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Effect of Soil Amendments and Water Requirements on Flax Yield, Fertilizer Use Efficiency and Water Productivity under Sandy Soil Condition

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Abstract: Water scarcity is one of the major problems for crop production in Egypt, which needs to reduce irrigationwater consumption via conservation of the mass of water around the crop root zone or keeping the soil-water balance in the crops like flax under sandy soil condition. Therefore, the field experiments were carried out at the Experimental Station of National Research Centre, Al-Nubaria district, El-Behira Governorate-Egypt in two successive winter 2016/2017 and 2017/2018 seasons. Irrigation treatments included four water irrigation management (25 %, 50 %, 75 % and 100 %) of the recommended water irrigation requirements and hydrogel as soil conditioner at rate of 16 kg/ fed. with or without organic manure at rate of 3 ton/fed. to attain the best flax water productivity under sandy soil condition. Results indicated that applying 75 % of water irrigation requirement to flax plants significantly surpassed all other water treatments in biological yield, seed yield and oil yield (kg/fed). The combined treatment of hydrogel with farmyard manure produced the highest seed yield/fed. with increase 39.46 %, the increase in oil and biological yields were 50.33 % and 34.27 %, respectively compared to the unamended soil treatment. Data revealed that the interaction irrigation treatment at 75 % of water requirement and hydrogel with farmyard manure surpassed all other treatments in biological yield (ton/fed), seed yield (ton/fed), oil yield (kg/fed) and nitrogen, phosphorus and potassium fertilizers use efficiencies. Water productivity of flax increased with decreasing water applied using hydrogel and organic manure, meanwhile; the highest values of water productivity (WP) for biological yield, seed yield and oil yield were achieved using 25% of water regime with incorporating hydrogel with organic manure in the soil. However the lowest WP values were recorded when the recommended irrigation practice at 100 % of water requirements. It might be suggested that the irrigation with 50% of water regime using hydrogel and organic manure is the best soil and water management for flax crop under sandy soil for saving water to new area irrigation under arid conditions.

Key words: Flax, hydrogel · Organic manure · Water regime · Sprinkler irrigation · Biological yield · Seed yield and oil yield · Water productivity

INTRODUCTION

Flax (*Linum usitatissimum* L.) is an old economic crop grown as oil, fiber or dual purpose crop. The edible oil due to its quick drying properly is used for the preparation of paints, varnishes, printing ink, oil cloth and soap. In Egypt, flax plays an important role in the national economy owing to exportation beside or local manufacturing, at the allocated limited area [1]. Bakry *et al*., [2] showed that the differences in flax straw yield between the flax varieties could be attributed to the variation in their genetically constituents and their response to the ecosystem grown in.

Flax is the second fiber crop after cotton in Egypt with regard to the cultivated area and economic importance [3]. Nowadays, the benefits of flax have passed all expectations. Regardless the well-known ordinary uses, the crop has more benefits in producing feeding stuff for animals and poultry and moreover in producing some kinds of compact wood, popular in name

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particle board. The crop is also popular in several fine industries in which making electric insulations and non-textile medical materials are the most important. More valuable is that related to producing bank note papers. Flax seeds are widely used medicinally. They are used as emollient, demulcent and pectoral. The crushed seeds or linseed meal make a very useful poultice either alone or with mustard. In ulceration and superficial or deep-seated inflammation a linseed poultice allays irritation and pain promoters' suppuration [4].

Global population growth is estimated to increase to between 9.4 and 10.2 billion by 2050. More than half of this growth will be in Africa (+ 1.3 billion). The excess of global agricultural water use, as a function of population growth, economic development and changing consumption patterns, among other factors, is expected to be about 19 %, but it could be much higher if crop water productivity is not enhanced effectively. This increase will be much higher in arid and semi-arid zone. Rational agricultural water management will fundamentally influence to future global water security [5, 6].

For managing the irrigation system the soil-water-plant relationships should be taken in account as irrigation time and amount rely on soil water retention, weather and crop growth [7]. Hydrogel is splendid substrate for slow release and soil water holding, decline the fertilizer leaching; moreover it is nontoxic and eco-friendly for the soil [8].

Jat *et al*., [9] found that irrigation rate at 0.8 IW/CPE attained significantly higher growth parameters and yield, irrigation scheduled at 0.6 IW/CPE achieved the highest water productivity over other treatments. They reported that growth and yield components, seed yield and oil yield enhanced by applying 5.0 kg of hydrogel/ha which increased production efficiency and water productivity.

Hydrogels are super absorbents that absorb and store water hundreds of times their own weight, i.e. 400-1500 g water per dry gram of hydrogel [10]. Waly *et al*., [11] Found that treatment of (0.2 % hydrogel to soil) weight / weight may be effective tool to reduce water leaching from soil and recorded 93.4 % in seed yield, 95.3 % in biological yield, 92.9 % in 100 seed weight and 98.3 % in oil % in seeds compared to the treatment of recommended dose of irrigation in sunflower grown in greenhouse. El-Karamany *et al*., [12] in field trial on sugar beet clear that treatment of watering hydrogel for 48 hours at 90 DAS produced the highest fresh biological, fresh shoot and fresh root yields per plant also, leaf area and total chlorophyll, at harvest it produced highest fresh biological yield; fresh shoot weight; fresh root yield ton/fed. and root diameter but control (without hydrogel) recorded the highest root/shoot and root length. Due to technological characters of sugar beet roots treatment of watering hydrogel for 48 hours recorded the highest impurities and highest quality but recorded the lowest amino N; Na and near the lowest in K.

The soil of Nubaria District, Egypt like the sandy texture soils are characterize very low organic matter, low water holding capacity and high nutrient leaching losses. It is well known that such soil factors are known to limit mobility and availability of soil fertilizers therefore organic fertilization, as a particular way to supply macro and micro-nutrients. Organic fertilization can be considered practical to supply nutritional plant requirements. The effect of organic fertilizers on the soil properties such as physical, chemical and biological ones has been well known for a long time. Soil organic matter contains residues of plants and animals and primary & high polymer dynamic structure [13]. Mineral fertilizers caused environmental pollution. Recently, under Egyptian conditions agreat attention is being devoted to reduce high rates of mineral fertilizers, the cost of production and environmental pollution via reducing doses of nitrogen and phosphorus. Organic manure plays a direct role in plant growth as a source of all necessary macro and micronutrients in available forms during mineralization and improves physical and chemical properties of soils [14].

The combined application of organic manure and nitrogen (N) is effective when N application is adjusted Abd El Lateef Abd El Lateef *et al*., [15] and Dunjana *et al*., [16] investigated the effects of applying the cattle manure and mineral-N fertilizer on maize water productivity on clay and sandy soils. They noticed that the water productivity significantly improved with an increase in cattle manure and mineral-N fertilizer application over control in both soils, it was clearly associated with the steady-state infiltration rate on the clay soil and with soil organic carbon on the sandy soil. Bakry*et al*., [17]. Found that the greatest seed and straw yields of flax were obtained by planting Sakha-2 variety fertilized with 6.0 tons/fed organic fertilizer with sparing by 15 mg/L humic acid. The total saturated fatty acids were obtained from planting Amon variety fertilized with 6.0 tons/fed organic fertilizer and sparing 15 mg/L humic acid. Total unsaturated fatty acids were obtained from planting Amon variety fertilized by 3.0 tons/fed organic fertilizer. The objective of this study is to investigate the irrigation management for flax crop under sandy soil condition in semiarid zone in order to attain the best flax water productivity.

MATERIALS AND METHODS

The field experimentswere carried out at the Experimental Station of National Research Centre, Al-Nubaria district El-Behira Governorate-Egypt, in the 25th November in two successful winter 2016/2017 and 2017/2018 seasons. Soil of the experimen tal site was sandy soil. The mechanical and chemical analysis of the experimental soil is reported in Table-1, while irrigation water analysis shown in Table (2) according to [18].

The experimental design was split plot design with three replications, where water treatments occupied the main plots (25 %, 50 % 75 % and 100 % of IWR) and hydrogel at rate of 16 kg/ fed. with or without organic manure at rate of 3 ton/fed. were allocated in sub plots.

Hydrogel Preparation: Super absorbance starch (Hydrogel), in double jacketed reactor (60 litter capacity) equipped with condenser, variable speed motor temperature controller and heater, was added 40 litter water and 4 kg starch, the temperature was raised to 95°C for 30 minutes (starch gelatinization), the temperature of the content was adjusted again to 55°C with addition of 20 cm^3 of emulsifier, followed by the addition of acrylonitrile (AN) 4kg. The obtained product was agitated for 20 minutes, followed by the addition of suitable redox system as polymerization initiator during 30 minutes. After which the polymerization reaction was continued for another 3 hours, followed by the addition of 0.6- 0.7 equivalent to the AN amount of NaoH or KoH, the temperature was raised again to 90°C until the obtained ammonia was seared. The obtained hydrogel was filtered, dried and milled.

Materials Used Commercial Product Without Purification: Acrylonitrile (AN), Corn starch, Sodium hydroxyl and emulsifier.

Flax Cultivation and Fertilization: Flax seeds of Sakha-2 cultivar were sown in rows 3.5 meters long and the distance between rows was 20 cm apart, plot area was 10.5 m^2 (3.0 m in width and 3.5 m in length). The seeding rate was 2000 seeds/m^2. Pre-sowing, 150 kg/fed of calcium super-phosphate (15.5% P_2O_5) were used. Nitrogen was applied after emergence in the form of ammonium nitrate 33.5% at rate of 75 kg/fed in five equal doses. Potassium sulfate (48 % K_2O) was added at two equal doses of 50 kg/fed.

Water Regime: Theexperiment was conducted using the sprinkler irrigation system, reference evapotranspiration (ETo) was calculated using meteorological data at El-Behira in Egypt according FAO Penman Monteith equation [19]. Four Water regimes with sprinkler irrigation system were 2100, 1575, 1050 and 525 m^3 $fed.^{-1}$ $season^{-1}$ represented (100%, 75%, 50 % and 25% of irrigation water requirement for flax crop (IWR), respectively) for both seasons of 2016/2017and 2017/2018.

The irrigation water requirementwascalculated according to the following equation [20]:

Table 1: Some physical and chemical characteristics of the experimental soil

Season	Constant Depth (cm)	Coarse sand%	Fine sand%	Silt%	Clay%	Texture class
2016/17	00 - 30	40.7	44.6	10.7	4	sandy
	30 - 60	38.2	43	13.8	5	sandy
2017/18	00 - 30	38.7	42.6	13.7	5	sandy
	30 - 60	36.5	38.1	17.8	7.6	sandy

				Anions (meq/l)				Cations (meq/l)					
	pH	EC (ds/m)	SP	$CO_3^=$	HCO_3^-	Cl	$SO_4^=$	Ca^{++}	Mg^{++}	Na^+	K^+	$CaCo_3$ %	Organic Mater %
2016/17	7.95	1.59	23	-	0.32	12.70	1.98	4.00	1.80	9.00	0.20	1.90	0.38
2017/18	7.85	1.81	25	-	0.45	15.40	2.15	5.60	2.00	10.20	0.20	1.30	0.32

Table 2: Analysis of irrigation water

Properties	pH	EC dSm^{-1}	K^+	Na^+	Mg^{+2}	Ca^+	$SO4^{-2}$	HCO^{-3}	$CO3^{-2}$	Cl^-
Value	7.88	0.54	0.45	0.3	2.25	2.3	0.41	1.7	-	3.2

$$IWR = \frac{ETo*Kc*I}{Ea*(1-LR)} * 4.2$$

where IWR is irrigation water requirement m^3 / fed., ETois Reference evapotranspiration, Kc is Crop coefficient, I = Irrigation interval, day, Ea is Irrigation efficiency, 85%, LR is Leaching requirement = 10% of the total water amount delivered to the treatment.

Plant samples were taken after 60 days from sowing to determine growth characters and some biochemical parameters. Growth parameters in terms of, shoot length (cm), shoot fresh and dry weight (g) were determined. Plant samples were dried in an electric oven with drift fan at 70°C for 48 hr.

Chemical analyses measured were nitrogen (N), phosphorus (P) and potassium (K) concentrations %; total nitrogen was determined by the modified micro-Kjeldahl method, phosphorus was estimated colorometerically using NH4-Meta vanidate method, while potassium was measured photometrically by flame photometer [21]. Flax plants were pulled when signs of full maturity were appeared, then left on ground to suitable complete drying. Capsules were removed carefully. At harvest, plant height (cm), fruiting zone length (cm), number of fruiting branches/plant, number of capsules/plant, seed yield/plant (g), biological yield/plant (g) and 1000 seeds wt. (g), were recorded on random samples of ten guarded plants in each plot. Also, seed yield/fed (Kg/Fed), straw yield (ton/fed) and biological yield (ton/fed) were studied.

Oil Yield of Flax Seed: Oil yield (kg/fed) was calculated by Seed yield (kg/fed) * Seed oil content (%). Seed oil %: was determined by Soxhlet apparatus using petroleum ether (40°C - 60°C b.p) according to the Official Method [22].

Fertilizer Use Efficiency: This terminology refers to the production of crop yield / applied nitrogen, phosphorus or potassium. It was calculated according to (23) as follows:

Fertilizer use efficiency = Yield (kg/fed) /applied fertilizer (kg/fed)

where: Fertilizer use efficiency, (kg / kg).

Water Productivity of Flax Crop: Flax water productivity (WP) is an indicator of effectiveness use of irrigation water on crop production. WP flax was calculated according to [24] as follows:

WP Flax = Yield/ Irrigation water amount (kg m^{-3})

where: WP flax is the water productivity of flax crop (kg flax yield. m^{-3}irrigation water amount fed.$^{-1}$ season^{-1}). **Statistical analysis:** The datawere subjected to statistical analysis of variance of split plot design according to method described by [25] since the trend was similar in both seasons the homogeneity test Bartlet's equation was applied and the combined analysis of the two seasons was done according to the method [26]. Means were compared by using least significant difference (LSD) at 5%.

Correlative Studies: The relationship between different yield and yield components were determined. Simple correlation coefficient was determined according to [27].

RESULTS AND DISCUSSION

Effect of Water Treatments: Data presented in Table (3) and Figures (1, 2 and 4) show significant differences among different water requirements tested in all flax studied characters. In general, application of irrigation water at 75 and 100% to flax plants significantly surpassed all other water treatments in biological yield (ton/fed), seed yield (ton/fed) and oil yield (kg/fed). This is may be due to the increase in plant height, fruiting zone length (cm), technical stem length (cm), no. of fruiting branches /plant, no. of capsules/ plant, biological yield/ plant (g), straw yield/ plant (g), seed yield/ plant (g) and oil percentage.El-Karamany *et al*., [28]. Found that application of hydrogel to the soil and irrigation of sunflower with 75% of the recommended irrigation quantity produced the highest both oil% in seeds and oil yield kg/fed. also, it came in the second order in all other characters as compared to the best treatment which achieved94% in plant height; 93% in stem diameter; 84% in head diameter; 86% in biological yield/plant; 59% in head weight; 80% in seed yield/plant and 95% in seed yield/fed.

Effect of Soil Amendments Treatments: Data presented in Tables (7, 8 and 10) show highly significant differences between treatments of hydrogel, at the rate of 3.81 g/m^2 with or without farmyard manure and control in all studied characters for flax. Additions of hydrogel with farmyard manure produced seed yield/fed. with increase 39.46 %, the increase in oil yield kg/fed by 50.33 % and 34.27 % in biological yield ton/fed. than control. These increases due to growing 21.3% in plant height; 24% infruiting zone

Table 3: Effect of water regime on morphological and mineral contents of flax plants in sandy soil (Combined data of two seasons).

Water regime	Plant height cm	Fresh Weight/ plant (g)	Dry Weight/ plant (g)	N%	P%	K%
25% of IWR*	72.56	4.53	1.43	2.86	0.14	1.99
50% of IWR	81.48	6.05	1.90	3.53	0.14	2.14
75% of IWR	83.29	5.79	1.99	2.50	0.15	2.04
100% of IWR	82.94	6.23	1.89	2.77	0.17	1.63
LSD $_{0.05}$	2.02	2.03	0.62	0.84	0.01	0.27

*IWR is irrigation water requirement for flax crop.

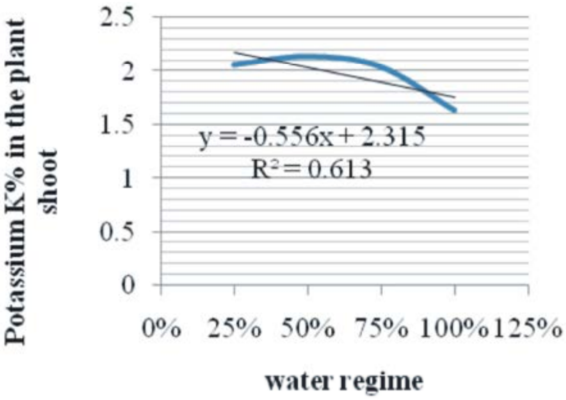

Fig. 1: Effect of water regime on potassium concentration % in plant shoot

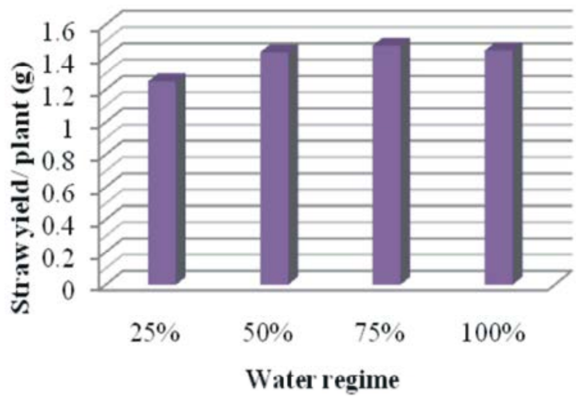

Fig. 2: Effect of water regime on straw yield per plant (g)

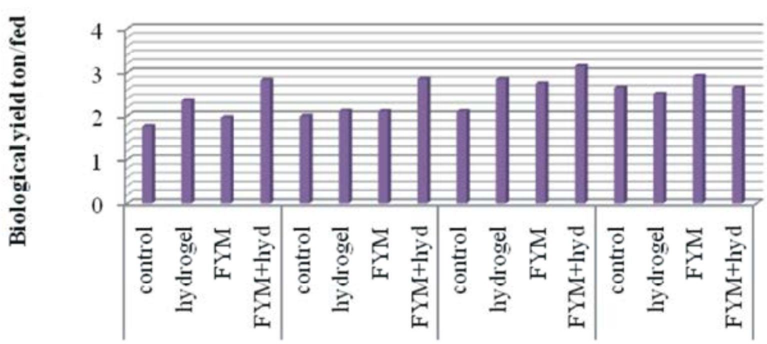

Fig. 3: Effect of water regime and soil amendments on biological yield of flax (ton/fed)

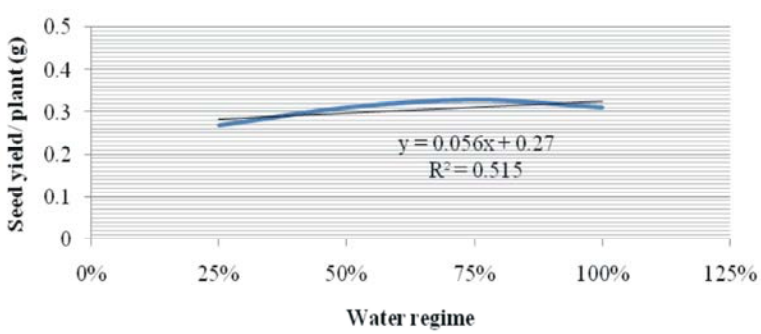

Fig. 4: Effect of water regime on seed yield per plant (g)

Table 4: Effect of water regime on yield and yield components of flax in sandy soil (Combined data of two seasons),

Water regime	Plant height (cm)	Fruiting zone length (cm)	Technical stem length (cm)	No. of fruiting branches /plant	No. of capsules/ plant	Biological yield/ plant (g)
25% of IWR*	76.75	19.42	57.33	4.08	9.08	1.52
50% of IWR	81.92	17.33	64.58	4.67	11.92	1.73
75% of IWR	89.83	18.58	71.25	4.92	11.58	1.80
100% of IWR	89.75	21.42	68.33	5.42	12.50	1.75
$LSD_{0.05}$	4.68	4.66	3.52	0.75	1.04	0.25

*IWR is irrigation water requirement for flax crop.

Table 5: Effect of water regime on nitrogen (NUE), phosphorus (PUE) and potassium (KUE) fertilizers use efficiency of flax in sandy soil (Combined data of two seasons)

Water regime	NUE biological yield kg/m^3	NUE seed yield kg/m^3	NUE oil yield kg/m^3	PUE biological yield kg/m^3	PUE seed yield kg/m^3	PUE oil yield kg/m^3	KUE biological yield kg/m^3	KUE seed yield kg/m^3	KUE oil yield kg/m^3
25% of IWR*	29.60	4.44	1.61	14.80	2.22	1.61	44.4	6.66	2.41
50% of IWR	30.13	5.47	1.98	15.07	2.74	1.98	45.2	8.21	2.97
75% of IWR	36.13	6.35	2.25	18.07	3.17	2.25	54.2	9.52	3.38
100% of IWR	35.73	7.26	2.64	17.87	3.63	2.64	53.6	10.89	3.96
$LSD_{0.05}$	1.37	0.51	0.33	0.43	0.41	0.31	0.61	1.13	0.57

*IWR is irrigation water requirement for flax crop.

Table 6: Effect of water regime on yield, yield components and water productivity of flax in sandy soil (Combined data of two seasons)

Water regime	Straw yield/ plant (g)	Seed yield/ plant (g)	Biological yield (ton/fed)	Seed yield (ton/fed)	Oil %	Oil yield (kg/fed)	WP biological yield kg/m^3	WP seed yield kg/m^3	WP oil yield kg/m^3
25% of IWR*	1.25	0.27	2.22	332.91	36.05	120.69	4.233	0.634	0.230
50% of IWR	1.43	0.31	2.26	410.5	35.99	148.33	2.155	0.391	0.141
75% of IWR	1.47	0.33	2.71	475.95	35.33	169.06	1.717	0.302	0.107
100% of IWR	1.44	0.31	2.68	544.44	36.39	198.12	1.275	0.259	0.094
$LSD_{0.05}$	0.26	0.03	0.03	5.91	0.75	3.39	0.318	0.102	0.030

*IWR is irrigation water requirement for flax crop

Table 7: Effect of soil amendments on morphological and minerals contents of flax plants in sandy soil (Combined data of two seasons)

Soil amendments	Plant height cm	Fresh Weight/ plant (g)	Dry Weight/ plant (g)	N %	P %	K %
Control	72.06	4.07	1.31	2.03	0.15	1.62
FYM	80.37	5.23	1.72	3.11	0.16	1.93
hydrogel	81.85	6.48	1.92	3.28	0.14	2.06
FYM+ hydrogel	85.98	6.81	2.26	3.25	0.14	2.18
$LSD_{0.05}$	5.67	2.64	0.59	0.39	0.01	0.15

Table 8: Effect of soil amendments on yield and yield components of flax in sandy soil (Combined data of two seasons)

Soil amendments	Plant height (cm)	Fruiting zone length (cm)	Technical stem length (cm)	No. of fruiting branches /plant	No. of capsules/ plant	Biological yield/ plant (g)
Control	74.33	16.67	57.67	3.83	1.23	8.00
FYM	87.42	20.50	66.92	5.08	1.80	11.75
hydrogel	86.33	18.92	67.42	4.83	1.87	12.42
FYM+ hydrogel	90.17	20.67	69.50	5.33	1.90	12.92
$LSD_{0.05}$	4.24	2.22	3.87	0.55	0.19	0.21

Table 9: Effect of soil amendments on nitrogen (NUE), phosphorus (PUE) and potassium (KUE) fertilizers use efficiency of flax in sandy soil(Combined data of two seasons)

Soil conditioner	NUE biological yield kg/m^3	NUE seed yield kg/m^3	NUE oil yield kg/m^3	PUE biological yield kg/m^3	PUE seed yield kg/m^3	PUE oil yield kg/m^3	KUE biological yield kg/m^3	KUE seed yield kg/m^3	KUE oil yield kg/m^3
Control	28.40	4.78	1.65	14.20	2.39	0.82	42.60	7.16	2.47
Organic manure	32.40	6.06	2.17	16.20	3.03	1.09	48.60	9.09	3.26
hydrogel	32.67	6.03	2.19	16.33	3.01	1.10	49.00	9.04	3.29
org+hydro	38.13	6.66	2.47	19.07	3.33	1.24	57.20	9.99	3.71
$LSD_{0.05}$	0.52	0.31	0.35	1.19	0.33	0.07	2.04	0.34	0.12

Table 10: Effect of soil amendments on yield and yield components of flax in sandy soil (Combined data of two seasons)

Soil conditioners	Straw yield/ plant (g)	Seed yield/ plant (g)	Biological yield ton/fed	Seed yield ton/fed	Oil %	Oil yield kg/fed	WP biological yield kg/m^3	WP seed yield kg/m^3	WP oil yield kg/m^3
Control	0.99	0.24	2.13	358.12	34.36	123.41	1.961	0.302	0.104
FYM	1.47	0.34	2.43	454.37	35.88	163.02	2.370	0.418	0.152
hydrogel	1.55	0.32	2.45	451.86	36.36	164.24	2.215	0.412	0.148
FYM+ hydrogel	1.58	0.32	2.86	499.44	37.16	185.52	2.835	0.455	0.169
$LSD_{0.05}$	0.22	0.03	0.02	5.58	0.45	2.65	0.400	0.014	0.011

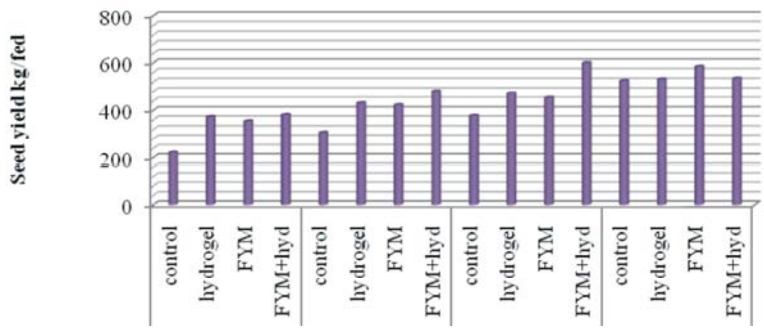

Fig. 5: Effect of water regime and soil amendments on Seed yield of flax (kg/fed)

length; 20.51% intechnical stem length; 33.16% inno. of fruiting branches /plant;54.5% inno. of capsules/ plant; 61.5 % in biological yield/ plan; 33.33% inseed yield/plant; 59.5% instraw yield /plant and oil percentage by 8.15 %compared to the untreated soil. It is clear from the data that application of organic manure or hydrogel alone were statistically equal in seed, biological and oil yields /fed while the combination of both soil amendments surpassed each treatment alone in these criteria. These results were in accordance with those obtained by [29, 30], they found that hydrogel amendments in sandy soils promoted seedlings survival and growth under arid conditions. Contrasting results may be related to the soil texture, thus hydrogel application in sandy soil promotes the water retention capacity and plant water potential [31, 32]. Under similar conditions Viero *et al*., [33] found only an increase in seedling growth when hydrogel was applied in combination with irrigation.Jahangir *et al*., [34] revealed that application of hydrogels can result in significant reduction in the required irrigation frequency particularly for coarse-textured soils. Waly, *et al*., [11] Concluded that treatment of (0.2 % hydrogel to soil) weight / weight may be effective tool to reduce water leaching from soil and recorded increase by 93.4 % in seed yield, 95.3 % in biological yield, 92.9 % in 100 seed weight and 98.3 % in oil % in seeds compared to the treatment of recommended dose of irrigation in sunflower grown in greenhouse.

The Interaction Effect: Data in Tables (9 and 10) and Figures (3 and 5) show effect of interaction between water requirements and different soil amendments treatments (hydrogel, with or without farmyard manure and control) on yield and yield components of flax under sandy soil condition. Data revealed that combined application of 75 % of water requirements and hydrogel with farmyard manure surpassed all other treatments in biological yield (ton/fed), seed yield (ton/fed) and oil yield (kg/fed). This is due to the increase in no. of capsules/ plant, biological yield/ plant (g) and straw yield/ plant (g).

Thoroughly the interaction between 75% water irrigation quantity and hydrogel produced the highest value of plant height (100 cm) without significant differences with 100 %of water requirements and hydrogel treatment (102. 33 cm) and recorded the highest value of technical stem length (80.76 cm).

Effect of the Interaction Between Water Regime and Soil Amendments on Fertilizers Use Efficiencies: Regarding the effect of water regime, data in Table (5) detected that increasing applied water to the soil led to increments in nitrogen, phosphorus and potassium fertilizers use efficienciesfor biological yield, seed yield and oil yield of flax. However, increasing water level by 100 % of ETc decreased biological yield.

Incorporating hydrogel, organic manure and hydrogel with organic manure in the soil clearly increased nitrogen, phosphorus and potassium fertilizers use efficiencies for biological yield, seed yield and oil yield of flax as shown in Table (9). The highest values of nitrogen, phosphorus and potassium fertilizers use efficiencies were obtained by applying hydrogel with organic manure to the soil. These results are in agreement with De Mamann *et al*. [35] who confirmed that hydrogelcan improve fertilizer-N efficiency biomass and grain yields of wheat; as the highest wheat yield per kilogram of N was attained by applying 30 and 60 kg ha^{-1} of hydrogel to the soil.

Concerning the interactions between the studied treatments, the obtained results in Table (13) elucidated the different effects of the interaction between water regimes, soil amendments on nitrogen, phosphorus and potassium fertilizer use efficiencies. The decrement in applied water with adding hydrogel, organic manure and hydrogel with organic manure in the soil decreased nitrogen, phosphorus and potassium fertilizer use efficiencies for biological yield, seed yield and oil yield of flax. Except for the combination of soil amendments + 100 % of the IWR, water applied reduced nitrogen, phosphorus and potassium fertilizers use efficiencies for biological yield, seed yield and oil yield of flax. [35].

Although the maximum nitrogen, phosphorus and potassium fertilizer use efficiencies were attained by the combination of (75 % of IWR water regime + applying hydrogel with organic manure), the difference is closed between the combination of (75 % of IWR water regime + applying hydrogel with organic manure) and the combination of (50 % of IWR water regime + applying hydrogel with organic manure). On the other hand, the minimum nitrogen, phosphorus and potassium fertilizer use efficiencies were recorded by the combination of (25 % of IWRwater regime + without applying soil amendments).

Effect of Interaction among Treatments on Flax Water Productivity: Data shown in Tables (6, 10 and 14) indicate that water productivity of flax under sprinkler system increased with decreasing water applied using hydrogel and organic manure, in details; the highest values of water productivity for biological yield, seed yield and oil yield were achieved using 25% of water requirements when hydrogel was incorporated with organic manure in the soil. However the lowest values were recorded by 100 % of water regime.

Although the water regime at 75 % using hydrogel and organic manure gave the highest values, the differences between 75% and 50 % of water regimes were merely 9.23 %, 19.92 % and 18.46 in biological yield, seed yield and oil yield, respectively. Moreover flax water productivity values via 50 % of water regime, hydrogel and organic manure were 2.714, 0.458 and 0.171 higher than the values of 75 % of water regime which recorded 1.994, 0.381 and 0.140 for biological yield, seed yield and oil yield, in sequence [28].

Therefore it could be concluded that the irrigation with 50% of water regime using hydrogel and organic manure is the best soil and water management for flax crop under sandy soil and save the rest of water

Table 11: Interaction between water regime and different treatments of (hydrogel, with or without farmyard manure and control) on morphological and minerals contents of flax plants in sandy soil (Combined data of two seasons)

Water regime	Treatments	Plant height cm	Fresh Weight/ plant (g)	Dry Weight/ plant (g)	N %	P %	K %
25% of IWR*	control	63.92	3.51	1.21	1.93	0.15	2.01
	FYM	71.92	4.17	1.40	2.70	0.15	2.07
	hydrogel	75.83	5.46	1.58	2.56	0.15	1.81
	FYM+ hydrogel	78.58	5.00	1.54	4.27	0.13	2.07
50% of IWR	control	71.67	3.67	1.29	3.08	0.15	1.98
	FYM	81.83	5.75	1.91	3.61	0.14	2.01
	hydrogel	84.00	6.78	1.98	4.10	0.12	2.22
	FYM+ hydrogel	88.42	7.98	2.43	3.33	0.13	2.33
75% of IWR	control	75.08	4.02	1.33	1.61	0.16	1.72
	FYM	83.83	5.35	1.70	3.33	0.15	2.45
	hydrogel	85.00	6.80	2.18	2.56	0.15	2.10
	FYM+ hydrogel	89.25	6.98	2.74	2.52	0.15	1.87
100% of IWR	control	77.58	5.10	1.40	1.51	0.17	0.76
	FYM	83.92	5.67	1.88	2.80	0.20	1.17
	hydrogel	82.58	6.88	1.93	3.92	0.15	2.13
	FYM+ hydrogel	87.67	7.27	2.35	2.87	0.16	2.45
LSD0.05		3.82	1.28	0.18	0.78	0.02	0.31

*IWR is irrigation water requirement for flax crop.

Table 12: Interaction water regime and different treatments of (hydrogel, with or without farmyard manure and control) on yield and yield components of flax in sandy soil (Combined data of two seasons)

Water regime	Treatments	Plant height (cm)	Fruiting zone length (cm)	Technical stem length (cm)	No. of fruiting branches /plant	No. of capsules/ plant	Biological yield/ plant (g)
25% of IWR*	control	70.00	17.00	53.00	3.33	5.33	1.00
	hydrogel	79.00	20.33	58.67	4.00	10.33	2.03
	FYM	73.33	20.00	53.33	4.00	10.00	1.34
	FYM+hyd	84.67	20.33	64.33	5.00	10.67	1.70
50% of IWR	control	72.33	18.67	53.67	3.33	7.67	1.17
	hydrogel	83.00	15.00	68.00	5.33	14.00	1.90
	FYM	80.33	18.67	61.67	4.67	12.33	1.77
	FYM+hyd	92.00	17.00	75.00	5.33	13.67	2.10
75% of IWR	control	75.00	14.67	60.33	3.67	9.00	1.11
	hydrogel	100.00	19.33	80.67	5.33	12.00	1.90
	FYM	93.67	19.00	74.67	5.33	11.00	2.00
	FYM+hyd	90.67	21.33	69.33	5.33	14.33	2.17
100 % of IWR	control	80.00	16.33	63.67	5.00	10.00	1.63
	hydrogel	83.33	21.00	62.33	4.67	13.33	1.63
	FYM	102.33	24.33	78.00	6.33	13.67	2.10
	FYM+hyd	93.33	24.00	69.33	5.67	13.00	1.63
LSD0.05		7.52	3.94	6.86	0.98	2.11	0.37

*IWR is irrigation water requirement for flax crop.

Table 13: Interaction water regime and different treatments of (hydrogel, with or without farmyard manure and control) on nitrogen (NUE), phosphorus (PUE) and potassium (KUE) fertilizers use efficiency of flax in sandy soil

Irrigation requirements	Treatments	NUE biological yield kg/m³	NUE seed yield kg/m³	NUE oil yield kg/m³	PUE biological yield kg/m³	PUE seed yield kg/m³	PUE oil yield kg/m³	KUE biological yield kg/m³	KUE seed yield kg/m³	KUE oil yield kg/m³
25% of IWR*	cont	23.47	2.96	1.01	11.73	1.48	0.51	35.20	4.45	1.52
	hydro	31.33	4.97	1.82	15.67	2.49	0.91	47.00	7.46	2.73
	org	26.13	4.74	1.72	13.07	2.37	0.86	39.20	7.10	2.58
	org+hydro	37.60	5.08	1.89	18.80	2.54	0.94	56.40	7.63	2.83
50% of IWR	cont	26.53	4.10	1.42	13.27	2.05	0.71	39.80	6.15	2.13
	hydro	28.13	5.74	2.10	14.07	2.87	1.05	42.20	8.61	3.15
	org	28.00	5.65	2.01	14.00	2.82	1.00	42.00	8.47	3.01
	org+hydro	38.00	6.41	2.39	19.00	3.20	1.19	57.00	9.61	3.58
75% of IWR	cont	28.00	5.03	1.67	14.00	2.52	0.84	42.00	7.55	2.51
	hydro	37.87	6.30	2.26	18.93	3.15	1.13	56.80	9.44	3.39
	org	36.53	6.05	2.15	18.27	3.03	1.08	54.80	9.08	3.23
	org+hydro	41.87	8.00	2.93	20.93	4.00	1.47	62.80	12.00	4.40
100% of IWR	cont	35.33	7.00	2.48	17.67	3.50	1.24	53.00	10.51	3.72
	hydro	33.33	7.09	2.58	16.67	3.55	1.29	50.00	10.64	3.87
	org	38.80	7.80	2.82	19.40	3.90	1.41	58.20	11.70	4.22
	org+hydro	35.33	7.14	2.69	17.67	3.57	1.35	53.00	10.71	4.04
LSD0.05		1.13	0.21	0.11	0.78	0.25	0.17	2.36	0.52	0.23

*IWR is irrigation water requirement for flax crop.

Table 14: Interaction water regime and different treatments of (hydrogel, with or without farmyard manure and control) on yield, yield components and water productivity of flax in sandy soil (Combined data of two seasons)

Water regime	Treatments	Straw yield/ plant (g)	Seed yield/ plant (g)	Biological yield ton/fed	Seed yield kg/fed	Oil %	Oil yield kg/fed	WP biological yield kg/m3	WP seed yield kg/m3	WP oil yield kg/m3
25% of IWR*	control	0.8	0.2	1.76	222.32	34.23	76.06	3.352	0.423	0.145
	hydrogel	1.72	0.31	2.35	372.9	36.53	136.23	4.476	0.71	0.259
	FYM	1.09	0.25	1.96	355.11	36.35	129.1	3.733	0.676	0.246
	FYM+hyd	1.39	0.31	2.82	381.31	37.07	141.37	5.371	0.726	0.269
50% of IWR	control	0.96	0.21	1.99	307.45	34.61	106.41	1.895	0.293	0.101
	hydrogel	1.58	0.32	2.11	430.52	36.56	157.4	2.01	0.41	0.15
	FYM	1.43	0.34	2.1	423.41	35.51	150.36	2.00	0.403	0.143
	FYM+hyd	1.75	0.35	2.85	480.62	37.28	179.16	2.714	0.458	0.171
75% of IWR	control	0.88	0.23	2.1	377.42	33.24	125.41	1.333	0.24	0.08
	hydrogel	1.55	0.35	2.84	472.15	35.93	169.65	1.803	0.3	0.108
	FYM	1.6	0.4	2.74	454.03	35.56	161.44	1.74	0.288	0.103
	FYM+hyd	1.83	0.33	3.14	600.19	36.61	219.73	1.994	0.381	0.14
100% of IWR	control	1.32	0.31	2.65	525.29	35.36	185.75	1.262	0.25	0.088
	hydrogel	1.35	0.28	2.5	531.89	36.42	193.7	1.19	0.253	0.092
	FYM	1.75	0.35	2.91	584.95	36.1	211.18	1.386	0.279	0.101
	FYM+hyd	1.33	0.3	2.65	535.64	37.68	201.83	1.262	0.255	0.096
LSD0.05		0.4	0.06	0.04	9.89	0.8	4.69	0.636	0.541	0.022

*IWR is irrigation water requirement for flax crop.

Table, 15: Correlation coefficients between biological, seed and oil yields/fed and oil % with other studied traits for flax (Combined data of two seasons).

Characters	Biological yield (ton/fed)	Seed yield (kg/fed)	Oil %	Oil yield (kg/fed)
plant height (cm)	0.77**	0.70**	0.48**	0.71**
Fruiting zone length (cm)	0.34*	0.34*	0.37**	0.37**
technical stem length (cm)	0.74**	0.65**	0.40**	0.66**
no. of fruiting branches /plant	0.68**	0.71**	0.47**	0.72**
no. of capsules/ plant	0.60**	0.76**	0.55**	0.78**
biological yield/ plant (g)	0.68**	0.62**	0.51**	0.64**
straw yield/ plant (g)	0.64**	0.59**	0.49**	0.61**
seed yield/ plant (g)	0.66**	0.60**	0.46**	0.61**
biological yield (ton/fed)		0.81**	0.51**	0.82**
seed yield (kg/fed)			0.47**	0.99**
oil %				0.57**
WP biological yield kg/m^3	- 0.13	- 0.53*	0.24	- 0.48
WP seed yield kg/m^3	- 0.14	- 0.42	0.36	- 0.35
WP oil yield kg/m^3	- 0.09	- 0.37	0.41	- 0.31

(25 % of water regime = 525 m^3) to irrigate new area of the desert under the arid condition. This may be in agreement with [16] and [7] who mentioned that the efficient water management lead to increasing soil water retention which is considered a vital issue for meeting future water demand for agriculture.

It might be suggested that decreasing water regime for flax to 50 % with applying hydrogel at 16 kg/fed and organic manure (3 ton/fed.) could be attain high flax yields and integrated soil and water management.

Correlation Coefficients: The correlative studies between different yield components parameters were assessed. Biological yield (ton /fed), seed yield (ton /fed), oil % and/ or oil yield(kg/fed) of flax showed very strong and positive ($P \leq 0.01$) correlation with other traits and yield components, namely Plant height (cm), Fruiting zone length (cm),technical stem length(cm), no. of fruiting branches/plant, no. of capsules/ plant, biological yield/ plant (g), straw yield/ plant (g), seed yield/ plant (g) (Table15). This indicates the importance of these traits in seed yield and yield component of flax.

Biological yield (ton /fed), seed yield (ton /fed), oil % and/ or oil yield (kg/fed) of flax showed negative and non significant correlation with other traits of water productivity of (biological, seed and oil yields) except water productivity of biological yield with seed yield shown significant and negative correlation (Table15).

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