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Original paper

Efect of sowing dates and seed rates of flax intercropped with sugar beet on productivity of both crops and competitive relationships

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Abstract The aim of intercropping flax on sugar beet is to increase the cultivated area with flax due to widely cultivated area of sugar beet. So, a field experiment was carried out to study the effect of various sowing dates and seed rates of flax intercropped with sugar beet on yield, quality and economic evaluation. The main-plots were assigned to three sowing dates of flax intercropped with sugar beet and the sub-plots were allocated to four seed rates of flax. The results show that sowing date of flax after 35 days from sowing (DFS) sugar beet resulted in the highest values of sugar beet yields and quality. Maximum values of flax straw and seed yields resulted from sowing flax after 21 DFS sugar beet. Intercropping sugar beet with flax at 12.5% from recommended seed rate on top sugar beet terraces attained the most elevated values of sugar beet yield and quality. Sowing flax at 50% from recommended rate resulted in the best values of flax technical and fruiting zone length, also straw and seed yield/hectare. The maximum yield and economic return of both crops were obtained from sowing flax at 12.5% from recommended rate after (21 or 35) DFS sugar beet.

Keywords Sowing dates, flax, intercropping, seed rates, sugar beet

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Introduction

Sugar beet (*Beta valgaris* var. *saccharifera* L.) is one of the main sugar crops in Egypt and many countries all over the world beside sugar cane. The importance of sugar beet is not only confined to sugar production, but also, used to produce many of products. Recently, sugar beet crop has a significant position in Egyptian crop rotation as winter crop not just in the fertile soils, but also in poor, saline alkaline and calcareous soils (ZALAT & al [1]; ABDELAAL [2]; ABDELAAL and TAWFIK [3]; ABDELAAL & al [4]; ABDELAAL & al [5]; ABDELAAL & al [6]; ALKAHTANI & al [7]). Thus, in Egypt, sugar beet has become an important crop for sugar production, the total area cultivated in 2018 season reached about 218999 hectare and the total production exceeded 11.223 million ton roots with an average of 51.247 t/ha (FAO [8]).

Flax (*Linum usitatissimum* L.) is one of the oldest cultivated crops, keeps on being widely grown for oil and fibers. Flax fibers are considered stem fibers and two to three times as strong as those of cotton and are naturally smooth and straight. Seeds flax are crushed to produce linseed oil and linseed meal. Linseed oil is a major ingredient in many fine paints, varnishes, and stains that are used to preserve, protect, and beautify wooden surfaces. Due to high amounts of omega-3 fatty acid, its cultivation and consumption is increasing as a healthy oil resource. In Egypt, the gap between the production and local consumption of flax increased, because it is difficult to increase flax area on account other major winter crops due to great competition among them. There are many efforts had done to improve the growth and yield production of flax (SHAHEIN & al [9]; RASHWAN & al [10]). However, this gap could be fairly minimized by increasing flax yield per unit area and by intercropping it with major winter crops such as sugar beet. In Egypt, the agricultural intensification which includes crop rotation, relay intercropping and intercropping of major crops with other crops had become urgent necessity to optimize the utilizing of limited cultivated area and to maximize the monetary returns of unit area (MASRI and SAFINA [11]). Several investigators reported agronomic advantage when sugar beet was intercropped with flax, which could provide the farmer with high gross returns. ABD EL LATEEF & al. [12] showed that intercropping sugar beet with flax significantly surpassed solid planting in flax length of fruiting zone and attained the highest number of capsules and biological yield plant. The total LER (LER_{flax} + $LER_{sugar\ beet}$) was 1.03 and 1.14 indicating that land use efficiency increased by 3 and 14%.

Sowing date means the impact of all natural conditions in large scale on growth and yield of all crops, which vary widely from region to other. Moreover, sowing date is an important factor, which affects the timing and length of vegetative and ripening stages, since environmental factors such as temperature and light differ with varying planting date. Sowing date also allows superposing the critical periods for oil yield and its parts with the moment of the growth season where more environmental resources are available (BALALIC & al [13]). So, it is very important to determine sowing date of flax that achieving the optimum limits for these factors in order to get higher yields. GALLARDO & al [14] concluded that delayed sowing date had a negative effect on seed yield and it`s components. RAHIMI & al [15] stated that delaying flax sowing significantly reduced plant height, number of branches and capsules/plant, and seed and fiber yields. SAGHAYESH & al [16] showed that sowing dates had a significant effect on all morphological characters. They added that an earlier sowing date (3rd March) led to better results. MAURYA & al [17] stated that yield attributes and yield of linseed sown on 4th November, which was significantly superior over both November 11th and 18th sown. HEMEID [18] showed that significant effects for sowing dates on seed index and number of seeds/capsules and seed weight/plant. The first and second cultivating dates were not significantly different from each other in straw yield/ha, but they significantly overcome on the yield of the third cultivating date. The sowing date of 15th Nov. significantly increased number of capsules/plant and seed yield/ha more than the other both sowing dates. KUMARI [19] revealed that sowing flax in the last week of November significantly increased seed and fiber yields, and also net return.

Plant density is a critical practice for determining the productivity of flax, where adjusting planting density is an important tool to optimize crop growth and maximize seed and fiber yields and quality parameters of flax. Plant density influences modulating crop environment and help to improve disease avoidance, thus adjusting plant density is an important tool to optimize crop growth and the time required for canopy closure and to achieve maximum biomass and seed yield. In this concern, DELESA and CHOFERIE [20] shown that the significant effects of seed rates were noticed on all yield components reflecting the importance of seeding rate for flax growth, yield and yield attributes. EMAM and DEWDAR [21] referred that increasing seeding rate significantly increased straw and seed yields in most cases. The favorable straw yield and its components (plant height, technical length, stem diameter and straw yield/plant) were observed, when flax plants were applied with seeding rate of 2250 seed/m^2. ERDOGDU & al [22] observed that the number of capsules and the weight of thousand grains significantly decreased with the increasing plant density (70 kg seed/ha), while seed yield was significantly increased. KATORE & al [23] indicated that the highest seed yield/ha was recorded in treatment having 22.5 kg seed ha^{-1}, which was at par with having 25 kg seed ha^{-1} and treatment having seed rate at 17.5 and 12.5 Kg ha-1. Net monetary return was noticed maximum in treatment having 22.5 kg seed ha^{-1} followed by treatment having 25 kg seed ha^{-1}. They concluded that the rate of 22.5 kg seed ha^{-1} is found optimum for irrigated linseed. XIE & al [24] showed that seed rates (450, 750, 1050 seeds m^{-2}) significantly affected on seed yield and oil yield. The highest seed rate produced greater seed and oil yields, and linolenic acid content compared to the lowest one.

Thus, this investigation was established to study the influence of sowing dates and seed rates of flax intercropped with sugar beet in order to improve the productivity of both flax and sugar beet, increasing the land use factor and increase farm income under the environmental conditions of Kafr El-Sheikh Governorate, Egypt.

Materials and Methods

A field experiment was performed twice at Sakha Agricultural Research Station Farm, Agricultural Research Center, Egypt, during the two winter growing seasons of 2018/2019 and 2019/2020 to study the impact of sowing dates and seed rates of flax (oil cultivar, Sakha 5) intercropped with sugar beet (Platos cultivar) on yield and quality of both crops as well as competitive relationships and economic evaluation.

Experimental design and treatments

The both field experiments were carried out in split-plot design with four replicates. The main-plots were assigned to sowing dates of flax intercropped with sugar beet as follows; sowing flax with sugar beet, sowing flax after 21 days from sowing (DFS) sugar beet and sowing flax after 35 DFS sugar beet. Where, sowing date of sugar beet was on 24th and 20th October in the 1st and 2nd seasons, in that order. While, sowing dates of flax were on 24th and 20th October (first sowing date), 14th and 11th November (second sowing date) and 28th and 25th November (third sowing date) in the 1st and 2nd seasons, respectively. The sub-plots were allocated to four seed rates of flax as follows; 12.5, 25.0, 37.5 and 50.0% from recommended seed rate. Where, the recommended seed rate of flax oil cultivar, Sakha 5 was 120 kg seeds/hectare (ha). Each experimental basic unit (sub-plot) included three terraces, each of 1.2 m width and 4.0 m length, resulted an area of 14.4 m^2 (1.2 X 4 X 3 =14.4 m^2). The preceding summer crop was rice (*Oryza sativa* L.) in both seasons.

Soil sampling and analysis

The soil samples from the experimental site were randomly taken from the upper 30cm of the soil surface during soil preparation in both 2018/2019 and 2019/2020 seasons, and then mechanical and chemical analyses of the soil were carried out by following the method described by PAGE [25] and its results are shown in Table (1). The averages of weather factors for Kafr El-Sheikh Governorate during the crop growing seasons are recorded in Table (2).

Cultural practices

The experimental land was well prepared through three ploughings, compaction, division and then divided into the experimental plots with dimensions as previously mentioned. Normal calcium superphosphate fertilizer (15.5% P_2O_5) as a source of phosphorus was applied as one dose for all plots during soil preparation at the rate of 475 kg/ha Sugar beet was intercropped with flax by sowing 3-5 balls/hill (seed rate was 9.5 kg/ha) using dry sowing method on both sides of terraces, 120 cm width, and 20 cm between hills at the aforementioned sowing dates in both seasons, and thinned after 30 days from sowing to 1 plant/hill to give 83333 plants/ha However, flax was intercropped with sugar beet by sowing the aforesaid flax seed rates on top sugar beet terraces at the aforementioned sowing dates in both seasons.

Table 1. The physical and chemical properties of the experimental site during 2018/2019 and 2019/2020 seasons.

Properties		2018/2019 season	2019/2020 season
A: Mechanical analysis:			
Sand %		9.85	9.76
Silt %		30.15	29.98
Clay %		60	60.26
Texture		Clay	Clay
B: Chemical analysis:			
pH		7.75	7.81
EC ds/m		2.95	2.65
Organic matter %		1.07	1.09
Total N %		0.14	0.13
Total carbonate %		61.4	61.38
CEC meq/100 g soil		61.44	61.42
SP %		78.45	78.38
SAR		4.51	4.68
Available mg/kg	N	28	25.4
	P	8.75	8.45
	K	255.7	365
Soluble cations meq/L	Ca++	6.46	6.25
	Mg++	6.36	5.41
	Na+	10.03	9.95
	K+	0.41	0.45
Soluble anions meq/L	CO3--	0	0
	HCO3-	4.5	4.16
	Cl-	9.56	8.5
	SO4--	11.09	10.87

In addition to the solo cultivation of both sugar beet and flax, according to the recommendations of the Ministry of Agriculture for each crop. Nitrogen fertilizer as ammonium nitrate (33.5%) at 190 kg N/ha was added in two equal doses, the first was applied after thinning sugar beet plants and before first irrigation (30 days from sowing) and the second before the second irrigation. Potassium sulphate (48% K_2O)

at the rate of 120 kg/ha was applied for experimental plots before the second irrigation. The other agricultural practices for flax and sugar beet were kept the same as normally practiced according to the recommendations of Ministry of Agriculture and Land Reclamation.

Table 2. Monthly averages of weather factors for Kafr El-Sheikh Governorate during 2018/19 and 2019/20 seasons.

Month	Season	Temperature C°			Relative Humidity %	Class A pan evaporation (mm/day)
		Max.	Min.	Mean		
October	2018	29.5	20.6	25	66	324
	2019	30.3	26.7	28.5	70.8	383.7
November	2018	25	17.4	21.2	70.6	160.2
	2019	27.9	25.1	26.5	65.6	230.8
December	2018	19.5	13.9	16.7	75.6	117.2
	2019	21.4	13.4	17.4	72.9	265.6
January	2019	18.9	12.3	15.6	67.8	113.8
	2020	18.4	11.8	15.1	74.7	208.8
February	2019	19.7	14.3	17	72.6	177.6
	2020	20.4	12.7	16.6	70.6	182.9
March	2019	21.7	17.6	19.7	72.2	285.8
	2020	22.6	15.6	19.1	67.5	511.9
April	2019	25.1	21.3	23.2	64.9	369.5
	2020	26	18.9	22.5	62.6	607.5
May	2019	31.9	25.4	28.7	57.2	682.9
	2020	31.9	23.8	27.9	53.7	770.3

Source: Meteorological Station at Sakha Agricultural Research Station 31˚ 07¯ N Latitude,30˚ 57¯ E Longitude with an elevation of about 6 meters above mean sea level (MSL).

Harvesting was done for sugar beet on 8th and 4th May in the first and second seasons, respectively. While, harvesting dates of flax were on 24th and 20th March (for first sowing date), 15th and 11th April (for second sowing date) and 29th and 25th April (for third sowing date) in the 1st and 2nd seasons, respectively.

The studied chaacters

Sugar beet characters

At maturity (at formerly harvesting dates) five plants from the two outer terraces were chosen at random, from the pure stand and from intercropped sub-plots of sugar beet to determine quality characters *i.e.,* total soluble solids (TSS%) in juice of fresh roots by using Hand Refract meter, sucrose percentage (%) was determined polarimetrically on lead acetate extract of fresh macerated roots (CARRUTHERS and OLDFIELD [26]) and purity percentage (%) was determined as a ratio between sucrose% and TSS% of fresh roots. Plants that were produced from the inner terrace of each sub-plot were collected and cleaned. Roots and tops were detached and weighted in Kilograms, then converted to estimate; root and top yields (t/ha) and sugar yield (t/fad) was calculated by multiplying root yield by sucrose percentage.

Flax characters

At full maturity, ten guarded flax plants were taken at random from each sub-plot (terrace) to estimate flax yield components *i.e.,* technical length (cm), stem diameter (mm.), fruiting zone length (cm.) and number of capsules/plant. Straw yield/ha (ton) and seed yield/ha (kg) were calculated from the whole sub-plot (terrace) area basis.

Competitive relationships

Land Equivalent Ratio (LER) was determined according to the following formula (WILLEY and RAO [27]):

$$\text{LER} = \frac{Yab}{Yaa} + \frac{Yba}{Ybb}$$

Where: **Yaa** and **Ybb** were pure stand of crop, a (sugar beet) and b (flax), respectively. **Yab** is mixture yield of (a) crop and **Yba** is mixture yield of (b) crop.

Aggressivity (Ag) was calculated as the following formula (MC-GILLCHRIST [28]):

- For crop (a),

$$A_{ab} = \frac{Y_{ab}}{Y_{aa} \; x \; Z_{ab}} - \frac{Y_{ba}}{Y_{bb} \; x \; Z_{ba}}$$

- and for crop (b),

$$A_{ba} = \frac{Y_{ba}}{Y_{bb} \; x \; Z_{ba}} - \frac{Y_{ab}}{Y_{aa} \; x \; Z_{ab}}$$

Where:

Aab = aggressively value for the component **a** (sugar beet).

Aba = aggressively value for the component **b** (flax).

Yab is intercrop yield of sugar beet, **Zab** is percentage of the area occupied by sugar beet.

- Relative Crowding Coefficient (RCC) or **K** was as follows (DE-WIT [29]):

$$K = Kab \times Kba$$

$$Kab = \frac{Yab \; x \; Zba}{(Yaa - Yab)Zab} \qquad Kba = \frac{Yba \; x \; Zab}{(Ybb - Yba)Zba}$$

Where: **a** is sugar beet and **b** is flax, respectively. **Zab** is a percentage of the area occupied by sugar beet and **Zba** is a percentage of the area occupied by flax.

Economic evaluations

Gross return from each treatment was calculated in U.S. Dollar (USD) according to the Ministry of Agriculture and Land Reclamation, Economic Affairs Sector, Agricultural Statistics. Where market price of sugar beet was 35.78 and 38.55 USD/ton, flax straw was 102.41 and 103.01 USD/ton straw and flax seed was 0.60 and 0.48 USD/kg in 2018/2019 and 2019/2020 seasons, respectively.

Statistical analysis

The obtained data were statistically analyzed as per the technique of analysis of variance (ANOVA) for the split-plot design using "MSTAT-C" computer software package (GOMEZ and GOMEZ [30]). Least significant difference (LSD) method was utilized to test the differences among treatment means at 5% level of probability (SNEDECOR and COCHRAN [31]).

Results and discussion

Sugar beet quality and yields

The data exposed in Tables (3) and (4) reveal that the effect of sowing dates of flax intercropped with sugar beet on sugar beet quality (total soluble solids "TSS", sucrose and apparent purity percentages) and yields (root, top and sugar yields/ha) was significant in both seasons. It can be stated that sowing date of flax after sowing sugar beet *i.e.* 28th and 25th November (third sowing date) in the 1st and 2nd seasons, respectively markedly resulted in the most elevated values of total soluble solids "TSS", sucrose and apparent purity percentages, root, top and sugar yields/ha as compared with other studied sowing dates in both seasons. Intermediate sowing date of flax after sowing sugar beet *i.e.* 14th and 11th November (second sowing date) in the two seasons, respectively was ranked secondly after third sowing date of flax. While, early sowing date of flax with sowing sugar beet *i.e.,* 24th and 20th October (first sowing date) in the first and second seasons, respectively registered the lowest values of sugar beet quality and yields in the two seasons. The increases in sugar beet quality and yields due to delay sowing of flax till 35 DFS might be attributed to the seasonable environmental conditions during this period for sugar beet which allow rapid germination, establishment, vegetative growth, development and ripening, consequently increasing dry matter accumulation , yield components as well as root , top and sugar yields per unit area. In addition, delaying flax sowing up to 35 days after sowing sugar beet reduces competition with sugar beet plants, which is reflected in increases in growth, quality and yields of sugar beet. Such results were obtained in some studies (BALALIC & al [13]; GALLARDO & al [14]; SAGHAYESH & al [16]; ABOU-ELELA [32]).

The obtained data in Tables (3) and (4) show that the studied seed rates of flax (12.5, 25.0, 37.5 and 50.0% from recommended seed rate *i.e.* 120 kg seeds/ha) intercropped with sugar beet exhibited significant effects on sugar beet quality (total soluble solids "TSS", sucrose and apparent purity percentages) and yields (root, top and sugar yields/ha) in both seasons. Intercropping sugar beet with flax by sowing flax at 12.5% from recommended seed rate on top sugar beet terraces attained the most elevated values of sugar beet quality and yields during the two winter seasons of 2018/2019 and 2019/2020. However, intercropping sugar beet with flax by sowing flax at 25% from recommended seed rate on top sugar beet terraces ranked secondly after the lowest seed rate and followed by sowing flax at 37.5% from recommended seed rate concerning its effect on sugar beet quality and yields in both seasons. Absolutely not, the highest seed rate of flax (sowing flax at 50% from recommended seed rate) gave the lowest values of all studied sugar beet quality and yields in the two growing seasons. Such impact of seed rates of flax intercropped with sugar beet might have been due to low seed rates of flax intercropped on top of sugar beet terraces reduced competition and mutual shading among sugar beet plants and flax plants, which affects the growth, quality and yield of sugar beet. These findings are in harmony with those reported by (SHEHA & al [33]; YASIN [34]; HANAFY & al [35]).

The interaction between cultivating dates and seed rates of flax intercropped with sugar beet demonstrate significant effect on sucrose percentage, root, top and sugar yields/ha in both seasons (Tables 3 and 4). However, total soluble solids (TSS) and apparent purity percentages showed insignificant effect as a result of the interaction between sowing dates and seed rates of flax intercropped with sugar beet in both growing seasons. The maximum values of sugar beet quality and yields were obtained from sowing flax at 12.5% from recommended seed rate after 35 days from sowing sugar beet (third sowing date) in both seasons. However, the second best interaction treatment for sugar beet quality and yields was gained from sowing flax at 12.5% from recommended seed rate after 21 days from sowing sugar beet (second sowing date) and followed by sowing flax at 37.5% from recommended seed rate after 35 days from sowing sugar beet (third sowing date) in both seasons. While, the lowest values of sugar beet quality and yields were obtained from sowing flax at 50.0% from recommended seed rate with sugar beet at the first sowing date *i.e.* 24th and 20th October in both seasons, respectively.

Table 3. Total soluble solids (TSS), sucrose and apparent purity percentages of sugar beet intercropped with flax as affected by sowing dates and seed rates of flax as well as their interaction during 2018/2019 and 2019/2020 seasons.

Characters		TSS (%)		Sucrose (%)		Purity (%)	
Treatments		2018/19	2019/20	2018/19	2019/20	2018/19	2019/20
Sowing dates:							
Sowing flax with sugar beet		22.95	22.48	18.30	17.90	79.73	79.61
Sowing flax after 21 DFS		23.56	23.15	18.62	18.21	78.94	78.57
Sowing flax after 35 DFS		23.78	23.38	19.38	18.98	81.65	81.19
LSD at 5 %		0.54	0.50	0.26	0.25	2.29	2.30
Seed rates of flax (ratio from recommended seed rate i.e. 120 kg seed/ha):							
12.5 %		24.26	23.86	20.11	19.70	83.12	82.57
25.0 %		23.93	23.53	19.24	18.84	80.46	80.13
37.5 %		23.64	23.13	18.68	18.28	79.03	79.07
50.0 %		21.88	21.50	17.02	16.62	77.83	77.38
LSD at 5 %		0.53	0.58	0.39	0.38	2.60	1.64
Interaction:							
Sowing flax with sugar beet	**12.5 %**	24.00	23.56	19.50	19.10	81.31	81.11
	25.0 %	23.80	23.40	19.20	18.80	80.68	80.35
	37.5 %	23.20	22.53	18.00	17.60	77.58	78.12
	50.0 %	20.80	20.43	16.50	16.10	74.71	74.25
Sowing flax after 21 DFS	**12.5 %**	24.26	23.90	19.62	19.19	80.88	80.30
	25.0 %	24.00	23.60	19.23	18.83	80.19	79.85
	37.5 %	23.73	23.26	18.98	18.58	80.00	79.88
	50.0 %	22.26	21.86	16.63	16.23	79.37	78.85
Sowing flax after 35 DFS	**12.5 %**	24.53	24.13	21.22	20.82	87.19	86.31
	25.0 %	24.00	23.60	19.30	18.90	80.50	80.19
	37.5 %	24.00	23.60	19.08	18.68	79.50	79.20
	50.0 %	22.60	22.20	17.93	17.53	79.42	79.05
LSD at 5 %		1.100	NS	NS	0.68	0.69	NS
Solo sugar beet		64.750	26.60	26.30	20.00	21.03	79.97

DFS = days from sowing.

Table 4. Root, top and sugar yields/ha of sugar beet intercropped with flax as affected by sowing dates and seed rates of flax as well as their interaction during 2018/2019 and 2019/2020 seasons.

Characters / Treatments		Root yield (t/ha)		Top yield (t/ha)		Sugar yield (t/ha)	
		2018/19	2019/20	2018/19	2019/20	2018/19	2019/20
Sowing dates:							
Sowing flax with sugar beet		47.648	47.971	16.593	16.912	8.762	8.631
Sowing flax after 21 DFS		51.524	51.814	17.914	18.198	9.650	9.510
Sowing flax after 35 DFS		56.088	56.374	19.457	19.779	10.943	10.771
LSD at 5 %		1.129	0.983	0.638	0.574	0.281	0.260
Seed rates of flax (ratio from recommended seed rate i.e. 120 kg seed/ha):							
12.5 %		59.112	59.436	20.476	20.826	11.921	11.743
25.0 %		53.555	53.833	18.586	18.881	10.310	10.171
37.5 %		49.262	49.540	17.171	17.429	9.219	9.074
50.0 %		45.088	45.405	15.721	16.048	7.688	7.564
LSD at 5 %		0.674	0.621	0.560	0.519	0.233	0.250
Interaction:							
Sowing flax with sugar beet	**12.5 %**	53.262	53.619	18.381	18.738	10.386	10.240
	25.0 %	48.976	49.333	17.136	17.310	9.405	9.276
	37.5 %	45.619	45.976	15.905	16.262	8.212	8.093
	50.0 %	42.738	42.952	14.952	15.333	7.048	6.917
Sowing flax after 21 DFS	**12.5 %**	59.762	60.143	20.667	21.000	11.729	11.545
	25.0 %	53.095	53.333	18.381	18.738	10.212	10.112
	37.5 %	48.929	49.167	17.183	17.381	9.290	9.138
	50.0 %	44.310	44.619	15.429	15.667	7.371	7.245
Sowing flax after 35 DFS	**12.5 %**	64.310	64.548	22.381	22.738	13.655	13.445
	25.0 %	58.595	58.833	20.238	20.595	11.314	11.124
	37.5 %	53.238	53.476	18.429	18.643	10.157	9.990
	50.0 %	48.214	48.643	16.786	17.143	8.648	8.529
LSD at 5 %		1.100	1.074	0.833	0.900	0.371	0.400
Solo sugar beet		64.750	65.012	22.660	22.881	13.774	13.571

DFS = days from sowing.

Flax yields and its components

Data in the Tables (5) and (6) reveal that there were significant differences among the three sowing dates of flax intercropped with sugar beet (sowing flax with sugar beet, sowing flax after 21 and 35 DFS sugar beet) on straw yield/ha, fruiting zone length and seed yield/ha in both seasons. While, technical length, stem diameter and number of capsules/plant of flax did not significantly affected by their sowing dates of flax in both seasons. The most marked and maximum values of flax straw yield and its components *i.e.* technical length, stem diameter and straw yield/ha in addition to seed yield and its attributes *i.e.* fruiting zone length, number of capsules/plant and seed yield/ha were resulted from the intermediate sowing date of flax after sowing sugar beet *i.e.* 14th and 11th November (second sowing date) in the first and second seasons, respectively followed by early sowing date (sowing flax on 24th and 20th October with sugar beet) and then late sowing date (sowing flax on 28th and 25th November after 35 DFS sugar beet sowing) in both seasons. Flax straw and seeds yields and its components were probably near maximum values at the intermediate sowing date might due to more suitable seasonable environmental conditions during this period such as temperature, day length and light intensity, which allow rapid germination, establishment, vegetative growth, development and ripening, consequently improve photosynthesis process and increase straw as well as seed yields per unit area (ABD EL LATEEF & al [12]; GALLARDO & al [14]; RAHIMI [15]; MAURYA & al [17]; HEMEID [18]).

The studied seed rates of flax (12.5, 25.0, 37.5 and 50% from recommended seed rate) intercropped with sugar beet exhibited significant effects on flax straw yield and its components *i.e.* technical length, stem diameter and straw yield/ha moreover, seed yield and its attributes *i.e.* fruiting zone length, number of capsules/plant and seed yield/ha in both seasons (Tables 5 and 6). Sowing flax at the highest seed rate (50% from recommended seed rate) in the intercropping system with sugar beet resulted in the best values of flax technical length, straw yield/ha, fruiting zone length and seed yield/ha at the same time the lowest values of stem diameter and number of capsules/plant during the two winter seasons of 2018/19 and 2019/20. These results may be due to the competition among the adjacent plants, which led to decrease the amount of solar radiations intercepted by plants, as well as less aeration and light distribution among plants, which led to decrease the photosynthetic activities and dry matter accumulation per plant, but at the same time, straw and seed yields/ha increased due to the increase in technical length, fruiting zone length and great number of flax plants per unit area. However, sowing flax at the lowest seed rate (12.5% from recommended seed rate) in the intercropping system with sugar beet produced the highest values of flax stem diameter and number of capsules/plant, simultaneously the lowest values of technical length, straw yield/ha, fruiting zone length and seed yield/ha in the two growing seasons. These results may be due to the high competition between the adjacent plants at higher plant density for light, water and nutrients, which led to decrease photosynthetic activities and produce less dry matter accumulated in different plant organs in individual plants (DELES and CHOFERIE [20]; EMAM and DEWDAR [21]; ERDOGDU & al [22]; KATORE & al [23]; XIE & al [24]).

Flax straw yield/ha, number of capsules/plant and seed yield/ha were significantly affected by the interaction between sowing dates and seed rates of flax intercropped with sugar beet in both seasons (Tables 5 and 6). The best values of flax straw yield/ha and seed yield/ha were obtained from sowing flax at 50.0% from recommended seed rate after 21 days from sowing sugar beet (second sowing date) in the first and second seasons, respectively. While, sowing flax at 12.5% from recommended seed rate after 35 days from sowing sugar beet (third sowing date) produced the lowest values of flax straw yield/ha, number of capsules/plant and seed yield/ha in both seasons. However, the most elevated values of flax number of capsules/plant were obtained from sowing flax at 12.5% from recommended seed rate after 21 DFS sugar beet *i.e.,* 14th and 11th November (second sowing date) in both seasons, respectively. While, sowing flax at 50.0% from recommended seed rate after 35 days from sowing sugar beet (third sowing date) produced the lowest values of flax number of capsules/plant in both seasons. The superiority in flax straw and seed yields and its components values at the intermediate sowing date might due to the more suitable seasonable environmental conditions with suitable seed rates of flax. These results are matching with those obtained by HUSSEIN and METWALLY [36]; EL-SHAMY and SHAHEIN [37].

Competitive relationships

The highest values of competitive relationship Land equivalent ratio "LER" (1.27 and 1.26) as presented in Table (7) were obtained from sowing flax at 50.0% from recommended seed rate after 21 DFS sugar beet (second sowing date) in the 1st and 2nd seasons, respectively and after 35 DFS sugar beet with the highest density in the second season only. While, the lowest values of LER (1.12 and 1.08) were recorded from sowing flax at12.5% and 25% from recommended seed rate, respectively with the first sowing date in both seasons. This result could be attributed to plant density of sugar beet was 100% of its pure stand, while the plant density of flax ranged from 12.5, 25, 37.5 up to 50% of its pure stand.

The highest values of competitive relationship Relative crowding coefficient "RCC" (44.75 and 39.63) as presented in Table (8) were obtained from sowing flax at 12.5% from recommended seed rate with 35 DFS sugar beet (third sowing date) in the first and second seasons, respectively. Nevertheless, sowing flax at 12.5% from recommended seed rate after 21 DFS sugar beet (second sowing date) came in the second rank regarding the aforementioned competitive relationships traits within together seasons, except for LER in the second season, it was belonged to 12.5% from recommended seed rate at 35 DFS sugar beet. As for RCC, the lowest ones (1.72 and 1.47) were recorded from sowing flax at 25% from recommended seed rate with first sowing date of sugar beet in the first and second seasons, in order.

Table 5. Technical length, stem diameter and straw yield/ha of flax intercropped with sugar beet as affected by sowing dates and seed rates of flax as well as their interaction during 2018/2019 and 2019/2020 seasons.

Characters / Treatments		Technical length (cm)		Stem diameter (mm)		Straw yield (t/ha)	
		2018/19	2019/20	2018/19	2019/20	2018/19	2019/20
Sowing dates:							
Sowing flax with sugar beet		55.89	54.733	1.933	2.042	1.938	1.724
Sowing flax after 21 DFS		57.81	55.642	1.95	2.133	2.045	1.798
Sowing flax after 35 DFS		55.86	53.567	1.875	2.025	1.481	1.433
LSD at 5 %		NS	NS	NS	NS	0.221	0.200
Seed rates of flax (ratio from recommended seed rate i.e. 120 kg seed/ha):							
12.5 %		51.18	49.01	2.233	2.378	0.926	0.836
25.0 %		52.87	50.88	2.156	2.289	1.371	1.319
37.5 %		58.76	56.80	1.678	1.811	2.002	1.833
50.0 %		63.26	61.88	1.611	1.789	2.986	2.619
LSD at 5 %		2.94	2.80	0.215	0.234	0.152	0.162
Interaction:							
Sowing flax with sugar beet	**12.5 %**	51.46	49.26	2.067	2.167	0.969	0.779
	25.0 %	53.33	51.16	2.233	2.333	1.517	1.436
	37.5 %	55.60	53.30	1.600	1.700	2.195	1.945
	50.0 %	63.06	60.53	1.567	1.767	3.071	2.738
Sowing flax after 21 DFS	**12.5 %**	52.46	50.30	2.333	2.433	1.040	0.979
	25.0 %	53.36	51.13	2.067	2.200	1.550	1.445
	37.5 %	60.66	58.8	1.633	1.767	2.243	2.014
	50.0 %	64.76	62.8	1.733	1.967	3.350	2.755
Sowing flax after 35 DFS	**12.5 %**	49.63	47.46	2.300	2.533	0.264	0.283
	25.0 %	51.93	50.36	2.167	2.333	1.048	1.079
	37.5 %	60.03	58.30	1.800	1.900	1.571	1.540
	50.0 %	61.96	62.33	1.533	1.700	2.540	2.364
LSD at 5 %		NS	NS	NS	NS	0.769	0.752
Solo flax		70.80	67.40	1.40	1.50	6.310	5.617

DFS = days from sowing.

Table 6. Fruiting zone length, number of capsules/plant and seed yield/ha of flax intercropped with sugar beet as affected by sowing dates and seed rates of flax as well as their interaction during 2018/2019 and 2019/2020 seasons.

Characters		Fruiting zone length (cm)		Number of capsules/plant		Seed yield (kg/ha)	
Treatments		2018/19	2019/20	2018/19	2019/20	2018/19	2019/20
Sowing dates:							
Sowing flax with sugar beet		16.95	19.11	18.75	21.91	636.7	564.3
Sowing flax after 21 DFS		19.43	21.59	20.75	23.66	677.4	566.4
Sowing flax after 35 DFS		16.62	18.7	17	20.66	497.9	517.4
LSD at 5 %		2.29	2.32	NS	NS	45.0	42.1
Seed rates of flax (ratio from recommended seed rate i.e. 120 kg seed/ha):							
12.5 %		16.78	18.75	23.77	27.55	461.9	376.4
25.0 %		16.81	19.08	18.33	21.66	544.3	460.2
37.5 %		18.00	20.22	18.00	21.00	621.7	558.1
50.0 %		19.07	21.15	15.22	18.11	788.1	802.9
LSD at 5 %		1.36	1.32	1.59	1.65	70.5	72.1
Interaction:							
Sowing flax with sugar beet	**12.5 %**	16.30	18.10	24.33	27.33	476.2	381.0
	25.0 %	16.20	18.53	19.00	22.00	574.5	484.0
	37.5 %	16.86	19.26	17.66	20.66	706.2	634.8
	50.0 %	18.43	20.56	14.00	17.66	789.5	757.9
Sowing flax after 21 DFS	**12.5 %**	18.33	20.43	26.66	29.66	531.7	411.9
	25.0 %	18.33	20.63	20.00	23.00	590.5	449.0
	37.5 %	20.03	22.20	20.33	23.33	642.9	531.7
	50.0 %	21.03	23.10	16.00	18.66	944.3	872.9
Sowing flax after 35 DFS	**12.5 %**	15.73	17.73	20.33	25.66	377.6	336.4
	25.0 %	15.90	18.10	16.00	20.00	468.1	447.6
	37.5 %	17.10	19.20	16.00	19.00	515.7	507.9
	50.0 %	17.76	19.80	15.66	18.00	630.0	777.6
LSD at 5 %		NS	NS	2.75	2.68	121.9	126.2
Solo flax		19.2	21.3	13	14	1609.5	1516.7

DFS = days from sowing.

Table 7. Land Equivalent Ratio (LER) and Aggressivity (Ag) of intercropping flax with sugar beet as affected by sowing dates and seed rates of flax during 2018/2019 and 2019/2020 seasons.

Character / Treatments		Land equivalent ratio (LER)			Aggressivity (Ag)
		Ls	Lf	LER	Ag s
		2018/2019 season			
Sowing flax with sugar beet	**12.50%**	0.82	0.3	1.12	-1.74
	25.00%	0.76	0.36	1.12	-0.84
	37.50%	0.7	0.44	1.14	-0.64
	50.00%	0.66	0.49	1.15	-0.48
Sowing flax after 21 DFS	**12.50%**	0.92	0.33	1.25	-1.93
	25.00%	0.82	0.37	1.19	-0.81
	37.50%	0.76	0.4	1.16	-0.43
	50.00%	0.68	0.59	1.27	-0.73
Sowing flax after 35 DFS	**12.50%**	0.99	0.23	1.23	-0.99
	25.00%	0.9	0.29	1.20	-0.32
	37.50%	0.82	0.32	1.14	-0.04
	50.00%	0.74	0.39	1.14	-0.06
		2019/2020 season			
Sowing flax with sugar beet	**12.50%**	0.82	0.25	1.08	-1.33
	25.00%	0.76	0.32	1.08	-0.65
	37.50%	0.71	0.42	1.13	-0.56
	50.00%	0.66	0.5	1.16	-0.51
Sowing flax after 21 DFS	**12.50%**	0.93	0.27	1.20	-1.40
	25.00%	0.82	0.3	1.12	-0.45
	37.50%	0.76	0.35	1.11	-0.25
	50.00%	0.69	0.58	1.26	-0.70
Sowing flax after 35 DFS	**12.50%**	0.99	0.22	1.21	-0.88
	25.00%	0.9	0.3	1.20	-0.34
	37.50%	0.82	0.33	1.16	-0.10
	50.00%	0.75	0.51	1.26	-0.42

DFS = days from sowing, s = sugar beet, f = flax.

Table 8. Aggressivity (Ag) and Relative Crowding Coefficient (RCC) of intercropping flax with sugar beet as affected by sowing dates and seed rates of flax during 2018/2019 and 2019/2020 seasons.

Character		Aggressivity (Ag)	Relative Crowding Coefficient (RCC)		
Treatments		Ag f	Ks	Kf	K
			2018/2019 season		
Sowing flax with sugar beet	**12.50%**	1.74	0.58	3.36	1.95
	25.00%	0.84	0.78	2.22	1.72
	37.50%	0.64	0.89	2.08	1.86
	50.00%	0.48	0.97	1.93	1.87
Sowing flax after 21 DFS	**12.50%**	1.93	1.5	3.95	5.91
	25.00%	0.81	1.14	2.32	2.64
	37.50%	0.43	1.16	1.77	2.06
	50.00%	0.73	1.08	2.84	3.08
Sowing flax after 35 DFS	**12.50%**	0.99	18.25	2.45	44.75
	25.00%	0.32	2.38	1.64	3.90
	37.50%	0.04	1.73	1.26	2.18
	50.00%	0.06	1.46	1.29	1.88
			2019/2020 season		
Sowing flax with sugar beet	**12.50%**	1.33	0.59	2.68	1.58
	25.00%	0.65	0.79	1.88	1.47
	37.50%	0.56	0.91	1.92	1.74
	50.00%	0.51	0.97	2	1.94
Sowing flax after 21 DFS	**12.50%**	1.40	1.54	2.98	4.61
	25.00%	0.45	1.14	1.68	1.92
	37.50%	0.25	1.16	1.44	1.67
	50.00%	0.70	1.09	2.71	2.97
Sowing flax after 35 DFS	**12.50%**	0.88	17.38	2.28	39.63
	25.00%	0.34	2.38	1.67	3.99
	37.50%	0.10	1.74	1.34	2.33
	50.00%	0.42	1.49	2.1	3.13

DFS = days from sowing, s = sugar beet, f = flax.

Table 9. Effect of the interaction between sowing dates and seed rates of flax on economic evaluation of intercropping flax with sugar beet during the two winter seasons of 2018/2019 and 2019/2020.

Treatments		Economic evaluation		
Sowing dates of flax	Seed rates of flax	Actual sugar beet root yield (USD)	Actual flax straw yield (USD)	Actual flax seed yield (USD)
			2018/2019	
Sowing flax with sugar beet	**12.50%**	801.81	66.20	120.48
	25.00%	737.29	103.61	145.36
	37.50%	686.75	149.94	178.67
	50.00%	643.37	209.82	199.76
Sowing flax after 21 DFS	**12.50%**	899.70	71.08	134.52
	25.00%	799.34	105.90	149.40
	37.50%	736.57	153.19	162.65
	50.00%	667.05	228.86	238.92
Sowing flax after 35 DFS	**12.50%**	968.13	18.07	95.54
	25.00%	882.11	71.57	118.43
	37.50%	801.45	107.35	130.48
	50.00%	725.84	173.55	159.40
Solo sugar beet		974.76	—	—
			2019/2020	
Sowing flax with sugar beet	**12.50%**	868.25	49.28	96.39
	25.00%	798.86	90.84	122.47
	37.50%	744.46	123.07	160.60
	50.00%	695.54	173.19	191.75
Sowing flax after 21 DFS	**12.50%**	973.86	61.93	104.22
	25.00%	863.61	91.45	113.61
	37.50%	796.14	127.41	134.52
	50.00%	722.53	174.28	220.84
Sowing flax after 35 DFS	**12.50%**	1045.18	17.95	85.12
	25.00%	952.65	68.25	113.25
	37.50%	865.90	97.47	128.49
	50.00%	787.65	149.58	196.75
Solo sugar beet		1052.71	—	—

DFS = days from sowing.

Table 10. Effect of the interaction between sowing dates and seed rates of flax on economic evaluation of intercropping flax with sugar beet during the two winter seasons of 2018/2019 and 2019/2020.

Treatments		Economic evaluation		
Sowing dates of flax	Seed rates of flax	Total income (USD)	Total cost (USD)	Economic return (USD)
			2018/2019	
Sowing flax with sugar beet	**12.50%**	988.49	567.53	421.02
	25.00%	986.27	592.83	393.43
	37.50%	1015.42	618.19	397.23
	50.00%	1052.95	643.49	409.46
Sowing flax after 21 DFS	**12.50%**	1105.24	567.53	537.77
	25.00%	1054.58	592.83	461.75
	37.50%	1052.47	618.19	434.28
	50.00%	1134.82	643.49	491.33
Sowing flax after 35 DFS	**12.50%**	1081.75	567.53	514.22
	25.00%	1072.11	592.83	479.28
	37.50%	1039.28	618.19	421.14
	50.00%	1058.80	643.49	415.30
Solo sugar beet		974.76	542.17	432.59
			2019/2020	
Sowing flax with sugar beet	**12.50%**	1013.86	587.83	426.02
	25.00%	1012.11	615.42	396.69
	37.50%	1028.13	643.01	385.12
	50.00%	1060.48	670.60	389.88
Sowing flax after 21 DFS	**12.50%**	1140.00	587.83	552.17
	25.00%	1068.67	615.42	453.25
	37.50%	1058.07	643.01	415.06
	50.00%	1117.59	670.60	446.99
Sowing flax after 35 DFS	**12.50%**	1148.25	587.83	560.42
	25.00%	1134.16	615.42	518.73
	37.50%	1091.87	643.01	448.86
	50.00%	1133.98	670.60	463.37
Solo sugar beet		1052.71	560.24	492.47

DFS = days from sowing.

Concerning the Aggressively (Ag), the highest value for flax (+1.93 and +1.40) and the lowest value for sugar beet (-1.93 and -1.40) were resulted from sowing flax at 12.5% from recommended seed rate after 21 DFS sugar beet (second sowing date) in the first and second seasons, in order. While, the lowest value of (Ag) for flax (+0.04 and +0.10) and the highest value for sugar beet (-0.04 and -0.10) were resulted from sowing flax at 37.5% from recommended seed rate after 35 days from sowing sugar beet (third sowing date) in the 1st and 2nd seasons, respectively. These results are expected since increased plant density of flax increased competition between intercrops species and decreased yield and its components consequently decreased relative yields of both crops. While, intercropping flax with sugar beet under the optimum plant density (12.5% from recommended seed rate) showed efficient utilization of land and environment resources by growing both crops. These results are in agreement with those obtained by SHEHA & al [33]; EL-SHAMY and SHAHEIN [37].

Economic evaluations

Concerning the economic evaluation of the interaction between sowing dates and seed rates of flax intercropped with sugar beet during the two winter seasons of 2018/2019 and 2019/2020, the data available in Tables (9) and (10) obvious show that the highest values of actual sugar beet root yield (968.13 and 1045.18 USD) in both seasons, respectively, total income (1148.25 USD) and economic return (560.42 USD) in the second season were obtained from sowing flax at 12.5% from recommended seed rate after 35 DFS sugar beet (third sowing date). However, the best values of actual flax straw yield (228.86 and 174.28 USD) and actual flax seed yield (238.92 and 220.84 USD) in both seasons, respectively and total income (1134.82 USD) in the first season were obtained from sowing flax at 50.0% from recommended seed rate after 21 DFS sugar beet (second sowing date). While, the highest value of economic return in the first season (537.77 USD) was recorded with 12.5% from recommended seed rate after 21 days from sowing sugar beet.

Conclusion

From the obtained results of this study under intercropping sugar beet and flax, it can be concluded that the maximum actual sugar beet root yield and economic return of both sugar beet and flax were obtained from sowing flax at 12.5% from recommended seed rate after (21 or 35) days from sowing sugar beet (second or third sowing date) under the environmental conditions of Kafr El-Sheikh Governorate, Egypt.

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Conflict of interest

The authors have no conflict of interest to declare.

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