The Effect of Water Stress on Seeds Production and Fiber Yield of Flax Crop Grown in Clay Soil

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ABSTRACT

A Field experiment was conducted Experimental Station Etay El-Baroud in during two successive seasons to study the effect of four irrigation rates on growth and production of three flax genotypes (Sakha 6, Giza 11, and Giza 12). Plant growth parameters, straw yield, fiber yield and seed yield were measured and four surface irrigation rates (40% of ET_o, 60% of ET_o, 80% of ET_o and 100% of ET_o) were applied in clay soil. Results showed that the irrigation treatment had a non-significant in plant height, technical stem length, length of fruiting, number of fruiting, number of capsules per plant, number of seeds in capsules of flax in two seasons. Meanwhile length of the fruiting zone, number of seed per plant, biological yield, straw yield, seed yield and fiber yield were significant difference with irrigation rates. Water stress adversely affected theses parameters. Flax cultivars differ in flax plant growth and yield component parameters. The interaction between water stress and flax cultivars revealed that Sakha 6 was the superiority tolerant flax genotypes in comparison with Giza 11 and Giza 12. The average applied irrigation water AIW throw two seasons were 1018, 1526, 2035 and 2544 m3/fed for 40, 60, 80 and 100% ETo irrigation treatments, respectively. The irrigation water productivity (IWP) was increasing with decreasing applied irrigation water. The highest value in IWP of straw yield was in Sakha 6 under 40 % ETo while the lowest was Giza 12 under fully irrigated. The highest value of seed IWP were in Giza 11 and Giza 12. It could be recommended that planting of Giza 11 to obtain highest seed yields and Giza 12 to obtain highest fiber yields and save more water. The highest value of fiber IWP was in Giza 12, only. It concluded that flax genotypes differed in its growth and yield components under water stress conditions.

Keywords: water stress; flax; *Linum usitatissimum* L; water productivity; Fiber yield.

INTRODUCTION

Flax (*Linum usitatissimum* L.) is a winter crop, flax is a prehistoric crop that used by ancient Egyptian to make clothes, paper, fishnet, and healthy eating and extract oil (Wu *et al.,* 2008). Abd- ElMohsen *et al.,* (2013) found that flax is the second fiber crop after cotton which is important in industry. Now there is demand for natural fibers more than cotton so the area for flax cultivation is increasing. Also flax seed has health benefits where it is rich in alpha-linolenic acid (ALA), which beneficial for heart diseases, breast and prostate cancer, and other health problems (Chen *et al.,* 2006). The Ministry of Agriculture in Egypt aims to increase the area of flax from 6000 feddan in 2021 to 10.000 feddan by 2025. This aim is to increase the production of oil the flax is rich in oil reach to 40% (Bakry *et al.,* 2012) and to obtain high quality flax raw materials to develop textile industry. This increase in agriculture areas needs more water. However, there is a shortage in water availability.

Drought becomes the most environmental stress that adversely affects plant growth and production. Decrease of water availability to flax crop reduces growth parameters. Kariuki *et al.,* (2016) found that subjecting of flax to permanent wilting point decreased leave growth, plant height and dry weight 20-40%. All growth parameters declined when 30-80% of available water was used. Also, Čeh *et al.,* (2020); Abou Gabal and Zaitoun (2015) reported that the environmental factors such as high temperature and water shortage negatively affected seed yield. Rashwan *et al.,* (2020) concluded that flax plants subjected to water stress at any growth stages affect significantly on plant growth and production. Under water stress chlorophyll content was decreased, however, proline and enzymes activities were increased (Rashwan *et al.,* 2019). Flax cultivars differ between each other in tolerant to water stress. Rashwan *et al.,* (2016) studied the effect of irrigation intervals on the straw, seed, oil, fiber yields and quality of flax cultivars. They concluded that the maximum values for main stem diameter, oil yield plant and oil percentage and straw yield per feddan was recorded in Sakha1 while Giza 10 recorded the maximum values for plant height, total fiber percentage and fiber yield per feddan under irrigation intervals 35 days. Leilah *et al.,* (2010) studied the effect of skipping one irrigation at

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different growth stages stem elongation, apical branching, flowering and seed filling on growth and yield for six flax cultivars. Skip-irrigation at stem elongation gave the highest values of stem length, stem diameter and straw yield per feddan. Flax cultivars differed significantly in their straw yield. The interaction between irrigation treatments and flax cultivars differed significantly for number of capsules/plants; number of seeds/plant and seed oil content. The objectives of our research were to: 1- study the effect of water stress/drought stress on flax fiber and seed production for different three flax genotypes (Sakha 6, Giza 11, and Giza 12) grown in clay soil. 2- to increase water productivity to save more water. 3- to find out the most tolerant flax genotypes to water stress.

MATERIALS AND METHODS

The field experiment was carried out at the Experimental station agricultural farm of Etay El-Baroud during two successive winter seasons (2019/2020 – 2020/2021) to study the effect of four irrigation rates on three flax (*Linum usitatissimum* L.) varieties in clay soil. The experiment design was split plots with three replicates. The irrigation rates were (40, 60, 80 and 100% of ETo) laid on main plots and flax varieties (Sakha 6, Giza 11, and Giza 12) were distributed in the sub-main plots. Planting and harvesting dates were at 11 November 15 April, respectively for the two seasons. The planting was in rows 3 m long and distance between rows was 20 cm apart and plot area 6 m^2 (Border strip). The seeding rate was (2000 seeds/m^2 – mainly 75 kg/fed). All agricultural practices were applied according to the recommendations of the Egyptian Ministry of agriculture and Land Reclamation for flax crop in this area. Soil samples were collected from experimental site to determine physical and chemical analysis before planting. All results and characteristics of analysis according to FAO (1970) and Page *et al.*, (1982) shown in (Table 1). The field capacity and permanent wilting point were measured by pressure membrane according to Israelsen and Hansen (1962). The average field capacity and permanent wilting point were 36% and 17.4%, respectively. The bulk density was 1.05 gm/cm^3.

Monthly means of some meteorological data during the period of growing seasons were collected from meteorological station at Etay El-Baroud Agricultural Research Station and used to calculate reference evapotranspiration (ET_o) values according to *Allen et al.*, (1998) (Table 2).

Calculation of Applied irrigation water (AIW)

The amount of applied irrigation water was measured by a flow meter and was calculated according to Vermeiren *et al.*, (1984) as follows:

$$AIW = \frac{ETc}{Ea}$$

$$ETc = ETo * Kc$$

Where, AIW is applied irrigation water (mm day^{-1}), ETc is crop evapotranspiration, ET_o is a reference evapotranspiration, Kc is the crop coefficient and E_a is irrigation efficiency (60% for surface irrigation). Calculating of the amounts of applied water in both seasons with irrigation rates were presented in table (3).

Irrigation water productivity (IWP)

The irrigation water productivity (IWP, kg/m^3) was calculated according to Jensen (1983) as follows:

$$IWP = \frac{Ya}{AW}$$

Where, Y_a is the seed yield of various treatments (kg ha^{-1}), and AW is seasonal applied water (m^3ha^{-1}).

Yield and yield component of flax:

After harvesting, the following characters were recorded on a random sample of ten plants from each plot:

1. Plant height
2. Technical stem of flax plant
3. The length of the fruiting zone
4. The number of capsules per plant
5. The number of seeds per plant
6. The number of seeds per plant
7. Weight of the whole plant or biological crop (kg/plot)
8. Weight of seeds per plot (kg/border)
9. Fiber weight

Statistical analyses

The data were analyzed by statistical analysis of variance according to method described by Snedecor and Cochran (1982). Bartlet's equation was applied and the combined analysis of the two seasons was done according to the method Gomez and Gomez (1984) using GenStat 18 (Payne *et al.*, 2017). Statistical analysis was done by ANOVA and LSD at 5% probability.

RESULTS AND DISCUSSION

Table (4) showed mean values of flax growth parameters in two successive winter growing seasons as related to applied water and flax genotypes. There was no significant difference between irrigation rates in two seasons and different flax growth parameters with the except it was a low significant in the length of fruiting zone at the season 2020/2021. The same result for plant length was observed by Kariuki *et al.*, (2016). There was a significant difference between flax genotypes in plant length, Technical stem, length of fruiting and number of fruiting in two seasons where Sakha 6 gave the highest values for those parameters in two seasons.

Table 1. Physical and chemical properties of the soil at the study site before planting.

Depth (cm)	Physical parameters				Chemical analysis									
					pH	EC dSm^{-1}	Cations				Anions			
	Sand (%)	Silt (%)	Clay (%)	Textural Class			K^+	Na^+	Ca^{2+}	Mg^{2+}	CO_3	HCO_3	Cl	SO_4
							meq l^{-1}							
0 – 30	7.09	32.50	60.42	Clay	8.12	1.93	1.56	8.17	6.12	3.54	-	0.85	10.11	8.43
30 – 60	10.7	32.10	57.20	Clay	8.47	2.35	1.1	12.1	6.3	4.1	-	9.8	11.8	2.6

Table 2. Mean of monthly values for some meteorological data and ET_o for the area under investigation during first and second growing seasons.

Month	Minimum Temp.(ºC)	Maximum Temp. (ºC)	Relative Humidity (%)	Wind Speed (m s^{-1})	Total rainfall (mm)	ET_o (mm day^{-1})	Maximum Temp. (ºC)	Minimum Temp. (ºC)	Relative Humidity (%)	Wind Speed (m s^{-1})	Total rainfall (mm)	ET_o (mm day^{-1})
	2019/2020						2020/2021					
November	15.27	28.60	58.07	3.30	0.10	4.37	14.63	24.97	64.57	3.65	18.40	3.77
December	10.53	21.51	65.22	3.68	16.60	3.06	11.14	23.03	63.80	3.12	1.10	3.01
January	8.16	18.30	70.15	3.72	26.60	2.55	9.21	21.80	63.98	3.38	4.60	3.03
February	8.46	20.68	67.65	3.73	20.80	3.24	9.11	22.25	64.93	3.56	27.50	3.57
March	9.94	24.58	62.49	4.79	62.20	4.83	9.97	23.45	63.22	4.43	70.9	4.50
April	12.35	27.18	60.62	4.39	8.90	5.67	11.63	29.74	53.96	4.26	0.40	6.36
Total					135.20						122.90	

Table 3. Applied Irrigation Water and irrigation rates for two successive seasons.

S/N	stages	days	ET_o, mm	AIW, mm	100% AIW, m^3/fed	80% AIW, m^3/fed	60% AIW, m^3/fed	40% AIW, m^3/fed
SEASON 1								
1	Initial	25	94.84	158.07	663.88	531.10	398.33	265.55
2	Develop	35	99.45	165.75	696.15	556.92	417.69	278.46
3	Mid	50	158.91	264.85	1112.37	889.90	667.42	444.95
4	Late	36	142.59	237.65	998.13	798.50	598.88	319.40
Total		146	495.79	826.32	3470.53	2776.42	2082.32	1308.36
SEASON 2								
S/N	**stages**	**days**	**ET_o, mm**	**AIW, mm**	**100% AIW, m^3/fed**	**80% AIW, m^3/fed**	**60% AIW, m^3/fed**	**40% AIW, m^3/fed**
1	Initial	25	90.45	158.07	663.88	531.10	398.33	265.55
2	Develop	35	105.53	165.75	696.15	556.92	417.69	278.46
3	Mid	50	166.62	264.85	1112.37	889.90	667.42	444.95
4	Late	46	171.30	237.65	998.13	798.50	598.88	399.25
Total		156	533.90	826.32	3470.53	2776.42	2082.32	1388.21

Table 4. Means of Flax growth parameters in two growing seasons as affected by irrigation amounts and flax varieties.

Treatment		Plant Height (cm)			Technical Stem (cm)			Length of the fruiting zone (cm)			Number of the fruiting zone		
		S1	S2	Mean	S1	S2	Mean	S1	S2	Mean	S1	S2	Mean
I_1		119.5^{a}	119.5^{a}	119.5	16.5^{a}	16.5^{a}	16.5	16.5^{a}	16.9^{ab}	16.7	6.4^{a}	6.6^{a}	6.5
I_2		119.6^{a}	120.0^{a}	119.8	18.2^{a}	18.2^{a}	18.2	18.2^{a}	18.2^{a}	18.2	6.3^{a}	6.2^{a}	6.25
I_3		120.0^{a}	120.7^{a}	120.35	17.7^{a}	17.7^{a}	17.7	17.7^{a}	15.6^{a}	16.65	6.2^{a}	6.2^{a}	6.2
I_4		119.0^{a}	119.3^{a}	119.15	18.0^{a}	18.0^{a}	18.0	18.0^{a}	17.3^{ab}	17.65	6.5^{a}	6.3^{a}	6.4
Mean		119.53	119.88	119.70	17.60	17.60	17.60	17.60	17.00	17.30	6.35	6.33	6.34
LSD									3.55				
V1		120.8^{b}	120.9^{b}	120.85	108.2^{b}	106.3^{b}	107.25	18.39^{a}	14.66^{a}	16.53	6.59^{b}	6.482^{b}	6.538
V2		118.2^{a}	119.1^{a}	118.65	99.8^{a}	100^{a}	99.9	16.84^{a}	18.62^{b}	17.73	6.65^{b}	6.512^{b}	6.581
V3		119.7^{b}	119.7^{ab}	119.7	102.6^{a}	102.1^{a}	102.35	17.5^{a}	17.69^{b}	17.60	5.83^{a}	6.031^{a}	5.931
Mean		119.57	119.90	119.73	103.53	102.80	103.17	17.58	16.99	17.28	6.36	6.34	6.35
LSD		1.5	1.6		4.45	3.46		6.29	2.55		0.41	0.24	
I_1	V1	121.1	120.5	120.80	105.2	103.0	104.10	15.75	17.75	16.75	6.9	6.93	6.92
	V2	117.6	119.0	118.3	95.0	97.8	96.4	15.38	15.50	15.44	6.53	6.55	6.54
	V3	118.8	119.5	119.15	102.4	102.0	102.20	18.25	17.50	17.88	5.83	6.38	6.11
I_2	V1	120.9	121.0	120.95	101.5	102.1	101.80	22.00	18.87	20.44	6.28	6.25	6.27
	V2	117.6	119.0	118.30	106.0	102.8	104.40	15.12	17.00	16.06	6.65	6.45	6.55
	V3	120.4	120.0	120.20	102.1	101.2	101.65	17.38	18.75	18.07	5.98	5.85	5.92
I_3	V1	121.0	122.5	121.75	121.0	114.6	117.80	20.55	8.00	14.28	6.43	6.41	6.42
	V2	117.5	119.5	118.5	99.9	100	99.95	17.12	22.00	19.56	6.50	6.55	6.53
	V3	120.0	120.2	120.10	104.9	103.0	103.95	15.38	16.75	16.07	5.73	5.78	5.76
I_4	V1	120.0	119.5	119.75	105.1	105.5	105.30	15.25	14.00	14.63	6.78	6.35	6.57
	V2	117.5	119.5	118.50	98.1	99.5	98.80	19.75	20.00	19.88	6.93	6.5	6.72
	V3	119.5	119.0	119.25	101.0	102.0	101.50	19.00	17.75	18.38	5.80	6.13	5.97
Mean		119.6	119.9	119.71	103.5	102.79	103.15	17.58	16.99	17.28	6.36	6.34	6.35
LSD		3.12	2.86		6.15	4.42		2.81	4.01		0.92	0.61	

I_1 = 40% ETo, I_2 = 60% ETo, I_3= 80% ETo and I_4= 100% ETo, V1 = Sakha 6 , V2= Giza 11 and V3= Giza 12

The interactions between water rates and flax genotypes showed that the water levels 80% ET_o in Sakha 6 obtained the highest values (121.75 cm. 117.8 cm) for plant height and technical stem length respectively, while Giza 11 gave the lowest values (118.3 cm, 96.4 cm). Nematallahi and Saeidi (2011) found that flax genotypes differ in their response to water and environmental stress. Some genotypes were drought tolerant and others were sensitive.

Table (5) displayed the means of number of capsules per plant, number of seeds in capsules and number of seed per plant. There was non-significant difference between irrigation treatments and those parameters in both seasons except number of seed per plant. The highest numbers of seeds in 80% ET_o were 70.72 and 72.5 in two seasons respectively. Where the lowest values in 40% ET_o was 57.94 and 57.3 in two seasons respectively. Reduction of irrigation rate from 80% ET_o to 40% ET_o decreased number of seeds per plant. Sadak and Bakry (2020) showed that water stress decease flax seed/plant through adversely affect metabolism activity in plant, growth parameters and yield components.

Also, there were non-significant difference between flax varieties except in number of capsules per plant in season 2 and number of seeds per capsules in season 1. Statistical results showed that Sakha 6 gave the highest values for both characters. These results are in agreement with those obtained by El-Borhamy *et al.*, (2022). The interaction between irrigation rates and flax varieties revealed that at water levels 80 % ET_0 and Sakha 6 gave the highest value (15.94 number of capsules/plant, 5.92 number of seed/plant and 75.6 number of seeds/plant) whereas water levels 40 % ET_0 Giza 11 gave the lowest values (11.5 number of capsules/plant, 4.35 number of seed/plant and 54.3 number of seeds/plant). Sakha 6 at 40 % ET_0 water levels is the superiority genotypes in comparison with Giza 11 and Giza 12.

Table 5. The effect of irrigation rates and varieties on number of capsules, number of seeds in capsules and number of seed per plant for Flax crop in two seasons

Treatment		Number of Capsules/plant			Number of Seeds in Capsules			Number of Seeds / Plant		
		S1	S2	Mean	S1	S2	Mean	S1	S2	Mean
I_1		13.2 [a]	12.1 [a]	12.65	4.65 [a]	4.65 [a]	4.65	57.94 [c]	57.3 [a]	57.62
I_2		14.3 [a]	14.0 [a]	14.15	4.792 [a]	4.792 [a]	4.792	62.58 [ab]	58.78[ab]	60.68
I_3		14.7 [a]	14.0 [a]	14.35	5.167 [a]	5.167 [a]	5.17	70.72 [c]	72.5 [c]	71.61
I_4		13.3 [a]	12.7 [a]	13.00	5.067 [a]	5.067 [a]	5.07	65.44 [bc]	65.39 [bc]	65.42
Mean		13.88	13.20	13.54	4.92	4.92	4.92	64.17	63.49	63.83
LSD		3.4	1.93		0.73	0.72		9	9	
V1		14.96 [a]	13.7 [b]	14.33	5.05 [ab]	4.913 [a]	4.9815	65.99 [a]	65.29 [a]	65.64
V2		13.59 [a]	13.41 [b]	13.50	4.562 [a]	4.656 [a]	4.609	62.05 [a]	61.49 [a]	61.77
V3		13.1 [a]	12.46 [a]	12.78	5.144 [b]	4.994 [a]	5.069	64.47 [a]	63.7 [a]	64.09
Mean		13.88	13.19	13.54	4.92	4.85	4.89	64.17	63.49	63.83
LSD		2.47	0.91		0.58	0.44		6.0	6.0	
I_1	V1	12.45	11.9	12.18	4.65	4.6	4.63	55.4	55	55.20
	V2	11.33	11.67	11.50	4.25	4.45	4.35	54.7	54.3	54.50
	V3	13.25	13.17	13.21	5.45	5.1	5.28	61	57.82	59.41
I_2	V1	16.15	14.97	15.56	4.55	4.65	4.60	64.2	60.9	62.55
	V2	15.5	15.37	15.44	4.38	4.5	4.44	62.6	57.62	60.11
	V3	13.93	11.3	12.62	5.05	4.75	4.90	63.7	62.6	63.15
I_3	V1	17.07	14.8	15.94	6	5.83	5.92	74.7	76.5	75.60
	V2	13.73	13.57	13.65	4.43	4.73	4.58	67.9	70.5	69.20
	V3	13.18	13.5	13.34	5.08	5.28	5.18	69.6	70.5	70.05
I_4	V1	14.15	13.12	13.64	5	4.58	4.79	69.7	68.75	69.23
	V2	12.88	12.52	12.70	5.2	4.95	5.08	63	63.55	63.28
	V3	13.97	13.37	13.67	5	4.85	4.93	63.6	63.87	63.74
Mean		13.96	13.27	13.62	4.92	4.86	4.89	64.18	63.49	63.83
LSD		4.79	2.46		1.04	1.0		24.22	21.8	

I_1 = 40% ETo, I_2 = 60% ETo, I_3= 80% ETo and I_4= 100% ETo, V1 = Sakha 6, V2= Giza 11 and V3= Giza 12

Result given in table (6) showed that there was a significant difference between all irrigation treatments and biological, straw yields except season two. The highest biological and straw yields were 1951.25 and 1616 kg/feddan, respectively at 60% ET_0 whereas the lowest values were 1298.15 and 1020.6 Kg/feddan at 40% ET_0. The reduction in biological and straw yields could be due to plant responses to water deficit. While water deficit affects directly on plant photosynthesis then plant dry matter production. The same results of reduction in both straw and biological yield of flax with reduction in irrigation were found by Rashwan et al. (2016). Table (6) also, found that there was non-significant between all flax genotypes in biological and straw yields. The interaction between irrigation rates and flax varieties showed that the highest value for the biological yield was 2310 Kg/fed in season two for Sakha 6 and the highest straw yield was 1977.5 Kg/fed also in Sakha 6 in the second season under irrigation rates 100% $ET_{0.}$ Whereas the lowest for the biological yield was 1120 Kg/feddan in season two for Giza 12 and the lowest straw yield was 822.5 Kg/feddan also in Giza 12 in the second season under irrigation rates 40% $ET_{0.}$ As we discussed above the water stress decreased flax yield components. At water level 40% ET_0 Sakha 6 was the superiority tolerant flax genotypes in comparison with Giza 11 and Giza 12. The means of biological and straw yield were 1391.3 Kg/Fed and 1181.3 Kg/Fed respectively. Flax genotypes differ in their response to water stress due to genetic factors are in agreement with results obtained El-Borhamy et al. (2017) and Torky (2020).

Table (7) presented the effect of different in the effect of irrigation rates on flax seed and fiber yields. There were also a significant difference between irrigation rates in two seasons on seed and fiber yields except seed yield in season 2. There was a decrease in both weights with decreasing water levels until 80 % ET_o.

Table 6. The effect of irrigation rates and varieties in biological, straw and seeds yield of Flax crop in two seasons.

Treat.		Biological yield (kg/fed)			Straw yield (kg/fed)		
		S1	S2	Mean	S1	S2	Mean
I_1		1324.4 ^{a}	1271.9 ^{b}	1298.15	1020.6 ^{a}	1020.6 ^{a}	1020.6
I_2		1913.1 ^{b}	1989.4 ^{b}	1951.25	1534.4 ^{b}	1697.5 ^{b}	1616.0
I_3		1764.7 ^{b}	1913.1 ^{b}	1838.9	1271.9 ^{ab}	1656.9 ^{b}	1464.4
I_4		1592.5 ^{ab}	1971.9 ^{b}	1782.2	1114.4 ^{a}	1738.1 ^{b}	1426.3
Mean		1648.675	1786.575	1717.625	1235.325	1528.275	1381.8
LSD		346.5	267.4		385	273	
V1		1670.9 ^{a}	1894.2 ^{a}	1782.55	1312.5 ^{a}	1614.2 ^{a}	1463.4
V2		1701.7 ^{a}	1759.1 ^{a}	1730.4	1225 ^{a}	1544.2 ^{a}	1384.6
V3		1572.9 ^{a}	1706.6 ^{a}	1639.75	1168.3 ^{a}	1426.6 ^{a}	1297.45
Mean		1648.5	1786.6333	1717.5667	1235.2667	1528.3333	1381.8
LSD		263.2	303.1		350	336	
I_1	V1	1382.5	1400.0	1391.3	1120.0	1207.5	1163.8
	V2	1347.5	1295.0	1321.3	980.0	1032.5	1006.3
	V3	1242.5	1120.0	1181.3	962.5	822.5	892.5
I_2	V1	1750.0	1750.0	1750.0	1697.5	1435.0	1566.3
	V2	2047.5	2082.5	2065.0	1417.5	1785.0	1601.3
	V3	1942.5	2135.0	2038.8	1487.5	1872.5	1680.0
I_3	V1	1767.5	2117.5	1942.5	1120.0	1837.5	1478.8
	V2	1837.5	1890.0	1863.8	1452.5	1645.0	1548.8
	V3	1688.4	1732.5	1710.5	1242.5	1487.5	1365.0
I_4	V1	1785.0	2310.0	2047.5	1312.5	1977.5	1645.0
	V2	1575.0	1767.5	1671.3	1050.0	1715.0	1382.5
	V3	1417.5	1837.5	1627.5	980.0	1522.5	1251.3
Mean		1648.6	1786.5	1717.5	1235.2	1528.3	532.0
LSD		534.8	454.8		581	483	

I_1 = 40% ETo, I_2 = 60% ETo, I_3= 80% ETo and I_4= 100% ETo, V1 = Sakha 6, V2 = Giza 11 and V3= Giza 12

Table 7. The effect of irrigation rates and varieties in seeds and fiber yields of Flax crop in two seasons.

Treat.		Seeds yield (kg/fed)			Fiber yield (kg/fed)		
		S1	**S2**	**Mean**	**S1**	**S2**	**Mean**
I_1		303.3 [a]	250.8 [a]	277.05	345.90 [d]	334.50 [c]	340.20
I_2		460.8 [b]	297.5 [a]	379.15	377.70 [c]	358.50 [b]	368.10
I_3		551.3 [c]	280.0 [a]	415.65	426.80 [a]	432.80 [a]	429.80
I_4		466.7 [bc]	303.3 [a]	385	412.90 [b]	428.50 [a]	420.70
Mean		445.52	282.9	364.21	390.83	389.70	390.26
LSD		89.6	68.6		10.45	14.84	
V1		433.2 [a]	280.0 [a]	356.6	364.70 [c]	365.10 [b]	364.90
V2		494.4 a	266.8 [a]	380.6	390.60 [b]	397.70 [a]	394.15
V3		409.1 [a]	301.8 [a]	355.45	417.20 [a]	402.90 [a]	410.05
Mean		445.57	282.87	364.22	390.83	388.57	389.70
LSD		145.6	74.9		6.25	13.01	
	V1	262.5	192.5	227.5	311.50	304.50	308.00
I_1	V2	367.5	262.5	315.0	361.20	341.20	351.20
	V3	280.0	297.5	288.8	364.90	357.90	361.40
	V1	385.0	315.0	350.0	366.60	343.00	354.80
I_2	V2	525.0	297.5	411.3	378.00	364.90	371.45
	V3	472.5	280.0	376.3	388.50	367.50	378.00
	V1	647.5	280.0	463.8	409.00	408.60	408.80
I_3	V2	560.0	245.0	402.5	414.40	444.50	429.45
	V3	446.3	315.0	380.7	457.10	445.40	451.25
	V1	437.5	332.5	385.0	371.50	404.20	387.85
I_4	V2	525.0	262.5	393.8	408.80	440.10	424.45
	V3	437.5	315.0	376.3	458.50	441.00	449.75
Mean		445.5	282.9	150.1	390.83	388.57	389.70
LSD		184.6	115.5		14.35	18.89	

I_1 = 40% ET_o, I_2 = 60% ET_o, I_3= 80% ET_o and I_4= 100% ET_o, V1 = Sakha 6, V2 = Giza 11 and V3= Giza 12

The lowest value in seed and fiber weights were observed in irrigation rates 40 % ET_0 were 277.05 Kg/fed and 340.20 Kg/fed for the two seasons respectively. Also, we noticed that there was non-significant between irrigation rates 80 % ET_0 and 100 % ET_0 except in seed and fiber weights in the first season. For flax genotypes there was non-significant in seed weights in the two seasons but for fiber weights there was a significant difference in the first season for three genotypes while in the second season there was a significant different between Sakha 6 with Giza 11 and Giza12. Giza 12 gave the highest fiber weights 417.2 Kg/fed and 402.9 Kg/fed for successive seasons.

Total applied irrigation water (AIW):

The data depicted in Table (8) that showed the applied irrigation water (AIW) through four plant stages under water applied rates to flax crop in two successive growing winter seasons. The applied irrigation water increased plant growth until maturity, then start decreasing as plant physiological characters. The total applied irrigation water was 979.9, 1469.9, 1959.8 and 2449.8 m^3/fed in the first season, and 1055.2, 1582.9, 2110.5 and 2638.1 m^3/fed in the second one under I1, I2, I3 and I4 water treatments, respectively. These results were in agreement with Bakry et al. (2019).

Irrigation Water Productivity (IWP):

The data in total (9) represented the effect of irrigation rates and varieties on irrigation water productivity (IWP) of straw, seeds and fiber yields of flax crop. The results clearly indicated that IWP increased with decreasing quantities of water under clay soil under border strip irrigation method. For the IWP straw yield the highest values were 1.14 kg/m^3 for Sakha 6 under high stress water 40% ET_o, meanwhile the lowest values were 0.40, 0.58 kg/m^3 AIW for Giza 11 and Giza 12 under Full Irrigation 100% ET_o. Regarded to IWP seeds yield the highest values were 0.38 and 0.28 kg/m^3 for Giza 11 and Giza 12 with low Irrigation applied. These results were in agreement with El-Borhamy et al. (2022). The lowest IWP were with full Irrigation it was 0.18 and 0.10 kg/m^3 under Giza 12 and Giza 11 with full irrigation treatment (100% of ETo).

Table 8. Applied irrigation water in two seasons for Fax crop.

Seasons	treatments	AIW of all stages Initial		Develop		Mid		Late		Total	
		mm	m^3/fed	mm	m^3/fed	mm	m^3/fed	mm	m^3/fed	mm	m^3/fed
S1	I1	44.6	187.5	46.8	196.6	74.8	314.1	67.1	281.8	233.3	979.9
	I2	66.9	281.2	70.2	294.8	112.2	471.1	100.7	422.7	350.0	1469.9
	I3	89.3	374.9	93.6	393.1	149.6	628.2	134.2	563.6	466.6	1959.8
	I4	111.6	468.6	117.0	491.4	187.0	785.2	167.8	704.6	583.3	2449.8
S2	I1	42.6	178.8	49.7	208.6	78.4	329.3	80.6	338.6	251.2	1055.2
	I2	63.8	268.2	74.5	312.9	117.6	494.0	120.9	507.9	376.9	1582.9
	I3	85.1	357.5	99.3	417.2	156.8	658.6	161.2	677.1	502.5	2110.5
	I4	106.4	446.9	124.2	521.4	196.0	823.3	201.5	846.4	628.1	2638.1

I_1 = 40% ETo, I_2 = 60% ETo, I_3= 80% ETo and I_4= 100% ETo

Table 9. The effect of irrigation treatments and Flax crop varieties on irrigation water productivity (IWP).

Treat.	Varieties	IWP, straw yield (kg/m^3)			IWP, Seeds yield (kg/m^3)			IWP, Fiber yield (kg/m^3)		
		S1	S2	Mean	S1	S2	Mean	S1	S2	Mean
I_1	V1	1.14	1.14	1.14	0.27	0.18	0.23	0.32	0.29	0.30
	V2	1.00	0.98	0.99	0.38	0.25	0.31	0.37	0.32	0.35
	V3	0.98	0.78	0.88	0.29	0.28	0.28	0.37	0.34	0.36
	Mean	1.04	0.97	1.00	0.31	0.24	0.27	0.35	0.32	0.33
I_2	V1	1.15	0.91	1.03	0.26	0.20	0.23	0.25	0.22	0.23
	V2	0.96	1.13	1.05	0.36	0.19	0.27	0.26	0.23	0.24
	V3	1.01	1.18	1.10	0.32	0.18	0.25	0.26	0.23	0.25
	Mean	1.04	1.07	1.06	0.31	0.19	0.25	0.26	0.23	0.24
I_3	V1	0.57	0.87	0.72	0.33	0.13	0.23	0.21	0.19	0.20
	V2	0.74	0.78	0.76	0.29	0.12	0.20	0.21	0.21	0.21
	V3	0.63	0.70	0.67	0.23	0.15	0.19	0.23	0.21	0.22
	Mean	0.65	0.78	0.72	0.28	0.13	0.21	0.22	0.21	0.21
I_4	V1	0.54	0.75	0.64	0.18	0.13	0.15	0.15	0.15	0.15
	V2	0.43	0.65	0.54	0.21	0.10	0.16	0.17	0.17	0.17
	V3	0.40	0.58	0.49	0.18	0.12	0.15	0.19	0.17	0.18
	Mean	0.45	0.66	0.56	0.19	0.11	0.15	0.17	0.17	0.17

I_1 = 40% ETo, I_2 = 60% ETo, I_3= 80% ETo and I_4= 100% ETo, V1 = Sakha 6 , V2= Giza 11 and V3= Giza 12

Whereas the highest IWP fiber yield was 0.37 and 0.34 kg/m^3 AIW for Giza 12 in the first and second seasons, respectively. While the lowest AIW value was 0.15 kg/m^3 in Sakha 6 and full Irrigation. These results are matching with findings of Jat *et al.*, (2018) and Bakry et al. (2019).

CONCLUSION

Deficit irrigation is adversely affecting some flax growth and yield parameters. Irrigation water productivity (IWP) revealed that Giza 11 and Giza 12 recorded the highest value for fiber yield and Giza 12 for seed production under stressed conditions. Flax genotypes/ cultivars differ in drought tolerant where Sakha 6 was the superior one. It could be concluded that Giza 11 is the recommended genotype for seed production and Giza 12 is the recommended genotype for fiber production besides saving more water.

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الملخص العربي

تأثير الإجهاد المائي على إنتاج البذوروالألياف لمحصول الكتان المزروع في تربة طينية

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أجريت تجربة حقلية خلال موسمين متتاليين لدراسة تأثير أربع معدلات ري على ثلاثة اصناف من الكتان (سخا ٦ وجيزة ١١ وجيزة ١٢) ، وتم قياس صفات نمو النبات ومحصول القش ومحصول الألياف وحاصل البذور في التربة الطينية. تم تطبيق أربع معدلات للري (٤٠ و٦٠ و٨٠ و١٠٠% من البخر نتح المرجعي) باستخدام الري السطحي. أظهرت النتائج عدم وجود معنوية بين معدلات الري والطول الكلي والطول الفعال وطول المنطقة الثمرية وعدد الأزهار وعدد الكبسولات للنبات وعدد البذور في كبسولات الكتان في الموسمين. في حين أن طول منطقة الإثمار وعدد البذور للنبات والمحصول البيولوجي للنبات ومحصول القش للنبات ومحصول البذور للنبات ومحصول الألياف للنبات كان لهما فرق معنوي بين معدلات الري. أثر الإجهاد المائي سلبا على هذه الصفات. تختلف أصناف الكتان في النمو ومكونات المحصول. أظهر التفاعل بين معاملات الري وأصناف الكتان أن سخا ٦ كانت أفضل التراكيب الوراثية بالمقارنة مع جيزة ١١ وجيزة ١٢. كان متوسط كميات المضافة خلال الموسمين(١٠١٨ و١٥٢٦ و٢٠٣٥ و٢٥٤٤ م^{٣}/الفدان) لمعاملات الري(٤٠ و٦٠ و٨٠ و١٠٠%) من البخر نتح المرجعي. كانت إنتاجية مياه الري (IWP) تزداد مع تناقص كميات المياه. أعلى قيمة في IWP لمحصول القش في سخا ٦ عند ري ٤٠٪ البخر نتح المرجعي وأقلها كانت في جيزة ١٢ تحت الري الكامل، وأعلى قيمة لانتاجية البذور IWP كانت في جيزة ١١ ، وأعلى قيمة لانتاجية الألياف IWP كانت في جيزة ١٢ . لذلك فانه يوصي بزراعة جيزا ١١ لانتاج البذور وجيزا ١٢ لانتاج الالياف بجانب توفير للمياه. وابرزت النتائج إلى أن الانواع الوراثية للكتان اختلفت في نموها ومكونات المحصول تحت ظروف الإجهاد المائي.

الكلمات المفتاحية: الاجهاد المائي، الكتان،الانتاجية المائية، انتاج الألياف.