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Effect of Soil and Foliar Nitrogen Fertilization on Performance and Economics of Linseed (*Linum usitatissimum* L.) Cultivation under Rainfed Conditions of Nagaland

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ABSTRACT

Background: Crop production relies heavily on essential nutrients. Balanced soil-applied fertilizers, along with foliar sprays, can improve input efficiency and crop performance, particularly in rainfed areas prone to moisture stress.

Method: A field investigation was conducted at the experimental farm of School of Agricultural Sciences, Nagaland University, Medziphema campus, during *rabi* season of 2021. The experiment was laid out in split plot design with three replications with four main factors comprising of soil-application of different doses of N (nitrogen) in two splits (based on RDF of 40 kg N ha^{-1}) *viz*., 100 % N, 75% N, 50% N and 25% N and five sub-factors comprising of foliar sprays of N *viz*. Control (water spray), single spray of Nanourea @ 3 ml $liter^{-1}$, two sprays of Nanourea @ 3 ml $liter^{-1}$, single spray of Urea @ 2% and two sprays of Urea @ 2 %.

Result: Among the different soil application treatments, significantly highest NUE (Agronomic Efficiency), seed yield (996.80 kg ha^{-1}) and stover yield (3032.10 kg^{-1}) was recorded with soil application of 100 % N ultimately recording the highest net return (Rs. 26004 ha^{-1}) and IBCR (5.80). Whereas, two sprays of Nanourea @ 3 ml L^{-1}, among foliar treatments, recorded the highest NUE (Agronomic Efficiency), seed and stover yield (918.44 kg ha^{-1} and 3032.26 kg ha^{-1} respectively) as well as net returns (Rs. 22988 ha^{-1}) and IBCR (5.5).

Key words: Foliar sprays, Linseed, Nitrogen fertilization, Soil application.

INTRODUCTION

Linseed, a dual-purpose rabi oilseed crop, valued for its oil and fiber yield, is gaining global recognition and is recommended as an immunity booster and nutraceutical post-COVID, offering a sustainable alternative to animal-based sources in diets. Its natural fibers are utilized in advanced synthetic science and eco-friendly product development (Dash *et al.,* 2022). In India, linseed cultivation covers 1.7 lakh hectares, yielding 1.1 lakh tonnes with a productivity of 644 kg ha^{-1}. Approximately 80% of production comes from Madhya Pradesh, Jharkhand, Chhattisgarh and Odisha (Anonymous, 2022). In Nagaland during 2022-23, linseed cultivation covered 3,930 hectares with a production of 3,030 MT and productivity of 771 kg ha^{-1} (Annual administrative report 2023-24). Major linseed growing districts in Nagaland include Dimapur, Mokokchung, Phek, Wokha, Peren and Mon, contributing 73% of the state's total production (Directorate of Economics and Statistics, 2021). Low linseed productivity in India is attributed to input-starved, moisture-stressed rainfed conditions, limited suitable varieties, poor soil quality, abiotic stresses and inadequate nutrient management (Rastogi *et al.,* 2013).

Research indicates that selecting high-yielding linseed varieties and implementing proper nutrient management strategies can substantially improve linseed performance, thereby impacting plant yield (Shahverdi *et al.,* 2020). Nitrogen promotes vegetative growth, cell division and enlargement, resulting in increased leaf area, improved growth, development, plant vigor and yield (Patel *et al.,* 2017). Pawar *et al*. (2023) observed that increasing nitrogen levels from 0 to 60 kg ha^{-1} led to enhanced growth and yield attributes in linseed, including plant height, branches per plant, capsules per plant, dry matter accumulation, seeds per capsule, test weight, seed yield per plant and straw yield per plant. Moreover, successive increases in nitrogen levels from 30 to 90 kg ha^{-1} significantly improved various growth parameters and seed yield of linseed (Dohat *et al.,* 2017).

The extensive and continuous imbalanced fertilizer application can harm soil properties and long-term

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productivity (Meena *et al.,* 2019). Optimal nitrogen doses are crucial, as both insufficiency and excess can lead to agronomic, environmental*and* economic problems (Anjana and Umar, 2017). Splitting nitrogen applications can enhance nutrient use efficiency, productivity and mitigate environmental impacts (Nascimento *et al.,* 2021). Foliar fertilization is gaining traction due to its direct nutrient delivery to crops, bypassing soil limitations. Foliar application, particularly of nitrogen fertilizers like nanourea, enhances nutrient utilization efficiency, crop performance*and* reduces soil pollution (Chander *et al.,* 2017). In view of the above stated facts, the present experiment was conducted to study the effect of soil and foliar application of nitrogenous fertilizers on performance as well as economics of linseed under rainfed conditions of Nagaland.

MATERIALS AND METHODS

The study was conducted at SAS: NU experimental farm during the *rabi* season of 2021. Soil was clayey loam soil with pH of 5.1, high in organic carbon (1.01%), high in available N (564.48 kg ha^{-1}) and medium in both available P (23.76 kg ha^{-1}) and K (179.53 kg ha^{-1}). The experiment was laid out in split plot design with 4 main factors *viz*., different doses of soil-applied N (100%, 75%, 50%, 25% in splits) and 5 sub-factors comprising of foliar sprays of N *viz*. Control (water spray), single spray of Nanourea @ 3 ml $liter^{-1}$, two sprays of Nanourea @ 3 ml $liter^{-1}$, single spray of urea @ 2% and two sprays of urea @ 2%. Single-spray treatments were applied at flowering, while two-spray treatments were applied at flowering and capsule development. Unreplicated control plots were also maintained for working out nitrogen use efficiency (NUE). Urea fertilizer was used for soil-applied N, based on RDF of 40:20:20 NPK ha^{-1}. Linseed variety "Kota Barani Alsi-4" was sown at 30 kg ha^{-1} with spacing of 30 cm × 5 cm, incorporating 5 t ha^{-1} of FYM during final land preparation. Cultivation economics was worked out as per prevailing market prices of inputs and outputs during 2021 *viz*., urea @ Rs. 17 kg^{-1}, SSP @ Rs. 16 kg^{-1}, MOP @ Rs. 32 kg^{-1}. Statistical analysis of data recorded during the course of the investigation was computed by following the standard ANOVA procedure as outlined by Gomez and Gomez (2010).

RESULTS AND DISCUSSION

Growth attributes

At both flower initiation and capsule development stages, plots treated with split application of 100% soil-applied N showed significantly greater height compared to those treated with 50% and 25% N doses (Table 1). Additionally, plots treated with 75% N were at par with 100% N and significantly taller than those treated with 25% N. Among foliar sprays, at flowering stage, two sprays of Nanourea @ 3 ml/L^{-1}, two sprays of urea @ 2% and single spray of Nanourea @ 3 ml L^{-1} were at par and recording significantly taller plants compared to single spray of Urea @ 2% whereas, at capsule development stage, all foliar spray treatments were found to be at par with respect to plant height. Linseed growth responded significantly to nitrogen fertilization, which enhanced plant height, biomass, economic and seed growth rates with nitrogen application these findings are in line with observations made by Ullah *et al*. (2018). Devi *et al*. (2024) also reported that applying nano NPK (19:19:19) @ 1.5 % resulted in significantly tallest plants (40.50 cm) compared to other treatments and suggested that reduced nutrient leaching and improved nutrient use efficiency with gradual nutrient release can conserve soil nutrients for subsequent crops. Sashikumar *et al*. (2013) also reported that increase in plant height due to nitrogen application is attributed to the expansion of leaf area, leading to higher photosynthesis rates, increased assimilate production and greater plant dry matter.

With respect to plant dry weight (Table 1), soil application of 100 % N was found to be significantly superior compared to rest of the N doses where as, application of 75 % N also recorded significantly higher plant dry matter compared to 50 and 25% N. Whereas, all foliar treatments were found to record significantly higher plant dry matter over control, significantly highest plant dry matter was recorded with two sprays of Nanourea @ 3 ml L^{-1}, two sprays of urea @ 2% was also found to record significantly higher plant dry matter compared to single sprays of both Nanourea and urea. This aligns with Singh *et al*. (2021) who suggested that the increase in dry matter production from foliar application could be attributed to the rapid assimilation of nutrients, meeting the crop's immediate nutrient demands. With nitrogen playing a crucial role in various aspects of plant growth and development *viz*., synthesis of chlorophyll, protein, nucleic acid, hormone and vitamins as well as cell division and elongation. Moreover, foliar application of nano urea during critical crop growth stages effectively fulfils nitrogen requirements, leading to higher crop productivity and quality compared to conventional urea due to direct application of nutrients to target organs, ensuring a specific and rapid response.

Leaf greeness recorded at flowering with SPAD meter at 10 days after foliar spray treatments (Table 1) was found to be significantly higher with soil application of 100% N as compared to 50 and 25% N whereas, soil application of 75% N was also found to record higher SPAD values compared to 25% N. Among foliar spray treatments, while all treatments recorded significantly higher SPAD vaues compared to control, two sprays of Nanourea @ 3 ml L^{-1} was additionally found to record significantly higher SPAD values compared to single spray of urea @ 2%. The enhanced leaf greeness as observed with above mentioned treatments could be attributed to optimum uptake of nitrogen by the crop under the given treatments resulting in favorable physio-morphological responses from the crop. Yadav *et al*. (2021) also reported significantly higher chlorophyll content, leaf relative water content and excised leaf water loss eithcombined foliar application of urea and potassium chloride at 2% each at 50% flowering and 50% podding

stage compared to application at individual stages. Alongside phosphorus, nitrogen plays a crucial role in plant nutrition and synthesis of protein, protoplasm and chlorophyll leading to enhanced cell size, leaf area and photosynthesis. Phosphorus, on the other hand, supports root growth, seed formation*and* energy conversion processes (Singh *et al.,* 2019). Patel *et al*. (2017) also reported that sufficient nitrogen supply is essential for robust vegetative growth, dark green foliage, enhanced cell division and enlargement, expanded leaf surface and overall improved plant vigour, growth and yield.

Yield attributes and yield

Significantly highest number of capsules plant^{-1} and seeds capsule^{-1} (Table 1) was recorded with soil application of 100 % N followed by 75% N which was also found to record significantly higher capsules plant^{-1} and seeds capsule^{-1} compared to application of 50 and 25% N Among foliar sprays two sprays of Nanourea @ 3 ml L^{-1} was found to record significantly higher number of capsules plant^{-1} and seeds capsule^{-1} compared to both single sprays of Nanourea and urea as well as control whereas, two sprays of urea @ 2% was also found to be significantly superior compared to single spray of urea and control. One contributing factor could be that nitrogen and phosphorus application might have contributed to tissue differentiation, resulting in increased flower production and subsequent capsule development. Similar observation was also reported by Sameer *et al*. (2021) and Singh *et al*. (2013).

Significantly highest seed yield (Table 2) of 996.80 kgs ha^{-1} was recorded with soil application of 100% N followed by 75% N which was also found to be significantly higher compared to 50 and 25% N. Sakpal *et al*. (2022) also reported significantly enhanced growth, development, yield and yield attributes in cowpea with application of 100% RDF compared to 75% and 50% RDF. While all foliar treatments were found to record significantly higher seed yields compared to control, significantly highest seed yield of 918.44 kgs ha^{-1} was recorded with two sprays of Nanourea @ 3 ml L^{-1}, two sprays of Urea @ 2% was also found to be record significantly higher seed yield compared to single spray of Urea. Studies by Soethe *et al*. (2013) also highlight the significant impact of nitrogen levels on yield-related parameters such as plant height, capsules per plant, 1000-seed weight and seed yield. Nitrogen fertilizers consistently lead to a substantial increase in seed yield due to enhanced plant vigour and enhanced photosynthesis due to higher availibility of nitrogen and phosphorus. Consequently, key yield attributes like capsules plant^{-1}, seeds capsule^{-1}, are improved resulting in overall increased seed yield (Sameer *et al.,* 2021).

Stover yield (Table 2) of 3032.10 and 2717 kg ha^{-1} recorded by soil application of 100 and 75% N respectively were statistically at par and significantly higher compared to control whereas, among foliar spray treatments, excluding control which recorded the lowest stover yield, significantly higher stover yield of 3032.26 kgs ha^{-1} was recorded with two sprays of Nanourea @ 3ml L^{-1} compared to both single sprays of Nanourea and Urea whereas two sprays of Urea @ 2% was also found to record significantly higher stover yield compared to single spray of Urea. Significantly higher stover yields recorded by above cited treatments coud be

Table 1: Effect of soil and foliar N fertilization on growth and yield attributes of linseed.

Treatment	Plant height (cm)		Dry matter (g/m^2)	Leaf greeness	Capsules plant^{-1} (No.)	Seed capsule^{-1} (No.)
	*1	*2		*3		
Soil application of N						
100% N	53.24	68.40	409.98	50.94	43.42	9.74
75% N	53.33	63.02	370.16	48.36	36.96	8.32
50% N	49.39	56.30	298.96	42.97	32.16	7.17
25% N	48.13	56.12	291.58	42.29	29.19	6.38
SEm±	0.83	68.40	6.15	1.31	0.92	0.27
CD (P≤0.05)	3.76	63.02	27.71	5.91	4.14	1.23
Foliar sprays of N						
Control (Water spray)	46.94	56.67	300.25	42.78	28.71	6.60
Single spray of Nanourea @ 3 ml L^{-1}	51.85	61.15	338.08	46.43	34.66	8.09
Two sprays of Nanourea @ 3 ml L^{-1}	53.84	63.34	387.58	48.29	42.64	8.73
Single spray of Urea @ 2%	49.78	60.77	315.75	45.19	32.15	7.63
Two sprays of Urea @ 2%	52.71	62.88	371.70	48.03	39.00	8.48
SEm±	0.68	1.22	5.11	0.99	0.95	0.21
CD (P≤0.05)	2.06	3.67	15.33	2.97	2.86	0.63

*1At flower initiation stage.

*2At capsule development stage.

*3At 10 days after foliar spray treatments at flowering stage (SPAD).

attributed to significantly superior growth attributes recorded under those treatments which interm can be attributed to the positive growth response of the crop to optimum nitrogen supply to the plants as discussed above under growth attributes section.

Plant N content, N uptake and NUE

With respect to plant N content at flowering and capsule development 10 days after foliar spray treatments (Table 2), at both stages soil application of 100% N was found to record significantly highest plant N content followed by 75% N which was also found to record significantly higher plant N content compared to 25% N whereas, at both stages, all foliar spray treatments were found to record significantly higher plant N content compared to control, two sprays of Nanourea @ 3 ml L^{-1} was found to record significantly highest plant N content compared to the rest of the foliar spray treatments which was followed by two sprays of Urea @ 2% which was also found to record significantly higher plant N content compared to single sprays of both Nanourea and Urea. Significant variations were also recorded with respect to N uptake by seed and stover (Table 2). Soil application of 100% N was found to record significantly higher N uptake in both seed and stover compared to 50 and 25% N whereas, application of 75% N was also found to record significantly higher N uptake in seed compared to 25% N. With respect to foliar sprays, whereas all treatments were found to record significantly higher N uptake in both seed and stover compared to control, significantly highest N uptake in both seed and stover was recorded with two sprays of Nanourea @ 3ml L^{-1} followed by two sprays of Urea @ 2% which was also found to record significantly higher N uptake in both seed and stover compared to single sprays of both Nanourea and Urea. The enhanced nitrogen supply and uptake by plants likely stimulated various physiological processes, leading to increased growth and yield parameters, including seed and stover yields. Suresh *et al*. (2018) reported that applying 120 and 140 kg N ha^{-1} equally improved nitrogen uptake in grain and stover of pearl millet compared to 100 kg N ha^{-1}. Higher nitrogen levels were found to enhance growth and yield attributes, leading to increased NPK uptake and higher grain and stover yields in pearl millet. Beig *et al.,* (2020) also stated that foliar application is valued for its rapid nutrient absorption and efficient utilization, reducing leaching losses and fixation and aiding in nutrient regulation, especially in areas heavily reliant on nitrogenous urea fertilizers with limited effectiveness.

With respect to NUE (agronomic efficiency) [Table 2], significantly higher NUE was recorded with soil application of 100 and 75% N, which were at par, compared to 50 and 25% N, whereas, among foliar spray treatments significantly highest NUE was recorded with two sprays of Nanourea @ 3 ml L^{-1} followed by single spray of Nanourea while single and two spray of urea @ 2% were also found to record significantly higher NUE compared to control. Comprehensive studies show that applying chelated fertilizer on leaves reduces total fertilizer usage while maintaining high efficiency. Foliar fertilizer application post soil fertilization enhances trace element levels and crop yield, improving soil health (Niu *et al.,* 2021). Jung *et al*. (2016) also found increased total N, N uptake*and* nutrient use efficiency (NUE) with higher N application rates. Nano fertilizer formulations offer controlled nutrient release, boosting NUE, increasing yields and potentially mitigating soil pollution from excessive fertilizer use.

Table 2: Effect of soil and foliar N fertilization on yield and N uptake in linseed.

Treatment	Yield (kg ha^{-1})		Plant N content (%)		N uptake(kg ha^{-1})		NUE*3
	Seed	Stover	*1	*2	Seed	Stover	kg kg^{-1}
Soil application of N							
100% N	996.80	3032.10	1.29	1.69	54.85	35.19	6.60
75% N	829.95	2717.80	1.01	1.39	42.16	25.65	5.35
50% N	662.10	2299.47	0.94	1.20	33.43	19.15	3.69
25% N	562.25	2229.88	0.72	1.08	28.38	18.38	2.60
SEm±	24.47	122.13	1.29	0.06	2.11	2.25	0.32
CD (P≤0.05)	110.13	549.60	1.01	0.29	9.52	10.14	1.46
Foliar sprays of N							
Control (Water spray)	574.50	1952.22	0.75	0.94	26.58	15.38	2.36
Single spray of Nanourea @ 3 ml L^{-1}	770.75	2593.44	0.95	1.30	41.17	25.80	5.12
Two sprays of Nanourea @ 3 ml L^{-1}	918.44	3032.26	1.35	1.72	50.79	31.76	7.16
Single spray of Urea @ 2%	730.19	2440.07	0.80	1.23	36.26	21.99	3.86
Two sprays of Urea @ 2%	820.00	2831.07	1.09	1.51	43.72	28.05	4.29
SEm±	66.21	95.56	0.05	0.05	1.13	1.05	0.33
CD (P≤0.05)	91.23	286.50	0.25	0.15	3.38	3.17	1.00

*1At 10 days after foliar spray treatments at flowering.

*2At 10 days after foliar spray treatments at Capsule development.

*3Agronomic efficiency.

Table 3: Cultivation economics of different N treatments.

Treatment	Cost of cultivation (Rs. ha^{-1})	Gross returns (Rs. ha^{-1})	Net returns (Rs. ha^{-1})	IBCR
Soil application of N				
100% N	18852	44856	26004	5.8
75% N	18478	37348	18869	4.5
50% N	18104	29795	11690	3.0
25% N	17747	25301	7554	2.0
SEm±	-	1101	1101	0.27
CD (P≤0.05)	-	4956	4956	1.21
Foliar sprays of N				
Control (Water spray)	17722	25853	7582	1.8
Single spray of Nanourea @ 3 ml L^{-1}	17758	34684	16378	3.9
Two sprays of Nanourea @ 3 ml L^{-1}	17793	41330	22988	5.5
Single spray of Urea @ 2%	17729	32858	14581	3.5
Two sprays of Urea @ 2%	17735	36900	18616	4.5
SEm±	-	993	993	0.25
CD (P≤0.05)	-	2979	2979	0.77

Economics of treatments

Among soil applications of nitrogen fertilizers, the highest cost of cultivation (Table 3) was recorded with 100% N, while the lowest was observed with 25% N**.** Among foliar sprays, excluding control, the highest and lowest cost of cultivation was recorded with two sprays of Nanourea @ 3 ml L^{-1} and single spray of Urea @ 2% respectively. The highest gross return, net return and IBCR (Table 3) of Rs. 44856 ha^{-1}, Rs. 26004 ha^{-1} and 5.80 respectively was obtained with soil application of 100% N followed by application of 75% N recording net return and IBCR of Rs. 18869 ha^{-1} and 4.5 respectively whereas, among foliar spray treatments two sprays of Nanourea @ 3ml L^{-1} was found to record the highest gross and net returns of Rs. 41330 ha^{-1} and Rs. 22988 ha^{-1} respectively with IBCR of 5.5 followed by two sprays of urea @ 2% with net returns of Rs. 18616 ha^{-1} and IBCR of 4.5. Increasing nitrogen levels boosted net returns and benefit-cost ratio by maximizing recovery while minimizing expenditure, as evidenced by studies like Sameer *et al*. (2021) and Gaikwad *et al*. (2020). They observed higher gross and net monetary returns with nitrogen and phosphorus application, especially with increased fertilizer doses in linseed.

CONCLUSION

The study highlights the significant impact of nitrogen management in linseed through split soil and foliar applications on growth, yield and nutrient uptake under rainfed conditions. Soil application of 100% N supplemented with foliar sprays of Nanourea @ 3 ml L^{-1} at flowering and capsule development stages showed superior growth and yield attributes. With respect to economics, soil application of 100% N was also found to record the highest net return of Rs. 26004 ha^{-1} and IBCR of 5.80 while, among foliar sprays, two sprays of Nanourea @ 3 ml L^{-1} recorded the highest net returns and IBCR of Rs. 22988 ha^{-1} and 5.5 respectively. The findings suggest that the evaluated technology could be a cost-effective production method for linseed under rainfed conditions, enhancing productivity and sustainability. Further research validation is warranted, with the potential to revive linseed cultivation in the country and appeal to rainfed farmers.

Ethical statement

The research is conducted ethically and in compliance with relevant guidelines and regulations.

Conflict of interest

All authors declare that they have no conflict of interest.

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