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VB Awasarmal
Associate Professor, Department of Agronomy, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India

SV Thombre
Assistant Professor, Department of Agronomy, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India

AB Thombre
PG Scholar, Department of Agronomy, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India

AR Shikari
M.Sc. (Agri), Department of Agronomy, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India

Corresponding Author:
VB Awasarmal
Associate Professor, Department of Agronomy, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani, Maharashtra, India

Effect of sulphur levels and spacings on growth and yield of Linseed (*Linum usitatissimum* L.)

VB Awasarmal, SV Thombre, AB Thombre and AR Shikari

Abstract
The field experiment was conducted during *rabi* season 2020-21 at Department of Agronomy, College of Agriculture, Parbhani with a view to study effect of sulphur levels and spacings on yield and economics of Linseed. The experiment was conducted in split plot design consisting of 12 treatments replicated thrice. The gross and net plot sizes were 5.4 m x 4.5 m and 4.8 m x 4.2 m respectively. The seeds were sown at different spacings as per treatments. The periodical observations and yield data were recorded on growth and yield contributing characters. Results revealed that growth attributes like plant height, number of functional leaves, number of branches, dry matter accumulation was recorded significantly superior in treatment T_4 *i.e*., spacing of 45 cm x 15 cm. Whereas, seed yield (kg ha^{-1}) was significantly higher in narrow spacing *i.e.*, 30 cm x 10 cm (T_2). But sulphur showed significant difference in both growth and yield attributes. In treatments where 20 kg sulphur (Bensulf (S-90%)) per ha was applied (S_3) recorded significant result than rest of the treatments. Thus, it was concluded that treatment T_2 (30 cm x 10 cm) and S_3 (20 kg ha^{-1}) was productive and profitable as compared to all other treatment.

Keywords: Linseed, spacings, sulphur levels, seed yield

Introduction
Linseed (*Linum usitatissimum* L.) also known as flax, is one of the earliest cultivated field crops and belongs to family Linaceae. Sulphur (S) plays an important role in determining the quality of oil derived from these crops. Sulphur is required for the formation of proteins, vitamins and chlorophyll. Use of sulphur free fertilizers is one of the main reasons for the shortage of sulphur in Indian soils. A balanced fertilization which includes sulphur is necessary for the quality growth of oilseed crops. The use of sulphur is one of the most important factors in increasing yields. Sulphur plays an important role in the formation of amino acids, synthesis of proteins, chlorophyll and oil (Singh and Singh, 2007) [9]. Balanced use of sulphur commensurate with crop needs and soil nutrient status is indispensable for sustained production of high yield level. Experimental evidences indicate that sulphur is most essential plant nutrient which is generally lacking in Indian soil. Sulphur is also associated with flowering, nodulation and the quality of oilseeds. The sulphur deficiency disrupts nitrogen metabolism, reduce protein quality and induces carbohydrates accumulation. Spacing is dependent upon the expected growth of a particular crop and variety in a given agro-climatic condition. Therefore, optimum plant spacing is one of the most important factors in increasing the yield hectare^{-1}. At closer spacing, number of capsules per plant, number of seed per capsule, weight of capsule and seed weight per plant were decreased and vice versa. Therefore, it is necessary to find out the optimum plant population for getting higher yield.

Materials and Methods
The current study was conducted at the Agricultural Research Farm within the Department of Agronomy at the College of Agriculture in Parbhani, Maharashtra, during the *rabi* season. The soil in the experimental area had a clayey texture and a slightly alkaline pH, with low levels of organic carbon, available nitrogen, and phosphorus, but moderately high levels of available potassium. The field experiment followed a Split plot design with three replications, and the gross plot size was 5.4 m × 4.5 m. The treatments included four different spacings as main plot treatments and three levels of sulphur as sub-plot treatments. The main plot treatments (spacing) were designated as follows: T_1: 30 × 15 cm², T_2: 30 × 10 cm², T_3: 45 × 10 cm² and T_4: 45 × 15 cm². The sub-plot treatments (sulphur levels) were designated as: S_1: 0 kg ha^{-1}, S_2: 10 kg ha^{-1}, S_3: 20 kg ha^{-1}.

Seeds of the LSL-93 variety were sourced from the Oilseed Research Station in Latur, V.N.M.K.V., Parbhani. Sowing was carried out by dibbling the seeds at a depth of 5 cm, following the specified spacing for each treatment. Gap filling was promptly performed after emergence, and thinning took place 12 days after sowing. The produce from each designated plot was harvested, appropriately labelled, bundled, and placed in the threshing yard. After thorough drying, the bundles were threshed, winnowed, and cleaned, with the weight of the seeds recorded for analysis.

Results and Discussion

Plant height (cm)

Data presented in Table 1 revealed that plant height (cm). The mean plant height at 30, 45, 60, 75 DAS and at harvest were 14.33, 19.63, 24.42, 26.64, and 27.11 cm respectively. At 45 DAS the significantly taller plant was observed under the treatment T_2 (30 cm x 10 cm) while minimum plant height was recorded under treatment T_4 (45 cm x15 cm). Plant height decreased with increasing row spacing up to highest row spacing of T_4 (45 cm x 15 cm). Similar trend was observed at 60, 75 DAS and at harvest. The individual effect of row spacings was found to be significant except for 30 DAS. The significantly highest plant height was observed in treatment T_2 (30 cm x 10 cm) which was 31.38 cm over treatment T_3 (45 cm x 10 cm) and T_4 (45 cm x15 cm) and found at par with treatment T_1 (30 cm x 15 cm) at harvest. The decrease in plant height of linseed in wider spacing was may be due to availability of more space and solar radiation (Khan *et al.* 2005) [4]. The effect of fertilizer levels on plant height was found significant at all growth stages except at 30 DAS. At 45 DAS highest plant height was recorded in treatment S_3 where 20 kg sulphur per ha was applied. It was significantly superior over rest of the treatments. Lowest plant height was observed in treatments where sulphur was not applied *i.e.*, S_1 (control). Similar trend was observed at 60, 75 DAS and at harvest.

The increase in plant height of linseed due to application of sulphur might be due to effect of sulphur in metabolism of growing plants which is directly related with cell division, enlargement and elongation, vigorous root growth and formation of chlorophyll resulting in higher photosynthesis. This all led to higher plant height. Similar result was recorded by Bainade *et al.* (2019) [1]. The interaction effect of spacings and sulphur levels on plant height (cm) was found non-significant at all stages of crop growth.

Table 1: Mean plant height (cm) of linseed as influenced by different treatments at various growth stages of crop

Treatments	30 DAS	45 DAS	60 DAS	75 DAS	At Harvest
Spacings (cm)					
T_1: 30 cm x 15 cm	14.69	20.82	27.17	29.11	29.62
T_2: 30 cm x 10 cm	15.05	22.29	27.44	30.75	31.38
T_3: 45 cm x 10 cm	13.69	17.75	21.71	23.55	23.95
T_4: 45 cm x 15 cm	13.92	17.68	21.39	23.17	23.51
SE ±	1.92	1.82	2.26	2.67	2.63
CD at 5%	NS	4.46	5.55	6.55	6.44
Sulphur levels (kg ha^{-1})					
S_1: 0	12.76	13.30	15.58	17.89	18.36
S_2: 10 kg ha	15.10	19.65	24.50	26.53	26.99
S_3: 20 kg ha	15.16	25.95	33.20	35.52	35.99
SE ±	4.86	1.90	2.78	2.66	2.79
CD at 5%	NS	5.76	8.33	7.97	8.36
Interaction (T X S)					
SE ±	5.50	2.72	3.72	3.89	3.96
CD at 5%	NS	NS	NS	NS	NS
GM	14.33	19.63	24.42	26.64	27.11

Number of functional leaves plant^{-1}

Data presented in Table 2 revealed that number of functional leaves plant^{-1}. The rate of increase in number of functional leaves plant^{-1} was very fast up to 60 DAS and later on it decreased due to leaf senescence. The mean number of functional leaves at 30, 45, 60, 75 and at harvest were 50.19, 65.51, 72.26, 76.01 and 24.46 leaves plant^{-1} respectively. The higher number of functional leaves per plant were recorded by the treatment T_4 (45 cm x 15 cm) which was significantly superior than rest of the spacings *i.e.*, T_1 (30 cm x 15 cm) and T_2 (30 cm x 10 cm) however it was at par with treatment T_3 (45 cm x 10 cm). Maximum number of functional leaves was recorded at 75 DAS (84.84). Number of leaves increased when sown at wider spacing. At 45 DAS, application of 20 kg sulphur ha^{-1} (S_3) recorded highest number of functional leaves (70.52) than rest of the treatments *i.e.*, S_1 (control) and S_2 (10 kg ha^{-1}). Similar trend was observed at 60, 75 DAS and at harvest. Number of leaves goes on decreasing after 75 DAS due to leaf senescence. Similar results were recorded by Bainade *et al.* (2019) [1].

The interaction effect of spacings and sulphur levels on number of functional leaves per plant was not evident at any stage of crop growth.

Table 2: Periodical number of functional leaves of Linseed as influenced by different treatments

Treatments	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS
Spacings (cm)					
T_1: 30 cm x 15 cm	47.75	62.00	68.09	71.19	22.80
T_2: 30 cm x 10 cm	46.52	55.88	63.23	66.02	17.64
T_3: 45 cm x 10 cm	46.14	70.70	77.16	81.97	27.00
T_4: 45 cm x 15 cm	58.92	73.48	80.56	84.84	30.40
SE ±	1.11	1.26	1.44	1.26	2.04
CD at 5%	NS	3.08	3.52	3.08	5.19
Sulphur levels (kg ha^{-1})					
S_1: 0	51.34	60.54	67.75	71.11	19.56
S_2: 10 kg ha	45.82	65.50	72.30	76.03	24.58
S_3: 20 kg ha	54.84	70.52	76.75	80.88	29.26
SE ±	1.23	1.63	1.43	1.56	1.55
CD at 5%	NS	4.90	4.28	4.69	4.66
Interaction (T X S)					
SE ±	2.00	2.14	2.09	2.08	2.62
CD at 5%	NS	NS	NS	NS	NS
GM	50.19	65.51	72.26	76.01	24.46

Number of branches plant^{-1}

Data on mean number of branches plant^{-1} as influenced by different treatments are presented in Table 3. The mean number of branches at 30, 45, 60, 75 and at 90 DAS were 2.77, 4.93, 5.95, 6.88 and 7.16 respectively. Highest number of branches were observed in treatment T_4 (45 cm x 15 cm). Treatment T_4 (45 cm x 15 cm) was found significantly superior over T_1 (30 cm x 15 cm) and T_2 (30 cm x 10 cm) and statistically at par with T_3 (45 cm x 10 cm). These results were obtained might be due to the reason that wider spacing favored the plant to produce maximum branches. Similar result was recorded by Gaikwad *et al.* (2020) [2]. The effect of sulphur levels on number of branches per plant was found significant at all growth stages except at 30 DAS. At 45 DAS, sulphur level *i.e.*, S_3 (20 kg ha^{-1}) recorded significantly superior (6.87) number of branches per plant over S_1 (control) and S_2 (10 kg ha^{-1}) sulphur levels. Lowest number of branches (2.99) were observed in controlled treatment where no sulphur was applied. The above results are in conformity with Bainade *et al.* (2019) [1].

The interaction effect of spacings and sulphur levels on number of branches per plant was found non-evident at all stages of crop growth.

Table 3: Mean number of branches plant^{-1} of linseed as influenced by various treatments at different growth stages of crop

Treatments	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS
Spacings (cm)					
T_1: 30 cm x 15 cm	2.78	4.23	5.27	6.05	6.41
T_2: 30 cm x 10 cm	2.46	4.19	5.06	5.88	6.14
T_3: 45 cm x 10 cm	3.14	5.45	6.56	7.72	8.03
T_4: 45 cm x 15 cm	2.70	5.88	6.93	7.87	8.06
SE ±	0.57	0.59	0.61	0.72	0.65
CD at 5%	NS	1.44	1.50	1.76	1.61
Sulphur levels (kg ha^{-1})					
S_1: 0	2.53	2.99	3.84	4.11	4.61
S_2: 10 kg ha	2.94	4.96	5.96	6.85	7.06
S_3: 20 kg ha	2.84	6.87	8.08	9.68	9.81
SE ±	1.39	0.60	0.68	0.84	0.80
CD at 5%	NS	1.81	2.04	2.53	2.40
Interaction (T X S)					
SE ±	1.43	0.87	0.95	1.15	1.07
CD at 5%	NS	NS	NS	NS	NS
GM	2.77	4.93	5.95	6.88	7.16

Mean total dry matter plant^{-1} (g)

Data in respect of periodical accumulation of mean total dry matter plant^{-1} (g) amongst the various plant parts as affected by various treatments are presented in Table 4. The data revealed that the mean dry matter accumulation per plant increased up to harvest. The mean total dry matter production was 0.27, 2.44, 5.37, 6.65 and 7.92 g plant^{-1} at 30, 45, 60, 75 DAS and at harvest respectively. At 45 DAS, treatment T_4 (45 cm x 15 cm) showed the largest accumulation of dry matter. At all growth stages with the exception of 30 DAS, it was discovered that sulfur levels had a substantial impact on the total dry matter accumulation per plant. The substantial function that sulphur plays in cell proliferation and differentiation, root elongation, which reflects into increased nutrient absorption, and photosynthate generation, which reflects into increased dry matter production, may all contribute to higher dry matter accumulation caused by sulfur. Lawania *et al*. (2015) [6] and Patil *et al*. (2018) [7] reported similar outcomes. At every stage of crop growth, the impact of spacing and sulphur levels on the accumulation of dry matter per plant was determined to be non-significant.

Table 4: Mean total dry matter plant^{-1} (g) as influenced by different treatments at various growth stages of crop

Treatments	30 DAS	45 DAS	60 DAS	75 DAS	At harvest
Spacings (cm)					
T_1: 30 cm x 15 cm	0.24	1.86	4.55	5.80	7.09
T_2: 30 cm x 10 cm	0.22	1.53	4.36	5.62	6.73
T_3: 45 cm x 10 cm	0.34	2.83	5.99	7.36	8.85
T_4: 45 cm x 15 cm	0.35	3.58	6.61	7.85	9.02
SE ±	0.04	0.39	0.47	0.58	0.72
CD at 5%	NS	0.96	1.15	1.42	1.78
Sulphur levels (kg ha^{-1})					
S_1: 0	0.20	0.74	3.41	4.16	4.52
S_2: 10 kg ha	0.29	2.46	5.41	6.67	7.88
S_3: 20 kg ha	0.30	4.14	7.31	9.15	11.37
SE ±	0.02	0.53	0.62	0.81	1.03
CD at 5%	NS	1.59	1.86	2.42	3.08
Interaction (T X S)					
SE ±	0.05	0.68	0.36	1.03	1.31
CD at 5%	NS	NS	NS	NS	NS
GM	0.27	2.44	5.37	6.65	7.92

Seed yield (kg ha^{-1})

The data of seed yield was presented in Table 5. Mean seed yield recorded was 855.72 kg ha^{-1}. Among different spacing on seed yield presented in Table 1 revealed that the treatment T_2 (30 cm x 10 cm) produced significantly highest seed yield which was found at par with treatment T_1 (30 cm x 15 cm) than rest of the treatments. This may be due to greater planting density as optimum plant population was very important yield component in field crops (Khare *et al*. 1996) [5]. Significantly highest seed yield was recorded with the application of 20 kg sulphur ha^{-1} than rest of the treatments *i.e.*, S_1 (control) and S_2 (10 kg ha^{-1}). Increase in seed yield with increase in sulphur level was might be due to the reason that sulphur was involved in the formation of chlorophyll, which promotes photosynthesis and activation of enzyme (Jimo & Singh 2017) [3]. Lowest seed yield was recorded in treatments where sulphur was not applied. Sulphur application has been reported to favour yield due to proper partitioning of photo syntheses from source to sink (Singh *et al.* 2013) [8].
The interaction of spacings and sulphur levels on seed yield was not found significant.

Table 5: Seed yield (kg ha^{-1}) of linseed as influenced by different treatments

Treatments	Seed yield (kg ha^{-1})
Spacings (cm)	
T_1: 30 cm x 15 cm	927.40
T_2: 30 cm x 10 cm	1022.13
T_3: 45 cm x 10 cm	789.65
T_4: 45 cm x 15 cm	683.72
SE ±	86.41
CD at 5%	211.46
Sulphur levels (kg ha^{-1})	
S_1: 0	619.44
S_2: 10 kg ha	856.61
S_3: 20 kg ha	1091.14
SE ±	77.97
CD at 5%	233.76
Interaction (T X S)	
SE ±	119.61
CD at 5%	NS
GM	855.72

Conclusion

Among the different treatments, spacing of 30 cm x 10 cm was found productive and profitable as compared to 45 cm x 15 cm, except spacing of 30 cm x 15 cm and 45 cm x 10 cm. Among different sulphur levels, application of 20 kg ha^{-1} was found economically feasible than rest of the treatments. The results underscore the importance of considering both spacing and sulphur application as integral components of linseed cultivation practices.

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