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Crop water productivity for sunflower under different irrigation regimes and plant spacing in Gezira Scheme, Sudan

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Abstract: Two field experiments with Sunflower on deep cracking soil with heavy clay (vertisol) were conducted at Gezira Research Station Farm during two consecutive winter seasons, in WadMedani, Sudan. The crop was sown in the third week of November and in the first week of December for seasons 2012 and 2013 respectively. The experimental design was split plot design with three replicates. The Sunflower hybrid tested in the study was Hysun 33. The objective of this study was to determine the effect of three different irrigation intervals of 10, 15 and 20 days and two intra-row plant spacings of 30 cm and 40 cm on yield and yield components of Sunflower. The seed yields obtained from the different treatments were in the ranges of 1890-3300 kg/ha and 1590-3290 kg/ha for the first and second season respectively. The study clearly indicated that the highest seed yield was obtained when the crop was sown at 40 cm plant spacing and irrigated every 10 days. The corresponding computed on average crop water productivity was in the range of 0.31-0.43 kg/m^3. The highest crop water productivity was achieved from irrigation every15 days in both planting spacings.

Keywords: water productivity, seed yield, Sunflower, plant spacing

Introduction

Sunflower (*Helianthus annuus* L.) is the fourth seed oil crop in the world trade with around 9 million tons for annual production with cultivated area over 22 million hectares. It is one of the important oil crops in the world as well as in Sudan. It can be used for many purposes, mainly for oil extraction, animal feed and human food. It is considered as third important seed oil crop and cash crop after Groundnut, Cotton and Sesame. It can be grown as summer and winter crop under rainfed and irrigated conditions. In Sudan the area under the crop is increasing continuously with time. Crop water productivity of Sunflower is low in Gezira Scheme due to shortage in water supply during the sensitive crop stages. This problem is aggravated towards the end of the growing season, because of the shortage in water supply from the main canal. To solve this problem and save water in Gezira Scheme, alternative irrigation technologies would have to be employed, including the application of deficit irrigation, which is the focus of this paper. Doorenbos, (1979) reported that Sunflower is considered to be tolerant to water deficit to some extent. In areas of low rainfall, supplementary irrigation can boost the productivity of the crop. Kazemeini *et al.* (2009) concluded that seed yield and oil content of Sunflower were the major sensitive parameters to water deficit during the flowering and reproduction formation stages. Kaya and Kolsarici (2011) stated that all the yield components were affected by the number of irrigations. Moreover, they found that seed yield increased with increasing number of irrigations. It has been shown elsewhere, that maximum yield response to limited irrigation can be achieved with irrigation schedules, and in many regions when water is insufficient to irrigate all the land available, irrigation strategies should be availed to farmers. The objective of this study was to examine the effect of three irrigation intervals with two intra-row plant spacings on yield and yield components, crop water productivity and economic water productivity of Sunflower under Gezira clay conditions.

Materiels and methods

The experiment was conducted at Gezira Research Station Farm located in WadMedani city, Sudan, at the latitude 14º23 N and longitude 33°39 E (Figure 1). The area has an arid to semi- arid climate with an average precipitation of 250-350 mm during the rainy season (late June to late September) El Naim and Ahmed , (2010).

Two experiments were carried out during the winter season starting in the second week of November 2012 and in the first week of December in 2013. The experiments were designed as a split plot experiment based on a randomized complete block design (RCBD), with three replicates, the irrigation treatments in the main plot and plant spacing in the subplot. Each subplot had 10 m of length and 5 m of width (total area was 50 m^2) with 6 rows. The experimental treatment consisted of three irrigation intervals 10, 15, 20 days designated as W1, W2, and W3 and within row spacings of 30 and 40 cm specified as S1 and S2. The Hysun 33 cultivar, the major adapted hybrid was grown. The crop was sown on the top of the ridge 80 cm apart. Three seeds were sown in each hole and then thinned to one plant two weeks after emergence; all other agronomic practices were kept uniform for all the treatments. The amounts of water applied for each treatment were measured during the whole season by using a current meter, which was fixed in the inlet of the Abu sita (small water canal to irrigate 2.1 ha

(5 feddan) to measure the discharge of water entering each plot separately. The total number of plots was 18. The soil is heavy clay classified as vertisol. Table 1 gives details of chemical and physical analyses for the experimental site, which were done at the Land and Water Research Centre Laboratory, WadMedani, Sudan. The climatic data, such as maximum and minimum temperature, relative humidity, wind speed and hours of sunshine were obtained from the nearest meteorological station (Table 2). Fertilizer in the form of urea at the rate of 205 kg/ha (86 kg/feddan (local unit) was added as recommended for Sunflower, half with the second irrigation (after 10 days) and the second half at flowering after two months. Weeds were controlled manually during the whole growing season. Harvest was done in the second week of March for the two seasons. Statistical analyses was done using Statistix.9 software computer program (Statistix, 2010).

Table 1 - Soil chemical and physical characteristics of the experimental field.

Depth (cm)	Clay (%)	Silt (%)	Sand fine (%)	$CaCO_3$ %	BD (g/cm^3)	FC (%)	PWP (%)	OM (%)	pH	Hydraulic conductivity cm/hr
0-30	58	25	13	5.2	1.60	38.2	20.7	0.34	7.9	2.23
30-60	60	28	9	4.8	1.52	45.9	24.9	0.31	8.1	2.61
60-90	54	31	7	5.0	1.78	41.9	22.8	0.13	8.0	0.22

Sources: Land and Water Research Centre laboratory (2012), Sudan.

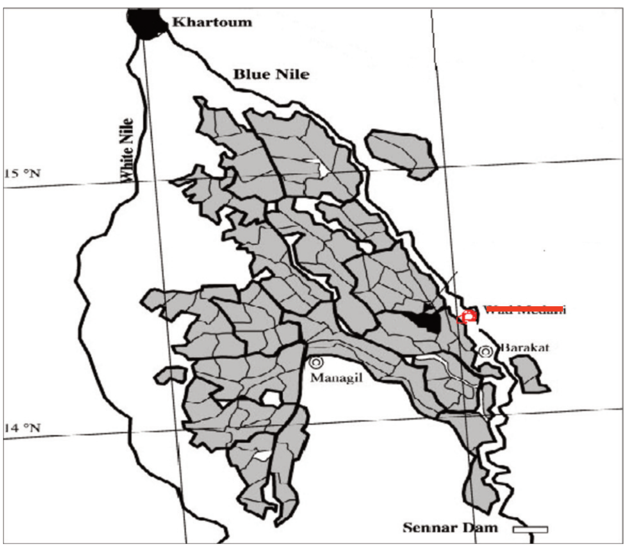

Figure 1 - Map of the location of Gezira Scheme.

Table 2 - Mean monthly climatic data of Gezira Research Station for the two growing seasons (2012/13 and 2013/14).

Month	Max.temp. (°C)	Min.temp. (°C)	RH (%)	Sunshine (h)	Windspeed (m/s)
			2012/2013		
November	37.1	18.7	40	10.5	1.6
December	34.8	15.5	30	10.7	1.8
January	33.8	15.2	31	10.5	2.3
February	38.4	19.1	28	10.3	2.5
March	39.1	19.9	24	9.8	2.5
April	42.5	21.3	23	10.5	1.8
			2013/2014		
December	33.6	16.5	32	10.7	1.89
January	34.2	15.5	35	10.7	2.68
February	35.4	20.9	34	10.5	2.32
March	39.5	22.3	30	9.6	2.27
April	41.3	25.6	31	7.5	3.52

Source: WadMedani Meteorological Station (2013), Sudan.

Results

Plant height

Crop parameters such as plant height and head diameter are presented in (Table 3). The highest plant height (161 cm) was obtained from irrigation every 10 days with plant spacing 40 cm (W1S2) in the first season. In contrast, the lowest one was obtained from irrigation every 20 days in both plant spacings. Plant height decreased considerably with decreased plant spacing. This finding is in line with (Unger, 1983) who indicated that the plants in the narrow inter-row spacing were significantly taller than those at the wider spacing due to high competition in the row, the plants in the small spacing grew taller than in the wider spacing.

Number of filled seeds per head

On the other hand, there were significant differences in number of filled seeds among irrigation treatments and plant spacing (Table 3). Irrigation every 10 days and plant spacing 40 cm had the highest number of filled seeds and total seed yield. Kazemeini *et al.* (2009) reported that wider within row spacing and increased number of irrigations generally resulted in more filled seeds being produced. Ghani *et al.*

Table 3 - Effect of irrigation and intra-row plant spacing, and their interactions on crop parameters of Sunflower for two winter seasons 2012/13 and 2013/14.

Irrigation/ plant spacing treatment	Plant height (cm)	Head diameter (cm)	Stem diameter (cm)	Number of filled seeds	Total yield (kg/ha)	Weight of 100 seeds (g)
			2012/2013			
W1S1	160a	17b	1.2a	1020a	3230ab	5.1a
W1S2	161a	21a	1.4a	1180ab	3300a	5.2a
W2S1	150ab	18ab	1.2a	1060a	3120b	4.8ab
W2S2	152ab	21a	1.6a	1090a	2910c	5.1a
W3S1	126b	15c	1.2a	663c	1890d	4.6b
W3S2	131b	17b	1.4a	928b	1890d	5.1a
Mean	146	18	1.3a	990b	2720	5.0a
SE±	3.79	0.71	0.15	62.4	165	0.39
CV%	4.49	6.62	20.07	11.2	10.5	7.53
			2013/2014			
W1S1	164a	20b	1.2a	1180b	3210b	5.8b
W1S2	157ab	23a	1.3a	1270a	3290a	6.0a
W2S1	153ab	20b	1.2a	1120ab	2860d	5.3c
W2S2	151ab	20b	1.2a	1220a	3050c	5.2c
W3S1	144b	17c	1.0a	1000c	1830e	5.1c
W3S2	138b	19bc	1.0a	960d	1590f	5.2c
Mean	151.5	20.0	1.15	1120	2550	5.4bc
SE±	5.80	0.47	0.05	40.6	96. 6	0.1
CV%	4.71	4.12	9.70	7.0	6.3	3.8

(2000) concluded that the number of filled seeds increased linearly with each increase in irrigation frequency. The wider plant spacing had a higher number of seeds per head and seed weight.

Seed yield

Seed yield was determined under different irrigation intervals to investigate the effect of differences in water application during the respective growth stages on final seed yield. The results stated that Sunflower was more sensitive to water stress during the flowering and seed filling stages. Seed yield significantly improved by optimum irrigation after the start of the flowering and seed filling stages. However, higher seed yield was obtained from irrigation every 10 days (W1) followed by that of irrigation every15 days (W2) and the lower seed yield from irrigation every 20 days (W3) irrespective of plant spacing. Maximum yield values of 3290 and 3300 kg/ha were obtained under irrigation every 10 days with plant spacing of 40 cm. The results showed that 40 cm (S2) plant spacing in all irrigation treatments achieved highest seed yield and largest head diameter compared to 30 cm (S1) except for some treatments, which were affected by birds attack. The lower seed yield with 30 cm plant spacing was probably due to high competition between plants. Unger (1983) indicated that limited irrigation water applied during growth stages can significantly increase yield even during heading, flowering and seed filling stages. While Erdem and Delibas (2003) indicated that Sunflower is not sensitive crop to water deficit during the total growing period. Sedghi *et al.* (2008) reported that the highest seed weight was obtained from the lowest density due to maximum light interception per plant. Moreover, increasing the irrigation interval to 20 days reduced seed yield by more than 43% and 48% in the first and second season respectively (Table 4). Kazemeini *et al.* (2009) reported that seed yield was significantly affected by water stress during the critical growth stages.

Also results in Table 3 show the interaction effects of irrigation intervals and intra-row plant spacing on some crop parameters. Larger head diameter was observed at wider intra-row spacing (40 cm) with irrigation interval every 10 days (W1S2). This may be due to a better environment created of that treatment, which resulted in better performance of the crop. Taller plants with small head diameter of close intra-row spacing may be due to the competition of plants for nutrients, light, moisture and carbohydrates, also due to lack of enough space for lateral growth. On the other hand, the extended irrigation interval of 20 days (W3) resulted in a smaller head diameter. Khalifa (1981) recommended 45 cm plant spacing for rainfed planting and 30 cm plant spacing for irrigated production of Sunflower under semi-arid conditions. El Naim and Ahmed (2010) investigated the effect of irrigation intervals of 7, 14 and 21 days, and plant spacing of 15 and 30 cm on yield, yield components and water use efficiency of two Sunflower hybrids under dry conditions. They reported that plant spacing and hybrids had no significant effect on seed yield and oil content. In contrast, the highest water use efficiency under irrigation interval of 7 days was achieved.

Oil and protein content

Razi and Assad (1999) stated that water stress significantly decreased yield and its components but oil content did not change significantly and they added that the direct effect of seed oil content was lower than its correlation with seed yield. Kaya and Kolsarici (2011) did not find any relationship between irrigation and oil content. Basher and Mohamed (2014) indicated that the oil content increased when increasing the amount of irrigation. Figure 2 shows the comparative results between the two seasons in oil content (% from dry seed weight), which clearly illustrated that there was no significant difference among treatments. The highest oil percentage (40%)

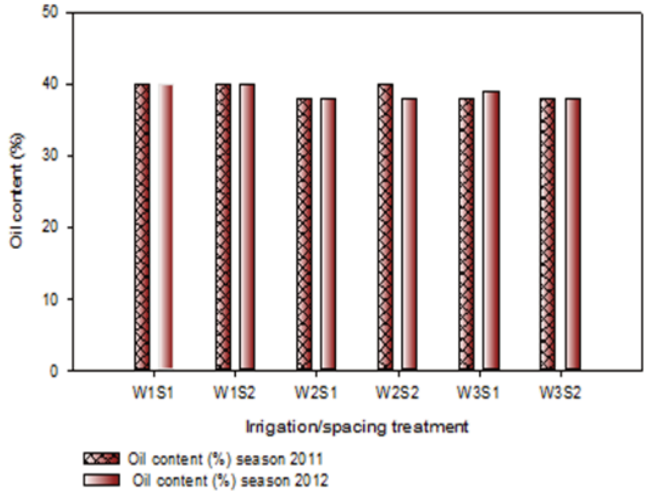

Figure 2 - Seed oil content (%) for two growing seasons 2011 and 2012.

was recorded when Sunflower was irrigated every 10 days under both plant spacing in two seasons, while the lowest oil content (38%) was recorded under the prolonged irrigation interval of 20 days. In the two seasons, results clearly showed that there were no significant differences in protein content among all treatments.

Discussion

The optimal use of irrigation water is essential where and when there is insufficient water for crop demand. In this context, irrigation efficiency, strictly related to applying water at the right period and the right amount (irrigation timing and depth), is essential for water resources management. It is important to analyse the effect of water supply on crop yields. The effect of water stress on crop development and yield depends on crop variety, magnitude and period of occurrence of water deficit. The most agronomical practices involved in Sunflower husbandry (genotype, row spacing, irrigation, fertilization) affect yield by developing crop growth and biomass. Among these agronomical practices, intra-row plant spacing is the most important factor that has a direct effect on crop growth and final seed yield. Sowing dates, cultivation methods and seed rates are well known for most crops grown in Gezira Scheme. However, these agronomic practices are less significant aspects in producing optimum seed yield. The radiation and light quality may affect Sunflower development from flowering until seed formation. Plant spacing may affect the utilization of light, water and nutrients. In most cases, these factors are confounded by their effects on growth development. The significant effect of radiation and light quality as a factor accelerating crop growth development under different climatic and field conditions is unknown.

The magnitude of the effects of these factors was observed in our experiments, mostly in narrow plant spacing due to competition between plants. Yield and yield components are affected as a result of wider plant spacing. Seed yield increased significantly with increase in intra-row plant spacing from 30 to 40 cm. The only yield component not affected significantly was stem diameter, which was the same in the two intra-row plant spacings in the two growing seasons. The results of response of oil content to different irrigation treatments and two plant spacings showed that there was no significant effect on oil content. Seed number was inversely proportional to the increase in plant density. Sedghi *et al.* (2008) reported that plant density had a significant effect on the growth characteristics of Sunflower. Also he indicated that both 1000-seed weight and the number of grains per head decreased significantly with increasing plant density. Water stress during the flowering until seed filling stages had the greatest effect on seed yield of Sunflower. Nazariyan *et al.* (2009) showed the effect of water stress on seed formation until the end of the growing season. He found that the yield components were affected especially by 1000-seed weight and head diameter. Ali *et al.* (2013) recorded that higher seed yield was produced from the control treatment (full irrigation). However, crops suffering from water deficit during flowering and seed filling stages can have an effect on oil and protein content. On the other hand, this may cause reduction in the carbohydrate accumulation in seeds and this enhances nitrogen compounds which results in high protein compared to wet conditions.

Total applied water (m^3/ha)

Water was applied individually to each plot and was measured during the whole growing season. Average water applied per irrigation was calculated for each treatment in m3/ha. Seasonal water applied and the reduction in seed yield due to different amounts of irrigation water is presented in Table 4. The irrigation treatment started after the third irrigation when plants completed the establishment period. Thus, the reduction in seed yield was higher in treatment W3 by 43-48% compared to full irrigation (W1). Whereas, the reduction in seed yield in treatment W2 (mild stress) was somewhat less between 6-13% owing to the sufficient water availability during the sensitive growth stages. Treatments which were stressed during the critical growth stages had a higher seed yield reduction compared to full irrigation. The percentages of water saving under different irrigation treatments that had no significant effect on seed yield compared to full irrigation were 31 to 36% in the first and second season respectively. Irrigation interval of 10 days was recorded higher irrigation numbers of 9 and the lower irrigation numbers of 6 were recorded in 15 and 20 days irrigation intervals.

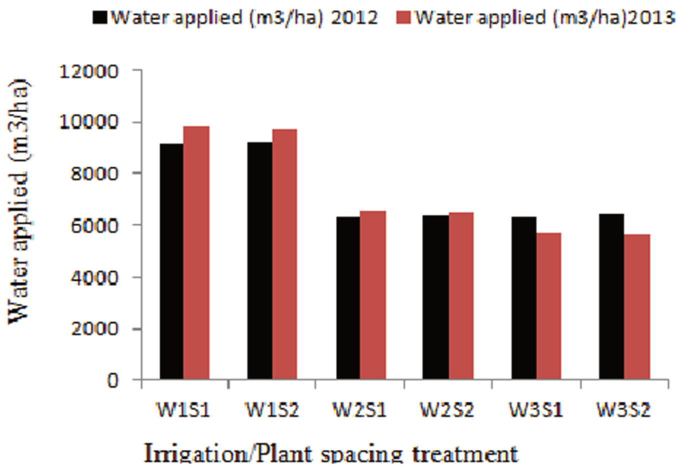

Figure 3 - Water applied (m^3/ha) for two growing seasons of 2012 and 2013.

Table 4 - Number and amount of irrigation water applied for each treatment and yield reduction for two winter seasons 2012/13 and 2013/14.

Irrigation/plant spacing treatment	Irrigation water applied (m^3/ha)	Number of irrigation	Average per irrigation	Seed yield (kg/ha)	Yield reduction %
		2012/2013			
W1S1	9120	9	1010	3230	3
W1S2	9220	9	1030	3300	0
W2S1	6330	6	1060	3120	6
W2S2	6380	6	1060	2910	12
W3S1	6300	6	1080	1890	43
W3S2	6470	6	1080	1890	43
		2013/2014			
W1S1	9780	10	978	3210	2
W1S2	9730	10	973	3290	0
W2S1	6600	6	1100	2860	13
W2S2	6500	6	1080	3050	9
W3S1	5730	5	1146	1830	43
W3S2	5670	5	1134	1590	48

Crop and economic water productivity

The main challenge of the agricultural sector is to produce more food with less water use, which can be achieved by increasing crop water productivity (Kijne *et al.*, 2003). Water is the most limiting factor for agricultural production in many regions, maximizing crop water productivity may be economically more profitable for the farmers than maximizing yield (English and Raja, 1996). For local farming systems, opportunities to improve Sunflower seed yield are mostly associated with management decisions made at planting. Crop water productivity is a key to evaluate deficit irrigation strategies, which is defined as the ratio between marketable yield and volume of water applied or consumed by the crop (Molden *et al.,* 2010). The following equation was used to calculate the crop water productivity (WP):

$$WP\ (kg/m^3) = \text{seed yield (kg/ha)/water applied } (m^3/ha) \quad (1)$$

WP can be achieved by using deficit irrigation strategies. Therefore, in this study higher WP was obtained under mild water stress of 15 days irrigation interval and ranged between 0.36 and 0.49 kg/m^3. Significant differences were detected between the different irrigation treatments and plant spacing interactions. WP recorded its highest values of 0.44 and 0.46 kg/m^3 with both intra-row plant spacings and an irrigation interval of 15 days for the first season and 0.36 kg/m^3 for 10 and 15 days interval with both plant spacings in the second season. While it declined to its lowest level (0.28 kg/m^3) with plant spacing 40 cm and irrigation interval of 20 days in the second season, due to the low yield obtained with a high amount of water applied (Table 5). As a result, irrigation every 20 days led to severe crop suffering during its reproductive periods, which extremely lowered seed yield. The irrigation interval of 15 days (W2) resulted in highest crop water productivity of 0.46 kg/m^3, but did not differ much from the crop water productivity of irrigation every 10 days (W1). Despite increasing the irrigation interval from 10 days to 15 days, no significant impact was observed in seed yield but in crop water productivity it was obvious. Although the yield increased with increases in water use, WP decreased. Under such circumstance, Sunflower is considered as lower sensitive crops to water deficit and it will be attractive crop if the current market prices are increased and the irrigation systems are improved. The impact of water stress on yield related economic productivity may be positive depending upon the irrigation system, yield values and irrigation system performance (Rodrigues and Pereira, 2009). Figure 4 shows the results of calculating WP and economic water productivity (EWP) which are plotted against different treatments for the 2012 and 2013 winter seasons. Higher WP of 0.46 and 0.36 kg/m^3 was obtained in the first and second season under full irrigation (W1) and mild deficit irrigation, while the lower WP was obtained under severe water stress (0.28 kg/m^3).

The same trend was observed in EWP; similarly, highest WP and EWP were obtained from mild water stress of the irrigation interval of 15 days. Higher economic water productivity was obtained from 10 and 15 days irrigation intervals while severe water stress decreased economic water productivity to lower average values of 0.19 and 0.22 US$/m^3. Deficit irrigation increases the water productivity, and therefore, economic water productivity.

Table 5 - Crop water productivity (kg/m^3) and economic water productivity under different treatments for two winter seasons of 2012/13 and 2013/14.

Irrigation/plant spacing treatment	WP (kg/m^3)	EWP (US$/m^3)	WP (kg/m^3)	EWP (US$/m^3)
	2012/2013		*2013/2014*	
W1S1	0.35	0.27	0.34	0.21
W1S2	0.36	0.27	0.36	0.22
W2S1	0.49	0.38	0.36	0.27
W2S2	0.44	0.35	0.33	0.29
W3S1	0.30	0.23	0.32	0.20
W3S2	0.29	0.22	0.28	0.18

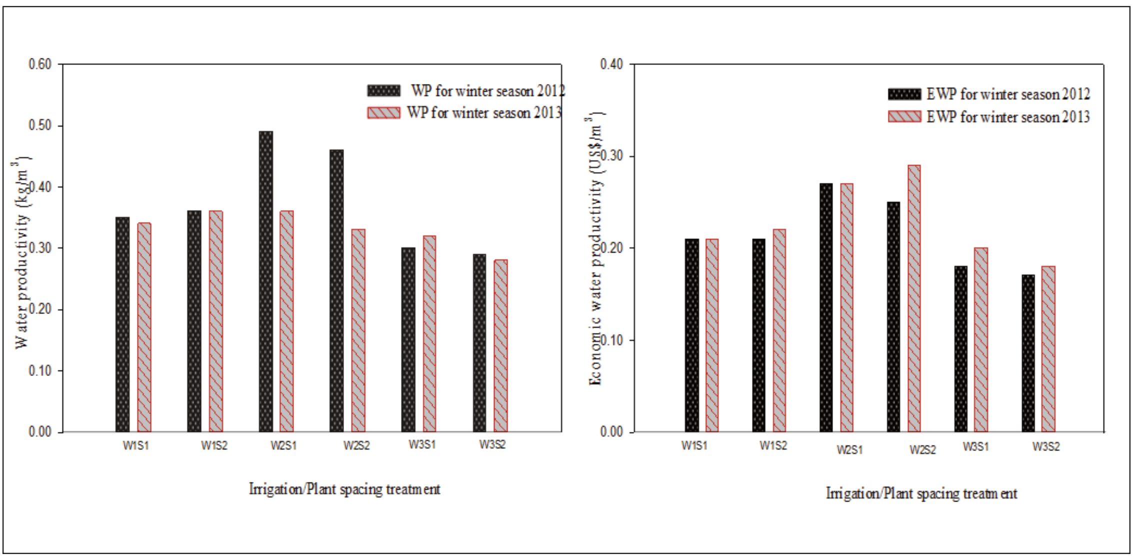

Figure 4 - Crop water productivity (kg/m^3) and economic water productivity for Hysun 33 for two seasons 2012 and 2013.

Conclusion

The results concluded that increasing irrigation intervals from 10 days to 20 days to irrigate Sunflower resulted in a significant decrease in seed yield/ha and yield components as well as in the percentage of oil content. This attributed to the low available soil water in the root zone. The study revealed that irrigating Sunflower every 10 days coupled with 40 cm plant spacing (W1S2) resulted in the highest seed yield followed by W2 while the irrigation interval of 20 days significantly reduced the seed yield irrespective of the within intra-row plant spacing. The highest WP was achieved with both plant spacings when Sunflower was irrigated every 15 days. EWP would be helpful for determining the profitability and productivity of Sunflower under such conditions. Thus, 15 days irrigation interval was recorded the highest level of productivity (0.36-0.46 kg/m^3) in the two seasons. It showed as economic indicator and may be an appropriate tool for assessing impacts of deficit irrigation and water prices. Crop water productivity is an important key when considering irrigation system and water management. On the other hand, crop water productivity can be increased by increasing yield achieved with less water per unit area. In addition, in order to produce more crops with less water, water management strategies and practices need to be considered.

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References

Ali D. Mohammadreza Naderidarbaghshahi, Abdolmajid Rezael., Bahram Majdnasiri., 2013. Effect of Water Deficiency Stress on Yield and Yield Component of sunflower Cultivars in Asfahan. International Journal of Farming and Allied Sciemces 2:1319-1324.

Bashir M. A. A. M., Younis M., 2014. Evaluation of full and deficit irrigation on two Sunflower hybrids under semi-arid environment of Gezira, Sudan. journal of Agri-Food and Applied Sciences 2:53-59.

Doorenbos J. A., Kassam. A. H., 1979. Yield Response to water Irrigation and Drainage Paper No.33, FAO,Italy: pp 193.

El Naim A. M., Ahmed M. F., 2010. Effect of Irrigation Intervals and Inter-row Spacing on Yield, Yields Components and Water Use Efficiency of Sunflower (Helianthus annuus L). Journal of Applied Sciences Research 6.

English M., Raja S. N., 1996. Perspectives on Deficit Irrigation. agric Water

Management 32:1-14.
Erdem T., Delibas L., 2003. Yield response of sunflower to water stress under Tekirdag conditions. Helia 26:149-157.
Ghani A., Hussain M., Qureshi M. S., 2000. Effect of different irrigation regimens on the growth and yield of sunflower. International Journal of Agriculture and Biology 2:334-335.
Kaya M. D., Kolsarici O., 2011. Seed yield and oil content of some sunflower (Helianthus annuus L.) hybrids irrigated at different growth stages. African Journal of Biotechnology 10:4591-4595.
Kazemeini S. A., Edalat M., Shekoofa A., 2009. Interaction effects of deficit irrigation and row spacing on sunflower (Helianthus annuus L.) growth, seed yield and oil yield. Afr. J. Agri. Res 4:1165-1170.
Khalifa F. (1981) Some factors influencing the development of sunflower (Helianthus annuus L.) under dry farming systems in Sudan. Journal of Agricultural Science, Cambridge 97:45-53.
Kijne J. W., Barker R., Molden D. J., 2003. Water productivity in agriculture [electronic resource]: limits and opportunities for improvement CABI.
Molden D., Oweis T., Steduto P., Bindraban P., Hanjra M. A., Kijne J., 2010. Improving agricultural water productivity: between optimism and caution. Agricultural Water Management 97:528-535.
Nazariyan G., Mehrpooyan M., Khiyavi M., 2009. Study of effects of drought stress on yield and yield components of four sunflower cultivars in Zanjan, Iran. 9نشريه علمی اکوفيزيولوژي گياهي
Razi H., Assad M. T., 1999. Comparison of selection criteria in normal and limited irrigation in sunflower. Euphytica 105:83-90. DOI: 10.1023/a:1003472212917.
Rodrigues G. C., Pereira L. S., 2009. Assessing economic impacts of deficit irrigation as related to water productivity and water costs. Biosystems engineering 103:536-551.
Sedghi M., Sharifi R. S., Namvar A., Khandan-e-Bejandi T., Molaei P., 2008. Responses of sunflower yield and grain filling period to plant density and weed interference. Research Journal of Biological Sciences 3:1048-1053.
Unger P. W., 1983. Irrigation effect on sunflower growth, development, and water use. Field Crops Research 7:181-194.