Effect of planting methods of flax on garlic yield under different intercropping patterns

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Abstract

The purpose of this experiment was to investigate yield, yield components and economic evaluation of flax (Sakha 5) and garlic (Sids 40) under various planting methods and intercropping patterns. The experimental design was a split-plot design with four replicates. The main-plots were assigned to the three cultivating methods and the sub-plots were allocated to the four intercropping patterns. The results indicated that drilling as planting method achieved the highest values for most studied characters in both seasons for flax and garlic, except for number of cloves/plant and plant height in garlic. Intercropping system with low garlic density (100% flax + 12.5% garlic) produced the maximum values for stem diameter, straw yield, number of capsules and seed/plant, seed index and seed yield for flax and number of leaves and cloves/plant, head diameter and weight for garlic in both seasons. The highest bulb yield of garlic was achieved with intercropping 100% flax + 37.5% garlic in both seasons. It can be concluded that the most economic returns for both crops were obtained from drilling as planting method with intercropping pattern 100% flax + 37.5% garlic under the environmental conditions of North Delta of Egypt.

Keywords: Intercropping, Land equivalent ratio (LER), Aggressivity (Ag), Relative crowding coefficient (RCC), economic evaluation

INTRODUCTION

Flax (*Linum usitatissimum* L.) is an ancient fiber crop. Egyptians knew flax since thousands of years and have grown this crop for a dual purpose (fibers and seeds). Flax ranks second to cotton as a fiber crop in Egypt, where it has a major impact on the national economy due to local industry and fiber exports. Flax fibers are stem fibers that are two to three times stronger than cotton fibers and are inherently smooth and straight. The long fibers are spun into linen yarns, moved into toweling, clothing fabrics and textiles. The short fibers (tow), are used for twins, paper manufacture and packing. Flax Seeds 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. The entire cultivated area of flax crop in Egypt reached about 8 609 hectares in 2021 season, producing 7 600 tons of fibers (FAO, 2023).

Garlic (*Allium sativum* L.) is among the most important vegetable crops in Egypt for both local and export markets. Garlic is the second most extensively utilized of the cultivated bulb crops, after onion, and one of the most crucial vegetable crops in Egypt since 3000 B.C. (Ipek and Simon, 2002). Garlic can be eaten raw as a whole clove or in tomato salads or cooked as a spice and flavouring element. Garlic has been used for a variety of therapeutic purposes, including use as hypoglycemic, hypochloterlamic, antispasmolytic and antihypertensive agent (Brahamchar and Augusti, 1962; Augusti, 1977 and El-Hadidy *et al*., 1981). Garlic is a high-value commercial crop because of its numerous uses in local consumption, food processing, and exports (AL-Otayk *et al*., 2008 and Eleshmawiy *et al*., 2010). In Egypt, the cultivated area is about 16 757 hectares with total production 348 230 tons in 2021 season (FAO, 2023).

Improvement of cultural practices such as sowing method can plays an important role in increasing flax productivity. Differences between planting methods (broadcasting and drilling) in flax were not significant for top branching zone length, number of capsules/plant, seeds number/plant, seeds number/capsule, seed yield/plant as well as per feddan (feddan = 4200 m^2), and oil content (El kholy, 1999). El Azzouni *et al.* (2006) reported that the drilling cultivating method significantly surpassed broadcast cultivating method in straw and fiber yields and their components in flax. El Borhamy (2011) showed that the differences between planting methods in flax were insignificant on technical length, stem diameter, straw yield, number of seeds and seed yield per plant. While, the variations were significant in straw and seed yield, seed index and seed oil content, whereas drilling was greater than broadcasting. Sorour *et al.* (2015) showed that the planting method significantly affected all studied characters in flax except technical length, stem diameter and seed index. Planting method affected significantly plant height, yield and its components, seed yield and its components and on fiber yield and its related characters (Shaheen, 2017). El Hag (2019) detailed that drill planting method achieved the highest values for all the studied characters in flax compared with broadcast method except for stem diameter and fruiting zone length.

In Egypt, agricultural intensification, which includes crop rotation, relay intercropping, and intercropping of key crops with other crops, has become a pressing need to maximise monetary returns per unit area while maximising the use of scarce farm land (Masri and Safina, 2015). Under intercropping system, attention should be given to the crops that can grow together with minimal competition and maximum profit (Aboukhadra *et al*., 2013; Abdel Motagally and Metwally, 2014). Abd El Lateef *et al.* (2019) showed that intercropping sugar beet with flax outperformed solid planting significantly in terms of flax length of fruiting zone, capsules number and biological yield. The total Land Equivalent Ratio (LER) (LER flax + LER sugar beet) was 1.03 and 1.14 indicating that land use was efficiency raised by 3 and 14%. Abd-Rabboh *et al.* (2021) showed that when sugar beet and flax were intercropped, the maximum sugar beet root production and economic return of both crops were attained by sowing flax at 12.5% of the required seed rate following (21 or 35) days of sowing sugar beet at 100% of the recommended seed rate (second or third sowing date).

The purpose of this study is to evaluate the influence of planting methods and different intercropping patterns of garlic intercropped with flax in order to enhance productivity of both crops, increasing the land use factor and raise farm revenue under the environmental conditions of North Delta of Egypt.

MATERIALS AND METHODS

At the Experimental Farm of Sakha Agricultural Research Station, Agricultural Research Center (ARC), Egypt, two field experiments were established during two successive winter seasons of 2020/21 and 2021/22. The primary goal of this research is to find the optimal planting method and best intercropping pattern for yield and its components for flax (oil cultivar, Sakha 5) and garlic (Sids 40 cultivar), as well as competitive relationships and economic evaluation.

Experimental design and treatments

The experimental design was a split-plot design with four replicates, where each experimental sub-plot area was 14.7 m^2 included three terraces, each one 1.4 m width and 3.5 m length, resulted an area of 14.7 m^2 (1.4 x 3.5 x 3 =14.7 m^2 for each basic unit).

The main-plots were assigned to the three planting methods of flax; broadcast, drilling and hills (consists of 4 rows and the distance between hills was 10 cm for each terrace), where the sub-plots were allocated to the four intercropping patterns for garlic on flax as follows; 100% flax + 12.5% garlic, 100% flax + 25% garlic, 100% flax + 37.5% garlic and 100% flax + 50% garlic. Where, the recommended seed rate of flax Sakha 5 cultivar was 140 kg and Sids 40 cultivar was 950 kg per hectare, respectively.

The soil of the experimental field was clay in texture. The preceding summer crop was maize in both seasons of study. Mechanical and chemical analysis for the experimental sites in the first and second seasons is presented in table 1.

Table 1: The physical and chemical properties of the experimental site in 2020/2021 and 2021/2022 seasons

Properties		2020/2021 season	2021/2022 season
Mechanical analysis			
Sand %		9.71	9.80
Silt %		30.3	29.9
Clay %		59.9	60.3
Texture		Clayey	Clayey
Chemical analysis			
pH		7.68	7.82
EC ds/m		2.90	2.85
Organic matter %		1.30	1.25
Available mg/kg	N	26.3	27.1
	P	8.70	8.65
	K	250.8	260.5
Soluble cations meq/L	Ca^{++}	6.63	6.42
	Mg^{++}	5.92	6.86
	Na^{+}	10.5	9.91
	K^{+}	0.45	0.46
Soluble anions meq/L	CO_3^{--}	0	0
	HCO_3^{-}	4.60	4.48
	Cl^{-}	9.26	8.92
	SO_4^{--}	11.1	10.8

During soil preparation, all phosphorus fertilizer requirement as calcium super phosphate (15.5% P_2O_5) was added at the rate of 240 kg/ha, in addition to nitrogen fertilizer at the rate of 110 kg N/ha as ammonium nitrate (33.5% N) in two doses of equal size, the first before the second irrigation while the second one was applied before the third irrigation.

Flax was sown using dry sowing method on the top of terraces, 140 cm width on 30th October and 1st November in both seasons, respectively. Garlic bulbs were separated with care into individual cloves and cloves were soaked overnight in tap water before planting to enhance sprouting. The garlic was intercropped with flax on both sides of terraces on 30th October and 1st November, for the first and second seasons. In addition to the solo cultivation of both flax and garlic was according to the recommendations of the Ministry of Agriculture for each crop.

Flax characters

At maturity, ten marked plants were chosen at random from the pure stand and from intercropped sub-plots to register the following traits *i.e.,* technical length (cm), stem diameter (mm), fruiting zone length (cm), number of capsules/plant, number of seeds/plant and seed index (g), Straw yield/ha (ton) and seed yield/ha (kg).

Garlic characters

At harvest, data on ten randomly singular plants from each sub-plot were recorded to determine the averages of the individual plant traits *i.e.,* plant height (cm), number of leaves/plant, head diameter (cm), head weight (g) and number of cloves/plant. As for, total yield (ton/ha.), the yield of each plot was weighted and expressed as ton/hectare.

Competitive relationships

Land equivalent ratio (LER) was determined according to the formula described by Willey and Rao (1980):

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

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

b- Aggressivity (Ag) was calculated according to McGillchrist (1965) as the following formula:

For crop (a),

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

and for the crop (b),

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

Where:

Aab = Aggressivity value for the component **a** (flax).

Aba = Aggressivity value for the component **b** (garlic).

Yab is the intercrop yield of **flax**, **Zab** is the percentage of the land that is occupied by garlic.

c- Relative crowding coefficient (RCC) or K was calculated according to De-Wit (1960) as follows:

$$\mathbf{K = Kab \times Kba}$$

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

Where: **a** is **flax** and **b** is the **garlic**, respectively. **Zab** is the percentage of the land that is occupied by **flax**, and **Zba** is the land that is occupied by **garlic**.

Economic evaluations

Gross return from each treatment was calculated in Egyptian Pound (**LE**), and then converted to U.S. Dollar (**USD**) as stated by the Egyptian Ministry of Agriculture and Land Reclamation, Economic Affairs Sector, Agricultural Statistics. Where, market price of garlic was 446 and 218 USD/ton, flax straw was 223 and 164 USD/ton straw and flax seed was 0.76 and 0.82 USD/kg in 2020/2021 and 2021/2022 seasons, respectively.

Net return = Total income – Total costs.

Statistical analysis

The data was statistically analysed using the method of analysis of variance (ANOVA) for the split-plot design as published by Gomez and Gomez (1984) using the "MSTAT-C" software package. In addition, treatment means were compared by using the least significant difference (LSD) method at 5% level probability as described by Snedecor and Cochran (1980).

RESULTS AND DISCUSSION

Yield and its components of flax

All the studied characters of flax significantly affected by planting methods when intercropped with garlic, except for the seed index in each season (Tables 2 and 3). Drilling cultivating method recorded the highest values for all studied characters in both seasons, followed by broadcast method while the lowest values were obtained by hills cultivating method. The differences between drilling and broadcast sowing methods did not reach the level of significance. These results can be attributed to the regularity of planting distances, which in turn leads to the regularity of germination and ensuring obtaining homogeneous plants with less competition compared to other cultivation methods. These findings support those previously reported by El Azzouni *et al.* (2006), El Borhamy (2011), Sorour *et al.* (2015), (Shaheen, 2017) and El Hag (2019).

With respect to intercropping patterns, significant differences of all the studied characters of flax except for the seed index in both seasons were observed (Tables 2 and 3). The highest plant density (100% flax + 50% garlic) recorded the highest values for technical length and fruiting zone length in both study seasons. While, the lowest plant density (100% flax + 12.5% garlic) obtained the best results for stem diameter, straw yield, number of capsules and seeds/plant and seed yield. The superiority of high density in increasing technical length and fruiting zone length might be due to shading under conditions of dense planting, which led to reducing light intensity and to competition for sunlight making the plants grow taller to exploit light to a maximum in denser plant populations. So, these findings attributed mainly to the role of competition among plants on available environmental elements with increasing or decreasing the plant density. These results are in line with those recorded by Aboukhadra *et al.* (2013), Abdel Motagally and Metwally, (2014), Abd El Lateef *et al.* (2019) and Abd-Rabboh *et al.* (2021).

The interaction between planting methods and intercropping patterns exhibited a significant influence on straw yield (ton/ha), number of capsules/plant and seed yield (kg/ha) in each season (Tables 2 and 3). Furthermore, data revealed that the highest values of aforementioned characters belonged to drilling sowing method with the lowest plant density (100% flax + 12.5% garlic).

Yield and its components of garlic

The data in tables 4 and 5 showed that planting methods had a significant effect on most garlic characters, except for number of leaves/plant and number of cloves/plant in the first and both seasons, respectively. The presented data showed that drilling cultivating method significantly exceeded broadcast and hills in number of leaves/plant, head diameter, head weight and bulb yield (ton/ha) in both growing season. However, broadcast sowing method significantly recorded the tallest plants. The superiority of drilling cultivating method in increasing most studied characters might be due to help the plants got to gain suitable irrigation water and nutrients accord-

Table 2: Technical length, stem diameter, straw yield and fruiting zone length of flax (f) intercropped with garlic (g) as affected by planting methods and intercropping systems

Characters / Treatments		Technical length (cm)		Stem diameter (mm)		Straw yield (ton/ha)		Fruiting zone length (cm)	
		2020/21	2021/22	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22
Planting methods									
Broadcast		62.9	60.7	1.9	1.8	5.841	5.315	19.4	19.2
Drilling		64.1	62.3	2.0	1.9	6.137	5.915	20.3	19.7
Hills		57.6	57.4	1.8	1.6	4.580	4.403	18.1	17.9
LSD at 5 %		1.5	3.0	0.1	0.1	0.827	0.604	1.5	1.3
Intercropping systems:									
100% flax + 12.5% garlic		55.7	54.4	2.0	2.0	6.128	5.658	18.0	17.0
100% flax + 25% garlic		59.8	58.2	2.0	1.9	5.867	5.452	18.7	18.6
100% flax + 37.5% garlic		63.7	61.8	1.9	1.7	5.714	5.266	19.6	19.7
100% flax + 50% garlic		66.9	66.2	1.8	1.5	4.368	4.469	20.8	20.5
LSD at 5 %		3.7	3.1	0.1	0.1	0.556	0.496	1.1	1.2
Interaction									
Broadcast	100% f + 12.5% g	56.8	54.2	2.0	2.0	6.087	5.570	18.1	17.0
	100% f + 25% g	60.3	58.3	2.0	1.9	6.037	5.450	18.7	19.0
	100% f + 37.5% g	65.8	62.7	1.9	1.7	5.897	5.287	19.6	20.1
	100% f + 50% g	68.8	67.6	1.8	1.5	5.343	4.953	21.1	20.7
Drilling	100% f + 12.5% g	57.3	55.5	2.1	2.0	6.423	6.153	18.8	17.9
	100% f + 25% g	62.3	60.1	2.0	2.0	6.410	5.927	19.7	19.4
	100% f + 37.5% g	67.2	63.6	2.0	1.9	6.270	5.880	20.8	20.4
	100% f + 50% g	69.5	70.1	1.9	1.7	5.443	5.700	21.9	21.2
Hills	100% f + 12.5% g	53.2	53.5	2.0	1.9	5.873	5.250	17.0	16.1
	100% f + 25% g	56.6	56.1	1.9	1.8	5.153	4.980	17.6	17.3
	100% f + 37.5% g	58.1	59.0	1.7	1.5	4.977	4.630	18.5	18.7
	100% f + 50% g	62.5	60.9	1.6	1.3	2.317	2.753	19.4	19.5
LSD at 5 %		NS	NS	NS	NS	0.964	0.860	NS	NS
Solo flax		69.2	68.1	1.9	1.8	6.652	6.307	20.3	19.9

Table 3: Number of capsules/plant, number of seeds/plant, seed index and seed yield of flax (f) intercropped with garlic (g) as affected by planting methods and intercropping systems

Characters / Treatments		Number of capsules/ plant		Number of seeds/ plant		Seed index (g)		Seed yield (Kg/ha.)	
		2020/21	2021/22	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22
Planting methods									
Broadcast		20.0	19.6	121.1	117.3	7.06	7.00	1474	1419
Drilling		21.2	20.6	134.2	132.5	7.15	7.08	1503	1442
Hills		18.2	17.8	102.2	95.3	6.89	6.87	1278	1316
LSD at 5 %		1.3	1.0	16.8	15.2	NS	NS	135	60.8
Intercropping systems									
100% flax + 12.5% garlic		22.0	21.3	132.2	128.2	7.18	7.16	155	1436
100% flax + 25% garlic		20.3	19.8	125.2	119.4	7.11	7.07	1509	1417
100% flax + 37.5% garlic		19.2	18.8	118.8	115.5	7.01	7.00	1482	1393
100% flax + 50% garlic		17.6	17.6	100.5	97.0	6.84	6.71	1131	1324
LSD at 5 %		1.2	1.0	14.4	12.1	NS	NS	96.0	57.6
Interaction									
Broadcast	100% f + 12.5% g	21.8	20.3	133.8	128.0	7.17	7.15	1576.65	1450
	100% f + 25% g	20.6	20.3	125.4	126.5	7.11	7.11	1530.32	1442
	100% f + 37.5% g	19.9	19.4	122.2	124.2	7.10	7.06	1498.75	1376
	100% f + 50% g	17.6	18.6	103.1	90.4	6.85	6.68	1289.86	1409
Drilling	100% f + 12.5% g	25.3	24.0	148.2	143.0	7.27	7.20	1617.16	1476
	100% f + 25% g	21.4	20.5	143.5	135.2	7.26	7.14	1549.51	1447
	100% f + 37.5% g	20.1	19.4	130.7	132.9	7.13	7.12	1545.33	1433
	100% f + 50% g	17.9	18.7	114.3	118.8	6.95	6.86	1299.93	1412
Hills	100% f + 12.5% g	19.1	19.5	114.7	113.6	7.09	7.11	1459.38	1383
	100% f + 25% g	18.8	18.6	106.6	96.7	6.96	6.98	1447.11	1361
	100% f + 37.5% g	17.6	17.7	103.4	89.4	6.80	6.81	1401.47	1371
	100% f + 50% g	17.2	15.5	84.0	81.7	6.71	6.59	802.30	1150
LSD at 5 %		2.2	1.8	NS	NS	NS	NS	166.22	99.5
Solo flax		21.6	21.2	138.0	135.0	7.13	7.07	1655.88	1524

ing to the regularity of planting distances than the plants in other planting methods, consequently improving the plant growth. Results of Nourai (1994) and Ingle *et al.* (2000) are in agreement with our conclusions.

Data showed in tables 4 and 5 showed that all the studied characters of garlic were significantly affected by intercropping patterns when intercropped with flax, except for the number of cloves/plant in each season. The lowest plant density (100% flax + 12.5% garlic) recorded the highest values for number of leaves/plant, head diameter, head weight and number of cloves/plant in both growing seasons. The longest plants were achieved by the highest plant density (100% flax + 50% garlic) in the 1st and 2nd seasons. Intercropping pattern (100% flax + 37.5% garlic) achieved the best results for bulb yield (ton/ha) in each season. The superiority of lowest density in increasing

Table 4: Plant height, number of leaves/plant and head diameter of garlic intercropped with flax as affected by planting methods and intercropping systems

Characters		Plant height (cm)		Number of leaves/plant		Head diameter (cm)	
Treatments		2020/21	2021/22	2020/21	2021/22	2020/21	2021/22
Planting methods							
Broadcast		73.9	75.6	6.7	7.3	5.0	4.9
Drilling		67.9	68.7	7.8	7.9	5.6	5.6
Hills		71.2	70.8	7.3	7.6	5.2	5.3
LSD at 5 %		4.1	5.1	NS	0.3	0.3	0.2
Intercropping systems							
100% flax + 12.5% garlic		64.2	65.5	8.7	8.9	6.0	6.2
100% flax + 25% garlic		69.2	70.0	7.7	8.2	5.4	5.6
100% flax + 37.5% garlic		73.5	73.0	6.7	7.1	5.0	5.1
100% flax + 50% garlic		77.2	78.3	5.9	6.2	4.5	4.3
LSD at 5 %		3.9	4.4	0.8	0.5	0.3	0.3
Interaction							
Broadcast	100% flax + 12.5% garlic	68.6	71.3	7.6	8.8	6.0	6.1
	100% flax + 25% garlic	72.8	74.8	6.9	8.0	5.0	4.9
	100% flax + 37.5% garlic	74.9	75.7	6.6	6.8	4.6	4.7
	100% flax + 50% garlic	79.1	80.6	5.6	5.8	4.4	4.1
Drilling	100% flax + 12.5% garlic	60.5	61.2	9.4	9.2	6.1	6.3
	100% flax + 25% garlic	65.2	66.9	8.3	8.5	6.0	6.3
	100% flax + 37.5% garlic	71.8	70.6	7.0	7.2	5.6	5.4
	100% flax + 50% garlic	74.1	76.1	6.4	6.7	4.7	4.4
Hills	100% flax + 12.5% garlic	63.4	64.0	9.1	8.9	6.0	6.2
	100% flax + 25% garlic	69.6	68.4	7.8	8.1	5.1	5.5
	100% flax + 37.5% garlic	73.7	72.8	6.6	7.2	5.0	5.2
	100% flax + 50% garlic	78.2	78.2	5.8	6.1	4.5	4.3
LSD at 5 %		NS	NS	NS	NS	0.5	0.5
Solo garlic		75.9	77.6	9.1	9.2	6.2	6.3

Table 5: Head weight, number of cloves/plant and bulb yield of garlic intercropped with flax as affected by planting methods and intercropping systems

Characters		Head weight (g)		Number of cloves/plant		Bulb yield (ton/ha)	
Treatments		2020/21	2021/22	2020/21	2021/22	2020/21	2021/22
Planting methods							
Broadcast		42.4	42.4	15.1	15.6	4.23	4.20
Drilling		47.5	49.2	15.2	15.8	4.68	4.62
Hills		45.1	46.8	15.3	15.5	4.34	4.56
LSD at 5 %		2.42	2.74	NS	NS	0.23	0.24
Intercropping systems							
100% flax + 12.5% garlic		50.4	56.3	15.9	16.2	2.08	2.33
100% flax + 25% garlic		48.5	48.3	15.2	15.7	4.09	4.13
100% flax + 37.5% garlic		47.1	45.4	15.0	15.3	6.08	5.75
100% flax + 50% garlic		34.0	34.7	14.6	15.3	5.41	5.61
LSD at 5 %		2.03	2.63	NS	NS	0.20	0.23
Interaction							
Broadcast	100% flax + 12.5% garlic	48.6	49.2	15.5	16.2	2.03	2.31
	100% flax + 25% garlic	46.4	47.1	15.4	15.5	3.99	4.06
	100% flax + 37.5% garlic	44.2	42.4	15.0	15.3	5.84	5.39
	100% flax + 50% garlic	30.5	31.0	14.3	15.4	5.07	5.03
Drilling	100% flax + 12.5% garlic	52.9	63.3	16.2	16.2	2.14	2.35
	100% flax + 25% garlic	50.7	49.3	15.0	15.7	4.22	4.24
	100% flax + 37.5% garlic	49.9	47.0	14.8	15.3	6.33	5.97
	100% flax + 50% garlic	36.6	37.2	14.9	15.9	6.01	5.92
Hills	100% flax + 12.5% garlic	49.7	56.3	16.1	16.3	2.09	2.32
	100% flax + 25% garlic	48.5	48.5	15.1	15.7	4.05	4.10
	100% flax + 37.5% garlic	47.3	46.7	15.2	15.4	6.08	5.91
	100% flax + 50% garlic	34.9	35.8	14.6	14.7	5.14	5.89
LSD at 5 %		NS	4.55	NS	NS	0.35	0.40
Solo garlic		56.51	58.1	15.8	16.1	23.9	24.3

number of leaves/plant, head diameter, head weight and number of cloves/plant may be due to the fewer number of plants per square meter that consequently reduce the competition among them leading to increase the capacity of plants to absorb water and nutrients. The increase in total bulbs yield/ha by raising plant density was mainly attributed to the increase in number of plants/ha, which was high enough to compensate the detected decrease in bulb weight/plant. Similar differences among intercropping systems in garlic were reported by Castellanos *et al.* (2004), Olfati *et al.* (2016) and Hussien and EL-Shamy (2017).

As for the interaction effect between planting methods and intercropping patterns, tables 4 and 5 reflected that the interaction exhibited a significant effect on head diameter and bulb yield in both seasons, head weight in the 2nd season only. Data indicated that the highest values of head diameter and head weight characters were observed in the drilling sowing method with the lowest plant density (100% flax + 12.5% garlic), while the highest bulb yield was obtained by drilling sowing method with intercropping pattern (100% flax + 37.5% garlic).

Land equivalent ratio (LER)

The data presented in table 6 showed interaction between planting methods and intercropping patterns of flax and garlic and their competitive relationships in both growing seasons. The highest values of competitive relationship Land equivalent ratio "LER" (1.21 and 1.18) were obtained from intercropping garlic at 37.5% with flax at 100% under drilling cultivating method in the 1st and 2nd seasons, respectively. The lowest LER belonged to intercropping system (100% flax + 50% garlic) with hills sowing method in each season.

Aggressivity (A)

Data in Table 6 revealed the highest aggressivity values were always obtained from the highest plant density (100% flax + 50% garlic) with broadcast and drilling cultivating method in both seasons, respectively. The most extreme values for flax (+0.37 and +0.42) and the lowest values for garlic (-0.37 and -0.42) resulted from the aforementioned treatments. It means that the main crop (flax) was the dominant crop, while garlic was the dominated crop in the course of this study. The aggressive behavior may be due to the taller plants of main crop that cause shading on the short plants of garlic.

Relative crowding coefficient (RCC)

Concerning the competitive relationship Relative Crowding Coefficient (RCC), the highest values of RCC (5.70 and 4.60) as presented in table 6 were from intercropping garlic at 37.5% with flax at 100% under drilling cultivating method in the 1st and 2nd seasons, in order, and the lowest RCC were always from the highest plant density (100% flax + 50% garlic) under hills sowing method.

Table 6: Land Equivalent Ratio (LER), Aggressivity (Ag) and Relative Crowding Coefficient (RCC) of intercropping garlic (g) with flax (f) as affected by planting methods

Treatments	Character	Land equivalent ratio (LER)			Aggressivity (Ag)		Relative Crowding Coefficient (RCC)		
		Lf	Lg	LER	Ag f	Ag g	Kf	Kg	K
2020/2021 season									
Broadcast	100% f + 12.5% g	0.92	0.08	1.01	0.24	-0.24	1.49	0.74	1.10
	100% f + 25% g	0.91	0.17	1.08	0.24	-0.24	2.55	0.80	2.05
	100% f + 37.5% g	0.89	0.24	1.13	0.24	-0.24	3.04	0.86	2.62
	100% f + 50% g	0.80	0.21	1.01	0.37	-0.37	1.98	0.54	1.06
Drilling	100% f + 12.5% g	0.97	0.09	1.06	0.25	-0.25	3.75	0.79	2.95
	100% f + 25% g	0.96	0.18	1.13	0.25	-0.25	5.71	0.86	4.90
	100% f + 37.5% g	0.94	0.26	1.21	0.24	-0.24	5.95	0.96	5.70
	100% f + 50% g	0.81	0.25	1.06	0.31	-0.31	2.15	0.67	1.45
Hills	100% f + 12.5% g	0.88	0.09	0.97	0.18	-0.18	0.94	0.76	0.72
	100% f + 25% g	0.79	0.17	0.96	0.12	-0.12	0.97	0.82	0.79
	100% f + 37.5% g	0.77	0.25	1.02	0.09	-0.09	1.24	0.91	1.13
	100% f + 50% g	0.38	0.21	0.59	-0.05	0.05	0.30	0.55	0.16
2021/2022 season									
Broadcast	100% f + 12.5% g	0.90	0.10	0.99	0.14	-0.14	1.08	0.84	0.91
	100% f + 25% g	0.88	0.17	1.05	0.21	-0.21	1.84	0.80	1.47
	100% f + 37.5% g	0.85	0.22	1.07	0.26	-0.26	2.14	0.76	1.62
	100% f + 50% g	0.81	0.21	1.02	0.40	-0.40	2.17	0.52	1.13
Drilling	100% f + 12.5% g	0.97	0.10	1.07	0.20	-0.20	4.74	0.86	4.06
	100% f + 25% g	0.94	0.17	1.12	0.24	-0.24	4.04	0.84	3.41
	100% f + 37.5% g	0.93	0.25	1.18	0.28	-0.28	5.30	0.87	4.60
	100% f + 50% g	0.91	0.24	1.15	0.42	-0.42	4.95	0.64	3.19
Hills	100% f + 12.5% g	0.85	0.10	0.94	0.08	-0.08	0.69	0.85	0.59
	100% f + 25% g	0.81	0.17	0.98	0.13	-0.13	1.06	0.81	0.86
	100% f + 37.5% g	0.77	0.24	1.01	0.12	-0.12	1.23	0.86	1.05
	100% f + 50% g	0.50	0.24	0.74	0.01	-0.01	0.50	0.64	0.32

Economic evaluations

As for the economic evaluation of the interaction between planting methods and intercropping patterns of flax and garlic during the two winter seasons of 2020/2021 and 2021/2022, the data in table 7 referred that the highest values of total income (5393 and 3441 USD) and economic return (3488 and 1907 USD) in both seasons, respectively were obtained from intercropping garlic at 37.5% from the recommended seed rate with 100% flax under drilling sowing method.

CONCLUSION

We conclude from the obtained results and from the economical point of view that intercropping garlic plants with flax using the intercropping pattern (100% flax + 37.5% garlic) with drilling planting method could be suggested for the maximum levels of productivity of both crops, increasing the land use factor and raising farm revenue under the environmental conditions of North Delta of Egypt.

Table 7: Effect of the interaction between planting methods and intercropping systems on economic evaluation of intercropping garlic (g) with flax (f)

Treatments		Economic evaluation					
Planting methods	**Intercropping systems**	**Actual flax straw yield (USD)**	**Actual flax seed yield (USD)**	**Actual garlic yield (USD)**	**Total income (USD)**	**Total cost (USD)**	**Net return (USD)**
2020/2021							
Broadcast	100% f + 12.5% g	1357	1198	905	3460	1590	1869
	100% f + 25% g	1346	1163	1780	4289	1748	2541
	100% f + 37.5% g	1315	1139	2604	5057	1905	3152
	100% f + 50% g	1191	980	2259	4431	2062	2368
Drilling	100% f + 12.5% g	1432	1229	954	3615	1590	2024
	100% f + 25% g	1429	1178	1883	4489	1748	2742
	100% f + 37.5% g	1398	1174	2820	5393	1905	3488
	100% f + 50% g	1213	988	2682	4883	2062	2821
Hills	100% f + 12.5% g	1309	1109	931	3349	1590	1759
	100% f + 25% g	1149	1100	1807	4056	1748	2308
	100% f + 37.5% g	1109	1065	2710	4885	1905	2979
	100% f + 50% g	516	610	2291	3418	2062	1355
Solo flax		1483	1258	-----	2741	1433	1308
2021/2022							
Broadcast	100% f + 12.5% g	912	1189	505	2606	1352	1254
	100% f + 25% g	892	1183	886	2961	1443	1518
	100% f + 37.5% g	866	1129	1176	3170	1534	1637
	100% f + 50% g	811	1156	1098	3065	1625	1441
Drilling	100% f + 12.5% g	1008	1211	513	2731	1352	1380
	100% f + 25% g	971	1186	925	3082	1443	1639
	100% f + 37.5% g	963	1175	1303	3441	1534	1907
	100% f + 50% g	933	1158	1292	3384	1625	1759
Hills	100% f + 12.5% g	860	1134	507	2501	1352	1149
	100% f + 25% g	815	1116	896	2828	1443	1385
	100% f + 37.5% g	758	1124	1291	3173	1534	1640
	100% f + 50% g	451	943	1286	2680	1625	1055
Solo flax		1032	1249	-----	2282	1261	1021

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