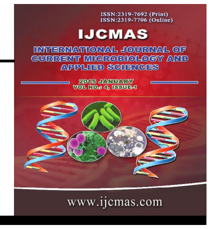

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Original Research Article

Seeding rates and phosphorus source effects on straw, seed and oil yields of flax (*Linum usitatissimum* L.) grown in newly-reclaimed soils

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A B S T R A C T

Seeding rate and phosphorus source were proved to affect the straw, seed and oil yields of flax. Therefore, three seeding rates (i.e., 1750, 2000 and 2250 seed/m^2) and two phosphorus sources (i.e., single super phosphate; SSP and rock phosphate; RP) were used in this study to evaluate their effects on flax (variety Sakha -1) at the Experimental Farm of the Faculty of Agriculture, at Fayoum in the two successive growing seasons 2010/2011 and 2011/2012. Results showed that mean squares of seeding rates were significant for straw, seed and oil yields, indicating different responses of mean performances of flax plants under the experimental seeding rates and phosphorus sources treatment. Increasing seeding rate significantly increased straw, seed and oil yields in most cases in both seasons. The favorable straw yield and its components (i.e., plant height, technical length, number of higher branches plant^{-1}, stem diameter and straw yield plant^{-1}) were observed when flax plants were applied with seeding rate of 2250 seed/m^2. In addition, soil application with SSP ranked as the first of favorable treatments, enhancing flax seed, oil % and oil yield feddan^{-1}. Thus, it could be concluded that the soil application of 2250 seed/m^2 with SSP was the best favorable treatment for producing significantly higher straw, seed and oil yields.

Keywords

Flax,
Seed rates,
Phosphorus sources,
Reclaimed soil

Introduction

Flax (*Linum usitatissimum* L.) is an important industrial crop mostly grown in newly-reclaimed soils under surface irrigation in the middle eastern countries, including Egypt. The linseed contains about 36 to 48% oil content. It is an important source of essential fatty acids for human diets, and has several health benefits (Millis, 2002).

The cultivated area through the last 20 years was decreased from 60 to 30 thousands feddan. This is due to the great competition of other economic winter crops, resulting in a gap between production and consumption (El-Nagdy*et al*., 2010). Consequently, Egypt imports flax seeds for extracting oil from Belgium and Netherlands. Therefore, it is necessary to increase flax productivity per unit area which could be achieved by using high yielding cultivars and improving the agricultural treatments (Hussein, 2007 and Ibrahim, 2009).

The future success of flax cultivation in Egypt will depend on yield potential and yield stability of modern dual purpose cultivars and production system applied in marginal soils (Abo El-Zahab *et al.*, 2010).

The application of essential nutrients in optimum quantity is the key to increase and maintenance of crop production (Cisse and Amar, 2000). Phosphorus is a structural component of nucleic acids and plays a crucial role in reproductive growth. It is an essential nutrient for crop production due to its improvement of physiological functions (Jiao *et al.*, 2013). Singh and Verma (1998) and Ali *et al.* (2002) found that linseed had a significant response to phosphorus application. In this respect, Grant *et al.* (1999) and Khan *et al.* (2000) reported that, mean performances of flax differed for seed and straw yields with the application of phosphorus fertilizers.

Concerning seeding rate, studies by Abdlwahed (2002) and Kinber (2003) revealed that increasing seeding rate found to increase seed and straw yields/m^2. On the other hand, straw and seed yields plant^{-1} were decreased by increasing seeding rate. With respect, Casa *et al.* (1999) and Hassan and Leitch (2000) reported that, plant height was increased by increasing seed rate while, stem diameter was decreased.

The main objective of the present investigation was to study the effect of three seeding rates and two phosphorus sources on straw, seed and oil yields of flax (Sakha-1 variety).

Materials and Methods

Two field experiments were conducted during the two successive seasons 2010/2011 and 2011/2012 at the Experimental Farm of the Faculty of Agriculture, Fayoum University, Southeast Fayoum (29º 17'N; 30º 53'E), Egypt to study the effect of seeding rates and phosphorus sources on economic traits of flax (Sakha-1 variety).

Treatments were randomly arranged in a split-plot design with three replications where the three seeding rates (i.e., A_1; 1750, A_2; 2000 and A_3; 2250 seed/m^2) were allotted to the main plots, while the two phosphorus sources [B_1; single super phosphate (SSP 15.5% P_2O_5) and B_2; rock phosphate (RP 30% P_2O_5)] were distributed randomly in sub-plots. The experimental unit comprised 6 m^2 (1/700 feddan, one feddan = 4200 m^2) with 3m long and 2m wide, forming ten rows of 20 cm between rows. Flax seed were sown on the second week of November in both seasons. Normal cultural practices for flax production as recommended were followed. Physical and chemical analyses of the experimental plots are presented in Table 1.

Measurements of different flax yields

At full maturity, ten individual plants were taken randomly from each experimental plot to record the following traits:

Straw yield and its component **[**i.e., plant height (cm), technical length (cm), number of higher branches plant^{-1}, stem diameter (mm) and straw yield plant^{-1} (g)], Seed yield and its contribution **[**i.e., number of capsules plant^{-1}, number of seeds capsule^{-1}, 1000-seed weight (g), seed yield plant^{-1} (g) and seed yield feddan^{-1} (kg)] and Oil yield [i.e., oil percentage and oil yield feddan^{-1} (kg)].

Statistical analysis:

All collected data were statistically analyzed according to technique of analysis of variance MSTAT-C. The differences among means were detected by LSD test at 5% level of probability (Gomez and Gomez, 1984).

Result and Discussion

Analysis of variance

Mean squares of straw yield and its component are presented in Table 2. Mean squares of seeding rates (A) were significant for technical length and stem diameter in both seasons. Also, mean squares of seeding rates were significant for plant height trait in only the first season, indicating different responses of mean performances of flax plants under the experimental treatments of seeding rates. While, the same treatments were not significant for number of higher branches plant^{-1}, number of capsules plant^{-1} and straw yield plant^{-1} over both seasons. Similar trend was observed by Casa *et al.*, (1999).

Results in Table 2 also revel the P sources; mean squares (B) were significant affected number of higher branches plant^{-1} and stem diameter traits. Moreover, analysis of variance showed a significant variation due to treatment of flax plants by P fertilizer applications for plant height and number of capsules plant^{-1} in the second season, and straw yield plant^{-1} in the first one.

Data in Table 2, show that the analysis of variance were significantly differed for number of seeds capsule^{-1} and seed yield feddan^{-1} under seeding rates in the first season and were significantly differed for seed yield plant^{-1} in both seasons. In addition, data in Table 2 reveal that treatments of plants with phosphorus showed significant differences for characteristics of seed and its component, except for seed yield feddan^{-1}, which was insignificant in the first season, indicating different responses of mean performances of flax plants under the experimental treatments of P.

Generally, analysis of variance showed significant differences of oil percentage and oil yield feddan^{-1} in both seasons. This is in general agreement with the work done by khajani *et al.*, (2012).

Mean squares in Table 2 clear that the interaction effects of seeding rates (A)× phosphorus sources (B) for straw, seed and oil yields and their components had no significant effect in the two seasons, except for number of capsule plant^{-1} in the second season.

Mean performances

a. Straw yield and its components

Results presented in Table 3, indicate that straw yield and related contributions (i.e., plant height, technical length, number of higher branches plant^{-1}, stem diameter and straw yield plant^{-1}) were significantly affected by the treatments of phosphorus sources and/or seed rates for most cases in both seasons. The highest values of straw yield plant^{-1} were obtained with SSP treatment over both seasons. Grant *et al.* (1999) and Khan *et al.* (2000) reported that mean performances of straw yield of flax differed with treatment of phosphorus fertilizers. The data also indicate that the application of seeding rate of 2250 seeds/m^2 significantly increased straw yield plant^{-1} compared to the other seeding rates of 1750 or 2000 seeds/m^2. Among seeding levels, the lowest rate of 1750 seeds/m^2 had the highest number of higher branches plant^{-1} and stem diameter in the first and second seasons. The enhanced straw yield plant^{-1} may be attributed to the highest level of seed rate (A_3; 2250 seeds/m^2) that encouraged the increase in plant height, collecting highest dry mass (Table3).

The highest plant height (110.97 cm) and technical length (87.40 cm) were obtained with seeding rate of 2250 seeds/m^2, in the first season. While, the lowest values of the two previously traits were obtained with seeding rate of 1750 seeds/m^2, over both seasons, respectively. Similar trend was observed by Casa *et al.* (1999), Hassan and Leitch (2000) who reported that, plant height was increased by the increase in seed rate.

Statistical analysis revealed that different phosphorus sources and seeding rate and their interactions (A×B) had a significant effect on technical length in the second season, also P sources showed a significant differences in plant height. Application of B treatments increased plant height and technical length with application of SSP as a form of phosphorus (B_1) compared to RP (B_2). The obtained values were 102.26 and 81.81 cm for plant height and technical length under B_1 treatment in the second season, respectively. As well as, the B_1 showed a significant differences of the previous two traits compared to B_2 in both seasons. This is in general agreement with the work done by Ali *et al.* (2002) and Jiao *et al*. (2013).

Results in Table 3 showed that the interactions between treatments of phosphorus and seeding rates had no significant effect on straw yield and its contribution, except technical length, which recorded significant values in the second season.

b. Seed yield and its components

Data in Table 4 show, in general, significant differences ($p \leq 0.05$) of treatments of seeding rates or phosphorus sources on seed yield and its component (i.e., number of capsules plant^{-1}, number of seeds capsule^{-1}, 1000-seed weight, seed yield plant^{-1}, seed yield feddan^{-1}).

The respective values of number of capsules plant^{-1}, exerted significant differences under seeding rate or P source. This trait recorded 12.37 and 12.97 under the application of SSP, and 11.77 and 10.69 under the treatment of RP in both seasons, respectively. On the other hand, this trait scored 13.43 and 10.90 under the seeding rate of 2250 seeds/m^2. The highest values of seed yield and related components were obtained with the treatment of the highest level of seeding rates (Abdlwahed, 2002).

Regarding number of seeds capsule^{-1}, significant differences were observed among the three seeding rates in the first season. The treatment of 1750 seeds/m^2 gave significantly the highest seeds capsule^{-1} (7.71). In addition, the highest significant values of seeds capsule^{-1} (7.77 and 7.43) were recorded under SSP application compared to RP over both seasons, respectively.

With respect to seed index (Table 4), it is obvious that there were no significant among seed rates in both seasons. The highest values of 1000-seed weight were found under the treatment of A_1 (1750 seeds/m^2). P sources had significant effect on seed index over the two seasons. The highest values were recorded under application of SSP.

Concerning seed yield plant^{-1}, results clear that the treatments of seeding rate or phosphorus source had significant effect in both seasons. The highest values of seed yield plant^{-1} (1.18 and 1.16 g) were obtained at seeding rate of 1750 seeds/m^2 in both seasons, respectively. The increased seed yield plant^{-1} under the lowest seeding rates (1750 seeds/m^{2}) compared to the seed rates may be attributed to the favorable distribution plants. This means that the limited number of plants grown in a unit area enables plants to obtain all requirements of nutrients, sunlight, irrigation water and all other cultural practices, positively reflection vigorous plant growth and consequently higher seed yield plant^{-1}.

Application P fertilization at the form of SSP (15.5 % P_2O_5) significantly increased seed yield plant^{-1} compared to RP. These results may be due to the early soil enrichment with P nutrition that increased the dry matter partitioning to the seeds at late development stage. In addition, P supply prior to early stage of growth had a much greater positive effect on final seed yield than P supply in later growth of the crop. These results were in line with those of Gavito and Miller (1998), Grant *et al.* (2001) and Ali *et al.* (2002).

Results in Table 4 reveal that seeding rates and forms of P had significant effect on seed yield feddan^{-1}. Data indicate that the highest mean values of seed yield feddan^{-1} (593.36 kg) was obtained under seeding rate of the 2250 seeds/m^{2} in the first season compared to other seeding rates. This may be due to increased components of seed yield (number of capsules plant^{-1} and number of seeds capsule^{-1}). A marked effect had been reported by Abdlwahed (2002) and Kinber (2003).

Data in Table 4 show that the interactions between the two variables under study; phosphorus sources and seeding rates had no significant effect on seed yield and its components, except for number of capsules plant^{-1} in the second season.

Table.1 Physical and chemical analysis of the experimental sites

Component	2010/2011 season	2011/2012 season
Particle size distributions %		
Sand	76.73	77.43
Silt	12.00	11.20
Clay	11.27	11.37
Soil texture	Sandy loam	Sandy loam
Chemical analysis		
pH	7.31	7.67
ECe dS/m	3.57	3.44
Organic matter %	0.80	0.78
Total Nitrogen (%)	0.063	0.061
Available P (ppm)	5.76	5.61
Available K (ppm)	144	141

Table.2 Analysis of variance of various parameters affected by seeding rates and phosphorus sources in flax (Sakha-1 variety).

S.O.V.	D.F.	Plant height (cm)	Technical length (cm)	No. of higher branches plant^{-1}	Stem diameter (mm)	Straw Yield plant^{-1} (g)	No. of capsules plant^{-1}	No. of seeds capsule^{-1}	1000-seed weight (g)	Seed yield plant^{-1} (g)	Seed yield feddan^{-1} (kg)	Oil %	Oil yield feddan^{-1} (kg)
2010/2011 season													
Replicates	2	802.73	93.47	11.844	0.0093	0.01402	9.647	0.496	0.0051	0.06167	40617	0.678	5055.4
Seed Rates (A)	2	780.11*	322.12*	2.816^{ns}	0.0657*	0.24404^{ns}	14.812^{ns}	4.653**	1.0553^{ns}	0.33669*	108178*	17.187**	20618.9*
Error (a)	4	72.19	45.27	3.665	0.0084	0.18104	26.588	0.251	0.2594	0.03349	12649	0.8420	1853.8
P sources (B)	1	1.23^{ns}	202.00^{ns}	15.680*	0.1027**	0.53734*	1.620^{ns}	20.386**	1.5842*	0.37816***	42142**	11.698*	9448.3**
A x B	2	45.52^{ns}	36.63^{ns}	3.420^{ns}	0.0053^{ns}	0.03427^{ns}	0.332^{ns}	0.356^{ns}	0.0662^{ns}	0.00930^{ns}	2193^{ns}	0.168^{ns}	536.5^{ns}
Error (b)	6	86.09	39.39	1.480	0.0050	0.06111	8.581	1.149	0.1356	0.01110	4956	1.140	679.3
2011/2012 season													
Replicates	2	148.62	32.77	0.562	0.0101	0.7601	30.411	0.0913	0.5863	0.03854	24315	1.1989	3895
Seed Rates (A)	2	199.15^{ns}	262.63**	1.482^{ns}	0.0231*	0.1050^{ns}	6.474^{ns}	4.8963^{ns}	0.9504^{ns}	0.32974*	23042^{ns}	1.8053^{ns}	4134^{ns}
Error (a)	4	50.19	7.26	3.933	0.0020	0.1840	11.391	1.6957	0.1673	0.02854	18141	0.6030	2816
P sources (B)	1	447.0*	290.41**	21.780**	0.1227**	0.1284^{ns}	23.347**	12.2528*	1.9339**	0.24267**	50306^{ns}	10.9379**	10004^{ns}
A x B	2	9.21^{ns}	98.11*	0.212^{ns}	0.0067^{ns}	0.0278^{ns}	13.351*	0.0031** ns	0.3843^{ns}	0.01171^{ns}	5244^{ns}	1.3059^{ns}	630^{ns}
Error (b)	6	15.53	14.28	1.403	0.0028	0.1465	1.703	0.4833	0.1333	0.00763	11145	0.4220	1725

*$P < 0.05$ ** $P < 0.01$ NS: not significant

Table.3 Mean values of flax (Sakha-1 variety) straw yield and its components as affected by seeding rates and phosphorus sources grown in 2010/2011 and 2011/2012 seasons

Treatment		Plant Height (cm)	Technical Length(cm)	No. of Higher Branches plant^{-1}	Stem Diameter (mm)	Straw Yield plant-1 (g)
2010/2011 season						
Seed Rate (A)	1750 plants/m^2	88.17	72.78	8.07	2.25	1.76
	2000 plants/m^2	99.15	81.00	6.70	1.73	1.89
	2250 plants/m^2	110.97	87.40	7.47	1.63	2.15
LSD_a		**13.61***	**10.78***	**NS**	**0.47***	**NS**
Phosphorus Sources (B)	SSP	99.69	83.74	8.34	2.11	2.11
	RP	99.17	77.04	6.48	1.63	1.67
LSD_b		**6.56****	**NS**	**1.40***	**0.26****	**0.29***
Interaction (AxB)	$A_1 B_1$	90.13	75.97	9.80	2.57	2.01
	$A_1 B_2$	86.20	69.60	6.33	1.93	1.50
	$A_2 B_1$	96.23	81.97	7.53	2.00	2.04
	$A_2 B_2$	102.07	80.03	5.87	1.47	1.74
	$A_3 B_1$	112.70	93.30	7.70	1.77	2.26
	$A_3 B_2$	109.23	81.50	7.23	1.50	2.04
LSD_{ab}		**NS**	**NS**	**NS**	**NS**	**NS**
2011/2012 season						
Seed Rate (A)	1750 plants/m^2	92.22	72.47	7.55	2.15	1.84
	2000 plants/m^2	96.080	75.72	6.58	2.03	2.08
	2250 plants/m^2	103.55	85.20	6.87	1.77	1.88
LSD_a		**NS**	**4.32****	**NS**	**0.23***	**NS**
Phosphorus Sources (B)	SSP	102.27	81.81	8.10	2.24	2.02
	RP	92.30	73.78	5.90	1.72	1.85
LSD_b		**4.55****	**4.35****	**1.37****	**0.20****	**NS**
Interaction (AxB)	$A_1 B_1$	97.33	75.87	8.87	2.53	1.97
	$A_1 B_2$	87.10	69.07	6.23	1.77	1.70
	$A_2 B_1$	99.76	76.03	7.57	2.23	2.09
	$A_2 B_2$	92.40	75.40	5.60	1.83	2.08
	$A_3 B_1$	109.70	93.53	7.87	1.97	2.00
	$A_3 B_2$	97.40	76.87	5.87	1.57	1.77
LSD_{ab}		**NS**	**7.55***	**NS**	**NS**	**NS**

SSP: Single super phosphate, RP: Rock phosphate
*$P < 0.05$ ** $P < 0.01$ NS: not significant

Table.4 Mean values of flax (Sakha-1 variety) seed yield and its components as affected by seeding rates and phosphorus sources grown in 2010/2011 and 2011/2012 seasons

Treatment		No. of capsules plant^{-1}	No. of seeds capsule^{-1}	1000- seed weight (g)	Seed yield plant^{-1}(g)	Seed yield feddan^{-1} (kg)
2010/2011 season						
Seed Rate (A)	1750 plants/m^2	10.35	7.71	8.39	1.18	336.54
	2000 plants/m^2	12.42	6.29	7.69	0.91	532.94
	2250 plants/m^2	13.43	6.10	7.63	0.70	593.36
LSD_a		**NS**	**0.80****	**NS**	**0.29***	**182.25***
Phosphorus Sources (B)	SSP	12.37	7.77	8.20	1.07	536.00
	RP	11.77	5.64	7.61	0.78	439.23
LSD_b		**NS**	**1.41****	**0.42***	**0.12****	**81.20****
Interaction (AxB)	A_1 B_1	10.90	9.02	8.80	1.34	363.58
	A_1 B_2	9.80	6.41	7.97	1.00	309.50
	A_2 B_1	12.50	7.11	7.90	1.07	596.88
	A_2 B_2	12.33	5.47	7.47	0.75	469.00
	A_3 B_1	13.70	7.18	7.88	0.80	647.54
	A_3 B_2	13.17	5.03	7.37	0.60	539.18
LSD_{ab}		**NS**	**NS**	**NS**	**NS**	**NS**
2011/2012 season						
Seed Rate (A)	1750 plants/m^2	12.95	7.64	8.21	1.16	397.46
	2000 plants/m^2	11.63	6.19	7.55	1.00	488.01
	2250 plants/m^2	10.90	5.99	7.49	0.69	516.03
LSD_a		**NS**	**NS**	**NS**	**0.27***	**NS**
Phosphorus Sources (B)	SSP	12.97	7.43	8.08	1.07	520.04
	RP	10.69	5.78	7.42	0.83	414.30
LSD_b		**1.51****	**1.23****	**0.42****	**0.10****	**NS**
Interaction (AxB)	A_1 B_1	14.73	8.44	8.82	1.26	482.44
	A_1 B_2	11.67	6.84	7.60	1.06	312.49
	A_2 B_1	13.83	7.03	7.67	1.17	514.77
	A_2 B_2	9.43	5.35	7.43	0.83	461.24
	A_3 B_1	10.33	6.82	7.75	0.78	562.89
	A_3 B_2	11.47	5.15	7.23	0.61	469.18
LSD_{ab}		**2.61***	**NS**	**NS**	**NS**	**NS**

SSP: Single super phosphate, RP: Rock phosphate

*$P < 0.05$ ** $P < 0.01$ NS: not significant

Table.5 Mean values of flax (Sakha-1 variety) oil % and oil yield as affected by seeding rates and phosphorus sources for plants grown in 2010/2011 and 2011/2012 seasons

Treatments		Oil %	Oil yield feddan^{-1}(kg)	Oil %	Oil yield feddan^{-1}(kg)
		2010/2011 season		**2011/2012 season**	
Seed Rate (A)	1750 plants/m^2	36.95	123.71	37.29	148.29
	2000 plants/m^2	37.58	200.83	38.27	187.95
	2250 plants/m^2	40.15	238.75	38.21	197.91
LSD_a		**1.47****	**69.01***	**NS**	**NS**
Phosphorus Sources (B)	SSP	39.03	210.67	38.71	201.63
	RP	37.12	164.85	37.15	154.48
LSD_b		**1.23***	**30.01****	**0.75****	**NS**
Interaction (AxB)	A_1 B_1	37.57	135.74	37.68	181.55
	A_1 B_2	36.33	111.69	36.91	115.04
	A_2 B_1	38.43	229.94	38.93	200.80
	A_2 B_2	36.73	171.71	37.61	175.11
	A_3 B_1	41.09	266.35	39.50	222.54
	A_3 B_2	39.20	211.15	36.91	173.28
LSD_{ab}		**NS**	**NS**	**NS**	**NS**

SSP: Single super phosphate, RP: Rock phosphate
*$P < 0.05$ ** $P < 0.01$ NS: not significant

c. Oil % and oil yield

Results present in Table 5 show that the mean performances of oil % and oil yield under the treatments of seeding rates or P sources. The data show that there were significant differences under either seeding rates or phosphorus sources. The obtained values were 40.15 and 38.21 % for oil percentage, and 238.75 and 197.91 kg for oil yield feddan^{-1} under the treatment of A_3; (2250 seeds/m^2), in both seasons, respectively. Furthermore, the obtained values were 39.03 and 38.71 % for oil percentage, and 210.67 and 201.63 Kg for oil yield under the soil application with B_1(SSP; 15.5% P_2O_5) in the first and second seasons, respectively. These results are in line with those of Ali *et al.* (2002) and Khan *et al.* (2010), who found a significant effect of phosphorus application on oil content and oil yield. Increasing in oil % and oil yield under the treatment of SSP can be due to increase in the biosynthesis of fatty acid, as a result of higher ATP formed due to the enough existence of P. This saved abundant energy needed to fatty acid biosynthesis (Taize and Zeiger, 2002).

Under the newly-reclaimed soil condition, it could be concluded that the highest straw, seed and oil yields and their components may be obtained under the application phosphorus in the form of single super phosphate (15.5 % P_2O_5) and seeding rate at 2250 seeds/m^2.

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