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Maximising the Yield and its Components of Two New Flax Cultivars by using Combinations of Mineral and Bio-Fertilizer

Abdelmasieh, W. K. L.*; Sabah M. Abo El-Komsan and I. M. Sallam

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Fiber Crops Research Department, Field Crops Research Institute, Agricultural Research Center, Giza, Egypt.

ABSTRACT

Two field trials were performed during 2020/2021 and 2021/2022 seasons at Sakha Agricultural Research Station to determine the optimum levels of mineral fertilizer (Nitrogen) and bio-fertilizers (*Azotobacter* and *Azospirillum*) for yield and yield attributes for new flax cultivars (Sakha 5 and Sakha 6). Split-plot design with four replicates was the experimental design. The main-plots were selected for ten mineral and bio-fertilizers treatments and the sub-plots were chosen for two flax cultivars. The results referred that using 100% of the recommended dose of nitrogen (RDN) or 75% RDN + *Azotobacter* + *Azospirillum* treatments significantly achieved the highest values for technical length, stem diameter, straw yield/plant and per feddan, fruiting zone length, number of capsules/plant, seed yield per plant and also per feddan, oil content %, oil yield/fed, also fiber length, fiber % and fiber yield/fed through each season. Sakha 6 cultivar significantly outperformed Sakha 5 in technical length, stem diameter, straw yield/plant and per feddan, seed index, seed yield/plant, fiber length, fiber % and fiber yield/fed, while Sakha 5 was superior in number of capsules/plant, oil content % and oil yield/fed in the first and second seasons. It can be concluded that the most economic return for farmers was gained from using the combination of 75% of the recommended dose of nitrogen + *Azotobacter* + *Azospirillum* bacteria with Sakha 6 cultivar for the best straw and fiber yield per fed or with Sakha 5 cultivar for the best oil yield per fed under the environmental conditions of North Delta of Egypt.

Keywords: Mineral fertilizers, bio-fertilizers, flax cultivars

INTRODUCTION

Flax (*Linum usitatissimum* L.) is one of the earliest fiber crops in Egypt. Flax has been known for many centuries and was used by the ancient Egyptians for dual purposes (fibers and seeds). Due to exports as well as domestic industry, flax plays a significant part in Egypt's national economy. In Egypt, flax is regarded as the second-largest fiber crop behind cotton in terms of both commercial value and area cultivated (El Harriri *et al.*, 1998). The long fibers are spun into linen yarns and used to make textiles, garments, and towels. The short fibers (tow) are employed in the production of paper, twin, and packaging. Linseed oil and linseed meal are made from crushed flax seeds. Oil is used to make paints, varnishes, printing ink, oil cloth, and soap because it dries quickly in the air. Egypt's complete flax crop cultivation area reached about 8609 hectares in 2021 season, producing 7600.74 tonnes of fibers (FAO, 2023).

Mineral and nutritional shortages in the population are a problem in many developing nations worldwide. (Dhaliwal *et al.*, 2022). Numerous studies came to the conclusion that nitrogen fertilizer, when used in the proper and necessary quantity, might increase flax yield, yield characteristics and quality. Therefore, an effective fertilizing strategy is required to maximize flax cultivation and its qualitative and quantitative properties (Dordas, 2010). Abdel-Galil *et al.* (2015) indicated that increasing the rate of mineral nitrogen fertilizer to 178.5 kg N/ha had the greatest values for plant height, technical length of the main stem, number of capsules/plant, number of seeds/capsule, 1000– seed weight, seed yields per plant as well as per ha and oil, straw and fiber yields per hectare. On the contrary, by raising mineral N fertilizer rates, flax seed oil content was lowered. According to El-Borhamy (2016), nitrogen fertilizer is crucial for plant growth and for increasing the production of crops. Increasing the nitrogen level from 30 to 60 kg/fed noticeably increased straw yield/plant, straw yield/fed, fiber length, fruiting zone length and number of capsules/plant. The best values for seed yield and its characteristics were obtained by adding 45 kg N/fed. Nitrogen-fertilized varieties, according to Brunšek *et al.* (2022), had thicker stems, longer technical stem and fiber lengths, slightly coarser and stronger fibers.

Particularly in Egypt, where the cost of chemical nitrogen fertilizers has soared in recent years, the consumption of expensive mineral fertilizers is a constraint for low-income farmers and raises the price of crop production. Both the economic and ecological costs of fertilizer use will eventually become unaffordable given the state of fertilizer production technology and the ineffective fertilizer application techniques currently in use (Dixon and Wheeler, 1986). Therefore, the significance of reducing the usage of mineral fertilizers, specifically nitrogen fertilizers appears. Consequently, the importance of using bio-fertilizers with nitrogen fertilizers becomes clear as an attempt to reduce the rates of use of those mineral fertilizers. Zahana and Abo-Kaied (2007) indicated that using bio-fertilizer application resulted in a significant increase in plant height, technical stem length, straw yield/plant, straw and fiber yield per feddan, No. of capsules per plant, No. of seeds per capsule, 1000-seed weight, seed weight/plant, seed yield/fed, oil yield/fed and also, the bio-fertilization significantly raised oil %, fiber % and fiber length. Contrarily,

* **Corresponding author.**
E-mail address: william.karam.arc@gmail.com
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fiber fineness decreased when using bio-fertilizer. Al-Sudani and Al-Baldawi (2018) found that using bio-fertilization (*Pseudomonas fluorescens, Azospirillum brasilense* and mixture of two fertilizers) improved the most vegetative traits for the flax, which was reflected in the increase of seed yield owing to the increment of two components of the plant, namely number of capsules and number of seeds in the capsule as well as its role in increasing the percentage and yield of the oil, so that the bio-mixture can be an alternative to chemical fertilizers. According to Omar *et al.* (2021), the maximum values of straw and seed yields, as well as their various components, were obtained by the dual mineral application of N with N bio-fertilizer (Nitrobein plus 30 kg N/fed).

Increasing the productivity of flax can be accomplished by either horizontal expansion or vertical expansion and since horizontal expansion is costly, so this can be carrying out through vertical expansion through the cultivation of high-yielding flax varieties. Kineber *et al.* (2015) found that the new flax cultivars Sakha 5 and Sakha 6 were much greater in straw yield, seed yield, fiber yield, oil yield, fiber % and oil % than the commercial check cultivar Sakha 2. As stated by Kumar *et al.* (2018), there are noticeable differences amongst flax cultivars in terms of plant height, number of branches, number of capsules, and seed index. Dawood *et al.* (2019) came to the conclusion that plant height, number of fruiting branches, number of capsules, seed index and seed yield differed significantly for various flax cultivars. Drej and Noaman (2021) clarified that Sakha 6 cultivar outperformed in most of the evaluated characteristics, having the best values of plant height, No. of fruiting branches, No. of capsules per plant, seed index and seed yield, with the exception of characteristic of the No. of seeds per capsule in which the cultivar Sakha 5 surpassed the other varieties (Sakha 1, Sakha 4, Sakha 5, Sakha 6 and local).

Therefore, this research was conducted to determine the best fertilizer rate for two new varieties of flax, and as an attempt to reduce the cost of using mineral fertilizers through the use of bio-fertilizers.

MATERIALS AND METHODS

A field experiments were performed at the Experimental Farm of Sakha Agricultural Research Station at North Delta Region, Agricultural Research Center (ARC), Egypt, throughout the two winter growing seasons of 2020/2021 and 2021/2022. This study's aimed to determine the suitable rate of mineral fertilizers and bio-fertilizers to maximize the yield and its attributes of two new flax cultivars *i.e.* Sakha 5 and Sakha 6.

Each field trial was assigned in a split-plot design with four replicates, where sub-plot area was 6 m^2 (2 x 3m). The main-plots were assigned to ten mineral and bio-fertilizers combinations, where the two flax cultivars were putted in the sub-plots. The experimental treatments were as follows:

A. Mineral and bio-fertilizers combinations:

1- 100% of the recommended dose of nitrogen (RDN).
2- 25% RDN + *Azotobacter*.
3- 25% RDN + *Azospirillum*.
4- 25% RDN + *Azotobacter* + *Azospirillum*.
5- 50% RDN + *Azotobacter*.
6- 50% RDN + *Azospirillum*.
7- 50% RDN + *Azotobacter* + *Azospirillum*.
8- 75% RDN + *Azotobacter*.
9- 75% RDN + *Azospirillum*.
10- 75% RDN + *Azotobacter* + *Azospirillum*.

B. Flax cultivars:

1- Sakha 5 (oil type).
2- Sakha 6 (dual type).

The pedigree of the different flax cultivars is presented in Table 1.

Table 1. The pedigree of the two studied flax genotypes

No.	Genotypes	Classification	Source
1-	Sakha 5	Oil type	I. 370 x I. 2561
2-	Sakha 6	Dual type	S.420 × Bombay

The soil texture at the experimental location is clay. Maize (*Zea mays* L.) was the prior summer crop in both study seasons. Mechanical and chemical analysis for the experimental sites in the first and second seasons is tabulated in Table 2.

During soil preparation, the recommended phosphorus requirement fertilizer as calcium super phosphate (15.5% P_2O_5) was added at the rate of 100 kg/fed. As for biofertilization, nitrogen fixing bacteria were used in the form of *Azotobacter spp.* and *Azospirillum spp.*, which obtained from Agricultural Research Center (ARC), Giza, Egypt, Ministry of Agriculture. The addition of the bio-fertilizers with sand was prior to sowing irrigation directly using the broadcast method at the rate of 400 g/fed for each type of bacteria. In addition, the nitrogen fertilizer at the rate of 45 kg N/fed as ammonium nitrate (33.5% N) was added in two doses of equal size, the first half of nitrogen before the second irrigation, while the second one was applied before the third irrigation.

Flax was sown using broadcast sowing method with the recommended seed rate for every genotype on 31st October and 2nd November in both seasons, respectively. The other agricultural practices for flax were remained the same as normally practiced in accordance with the suggested recommendations of Ministry of Agriculture and Land Reclamation.

Table 2. The physical and chemical properties of the experimental site during 2020/2021 and 2021/2022 seasons.

Properties		2020/2021 season	2021/2022 season
A: Mechanical analysis:			
Sand %		9.71	9.80
Silt %		30.34	29.90
Clay %		59.95	60.30
Texture		Clayey	Clayey
B: Chemical analysis:			
pH		7.68	7.82
EC ds/m		2.90	2.85
Organic matter %		1.30	1.25
Available mg/kg	N	26.30	27.10
	P	8.70	8.65
	K	250.80	260.50
Soluble cations meq/L	Ca^{++}	6.63	6.42
	Mg^{++}	5.92	6.86
	Na^{+}	10.48	9.91
	K^{+}	0.45	0.46
Soluble anions meq/L	$CO3^{--}$	0	0
	$HCO3^{-}$	4.60	4.48
	Cl^{-}	9.26	8.92
	$SO4^{--}$	11.12	10.78

The studied characters:

At the harvest time, ten guarded plants were selected in random from each sub-plot to register the yield attributes.

Straw yield/fed (ton), seed yield/fed (kg), oil yield/fed (kg) and fiber yield/fed (kg) were calculated using the center one square meter of each subplot's area. Seed oil content percentage was determined according to the method described by A.O.A.C. (1990), using petroleum ether at (40–50°C) in a Soxhlet apparatus. Oil yield/fed (kg) was determined by multiplying seed oil content percentage and seed yield/fed. Fiber percentage was calculated by (weight of fiber yield/weight of straw yield after retting) x 100.

Yields and its components:

I. Straw yield and its components were: technical length (cm), stem diameter (mm), straw yield/plant (g) and straw yield/fed (ton).

II. Seed yield and its components were: fruiting zone length (cm), number of capsules/plant, seed index (weight of 1000 seeds) (g), seed yield/plant (g), seed yield/fed (kg), oil content percentage and oil yield/fed (kg).

III. Fiber yield and its components were: fiber length (cm), fiber percentage and fiber yield/fed (kg).

Statistical analysis:

The data was statistically analyzed using the method of analysis of variance (ANOVA) for the split-plot design as released 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 DISCUSSIONS

I. Straw yield and its components:

Data presented in Table 3 revealed that mineral and bio-fertilizers combinations treatments showed a significant effect on all studied characters of straw yield and its components of flax in both growing seasons. Application of 100% of the recommended dose of nitrogen (RDN) or 75% RDN + *Azotobacter* + *Azospirillum* significantly increased technical length, stem diameter, straw yield/plant and straw yield/fed characters in the first and second seasons, without any significant differences between these both treatments. On the other hand, the application of 25% RDN + *Azotobacter* or 25% RDN + *Azospirillum* gave the lowest values of technical length, stem diameter, straw yield/plant and straw yield/fed characters of flax in each season. The increase in flax straw yield and its characters might be attributed to the suitable nitrogen amount, which is considered an essential element for flax growth to produce protoplasm and protein which is essential for cell division and meristematic activity, such this impact led to an increase in number of cells and cell size, consequently this is reflected in the plant growth characteristics such as technical length, stem diameter and straw yield whether for the plant or for feddan. These results are consistent with Mostafa *et al*. (2003), Zahana and Abo-Kaied (2007), Hussein (2012), El-Refaey *et al.* (2015), Al-Sudani and Al-Baldawi (2018) and Omar *et al*. (2021).

Table 3. Technical length, stem diameter, straw yield/plant and straw yield/fed of flax as affected by mineral and bio-fertilizers combinations and flax cultivars as well as their interaction during 2020/2021 and 2021/2022 seasons.

Characters		Technical length (cm)		Stem diameter(mm)		Straw yield/plant(g)		Straw yield(ton/fed)	
Treatments		2020/2021	2021/2022	2020/2021	2021/2022	2020/2021	2021/2022	2020/2021	2021/2022
Mineral and bio-fertilizers combinations:									
100% RDN		74.3	75.9	2.5	2.8	1.11	1.15	2.985	3.092
25% RDN + *Azotobacter*		47.6	50.0	1.5	1.5	0.61	0.68	1.602	1.730
25% RDN + *Azospirillum*		51.0	53.1	1.6	1.5	0.69	0.75	1.679	1.825
25% RDN + *Azotobacter* + *Azospirillum*		50.8	54.4	1.6	1.6	0.73	0.76	1.841	1.924
50% RDN + *Azotobacter*		59.1	58.8	1.8	1.8	0.85	0.85	2.140	2.259
50% RDN + *Azospirillum*		60.4	59.8	1.9	1.9	0.84	0.86	2.213	2.315
50% RDN + *Azotobacter* + *Azospirillum*		62.0	62.3	2.0	2.0	0.85	0.87	2.310	2.368
75% RDN + *Azotobacter*		65.6	66.9	2.2	2.3	0.97	0.98	2.633	2.650
75% RDN + *Azospirillum*		65.9	66.9	2.2	2.3	0.98	0.98	2.677	2.734
75% RDN + *Azotobacter* + *Azospirillum*		71.4	73.1	2.4	2.5	1.05	1.08	2.832	2.941
LSD at 5 %		8.9	5.1	0.4	0.4	0.11	0.15	0.257	0.183
Flax cultivars:									
Sakha 5		51.2	52.9	1.7	1.8	0.67	0.70	1.899	1.979
Sakha 6		70.4	71.3	2.2	2.3	1.06	1.09	2.684	2.789
LSD at 5 %		4.5	2.3	0.1	0.1	0.05	0.05	0.065	0.080
Interaction:									
100% RDN	Sakha 5	63.1	65.5	2.2	2.3	0.81	0.84	2.496	2.722
	Sakha 6	85.4	86.3	2.9	3.3	1.40	1.47	3.474	3.463
25% RDN + *Azotobacter*	Sakha 5	38.6	43.5	1.4	1.4	0.51	0.57	1.362	1.429
	Sakha 6	56.6	56.4	1.6	1.6	0.70	0.78	1.842	2.030
25% RDN + *Azospirillum*	Sakha 5	42.9	44.9	1.4	1.4	0.54	0.63	1.354	1.573
	Sakha 6	59.2	61.3	1.7	1.7	0.84	0.86	2.003	2.077
25% RDN + *Azotobacter* +*Azospirillum*	Sakha 5	42.8	45.9	1.4	1.5	0.60	0.61	1.542	1.609
	Sakha 6	58.8	62.9	1.8	1.7	0.86	0.90	2.140	2.238
50% RDN + *Azotobacter*	Sakha 5	50.8	50.3	1.5	1.6	0.65	0.67	1.728	1.754
	Sakha 6	67.4	67.3	2.0	2.0	1.05	1.04	2.553	2.763
50% RDN + *Azospirillum*	Sakha 5	51.1	51.9	1.6	1.8	0.67	0.68	1.778	1.779
	Sakha 6	69.7	67.7	2.2	2.0	1.02	1.05	2.647	2.852
50% RDN + *Azotobacter* +*Azospirillum*	Sakha 5	53.7	53.8	1.7	1.8	0.68	0.69	1.849	1.893
	Sakha 6	70.3	70.8	2.3	2.1	1.03	1.05	2.772	2.842
75% RDN + *Azotobacter*	Sakha 5	54.2	55.3	1.8	1.9	0.74	0.76	2.232	2.195
	Sakha 6	77.0	78.4	2.5	2.7	1.19	1.20	3.034	3.106
75% RDN + *Azospirillum*	Sakha 5	54.3	55.6	1.9	1.8	0.75	0.76	2.256	2.342
	Sakha 6	77.6	78.1	2.5	2.8	1.21	1.20	3.098	3.126
75% RDN + *Azotobacter* +*Azospirillum*	Sakha 5	60.6	62.6	2.0	2.1	0.79	0.81	2.388	2.494
	Sakha 6	82.3	83.5	2.7	3.0	1.31	1.35	3.276	3.389
LSD at 5 %		NS	NS	NS	0.4	0.15	0.17	0.205	0.253

RDN: (Recommended Dose of Nitrogen)

As shown in Table 3 there are significant differences in all studied characters of straw yield and its components between flax genotypes in both growing seasons. The results showed that Sakha 6 variety ranked first and surpassed Sakha 5 variety in straw yield and its components characters; technical length, stem diameter, straw yield/plant and straw yield/fed in the first and second growing seasons. Such results, mainly due to the variations in the genetical factors between the two tested cultivars, especially the potentiality of difference between oil and dual-purpose types of flax. Similar results were obtained by Kineber *et al.* (2015), El-Borhamy *et al.* (2017), Kumar *et al.* (2018), Dawood *et al.* (2019), EL-Shimy *et al.* (2019), Drej and Noaman (2021) and Elsorady *et al.* (2022).

The interaction between mineral and bio-fertilizers combination levels and flax cultivars exhibited a significant effect on stem diameter in the second season only, straw yield/plant and straw yield/fed in each season of study (Table 3). The result presented in Table 3 revealed that the highest values of stem diameter, straw yield/plant and straw yield/fed were obtained when Sakha 6 cultivar received the recommended dose of nitrogen (45 kg N/fed) or received 75% from the recommended dose of nitrogen + *Azotobacter* + *Azospirillum,* without any significant differences between these both treatments. While, fertilizing Sakha 5 cultivar with 25% from the advised dose of nitrogen + *Azotobacter* or with 25% from the recommended dose of nitrogen + *Azospirillum* recorded the lowest values of aforementioned characters.

II. Seed yield and its components:

Significant differences were observed among mineral and bio-fertilizers combinations treatments on fruiting zone length, number of capsules/plant (Table 4), seed yield/plant, seed yield/fed, oil content percentage and oil yield/fed (Table 5) in both seasons of the experiment. It could be noticed that application of 100% of the recommended dose of nitrogen (RDN) or 75% RDN + *Azotobacter* + *Azospirillum* achieved the best results without any significant differences between them for number of capsules/plant, seed yield/plant, seed yield/fed, oil content percentage and oil yield/fed in the first and second seasons and for fruiting zone length in the second season only, while using 100% of the advised dose of nitrogen (RDN) gained the highest values for fruiting zone length in the first season . Meanwhile, the combination of 25% from the recommended dose of nitrogen + *Azotobacter* recorded the lowest values for mentioned characters; fruiting zone length, number of capsules/plant, seed yield/plant, seed yield/fed, oil content percentage and oil yield/fed in the 1st and 2nd seasons.

Table 4. Fruiting zone length, number of capsules/plant and seed index of flax as affected by mineral and bio-fertilizers combinations and flax cultivars as well as their interaction during 2020/2021 and 2021/2022 seasons.

Characters / Treatments		Fruiting zone length (cm) 2020/2021	Fruiting zone length (cm) 2021/2022	Number of capsules /plant 2020/2021	Number of capsules /plant 2021/2022	Seed index (g) 2020/2021	Seed index (g) 2021/2022
Mineral and bio-fertilizers combinations:							
100% RDN		21.7	22.4	20.8	22.5	8.58	8.63
25% RDN + *Azotobacter*		11.6	12.6	12.2	13.2	7.82	7.91
25% RDN + *Azospirillum*		11.9	12.7	12.8	13.5	7.90	8.01
25% RDN + *Azotobacter* + *Azospirillum*		12.1	12.7	13.8	13.8	8.10	8.20
50% RDN + *Azotobacter*		14.2	14.0	14.8	14.5	8.19	8.33
50% RDN + *Azospirillum*		14.4	15.3	14.8	15.0	8.26	8.33
50% RDN + *Azotobacter* + *Azospirillum*		15.3	15.0	15.2	15.2	8.41	8.44
75% RDN + *Azotobacter*		17.2	17.2	17.5	17.8	8.46	8.49
75% RDN + *Azospirillum*		17.6	17.9	17.8	18.3	8.49	8.54
75% RDN + *Azotobacter* + *Azospirillum*		19.2	20.9	18.5	20.0	8.54	8.57
LSD at 5 %		2.4	2.8	2.7	2.7	NS	NS
Flax cultivars:							
Sakha 5		14.9	15.4	17.0	17.5	6.84	6.89
Sakha 6		16.1	16.7	14.6	15.2	9.71	9.80
LSD at 5 %		NS	NS	1.4	1.6	0.33	0.26
Interaction:							
100% RDN	Sakha 5	20.9	21.2	23.0	24.7	7.08	7.13
	Sakha 6	22.4	23.6	18.7	20.3	10.07	10.13
25% RDN + *Azotobacter*	Sakha 5	11.1	11.2	12.7	13.7	6.41	6.49
	Sakha 6	12.2	13.9	11.7	12.7	9.23	9.33
25% RDN + *Azospirillum*	Sakha 5	11.2	12.3	13.3	14.0	6.53	6.65
	Sakha 6	12.6	13.1	12.3	13.0	9.27	9.36
25% RDN + *Azotobacter* + *Azospirillum*	Sakha 5	11.2	12.6	15.0	14.3	6.69	6.81
	Sakha 6	12.9	12.7	12.7	13.3	9.50	9.58
50% RDN + *Azotobacter*	Sakha 5	13.5	13.6	15.7	15.7	6.77	6.85
	Sakha 6	14.8	14.4	14.0	13.3	9.61	9.81
50% RDN + *Azospirillum*	Sakha 5	13.9	14.6	16.0	16.0	6.82	6.84
	Sakha 6	15.0	15.9	13.7	14.0	9.70	9.83
50% RDN + *Azotobacter* + *Azospirillum*	Sakha 5	14.7	14.3	16.7	16.3	6.98	6.97
	Sakha 6	15.9	15.6	13.7	14.0	9.84	9.91
75% RDN + *Azotobacter*	Sakha 5	16.7	16.4	19.0	19.3	7.03	7.02
	Sakha 6	17.6	18.0	16.0	16.3	9.88	9.96
75% RDN + *Azospirillum*	Sakha 5	17.1	17.8	19.0	20.0	7.04	7.07
	Sakha 6	18.0	18.0	16.7	16.7	9.95	10.01
75% RDN + *Azotobacter* + *Azospirillum*	Sakha 5	19.0	20.3	20.0	21.3	7.06	7.08
	Sakha 6	19.5	21.5	17.0	18.7	10.02	10.06
LSD at 5 %		NS	NS	NS	NS	NS	NS

RDN: (Recommended Dose of Nitrogen)

Table 5. Seed yield/plant, seed yield/fed, oil content percentage and oil yield/fed of flax as affected by mineral and bio-fertilizers combinations and flax cultivars as well as their interaction during 2020/2021 and 2021/2022 seasons.

Characters		Seed yield/plant(g)		Seed yield(kg/fed)		Oil content (%)		Oil yield (kg/fed)	
Treatments		2020/2021	2021/2022	2020/2021	2021/2022	2020/2021	2021/2022	2020/2021	2021/2022
Mineral and bio-fertilizers combinations:									
100% RDN		0.90	0.95	643.47	669.55	44.1	44.5	283.10	297.95
25% RDN + *Azotobacter*		0.61	0.62	402.08	416.73	38.3	39.3	154.07	163.34
25% RDN + *Azospirillum*		0.64	0.65	408.26	421.78	39.3	40.3	160.59	171.06
25% RDN + *Azotobacter* + *Azospirillum*		0.64	0.66	421.39	437.60	39.9	40.4	167.41	177.58
50% RDN + *Azotobacter*		0.77	0.78	504.95	514.34	41.6	41.8	209.87	215.65
50% RDN + *Azospirillum*		0.78	0.79	509.88	523.01	41.9	42.3	212.93	221.50
50% RDN + *Azotobacter* + *Azospirillum*		0.79	0.80	522.74	536.59	42.3	42.9	221.56	229.77
75% RDN + *Azotobacter*		0.85	0.86	586.74	601.75	43.0	43.7	251.86	263.38
75% RDN + *Azospirillum*		0.86	0.87	587.64	603.04	43.5	44.3	255.16	267.46
75% RDN + *Azotobacter* + *Azospirillum*		0.87	0.91	618.86	630.37	43.9	44.3	271.47	278.26
LSD at 5 %		0.07	0.10	50.89	60.22	3.7	3.5	20.04	31.57
Flax cultivars:									
Sakha 5		0.72	0.73	526.27	542.98	43.3	43.6	229.22	238.65
Sakha 6		0.82	0.84	514.94	527.97	40.3	41.1	208.38	218.54
LSD at 5 %		0.04	0.04	NS	NS	1.9	1.8	13.74	15.32
Interaction:									
100% RDN	Sakha 5	0.84	0.89	651.28	677.02	45.8	45.9	297.09	311.61
	Sakha 6	0.96	1.01	635.66	662.07	42.3	43.0	269.10	284.29
25% RDN + *Azotobacter*	Sakha 5	0.56	0.57	401.93	419.67	39.0	39.9	156.46	167.28
	Sakha 6	0.67	0.67	402.24	413.79	37.7	38.7	151.67	159.40
25% RDN + *Azospirillum*	Sakha 5	0.59	0.60	413.61	427.90	41.1	41.8	169.66	179.11
	Sakha 6	0.69	0.70	402.91	415.65	37.6	38.8	151.52	163.00
25% RDN + *Azotobacter* +*Azospirillum*	Sakha 5	0.59	0.60	426.21	443.40	41.2	41.7	175.44	185.45
	Sakha 6	0.70	0.72	416.58	431.81	38.5	39.1	159.37	169.71
50% RDN + *Azotobacter*	Sakha 5	0.71	0.72	518.30	527.35	43.0	42.8	222.07	226.33
	Sakha 6	0.83	0.83	491.60	501.33	40.3	40.8	197.66	204.97
50% RDN + *Azospirillum*	Sakha 5	0.73	0.74	512.39	531.14	43.6	43.3	222.46	229.79
	Sakha 6	0.83	0.84	507.37	514.87	40.1	41.4	203.40	213.22
50% RDN + *Azotobacter* +*Azospirillum*	Sakha 5	0.74	0.77	526.67	544.16	43.7	44.1	230.00	239.40
	Sakha 6	0.84	0.84	518.81	529.03	41.0	41.6	213.13	220.13
75% RDN + *Azotobacter*	Sakha 5	0.80	0.81	593.51	611.56	44.5	45.2	263.79	276.47
	Sakha 6	0.89	0.92	579.97	591.94	41.5	42.1	239.94	250.28
75% RDN + *Azospirillum*	Sakha 5	0.81	0.82	594.24	608.22	45.5	46.0	270.01	279.56
	Sakha 6	0.90	0.92	581.05	597.86	41.5	42.6	240.31	255.36
75% RDN + *Azotobacter* +*Azospirillum*	Sakha 5	0.82	0.84	624.53	639.36	45.7	45.7	285.21	291.49
	Sakha 6	0.93	0.98	613.19	621.38	42.0	42.8	257.74	265.03
LSD at 5 %		NS	NS	NS	NS	NS	NS	NS	NS

RDN: (Recommended Dose of Nitrogen)

Such results mainly due to the availability of nitrogen as an important factor on distribution of photosynthetic assimilates between vegetative and reproductive organs. This will enhance leaf expansion, higher number of branches and number of capsule, consequently maximizing seed yield obtained and its components with the suitable nitrogen fertilization. Similar results were obtained by Mostafa *et al.* (2003), Garsid (2004), Zahana and Abo-Kaied (2007), Hussein (2012), El-Refaey *et al.* (2015), Al-Sudani and Al-Baldawi (2018) and Omar *et al.* (2021).

Data in Tables 4 and 5 revealed that the studied flax cultivars (Sakha 5 and Sakha 6) significantly differed in agronomic characters of seed yield and its components, except for the fruiting zone length and seed yield/fed in each season. Sakha 5 cultivar showed a significant superior compared with the other flax cultivar (Sakha 6) in regard to number of capsules/plant, oil content percentage and oil yield/fed, while Sakha 6 cultivar significantly surpassed Sakha 5 cultivar in seed index and seed yield/plant in each season of study. These variations are mainly due to the kind of the genetic material for each cultivar or to the variances in their genetical constitution and genetic factors makeup among the studied flax cultivars. These results are consistent with those detected by Kineber *et al.* (2015), El-Borhamy *et al.* (2017), Al-Sudani and Al-Baldawi (2018), Kumar *et al.* (2018), Dawood *et al.* (2019), EL-Shimy *et al.* (2019), Drej and Noaman (2021) and Elsorady *et al.* (2022).

As for the interaction effect between mineral and bio-fertilizers combination levels and flax cultivars, Tables 4 and 5 reflected that the interaction had no significant impact on fruiting zone length, number of capsules/plant, seed index, seed yield/plant, seed yield/fed, oil content percentage and oil yield/fed throughout the first and second seasons of study.

III. Fiber yield and its components:

The influence of various studied treatments of mineral and bio-fertilizers combinations on fiber yield and its components of flax were presented in Table (6). Application of 100% of the recommended dose of nitrogen (RDN) resulted in significant increases for fiber length, fiber percentage and fiber yield/fed in each season. In comparison with 100% of the recommended dose of nitrogen (RDN), comparable significant results for fiber length, fiber percentage and fiber yield/fed were obtained due to the treatment of 75% from the recommended dose of nitrogen + both types of bio-fertilizers (*Azotobacter* and *Azospirillum*) through both seasons. Table (6) also showed that the application of 25% from the recommended dose of nitrogen + *Azotobacter* gave the lowest values for mentioned characters; fiber length, fiber percentage and fiber yield/fed in both seasons of study. These findings are mainly due to the suitable nitrogen doses that improved flax growth parameters.

At the same time, there is a favorable influence of nitrogen on the individual fiber units at the critical period of flax plant growth and in turn enhance fiber quality and quantity. These results matched with those of Dordas (2010), Hussein (2012), Jasminka *et al*. (2014), Abdel-Galil *et al*. (2015), El-Borhamy (2016) and Brunšek *et al*. (2022).

Table 6. Fiber length, fiber percentage and fiber yield/fed of flax as affected by mineral and bio-fertilizers combinations and flax cultivars as well as their interaction during 2020/2021 and 2021/2022 seasons.

Characters		Fiber length (cm)		Fiber percentage (%)		Fiber yield (kg/fed)	
Treatments		2020/2021	2021/2022	2020/2021	2021/2022	2020/2021	2021/2022
Mineral and bio-fertilizers combinations:							
100% RDN		67.6	68.7	14.2	14.7	226.74	232.45
25% RDN + *Azotobacter*		56.0	57.8	11.7	12.3	154.26	160.69
25% RDN + *Azospirillum*		59.4	60.3	12.1	12.5	158.88	164.92
25% RDN + *Azotobacter* + *Azospirillum*		60.1	60.8	12.6	13.1	168.80	174.35
50% RDN + *Azotobacter*		61.3	62.4	12.6	13.1	192.60	198.49
50% RDN + *Azospirillum*		61.2	62.4	12.5	13.1	193.92	200.07
50% RDN + *Azotobacter* + *Azospirillum*		62.5	63.5	12.8	13.3	195.69	201.65
75% RDN + *Azotobacter*		63.5	64.9	13.0	13.5	211.16	216.99
75% RDN + *Azospirillum*		63.8	65.2	13.2	13.8	213.50	219.67
75% RDN + *Azotobacter* + *Azospirillum*		64.0	67.0	13.5	14.2	219.17	230.09
LSD at 5 %		5.3	4.4	1.3	1.3	31.19	31.56
Flax cultivars:							
Sakha 5		59.9	61.3	12.2	12.8	114.53	117.74
Sakha 6		64.0	65.3	13.4	13.9	272.41	282.13
LSD at 5 %		2.7	2.7	1.0	1.0	11.21	11.35
Interaction:							
100% RDN	Sakha 5	65.3	65.4	13.4	13.9	132.00	134.79
	Sakha 6	69.9	71.9	14.9	15.4	321.48	330.11
25% RDN + *Azotobacter*	Sakha 5	53.6	56.3	10.6	11.2	97.64	101.25
	Sakha 6	58.5	59.4	12.8	13.5	210.89	220.12
25% RDN + *Azospirillum*	Sakha 5	57.6	58.6	11.1	11.6	99.38	102.84
	Sakha 6	61.1	62.1	13.0	13.3	218.38	227.01
25% RDN + *Azotobacter* + *Azospirillum*	Sakha 5	58.3	59.5	12.1	12.7	100.27	102.67
	Sakha 6	62.0	62.1	13.0	13.5	237.33	246.03
50% RDN + *Azotobacter*	Sakha 5	60.2	61.1	12.2	12.7	115.85	118.45
	Sakha 6	62.4	63.7	13.1	13.4	269.36	278.53
50% RDN + *Azospirillum*	Sakha 5	60.4	61.5	12.0	12.6	116.32	119.28
	Sakha 6	62.0	63.3	13.0	13.5	271.51	280.85
50% RDN + *Azotobacter* + *Azospirillum*	Sakha 5	60.6	61.9	12.4	12.9	117.14	119.48
	Sakha 6	64.4	65.0	13.1	13.6	274.24	283.83
75% RDN + *Azotobacter*	Sakha 5	61.1	62.6	12.6	13.2	119.96	122.60
	Sakha 6	65.9	67.1	13.3	13.9	302.36	311.37
75% RDN + *Azospirillum*	Sakha 5	60.9	62.4	12.9	13.3	121.02	123.68
	Sakha 6	66.6	68.0	13.5	14.2	305.98	315.66
75% RDN + *Azotobacter* + *Azospirillum*	Sakha 5	61.1	64.0	13.0	13.6	125.78	132.40
	Sakha 6	66.9	70.1	14.0	14.7	312.56	327.78
LSD at 5 %		NS	NS	NS	NS	35.45	35.88

RDN: (Recommended Dose of Nitrogen)

Fiber length, fiber percentage and fiber yield/fed significantly affected by flax cultivars in both seasons, as shown in Table 6. The presented data indicated that Sakha 6 cultivar achieved significantly higher values for aforementioned characters compared with Sakha 5 cultivar through both seasons of study. These results may be due to the fact that dual genotypes generally exceeded oil types in plant height, technical stem length, straw yields per plant and per feddan, and hence fiber length, fiber percentage and fiber yield due to their genetic potential. These outcomes are consistent with those attained by Kineber *et al.* (2015), Kumar *et al.* (2018), Dawood *et al.* (2019) and Drej and Noaman (2021).

Concerning the interaction effect between mineral and bio-fertilizers treatments levels and flax cultivars, Table 6 referred that the interaction had no significant effect on fiber length or fiber percentage, while the interaction had a significant effect only on fiber yield/fed throughout the first and second seasons of study. Table 6 indicated that the maximum fiber yield/fed was gained when Sakha 6 cultivar received the recommended dose of nitrogen (45 kg N/fed) or received 75% from the recommended dose of nitrogen + *Azotobacter* + *Azospirillum*, without any significant differences between these both treatments in both seasons. While, the minimum fiber yield/fed was obtained from Sakha 5 cultivar with 25% from the advised dose of nitrogen + *Azotobacter* or with 25% from the recommended dose of nitrogen + *Azospirillum* in the first and second growing seasons.

CONCLUSION

Finally, it can be suggested that we can maximizing the yield and its components of flax subsequently increasing the economic return by using the combination of 75% from the recommended dose of nitrogen (33.75 kg N/fed) with nitrogen fixing bacteria (*Azotobacter* and *Azospirillum*) as a bio-fertilizer consequently save the cost of nitrogen fertilization with Sakha 6 flax cultivar for the best straw and fiber yield/fed or with Sakha 5 cultivar for the best oil yield/fed based on the environmental conditions of Northern Delta of Egypt.

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تعظيم إنتاجية المحصول ومكوناته لصنفيين جديدين من الكتان بأستخدام مخاليط من الأسمدة المعدنية والحيوية

وليم كرم لبيب عبد المسيح ، صباح محمد ابوالقمصان و إبراهيم محمود سلام

قسم بحوث محاصيل الألياف ، معهد بحوث المحاصيل الحقلية ، مركز البحوث الزراعية ، الجيزة ، مصر.

الملخص

أجريت تجربتين حقليتين خلال موسمى 2021/2020 و 2022/2021 فى المزرعة البحثية بمحطة البحوث الزراعية بسخا, بهدف دراسة أنسب معدلات السماد المعدنى (النيتروجين) والسماد الحيوى (أزوتوباكتر وأزوسبريلليم) للمحصول ومكوناته لصنفيين جديدين من الكتان (سخا 5 وسخا6). التصميم المستخدم فى التجربة هو تصميم القطع المنشقة مرة واحدة فى أربع مكرارت . أشتملت القطع الرئيسية على عشرة توليفات من التسميد الأزوتى والحيوى بينما أشتملت القطع المنشقة على صنفى الكتان . أشارت النتائج المتحصل عليها إلى أن أستخدام معاملة 100% من جرعة السماد النيتروجينى الموصى بها أومعاملة 75% من جرعة السماد النيتروجينى الموصى بها + أزوتوباكتر + أزوسبريلليم قد حققت معنوياً أعلى القيم بالنسبة لصفات الطول الفعال, سمك الساق, محصول القش / نبات وكذلك للفدان, طول المنطقة الثمرية, عدد الكبسولات / نبات , محصول البذرة / نبات وأيضا محصول البذرة / فدان, النسبة المئوية لمحتوى الزيت, محصول الزيت / فدان وكذلك طول الألياف , النسبة المئوية للألياف ومحصول الألياف / فدان فى كلا الموسمين . تفوق صنف الكتان سخا 6 معنوياً على الصنف سخا 5 فى صفات الطول الفعال , سمك الساق, محصول القش / نبات ومحصول القش / فدان , دليل البذرة , محصول البذرة / نبات , طول الألياف, النسبة المئوية للألياف ومحصول الألياف / الفدان , بينما الصنف سخا 5 كان متفوقاً فى عدد الكبسولات / نبات , النسبة المئوية لمحتوى الزيت ومحصول الزيت / فدان فى الموسم الأول والثانى من هذه الدراسة . ولذلك توصى هذه الدراسة أنه لتحقيق أقصى عائد أقتصادى للمزارعين يمكن أستخدام 75% من جرعة السماد النيتروجينى الموصى بها (33.75 كجم أزوت / الفدان) مع بكتريا تثبيت الأزوت (أزوتوباكتر وأزوسبريلليم) كسماد حيوى بمعدل 400 جم / فدان لكل نوع من البكتريا وذلك مع صنف الكتان سخا 6 وذلك للحصول على أفضل محصول قش وألياف / فدان أو أستخدامه مع صنف الكتان سخا 5 للحصول على أفضل محصول زيت / فدان وذلك تحت الظروف البيئية لمنطقة شمال دلتا مصر .