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EFFECT OF DIFFERENT IRRIGATION TREATMENTS ON YIELD, QUALITY AND WATER USE EFFICIENCY FOR SOME FLAX (*LINUM USITATISSIMUM*, L.) VARIETIES

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ABSTRACT: Two field experiments were carried out at the experimental farm of EL-Gemmiza Agricultural Research Station, EL-Gharbia Governorate, Agricultural Research Center (ARC) Egypt during the two successive seasons of 2019/2020 and 2020/2021 to study yield, quality and water use efficiency of four flax varieties viz., Giza 12, Giza 11, Sakha 6 (local dual purpose type varieties) and Iriana variety (introduced fiber one) as responded to three different irrigation treatments (1, 2 or 3 irrigations) added during growing season after sowing irrigation. A split plot design with four replicates was used in each experiment. Each experiment included 12 treatments, which were a combination of the three irrigation treatments and the four tested flax varieties. The main plots were assigned to the three irrigation treatments. The subplots were devoted to the four tested flax varieties. All the experimental plots received sowing irrigation similarly on the next day of sowing and 1, 2, or 3 irrigations were subsequently added to the plots during the growing seasons. The most important results as the average of the two growing seasons could be summarized as follows:

Significant increases in all straw and seed yield characters were achieved with the third irrigation treatment (sowing irrigation added with three irrigations) followed by the second irrigation treatment (sowing irrigation added with two irrigations), without significant difference between them in most characters. However, the first irrigation treatment (sowing irrigation added with one irrigation) recorded the lowest values for all characters, under study.

Significant varietal differences were observed for all studied characters. Giza 12 variety exceeded significantly all other three tested flax varieties in all straw characters. However, Sakha 6 variety followed by Giza 11 variety surpassed significantly the two other flax varieties i.e., Giza 12 and Iriana in all seed characters. Moreover, the Iriana variety recorded the highest values of fiber yield and quality, without significant differences between the Iriana variety and the Giza 12 variety in the most studied characters.

A significant interaction effect was observed between the three studied irrigation treatments and the four tested flax varieties on straw characters i.e., total plant height, main stem diameter, straw yield fed^{-1}, fiber yield fed^{-1}, total fiber %, and fiber fineness. The highest values of total plant height, main stem diameter, straw yield fed^{-1}, fiber yield fed^{-1}, and total fiber % were obtained from the Giza 12 variety when irrigated with three irrigations adding with sowing irrigation. However, the finest fibers were recorded for the Iriana variety when irrigated by applying three irrigations adding with sowing irrigation.

Also, a significant interaction effect was detected for seed characters i.e., number of capsules plant^{-1}, seed yield plant^{-1}, seed yield fed^{-1}, and oil yield fed^{-1}, whereas the highest values of these traits were obtained from the Sakha 6 variety when irrigated with three irrigations adding with sowing irrigation.

Keywords*:* Irrigation treatments, flax varieties, yield, yield components, yield quality and water use efficiency.

INTRODUCTION

Flax is considered one of the most important dual-purpose crops for oil and fiber production in Egypt and in the world, rich in oil (41 %), protein (20 %) and dietary fiber (28 %) (Bakry *et al.*, 2012). Production and processing of fibers

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and linseed reach back into the period of the ancient civilizations, their achievements were the basis for progress until today. The modern flax cultivars were developed regarding the purpose of use that fiber - type – flax or seed - type – flax. Fiber-type – flax is generally higher with fewer lateral branches and has longer fibers in the stem but lower yield of seeds. The intermediate type of flax that combines characteristics of both types is characteristic of indigenous cultivars, which are still preserved in areas with traditional production. Flax cultivated as a dual-purpose crop for fiber and for oil plays a significant role in Egyptian national income. Therefore, great efforts were made to increase the productivity of this crop by growing cultivars with high-yielding ability and by application of improved agronomic practices.

Irrigation is one of the most crucial factors contributing to increased flax productivity. Irrigation water could be considered a limiting factor, which has the greatest role for yield and yield components of flax crops. So, reducing the utilized amount of water will help to solve this problem and will maximize the benefits from the available irrigation water. With respect to irrigation treatments, Chorumale *et al.*, (2001) and Yenpreddiwar *et al.*, (2007) recorded significant increases in the yield attributes, yield, oil content and oil yield of flax with applying two irrigations, one applied at the flowering stage and the other one added at capsule filling stage compared with no irrigation and irrigation at flowering stage only. Also, Sharma *et al.*, (2012) mentioned that_irrigating flax plants at both 30 and 60 days after sowing (DAS) produced the highest values of growth traits compared with irrigation at 30 days after sowing (DAS) only. EL-Shimy *et al.*, (1988) found that irrigation at 25 % available soil moisture depletion resulted insignificant increases in flax straw and seed yields fed^{-1} as compared with irrigation at 75 % available soil moisture depletion. Atta *et al.*, (2007) indicated that 100 % of field capacity followed by 80 % level recorded the highest mean values of straw and seed yield traits, while 60% level recorded the lowest values. Hussein and Omer (2011) mentioned that shortening the irrigation intervals to every 28 days caused significant increases in straw, fiber and seed yield traits compared with the two irrigation intervals *i.e.*, every 35 days or 42 days; except fiber fineness trait which was significantly decreased. Rashwan *et al.*, (2016) observed significant differences among the three irrigation intervals (25, 35, and 45) on all yield traits except oil percentage and concluded that irrigated flax plants every 35 days gave the maximum values for all traits, while irrigation every 45 days gave the minimum values. Concerning flax varieties, significant differences were found between the four tested varieties. The yield of various varieties was studied by many investigators among them EL-Sabbagh *et al.*, (1998), AL-Thabet (2003), Atta *et al.*, (2007), Hussein and Omer (2011), EL-Hariri *et al.*, (2012), Bakry *et al.*, (2012) and Rashwan *et al.*, (2016). The main objectives of this work were to determine the most suitable irrigation requirements for some flax varieties under EL-Gharbia governorate conditions to study their effects on yields of fiber and seed as well as their qualities.

MATERIAL AND METHODS

Two field experiments were conducted during two successive seasons (2019/2020 and 2020/2021) at the experimental farm of EL-Gemmiza Agricultural Research Station, Agriculture Research Center (ARC). The location represents the conditions and circumstances of the Middle Nile Delta region. The soil of the experimental site was clay in texture. Soil samples were collected to determine soil particle size distribution and some chemical properties of the experimental site. The average values of these measurements at soil depth down to 30 cm are presented in Table (1). Bulk density and some hydrodynamic constants of the experimental soil are presented in Table (2). Calculating the amount of irrigation-applied water (IWA) in both seasons with irrigation treatments is presented in Table (3). The pedigree of these varieties is shown in Table (4).

Table 1. Soil particle size distribution and some chemical properties of the experimental site in the 2019/2020 and 2020/2021 seasons.

Particle size distribution						Chemical properties						
season	Coarse sand	Fine sand	Silt	Clay	Texture	O.M	EC	Available N	Available P	Available K	$Caco_3$	pH
	%	%	%	%		(%)	(ds m^{-1})	(mg kg^{-1})			(%)	(1:2.5)
2019/2020	2.95	14.88	31.27	51.50	Clay	1.75	1.15	39.92	19.60	254.16	2.45	7.58
2020/2021	3.15	13.43	34.52	52.08	Clay	1.88	1.20	45.38	21.26	287.55	2.63	8.12

Table 2. Bulk density and some hydrodynamic constants of the experimental soil.

Soil depth (cm)	Bulk density (gcm^{-3})	Field capacity (%, wt./wt.)	Wilting Point (%, wt./wt.)	Available water, mm
0 – 15	1.10	45.60	24.30	21.3
15 – 30	1.20	42.30	22.10	20.2
30 – 45	1.31	39.50	21.00	18.5
45 – 60	1.38	36.90	18.60	18.3
Mean	1.18	41.08	21.50	19.58

Table 3. Amount of supplied water in m^3 fed^{-1} during flax growing seasons 2019/2020 and 2020/2021.

Supplied water	2019/2020			2020/2021		
	I_1	I_2	I_3	I_1	I_2	I_3
Sowing irrigation	425.2	425.2	425.2	402.3	402.3	402.3
1^{St} irrigation	314.5	314.5	314.5	294.8	294.8	294.8
2^{nd} irrigation	-	289.6	289.6	-	244.6	244.6
3^{rd} irrigation	-	-	258.8	-	-	231.4
Total irrigation	739.5	1029.3	1288.1	697.1	941.7	1173.1
Rainfall	176.4	176.4	176.4	126.4	126.4	126.4
Total of water	915.9	1205.7	1464.5	823.5	1068.1	1299.5

Table 4: Classification and pedigree of the four tested flax varieties.

No.	Varieties	Pedigree	Origin
1	Giza 12	S. 2419 X S. 148/6/11	Local Variety
2	Giza 11	Giza 8 X S. 2419/1	Local Variety
3	Sakha 6	Giza 8 X S. 2419/1	Local Variety
4	Iriana	Imported from Holland	Introduction

The four tested flax varieties *i.e.*, Giza 12, Giza 11, Sakha 6 (local varieties) and Iriana (introduced one) were grown under three (I_1, I_2 and I_3) irrigation treatments in the first and the second seasons, respectively. Well, seedbed preparation was done. The experimental plot size was 3.0 meters long and 2.0 meters width occupying an area of 6 m^2. Phosphorus in the form of ordinary superphosphate (15.5 % P_2O_5) and potassium in the form of potassium sulphate (48.5 % K_2O) were applied before sowing at rates of 100 and 50 Kg fed^{-1}, respectively.

Seeds of the four flax varieties were hand drilled in rows, 15 cm apart at a sowing rate of 70 Kg seeds fed^{-1} for the three local varieties (Giza 11, Giza12 and Sakha 6) and 50 Kg seeds fed^{-1} for the introduced one (Iriana Variety). Sowing dates were 3rd and 5th November in the first and second seasons, respectively. Seeds were obtained from Fiber Crops Res, Dept. Field Crops Res. Institute, (ARC). Sowing irrigation was added the next day after sowing as recommended. Weeds were chemically controlled. Nitrogen fertilizer in the form of ammonium nitrate (33.5 % N) was added in two equal doses before the first and the second irrigations at a rate of 45 kg N fed^{-1}. Flax was preceded by rice in the two seasons. All other agricultural practices were applied as recommended for the region except for irrigation water which was applied according to the treatments.

A split plot design with four replications was used, where the three irrigation treatments were allocated in main plots, while the four tested flax varieties were devoted to the subplots. Empty area (2 m) was left as buffer area between all irrigation treatments to eliminate any interfere effect of irrigation water leakage. The treatments were as follows:

A- irrigation treatments (I)

I_1: Sowing irrigation + one irrigation.
I_2: Sowing irrigation + two irrigations.
I_3: Sowing irrigation + three irrigations.

B-Flax varieties

V_1: Giza 12
V_2: Giza 11
V_3: Sakha 6
V_4: Iriana

Data collected

At maturity, ten guarded plants were taken randomly from each subplot to determine the yield components of flax. However, yields of straw, fiber and seed per feddan were calculated from a central area of 2.5 m^2 which was estimated in kg m^{-2} and therefore it was converted to yields of fiber, straw ton fed^{-1} and seed yield (kg fed^{-1}). Seed oil percentage was determined by using the Soxhlet apparatus and using pure petroleum ether as solvent according to A.O.A.C (2000). Oil yield (kg fed^{-1}) was calculated by multiplying seed oil percentage x seed yield fed^{-1}. In addition, soil water relation characters were calculated. Data collected were classified as follows:

I-Yield and yield components

A. Straw yield and its related characters

1. Total plant height (cm): was measured from the soil surface to the highest point of the plant.
2. Technical stem length (cm): was determined from the soil surface to the first branch.
3. Main stem diameter (mm) measured by using buckles.
4. Straw yield $plant^{-1}$ (g).
5. Straw yield fed^{-1} (ton).
6. Fiber yield fed^{-1} (ton).
7. Total fiber percentage: (fiber yield fed^{-1}/straw yield fed^{-1}) X 100
8. Fiber length (cm).
9. Fiber fineness: was estimated according to Radwan and Momtaz 1966 as follows:

N.m = (N X L) / W where N.m metrical number.
N: number of fibers (20 fibers of 10 cm length).
L: length of fibers in mm.
W: weight of fibers in mg.

B. Seed yield and its related characters

1. No. of fruiting branches $plant^{-1}$.
2. No. of capsules $plant^{-1}$.
3. No. of seeds $capsule^{-1}$.
4. Seed index, as measured by 1000-seed weight in grams.
5. Seed yield $plant^{-1}$ (g).

6. Seed yield fed^{-1} (kg).
7. Seed oil percentage.
8. Oil yield fed^{-1} (kg).

II- Soil water relation

A. Irrigation water applied (IWA)

The amount of irrigation water applied (Wa) was computed as described by Giriappa (1983)

$$Wa = IW + Re$$

Where: IW = Irrigation water applied, and Re = Effective rainfall.

Irrigation water was applied to the experimental plots until reaching the end of the plot length. This was measured and delivered by a constant rectangular weir and the rate of discharge was 0.01654 m^3sec^{-1} at an effective head of 10 cm. The amount of water was calculated by the following equation:

$$A = Q \times T$$

Where: A = the volume of water delivered to the plot (m^3).
Q = the discharge of the weir ($m^3\ min^{-1}$)
T = the time of irrigation (minute).

Calculating the amounts of irrigation water applied (IWA) in both seasons with irrigation rates were presented in Table (3).

B. Productivity of irrigation water (IWP)

Productivity of irrigation water (kg m^{-3}) was calculated according to Ali *et al.* (2007) as follows:

$$IWP = Gy / IW$$

Where:
Gy = marketable yield, (seed, straw and fiber) kg fed^{-1}.
IW = Irrigation water applied, $m^3\ fed^{-1}$

Statistical analysis

Data collected in the two seasons were statistically analyzed according to the technique of analysis of variance (ANOVA) for the split-plot design as published by Snedecor and Cochran (1982). The means of the treatments were compared using the least significant differences (L.S.D) method at a 5% level of probability as published by Waller and Duncan (1969). However, combined analysis of variance for each character over the two seasons employing the method described by Leclerg *et al.*, (1966).

RESULTS AND DISCUSSION

I-Yield and yield components

A-Straw yield and its related characters

The mean values of straw yield and its related characteristics of four flax varieties as affected by irrigation treatments and studied flax varieties for each season and their combined are presented in Table (5). Statistical analysis of variance showed significant differences among the four tested flax varieties and the three irrigation treatments in all nine straw yield characters.

1-Effect of irrigation treatments

Data in Table (5) indicated that irrigation treatments significantly affected all straw yield characters under study in both seasons and combined. Applying I_3 treatment (sowing irrigation + three irrigations) caused a significant increase in straw characters *i.e.*, total plant height, technical length $plant^{-1}$, main stem diameter, straw yield $plant^{-1}$, straw yield fed^{-1}, fiber length and fiber fineness by 21.79 %, 20.85 %, 21.32 %, 57.08 %, 100.35 %, 120.47 %, 97.80 %, 20.30 % and 19.15 % as compared with I_1 treatment (sowing irrigation + one irrigation) as average for the two seasons. In this respect, no significant differences were detected in the same characters between the I_2 treatment (sowing irrigation + two irrigations) and the I_3 treatment (sowing irrigation + three irrigations) over the two seasons. The increase in most straw characters with increasing irrigation interval may be attributed to the presence of available moisture in the soil to the limit that increases the photosynthetic activity, thus flax plants can be grown better than in case of decreased soil moisture which reflects on an increase in straw yield characters. The increase in straw characters may be attributed to the increase in total plant height, technical length $plant^{-1}$, main stem diameter and straw yield plant^{-1}. Similar results were recorded by EL-Farouk *et al.*, (1989), EL-Sabbagh *et al.*, (1998), Mladinova (1998), Singh *et al.*, (2000), Chorumale *et al.*, (2001), Atta *et al.*, (2007), Hussein and Omer (2011), Abd EL-Daiem *et al.*, (2015) and Rashwan *et al.*, (2016).

2- Effect of varieties

Data presented in Table (5) reveal that the four flax varieties differed significantly in all straw characters in the two seasons and their combined. Giza 12 variety surpassed significantly the other tested flax varieties in all straw characters and yielded the Iriana variety by 11.20 %, 14.78 %, 22.73 %, 34.95 % and 28.02 % for total plant height, technical length plant^{-1}, main stem diameter, straw yield plant^{-1} and straw yield fed^{-1} as the average of the two seasons. Also, Giza 12 variety recorded the highest values of fiber yield fed^{-1} and fiber length, without a significant difference between this variety and Iriana variety for these two characters as the average of the two seasons. However, Iriana variety outyielded significantly Sakha 6 cv. by 47.51 %58.14 % and 11.43 % for fiber yield fed^{-1}, total fiber % and fiber fineness characters as the average of the two seasons, respectively. As shown in Table (5), the two studied flax varieties (Giza 11 and Sakha 6) recorded intermediate estimates for straw yield characters in the two seasons and their combined. The present results are due to the genetic variation of the four tested varieties. These results agree with those obtained by EL-Kady (1985), EL-Sabbagh *et al.*, (1998), AL-Thabet (2003), Atta *et al.*, (2007), Yenpreddiwar *et al.*, (2007), Hussein and Omer (2011), Bakry *et al.*, (2012), Hussein (2012), Rashwan *et al.*, (2016), EL-Borhamy (2016) and EL-Borhamy *et al.*, (2017).

Table (5): Mean values of total plant height (cm), technical length (cm), main stem diameter (mm), straw yield (g plant^{-1}) and straw yield (ton fed^{-1}) as affected by irrigation treatments, flax varieties and their interaction in 2019/20 and 2020/21 seasons and there combined.

Treatments	Total plant height (cm)			Technical length (cm)			Main stem diameter (mm)			Straw yield (g plant^{-1})			Straw yield (ton fed^{-1})		
	1St	2nd	Comb.	1St	2nd	Comb.	1St	2nd	Comb.	1St	2nd	Comb.	1St	2nd	Comb.
A-Irrigation treatments (I):															
I_1	94. 8	99.5	97.1	84.3	89.1	86.7	1.89	1.95	1.97	1.53	1.62	1.58	1.92	2.06	1.99
I_2	113.5	118.9	116.3	99.7	104.8	102.2	2.31	2.35	2.33	2.44	2.51	2.47	3.76	3.99	3.87
I_3	115.4	121.2	118.3	102.3	107.3	104.8	2.38	2.41	2.39	2.67	2.73	2.70	3.89	4.07	3.99
L.S.D 5%	4.15	4.36	4.02	3.23	3.55	3.12	0.34	0.38	0.27	0.322	0.385	0.353	0.482	0.515	0.47
B- Flax varieties (V):															
V_1	113.7	119.3	116.5	101.0	106.5	103.7	2.42	2.45	2.43	2.49	2.58	2.53	3.64	3.77	3.71
V_2	109.9	115.5	112.7	97.2	103.5	100.4	2.33	2.30	2.31	2.42	2.50	2.46	3.22	3.66	3.44
V_3	105.7	110.9	108.3	94.4	99.9	97.2	2.07	2.14	2.10	2.09	2.17	2.13	3.03	3.15	3.09
V_4	102.2	107.3	104.8	89.1	91.6	90.4	1.95	2.01	1.98	1.85	1.90	1.88	2.86	2.93	2.89
L.S.D 5%	2.98	3.16	2.04	2.62	2.78	2.45	0.22	0.25	0.18	0.21	0.25	0.20	0.29	0.33	0.28
C- (I X V)	*N.S*	*	*	*N.S*	*	*	*	*N.S*	*	*N.S*	*	*N.S*	*N.S*	*	*

I_1: Sowing irrigation + one irrigation, I_2: Sowing irrigation + two irrigations and I_3: Sowing irrigation + three irrigations
V_1: Giza 12, V_2: Giza 11, V_3: Sakha 6 and V_4: Iriana

Table (5): Cont.

Treatments	Fiber yield (ton fed^{-1})			Total fiber %			Fiber length (cm)			Fiber fineness (N.m)		
	1St	2nd	Comb.	1St	2nd	Comb.	1St	2nd	Comb.	1St	2nd	Comb.
A-Irrigation treatments (I):												
I_1	0.328	0.357	0.342	17.11	17.45	17.28	89.30	91.63	90.46	186.94	189..91	188.43
I_2	0.692	0.747	0.719	18.43	18.78	18.60	104.66	108.24	106.45	216.92	219.25	218.08
I_3	0.734	0.775	0.754	18.92	19.03	18.97	107.72	109.93	108.82	222.77	226.26	224.51
L.S.D 5%	0.085	0.096	0.061	1.25	1.32	0.99	3.18	3.42	2.27	16.89	18.58	15.44
B- Flax varieties (V):												
V_1	0.709	0.742	0.725	19.23	19.56	19.39	106.20	108.44	107.32	211.87	213.54	212.70
V_2	0.557	0.653	0.605	17.18	17.68	17.43	102.22	104.52	103.37	203.15	207.72	205.44
V_3	0.431	0.453	0.442	13.99	14.16	14.07	99.36	102.63	100.99	199.23	201.10	200.17
V_4	0.643	0.661	0.652	22.23	22.28	22.25	94.47	97.48	95.97	221.25	224.86	223.05
L.S.D 5%	0.075	0.083	0.072	1.16	1.18	1.08	2.75	2.96	2.13	11.755	13.16	14.55
C-(I X V)	*	*	*	*N.S*	*	*	*N.S*	*	*	*	*N.S*	*

I_1: Sowing irrigation + one irrigation, I_2: Sowing irrigation + two irrigations and I_3: Sowing irrigation + three irrigations
V_1: Giza 12, V_2: Giza 11, V_3: Sakha 6 and V_4: Iriana.

3- Effect of interaction

As average of the two seasons data presented in Table (6) showed that the interaction between irrigation treatments and flax varieties had a significant effect on straw yield characters *i.e.,* total plant height, main stem diameter, straw yield fed^{-1}, fiber yield fed^{-1}, total fiber % and fiber fineness characters. Data in the same table show that the longest plants (124.67 cm), the thickness plants (2.67 mm), the highest straw yield (4.473ton fed^{-1}) and the highest fiber yield (0.896 ton fed^{-1}) were obtained from the Giza 12 variety when received I_3 treatment (sowing irrigation + three irrigations). On the other hand, Iriana variety recorded a fiber yield (0.810 ton fed^{-1}) which did not differ significantly from the Giza 12 variety. On the contrary, Iriana variety produced the highest values of total fiber % (23.01 %) and recorded the finest fiber (236.962) when receiving I_3 treatment (sowing irrigation + three irrigations). A significant interaction between irrigation treatments and flax varieties was recorded with EL-Sabbagh *et al.,* (1998), AL-Thabet (2003), Hussein and Omer (2011), Bakry *et al.,* (2012) and Rashwan *et al.,* (2016).

Data presented in Table (6) reveal that the interaction between irrigation treatments and flax varieties was significant in straw yield fed^{-1}. Whereas the highest values were recorded by three irrigations (I_3) or two irrigations after sowing irrigation (I_2) with Giza 12 variety (4.473 and 4.424 ton fed^{-1}) respectively. The lowest straw yield per fed was recorded by one irrigation after sowing irrigation (I_1) with Iriana variety. These results revealed that the four tested varieties differ significantly in their response to irrigation treatments. These differences among the tested varieties could be due to genetic factors. These results were agreed with those obtained by Rashwan *et al.,* (2016) and Torky (2020).

Data in Table 6 showed also highly significant differences among flax varieties. Sakha 6 variety was the superior one for seed yield and its components. Sakha 6 and Giza 11 surpassed in seed yield fed^{-1} as the average of the two seasons. Comparable results were noticed by El-Seidy *et al.,* (2010), EL-Refaey *et al.,* (2010), Abo-kaied *et al.,* (2015) Kineber *et al.,* (2015), Rashwan *et al.,* (2016), Torky (2020) and Sallam *et al.,* (2023).

Table 6: The significant interaction between the three irrigation treatments and the four tested flax varieties on total plant height (cm), main stem diameter(mm), straw yield (ton fed^{-1}), fiber yield (ton fed^{-1}), total fiber % and fiber fineness (N.m) (combined analysis of 2019/2020 and 2020/2021 seasons).

Irrigation treatments	Flax varieties					Flax varieties				
	V_1	V_2	V_3	V_4		V_1	V_2	V_3	V_4	
	Total plant height (cm)				**L.S.D 5%**	**Fiber yield (ton fed^{-1})**				**L.S.D 5%**
I_1	102.21	99.97	95.62	90.73		0.411	0.346	0.247	0.369	
I_2	122.55	118.54	113.78	110.11	**3.96**	0.868	0.721	0.513	0.776	**0.094**
I_3	124.67	119.64	115.48	113.41		0.896	0.747	0.565	0.810	
L.S.D at 5%	**3.22**					**0.075**				
	Main stem diameter (mm)					**Total fiber %**				
I_1	2.03	1.97	1.89	1.78		18.53	16.79	12.96	20.84	
I_2	2.60	2.50	2.17	2.05	**0.15**	19.61	17.67	14.25	20.90	**1.95**
I_3	2.67	2.55	2.25	2.10		20.04	17.84	15.01	23.01	
L.S.D at 5%	**0.12**					**1.78**				
	Straw yield (ton fed^{-1})					**Fiber fineness (N.m)**				
I_1	2.218	2.062	1.909	1.770		191.223	183.997	180.719	197.758	
I_2	4.424	4.076	3.602	3.391	**0.278**	220.078	210.839	206.967	234.440	**8.334**
I_3	4.473	4.182	3.770	3.522		226.805	221.475	212.813	236.962	
L.S.D at 5%	**0.255**					**7.152**				

I_1: Sowing irrigation + one irrigation, I_2: Sowing irrigation + two irrigations and I_3: Sowing irrigation + three irrigations.
V_1: Giza 12, V_2: Giza 11, V_3: Sakha 6 and V_4: Iriana.

B-Seed yield and its related characters

Mean values of seed yield and its related characters for four flax varieties as affected by irrigation treatments in both seasons and they are combined are illustrated in Table (7).

1- Effect of irrigation treatments

Data in Table (7) show in both seasons and combined that irrigation treatments significantly affected all seed yield characters under study. Applying I_3 treatment (sowing irrigation + three irrigations) caused a significant increase in No. of fruiting branches plant^{-1}, No. of capsules plant^{-1}, No. of seeds capsule^{-1}, 1000-seed weight, seed yield plant^{-1}, seed yield fed^{-1}, seed oil percentage and oil yield fed^{-1} and exceeded I_1 treatment (sowing irrigation + one irrigation) by 7.03 %, 10.38 %, 14.47 %, 15.47 %, 11.25 %, 21.94 % and 4.31 % respectively for the abovementioned characters as the average of the two seasons. As shown in the same table the difference between I_2 treatment and I_3 treatment did not reach a significant level in both seasons and their combined for seed yield characters under study. These results indicate that exposing flax plants to water irrigation with I_3 treatment (sowing irrigation + three irrigations) was associated with a greater increase in all seed characters as compared to water stress (I_1 treatment). This is to be expected since water plays an important role in plants and moisture deficits can have a deleterious effect on most biological processes. The reduction in seed yield characters under I_1 treatment (sowing irrigation + one irrigation) may be attributed to the decrease in No. of fruiting branches plant^{-1}, No. of capsules plant^{-1}, No. of seeds capsule^{-1} and 1000-seed weight. These results agree with those obtained by EL-Kady (1985), EL-Farouk *et al.,* (1989), EL-Sabbagh *et al.,* (1998), AL-Thabet (2003), Atta *et al.,* (2007), Hussein and Omer (2011), Bakry *et al.,* (2012), Sharma *et al.,* (2012), Abd EL-Daiem *et al.,* (2015) and Rashwan *et al.,* (2016).

2- Effect of varieties

The differences among flax varieties in all seed yield studied characters reached a significant level in the two seasons and their combined (Table 7). Sakha 6 variety ranked first and surpassed significantly the other three flax varieties in most studied characters and yielded Iriana variety by 14.14 %, 15.97 %, 22.65 %, 73.80 %, 106.70 %, 109.19 %, 15.27 % and 141.67 % for all seed yield characters *i.e.,* No. of fruiting branches plant^{-1}, No. of capsules plant^{-1}, No. of seeds/capsule, 1000-seed weight, seed yield plant^{-1}, seed yield fed^{-1}, seed oil percentage and oil yield fed^{-1} as average of the two seasons, respectively. The differences between the four tested flax varieties may be attributed to genetic factors. Comparable results were obtained by EL-Sabbagh *et al.,* (1998), AL-Thabet (2003), Atta *et al.,* (2007), Hussein and Omer (2011), Hussein (2012), EL-Borhamy (2016), Rashwan *et al.,* (2016) and EL-Borhamy *et al.,* (2017).

Table (7): Mean values of No. of fruiting branches plant^{-1}, No. of capsules plant^{-1}, No. of seeds capsule^{-1} and 1000-seed weight as affected by irrigation treatments, flax varieties and their interaction in the 2019/2020 and 2020/2021 seasons and there combined.

Treatments	No. of fruiting branches plant^{-1}			No. of capsules plant^{-1}			No. of seeds capsule^{-1}			1000-seed weight (g)		
	1St	2nd	Comb.	1St	2nd	Comb.	1St	2nd	Comb.	1St	2nd	Comb.
A- Irrigation treatments (I)												
I_1	13.98	14.18	14.08	12.67	13.15	12.91	8.45	8.42	8.43	7.35	7.66	7.50
I_2	14.65	14.55	14.60	13.88	14.01	13.94	9.38	9.66	9.52	8.09	8.31	8.20
I_3	14.82	15.33	15.07	14.15	14.35	14.25	9.55	9.75	9.65	8.52	8.81	8.66
L.S.D 5%	0.47	0.35	0.56	0.25	0.36	0.32	0.65	0.55	0.46	0.50	0.54	0.48
B- Flax varieties												
V_1	14.25	14.55	14.40	13.67	13.82	13.74	9.16	8.96	9.06	8.57	8.76	8.66
V_2	14.57	15.12	14.84	13.91	14.13	14.02	9.57	9.89	9.73	8.86	9.09	8.97
V_3	15.58	15.42	15.50	14.44	14.61	14.52	9.85	9.98	9.91	9.31	9.53	9.42
V_4	13.51	13.66	13.58	12.26	12.79	12.53	7.93	8.24	8.08	5.18	5.66	5.42
L.S.D 5%	0.33	0.28	0.39	0.22	0.27	0.26	0.35	0.27	0.25	0.35	0.38	0.42
C- (I X V)	*N.S*	*N.S*	*N.S*	*N.S*	*	*	*N.S*	*N.S*	*N.S*	*N.S*	*N.S*	*N.S*

I_1: Sowing irrigation + one irrigation, I_2: Sowing irrigation + two irrigations and I_3: Sowing irrigation + three irrigations

V_1: Giza 12, V_2: Giza 11, V_3: Sakha 6 and V_4: Iriana

Table (7): Cont.

Treatments	Seed yield (g plant^{-1})			Seed yield (kg fed^{-1})			Seed oil %			Oil yield (kg fed^{-1})		
	1St	2nd	Comb.	1St	2nd	Comb.	1St	2nd	Comb.	1St	2nd	Comb.
A- Irrigation treatments (I)												
I_1	0.449	0.514	0.506	591.4	606.0	598.7	39.3	39.5	39.4	235.1	242.6	238.9
I_2	0.600	0.612	0.606	718.1	724.8	721.5	40.1	40.5	40.3	292.9	297.9	295.4
I_3	0.613	0.628	0.620	725.5	734.7	730.1	40.9	41.2	41.1	302.5	308.1	305.3
L.S.D 5%	0.058	0.062	0.041	45.88	39.98	41.64	0.46	0.53	0.68	28.25	30.66	31.48
B-Flax varieties												
V_1	0.556	0.561	0.558	685.2	695.8	690.5	41.8	41.8	41.8	285.0	291.2	288.1
V_2	0.646	0.663	0.654	789.7	795.2	792.4	42.7	42.8	42.7	337.9	340.7	339.3
V_3	0.733	0.747	0.740	838.7	853.8	846.2	40.8	41.3	41.1	342.6	353.5	348.1
V_4	0.348	0.369	0.358	399.9	409.2	404.5	35.5	35.8	35.6	141.8	146.2	144.0
L.S.D 5%	0.045	0.052	0.029	24.55	21.42	33.43	0.27	0.35	0.41	22.66	25.53	21.06
C- (I X V)	*N.S*	*	*	*	*	*	*N.S*	*N.S*	*N.S*	*	*	*

I_1: Sowing irrigation + one irrigation, I_2: Sowing irrigation + two irrigations and I_3: Sowing irrigation + three irrigations
V_1: Giza 12, V_2: Giza 11, V_3: Sakha 6 and V_4: Iriana

3- Effect of interaction

Data presented in Table (8) revealed that No. of capsules plant^{-1}, seed yield plant^{-1}, seed yield fed^{-1} and oil yield fed^{-1} characters were significantly affected by the interaction between irrigation treatments and flax varieties. The highest values of capsules number plant^{-1} (15.13), seed yield plant^{-1} (0.803 g), seed yield fed^{-1} (902.79 Kg) and oil yield fed^{-1} (381.18 Kg) were recorded with Sakha 6 variety when irrigated with I_3 treatment (sowing irrigation + three irrigations) as the average of the two seasons. Also, Giza 11 variety recorded the highest values of the above-mentioned characters when irrigated with I_2 treatment (sowing irrigation + two irrigations) with mean values of 14.28 capsules plant^{-1}, 0.685 g seeds plant^{-1}, 856.32 Kg seeds fed^{-1} and 372.32 Kg oil fed^{-1}, without significant differences between Giza 11 variety and Sakha 6 variety when irrigated with I_3 treatment (sowing irrigation + three irrigations) as average of the two seasons. The significant interaction between the two studied factors was obtained by EL-Sabbagh *et al.,* (1998), AL-Thabet (2003), Hussein and Omer (2011) and Bakry *et al.*, (2012).

II- Soil water relation

A. Irrigation water applied (IWA)

Data in Table (3) showed irrigation water applied (IWA) rates to flax crops in two successive growing winter seasons. The irrigation water applied increased plant growth until maturity, then started decreasing as plant physiological characteristics. The irrigation water applied was 915.5, 1205.7 and 1464.5 m^{-3} fed^{-1} in the first season and 823.5, 1068.1 and m1299.5 m^{-3} fed^{-1} in the second one under I_1, I_2, and I_3 water treatments, respectively. These results agreed with Bakry *et al.,* (2019).

B. Productivity of irrigation water (PIW, kg m^{-3})

The data in Table (9) represented the effect of irrigation rates and varieties on irrigation water productivity (IWP) of straw, seed and fiber yields of flax crops. The results indicated that

IWP increased with decreasing quantities of water under clay soil. Concerning the effect of irrigation treatments, the highest values were registered with irrigation treatment I_2 (sowing irrigation added with two irrigations) in the two seasons 3.12 and 3.31 kg m^{-3} respectively.

For straw yield, the IWP highest values were 3.336 kg m^{-3} for Giza 12 variety, meanwhile, the lowest values were 2.531 and 2.686 kg m^{-3} for Iriana and Sakha 6 varieties, respectively. Regarding seed yield IWP highest values were 0.756 and 0.704 kg m^{-3} for Sakha 6 and Giza 11 varieties respectively with low Irrigation applied. These results agreed with El-Borhamy *et al.,* (2022). The lowest IWP values were detected with full Irrigation it was 0.354 and 0.616 kg m^{-3} for Iriana and Giza 12 varieties with I_3 treatment (sowing irrigation added with three irrigations). Whereas the highest IWP fiber yield was 0.657 and 0.628 kgm^{-3} for Giza 12 variety in the first and second seasons, respectively. While the lowest values were 0.382 kg m^{-3} in Sakha 6 variety and full Irrigation. These results match with findings of Jat *et al.,* (2018) and Bakry *et al.,* (2019).

Sakha 6 variety was the superior one. It could be concluded that Sakha 6 variety is the recommended genotype for seed production and Giza 12 variety is the recommended genotype for fiber production besides saving more water.

Interaction effect between irrigation treatments and flax cultivars are illustrated in Fig. 1&2. Results showed that the best treatment for PIW seed was I_1 treatment with Sakha 6, Giza 11, Giza 12 and Iriana respectively while I_2 treatment for Giza 12 and Giza 11 recorded the highest PIW straw in the two seasons. Increasing PIW seed with Sakha 6 for I_1 and PIW straw for I_2 with Giza 12, resulted in decreasing amount of water applied for I_2 and increasing seed yield for Sakha 6 and straw yield for Giza 12 compared with the other cultivars.

Table 8: The significant interaction between the three irrigation treatments and the four tested flax varieties on No. of capsules plant^{-1}, seed yield (g plant^{-1}), seed yield (kg fed^{-1}) and oil yield (kg fed^{-1}) (combined analysis of 2019/2020 and 2020/2021 seasons).

Irrigation treatments	Flax varieties					Flax varieties				
	V_1	V_2	V_3	V_4		V_1	V_2	V_3	V_4	
	No. of capsules plant^{-1}				L.S.D 5%	Seed yield (kg fed^{-1})				L.S.D 5%
I_1	11.91	13.01	13.09	13.63		601.23	675.11	720.28	368.26	
I_2	12.72	13.94	14.32	14.79	0.72	732.91	845.85	885.60	421.44	54.28
I_3	12.94	14.28	15.13	14.65		739.33	856.32	902.79	423.89	
L.S.D at 5%	0.65					49.77				
	Seed yield (g plant^{-1})					Oil yield (kg fed^{-1})				
I_1	0.491	0.603	0.627	0.303		242.29	281.97	300.24	130.33	
I_2	0.588	0.676	0.788	0.372	0.064	305.33	358.55	362.72	150.03	18.95
I_3	0.595	0.685	0.803	0.400		315.98	372.32	381.18	151.69	
L.S.D at 5%	0.055					16.35				

I_1: Sowing irrigation + one irrigation, **I_2**: Sowing irrigation + two irrigations and **I_3**: Sowing irrigation + three irrigations.
V_1: Giza 12, **V_2**: Giza 11, **V_3**: Sakha 6 and **V_4**: Iriana

Table 9. Effect of irrigation water treatments and flax cultivars on the productivity of irrigation water (PIW) in the 2019/20 and 2020/21 seasons.

Treatments	Straw yield (kg fed^{-1})		WIP $_{Straw}$ (kg m^{-3})		seed yield (kg fed^{-1})		WIP $_{seed}$ (kg m^{-3})		Fiber yield (kg fed^{-1})		WIP $_{Fiber}$ (kg m^{-3})	
A-Irrigation treatments (I):												
I_1	1921	2059	2.10	2.50	591.42	606.02	0.646	0.736	328	357	0.358	0.434
I_2	3760	3987	3.12	3.31	718.09	724.82	0.596	0.679	692	747	0.609	0.699
I_3	3888	4086	2.65	3.14	725.48	734.69	0.495	0.565	734	775	0.501	0.596
B- Flax varieties												
V_1	3643	3768	3.225	3.336	685.16	695.83	0.607	0.616	709	742	0.628	0.657
V_2	3223	3658	2.854	3.239	789.67	795.19	0.699	0.704	557	653	0.493	0.578
V_3	3034	3154	2.686	2.792	838.65	853.81	0.743	0.756	431	453	0.382	0.401
V_4	2859	2930	2.531	2.594	399.85	409.21	0.354	0.362	643	661	0.569	0.585

I_1:Sowing irrigation + one irrigation, I_2: Sowing irrigation + two irrigations and I_3: Sowing irrigation + three irrigations.
V_1: Giza 12, V_2: Giza 11, V_3: Sakha 6 and V_4: Iriana

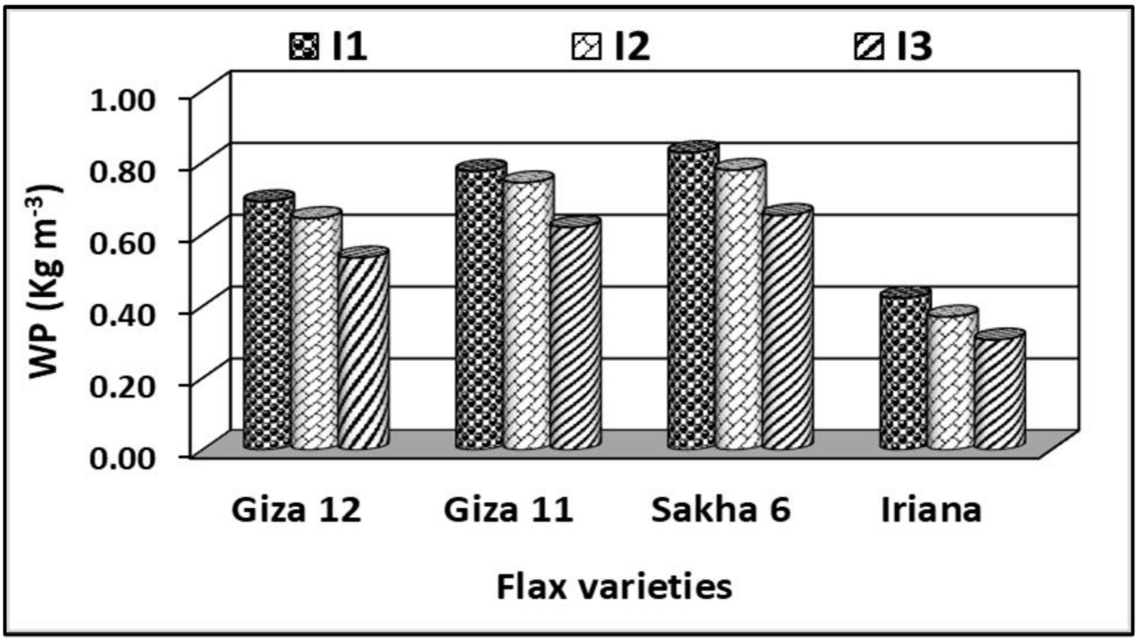

Fig. 1. Interaction effect between the three irrigation treatments and the four tested flax varieties on WP $_{Seed}$

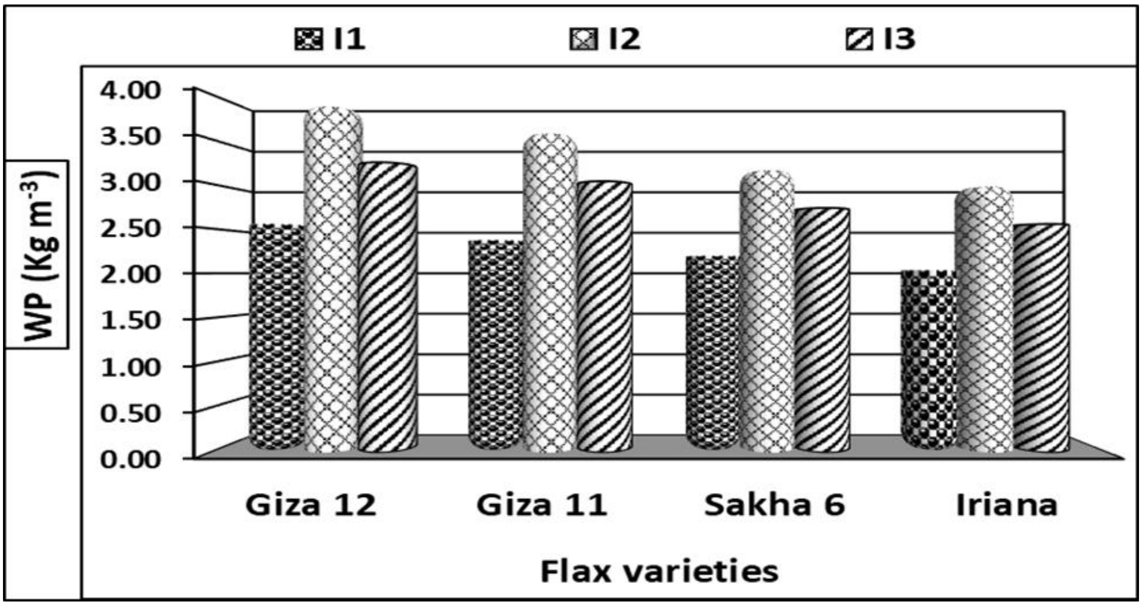

Fig. 2. Interaction effect between the three irrigation treatments and the four tested flax varieties on WP $_{Straw}$

CONCLUSION

From the present study. It can be concluded that: Irrigation has a significant role in flax production, whereas, receiving flax plants with two irrigations added after sowing irrigation during the growing season increased the productivity and quality of the tested flax varieties and saved the amount of water irrigation without any reduction in yields of straw and seeds and their qualities. Among the tested flax varieties, the Giza 12 variety was superior in straw yield characters, however, Sakha 6 variety followed by Giza 11 variety was superior in seed yield characters, moreover, the imported Iriana exceeded the other three tasted flax varieties in fiber yield characters.

Generally growing the dual-purpose types of flax (Giza 12, Giza11, and Sakha 6 varieties) in the Middle Nile Delta with receiving its plants with two irrigations added after sowing irrigation was more effective in saving water amount without significant reduction in yields of straw, fiber and seed and their qualities.

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تأثير معاملات الرى المختلفة على المحصول وجودته وكفاءة الاستهلاك المائى لبعض أصناف الكتان

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الملخص العربى

أقيمت تجربتان حقليتان بمزرعة محطة البحوث الزراعية بالجميزة – محافظة الغربية – مركز البحوث الزراعية خلال الموسمين الزراعيين ٢٠٢٠/٢٠١٩، ٢٠٢١/٢٠٢٠ لدراسة استجابة محصول وجودة وكفاءة استخدام المياه لأربعة أصناف كتان هي على التوالي جيزة ١٢، جيزة ١١، سخا٦ (طرز ثنائية الغرض) والمستورد إريانا (طراز ليفي) لثلاثة معاملات ري (رية الزراعة + ثلاث ريات، رية الزراعة + ريتين ، رية الزراعة + رية واحدة) خلال موسم النمو. وقد تم استخدام تصميم القطع المنشقة مرة واحدة في أربع مكررات حيث احتلت معاملات الري الثلاث القطع الرئيسية بينما وزعت الأصناف الأربعة المختبرة في القطع الشقية. وقد تم اعطاء رية الزراعة بالتساوي لجميع القطع التجريبية في اليوم التالي للزراعة كما هو متبع. وفيما يلي اهم النتائج التي تم الحصول عليها كمتوسط لموسمي الزراعة.

- أظهرت معاملات الري تأثيراً معنوياً لجميع الصفات المدروسة حيث سجلت معاملة الري رقم ٣ (رية الزراعة + ثلاث ريات) خلال موسم النمو أعلى القيم لصفات القش والبذرة تبعها في ذلك معاملة الري رقم ٢ (رية الزراعة + ريتين) خلال موسم النمو بدون فروق معنوية بين المعاملتين لمعظم الصفات المدروسة. بينما سجلت معاملة الري رقم ١ (رية الزراعة + رية) خلال موسم النمو أقل القيم لجميع الصفات المدروسة.

- أظهرت النتائج اختلافات معنوية بين الأصناف المختبرة لجميع صفات القش والبذرة، في هذا الخصوص تفوق الصنف جيزة ١٢ معنويا على بقية الأصناف الأخرى المختبرة في صفات القش، بينما تفوق الصنف سخا ٦ معنوياً في صفات البذرة حيث سجل أعلى القيم متبوعا بالصنف جيزة ١١ بدون فروق معنوية بين هذين الصنفين متفوقين على الصنفين الآخرين (جيزة ١٢ وإريانا). من ناحية أخرى سجل الصنف المستورد إريانا أعلى القيم لصفات الألياف بدون فروق معنوية بين هذا الصنف المستورد والصنف المحلى جيزة ١٢ لمعظم صفات الألياف.

- أظهر التحليل المشترك للموسمين تأثيراً معنوياً للتفاعل ما بين معاملات الري والأصناف لصفات الطول الكلى للنبات، سمك ساق النبات، محصول القش للفدان، محصول الألياف للفدان، النسبة المئوية للألياف الكلية ونعومة الألياف حيث سجل الصنف جيزة ١٢ أعلى القيم لهذه الصفات عند إضافة معاملة الري رقم ٣ (رية الزراعة + ثلاث ريات) والتي لم تختلف معنويا عن معاملة الري رقم ٢ (رية الزراعة + ريتين) بينما سجل الصنف المستورد إريانا أقل القيم لصفات الالياف عند إضافة معاملة الري رقم ١(رية الزراعة + رية واحدة) خلال موسم النمو.

- أيضاً كان هناك تفاعل معنوي بين معاملات الري والأصناف لصفات عدد كبسولات النبات، محصول البذرة للنبات، محصول البذرة للفدان ومحصول الزيت للفدان حيث سجل الصنف سخا ٦ أعلى القيم لهذه الصفات عند إضافة معاملة الري رقم ٣.

من الدراسة الحالية يمكن استنتاج ما يلي:

- كان لمعاملات الري دور معنوي في إنتاج الكتان حيث أدى إعطاء نباتات الكتان ثلاث ريات مشتملة رية الزراعة خلال موسم النمو الى زيادة انتاجية وجودة اصناف الكتان المختبرة مع ترشيد استخدام المياه وإضافة الاحتياجات المائية الفعلية دون حدوث نقص في محصول القش، والألياف، والبذرة، وجودتهم.

- فيما يتعلق بالأصناف فقد تفوق صنف الكتان جيزة ١٢ معنوياً على بقية الأصناف الأخرى المختبرة في صفات محصول القش بينما تفوق صنف الكتان سخا ٦ متبوعاً بالصنف سخا ١١ على الصنفين الآخرين (جيزة ١٢، إريانا) في صفات محصول البذرة. من ناحية أخري فقد تفوق صنف الكتان المستورد إريانا على الأصناف الأخرى المختبرة في صفات محصول الألياف بدون فروق معنوية بينه وبين الصنف المحلى جيزة ١٢ في معظم الصفات.

وبصفة عامة يمكن للأصناف المحلية تحمل الاجهاد المائي تحت الظروف المصرية وهذا ما اوضحته معظم نتائج الدراسة لذلك يمكن زراعة الأصناف جيزة ١٢ و جيزة ١١ وسخا ٦ في منطقة وسط الدلتا مع اعطاء نباتاتها ريتان خلال موسم النمو بخلاف رية الزراعة لترشيد استخدام المياه في ري محصول الكتان دون حدوث نقص معنوى في انتاجية محصول القش والألياف والبذور وجودتهم. وبناءً عليه يمكن الاعتماد بصفة اساسية على الاصناف المحلية فى ظل ظروف محدودية الموارد المائية.