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Effect of deficit irrigation on yield and yield components of sunflower (*Helianthus annuus* L.) on Gezira clay soil, Sudan

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Sunflower has become an important crop for both farmers and consumers in Sudan. It is a crop that fits well in the local cropping system and is considered one of the most important oil crops of the country. Regular irrigation intervals could be reduced in order to increase total yield and maximize water productivity. In contrast prolonged irrigation intervals during sensitive growth stages may result in reduction in total yield. The application of water below the evapotranspiration requirements is termed deficit irrigation (DI). The experiments were conducted at Gezira Research Station, WadMedani, Sudan, in a randomized complete block design with three replications. In this study irrigation intervals every week (W) during the whole growing period, 10 days interval (F1), 15 days interval (F2) and 20 days interval (F3) after flowering stage and 10 days interval (S1), 15 days interval (S2) and 20 days interval (S3) after seed filling stage were applied to study the effect of full and deficit irrigation on yield and yield components of sunflower crop during the two growing periods 2011/12 and 2012/13. Results showed that water stress decreased the number of filled seeds per head, weight of full seed and seed yield. The highest seed yield of (3130 and 3140 kg/ha) was obtained from full irrigation (W) and the lowest seed yield of (2082 and 2130 kg/ha) from irrigation every 20 days after flowering stage in the first and second season respectively. Results indicated that there were no-significant differences on head diameter, plant height and stem diameter when water deficit occurred after the flowering stages. Lower WP of 0.21 to 0.26 and 0.21 to 0.27 kg/m3 were obtained when sunflower irrigated every 20 days after flowering and seed filling stages in the first and second season respectively. Results revealed that water productivity was low under Gezira conditions.

Key words: Water productivity, deficit irrigation, sunflower, seed yield.

INTRODUCTION

The Sunflower is a drought adapted crop with a short growing season that requires relatively low irrigation requirements and makes it ideal for areas with limited irrigation supplies. Sunflower (*Helianthus annuus* L.), is

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an important oil crop of the world as well as in Sudan. It is an edible oil crop in Sudan; the seeds have high oil content (40 to 50%) and 30% digestible protein. They can thus be used as a source of food for humans or as a poultry feed. Sunflower cake can be made as animal feed. It can be cultivated in winter season (November) under irrigation, as a winter crop and in rain-fed areas as a summer crop (July). In recent years the Sunflower cultivation area has increased in Sudan, because of the moderate cultivation requirements and high oil yield. The yield of crops that are cultivated under rainfed conditions in Sudan has progressively declined with time, owing to changes in both quantity and distribution of rainfall. There is a great need to increase crop production to meet the demand of the rapidly growing population. The importance of irrigation to enhance crop production in the water scarce conditions of Sudan is yet to be translated into sustainable development options for irrigated agriculture, which can potentially raise the yield of Sunflower to 5 t/ha.

Although experimentation on sunflower in Sudan started as early as the 1940s, the real concern with its commercial production started late, mainly as a rain-fed crop, where rainfall is very erratic in the amount and distribution. However, some rain-fed areas have experienced significant drought. This led to shifting Sunflower cultivation to irrigated areas. For this reason determining crop water requirement and water productivity under irrigated agriculture is essential for planning and water resources management. In the future irrigation management will emphasize on maximizing the production per consumed unit of water, the water productivity, rather than maximizing yield per unit of area in irrigated agriculture under water scarcity. The water requirement for the crop is the most important factor, because water has a direct effect on the yield of the crop. Karam et al. (2007) reported that the increase in the irrigation interval reduced seed yield, plant height, head diameter, seed oil content and increased the number of un-filled seed. Anwar et al. (1995) stated that the yield and yield components of Sunflower were affected by the number of irrigation water supplies. As the number of irrigation water supplies increased the days to maturity, seed yield and plant height increased. D'Andria et al. (1995) concluded that yield components of sunflower were affected by irrigation treatments.

Water stress, particularly at the flowering stage, reduces fertilization and seed set due to dehydration of pollen grains. More studies were focused on the effect of drought on Sunflower yield (Stone et al., 1996; Faisal et al., 2006; Karam et al., 2007). Also water stress at the flowering stage was observed to be a limiting factor for seed filling, so significant reduction of unfilled seeds was observed as a result of irrigation deficit. Pejić et al. (2009) summarized that the period from flowering to maturity was the most sensitive towards water deficit. Many researchers stated that an irrigation interval of seven days in Sunflower improved seed yield, oil yield and water productivity. Yawson et al. (2011) reported that, Sunflower is considered to be tolerant to water deficit to some extent. Therefore, knowledge of the effects of irrigation scheduling on sunflower production and water productivity under water stress conditions is becoming increasingly important. Irrigation scheduling is particularly important since many field crops are more sensitive to water deficit at specific Phenological stages. In the season where there is insufficient water for crop demand, the optimum use of irrigation water is essential for water resources management. Optimum use implies the efficient irrigation water use and proper timing of irrigation to face the critical stages of growth of the crop concerned. It is important to analyze the effect of water supply on crop yields. The effect of water stress on growth and yield depends on crop varieties, magnitude and stages of occurrence of water deficit. In this study the water stress was after starting of 50% of flowering and seed formation stage to assess to what extent the water will reduce the yield under different irrigation intervals. The objective of this research is to study the effect of deficit irrigation on yield and yield components of Sunflower, and to assess the water productivity.

MATERIALS AND METHODS

Study area

The experiment was conducted at the Gezira Research Station Farm, which is located between longitude 14 .4° N and latitude 33 5° E in WadMedani in central Sudan and at an altitude of 405 MSL (mean sea level) (Figure 1). In particular, the soil of the study area is a deep, heavy soil (Vertisols) with 58 to 66% clay, 0.05% organic matter, a water infiltration rate of 1 mm/h and pH of 8.5 (Table 2). All agronomic practices were conducted during the two growing seasons of 2011 and 2012. Sunflower, variety Hysun 33 was sown in the mid of November for the two seasons. The seed rate was three seeds per hole at 30 cm inter-row plant spacing and 80 cm between rows. The plant was then thinned to one plant per hole after two weeks. The experimental design adopted was randomized complete block design (RCBD). Fertilizer was applied in the form of urea at the rate of 46% N, 86 kg N ha^{-1} in two split doses, one with the second irrigation (with thinning) and the rest at the flower initiation as recommended by Agricultural Research Corporation (ARC). The plot size was 50 m^2 (10 m×5 m). After emergence the field was irrigated every week up to flowering stage and then on the basis of water deficit at three irrigation levels. Weeding was done by hand after third irrigation and repeated four times during the whole season.

The irrigation treatments were seven using the furrow method including every week (W), 10 days (F1), 15 days (F2) and 20 days intervals (F3) after 50% flowering to physiological maturity and 10 days (S1), 15 days (S2) and 20 days intervals (S3) during seed filling stage to physiological maturity which replicated three times. Water applied for each treatment was measured during the whole growing season using a current meter device which was placed in Abu vi (Abu vi is a small canal to deliver water to the experimental plot) to measure the discharge of the water to each plot separately. The total number of the plots was 21. Daily weather data were collected from the nearby meteorological observatory of Gezira Meteorological Station in WadMedani (Table 1). Also the reference

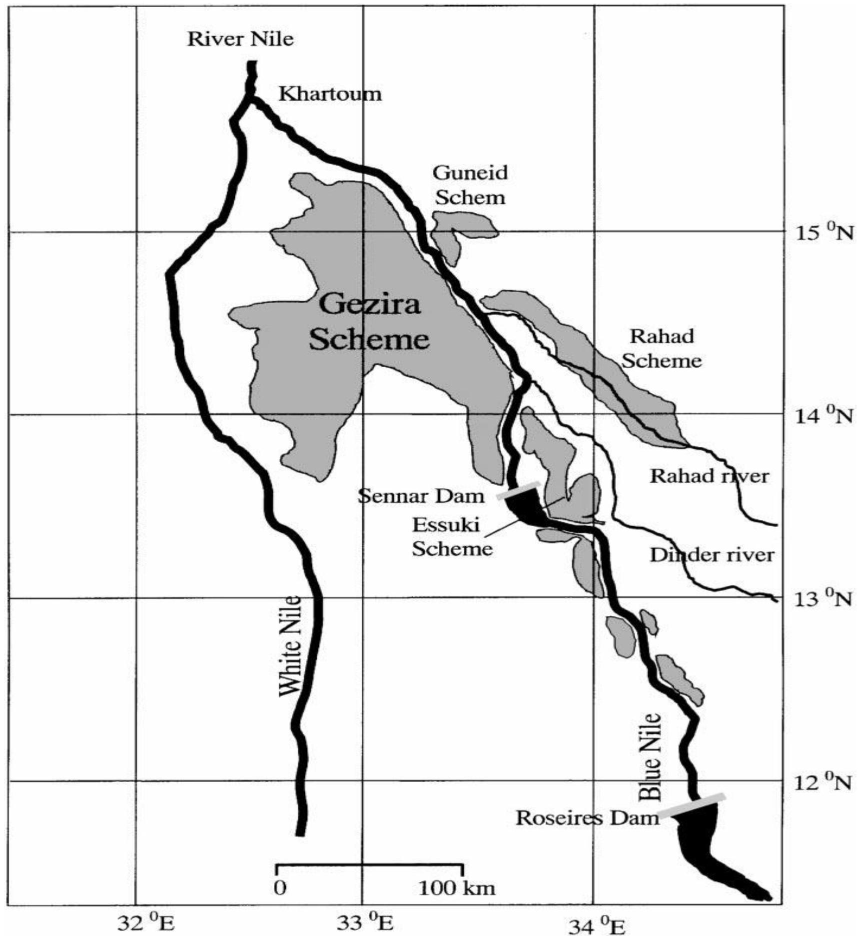

Figure 1. The location of the Gezira Scheme (Adopted from Abdelhadi et al. (2000).

Table 1. Mean monthly weather data of Gezira Research Station for the two growing seasons (2011/12 and 2012/13).

Month	Maximum temperature (ºC)	Minimum temperature (ºC)	Relative humidity (%)	Wind speed (m/s)	Sunshine (h)	ET0 (mm/day)
2011/2012						
November	35.8	15.5	35	1.9	11.2	6.0
December	35.6	15.2	31	1.9	10.8	5.6
January	33.9	15.3	30	2.3	10.5	6.1
February	37.7	19.1	28	2.5	10.3	7.6
March	38.9	19.8	24	2.5	9.9	7.9
2012/2013						
November	37.1	18.7	40	1.6	10.5	6.5
December	34.8	15.5	30	1.8	10.7	5.4
January	35.0	17.4	34	2.0	10.4	5.8
February	38.2	20.0	28	2.1	9.5	6.8
March	40.4	19.3	24	1.9	9.6	7.2

Source: WadMedani Meteorological Station (2013).

evapotranspiration for two growing seasons are plotted in Figure 2. Weeding was done by hand continuously during vegetative growth. Five plant samples were taken to determine the different crop parameters such as plant height (cm), head and stem diameter

Table 2. Soil chemical and physical characteristics of the experimental field.

Depth	Clay (%)	Silt (%)	Sand fine (%)	Sand Coarse (%)	Bulk density (g/cm^3)	Field capacity (vol %)	Wiliting point (vol%)	Organic matter (%)	pH
0 to 30	58	25	13	4	1.60	38.2	20.7	0.34	7.9
30 to 60	60	28	9	3	1.52	45.9	24.9	0.31	8.1
60 to 90	54	31	7	3	1.78	41.9	22.8	0.13	8.0

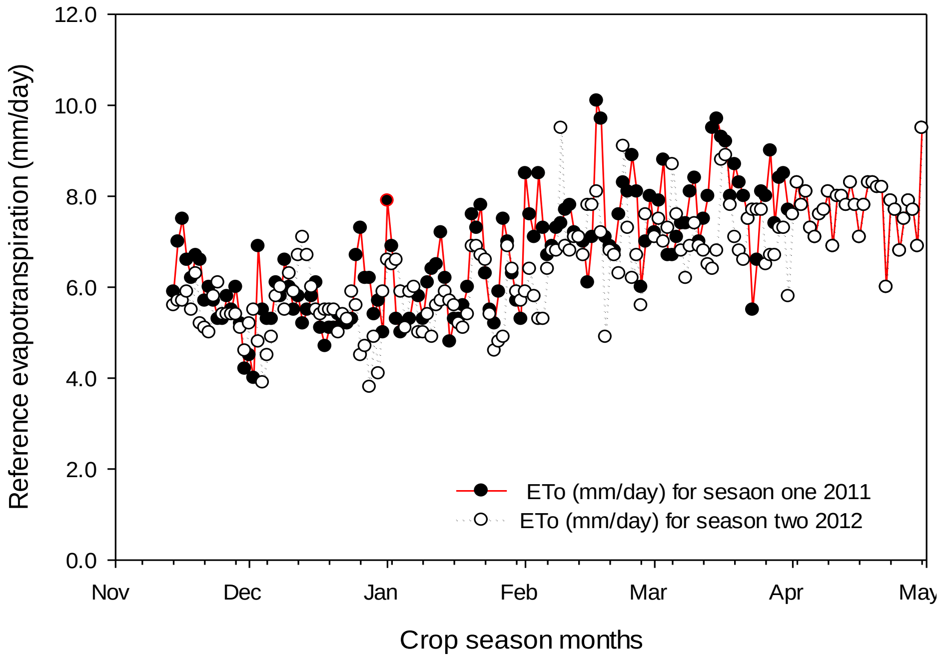

Figure 2. Reference evaporanspiration (ETo) mm/day for two growing seasons.

(cm), number of seeds per head, weight of full seeds, and final seed yield (kg/ha) after harvesting. Harvesting was done on 8 and 15 March during the respective seasons. Data were statistically analyzed using the Statistix 9.0 software and means comparison of data were conducted by Tukey's HSD at 5% probability.

RESULTS AND DISCUSSION

Table 1 displays the weather data for two growing seasons. Regarding the mean average temperature over the two seasons February was the hottest (37.9ºC) followed by November (36.5), and December (35.2) respectively. The warmest March was that of 2012 and the coolest January was that of 2011. The relative humidity generally decreased from November throughout to February. The reference evapotranspiration (ETo) was higher in January and February in 2011 (6.1 and 7.6) during the seed filling and physiological maturity. Analysis of variance for head and stem diameter, plant height, number of full seed, weight of seed per head and total yield as affected by different irrigation frequencies are presented in Table 3. Results showed that the water treatments had a significant effect on the number of seeds per head, weight of full seed and total yield. Seed yield of sunflower decreased (2080 kg/ha) as irrigation interval increased to 20 days after flowering and (2190 kg/ha) after seed filling stages in the first season. While in the second season the seed yield was decreased to 2130 kg/ha and to 2270 kg/ha after flowering and seed filling stages respectively.

The result is in line with the findings of Human et al. (1990), who concluded that water stress in stages of flowering, seed formation and seed filling in sunflower caused the most reduction of seed yield. Beyazgül et al. (2000) reported that the long period of water deficit at the sensitive growth stages caused a significant reduction in seed yield. Faisal et al. (2006) examined the effect of three irrigation intervals (7, 14 and 21 days) on seed and oil yields of a sunflower. They found that sunflower was sensitive to the long irrigation intervals and the reduction in seed and oil yields under prolonged irrigation was associated with a significant reduction in yield components.

Table 3. Effect of irrigation on crop parameters of Sunflower for two growing periods (2011/2012 and 2012/2013).

Irrigation treatment	Plant height (cm)	Head diameter (cm)	Stem diameter (cm)	Number of filled seeds	Weight of 100-seeds (g)	Yield (kg/ha)
2011/2012						
W	153^{a}	20^{b}	2.0^{a}	1060^{a}	5.8^{b}	3130^{a}
F1	153^{a}	19^{c}	2.0^{a}	987b	6.4^{a}	2670^{b}
F2	148^{c}	19^{c}	2.0^{a}	968^{c}	6.0^{a}	$2410b^{c}$
F3	150^{b}	19^{c}	2.1^{a}	851^{f}	5.7^{b}	2080^{h}
S1	152^{ab}	22^{a}	2.2^{a}	1070^{a}	5.5^{c}	2800^{b}
S2	150^{b}	20^{b}	2.1^{a}	868^{d}	5.9^{a}	2350^{c}
S3	150^{b}	19^{b}	2.0^{a}	883^{c}	6.0^{a}	2190^{d}
Mean	151	20	2.1	956	5.9	2400
SE±	2.40	0.82	0.11	102.42	0.38	223
CV%	2.74	2.27	9.06	18.83	11.19	16.10
2012/2013						
W	161^{a}	19^{a}	1.4^{a}	1030^{a}	4.7^{a}	3140^{a}
F1	160^{a}	17^{b}	1.4^{a}	1020^{a}	4.8^{a}	2880^{ab}
F2	160^{a}	16^{c}	1.4^{a}	905^{b}	4.5^{ab}	2510^{b}
F3	160^{a}	15^{d}	1.4^{a}	862^{c}	4.3^{c}	2130^{bc}
S1	161^{a}	17^{b}	1.5^{a}	955^{ab}	4.7^{a}	2840^{ab}
S2	158^{a}	15^{d}	1.3^{b}	920^{ab}	4.6^{b}	2350^{c}
S3	159^{a}	15^{d}	1.2^{b}	880^{c}	4.6^{b}	2270^{bc}
Mean	160	16	1.4	938	4.6	2590
SE±	1.43	1.23	0.09	55.19	0.18	202
CV%	1.54	13.11	12.55	10.12	6.91	10.13

Means followed by the same letters are not significantly different at 5% probability level according to Tukey's HSD.

They found that prolonged irrigation decreased the mean 1000–seed weight. These results are also supported by the findings of Iraj Alahdadi (2011) who reported that increase in the irrigation intervals reduced seed yield, number of seeds per head.

Seed yield (kg/ha)

Seed yield was determined under different irrigation intervals to investigate the effect of different water application during different growth stages on final seed yield. Table 3 demonstrates the results of seed yield and reduction percentage due to different irrigation intervals from three growing seasons. The results revealed that the highest seed yield was obtained from irrigation every week (W) and the lowest seed yield from every 20 days during flowering (F3) and seed filling (S3) stages and the other treatments varied between these two (Figure 3). The results indicated that reduction in seed yield was not significant 5 to 15% when increasing irrigation interval of 10 days after flowering and seed filling stages. Also, the reduction in seed yield was lower 18 to 25% when sunflower crop irrigated every 15 days after flowering and seed filling stages compared with a higher reduction of 34% on the seed yield when irrigation every 20 days after flowering stage was used.

The results stated that sunflower crop was more sensitive to soil water stress (SWS) during the elongation and flowering stages than during seed filling stage. Seed yield significantly improved by optimum irrigation applied after the start of flowering and seed filling stages. Deficit irrigation practices can be an alternate option for improving irrigation schedules and thereby increase crop productivity of restricted water resources under irrigated agriculture. However, deficit irrigation at late seed formation stage slightly increased seed yield in (S2) in comparison with the early flowering stage (Göksoy et al., 2004). Seed yield and number of filled seeds were found to vary significantly. In addition, irrigation deficiency can adversely affect the activities of reproductive organs such as grains and heads because of the high sensitivity of sunflower to water stress during flowering and pollination periods.

Plant height

The results showed that there were no significant differences between treatments in plant height, that is, plant height was not affected when water deficit occurred after flowering and seed filling stages (Table 3). During

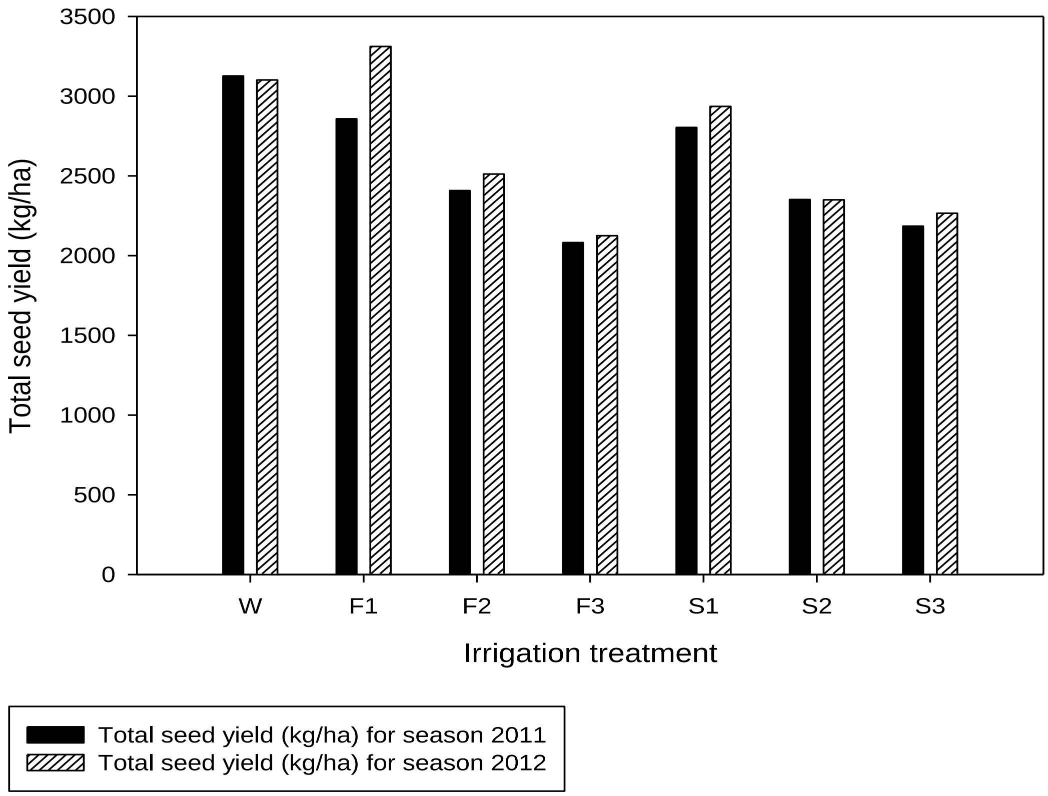

Figure 3. Seed yield of Sunflower under different irrigation intervals for two growing seasons.

the first season the plant height seemed to be shorter (148 to 153 cm) than in the second season (158 to 161 cm), whilst among treatments in the second season it is the same. This contradiction is probably because of differences in environments and material used (bad land preparation and impurity seeds). Thus confirming the findings of (Razi and Assad, 1999) who indicated that the plant height after flowering was not affected by water stress

Head diameter

Head diameter was significantly affected by water deficit during flowering and seed filling stages. Our results are in agreement with the findings of Ghani et al. (2000) who indicated that different irrigation levels had a significant effect on this parameter. Taha et al. (2001) concluded that there was a linear relationship between head diameter and the amount of irrigation levels.

Roshdi et al. (2006) showed that with increasing irrigation interval and applying water stress to sunflower at different crop stages, head diameter and seed yield decreased. Ali and Talukder (2008) stated that deficit irrigation had an effect on head diameter. In this study the smaller head diameter of 15 cm was recorded when the plant irrigated every 20 days after flowering and seed filling stages. While the largest head diameter of 19 and 20 cm was recorded under full irrigation treatment of weekly and 10 days irrigation intervals in two seasons.

Number of seeds per head

Under water deficit conditions, plants do not find enough water to absorb and then the seeds are more or less unfilled. Roshdi et al. (2006) reported that when water stress occurred, particularly during flowering, head diameter decreased and as a result the number of filled grains decreased. In this study there were significant differences between irrigation treatments, the higher number of (1060 and 1030) was observed in weekly irrigation interval (W) and the lower number of (851 and 861) were recorded in irrigation every 20 days (F3) in first and second season respectively. On the other hand, frequent irrigation resulted in the highest number of seeds per head (Table 3). This confirmed the results of Asbagh et al. (2009) who found that the higher seed number per head and seed yield were obtained from full irrigation treatment. Deficit irrigation at flowering stage was observed to be a limiting factor for the number of seeds/head and seed yield. Moreover, seed production was positively correlated to the number of seeds/head. In contrast, seed production increased with increased

Table 4. Oil and protein content (%) as affected by different irrigation intervals for two seasons (2011 and 2012).

Irrigation treatment	Oil content (%)	Protein content (%)	Oil content (%)	Protein content (%)
	Season 2011		Season 2012	
Weekly irrigation (W)	42	14.8	41	13.9
10 days after 50% flowering (F1)	42	13.9	42	13.8
15 days after 50% flowering (F2)	41	13.8	39	14.0
20 days after 50% flowering (F3)	37	14.1	38	13.7
10 days after seed filling stage (S1)	40	14.6	41	14.4
15 days after seed filling stage (S2)	39	14.7	38	13.8
20 days after seed filling stage (S3)	38	14.2	38	14.4

number of irrigations (Rawson and Turner, 1982). The increase in yield was mainly due to increase number of seeds/head and not to seed size. Sunflower showed slightly lesser performance under 15 days intervals compared to other treatments. Moreover, no seed yield was achieved by increasing the irrigation period to physiological maturity.

Oil seed content (%)

The oil percentage is an important evaluation parameter of sunflower quality, which may be affected by deficit irrigation. Sunflower seeds contain a good quality oil (37 to 42%) as well as high amounts of protein (14.8%). Previously, studies reported that the percentage of oil content of sunflower slightly decreased when the crop was exposed to water stress at flowering stage (Hamid and Abolfazl, 2013). Significantly, there were no differences observed in oil content among different irrigation treatments (Table 4).

The higher oil percentage (42%) was recorded when applied full irrigation during the whole growing season, and the lower percentage of (37%) when plants subjected to water stress at flowering stage, while water stress occurred after seed filling stage had no significant effect on it (Bashir and Mohamed, (2014). Oil content increased with increasing the amount of irrigation. Results from two seasons clearly showed that there were no significant differences in protein content among all treatments. The results showed that, water stress significantly ($P \leq 0.05$) decreased seed yield, yield components and seed oil content, but increased the seed protein content in all the irrigation treatments. However, the irrigation water stress did not have an effect in protein content.

Water productivity (kg/m^3)

There are many definitions for the term of water productivity (WP), WP may express a physical ratio between yield and water use, or between the value of the product and water use (Kijne et al., 2003; Palanisami et al., 2009). Therefore, it is important to define the concept used, in this paper water productivity (WP) is defined as the ratio between actual yield and the water applied. Table 5 demonstrates the water productivity for sunflower under different irrigation treatments. Water productivity was higher under weekly irrigation (0.26 kg/m^3) in the first season (Ali and Talukder, 2008), but in the second season it was higher (0.34 kg/m^3) than in the first season, also 10 days before flowering and seed filling stages. WP was lower when sunflower received irrigation at 20 days intervals after flowering (0.21 to 0.26 kg/m^3) and seed filling (0.21 to 0.27 kg/m^3) stages in the first and second season, respectively. The reduction was 20% and 25% in the first and second season respectively. Therefore, each additional m^3 of water yielded 0.26 kg of seed, whereas the output of other irrigation applications was much lower for each additional unit of water, 0.23 and 0.21 kg/m^3 of 15 and 20 days interval after flowering and seed filling stages respectively in the first season. Moreover, lower water productivity of 0.26 and 0.27 kg/m^3 were obtained from irrigation intervals of 20 days after flowering and seed filling stages in the second season respectively. Table 5 shows that higher and lower amount of water applied were recorded under seven days irrigation interval and 20 days irrigation interval after 50% flowering.

Conclusion

The highest seed yield was obtained from a weekly irrigation interval. According to this study, it is concluded that there was no significant effect of irrigation stress on plant height, stem diameter and 100-seed weight after flowering and seed filling stages. The results concluded that the most sensitive growth stages to water deficit were flowering and seed filling stages. The results revealed that the irrigation water productivity for sunflower was low under different irrigation intervals under Gezira conditions. The results also showed that water productivity was low under Gezira condition due to

Table 5. Water productivity (WP) of different irrigation treatments for season.

Irrigation treatment	Yield (kg/ha)	Irrigation supplied (m^3/ha)	WP kg/m^3
Season 2011/2012			
Every week	3130	12000	0.26
10 days after 50% flowering	2670	11200	0.24
15 days after 50% flowering	2410	10400	0.23
20 days after 50% flowering	2080	10400	0.21
10 days after seed filling stage	2800	10600	0.26
15 days after seed filling stage	2350	10900	0.22
20 days after seed filling stage	2190	10300	0.21
Season 2012/2013			
Every week	3140	9350	0.34
10 days after 50% flowering	2880	9400	0.31
15 days after 50% flowering	2510	8600	0.29
20 days after 50% flowering	2130	8240	0.26
10 days after seed filling stage	2840	9480	0.30
15 days after seed filling stage	2350	8540	0.28
20 days after seed filling stage	2270	8470	0.27

inefficiency in water use, weak performance of irrigation system and mismanagement.

Conflict of Interest

The authors have not declared any conflict of interest.

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REFERENCES

Abdelhadi A, Hata T, Tanakamaru H, Tada A, Tariq M (2000). Estimation of crop water requirements in arid region using Penman-Monteith equation with derived crop coefficients: a case study on Acala cotton in Sudan Gezira irrigated scheme. Agric. Water Manage. 45:203-214.

Ali MH, Talukder MSU (2008). Increasing water productivity in crop production-A synthesis. Agric. Water Manage. 95:1201-1213

Andrade FH (1995). Analysis of growth and yield of maize, sunflower and soybean grown at Balcarce, Argentina. Field Crops Res. 41:1-12.

Anwar M, Rahman S, Khan S, Quarish Z (1995). Response of sunflower varieties to different irrigation regimes during kharif season in Peshawar valley [Pakistan]. Sarhad J. Agric. P. 11.

AsbaghFT, Moghddam AF, Gottapeh A (2009). Influence of water stress and sowing date on sunflower yield and oil percentage. Res. J. Biol. Sci. 4:487-489.

Bashir MA, Mohamed YM (2014). Evaluation of full and deficit irrigation on two Sunflower hybrids under semi-arid environment of Gezira, Sudan. J. Agri-Food Appl. Sci. 2:53-59.

Beyazgül M, Kayam Y, Engelsman F (2000). Estimation methods for crop water requirements in the Gediz Basin of western Turkey. J. Hydrol. 229:19-26.

Faisal E, Ahmed BEA, Mahmoud MA, Ahmed F (2006). Effect of irrigation interval and planting density on seed and oil yields of sunflower hybrid. UK. J. Agric. Sci. 14:343-353.

Ghani A, Hussain M, Qureshi MS (2000). Effect of different irrigation regimens on the growth and yield of sunflower. Int. J. Agric. Biol. 2:334-335.

Göksoy A, Demir A, Turan Z, Dağüstü N (2004). Responses of sunflower (< i> *Helianthus annuus*</i> L.) to full and limited irrigation at different growth stages. Field Crops Res. 87:167-178.

Hamid RM, Abolfazl T (2013). Effect of water stress on quantitative and qualitative characteristics of yield in sunflower (*Helianthus annuus* L.). J. Novel Appl. Sci. 2:299-302.

Human JJ, Du Toit D, Bezuidenhout HD, De Bruyn LP (1990). The influence of plant water stress on net photosynthesis and yield of sunflower (*Helianthus annuus* L.). J. Agron. Crop Sci. 164:231-241.

Iraj Alahdadi HO, Fatanch PK (2011). Effect of Water Stress on Yield and yield components of Sunflower Hybrids. Afr. J. Biotechnol. 10:6504-6509.

Karam F, Lahoud R, Masaad R, Kabalan R, Breidi J, Chalita C, Rouphael Y (2007). Evapotranspiration, seed yield and water use efficiency of drip irrigated sunflower under full and deficit irrigation conditions. Agric. Water Manage. 90:213-223.

Kijne JW, Barker R, Molden DJ (2003). Water productivity in agriculture [electronic resource]: limits and opportunities for improvement CABI.

Palanisami K, Senthilvel S, Ramesh T (2009). Water productivity at different scales under canal, tank and well irrigation systems International Water Management Institute.

Pejić B, Maksimović L, Škorić D, Milić S, Stričević R, Ćupina B (2009). Effect of water stress on yield and evapotranspiration of sunflower. Helia 32(51):19-32.

Rawson H, Turner N (1982). Recovery from water stress in five sunflower (*Helianthus annuus* L.) cultivars. I. Effects of the timing of water application on leaf area and seed production. Funct. Plant Biol. 9:437-448.

Razi H, Assad MT (1999). Comparison of selection criteria in normal and limited irrigation in sunflower. Euphytica 105:83-90.

Roshdi M, Heydari Sharifabad H, Karimi M, Nourmohammadi G, Darvish F (2006). A Survey on the impact of water deficiency over the yield of sunflower seed cultivar and its components. J. Agric. Sci. 12:109-121.

Stone L, Schlegel A, Gwin R, Khan A (1996). Response of corn, grain sorghum, and sunflower to irrigation in the High Plains of Kansas. Agric.

Water Manage. 30:251-259.
Taha M, Mishra B, Acharya N (2001). Effect of irrigation and nitrogen on yield and yield attributing characters of sunflower. Ann. Agric. Res. 22:182-186.
Yawson DO, Bonsu M, Armah FA (2011). Water requirement of Sunflower (*Helianthus annuus* L.) in a tropical humid-costal savanna zone. J. Agric. Biol. Sci. 6.