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Impact of foliar application of nano-Nitrogen fertilizer on yield, nutrient uptake and quality of linseed (*Linum usitatissimum* L.)

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Abstract
In order to investigate the "Impact of foliar application of nano-Nitrogen fertilizer on yield, nutrient uptake and quality of linseed (*Linum usitatissimum* L.)" the current field experiment was carried out at the experimental farm Oilseed Research Station, Latur (MH.) during the *rabi* season 2021–2022. Eight treatments with three replications each were used in the randomized block design experiment. Based on the test weight, oil content, protein content, test weight, grain as well as straw yields of linseed, the results showed that treatment T_7–50 percent N (RDN) and 100 percent P and K through soil + two foliar sprays of 0.4 percent nano-N at 20 and 40 DAS recorded the highest nutrient uptake by seed and straw. which was on level with treatment T_8-25 percent N (RDN), 100 percent P and K + three sprays of 0.4 percent nano-N at 20, 40, and 60 DAS, but markedly better than all other treatments.

Keywords: Nano nitrogen, available NPK, total uptake, linseed, yield and quality

Introduction
An essential place in India's agricultural economy is held by oil seeds. The most important oilseed crop in India is linseed (*Linum usitatissimum* L.), which is planted alongside rapeseed-mustard (*Rabi*) as the winter season's oilseed crop in terms of both acreage and productivity. The same type of flax is used to grow linen and food for humans, yet the two products are typically not made from the same crop. Minerals like phosphorus are present in linseed seeds together with 20–25% protein and 35–45% oil.

As has been shown, flax responds effectively to nitrogen for crop emergence and seed production. low production caused due to stunted development, limited foliage, pale and green leaves, and a reduction in the number of capsules per plant caused by an inadequate supply of nitrogen to the crop. There are three main ways that nitrogen can escape from a field: denitrification, leaching and surface volatilization.

Due to extensive cultivation, excessive use of synthetic fertilizers, and inadequate application of organic fertilizers, the natural fertility of the soil has declined since the green revolution. The next frontier of nanotechnology for sustainable agriculture is fertilizers the size of nanoparticles. Materials with a nanometer size, typically in the form of nanoparticles, that contain macro and micronutrients and are applied to crops in a regulated manner are referred to as nano fertilizers.

Chemical types of nutrients are provided by conventional fertilisers, which frequently prevent plants from completely utilising them. It is essential to use fertilisers frequently because of these issues. It is widely recognised that an imbalance in fertilisation and a decline in soil organic matter have caused many crops' yields to start declining. Aside from the irreversible harm that excessive chemical fertiliser use does to the soil's structure, fertiliser application that is mineral imbalanced degrades plants, soil microflora, and ecosystem food chains, which in turn causes heritable mutations in subsequent consumer generations. Fertilisers high in phosphorus and nitrogen are now the main human-caused factor causing eutrophication in freshwater bodies and coastal ecosystems globally.

Materials and Methods
At the experimental farm Oilseed Research Station, Latur (MH.), a field experiment was conducted during the *rabi* season of 2021–2022. the test variety was LSL-93, sown in the

second week of October and harvested in the final week of January. The experimental field's soil had good drainage, a neutral reaction, and a black color. There were eight treatments and three replications in the randomized block design experiment. The treatment comprised of T_1 - control, T_2-100 percent NPK (RDN through soil), T_3 - 100 percent NPK +one foliar application of 0.4 percent nano-N at 40 DAS, T_4- 100 percent P and K + three foliar applications of 0.4 percent nano-N at 20, 40 and 60 DAS, T_5- 100 percent P and K + two foliar sprays of 0.4 percent nano-N at 20 and 40 DAS, T_6 - 75 percent N (RDN) and 100 percent PK +one foliar application of 0.4 percent nano-N at 40 DAS, T_7- 50 percent N (RDN) and 100 percent P and K +two foliar application of 0.4% nano-N at 20 and 40 DAS, T_8 -25 percent N (RDN) and 100 P and K + three spray of 0.4 percent nano-N at 20, 40 and 60 DAS

The experiment's yields, growth analysis and various morphological observations were recorded at 30, 60 and harvest stages in order to assess the treatment's impact. For linseed, fertilizer dosage recommendations are 60:30 kg N and P_2O_5 ha^{-1}, respectively. The crop was threshed manually, with grain and straw being collected in separate plots.

Results and Discussion

The findings of the current study, together with pertinent commentary, have been compiled under the following headings.

Grain yield (kg ha^{-1})

The highest grain yield (1434.23 kg ha^{-1}) was achieved after harvesting by applying treatment T_7-50 percent N (RDN), 100 percent P and K through soil + two foliar applications of nano-N @ 0.4 percent at 20 and 40 DAS. When linseed is harvested, the grain yield values are found to be comparable to treatment T_8-25 percent N (RDN), 100 percent P and K, and three foliar sprays of nano-N @ 0.4 percent at 20, 40 and 60 DAS (1395.76 kg ha^{-1}). For treatment T_1-control, the lowest grain yield (853.35 kg ha^{-1}) was observed.

The foliar application of nano fertilisers, which have a larger surface area due to their small particle size, may be the source of the increased linseed output. More photosynthates are produced as a result of the increased surface area that is available for different metabolic activities in the plant system. The synergistic effect of nano fertilisers on the efficiency of chemical fertilisers results in a high yield that is attributed to increased source and sink strength. This allows for greater nutrient absorption by plant cells, maximum growth of plant parts, and metabolic activities like photosynthesis, which leads to higher photosynthate accumulation and translocation to the plants economic parts. These results are in line with those reported by Ajitkumar and Midde *et al.* (2022) [1]. Straw yield (kg ha^{-1})

The treatment T_7- 50 percent N (RDN) and 100 percent P and K through soil + two foliar applications of nano-N @ 0.4 percent at 20 and 40 DAS recorded the maximum straw yield of linseed (2883.72 kg ha^{-1}). Nevertheless, the straw yield (2749.26 kg ha^{-1}) was found to be comparable to treatments T_8-25 percent N (RDN) and 100% PK + three foliar sprays of nano-N at 0.4 percent at 20, 40, and 60 DAS. While minimum straw yield was recorded in treatment T_2-100 percent NPK (RDN through soil i.e., 2102.23 kg ha^{-1} and followed by treatment T1-control (1828.12 kg ha^{-1}).

When administered as a foliar spray of nano urea fertiliser, the quick uptake of the fertiliser by plants and its ease of translocation may have improved rates of photosynthesis and increased dry matter buildup, which in turn yielded a larger straw yield. The harvest index increased when nano fertilisers were applied topically. They might also improve the capacity of plant cells to take in nutrients, which would promote the best possible development, when combined with conventional fertilisers. The results that were previously explained closely match those of Yadav *et al*. (2021) [10].

Table 1: Influence of foliar spraying of nano N fertilizer on grain yield and straw yield of linseed crop.

Treatments	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
T_1- Control	853.35	1828.12
T_2- 100% NPK (RDN through soil)	1117.73	2107.04
T_3- 100% NPK+ one 0.4% Nano-N foliar treatment at 40 DAS.	1209.58	2285.19
T_4- 100% PK + three Foliar treatment of 0.4% Nano-N at 20, 40 and 60 DAS	1312.98	2522.44
T_5- 100% P&K +two foliar treatment of 0.4% Nano- N at 20 and 40 DAS	1271.47	2412.3
T_6- 75% N (RDN) and 100% PK + one foliar treatment of 0.4% Nano-N at 40 DAS	1145.85	2239.03
T_7- 50% N (RDN) and 100% PK + two foliar treatment of 0.4% Nano-N at 20 and 40 DAS	1434.23	2883.72
T_8- 25% N (RDN) and 100 P&K + three spray of 0.4% Nano-N at 20, 40 and 60 DAS	1395.76	2749.26
S.E m ±	30.03	55.74
CD at 5%	92.17	164.86

N content in seed and straw

The increase in nitrogen content in grain 3.99 and 1.19% in straw was due to treatment T_7-50 percent N (RDN) and 100 percent P and K + two foliar application of 0.4 percent nano-N at 20 and 40 DAS and was noted at par with the treatment T_8-25 percent N (RDN) and 100 percent P and K + three spray of 0.4 percent nano-N at 20, 40 and 60 DAS i.e., nitrogen content in grain and straw i.e. (3.92 and 1.10%). However, the lowest nitrogen content in grain and straw (3.37 and 0.58%) was recorded in treatment T_1- Control.

Table 2: Influence of foliar spraying of nano N fertilizer on nitrogen content (%) in grain and straw of linseed crop.

Treatments	N Content in Grain	N Content in Straw
T_1- Control	3.27	0.58
T_2- 100% NPK (RDN through soil)	3.41	0.69
T_3- 100% NPK+ one 0.4% Nano-N foliar treatment at 40 DAS.	3.62	0.81
T_4- 100% PK + three Foliar treatment of 0.4% Nano-N at 20, 40 and 60 DAS	3.77	0.97
T_5- 100% P&K +two foliar treatment of 0.4% Nano- N at 20 and 40 DAS	3.74	0.94
T_6- 75% N (RDN) and 100% PK + one foliar treatment of 0.4% Nano-N at 40 DAS	3.52	0.76
T_7- 50% N (RDN) and 100% PK + two foliar treatment of 0.4% Nano-N at 20 and 40 DAS	3.99	1.19
T_8- 25% N (RDN) and 100 P&K + three spray of 0.4% Nano-N at 20, 40 and 60 DAS	3.92	1.10
S.E m ±	0.03	0.04
CD at 5%	0.10	0.11

Further data indicated that the among the alone foliar application of nano nitrogen the treatment T_4-100 percent P and K + three foliar sprays of 0.4 percent nano-N at 20, 40, and 60 DAS recorded significant increase in nitrogen content in grain 3.77 and 0.97% in straw. However, it was noted to be on par with treatment T_5- 100% P and K + two foliar sprays of 0.4% nano-N at 20 and 40 DAS), in nitrogen content in seed 3.74 and 0.94% in straw of linseed.

The application of soil and foliar nano nitrogen was found to enhance the uptake of nitrogen by linseed. This may be because the nano fertiliser has a larger surface area and particles smaller than those found in plant roots and leaves, which increases its penetration into the plant from the applied surface and enhances nutrient content and uptake by seed and straw. Rajput *et al*. found results that were almost identical (2022) [7].

Phosphorous and Potassium content in seed and straw

The phosphorous content in seed and straw was enhanced slightly by the foliar application of nano nitrogen fertilizer but not at the level of relevance because of same dose of application of phosphorous in all treatments excepts T_1-control. Among all the treatment T_7- 50 percent N (RDN) and 100 percent P and K + two foliar application of 0.4 percent nano-N at 20 and 40 DAS recorded maximum P_2O_5 content in seed 0.77% and straw 0.42%. The minimum values of phosphorous content in seed 0.60 and straw 0.30% was noted in treatment T_1-control.

Table 3: Influence of foliar spraying of nano N fertilizer on phosphorous and potassium content (%) in grain and straw of linseed crop.

Treatments	P_2O_5 Content in Grain	P_2O_5 Content in Straw	K_2O Content in Grain	K_2O Content in Straw
T_1- Control	0.60	0.30	0.67	0.89
T_2- 100% NPK (RDN through soil)	0.72	0.35	0.70	0.97
T_3- 100% NPK+ one 0.4% Nano-N foliar treatment at 40 DAS.	0.73	0.36	0.73	0.99
T_4- 100% PK + three Foliar treatment of 0.4% Nano-N at 20, 40 and 60 DAS	0.75	0.39	0.74	0.95
T_5- 100% P&K +two foliar treatment of 0.4% Nano- N at 20 and 40 DAS	0.74	0.37	0.74	0.96
T_6- 75% N (RDN) and 100% PK + one foliar treatment of 0.4% Nano-N at 40 DAS	0.73	0.36	0.73	0.97
T_7- 50% N (RDN) and 100% PK + two foliar treatment of 0.4% Nano-N at 20 and 40 DAS	0.77	0.42	0.79	1.11
T_8- 25% N (RDN) and 100 P&K + three spray of 0.4% Nano-N at 20, 40 and 60 DAS	0.76	0.40	0.77	1.02
S.E m ±	0.026	0.034	0.03	0.05
CD at 5%	NS	NS	NS	NS

The potassium content in seed and straw was increased considerably with the foliar application of nano nitrogen fertilizer but not reached to its level of significance. Among the treatments T_7-50 percent N (RDN) and 100 percent P and K + two foliar application of 0.4 percent nano-N at 20 and 40 DAS recorded maximum potassium content in grain (0.79%) and by straw (1.11%). The minimum values of potassium content in seed 0.67% and straw 0.89% was found in treatment T_1-control.

Available nitrogen

Among different treatments of nano nitrogen fertilizers, the higher available N (163.02 kg ha^{-1}) at 30 DAS, (167.69 kg ha^{-1}) at 60 DAS and (162.97 kg ha^{-1}) at harvest was recorded in treatment T_3-100% NPK + 1 foliar application of 0.4% Nano-N at 40 DAS, and noted at par with treatments T_2- 100% NPK (RDN through soil at 30 DAS (160.85 kg ha^{-1}), at 60 DAS (163.42kg ha^{-1}) and at harvest (159.32 kg ha^{-1}). The lowest available nitrogen (137.61 kg ha^{-1}) at 30 DAS, (137.85 kg ha^{-1}) at 60 DAS and (135.16 kg ha^{-1}) at harvest was observed in treatment T_1-control.

Additional data reveals that the available nitrogen was improved with T_7-50 percent N (RDN) and 100 percent PK + three sprays of 0.4 percent nano-N at 20, 40, and 60 DAS i.e., 149.03, 151.43, and 147.43 kg ha^{-1} at 30, 60 DAS, and after harvest of linseed, respectively, in comparison to levels of RDN application with three (20, 40, and 60 DAS) and two (20 and 40 DAS) sprays of nano nitrogen. It did, however, compare favourably to treatments T_8–25 percent N (RDN) and 100% P and K + three sprays of 0.4 percent nano-N at 20, 40, and 60 DAS, or, in other words, 144.15, 147.90, and 140.13 kg ha^{-1}at 30, 60 DAS, and following linseed harvest, respectively. The increased nitrogen availability during the linseed growth stage at 30, 60, and harvest may have resulted from residual fertiliser in the soil, as nano fertiliser contains more inorganic nitrogen than conventional fertiliser. The available nitrogen status is greatly increased by the varying nitrogen levels. This might be explained by a sufficient supply of nitrogen to satisfy crop demand. This could be the cause of the soil's higher accessible nitrogen status following harvest.

Table 4: Influence of foliar spraying of nano N fertilizer on available nitrogen at 30, 60 DAS and at harvest of linseed crop.

Treatments	Available N (kg ha^{-1})		
	30 DAS	60 DAS	At harvest
T_1- Control	138.85	134.16	130.00
T_2- 100% NPK (RDN through soil)	160.85	163.42	159.32
T_3- 100% NPK+ one 0.4% Nano-N foliar treatment at 40 DAS.	163.09	167.69	162.97
T_4- 100% PK + three Foliar treatment of 0.4% Nano-N at 20, 40 and 60 DAS	140.12	137.98	133.78
T_5- 100% P&K +two foliar treatment of 0.4% Nano- N at 20 and 40 DAS	138.98	135.12	130.14
T_6- 75% N (RDN) and 100% PK + one foliar treatment of 0.4% Nano-N at 40 DAS	154.34	156.12	153.12
T_7- 50% N (RDN) and 100% PK + two foliar treatment of 0.4% Nano-N at 20 and 40 DAS	149.03	151.43	147.43
T_8- 25% N (RDN) and 100 P&K + three spray of 0.4% Nano-N at 20, 40 and 60 DAS	144.15	147.90	140.13
S.E m ±	1.79	1.70	1.53
CD at 5%	5.15	5.18	4.18

Available phosphorous and potassium

Among different nano nitrogen fertilizer treatments, the higher available P_2O_5 at 30 DAS (13.02 kg ha^{-1}), at 60 DAS (12.92 kg ha^{-1}) and at harvest (10.36 kg ha^{-1}) was recorded in treatment T_7-50 percent N (RDN) and 100 percent P and K + two foliar application of 0.4 percent nano-N at 20 and 40 DAS. The lowest P_2O_5 at 30 DAS (8.23 kg ha^{-1}), at 60 DAS (7.91 kg ha^{-1}) and at harvest (7.02 kg ha^{-1}) was found in treatment T_1-control.

Table 5: Influence of foliar spraying of nano N fertilizer on available phosphorous at 30, 60 DAS and at harvest of linseed crop.

Treatments	Available P_2O_5 (kg ha^{-1})		
	30 DAS	60 DAS	At harvest
T_1- Control	8.50	7.24	6.50
T_2- 100% NPK (RDN through soil)	12.31	11.39	9.25
T_3- 100% NPK+ one 0.4% Nano-N foliar treatment at 40 DAS.	12.53	11.52	9.01
T_4- 100% PK + three Foliar treatment of 0.4% Nano-N at 20, 40 and 60 DAS	12.21	11.71	9.99
T_5- 100% P&K +two foliar treatment of 0.4% Nano- N at 20 and 40 DAS	12.67	11.98	9.72
T_6- 75% N (RDN) and 100% PK + one foliar treatment of 0.4% Nano-N at 40 DAS	12.43	11.32	9.33
T_7- 50% N (RDN) and 100% PK + two foliar treatment of 0.4% Nano-N at 20 and 40 DAS	13.02	12.92	10.36
T_8- 25% N (RDN) and 100 P&K + three spray of 0.4% Nano-N at 20, 40 and 60 DAS	12.89	11.96	9.88
S.E m ±	0.50	0.57	0.59
CD at 5%	NS	NS	NS

The higher available potassium (413.43 kg ha^{-1}) at 30 DAS, (410.57 kg ha^{-1}) at 60 DAS and (406.57 kg ha^{-1}) at harvest was recorded in treatment T_3-100 percent NPK + one foliar application of 0.4 percent Nano-N at 40 DAS. The lowest available potassium at 30 DAS (409.71 kg ha^{-1}), at 60 DAS (406.11 kg ha^{-1}) and at harvest (402.81 kg ha^{-1}) was found in treatment T_1-control.

The decrease in potassium availability in soil at 30, 60 and at harvest could be due to there is no recommendation of application of potassium at the time of sowing. Hence it was observed that the potassium availability was decreased as increment in crop growth period.

Table 6: Influence of foliar spraying of nano N fertilizer on available potassium at 30, 60 DAS and at harvest of linseed crop.

Treatments	Available K_2O (kg ha^{-1})		
	30 DAS	60 DAS	At harvest
T_1- Control	409.71	406.11	402.81
T_2- 100% NPK (RDN through soil)	412.23	406.26	404.19
T_3- 100% NPK+ one 0.4% Nano-N foliar treatment at 40 DAS.	413.43	410.57	406.57
T_4- 100% PK + three Foliar treatment of 0.4% Nano-N at 20, 40 and 60 DAS	412.90	408.75	405.07
T_5- 100% P&K +two foliar treatment of 0.4% Nano- N at 20 and 40 DAS	410.59	407.59	403.26
T_6- 75% N (RDN) and 100% PK + one foliar treatment of 0.4% Nano-N at 40 DAS	411.62	409.20	405.86
T_7- 50% N (RDN) and 100% PK + two foliar treatment of 0.4% Nano-N at 20 and 40 DAS	412.83	408.43	404.59
T_8- 25% N (RDN) and 100 P&K + three spray of 0.4% Nano-N at 20, 40 and 60 DAS	412.08	408.78	405.42
S.E m ±	0.78	0.56	0.87
CD at 5%	NS	NS	NS

Oil content and Protein content

From the data it was observed that the application of 50 percent RDN through soil and 100 percent P and K + two foliar spray of nano N @ 0.4 percent at 20 and 40 DAS (T_7), recorded maximum oil content (38.14 percent) which was numerically superior over rest of the treatments. The maximum oil yield (549.34 kg ha^{-1}) obtained in treatment T_7 which was significantly superior over rest of the treatments and found at par with treatment T_8 (530.63 kg ha^{-1}). The lowest oil content (36.13%) and oil yield (307.22 kg ha^{-1}) was recorded in treatment T_1-(control).

From the data it was observed that the application of 50 percent RDN through soil and 100 percent P and K + two foliar spray of nano N @ 0.4 percent at 20 and 40 DAS (T_7), recorded maximum protein content (24.97%) which was numerically superior over rest of the treatments. However,

protein content (24.51 percent) and were found at par with application of treatment T_8-25 percent N (RDN) and 100 percent PK + three foliar spray of nano-N @ 0.4 percent at 20, 40 and 60 DAS). The lowest oil content (36.13%) was noticed in treatment T_1-control.

Table 7: Influence of foliar spraying of nano N fertilizer on oil content and protein content of linseed.

Treatments	Oil content (%)	Protein content (%)
T_1- Control	36.13	22.24
T_2- 100% NPK (RDN through soil)	37.04	22.35
T_3- 100% NPK+ one 0.4% Nano-N foliar treatment at 40 DAS.	37.27	22.99
T_4- 100% PK + three Foliar treatment of 0.4% Nano-N at 20, 40 and 60 DAS	37.71	23.89
T_5- 100% P&K +two foliar treatment of 0.4% Nano- N at 20 and 40 DAS	37.58	23.55
T_6- 75% N (RDN) and 100% PK + one foliar treatment of 0.4% Nano-N at 40 DAS	37.11	22.02
T_7- 50% N (RDN) and 100% PK + two foliar treatment of 0.4% Nano-N at 20 and 40 DAS	38.14	24.97
T_8- 25% N (RDN) and 100 P&K + three spray of 0.4% Nano-N at 20, 40 and 60 DAS	37.93	24.51
S.E m ±	0.82	0.34
CD at 5%	NS	0.92

Conclusion

The application of foliar-sprayed nano nitrogen fertilizer, as an alternative to soil-applied fertilizers, in conjunction with synthetic fertilizers for linseed proved to be highly successful in raising the production of grains and straw. According to this study, it is possible to replace 50% of the nitrogen applied to the soil with nano nitrogen fertilizer by applying it topically. This would increase the amount of NPK in grain and straw, as well as the amount of NPK that is available for use after harvest and quality metrics like the oil and protein content of the linseed crop. Additionally, by enhancing the physical and chemical characteristics of the soil, the foliar application of nano nitrogen fertilizer will reduce soil pollution and improve soil fertility.

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