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Effect of Deficit Irrigation at Different Growth Stages on Yield and Water Productivity of Sunflower (*Helianthus annuus* L.), Gezira State, Sudan

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Abstract: In arid and semi-arid regions, water scarcity is the main limiting factor, where it is difficult to apply full crop water requirements for sustainable crop growth and yield. Therefore, it is important to determine how to maximize crops yield under water deficit conditions. Deficit irrigation is water management method in which water will be saved with accepting little yield reduction without any severe damage to the plant. This study was conducted at the experimental farm of the faculty of agricultural sciences, university of Gezira, Sudan during season 2017 and 2019. The objective of this study was to evaluate the effect of deficit irrigation at different crop stages on yield and yield components of sunflower. A randomized complete block design with three replications was used. Five irrigation treatments were used: Irrigation every 10 days throughout the season as control (T_1), skipping irrigation during vegetative stage (T_2), during heading stage (T_3), during flowering stage (T_4) and during seed filling stage (T_5). The parameters studied consist of plant height (cm), stem diameter (cm), head diameter (cm), head weight (g), number of seeds per head, empty seeds (%), seed yield (kg/ha) and water productivity (kg/m^3). The results showed that deficit irrigation significantly affected yield and yield components. Although there were significant differences between treatments of irrigation, but there were no significant differences between means of full irrigation and when deficit irrigation is applied at heading stage. The maximum yield was found (2173 and 2176 kg/ha) obtained by full irrigation followed by deficit irrigation at heading stage (2122 and 2172 kg/ha) for the two seasons respectively. The minimum seed yield (1448 and 1146 kg/ha) for the two seasons, was achieved when applying deficit irrigation at flowering stage which was significantly differentthus indicating the sensitivity of this stage to deficit irrigation. Water productivity in full irrigation was found (0.35 and 0.37 kg/m^3) and in deficit irrigation at heading stage was (0.31 and 0.36 kg/m^3) for the two seasons and also show no significant differences. The study recommended that, for maximum seed yield and efficient water use, deficit irrigation could be applied at heading stage and should be avoided during flowering and seed filling stages.

Key words: Deficit irrigation · Water management · Sunflower

INTRODUCTION

Sunflower (*Helianthus annuus* L.) originates from Central and North America. It is considered the fourth oilseeds crop in the world and has a wide range of adaptability and highest oil seed content. Sunflower oil is highly demanded for human consumption and chemical cosmetic industries [1]. The total production of sunflower is approximately 45 million tons and the area under its cultivation was 26 million hectares in the world [2]. Sunflower was introduced in Sudan in the 20th century, but commercial production at large-scale started in the late 1980s by the private sector. In arid and semi-arid regions, water scarcity is main limiting factor, where it is difficult to apply the optimum crop water requirements to achieve the crop maximum growth and yield. Therefore, it is important to determine how to obtain maximum crop yields under water deficit conditions. The application of regulated water deficit strategies is one of the most promising techniques to improve water productivity [3].

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Deficit irrigation is a water management method in which water will be saved with accepting little yield reduction without any severe damage to the plant [4]. Many researchers around the world found that water stress will reduce plant height when applied during different growth stages Talha and Osman [5]; Sionit [6]; Unger [7]; Venkanna *et al*. [8] and D'Anderia *et al*. [9]. Water stress has a large impact on yield compared to the limited impact on biomass. In simple terms, crops that face water stress at critical stages may have a considerable lower harvestable yield than crops imposed to the same water stress during less critical stages. It was found that full irrigation from flowering till late flowering resulted in the highest seed yield and also the highest oil yield and seed weight [10]. Bashir and Mohamed [11] stated that the maximum yield was obtained with full irrigation followed by deficit irrigation after 90 days from planting. Also the total water use increases with increased number of irrigations but yield increases were not proportional to water use, especially for adequate and full irrigation treatments. Iqbal *et al.* [12] stated that worldwide water stress is considered as one of the most important factors limiting crop development and yield and that several studies have been conducted to assess the effect of water stress on plant growth, yield and leaf photosynthesis.

The objective of this study is to test the effects of deficit irrigation at different growth stages (early stage, heading stage, flowering stage and seed filling stage) on yield and water productivity of sunflower under Gezira conditions, Sudan.

MATERIALS AND METHODS

The experiment was carried out during the growing season of 2017 and 2019, at the experimental farm, university of Gezira, Sudan, latitude 14.4° N, Longitude 33.5° E and altitude of 405 meters above the mean sea level (MSL). The Gezira clay soil lies within the dry zone. The average annual rainfall which occurs between mid-June and September is about 254 mm [13]. Sunflower, Damazin variety was sown by hand on 8th April. 3 - 4 seeds per hole were sown on top of the ridge, thinned to two plants after one week and to one plant after another week. The spacing was 80 cm between ridges and 20 cm between holes. Hand weeding was practiced twice before starting taking the samples. Thecultural practices of the crop were done according to the recommendation of Agricultural Research Corporation(ARC), Sudan as described in Bashir and Mohamed [11]. Deficit irrigation was applied on sunflower crop in different crop stages. A full irrigated crop (8 irrigations) was used as a control (T_1). A deficit of one irrigation was applied at different crop stages, which include; skipping irrigation during vegetative stage (T_2), skipping irrigation during heading stage (T_3), skipping irrigation during flowering stage (T_4) and skipping irrigation during milk ripening stage (T_5). Experiment was arranged in a randomized complete block design (RCBD) with three replications. Water applied for each treatment was measured for the whole season by using a Parshal flume, which was fixed in the small field canal called Abu VI (Abusitta).Total crop yield was calculated by equation (1).

$$yield\left(\frac{kg}{ha}\right)=\frac{\left(\frac{yield}{m^2}\right)g}{1000}kg \quad (1)$$

Crop water productivity (CWP) was calculated by using equation (2).

$$CWP(\frac{kg}{m^3})=\frac{yield(\frac{kg}{ha})}{water\ applied(m^3/ha)} \quad (2)$$

Different plant growth parameters data which include plant height (cm), stem diameter (cm), head diameter (cm), head weight (g), number of seeds per head, percentage of empty seeds per head, total seed yield (kg/ha), water productivity (kg/m^3), were measured and analyzed using standard analysis of variance (ANOVA). Means separation was carried out using the least significant difference (LSD) for the different characters.

RESULTS AND DISCUSSIONS

Plant Height (cm): The effect of deficit irrigation on the plant height of sunflower in the two seasons is shown in Table (1) and (2). The results showed that the maximum plant height was obtained in full irrigation treatment (142.8 and 146.9 cm) for the two seasons respectively, followed by skipping irrigation at heading stage (139.6 cm). The minimum plant height was appearing when skip irrigation at vegetative stage in the two seasons (122.7 and 125.9 cm) respectively. Statistical analysis and LSD mean separation clarify that the difference in plant height is highly significant at ($P \leq 0.01$) between full irrigation and all other treatments and also the difference is highly significant between skipping irrigation in heading stage and all other treatments at the same

Table 1: Effect of deficit irrigation on different crop parameters (2017)

Treatments	Plant height (cm)	Stem diameter (cm)	Head diameter (cm)	Head weight (g)	Number of seeds per head	Number of empty seeds per head%	Total seed yield (kg/ha)	Water productivity (kg/m^3),
T_1	142.8 a	2.4 a	13.3 a	64.6 a	854 a	4.8 c	2173 a	0.35 a
T_2	122.7 c	1.9 d	10.5 b	49.2 ab	733 b	7.2 b	1771 b	0.28 bc
T_3	139.7 ab	2.1 c	13.1 a	51.4 ab	854 a	5.5 c	2122 a	0.31 ab
T_4	135.1 b	2.2 bc	12.9 a	57.8 ab	726 b	9.7 a	1448 c	0.25 d
T_5	139.3 ab	2.4 ab	12.4 a	43.7 b	706 b	8.7 a	1596 bc	0.27 cd
Sig level	**	**	*	*	**	**	**	**
SE±	1.9542	0.067	0.6903	5.54	26.44	0.311	76.74	0.0102

* Significant at P= 0.05 level** Significant at P= 0.01 levelN.S= not significant, T_1control, T_2 skipping irrigation at vegetative, T_3 skipping irrigation at heading, T_4 skipping irrigation at flowering, T_5 skipping irrigation at seed filling

Table 2: Effect of deficit irrigation on different crop parameters (2019)

Treatments	Plant height (cm)	Stem diameter (cm)	Head diameter (cm)	Head weight (g)	Number of seeds per head	Number of empty seeds per head%	Total seed yield (kg/ha)	Water productivity (kg/m^3),
T_1	146.9 a	2.5 a	13.4 a	64.9 a	854 a	5.0 d	2177 a	0.37 a
T_2	125.9 c	1.9 d	10.4 c	49.8 d	733 b	7.3 c	1771 b	0.28 b
T_3	139.6 b	2.1 c	13.1 a	63.6 b	854 a	5.0 d	2172 a	0.36 a
T_4	138.4 b	2.3 b	12.5 b	57.9 c	736 b	9.7 a	1446 d	0.25 c
T_5	140.4 b	2.5 a	12.5 b	43.6 c	705 c	8.7 b	1595 c	0.27 b
Sig level	**	**	**	**	**	**	**	**
SE±	1.53	0.05	0.08	0.22	5.03	0.07	1.65	0.01

* Significant at P = 0.05 level ** Significant at P = 0.01 level N.S = not significant, T_1control, T_2 skipping irrigation at vegetative, T_3skipping irrigation at heading, T_4 skipping irrigation at flowering, T_5 skipping irrigation at seed filling

probability ($P \leq 0.01$). Plant height showed no significant difference when skip irrigation at flowering andmilk ripening stage. These results were in the same line of Ahmed *et al*. [14] who noticed that increased irrigation water increased plant height and also many other studies prove that as a general rule water stress reduce plant height such as Teama and Mahmoud, [15]; Shouk, [16]; Badr El-Din [17]; Sionit [6] and Venkanna *et al*. [8] wrote that as irrigation water depth increased plant height increased. The results also showed the sensitivity of plant height to water stress at vegetative crop stage so it is crucial to avoid water stress at this period.

Stem Diameter (cm): Stem diameter is one of the parameters to evaluate the status of the crop as affected by water stress. In this study the maximum stem diameter, for the two seasons, was found when the crop took its full irrigation and when irrigation was skipped at seed filling stage (2.4 and 2.5 cm) for the two seasons respectively, with high significant difference from all other treatments as shown in Table (1) and (2). In filling stage the crop reach it is maximum vegetative development and water stress in this stage will not affect stem diameter any more. Severe water stress decreased stem diameter to its minimum value when water stress happened during vegetative stage (1.9 cm). These results were in agreement with the results of Teama and Mahmoud [15] and Badr El-Din [17] who found that the greatest reduction in stem diameter was obtained when plants were subjected to water stress before flowering.

Head Diameter (cm): Always there is a positive correlation between the head diameter and total crop seed yield in sunflower. The effect of deficit irrigation on head diameter of sunflower is shown in Table (1) and (2). There were significant differences ($P \leq 0.05$) in the first season and highly significant difference ($P \leq 0.01$) in the second season between irrigation treatments. The highest value of head diameter was obtained by full irrigation (13.3 and 13.4 cm) for the two seasons respectively, while the lowest value was obtained by skipping irrigation at early stage (10.5 and 10.4 cm) for the two seasons respectively. In the two seasons the next value of head diameter (13.1 cm) was found when water stress happened at heading stage and with no significant difference from full irrigation treatment. Many studies found the same results like Cox and Jolliff [18] who mentioned that well irrigated sunflower produced larger heads compared to deficit one. Bakhsh *et al*. [19]; Khot and Patil, [20] reported that head diameter of sunflower was increased with increase in number of irrigations. For water management strategies, deficit irrigation should be avoided at early stages which involve crop vegetative development stages.

Head Weight (g): Head weight is one the most important indicators for the total crop yield and it is highly affected by water stress during different stages. The effect of deficit irrigation on the head seed weight of sunflower is shown in Table (1) and (2). Full irrigated crop recorded the maximum head weight for the two seasons respectively (64.6 and 64.9 g) with no significant difference from all other treatment except from skipping irrigation during milk ripening stage at ($P \leq 0.05$) in season 2017, but the difference is highly significant from all other treatment at ($P \leq 0.01$) in season 2019. The next value to full irrigation is differ from season to season, in season 2017 the next value of head weight was obtained when water stress was applied during flowering stage (57.8 g) with no significant difference from all other treatments. In 2019 the situation is different and next value of head weight was found when water stress is applied during heading stage (63.6 g) with significant difference from other treatments.

Number of Seeds per Head: Number of seeds per head is also a good indicator for total productivity. Water stress had influence on the number of seed per head in the two seasons as shown in Table (1) and (2). Full irrigation and deficit irrigation during heading stage gave the same and high number of seed per head in the two seasons (854) and it is significantly different from all other treatments at ($P \leq 0.01$). The sever effect of water stress on the number of seeds per head appeared clearly in skipping irrigation during milk ripening stage which gave the lowest value (705). These results were in agreement with Rawson and Turner [21] and Venkanna *et al.* [8] who mentioned that the number of seeds per head increased as irrigation water increased. Hall *et al*. [22] found that water stress is able to cause a slight decrease in grain number at maturity.

Percentage of Empty Seeds (%): Results of this study revealed that water stress on sunflower increased the percentage of empty seeds which had negative impact on overall crop yield as shown in Table (1) and (2). The high percentage of empty seed (9.7%) was found when water stress wad applied during flowering stage in the two seasons, while the low percentage (4.8% and 5%) for the two season respectively were associated with full irrigated crop.Results proved that deficit irrigation particularly at flowering stage reduced seed set due to dehydration of pollen grain. Ishag [23] reported similar results and noticed the presence of large number of empty seeds per head when sunflower was subjected to water stress at flowering stage. Lazim [24] and Human *et al.* [25] observed that severe water stress at seed filling resulted in large numbers of empty seed.

Total Seed Yield (kg/ha): The effect of deficit irrigation on final seed yield of sunflower is shown in Table (1) and (2). Irrigation levels effect on grain yield of sunflower showed highly significant differences at ($P \leq 0.01$). The highest yield was obtained by full irrigated crop (2173 and 2177 kg/ha) in the two seasons respectively followed by skipping irrigation at heading stage (2122 and 2172 kg/ha) for the same seasons. The lowest grain yield was found in skipping irrigation at flowering stage (1448 and 1446 kg/ha)in the two seasons respectively. Although there were highly significant differences ($P \leq 0.01$) between different irrigation treatments, it was found that there was no significant difference ($P \leq 0.01$) when skipping irrigation during heading stage and full irrigation. Hall *et al* [22]; Karami [26]; Unger [10; Sadras and Calvino [27] all found an increase in seed yield with increase in frequency and amount of irrigation. Roshdi *et al*. [28] concluded that water stress during the flowering stage has a significant effect on yield and yield components of Sunflower. Mohammed *et al*. [29] indicated that water stress during the flowering and seed filling stages causes considerable reduction in seed yield of Sunflower.Bashir and Mohamed [11] stated that the maximum yield was obtained with full irrigation followed by deficit irrigation after 90 days from planting.

Water Productivity (kg/m^3): For water resources planning, water productivity is an important indicator especially in dry areas. In full irrigation crop the cubic meter of irrigation water produced (0.35 and 0.37 kg) of seeds for the two seasons which was the maximum value obtained in this study. The mean of water productivity in all treatment was significantly different from full irrigation mean at ($P \leq 0.01$). Water productivity, when skipping irrigation during heading stage recorded (0.31 and 0.36) kg/m^3 which is not significant in difference from full irrigation crop. The minimum value of water productivity in the two seasons was obtained when skipping irrigation at flowering stage (0.25 kg/m^3) and it is significantly different from the mean of all other treatments. With the ever limitation in water resources for agricultural uses, irrigation strategies that focus on deficit irrigation as a way to optimize water productivity and achieve higher crop yields per unit of irrigation water are advisable in scarce water resources environments [30]. By eliminating irrigation that has the lower impact on yield, the resulting yield reduction may be small compared with the benefits gained by diverting the saved water to irrigate other crops [4, 31, 32, 33, 34]. In addition, deficit irrigation has potential benefits resulting from reduced irrigation costs [31].

CONCLUSIONS ANDRECOMMENDATIONS

Based on the results of the study for the two seasons in the environment of Gezira, Sudan the study concluded that:

- The maximum crop yield was obtained when applying full irrigation requirements, but under water scarcity conditions deficit irrigation could be applied at heading stage without sever reduction in yield and as the same time save irrigation water to irrigate other crops.
- Application of deficit irrigation at flowering and seed filling stage reduced the crop yield to it is minimum value.The reduction in sunflower seed yield under skipping irrigation at flowering and seed filling was associated with substantial reduction in yield components.

So it is recommended that skipping irrigation during heading is the best choice for maximum yield under deficit irrigation condition.Water stress during flowering and seed filling stages of sunflower should be avoided because of high reduction in yield.

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