The Pharma Innovation Journal 2023; 12(7): 1841-1845

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(7): 1841-1845

www.thepharmajournal.com
Received: 26-04-2023
Accepted: 29-05-2023

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Response of linseed (*Linum usitatissimum* L.) to row spacing and fertility level

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Abstract
An experiment was conducted during *rabi* season, October 2021 to February 2022at the Agronomy Main Research Farm of College of Agriculture under Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, India to study the effect of row spacing and fertility level on yield and economics of linseed crop. The experiment was laid out in split plot design with three replications comprising of three row spacing in main plot (20, 25 & 30 cm) and five fertility levels in sub plot (0:0:0, 20:10:10, 40:20:20, 60:30:30 & 80:40:40 kg N:P_2O_5:K_2O kg ha^{-1}). The row spacing of 25 cm resulted in maximum grain yield of 617.8 kg ha^{-1}. Grain yield increased with increase fertility level up to 60:30:30 kg N:P_2O_5:K_2O ha^{-1}, beyond which it was not significant. Application of 60:30:30 kg N:P_2O_5:K_2O ha^{-1} produced 134.3% higher grain yield than the control plot. Narrow row spacing of 20 cm resulted in the maximum yield of straw (1815.1 kg ha^{-1}) due to the highest plant stand. The fertility level of 80:40:40 kg N:P_2O_5:K_2O ha^{-1} produced maximum quantity of straw (1919.8 kg ha^{-1}), which was statistically at par with the fertility levels of 60:30:30 and 40:20:20 kg N:P_2O_5:K_2O ha^{-1}. Maximum net profit of ₹ 16,577 ha^{-1} was obtained from the row spacing of 25 cm. Maximum benefit-cost ratio of 1.70 was obtained from the crop receiving 60:30:30 kg N:P_2O_5:K_2O ha^{-1}.

Keywords: Economics, fertility, linseed, *Linum usitatissimum,* spacing, yield

Introduction
Linseed (*Linum usitatissimum* L.) has occupied a leading position among oilseed crops due to its use in pharmaceutical, chemical, food and animal feed industries (Zając *et al*., 2012) [28]. It is mainly cultivated for production of oil, fibre and industrial raw materials. It is an emerging oilseed crop (Patel *et al*., 2017) [23] and one of the ancient fibre crops of world (Jana *et al*., 2018) [12]. Linseed is mainly grown for seeds, which is used for extracting oil (Chopra and Badiyala, 2016) [6]. Linseed oil is used for manufacturing of paints, varnishes, printing inks, leather, soap, etc. Nearly 20% of linseed oil produced in India is generally used by the farmers and the rest is used for the manufacturing of paints, varnish, oilcloth, linoleum, printing ink etc. (Naik *et al*., 2017) [21]. Linseed occupies an important position among oilseed crops grown during *rabi* season (Mohanty and Sahoo, 2022) [2]. Due to increased demand, emphasis is given on increasing production of linseed (Devedee *et al*., 2019) [8]. In India, linseed cultivation is mostly limited to marginal and sub-marginal land with inadequate supply of agri-inputs such as fertilizer and pesticides, which is the major cause of low productivity (Kumar and Kumar, 2015) [17]. Productivity of linseed suffers due to meager supply of inputs and poor moisture management practices. Under Ethiopia condition, Kassaye *et al.* (2018) [13] observed improper fertilization as the limiting factors for linseed production.
Among various agro-techniques, application of nitrogen, phosphorus, potassium and sulfur play vital role to obtain expected yield (Singh *et al*., 2013) [25]. There is requirement of 4.09 kg N, 1.11 kg P_2O_5 and 4.25 kg K_2O for production of one quintal linseed grain (Singh *et al*., 2019) [26]. Bhanwariya *et al*. (2013) [3] recorded more no. of capsules per plant and heavier seed with increase in fertilizer application as compared to no fertilizer control. Channabasavanagouda *et al*. (2018) [5] recorded significantly higher seed yield of 861 kg ha^{-1} and stover yield of 1624 kg ha^{-1} with application of 60:30:30 kg N:P_2O_5:K_2O ha^{-1}. Kumar and Deka (2016) [15] obtained optimum yield with application of 60 kg N, 45 kg P_2O_5 and 30 kg K_2O ha^{-1}. Kumar (2017) [14] recorded maximum yield of grain and straw with application of 80:60:40:40 kg N:P_2O_5:K_2O:S ha^{-1}. Bora *et al*. (2018) [4] recommended 40 kg N, 20 kg P_2O_5 and 10 kg K_2O ha^{-1} to obtain expected yield.
Plant population is an important factor that determines the growth, development and crop yield (Kumar and Kumawat, 2014) [18].

Kumar *et al*., (2015) [16] opined that optimum plant population is the pre-requisite for obtaining maximum yield. Himabindu and Singh (2021) [11] opined that inter and intra row spacing are crucial for production of any crop. Arslanoglu *et al*. (2022) [2] have reported visible impact of plant density on the morphological behaviour of linseed plant. Tadeusz *et al*. (2020) [27] recorded enhanced leaf area index with closure spacing. Gaikwad *et al*. (2019) [10] recorded maximum grain yield from linseed crop grown at a spacing of 30 cm× 5 cm. But, Tadeusz *et al*. (2020) [27] reported reduction in grain yield with increase in seed rate. However, there was no effect of planting density on yield (Andruszczak *et al*., 2015) [1] or yield attributes (Nakamoto and Horimoto, 2018) [22]. With this background, it was felt necessary to determine row spacing and suitable level of fertilizer application to obtain expected yield from linseed crop.

Materials and Methods

The field experimentation was taken up at the Main Research Farm, Department of Agronomy, College of Agriculture, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, India during *rabi* season, October 2021 to February 2022. The experimental field was situated under the East and South Eastern Coastal Plain Zone of Odisha. Thesoil was sandy loam with pH value of 5.7. The soil was medium in available nitrogen, phosphorus and potassium. The experiment was conducted with three main plots (row spacing of 20, 25 & 30 cm) and five sub plots (fertility levels of 00:00:00, 20:10:10, 40:20:20, 60:30:30 & 80:40:40 kg $N:P_2O_5:K_2O$ kg ha^{-1}) laid in split plot design with three replications. Seeds of the variety Kota Barani Alsi 4 (RL 10193) was sown on 1st November 2021. All the phosphorus & potassium and 50% of nitrogen were applied as basal fertilizer and remaining half of nitrogen was provided at 30 days after sowing as top dressing. Observations were recorded on various parameters such as plant growth, yield attributes, yield and economics of cultivation. The observations were analysed statistically in the technique of standard analysis of variance to derive the inference.

Results and Discussion

Under wider row spacing of 30 cm, the plants avail adequate space along with ample of soil moisture and plant nutrients for efficient foliage production. On the contrary, narrow row spacing of 20 cm adversely affected the growth and development of the plant due to competition for solar radiation, soil moisture and plant nutrients. Obviously, the plat population was highest (921 thousand ha^{-1}) with the narrow spacing of 20 cm. Although growth of individual plant was affected, $unit^{-1}$ area value of dry matter accumulation was18.7% more with narrow spacing of 20 cm than 30 cm due to higher plant population. Maximum dry weight of 251.9 g m^{-2} was attained with row spacing of 20 cm because of presence of more no. of plants per unit area.

Variation in fertility level did not have any effect on plant population of the crop. Enhanced application of fertilizer facilitated growth of leaf canopy and plant height, which might have resulted in higher quantity of dry matter production. The dry matter accumulation at maturity reached its peak (266.5 g m^{-2}) with the fertility level of 60:30:30 kg $N:P_2O_5:K_2O$ ha^{-1}, beyond which the enhancement was not significant (Table 1). Additional application of fertilizer might have enhanced production of dry matter, which attained its optimum value with application of 60:30:30 kg $N:P_2O_5:K_2O$ ha^{-1}. Singh *et al*. (2010) [24] reported that adequate supply of major nutrients produced more vegetative parts resulting in higher accumulation of dry matter.

Availability of sunlight, water and plant nutrients, determined by row arrangements had considerable effect on physiological activities of the plant, which eventually influenced the yield attributing characters such as number of capsule $plant^{-1}$, seed count and seed weight. In case of wider row spacing of 30 cm, there was maximum number of capsules $plant^{-1v}$ (26.2) with highest number (7.8 $plant^{-1}$) of heavier seeds (6.1 g $thousand^{-1}$) due to increased photosynthesis and higher intake of pant nutrients for individual plants as a result of availability of more space for the plants. However, seed count per capsule and seed weight were not significantly influenced by row spacing. Similar result was also obtained by Darja and Stanislav (2008) [7] under Slovenia situation, who recorded the highest grain weight with wider row spacing. Inadequate availability of sunlight, water and nutrient for individual plants in case of narrow row spacing of 20 cm might have resulted in poor value with regards to yield attributing characters. Availability of more spacing in case of wider spaced crop augmented more foliage growth, which was reflected in higher values of capsule count per plant, seed count in capsule and seed weight.

External application of plant nutrients through chemical fertilizer stimulated plant growth, which was reflected in enhanced value of yield attributing characters at the highest level of fertility. Non application of fertilizer drastically reduced the production of capsule $plant^{-1}$, seeds $capsule^{-1}$ and seed weight due to inadequate availability of plant nutrients during vegetative and reproductive stages. The number of capsule per plant increased with application of fertilizer up to a level of 40:20:20 kg $N:P_2O_5:K_2O$ ha^{-1} beyond which the enhancement was not significant. Capsule number per plant, being a genetically controlled trait might not have distinctively influenced by variation in fertilizer application. Of course, 1000 seed weight increased linearly with increase in fertility level, but it was not statistically significant beyond application of 40:20:20 kg $N:P_2O_5:K_2O$ ha^{-1}. However, maximum value of capsule $plant^{-1}$ (26.3), seed $capsule^{-1}$ (7.9) and 1000 seed weight (6.4 g) were obtained with application of 80:40:40 kg $N:P_2O_5:K_2O$ ha^{-1} as a result of more intake of plant nutrients at the highest level of fertility. Earlier, Meena *et al*. (2011) [19] obtained maximum number of capsule $plant^{-1}$, seed $countcapsule^{-1}$ and heaviest seed with application of 60 kg N, 30 kg P_2O_5, 30 kg K_2O and 30 kg S ha^{-1} due to higher uptake of nutrients by the plant.

Yield of linseed is the outcome of yield attributing factors like plant stand, capsule number, seed count and seed weight; which are considerably influenced by row spacing. Although wider row spacing enhanced the number of capsule $plant^{-1}$, seed count $capsule^{-1}$ and 1000 seed weight; the effect was nullified due to higher plant population obtained in the narrow row spacing of 25 cm or 20 cm. On the other hand, closure spacing resulted in lower values of the yield attributing factors thereby capping the yield enhancement with the row spacing of 20 cm. Hence, maximum yield of 617.8 kg ha^{-1} was obtained from the intermittent spacing of 25 cm between the rows (Table 2). This is because the higher values of yield attributing parameters in case of wider row spacing of 30 cm were nullified due to the lowest number of plant stand whereas the effect of highest plant population in case of narrow row spacing of 20 cm was not reflected in ultimate yield because of lower values of yield attributing factors. Higher values of yield attributing factors than 20 cm row spacing and higher plant population than the row spacing of 30 cm might be the reason for obtaining more yield in case of row spacing of 25 cm. However, Andruszczak *et al*. (2015) [1] did not record any significant effect due to row spacing of 15 cm or 25 cm on seed yield of linseed.

Grain yield increased linearly with every supplemental enhancement of fertility level up to 60:30:30 kg $N:P_2O_5:K_2O$ ha^{-1}, beyond which it was not significant. Application of 60:30:30 kg $N:P_2O_5:K_2O$ ha^{-1} produced 134.3% higher grain yield than the control plot due to 41.4% more capsule $plant^{-1}$, 22.2% more number of seed $capsule^{-1}$ and production of 14.8% heavier seeds. The optimum vales of yield attributing characters obtained with application of 60:30:30 kg $N:P_2O_5:K_2O$ ha^{-1} might be the reason for obtaining optimum yield with that fertility level. Channabasavanagouda *et al*. (2018) [5] also recorded maximum seed yield of 861 kg ha^{-1} with application of 60:30:30 kg $N:P_2O_5:K_2O$ ha^{-1}.

The highest plant stand (921.0 t ha^{-1}) with closure row spacing of 20 cm was the single most factor for contributing to enhanced straw yield (1815.1 kg ha^{-1}). The yield of straw was maximum with narrow row spacing of 20 cm due to accommodating maximum number of plants per unit area. On the contrary, minimum straw yield of 1459.0 kg ha^{-1} was recorded in the wider spaced crop (30 cm×5 cm) due to minimum plant population. Production of more foliage with application of 80:40:40 kg $N:P_2O_5:K_2O$ ha^{-1}resulted in the maximum straw yield of 1919.8 kg ha^{-1}, of course statistically similar with the fertility level of 60:30:30 or 40:20:20 kg $N:P_2O_5:K_2O$ ha^{-1}. The crop might not have responded significantly to the fertility level beyond 40:20:20 kg $N:P_2O_5:K_2O$ ha^{-1} for growth of stem and foliages. Earlier, Channabasavanagouda *et al*. (2018) [5] also recorded significantly higher yield of straw with application of 60:30:30 kg $N:P_2O_5:K_2O$ ha^{-1}. Harvest index, being influenced by the yield of grain and straw exhibited dissimilarity at different spacing arrangements. Harvest index was the maximum (26.5%) in the plot with wider row spacing of 30 cm due to reduced straw yield. Additional benefit of grain yields due to higher level of fertility increased the harvest index substantially. Application of 80:40:40 or 60:30:30 kg $N:P_2O_5:K_2O$ ha^{-1} resulted in statistically comparable values of harvest index may be due to comparable increase in yield of grain and straw. Channabasavanagouda *et al*. (2018) [5] also recorded maximum harvest index with application of 60:30:30 kg $N:P_2O_5:K_2O$ ha^{-1}.

The economics of cultivation play a vital role in taking decision whether to grow the crop. Maximum net profit of ₹ 16,577 ha^{-1} was obtained with row spacing of 25 cm due to higher grain yield. Minimum yield of grain and higher cost of cultivation with the narrow row spacing of 20 cm might be the cause of the lowest net profit of ₹ 8427 ha^{-1} and minimum benefit-cost ratio of 1.26 (Table 2). Under Varanasi situation, Meena *et al*. (2011) [19] recorded maximum net profit with medium seed rate having optimum plant population. Levels of fertility had substantial effect on net profit and benefit-cost ratio. Increase in fertilizer application added to the cost of cultivation due to additional cost of fertilizer and expenditure incurred in its application. But, the enhanced yield obtained with increased level of fertilizer application surpassed the effect of additional expenditure up to the fertility level of 60:30:30 kg $N:P_2O_5:K_2O$ ha^{-1}. Hence, increase in fertility level up to 60:30:30 kg $N:P_2O_5:K_2O$ ha^{-1} increased the benefit-cost ratio (1.70) by harmonizing the cost of production and value of produce. Earlier, Gaikwad *et al*. (2020) [9] reported higher gross monetary return and net profit with application of 90:45:45 kg $N:P_2O_5:K_2O$ ha^{-1}.

Table 1: Effect of row spacing and fertility level on dry matter and yield attributes of linseed

Treatments	Plant stand ('000 ha^{-1})	Dry matter accumulation (g m^{-2})	Capsule $plant^{-1}$	Seed $capsule^{-1}$	1000 seed weight (g)
Row spacing (cm)					
20	921.0	251.9	21.8	7.2	5.8
25	741.3	242.8	23.7	7.3	6.0
30	608.2	212.3	26.2	7.8	6.1
S.Em (±)	8.20	4.34	0.61	0.34	0.09
CD (0.05)	32.18	17.04	2.40	NS	NS
$N:P_2O_5:K_2O$ (kg ha^{-1})					
0:0:0	759.6	163.4	18.6	6.3	5.4
20:10:10	759.3	209.6	22.2	7.6	5.7
40:20:20	755.7	252.5	26.1	7.8	6.1
60:30:30	752.1	266.5	26.3	7.7	6.2
80:40:40	757.5	286.5	26.3	7.9	6.4
S.Em (±)	8.00	8.48	0.97	0.34	0.13
CD (0.05)	NS	24.76	2.82	0.98	0.39

Table 2: Effect of row spacing and fertility level on yield and economics of linseed

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index (%)	Cost of cultivation (₹ ha^{-1})	Net profit (₹ ha^{-1})	Benefit: cost ratio
Row spacing (cm)						
20	508.0	1815.1	21.5	28945	8427	1.26
25	617.8	1711.1	26.3	28379	16577	1.54
30	530.9	1459.0	26.5	27888	10733	1.37
S.Em (±)	11.31	61.05	1.02	342.3	1030.6	0.038
CD (0.05)	44.42	239.66	4.00	NS	4046.1	0.148
$N:P_2O_5:K_2O$ (kg ha^{-1})						
0:0:0	304.4	1225.1	20.0	22411	125	1.01
20:10:10	403.7	1571.7	21.0	27067	2764	1.11
40:20:20	583.6	1748.4	26.1	29457	13147	1.45
60:30:30	713.3	1843.5	28.2	30680	21097	1.70
80:40:40	755.9	1919.8	28.6	32406	22429	1.69
S.Em (±)	22.13	66.16	0.97	431.2	1642.3	0.059
CD (0.05)	64.59	193.11	2.83	1258.6	4793.7	0.173

Conclusion

The row spacing of 25 cm yielded maximum grain and resulted in maximum net profit. Application of 60:30:30 kg $N:P_2O_5:K_2O$ ha^{-1} fertilizer resulted in optimum grain yield and net profit with maximum benefit-cost ratio. Hence, it is inferred that optimum yield and net profit can be obtained from linseed crop grown with a row spacing of 25 cm and fertility level of 60:30:30 kg $N:P_2O_5:K_2O$ ha^{-1}. However, further investigation is required to confirm the findings under various agro-climatic conditions.

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