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Influence of Three Cropping Sequences and Mineral Nitrogen Fertilizer Rates on Flax Productivity and Profitability Under Different Planting Dates in Sandy Soil

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Abstract: The development of modern ecologically and profitable management for flax has a significant importance. A two-year study was carried out at Ismailia Agricultural Experiments and Research Station, ARC, Ismailia governorate, Egypt during 2013/2014 and 2014/2015 seasons to decrease mineral nitrogen (N) inputs of flax with increasing profitability for Egyptian farmer under different cropping sequences and planting dates in sandy soil. This experiment included 27 treatments which were the combinations of three cropping sequences (peanut / flax, peanut /fahl berseem/ flax and peanut / fodder maize / flax), three flax planting dates (5^{th} November, 15^{th} November and 25^{th} November) and three mineral N fertilizer rates (107.1, 142.8 and 178.5 kg N/ha). A split split plot distribution in randomized complete block design was used. The results indicated growing fahl berseem in the transition period between peanut and flax increased plant height, technical length of the main stem, number of capsules per plant, number of seeds per capsule, 1000 – seed weight, seed yields per plant and per ha and oil, straw and fiber yields per ha in comparison with those grown after peanut or fodder maize. On the other hand, growing flax after peanut or fodder maize increased flax seed oil content. Seed, oil, straw and fiber yields per ha were decreased with delaying planting date of flax. The highest mineral N fertilizer rate had the highest values of plant height, technical length of the main stem, number of capsules per plant, number of seeds per capsule, 1000 – seed weight, seed yields per plant and per ha and oil, straw and fiber yields per ha. Conversely, flax seed oil content was decreased by increasing mineral N fertilizer rates. With regard to all the interactions of this study, all the studied traits of flax were affected significantly by all the interactions. Growing flax plants in the early date (5^{th} November) after cutting fahl berseem gave the highest seed, oil, straw and fiber yields per ha with decreasing mineral N fertilizer rate per ha by twenty five percent under sandy soil conditions.

Keywords: Peanut, Fahl Berseem, Fodder Maize, Flax Planting Dates, Crop Sequences, Mineral N Fertilizer Rates, Net Return

1. Introduction

In Egypt, the gap between oil production and consumption reached about 85 percent (FAO, 2012) and it is not feasible to expand the area in the Nile Valley and Delta for oil seed crops because of high competition from the other winter crops such as wheat and berseem. Consequently, there is the need to expand the scope of oil seed crops cultivation through reclaimed soils, where this gap could be minimized by optimizing some agricultural practices in these soils. It is known that peanut *(Arachis hypogaea* L.) is the conventional crop in Ismailia governorate where it is one of the most important oilseed crops of the world (Onemli, 2012). Peanut cultivated area reached about 44,653 thousands ha in new lands in 2012 with an average yields of 3.22 tons per ha (Bulletin of Statistical Cost Production and Net Return, 2013).

On the other hand, flax (*Linum usitatissimum* L.) is adapted to many environments mainly in temperate climates (Casa *et al*., 1999 and Adugna and Labuschagne, 2003). It is considered one of the most important dual purpose crops for oil and fiber production in Egypt and the world. It plays an important role in the national economy due to its importance in exportation and many local industrial purposes. Flax oil has a high percentage of essential fatty acids, 75% polyunsaturated fatty acids, 57% alpha linolenic acid, which is an omega-3 fatty acid, and 16% linoleic acid, which is an omega-6 fatty acid (Morris, 2005). However, flax cultivated area in new lands reached about 31.1 ha in 2012 (Bulletin of Statistical Cost Production and Net Return, 2014).

For that should increase flax productivity in these soils by choice the suitable preceded crop, flax planting date and mineral nitrogen (N) fertilizer rate, especially the use of expensive chemical N fertilizers in Egypt is a limiting factor for the low-income farmers and increases the cost of crop production where prices of chemical N fertilizers during a few years were increased. With the current technology for fertilizer production and the inefficient methods employed for fertilizer application, both the economic and ecological costs of fertilizer usage will eventually become prohibitive (Dixon and Wheeler, 1986). In this concern, Rahimi *et al*. (2011) studied eight varieties of flaxseed, five planting dates and rates of 0 to 150 kg per ha, and they found that the first sowing date March 14, along with 100 and 150 kg N per ha produced the highest yield and production components.

Also, there is another problem faces some Egyptian farmers during the summer season in these soils where they have to conserve some forage crops for increasing their net return and cattle feeding under sandy soil conditions. Accordingly, it was necessary to find a modern agricultural technical practice such as triple cropping sequences for these crops like maize (*Zea mays* L.) or berseem (*Trifolium alexandrinum* L.) during transition period between peanut and flax, especially maize often fails to reach the stage of mature grain. Forage maize became one of the most important feed stuff for ruminants specially cattle (Rouanet, 1987). Moreover, maize proved to be most suitable forage as it is characterized by its high energy content and considerable protein content, compared to other cereal forage crops (Ipperisiel *et al.*, 1989).

Furthermore, cultivation of legumes led to a greater exploitation of soil N by the succeeding crops (Senaratne and Hardarson, 1988). The inclusion of leguminous fodder crops as berseem, which capable of supplying green fodder after 70 days from sowing by one cut "fahl", during transition period between two field crop had the ability of enriching the N content of sandy soil by fixing N from the air, in addition to improving the productivity of soil (Abdel-Galil *et al*., 2015). So, the present study was conducted to decrease mineral N inputs of flax with increasing profitability for Egyptian farmer under different cropping sequences and planting dates in sandy soil.

2. Materials and Methods

A two-year study was carried out at Ismailia Agricultural Experiments and Research Station, A.R.C., Ismailia governorate (Lat. 30° 35' 30" N, Long. 32° 14' 50" E, 10 m a.s.l.), Egypt during 2013/2014 and 2014/2015 seasons to decrease mineral N inputs of flax with increasing profitability for Egyptian farmer under different cropping sequences and planting dates in sandy soil. Table (1) shows chemical analyses of the experimental soil after harvest peanut and before sowing flax in the two growing seasons. Mechanical analysis of the experimental soil had 10.39 percent clay, 2.25 percent silt and 87.36 percent sand, and loamy sand texture. The experimental soil was analyzed according to the method described by Chapman and Pratt (1978). These analyses of the soil (0-20 cm) were done by General Organization for Agricultural Equalization Fund, Agricultural Research Center, Giza, Egypt. This experiment included 27 treatments which were the combinations of three cropping sequences (peanut / flax, peanut /fahl berseem/ flax and peanut / fodder maize / flax), three flax planting dates (5thNovember, 15th November and 25th November) and three mineral N fertilizer rates (107.1, 142.8 and 178.5 kg N/ha).

Table 1. *Available soil N content after peanut, fahl berseem and fodder maize harvest in 2013 and 2014 seasons.*

Cropping sequences	**Growing season**	
	2013	**2014**
	Available soil N content (ppm)	**Available soil N content (ppm)**
Peanut/flax	36.8	39.1
Peanut/fahl berseem/flax	48.5	50.0
Peanut/fodder maize/flax	31.3	35.5

Sprinkler irrigation was the irrigation system in the area. In the two seasons, peanut and berseem seeds were inoculated by *Bradyrhizobium* and *Rhizobium trifolii*, respectively, before seeding it. Peanut was seeded at 10 cm between hills with one plant per hill after thinning. In the autumn season, fahl berseem was drilled at the rate of 59.5 kg per ha, meanwhile, fodder maize was seeded at 15 cm between hills with one plant per hill. In the winter seasons, flax seeds were drilled at the rate of 166.6 kg per ha. Calcium super phosphate (15.5% P_2O_5) at rate of 476 kg per ha and potassium sulfate (48.0 % K_2O) at rate of 238 kg per ha were applied during soil preparation for sowing peanut in the summer season. The previous rates of calcium super phosphate and potassium sulfate were also applied during soil preparation for sowing flax in the winter season. Calcium sulfate at rate of 1190 kg per ha was applied for peanut after 35-40 days from peanut sowing. Mineral N fertilizer at rate of 285.6 kg per ha were applied for fodder maize in the two equal doses, meanwhile, it was not applied for fahl berseem. Normal practices for growing all crops were used as recommended in the area. Flax cultivar Sakha2 was used. Peanut plants cv. Ismailia 1 was sown on April 28th and 24th at 2013 and 2014 summer seasons, respectively, while, fahl berseem cv. Gemmiza 1 and fodder maize cv. T.W.C. 310 were sown on August 25th and 21st at 2013 and 2014 seasons. Flax was sown on November 5th, 15th and 25th at 2013 and 2014 winter seasons. Peanut plants were uprooted on August 15th and 14th at 2013 and 2014 summer seasons, while, fahl berseem was cut on November 3rd and 2nd at 2013 and 2014 winter season and flax was harvested on April 22nd and 19th at 2014 and 2015 summer season, respectively.

A split – split plot distribution in randomized complete block design in three replicates was used. Cropping sequences (peanut/flax, peanut/fahl berseem/flax and peanut/fodder maize/flax) were randomly assigned to the main plots, the flax planting dates were allotted in subplots and mineral N fertilizer rates of flax were allocated in sub – sub plots. Each plot contained six ridges, each ridge was 3.0 m in length, 0.6 m in width and the plot area was 10.8 m^2.

2.1. The Studied Traits

These traits were measured at harvest on ten guarded plants of flax from each plot: plant height 'cm' (from the cotyledonary node till the top of the plant), technical length of the main stem 'cm' (from the cotyledonary node till the beginning of apical branching zone of the main stem), number of capsules per plant, number of seeds per capsule, 1000 – seed weight, seed yields per plant and per ha, seed oil content, oil, straw and fiber yields per ha and fiber length. Oil content in flax seeds was determined by A.O.A.C. (2000). This analysis was performed in Seed Technology Research Department, Field Crops Research Institute, Agricultural Research Center, Giza, Egypt. Seed and straw yields of flax per ha (ton) were recorded on the basis of experimental plot area by harvesting of all plants of each plot. Oil yield of flax per ha (ton) was calculated by multiplying seed oil content × seed yield per ha. Straw yield of flax per ha (ton) was estimated according to weight of air dried straw yield per one m^2 of each plot. Fiber yield of flax per ha (ton) was estimated according to fiber yield per one m^2 of each plot. Fiber length (cm); fiber ribbons of 10 plants from each plot were extracted individually and mean length of each ribbon was measured. This analysis was performed in Fiber Crops Research Department, Field Crops Research Institute, Agricultural Research Center, Giza, Egypt. Seed and straw yields of flax per ha (ton), pod yield of peanut per ha (ton), forage yield of berseem per ha (ton) and green fodder yield of maize per ha (ton) were estimated on the basis of experimental plot area.

2.2. Net Return

Peanut pods and flax seeds and fibers prices presented by (Bulletin of Statistical Cost Production and Net Return, 2013 and 2014) were used, while forage yield of berseem and green fodder yield of maize prices presented by market price (2012) were used. Net return was calculated as follows: Net return = total costs – total return according to cropping system.

2.3. Statistical Manipulation

Analysis of variance of the obtained results of each season was performed. The measured variables were analyzed by ANOVA using MSTATC statistical package (Freed, 1991). Mean comparisons were done using least significant differences (L.S.D) method at 5% levels of probability to compare differences between the means (Gomez and Gomez, 1984).

3. Results and Discussion

3.1. Cropping Sequences

All the studied flax traits were affected significantly by cropping sequences in the combined data across 2013/2014 and 2014/2015 seasons (Tables 2, 3 and 4). Growing flax after fahl berseem caused significant increase in plant height, technical length of the main stem, number of capsules per plant, number of seeds/capsule, 1000 – seed weight, seed yields per plant and per ha, seed oil content, oil, straw and fiber yields per ha and fiber length in comparison with those grown after peanut or fodder maize in the combined data across 2013/2014 and 2014/2015 seasons. There were no significant differences between growing flax after peanut or after fodder maize on all the studied flax traits. Growing flax after fahl berseem increased $(P \leq 0.05)$ seed, oil, straw and fiber yields per ha by 22.85, 26.92, 16.21 and 14.81 percent as compared with those grown after peanut, respectively. Also, growing flax after fodder maize increased ($P \leq 0.05$) seed, oil, straw and fiber yields per ha by 28.35, 37.50, 19.44 and 14.81 percent as compared with those grown after fodder maize, respectively.

These results could be due to peanut / fahl berseem / flax had yield advantage occurred because there was available soil N content (Table 1) as response of the beneficial effect of N released from the decomposition of the preceded legumes residues which could be more completely absorbed and converted to flax biomass in comparison with the other two crop sequences. Hence, appreciable yield increases observed in the succeeding crops following legumes compared to cereal were due to an N-conserving effect, carry-over of N from the legume residue and to greater uptake of soil N by the succeeding crops when previously cropped to legumes (Senaratne and Hardarson, 1988). It is observed that fahl berseem was used as trap crop to capture left over N from the soil after peanut uprooting and improved total count of rhizobia that increased available soil N content and soil fertility (Abdel-Galil *et al*., 2015). These results are in the same context with those by Pandey *et al.* (2008) who concluded that massive loss of native soil N occurs in rice-wheat rotations when fields are left bare fallow during the dry-to-wet season transition period. Growing grain legumes and green manure crops during the transition season can immobilize soil N in the plant biomass in addition to adding N from the atmosphere. They added that reduced amounts of available soil N by growing crops during dry to wet season transition period result reduced N losses by both leaching and denitrification.

Table 2. *Effect of cropping sequences, flax planting dates, mineral N fertilizer rates and their interactions on plant height, technical length, number of capsules/plant, number of seeds/capsule, combined data across 2013/2014 and 2014/2015 seasons.*

Treatments		Plant height (cm)				Technical length (cm)				Capsules/plant (no.)				Seeds/capsule (no.)			
		N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean
Peanut/flax	D_1	89.36	90.81	92.03	90.73	70.71	71.34	71.96	71.33	15.72	16.03	16.38	16.04	7.73	7.98	8.15	7.95
	D_2	88.44	89.73	91.27	89.81	70.32	70.90	71.51	70.91	15.43	15.77	16.06	15.75	7.48	7.66	7.87	7.67
	D_3	86.22	87.68	88.37	87.42	69.98	70.47	71.06	70.50	15.17	15.49	15.78	15.48	7.15	7.37	7.55	7.35
Mean		88.00	89.40	90.55	89.31	70.33	70.90	71.51	70.91	15.44	15.76	16.07	15.75	7.45	7.67	7.85	7.65
Peanut/fahl berseem/flax	D_1	89.72	92.20	92.49	91.47	71.02	71.99	72.26	71.75	16.13	16.51	16.79	16.47	8.44	8.79	8.86	8.69
	D_2	88.81	91.15	91.72	90.56	70.67	71.53	71.88	71.36	15.82	16.28	16.52	16.20	8.12	8.45	8.53	8.36
	D_3	86.59	88.32	88.76	87.89	70.35	71.29	71.61	71.08	15.55	16.00	16.21	15.92	7.83	8.18	8.24	8.08
Mean		88.37	90.55	90.99	89.97	70.68	71.60	71.91	71.39	15.83	16.26	16.50	16.19	8.13	8.47	8.54	8.38
Peanut/fodder maize/flax	D_1	89.21	90.67	91.92	90.60	70.62	71.27	71.82	71.23	15.61	15.98	16.31	15.96	7.69	7.95	8.10	7.91
	D_2	88.30	89.58	91.11	89.66	70.18	70.79	71.42	70.79	15.34	15.66	15.97	15.65	7.32	7.61	7.81	7.58
	D_3	86.14	87.56	88.21	87.30	69.87	70.41	70.97	70.41	15.03	15.40	15.74	15.39	7.01	7.32	7.53	7.28
Mean		87.88	89.27	90.41	89.18	70.22	70.82	71.40	70.81	15.32	15.68	16.00	15.66	7.34	7.62	7.81	7.59
Mean of planting dates	D_1	89.43	91.22	92.14	90.93	70.78	71.53	72.01	71.43	15.82	16.17	16.49	16.15	7.95	8.24	8.37	8.18
	D_2	88.51	90.15	91.36	90.01	70.39	71.07	71.60	71.02	15.53	15.90	16.18	15.86	7.64	7.90	8.07	7.87
	D_3	86.31	87.85	88.44	87.53	70.06	70.72	71.21	70.66	15.25	15.63	15.91	15.59	7.33	7.62	7.77	7.57
Mean of mineral N rates		88.08	89.74	90.64	89.49	70.41	71.10	71.60	71.03	15.53	15.90	16.19	15.86	7.64	7.92	8.07	7.87
L.S.D. 0.05 Cropping sequences (S)					0.42				0.29				0.25				0.14
L.S.D. 0.05 Planting dates (D)					0.34				0.22				0.21				0.11
L.S.D. 0.05 Mineral N fertilizer rates (N)					0.25				0.16				0.16				0.07
L.S.D. 0.05 S x D					0.46				0.32				0.27				0.15
L.S.D. 0.05 S x N					0.49				0.35				0.29				0.16
L.S.D. 0.05 N x D					0.37				0.24				0.23				0.12
L.S.D. 0.05 S x D x N					0.54				0.38				0.32				0.19

D_1: 5th November, D_2: 15th November and D_3: 25th November. N_1: 107.1 kg N/ha, N_2: 142.8 kg N/ha and N_3: 178.5 kg N/ha.

Table 3. *Effect of cropping sequences, flax planting dates, mineral N fertilizer rates and their interactions on 1000 – seed weight, seed yield/plant, seed yield/ha, seed oil content, combined data across 2013/2014 and 2014/2015 seasons.*

Treatments		1000 – seed weight (g)				Seed yield/plant (g)				Seed yield/ha (ton)				Seed oil content (%)			
		N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean
Peanut/flax	D_1	8.25	8.34	8.42	8.33	0.72	0.77	0.83	0.77	0.68	0.82	0.94	0.81	38.9	38.7	38.4	38.6
	D_2	8.17	8.26	8.36	8.26	0.60	0.65	0.71	0.65	0.58	0.71	0.82	0.70	38.6	38.5	38.1	38.4
	D_3	8.03	8.14	8.23	8.13	0.47	0.52	0.59	0.52	0.47	0.60	0.74	0.60	38.1	37.9	37.6	37.8
Mean		8.15	8.24	8.33	8.24	0.59	0.64	0.71	0.64	0.57	0.71	0.83	0.70	38.5	38.3	38.0	38.2
Peanut/fahl berseem /flax	D_1	8.47	8.53	8.62	8.54	0.95	1.04	1.09	1.02	0.83	1.02	1.05	0.96	38.5	38.3	38.0	38.2
	D_2	8.36	8.47	8.55	8.46	0.87	0.94	0.98	0.93	0.76	0.92	0.94	0.87	38.3	38.0	37.6	37.9
	D_3	8.25	8.36	8.43	8.34	0.76	0.84	0.86	0.82	0.66	0.81	0.83	0.76	37.8	37.6	37.1	37.5
Mean		8.36	8.45	8.53	8.44	0.86	0.94	0.97	0.92	0.75	0.91	0.94	0.86	38.2	37.9	37.5	37.8
Peanut /fodder maize/flax	D_1	8.23	8.32	8.40	8.31	0.70	0.74	0.80	0.74	0.66	0.79	0.90	0.78	39.8	39.7	39.5	39.6
	D_2	8.17	8.25	8.35	8.25	0.58	0.64	0.68	0.63	0.55	0.69	0.78	0.67	39.6	39.6	39.3	39.5
	D_3	8.00	8.13	8.21	8.11	0.46	0.50	0.57	0.51	0.44	0.57	0.70	0.57	39.3	39.2	39.0	39.1
Mean		8.13	8.23	8.32	8.22	0.58	0.62	0.68	0.62	0.55	0.68	0.79	0.67	39.5	39.5	39.2	39.4
Mean of planting dates	D_1	8.31	8.39	8.48	8.39	0.79	0.85	0.90	0.84	0.72	0.87	0.96	0.85	39.0	38.9	38.6	38.8
	D_2	8.23	8.32	8.42	8.32	0.68	0.74	0.79	0.73	0.63	0.77	0.84	0.74	38.8	38.7	38.3	38.6
	D_3	8.09	8.21	8.29	8.19	0.56	0.62	0.67	0.61	0.52	0.66	0.75	0.64	38.4	38.2	37.9	38.1
Mean of mineral N rates		8.21	8.30	8.39	8.30	0.67	0.73	0.78	0.72	0.62	0.76	0.85	0.74	38.7	38.6	38.2	38.5
L.S.D. 0.05 Cropping sequences (S)					0.07				0.04				0.08				0.63
L.S.D. 0.05 Planting dates (D)					0.04				0.03				0.06				0.42
L.S.D. 0.05 Mineral N fertilizer rates (N)					0.03				0.02				0.04				0.21
L.S.D. 0.05 S x D					0.08				0.05				0.09				0.68
L.S.D. 0.05 S x N					0.09				0.06				0.11				0.73
L.S.D. 0.05 N x D					0.06				0.04				0.07				0.46
L.S.D. 0.05 S x D x N					0.11				0.09				0.15				0.79

D_1: 5th November, D_2: 15th November and D_3: 25th November. N_1: 107.1 kg N/ha, N_2: 142.8 kg N/ha and N_3: 178.5 kg N/ha.

Table 4. *Effect of cropping sequences, flax planting dates, mineral N fertilizer rates and their interactions on oil, straw and fiber yields/ha and fiber length, combined data across 2013/2014 and 2014/2015 seasons.*

Treatments		Oil yield (ton/ha)				Straw yield (ton/ha)				Fiber yield (ton/ha)				Fiber length (cm)			
		N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean
Peanut/flax	D_1	0.26	0.31	0.36	0.31	3.8	4.0	4.3	4.0	0.55	0.58	0.62	0.58	64.8	72.3	81.7	72.9
	D_2	0.22	0.27	0.31	0.26	3.5	3.7	4.0	3.7	0.51	0.54	0.59	0.54	60.4	68.2	76.6	68.4
	D_3	0.17	0.22	0.28	0.22	3.2	3.5	3.7	3.4	0.47	0.50	0.55	0.50	56.2	63.0	72.5	63.9
Mean		0.21	0.26	0.31	0.26	3.5	3.7	4.0	3.7	0.51	0.54	0.58	0.54	60.4	67.8	76.9	68.3
Peanut/fahl berseem/flax	D_1	0.32	0.39	0.40	0.37	4.3	4.8	5.0	4.7	0.62	0.69	0.71	0.67	75.6	86.9	94.1	85.5
	D_2	0.29	0.35	0.35	0.33	4.0	4.4	4.6	4.3	0.59	0.65	0.67	0.63	68.0	80.4	89.2	79.2
	D_3	0.25	0.30	0.30	0.28	3.8	4.2	4.3	4.1	0.55	0.60	0.62	0.59	63.4	75.7	85.8	74.9
Mean		0.28	0.34	0.35	0.32	4.0	4.4	4.6	4.3	0.58	0.64	0.66	0.62	69.0	81.0	89.7	79.9
Peanut/fodder maize/flax	D_1	0.26	0.31	0.35	0.30	3.5	3.8	4.2	3.8	0.57	0.60	0.62	0.59	64.7	71.8	81.2	72.5
	D_2	0.21	0.27	0.30	0.26	3.2	3.7	4.0	3.6	0.51	0.54	0.57	0.54	59.1	66.9	75.7	67.2
	D_3	0.17	0.22	0.27	0.22	3.0	3.5	3.7	3.4	0.45	0.49	0.53	0.49	55.4	61.8	70.3	62.5
Mean		0.21	0.26	0.30	0.25	3.2	3.6	3.9	3.6	0.51	0.54	0.57	0.54	59.7	66.8	75.7	67.4
Mean of planting dates	D_1	0.28	0.33	0.37	0.32	3.8	4.2	4.5	4.1	0.58	0.62	0.65	0.61	68.3	77.0	85.6	76.9
	D_2	0.24	0.29	0.32	0.28	3.5	3.9	4.2	3.8	0.53	0.57	0.61	0.57	62.5	71.8	80.5	71.6
	D_3	0.19	0.24	0.28	0.24	3.3	3.7	3.9	3.6	0.49	0.53	0.56	0.52	58.3	66.8	76.2	67.1
Mean of mineral N rates		0.23	0.28	0.32	0.28	3.5	3.9	4.2	3.8	0.53	0.57	0.60	0.56	63.0	71.8	80.7	71.8
L.S.D. 0.05 Cropping sequences (S)					0.03				0.22				0.02				8.64
L.S.D. 0.05 Planting dates (D)					0.01				0.17				0.01				6.93
L.S.D. 0.05 Mineral N fertilizer rates (N)					0.01				0.13				0.01				5.32
L.S.D. 0.05 S x D					0.04				0.25				0.02				8.82
L.S.D. 0.05 S x N					0.05				0.28				0.03				9.12
L.S.D. 0.05 N x D					0.03				0.21				0.02				7.17
L.S.D. 0.05 S x D x N					0.07				0.33				0.04				9.48

D_1: 5th November, D_2: 15th November and D_3: 25th November. N_1: 107.1 kg N/ha, N_2: 142.8 kg N/ha and N_3: 178.5 kg N/ha.

3.2. Flax Planting Dates

All the studied flax traits were affected significantly by flax planting dates in the combined data across 2013/2014 and 2014/2015 seasons (Tables 2, 3 and 4). Growing flax in the early date (5th November) caused significant increase in plant height, technical length of the main stem, number of capsules per plant, number of seeds/capsule, 1000 – seed weight, seed yields per plant and per ha, seed oil content, oil, straw and fiber yields per ha and fiber length in comparison with those grown in the other planting dates.

These results could be due to growing flax in 5th November benefited from suitable plant growth resources which reflected on high seed germination, the timely appearance of seedling and the optimum development of the root system in comparison with the other dates. Consequently, significant increments of plant height and number of capsules per plant in the early date (5th November) may be attributed to flax plant had the longest period of vegetative growth during available normal climatic conditions from stem elongation stage to pollination process and until late seed distribution as compared with the other two dates, especially low day temperatures could be increased carbon dioxide assimilation rates and more photosynthates for increasing the internode length that is the distance between each leaf and number of capsules per plant under sandy soil conditions.

These results are in agreement with those observed by Mirshekari *et al*. (2012) who showed that early sowing had a dominant positive effect on plant height of flax during the vegetative stage. Also, they added that the lower capsule numbers observed with later flowering may be due to a temperature effect on pollination and ovary survival in delayed sowing dates. Moreover Saghayesh *et al.* (2014) indicated that early sowing date causes create more capsules per plant.

Moreover, growing flax in 5th November led to significant increments in 1000 – seed weight and seed yield per plant. These data could be attributed to increase in reproductive growth of flax plant as a result of available normal climatic conditions and reflected positively on number of capsules per plant, number of seeds per capsule and finally seed yield per plant. These results are in agreement with those reported by Lisson and Mendham (2001) who found that high temperatures during the period of reproductive growth lead to decline of reproductive growth period, failure in the number of capsules and finally decrease the number of seeds and then the decline comes to seed yield. Sowing date study with flaxseed identified maximum seed yield from an early sowing from flowering to late grain fill. Also, Saghayesh *et al.* (2014) indicated that seed weight was maximum in first sowing date and decreased with delaying sowing.

On the other hand, seed yield per ha was decreased *(P ≤ 0.05)* by delaying date of planting flax to 25th November. This result may be due to the reductions in number of capsules per plant and number of seeds per capsule as a result of decreasing dry matter accumulation in leaves that reflected negatively on photosynthates translocated from leaves to seeds during seed filling period. These results are in accordance with those obtained by Al-Doori (2012) who showed that the increases in seed yield per hectare due to sowing on earlier time may be due to the increases in number of branches per plant and number of capsules per plant reflecting increase in seed yield.

Growing flax in the early date (5th November) caused significant increments in seed oil content and oil yield per ha as a result of low temperatures during the period of reproductive growth led to increase in seed oil content and oil yield per ha. Maximize the use of natural resources allows superposing the critical periods for oil yield and its components with the moment of the growth season where more environmental resources are available (Balalic *et al*., 2012).

These results are in accordance with those obtained by Silva (2005) who found that increased temperature during seed filling was a major cause of reduced oil percentage and yield. Also, Al-Doori (2012) indicated that the increases in oil yield in the earlier sowing compared the other studied sowing dates may be due to the increases in seed yield. Moreover, Mirshekari *et al.* (2012) showed that climatic conditions could be considered as a determining factor for oil percentage and yield. Furthermore, Gallardo *et al*. (2014) who reported that the delay in planting date displaces seed filling to periods of high temperature which affected their oil content and yield. They added that oil yield showed a significant response to planting date, decreasing from 844.75 kg/ha to 644.35 kg/ha in the late date.

3.3. Mineral N Fertilizer Rates

All the studied flax traits were affected significantly by mineral N fertilizer rates in the combined data across 2013/2014 and 2014/2015 seasons (Tables 2, 3 and 4). Flax plants that received the highest mineral N fertilizer rate (178.5 kg N/ha) had the highest values *(P ≤ 0.05)* of plant height, technical length of the main stem, number of capsules per plant, number of seeds/capsule, 1000 – seed weight, seed yields per plant and per ha, oil, straw and fiber yields per ha and fiber length in comparison with those received the other mineral N fertilizer rates.

The increase in plant height and technical length of the main stem with increasing mineral N fertilizer rate up to 178.5 kg N/ha could be explained by the stimulation effect for cell elongation directly after division (Dixit and Sharma, 1993). Also, El-Nagdy *et al.* (2010) found that plant height was 66.8, 83.7 and 105. 9 cm by adding 25, 50 and 100% of the recommended mineral N fertilizer rate of flax, respectively. Similar results were reported by Abd El-Samie and El-Bially (1996) who revealed that there was a significant increase in plant height and technical length of the main stem with increasing the applied N from 30 to 60 kg N per unit area.

It is observed that increasing mineral N fertilizer rates from 107.1 to 178.5 kg N/ha increased plant growth and development that reflected positively on yield and its attributes. There was relation between the income growth of flaxseed and the increase of major components such as the seed weight per plant, number of capsules per plant and the effect of N on the growth rate and absorption N rate of culture (Dordas, 2010). Variable number of capsules per plant had the highest effect on crop productivity (Gauraha and Rao, 2011). Similar results were observed by El-Nimr *et al.* (1997) who demonstrated that increase of N levels from 45 to 70 kg N/unit area caused a significant increase in number of capsules per plant, straw, fiber and seed yields per unit area. Moreover, Rahimi and Bahrani (2011) found in studies with flaxseed response to N fertilization, as well as rates of 100 to 150 kg/ha, with 1511 and 1518 kg/ha, respectively.

On the other hand, flax plants received the highest mineral N fertilizer rate (178.5 kg N/ha) had the lowest seed oil content *(P ≤ 0.05)* in comparison with those received the other mineral N fertilizer rates. The reduction in seed oil content with the highest mineral N fertilizer rate (178.5 kg N/ha) may be due to a dilution effect as a result of increasing of protein accumulated in the seed. Conversely, the increase in oil yield could be interpreted by the increments in seed yield and seed oil content.

These results are in accordance with those obtained by Hocking and Pinkerton (1991) who indicated that the reduction in oil content with high N availability occurs because of a “dilution effect”. As N promotes vegetative growth, delaying grain fill and maturity, other components such as protein and starch are accumulated in the seed diluting the oil. A decrease in oil content with high N rates has been reported before in flaxseed (Hocking, 1995 and Hocking *et al*., 1997). Also, Berti *et al*. (2009) showed that increasing rates of N decreased oil content. Moreover, El-Nagdy *et al.* (2010) revealed that the increase of the rates of mineral N from 25 to 100% increased seed oil production.

3.4. Response of Cropping Sequences to Mineral N Fertilizer Rates

All the studied flax traits were affected significantly by the interaction between cropping sequences and mineral N fertilizer rates in the combined data across 2013/2014 and 2014/2015 seasons (Tables 2, 3 and 4). Flax plants that grown after fahl berseem and received the highest mineral N fertilizer rate (178.5 kg N/ha) had higher values of plant height, technical length of the main stem, number of capsules per plant, number of seeds/capsule, 1000 – seed weight, seed yields per plant and per ha, seed oil content, oil, straw and fiber yields per ha and fiber length, meanwhile, flax plants that grown after peanut or fodder maize and received the lowest mineral N fertilizer rate (107.1 kg N/ha) had the lowest values of all the studied traits of flax.

These data indicate that each of these two factors act dependently on all the studied traits of flax meaning that cropping sequences responded differently *(P ≤ 0.05)* to mineral N fertilizer levels for all the studied traits of flax.

3.5. Response of Cropping Sequences to Flax Planting Dates

All the studied flax traits were affected significantly by cropping sequences x flax planting dates in the combined data across 2013/2014 and 2014/2015 seasons (Tables 2, 3 and 4). Flax plants that grown after fahl berseem in early date (5th November) had higher values of plant height, technical length of the main stem, number of capsules per plant, number of seeds/capsule, 1000 – seed weight, seed yields per plant and per ha, oil, straw and fiber yields per ha and fiber length, meanwhile, flax plants that grown after peanut or fodder maize in the late date (25th November) had the lowest values of all the studied traits of flax.

These data show that each of these two factors act dependently on all the studied traits of flax meaning that cropping sequences responded differently *(P ≤ 0.05)* to flax planting dates for all the studied traits of flax

3.6. Response of Flax Planting Dates to Mineral N Fertilizer Rates

All the studied flax traits were affected significantly by the interaction between flax planting dates and mineral N fertilizer rates in the combined data across 2013/2014 and 2014/2015 seasons (Tables 2, 3 and 4). Flax plants that grown in early date (5th November) and received the highest mineral N fertilizer rate (178.5 kg N/ha) had higher values of plant height, technical length of the main stem, number of capsules per plant, number of seeds/capsule, 1000 – seed weight, seed yields per plant and per ha, oil, straw and fiber yields per ha and fiber length, meanwhile, flax plants that grown in the late date (25th November) and received the lowest mineral N fertilizer rate (107.1 kg N/ha) had the lowest values of all the studied traits of flax.

These data reveal that each of these two factors act dependently on the studied traits of flax meaning that flax planting dates responded differently *(P ≤ 0.05)* to mineral N fertilizer levels for the studied traits of flax. These results are in agreement with those obtained by Rahimi *et al*. (2011) who found that the first sowing date March 14th , along with 100 and 150 kg/ha of N produced the highest yield and production components.

3.7. Response of Cropping Sequences to Mineral N Fertilizer Rates and Flax Planting Dates

All the studied flax traits were affected significantly by cropping sequences x flax planting dates x mineral N fertilizer rates in the combined data across 2013/2014 and 2014/2015 seasons (Tables 2, 3 and 4). Flax plants that grown after fahl berseem in early date (5th November) and received the highest mineral N fertilizer rate (178.5 kg N/ha) had higher values of plant height, technical length of the main stem, number of capsules per plant, number of seeds/capsule, 1000 – seed weight, seed yields per plant and per ha, oil, straw and fiber yields per ha and fiber length, meanwhile, flax plants that grown after peanut or fodder maize in the late date (25th November) and received the lowest mineral N fertilizer rate (107.1 kg N/ha) had the lowest values of all the studied traits of flax. The oil content and yield are complex quantitative traits, determined by genetic and environmental factors, along with interaction between them (Leon *et al.,* 2003).

These data reveal that there was effect *(P ≤ 0.05)* of cropping sequences x flax planting dates x mineral N fertilizer rates on the studied traits of flax.

3.8. Net Return

The cropping sequence (peanut / fahl berseem / flax) increased total and net returns by 78.84 and 150.80 per cent, respectively, as compared with the cropping sequence (peanut / flax) in combined data across 2013/2014 and 2014/2015 seasons (Table 5). Net return was varied between treatments from US$ 1207 per ha by growing flax that grown in the late date (25th November) and received the lowest mineral N fertilizer rate (107.1 kg N/ha) after peanut to US$ 3940 by growing flax that grown in the early date (5th November) and received the highest mineral N fertilizer rate (178.5 kg N/ha) after fahl berseem.

It is noticed that growing leguminous crop after peanut and before flax is more profitable for Egyptian farmers.

4. Conclusion

It is concluded that triple crop sequence (peanut / fahl berseem / flax) with growing flax in 5th November that received 142.8 kg N per ha was a very important management for increasing flax fiber and seed yields per ha, as well as, farmer's benefit under sandy soil conditions.

So a correct decision on the cropping sequence should be based on thoroughly understanding of the environmental factors which influence growth, development and yield.

Table 5. *Financial return as affected by cropping sequences, flax planting dates, mineral N fertilizer rates and their interactions, combined data across 2013/2014 and 2014/2015 seasons.*

Treatments		Preceded crops	Yield/ha (ton)											
			Flax seed				Flax fiber				Total (seed + fiber)			
			N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean
		Peanut												
Peanut/flax	D_1		0.68	0.82	0.94	0.81	0.55	0.58	0.62	0.58	1.23	1.40	1.56	1.39
	D_2		0.58	0.71	0.82	0.70	0.51	0.54	0.59	0.54	1.09	1.25	1.41	1.25
	D_3		0.47	0.60	0.74	0.60	0.47	0.50	0.55	0.50	0.94	1.10	1.32	1.12
Mean		2.73	0.57	0.71	0.83	0.70	0.51	0.54	0.58	0.54	1.08	1.25	1.43	1.25
		Fahl berseem												
Peanut/fahl berseem/flax	D_1		0.83	1.02	1.05	0.96	0.62	0.69	0.71	0.67	1.45	1.71	1.76	1.64
	D_2		0.76	0.92	0.94	0.87	0.59	0.65	0.67	0.63	1.35	1.57	1.61	1.51
	D_3		0.66	0.81	0.83	0.76	0.55	0.60	0.62	0.59	1.21	1.41	1.45	1.35
Mean		42.79	0.75	0.91	0.94	0.86	0.58	0.64	0.66	0.62	1.33	1.56	1.60	1.50
		Fodder maize												
Peanut/fodder maize/flax	D_1		0.66	0.79	0.90	0.78	0.57	0.60	0.62	0.59	1.23	1.39	1.52	1.38
	D_2		0.55	0.69	0.78	0.67	0.51	0.54	0.57	0.54	1.06	1.23	1.35	1.21
	D_3		0.44	0.57	0.70	0.57	0.45	0.49	0.53	0.49	0.89	1.06	1.23	1.06
Mean		36.04	0.55	0.68	0.79	0.67	0.51	0.54	0.57	0.54	1.06	1.22	1.36	1.21

Treatments		Preceded crops	Financial return/ha (US$)											
			Flax				Total return				Net return			
			N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean	N_1	N_2	N_3	Mean
		Peanut												
Peanut/flax	D_1		1034	1177	1312	1174	3941	4084	4219	4081	1451	1600	1680	1577
	D_2		917	1051	1186	1051	3824	3958	4093	3958	1334	1474	1554	1451
	D_3		790	925	1085	933	3697	3832	3992	3840	1207	1348	1453	1336
Mean		2907	913	1051	1194	1052	3820	3958	4101	3959	1330	1474	1562	1455
		Peanut + fahl berseem												
Peanut/fahl berseem/flax	D_1		1219	1438	1480	1379	7109	7328	7370	7269	3728	3923	3940	3863
	D_2		1135	1320	1354	1269	7025	7210	7244	7159	3644	3805	3814	3754
	D_3		1017	1186	1219	1140	6907	7076	7109	7030	3526	3671	3679	3625
Mean		5890	1123	1314	1351	1262	7013	7204	7241	7152	3632	3799	3811	3747
		Peanut + fodder maize												
Peanut/fodder maize/flax	D_1		1034	1169	1278	1160	7330	7465	7574	7456	3364	3475	3559	3466
	D_2		891	1034	1135	1020	7187	7330	7431	7316	3221	3340	3416	3325
	D_3		748	891	1034	891	7044	7187	7330	7187	3078	3197	3315	3196
Mean		6296	891	1031	1149	1023	7187	7327	7445	7319	3221	3337	3430	3329

Prices of main products are that of 2012: US$ 94.01 for ton of green fodder maize; US$ 1060.95 for ton of peanut pods; US$ 69.71 for ton of berseem green forage and US$ 841.3 for ton of flax (seed + fiber), D_1: 5th November, D_2: 15th November and D_3: 25th November, N_1: 107.1 kg N/ha, N_2: 142.8 kg N/ha and N_3: 178.5 kg N/ha.

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