randomly selected plants from each plot in each growing season. Head diameter was measured using measuring tape. Seeds yield·plant^{-1} and seed index (g) were obtained from clean seeds by weighing the seeds on a precise digital balance. Clean seeds yield of 1 m^2 from the center of each plot were weighed using the precise digital balance and converted to total seeds yield in Mg·ha^{-1}. Oil content was measured as indicated in Khan & Akmal (2014). WP in (kg·m^{-3} was estimated by dividing seeds yield (kg·ha^{-1}) by the depth of water applied including rainfall (m^3·ha^{-1}).

Statistical analysis

The data of both growing seasons were statistically analyzed through analysis of variance procedures and the revised least significant difference (RLSD) test were used to compare between the means after applying the statistical analysis assumptions using SAS (2006).

RESULTS

Daily and seasonal water supplies

The result of daily water supply is presented in Figure 1. Results indicated that the highest water supply was recorded in 40 cm row spacing followed by 50 and 60 cm row spacing, respectively, for both irrigation water regimes and both growing seasons. Water supply of 100% FC treatment was higher than that of 65% FC treatments.

Seasonal water supply results (Figure 2) showed clear reduction in irrigation water supply by increasing row spacing for both irrigation water regimes. Results also show a slight increase in supplied water for the second growing

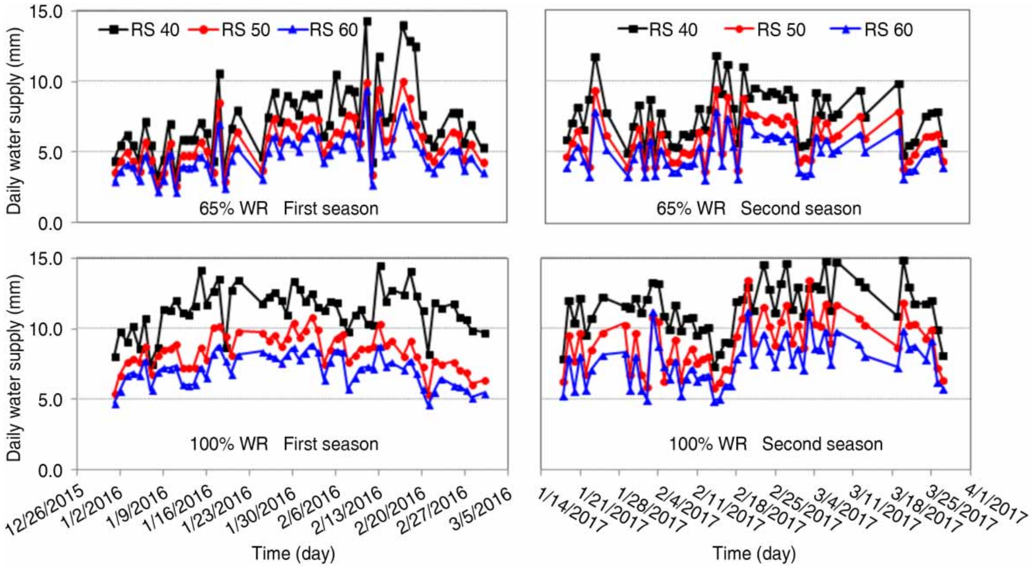

Figure 1 | Daily water supply for sunflower crop as affected by irrigation water regimes and row spacing in both growing seasons of 2016 and 2017.

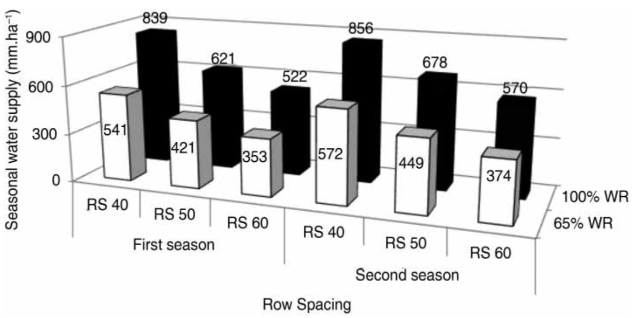

Figure 2 | Seasonal water supply for sunflower crop as affected by irrigation water regimes and row spacing in both growing seasons of 2016 and 2017.

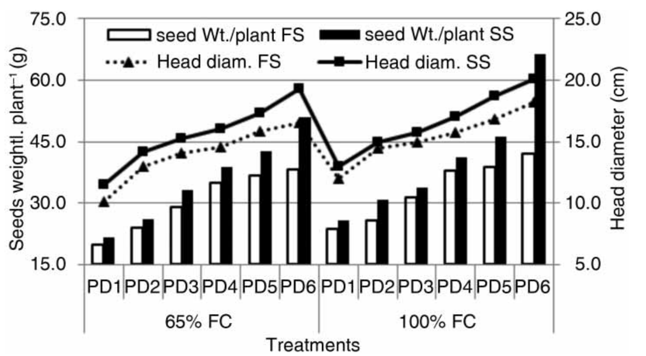

Figure 3 | Head diameter and seeds weight·plant^{-1} for sunflower crop under the effect of the interaction between irrigation water regimes and plant densities in both growing seasons of 2016 and 2017 FS: first season, SS: second season). Revised least significant differences (RLSD) for head diameter were 2.05, 2.04, and for seeds weight·plant^{-1} were 3.46 and 5.26 in the first and the second growing seasons, respectively.

season compared with the first one in both investigated water regimes.

Head diameter and seeds weight·plant^{-1}

Results of head diameter and seeds weight·plant^{-1} are presented in Figure 3. Head diameter showed significant differences as affected by irrigation water regimes and plant density (Figure 3, dot and solid lines). 100% FC treatment increased head diameter by about 10% compared with 65% FC treatment. Head diameter was significantly and gradually increased by decreasing plant density in both growing seasons. The highest head diameter was recorded in PD6 and gradually deceased to reach minimum in PD1. Head diameter of the second growing season was higher than that of the first growing season.

Results of seeds weight·plant^{-1} followed the same trend as in head diameter where it increased by about 12% as an average over the two growing seasons in 100% FC treatment compared with 65% FC treatment. Results also show significant effects for plant density on seeds weight·plant^{-1}. The highest significant seeds weight/plant were produced from PD6 followed by PD5, PD4, PD3, PD2 and PD1, respectively (Figure 3, bar type). Seeds weight·plant^{-1} was higher in the second growing season compared with that of the first growing season.

When comparing the results under the effect of the interaction between irrigation water regimes and plant density, the highest head diameter and seeds weight·plant^{-1} were obtained from PD6 of 100% FC followed by the same plant density of 65% FC. Then it gradually decreased following the same trend to reach minimum in PD1 of 100% FC followed by PD1 of 65% FC treatment in both growing seasons (Figure 3).

Seed index (100-seeds weight)

Results of seed index (100-seeds weight) presented in Figure 4 indicated that 100% FC treatment increased seed index by about 13% as an average over the two growing seasons compared with 65% FC treatment. Similar behavior was recorded for the seed index as explained in head diameter, where the highest seed index was obtained from PD6, followed by PD5, PD4, PD3, PD2, and PD1 in both growing seasons, respectively.

The increase in seed index was higher in the second growing season than in the first one, especially in PD6 treatment. Comparing the results based on the effect of the interaction between irrigation water regime and plant density, results showed that the highest seed index was obtained from PD6 of 100% FC treatment followed by PD6 of 65% FC treatment in the second growing season and then by the same sequence in the first growing season. The least seed index was found in PD1 of 65% FC treatment followed by the PD1 under 100% FC treatment in both growing seasons.

Seeds yield and WP

Results of seeds yield and WP presented in Figure 5 showed significant differences as affected by irrigation water regimes and plant density. The highest significant seeds yield was obtained from PD2 followed by PD6 and PD3 in the first season and from PD2 followed by PD1, PD6 and PD3 in the second growing season under 100% FC treatment. However, in 65% FC treatment, the highest seeds yield was obtained from PD3 followed by PD2 and PD4 in the first growing season and from PD3 followed by PD1, PD2 and PD4 in the second growing season (Figure 5, solid and dot lines). The least significant yield was obtained from PD5 of 65% FC in both growing season followed by the same treatment under 100% FC treatment. Increasing irrigation water regimes sharply reduced WP. The highest WP was obtained from PD3 followed by PD6 and PD2 under 65% FC treatment, then followed by the same sequences under 100% FC treatment in both growing seasons (Figure 5, bar type). The least significant WP was recorded in PD1 of the first growing season followed by PD4 of the second growing season under 100% FC treatments followed by the same treatments and order under 65% FC treatment.

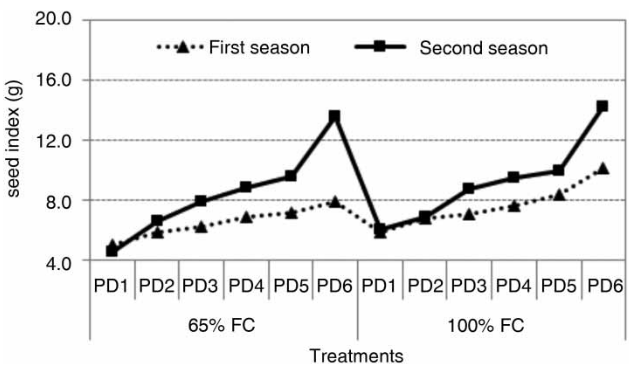

Figure 4 | Seed index (100-seeds weight) for sunflower crop under the effect of the interaction between irrigation water regimes and plant densities in both growing seasons of 2016 and 2017. Revised least significant differences (RLSD) 1.40 and 0.88 in the first and the second growing seasons, respectively.

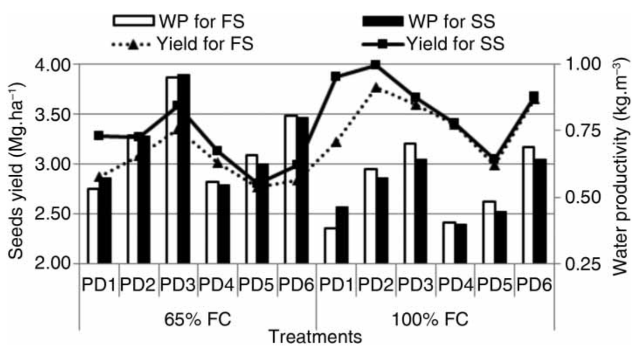

Figure 5 | Total seeds yield and WP for sunflower crop under the effect of the interaction between irrigation water regimes and plant densities in both growing seasons of 2016 and 2017 (FS: first season, SS: second season). Revised least significant differences (RLSD) for seeds yield were 0.80, 0.17, and for WP were 0.0106 and 0.0100 in the first and the second growing seasons, respectively.

Oil content (%)

Results of oil content as affected by irrigation water regimes and plant densities are presented in Figure 6. Results revealed that oil content under 65% FC treatment was slightly lower than that of 100% FC treatment. Reducing water supply from 100% FC to 65% FC resulted in about 7.1% oil content reduction as an average for both season. Oil content was almost similar under all investigated plant densities but was higher under 100% FC treatment compared with those under 65% FC treatment.

DISCUSSION

The reduction in daily and seasonal water supplies by decreasing water regime and/or increasing row spacing might be due to the lower supply of irrigation water under 65% FC treatment than that supplied in 100% FC treatment. Increasing row spacing from RS 40 to RS 50 and RS 60 decreased the number of dripper lines/hectare. Therefore, the least number of dripper lines were in RS 60 while the maximum dipper lines were in RS 40. Thus, the highest daily and seasonal water supplies were recorded in RS 40 while the least were found in RS 60 under both water regimes (Ismail & Moussa 2014; Ismail 2016).

The reduced head size in case of the reduced water regime and closer plant spacing might be due to more inter-plant competition for nutrients, moisture, light and air, thus producing heads having a smaller diameter (Ion *et al.* 2015). Decreasing seeds yield per plant could be attributed to the negative and significant correlation between drought stress and seeds yield of a single plant. Negative effect of drought stress on yield component and seeds of sunflower has been reported by Gholinezhad *et al.* (2009). Increasing plant density gradually decreased seeds weight per plant because high plant population would lead to decrease the individual plant characteristics (leaf area, head diameter and seed index) due to the decrease in allocation of nutritional resources in higher densities compared to more lax populations (Ali *et al.* 2012).

Seed index (100-seeds weight) was reduced under 56% FC treatment compared with that under 100% FC treatment. These results may be due to the lack of stored carbohydrates before the pollination stage at productive parts and to the decreasing durability of leaf area at plants which normally accompanied crops growing under water stress and resulted in a short period for their grain filling. The average value of seed weight is initially determined by the quantity of elaborated matter available to be transported to the head from the flowering stages to grain maturity stage which is a function of the durability of the leaf area after flowering stage (Gholinezhad *et al.* 2009). There was a gradual significant increase in 100-seeds weight with the decrease in plant density. It was due to less plant population that produced significantly bold seeds due to less competition and more availability of light, nutrients and feeding area per plant as compared to higher plant population (Ali *et al.* 2012).

The highest seeds yield obtained from 100% FC treatments compared to 65% FC might be due to the proper water requiems and supply because the response of seeds per head and seed weight of sunflower was found to be linearly related to the amount of irrigation (Buriro *et al.* 2015; Ismail 2016). Results also showed higher seeds yield per hectare under high plant density compared with that under low plant density. Increasing plant density decreased single plant yield but area yield increased (Gholinezhad *et al.* 2009). These results indicate that under optimum production conditions (proper irrigation and water supply, sufficient fertilizers and meeting temperature and light requirements) use of high plant densities can be useful to maximize seeds because seeds yield per unit of area is expected to increase

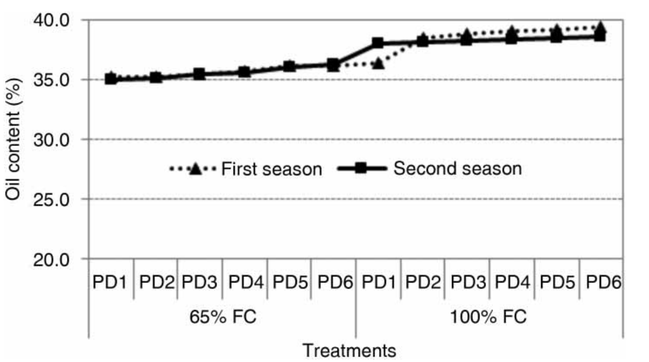

Figure 6 | Oil content for sunflower crop under the effect of the interaction between irrigation water regimes and plant densities in both growing seasons of 2016 and 2017. Revised least significant differences (RLSD.05) was not significant (NS).

due to the increase in the number of plants per area. Oil content was reduced by the decrease in irrigation water regime. The results are in line with those reported by Alahdadi *et al.* (2011) who found that water stress treatments decreased the oil content in all sunflower hybrids. Increasing plant density insignificantly decreased oil %. These results are in conformation with those of Nel *et al.* (2000) who reported that oil contents were not affected significantly by planting density.

Decreasing irrigation water regime increased WP. The results could be due to the decrease in water losses due to the reduction in water supply. WP was found to increase as a result of decreasing losses since it affected by reducing deep percolation, canopy interception, soil type, and cultural and management practices (Al-Jamal *et al.* 2001; Ismail 2016). The treatments of plant density which produced the highest yield resulted in higher WP, especially under the low water regime. This may be due to the ability of sunflower to use water effectively from the soil profile. When proper irrigation, sufficient fertilizers application and temperature and light requirements were completed, the use of high plant densities can be useful to maximize sunflower seeds yield and consequently WP (Buriro *et al.* 2015).

Maximum sunflower seeds production in the current study was obtained from the interaction of 50 cm row spacing with 15 cm inter row spacing (PD2) under 100% FC treatment and from 60 cm row spacing with 15 cm inter row spacing (PD3) under 65% FC treatment. Both interaction treatments maximized total seed yield, WP especially under the low water regime, consequently, the final oil production is expected to be optimized. In these interaction treatments, 50 cm row spacing alongside 15 cm inter row spacing under full irrigation water regime or 60 cm row spacing alongside 15 cm inter row spacing under 65% FC resulted in an ideal plant arrangement, which led to a uniform distribution of plants across the area. This uniform distribution provided each plant with an equal opportunity to intercept more light, which improves plant growth, yield and yield components of sunflower crop per unit area. As a result, an increase in total seeds yield was obtained. The results are in conformity with those published by Ismail & Moussa (2014) and Ismail (2016).

CONCLUSION

The obtained results from this study clearly revealed that decreasing irrigation water regime to 65% of FC reduced daily and seasonal water supplies, yield, yield attributes and oil content of sunflower crop but increased WP. Increasing plant density resulted in significant reduction in head diameter, seeds yield/plant and seed index. Oil content was not significantly affected by plant density. The combination of 50 cm row spacing with 15 cm inter row spacing under 100% FC and 60 cm row spacing with 15 cm inter row spacing under 65% FC produced the highest significant seeds yield and WP. In these combinations, using full irrigation requirement increased seeds yield by about 10% compared with the stressed one. However, the stress combination increased WP by about 38% compared with full irrigation combination. This result could be helpful for taking policy decision regarding efficient irrigation and water management under prevailing water scarcity situation. Therefore, stress combination is recommended for use under limited water resources like the conditions prevailing in the western region of Saudi Arabia. When water resource is not a limited factor, full irrigation combination can be used to produce the optimum yield.

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