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Research Paper

Evaluation of nano-urea foliar application on productivity and profitability of linseed (*Linum usitatissimum*)

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ABSTRACT

A field experiment was conducted during *rabi* season of 2021–22 and 2022–23 to study the effect of nitrogen levels and nano-urea on growth, yield attributes, yield and economics of linseed. The experiment was laid out in split plot design with main plot treatments consisting of soil application of 100%, 75%, 50% and 25% of recommended nitrogen levels applied in 2 splits 50% as basal application and 50% as top dressing and subplot treatments consisting of foliar application of different doses of nitrogenous fertilizers as, one water spray, one spray of nano-urea @ 3 ml/litre at flower initiation stage, 2 sprays of nano-urea @ 3 ml/litre at flower initiation and capsule development stage, one spray of 2% urea at flower initiation stage and 2 sprays of 2% urea at flower initiation and capsule development stage. The soil application of 100% recommended level of nitrogen was found to record significantly highest linseed growth and yield attributes, seed yield, stover yield, gross return, net return and benefit: cost ratio which was statistically similar to 75% recommended level of nitrogen but showed its significant superiority over rest of the treatments. Similarly, foliar application of two sprays of nano-urea @ 3 ml/litre at flower initiation and capsule development stage led to significant enhancement in primary and secondary branches/plant, capsules/plant, seeds/capsule, test weight, seed yield, stover yield, gross return, net return and B:C ratio as compared to other foliar nitrogen management practices except foliar application of one spray of nano-urea @ 3 ml/litre at flower initiation stage.

Key words: Foliar application, Nano-urea, Soil application, Yield attributes Linseed

Linseed (*Linum usitatissimum* L.), commonly known as flax, is an important *rabi* oilseed crop valued for its dual-purpose use like extraction of oil and production of fiber. Linseed oil is rich in α-linolenic acid (omega-3 fatty acids), which makes it highly beneficial for both nutritional and industrial applications. Approximately 80% of the oil is utilized in industries for manufacturing paints, varnishes, linoleum, printing inks, soaps and a wide range of coatings (Hussain *et al*., 2009). The fiber derived from linseed also holds significant economic value due to its high tensile strength and durability and is well-suited for blending with natural fibers such as wool, cotton and silk, thereby adding versatility to textile production.

Globally, India holds the second-largest area under linseed cultivation after Canada, contributing around 17.15% of the total global cultivated area. However, its share in global production is only 7.74%, primarily due to low productivity levels averaging around 502 kg/ha. The country cultivates linseed on approximately 1.2 million hectares, contributing nearly 31% to the national oilseed basket. Despite a vast cultivation area, productivity remains significantly below the potential yield observed in research trials and experimental fields. This yield gap is largely attributed to suboptimal crop management practices, with nutrient management (particularly nitrogen fertilization) being one of the most critical limiting factors.

Nitrogen is an essential macronutrient for plant growth and development, playing a pivotal role in key physiological and metabolic processes such as photosynthesis, protein synthesis and enzyme activation (Leghari *et al*., 2016). Efficient nitrogen management is crucial for optimizing yield potential in linseed. However, conventional nitrogen fertilizers often exhibit low use efficiency due to significant losses through leaching, volatilization and denitrification, which not only reduces crop uptake but also causes environmental pollution and economic losses.

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To address these challenges, nanotechnology-based interventions such as nano-fertilizers have emerged as innovative and efficient alternatives to traditional fertilizer applications. Nano-urea, a recent advancement in this domain, comprises ultra-small particles (1–100 nm in size) that possess high surface area, enhanced reactivity and controlled release properties. These features improve the availability and uptake of nitrogen by plants, minimize losses and enhance nutrient use efficiency (Veronica and Bachtiar, 2014; Liu and Lal, 2015). Nano-fertilizers also exhibit dual charges on their surfaces, allowing them to interact more effectively with soil particles and plant tissues, thereby improving nutrient retention and translocation within the plant system.

Given the importance of improving nitrogen use efficiency and reducing fertilizer dependency, nano-urea holds significant promise for sustainable agriculture. However, limited studies have been conducted to evaluate its effect in combination with different soil-applied nitrogen levels in linseed under field conditions. Therefore, the present investigation was carried out to assess the influence of varying nitrogen levels and foliar application of nano-urea on the growth parameters, yield attributes, productivity and economic returns of linseed.

MATERIALS AND METHODS

A field experiment was conducted at research farm of Birsa Agricultural University, Kanke, Ranchi (23°317‘N, 85°19‘E, 625 m above mean the sea-level) during the *rabi* seasons of 2021–22 and 2022–23. The climate of site is sub-humid with hot summer and cold winter. Mean monthly maximum temperature and pan-evaporation was recorded highest in April, whereas, the mean monthly minimum temperature was the lowest in December. An average amount of 23 mm and 25.5 mm rainfall received during the first and second year of cropping period. Initial status of soil (0–15 cm) of experimental field was sandy loam (61.3% sand, 22.5% silt and 16.2% clay) in nature, low in organic carbon (0.42%) and available nitrogen (227 kg N/ha), high in available phosphorus (36 kg P_2O_5/ha), medium in available potassium (160.2 kg K_2O/ha) and neutral in soil reaction (*p*H 5.80). The experiment was laid out in a split plot design with 2 replications. In the main plot, four nitrogen levels, viz. 100% N (N_1); 75% N (N_2); 50% N (N_3) and 25% (N_4) were taken while 5 foliar nitrogen management, viz. water spray (F_1); One spray of nano-urea @ 3 ml /litre of water at flower initiation stage (F_2), Two sprays of nano-urea @ 3 ml /litre of water at flower initiation and and capsule development stage (F_3), One spray of 2% urea at flower initiation stage (F_4) and Two sprays of 2% urea at flower initiation and capsule development stage (F_5) were taken in sub-plots. Nano-urea containing 4% nitrogen was applied as foliar spray at the rate of 3 ml/litre of water. For field application, a total of 1500 ml nano-urea was diluted in 500 litres of water per hectare and sprayed at two critical crop stages, i.e., flower initiation and capsule development. This ensured uniform coverage and effective nutrient absorption. Linseed variety “Priyam” was seeded directly using 25 kg seed/ha in rows spaced at 30 cm on 18th November 2021 and 16th November 2022 after basal application of fertilizer. Full dose of phosphorus (20 kg P_2O_5/ha) and potash (20 kg K_2O/ha) along with 50% nitrogen level of each treatment (recommended nitrogen level 30 kg N/ha) were applied as basal and rest 50% of nitrogen level of treatment applied at 20 days after sowing. The nitrogen, phosphorus and potash applied to linseed crop were met through urea, diammonium phosphate and muriate of potash respectively.

The primary branches/plant, secondary branches/plant, capsules/plant and seeds/capsule at maturity stage were counted by selecting 5 tagged plants from each plot carefully and averaged. The seeds were randomly selected and thousand seeds were counted from each plot of obtain the test weight of seeds. The counted grains were dried to 14% moisture and then weighed. The grain yield obtained by separating cleared grain and stover of each net plot weighed in kg and finally converted into kg/ha for statistical analysis. The stover yield kg/plot was calculated by subtracting grain yield from the total bundle weight. The harvest index is the ratio of grain yield and biological yield multiplied by 100 which was calculated by the following formula:

$$\textbf{Harvest index (\%)} = \frac{\textbf{Grain yield}}{\textbf{Grain yield + Straw yield}} \textbf{X 100}$$

RESULTS AND DISCUSSION

Effect on dry matter accumulation and yield attributing characters at harvest in linseed

The data pertaining to dry matter accumulation and yield-attributing characters of linseed as influenced by nitrogen levels and foliar nitrogen application during 2021–22 and 2022–23 are presented in Table 1. Among the nitrogen treatments, application of 100% recommended dose of nitrogen (30 kg N/ha) recorded the highest values of dry matter accumulation (3.7 and 3.9 g/plant), primary branches per plant (5.0 and 5.2), secondary branches per plant (18.7 and 19.6), capsules per plant (29.7 and 31.1), seeds per capsule (7.0 and 7.4) and 1000-seed weight (7.7 g and 8.0 g) during 2021–22 and 2022–23, respectively. However, these values were statistically at par with those obtained under 75% recommended nitrogen (22.5 kg N/ha), indicating that a 25% reduction in nitrogen did not significantly affect these traits. In contrast, the lowest values for these parameters were observed under 25% recom-

Table 1. Effect of Nitrogen management practices on yield attributing characters of linseed (2021–22 and 2022–23)

Treatment	Dry matter accumulation at harvest (g/plant)		Primary branch/ plant		Secondary branch/plant		Capsules/ plant		Seeds/ capsule		1,000-seed weight (g)	
	2021–22	2022–23	2021–22	2022–23	2021–22	2022–23	2021–22	2022–23	2021–22	2022–23	2021–22	2022–23
Nitrogen level												
N_1, 100% N	3.7	3.9	5.0	5.2	18.7	19.6	29.7	31.1	7.0	7.4	7.7	8.0
N_2, 75% N	3.5	3.8	4.9	5.1	18.0	18.8	28.9	30.2	6.9	7.2	7.6	7.9
N_3, 50% N	3.2	3.3	4.6	4.7	16.7	17.3	25.5	26.5	6.5	6.8	7.2	7.7
N_4, 25% N	2.5	2.7	4.1	4.3	14.1	14.6	21.5	22.2	6.1	6.3	6.7	7.2
SEm±	0.14	0.14	0.08	0.09	0.56	0.58	0.92	0.96	0.11	0.12	0.11	0.16
CD (P=0.05)	0.6	0.7	0.4	0.4	2.5	2.6	4.2	4.3	0.5	0.5	0.5	0.7
Foliar nitrogen management practices												
F_1, Water spray	2.9	3.1	4.3	4.4	14.9	15.4	24.4	25.4	6.2	6.4	7.2	7.6
F_2, One spray of nano-urea @ 3 ml/litre of water at flower initiation stage	3.4	3.6	4.7	4.9	17.7	18.4	27.2	28.4	7.0	7.3	7.4	7.7
F_3, Two sprays of nano-urea @ 3ml/litre of water each at flower initiation stage and capsule development stage	3.6	3.9	5.1	5.3	19.5	20.4	28.6	29.9	7.1	7.4	7.4	7.8
F_4, One spray of 2% urea at flower initiation stage	3.2	3.3	4.5	4.7	16.5	17.1	25.8	26.8	6.4	6.6	7.3	7.6
F_5, Two sprays of 2% urea at flower initiation and capsule development stage	3.3	3.4	4.6	4.8	15.8	16.4	26.0	27.1	6.5	6.8	7.3	7.7
SEm±	0.11	0.12	0.16	0.16	0.87	0.90	0.84	0.88	0.20	0.21	0.15	0.15
CD (P=0.05)	0.3	0.3	0.5	0.5	2.6	2.7	2.5	2.6	0.6	0.6	NS	NS
Interaction (AXB)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

mended nitrogen, which suggests that insufficient nitrogen limits vegetative growth and reproductive development in linseed. The improvement in yield attributes under higher nitrogen levels may be attributed to the role of nitrogen in promoting meristematic activity, cell division and elongation. Nitrogen also plays a key role in enhancing chlorophyll content and photosynthetic efficiency, which leads to better translocation of assimilates from source to sink, thereby supporting flower initiation and capsule development. These findings are in agreement with those reported by Sujatha and Gangadhara Rao (2019) and Kumar *et al*. (2022), who observed similar positive responses of linseed yield components to nitrogen application.

Among the foliar nitrogen treatments, the application of 2 sprays of nano-urea @ 3 ml/l, one at flower initiation and another at capsule development stage (treatment F_3), significantly enhanced the number of dry matter accumulation (3.6 and 3.9 g/plant), primary branches (5.1 and 5.3), secondary branches (19.5 and 20.4), capsules/plant (28.6 and 29.9) and seeds per capsule (7.1 and 7.4) in both years. This treatment also maintained a higher test weight compared to other foliar applications. The performance of F_3 was significantly superior to the rest of the foliar nitrogen treatments, including conventional 2% urea spray and water spray. The enhanced plant growth and yield attributes with nano-urea application may be attributed to the ultra-small particle size of nano-urea, which ensures better foliar absorption, efficient translocation and controlled release of nitrogen. This leads to improved nitrogen availability during critical growth stages, supporting chlorophyll synthesis, enhanced photosynthesis and dry matter accumulation. The findings are corroborated by earlier studies of Mishra *et al*. (2020), who also reported better growth and yield performance in oilseed crops following nano-urea application.

Effect on seed and stover yield in linseed

The seed yield (kg/ha), stover yield (kg/ha) and harvest index (%) of linseed as influenced by varying nitrogen levels and foliar nitrogen applications are presented in Table 2 and Figure 1. Application of the 100% recommended nitrogen dose (30 kg N/ha) resulted in the highest seed yield (1,442 kg/ha and 1,512 kg/ha) and stover yield (2,652 kg/ha and 2,777 kg/ha) during 2021–22 and 2022–23, respectively. This treatment was significantly superior to the 50% and 25% nitrogen levels; however, it remained statistically at par with the 75% recommended nitrogen dose in terms of seed yield, stover yield and harvest index. These results indicate that a 25% reduction in nitrogen did not compromise yield significantly, suggesting improved nitrogen use efficiency under 75% N application.

Among foliar nitrogen treatments, the highest seed yield (1,365 kg/ha and 1,427 kg/ha) and stover yield (2,507 kg/ha and 2,619 kg/ha) were recorded with the application of two sprays of nano-urea @ 3 ml/l, applied at flowering initiation and capsule development stages. The superior performance of this treatment may be attributed to the nanoscale particle size, which offers a larger surface area, enabling better leaf adherence, higher absorption and efficient nutrient translocation. Enhanced nitrogen availability at critical growth stages supports photosynthetic efficiency and dry matter accumulation, thereby improving both vegetative and reproductive growth. These findings are in agreement with those of Ajitkumar *et al*. (2021) and Midde *et al*. (2022), who also observed yield enhancement through nano-fertilizer application in oilseed crops. Additionally, a single spray of nano-urea proved more effective than a single conventional 2% urea spray, highlighting the potential of nano-formulations in enhancing nitrogen use efficiency. The increased effectiveness of nano-urea can be attributed to its ultra-small particle size (1–100 nm), controlled-release properties and higher foliar uptake, resulting in reduced volatilization losses and improved nitrogen availability. The findings are consistent with those of Liu and Lal (2015) and Veronica and Bachtiar (2014), who reported improved crop performance and nutrient uptake with nano-fertilizer applications.

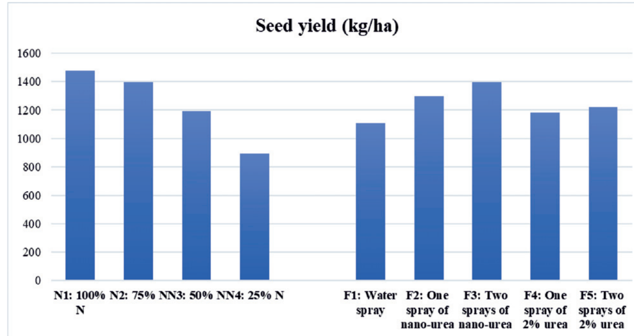

Fig. 1. Effect of nitrogen levels and foliar spray treatments on seed yield (kg/ha), based on the mean data of 2021–22 and 2022–23.

Regarding harvest index, no significant differences were observed across varying nitrogen levels or foliar treatments in either year. These observations corroborate the findings of Yadav *et al*. (2021) and Rajput *et al*. (2022), who also reported a non-significant influence of nitrogen management on harvest index in linseed.

Effect on economics in linseed

The economics of linseed as influenced by nitrogen level and foliar application of nitrogen are presented in Table 3 and Figure 2. The linseed crop gave maximum gross return (₹66,407/ha and ₹66,681/ha), net return (₹41,905/ha and ₹42,179/ha) and B:C ratio (1.7 and 1.7), with 100% recommended dose of nitrogen application

Table 2. Effect of Nitrogen management practices on seed, straw yield and harvest index of linseed (2021–22 and 2022–23)

Treatments	Seed Yield (kg/ha)		Stover Yield (kg/ha)		Harvest Index (%)	
	2021–22	2022–23	2021–22	2022–23	2021–22	2022–23
A. Nitrogen level						
N_1, 100% N	1,442	1,512	2,652	2,777	35.24	35.27
N_2, 75% N	1,366	1,428	2,572	2,685	34.59	34.61
N_3, 50% N	1,168	1,214	2,278	2,366	33.96	33.98
N_4, 25% N	880	910	1,811	1,866	32.63	32.69
SEm±	22.5	23.4	46.5	48.5	0.81	0.82
CD (P=0.05)	101	105	209	218	NS	NS
B. Foliar nitrogen management practices						
F_1, Water spray	1,084	1,127	2,161	2,241	33.07	33.11
F_2, One spray of nano-urea @ 3 ml/litre of water at flower initiation stage	1,270	1,325	2,401	2,503	34.58	34.61
F_3, Two sprays of nano-urea @ 3 ml/litre of water each at flower initiation stage and capsule development stage	1,365	1,427	2,507	2,619	35.16	35.17
F_4, One spray of 2% urea at flower initiation stage	1,157	1,204	2,260	2,351	33.68	33.71
F_5, Two sprays of 2% urea at flower initiation and capsule development stage	1,195	1,246	2,310	2,404	34.04	34.08
SEm±	32.8	34.2	66.0	68.3	0.86	0.85
CD (P=0.05)	98	102	197	204	NS	NS
C. Interaction (AXB)	NS	NS	NS	NS	NS	NS

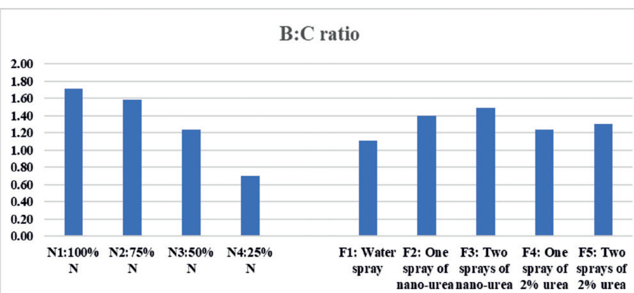

Fig. 2. Effect of nitrogen levels and foliar spray treatments on the benefit-cost (B:C) ratio, based on pooled mean data from 2021–22 and 2022–23.

during both the years of 2021–22 and 2022–23 respectively which was statistically at par to 75% recommended dose of nitrogen application. However, application of 100% recommended dose of nitrogen brought significant improvement in gross return, net return and B:C ratio then 50% and 25% recommended dose of nitrogen application. The increase in gross return, net return and B:C ratio with each increment in nitrogen level might be due to enhanced yield obtained with increasing dose of nitrogen level resulting in substantially higher income which not only covered the cost of nitrogen but also increased linseed profit. Similar results were also observed by Kumar *et al.* (2014) and Mohapatra *et al.* (2020).

The marked effect of nitrogen management through foliar application was noticed on economic parameters like gross return, net return and B:C ratio. Among foliar nitrogen management practices, maximum gross return (₹62,841/ha and ₹63,085/ha), net return (₹37,666/ha and ₹37,911/ha) and B:C ratio (1.4 and 1.4) was observed when the crop was sprayed twice with nano-urea @ 3ml / litre at flower initiation stage and capsule development stage which was found comparable to one spray of nano-urea @ 3ml /litre of water at flower initiation stage. But the former recorded significantly higher gross return, net return and B:C ratio over other foliar applied nitrogen treatments. The variation in yield with foliar nitrogen management practices were responsible for higher gross return, net return and B:C ratio with two spray of nano-urea @ 3ml /litre at flower initiation stage and capsule development stage. These finding collaborate with the finding of Rajput *et al.* (2022).

Based on two years of experimentation, application of 75% recommended nitrogen (22.5 kg/ha) significantly enhanced yield and profitability over lower nitrogen levels. Among foliar treatments, nano-urea spray (3 ml/l) at flowering initiation stage proved more effective than water spray or conventional urea, indicating its economic suitability in linseed production.

Table 3. Effect of nitrogen management practices on cost of cultivation, gross return, net return, Benefit: cost ratio of linseed (2021–22 and 2022–23)

Treatment	Gross return (₹/ha)		Net return (₹/ha)		B:C ratio	
	2021–22	2022–23	2021–22	2022–23	2021–22	2022–23
A. Nitrogen level						
N_1, 100% N	66,407	66,681	41,905	42,179	1.71	1.72
N_2, 75% N	63,025	63,274	38,653	38,903	1.58	1.59
N_3, 50% N	54,058	54,251	29,818	30,011	1.23	1.24
N_4, 25% N	40,948	41,070	16,838	16,960	0.70	0.70
SEm±	903	900	903	901	0.04	0.04
CD (P=0.05)	4,065	4,052	4,065	4,053	0.17	0.17
B. Foliar nitrogen management practices						
F_1, Water spray	50,274	50,450	26,396	26,572	1.10	1.11
F_2, One spray of nano-urea @ 3 ml /litre of water at flower initiation stage	58,605	58,829	34,078	34,302	1.39	1.40
F_3, Two sprays of nano-urea @ 3 ml /litre of water each at flower initiation stage and capsule development stage	62,841	63,085	37,666	37,911	1.49	1.50
F_4, One spray of 2% urea at flower initiation stage	53,548	53,745	29,605	29,803	1.24	1.24
F_5, Two sprays of 2% urea at flower initiation and capsule development stage	55,280	55,485	31,274	31,479	1.30	1.31
SEm±	1,391	1,391	1,391	1,391	0.06	0.06
CD (P=0.05)	4,172	4,171	4,172	4,171	0.17	0.17
C. Interaction (AXB)	NS	NS	NS	NS	NS	NS

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