E-ISSN: 2618-0618
P-ISSN: 2618-060X

www.agronomyjournals.com
2024; SP-7(10): 404-409
Received: 05-08-2024
Accepted: 13-09-2024

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Studies on nitrogen management in linseed (*Linum usitatissimum* L.) through nano urea

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DOI: https://doi.org/10.33545/2618060X.2024.v7.i10Sf.1802

Abstract
A field experiment was conducted at MARS, UAS, Raichur during *Rabi*, 2023-24 to study the nitrogen management in linseed (*Linum usitatissimum* L.) through nano urea. The experiment was laid out in split plot design consisting of four main plots consisting recommended dose of nitrogen levels *i.e*., 100%, 75%, 50% and 25% and five sub plots involving nano urea and conventional urea levels *i.e*., no spray of nano urea, one spray of nano urea @ 3 ml l^{-1} at flower initiation, two sprays of nano urea @ 3 ml l^{-1} at flower initiation stage and capsule development stage, one spray of 2% urea at flower initiation stage, two sprays of 2% urea at flower initiation stage and capsule development stage each were replicated thrice. The results of the experiment indicated that the application of 100% RDN recorded the higher seed yield (914 kg ha^{-1}), straw yield (1731 kg ha^{-1}), harvest index (35%), higher gross returns (Rs. 45,684 ha^{-1}), net returns (Rs. 29,863 ha^{-1}) and B:C (2.89).With respect to nano urea levels, two sprays of nano urea @ 3 ml l^{-1} at flower initiation stage and capsule development stage recorded significantly higher seed yield (Rs. 838 kg ha^{-1}), straw yield (1669 kg ha^{-1}), harvest index (33%), gross returns (Rs. 41,925 ha^{-1}) net returns (Rs. 25,894 ha^{-1}) and B:C (2.60). Among interaction effects, application of 100% RDN + two sprays of nano urea @ 3 ml l^{-1} at flower initiation stage and capsule development stage recorded significantly higher seed yield (984 kg ha^{-1}), straw yield (1827 kg ha^{-1}), harvest index (36%), gross returns (Rs. 49,184 ha^{-1}), net returns (Rs. 32,267 ha^{-1}) and B:C (2.91). Application of 100% RDN (50% basal + 50% top dressing) along with foliar application of nano urea @ 3 ml 1^{-1} at flower initiation and capsule development stage or foliar application of urea @ 2% at flower initiation and capsule development stage was found beneficial in getting the higher seed yield, net returns and benefit cost ratio.

Keywords: Linseed, nitrogen management, nano urea

Introduction
Linseed also referred as flax (*Linum usitatissimum* L.) is a self-pollinated crop widely adapted to temperate climates of the world. It is known as *Agasi* in Kannada, *Javas* or *Alashi* in Marathi, *Alsi* in Hindi and *Ousahalu* in Telugu. It is an annual plant belongs to the genus *Linum* and the family *Linaceae*. In fact, the name *Linum* is originated from the Celtic word "*lin"* or "thread" and the name *usitatissimum* is a Latin word meaning for "most useful" (Kolodziejczyk and Fedec, 1995) [10]. It is believed that flax is originated in the Middle East or Indian regions. Linseed is one of the most versatile and useful crop that have been grown for thousands of years. It is cultivated as a commercial or subsistence crop in over 30 countries. It is a great source of nutrients and contains 33 to 47 per cent of oil. Out of total oil produced, about 20 per cent is used at farmer's level and the rest 80 per cent oil goes to industries for various purposes. Linseed oil is rich in α-linolenic acid (> 66%) which is a polyunsaturated fatty acid that has nutritional benefits (Wood, 1997) [19]. Beside α-linolenic acid, it contains omega-3 fatty acid, soluble fibre, insoluble fiber and lignans. Linseed's essential fatty acids have anti-inflammatory properties, offering health benefits to a number of chronic diseases such as heart disease, diabetes and arthritis (Sarkar and Sarkar, 2017) [16].
In linseed, nitrogen use efficiency (NUE) can range widely but is often reported under conventional practices as NUE by crops was very low in conventional fertilizers (50-70%). Foliar application of nitrogen sources along with soil application helps to minimize the losses

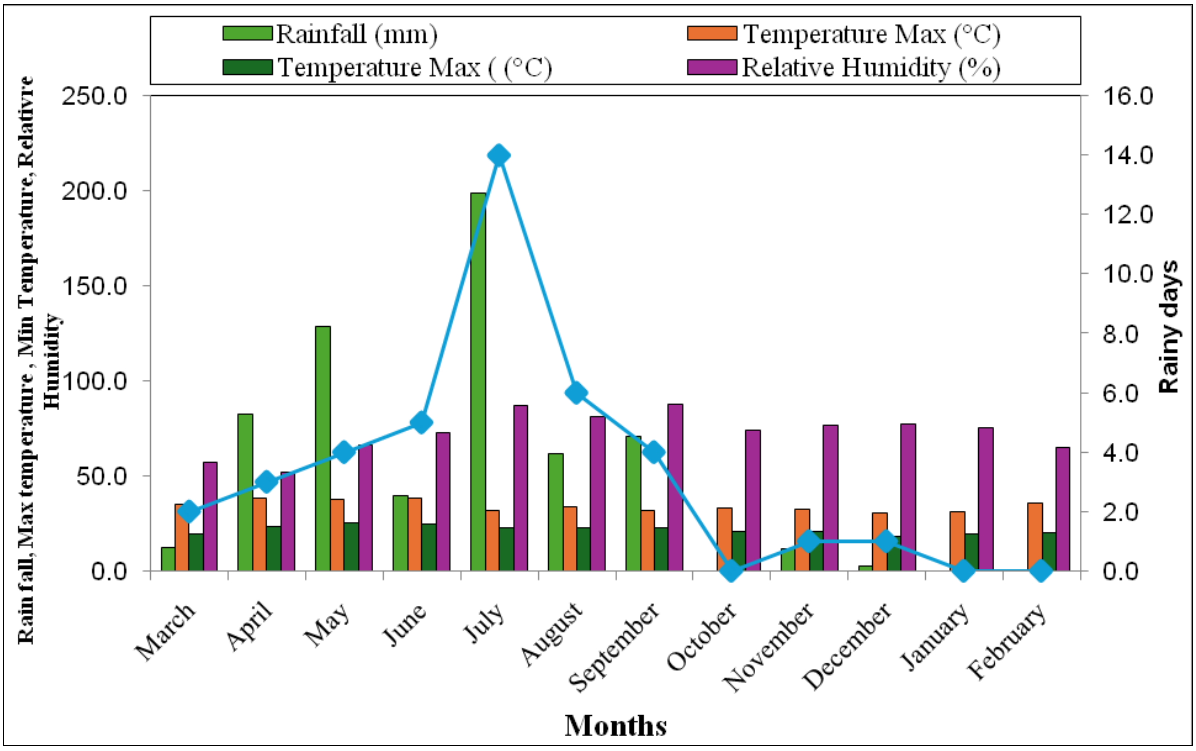
through leaching, volatilization and denitrification, ensuring more nitrogen is available to the crop and helps to increase NUE. Numerous attempts to increase the NUE have so far met with little success and the time may have come to apply nanotechnology to solve some of these problems. Nanotechnology is gradually moving from the experimental stage to the operational and practical stage. It will lead to a more tangible presence of the technology in the agricultural sector.

As a result, nano fertilizers are considered as efficient alternate fertilizers compared to conventional fertilizers to improve the dissolution rate and to enhance the nutrient use efficiency due to their smaller size. So that the particle can easily penetrate into the root and leaf cuticular cells through soil and foliar applications, respectively. Eventhough nano fertilizers are much interested by the farmers due to their much potentiality as compared to conventional fertilizers, but the people are unaware about the commercial products and their effectiveness on plants health. Hence, there is a continuous efforts are need to find out the optimum nitrogen levels and foliar application of nano urea for growing linseed to increase the productivity along with reduced rate of conventional fertilizer and increased nitrogen use efficiency.

Materials and Methods

The Main Agricultural Research Station UAS, Raichur falling under North Eastern Dry Zone of Karnataka is located at 16° 12′ N latitude and 77° 20′ E longitude and at an altitude of 389 m above mean sea level. During the experimental period, the mean monthly maximum air temperature ranged between 33.4 °C (October-2023) to 35.6 °C (February -2024) and mean monthly minimum air temperature ranged between 21.0^0 (October-2023) to 20.1 °C (February-2024). October month recorded higher relative humidity (74.3%). The actual rainfall received during the experiment period was 14.4 mm. However, the rainfall received during August (61.6 mm) and September (70.8 mm) months helped to have sufficient residual moisture content in the soil for successful establishment of the crop.

A field experiment was laid out during *rabi*, 2023-24 at Main Agricultural Research Station, UAS, Raichur. The linseed variety (NL-115) seeds were sown on 28th October, 2023 with a spacing of 30 cm × 5 cm when there was sufficient moisture in *vertisols* of the experimental site. The crop was fertilized with recommended dose of fertilizers (40:20:20 kg NPK ha^{-1}, respectively).



The experiment was laid out in split plot design with three replications. There were twenty treatment combinations, consisting RDN levels *i.e.*, 100%, 75%, 50% and 25% in main plots and five sub plots involving nano urea and conventional urea levels *i.e.*, no spray of nano urea, one spray of nano urea @ 3 ml l^{-1} at flower initiation, two sprays of nano urea @ 3 ml l^{-1} at flower initiation stage and capsule development stage, one spray of 2% urea at flower initiation stage, two sprays of 2% urea at flower initiation stage and capsule development stage each were replicated thrice in main plots. The crop grown with the residual moisture of monsoon rains without any protective irrigations.

IFFCO developed nanotechnology based liquid nano urea fertilizer to address the imbalanced and excessive use of conventional urea. This nano urea fertilizer has been developed indigenously, for the first time in the world at IFFCO Nano Biotechnology Research Centre (NBRC), Kalol, Gujarat through a proprietary patented technology. Nano urea (liquid) is a source of nitrogen which is a major essential nutrient required for proper growth and development of a plant. Nitrogen is a key constituent of amino acids, enzymes, genetic materials, photosynthetic pigments and energy transfer compounds in a plant. Typically, nitrogen content in a healthy plant is in the range of 1.5 to 4 per cent. Foliar application of nano urea (liquid) at critical crop growth stages of a plant effectively fulfils its nitrogen requirement and leads to higher crop productivity and quality in comparison to conventional urea.

Harvesting was done at physiological maturity of the crop. The net plot area as per the treatments was harvested by cutting the plants to the ground level. After harvesting of the crop was threshed by beating with wooden sticks. The separated seeds were winnowed, cleaned and grain and straw yield were expressed in kilogram per hectare. The harvest index was calculated by using the formula suggested by (Donald, 1962) [6]. The yield attributes and yield observations were recorded from the net plots and grain yield was converted to hectare basis in kilograms. The economics of each treatment was computed with prevailing market prices of the corresponding year. The yield was further computed for gross and net returns as well BC ratio to assess the profitability. The benefit-cost ratio was worked out by dividing the gross returns by the total cost of cultivation of respective treatments. The data collected from the experiment at different growth stages and at harvest were subjected to statistical analysis as described by Gomez and Gomez (1984) [7]. The level of significance used for ‘F’ and ‘t’ tests was P=0.05. Critical Difference (CD) values were calculated at 5 per cent probability level if the F test will found to be significant

Results and Discussion

Effect on yield and yield attributing parameters of linseed as influenced by nitrogen management through fertilizers and foliar application of nano urea

Number of capsules per plant differed significantly due different levels of RDN, foliar spray of nano urea and their interactions. Significantly higher number of capsules per plant (48.70) was recorded with application of 100% RDN as compared to others RDN levels. However, significantly lower number of capsules were recorded in the plots that received 25% RDN (30.59).

Among the different levels of nano urea, two sprays of nano urea @ 3 ml 1^{-1} at flower initiation and capsule development stage recorded significantly higher number of capsules per plant (45.30) and it was on par with application of two sprays of 2% urea at flower initiation and capsule development stage (43.15). However, significantly lower number of capsules per plant (35.49) recorded in control (no spray of nano urea).

This was due to the application of conventional urea and nano urea which might have maintained the high soil fertility status and moisture content. The superiority of these practices which helped to produce more photosynthates and numerous metabolites needed for such yield attributes. Significant improvement in growth characters also might have resulted in maximum number capsules per plant under these treatments. Jain and Jain (2016) [9]. Also reported similar results in linseed.

Number of seeds per capsule differed significantly due to different levels of RDN and foliar spray of nano urea. Significantly higher number of seeds per capsule (8.75) was recorded with application of 100% RDN as compared to others. However, significantly lower seeds per capsule were recorded in 25% RDN (7.55).

Among the different levels of nano urea, two sprays of nano urea @ 3 ml 1^{-1} at flower initiation and capsule development stage recorded significantly higher number of seed per capsule (8.53) and it was found on par with two sprays of 2% urea at flower initiation and capsule development stage (8.39). Nevertheless, significantly and lower number of seed per capsule (7.78) recorded in control (no spray of nano urea).

Significant difference in the thousand seed weight of linseed was observed due to different levels of RDN. Significantly higher thousand seed weight was observed in the treatment receiving 100% RDN (8.14 g) as compared to others treatments. However, significantly lower thousand seed weight (7.06 g) was observed in the treatment receiving 25% RDN.

Among the subplot treatment, significant differences was observed due foliar application of nano urea and conventional urea. Significantly higher thousand seed weight (7.94 g) was recorded with two sprays of nano urea @ 3 ml 1^{-1} at flower initiation and capsule development stage and it was found on par with two sprays of 2% urea at flower initiation and capsule development stage (7.81g) and lower thousand seed weight (7.43 g) was recorded in control (no spray of nano urea).

Seed yield (kg ha^{-1}) of linseed is a pivotal factor in linseed production, influencing productivity and efficiency, economic viability, fiber quality and international competitiveness. Optimizing seed yield through effective nutrient management practices and technological innovations is crucial for maximizing the benefits and ensuring the long-term success of linseed production.

Seed yield of linseed differed significantly due to different levels of RDN. Significantly higher seed yield was recorded with application of 100% RDN (914 kg ha^{-1}) as compared to others RDN levels. However, significantly lower seed yield was recorded with 25% RDN (613 kg ha^{-1}).

Among the foliar sprays of nano urea and conventional urea at different stages seed yield also varied significantly. Two sprays of nano urea @ 3 ml 1^{-1} at flower initiation and capsule development stage produced significantly higher seed yield (838 kg ha^{-1}) and it was found on par with application of two sprays of 2% urea at flower initiation and capsule development stage (810 kg ha^{-1}) and lower seed yield was observed in control where no spray of nano urea was carried out (708 kg ha^{-1}).

Many factors both externally and internal influence the crop growth and productivity. Nutrient management is one such important factor which largely decides the size of the crop produced. The economic yield of a plant is an outcome of a series of integrated interactions of various biological events involving biochemical, physiological and morphological changes which takes place during its development in accordance with the supply of light, water and nutrients (Donald, 1962) [6].

Higher seed yield was recorded with application of 100% RDN might be attributed to increase in number of branches. Branches are the most important character of the crop which bears capsules and ultimately increase the crop yield this was concluded by Nawange *et al.* (2011) [12]. Increase in leaf area due to optimum nutrients resulted in higher photosynthetic activity and higher supply of photosynthates to developing pods for proper seed filling and thus contributing to higher yield. Goud *et al.* (2014) [8] and Kumar *et al.* (2015) [11] also reported similar results.

Foliar spray of nano urea @ 3 ml 1^{-1} at flower initiation and capsule development stage resulted in significantly higher yield, which might be attributed to optimum and balanced nitrogen availability throughout the crop season, particularly during crucial periods of crop development. Similar results were also obtained by Valadkhan *et al.* (2015) [18] and Beeresha (2018) [1].

The straw yield of linseed was significantly influenced by different levels of RDN, foliar spray of nano urea and their interactions. Application of 100% RDN recorded significantly higher straw yield (1731 kg ha^{-1}) as compared to others RDN levels. However, significantly lower straw yield (1443 kg ha^{-1}) was recorded in the plots receiving 25% RDN.

Among the foliar application of nano urea and conventional urea, significantly higher straw yield (1669 kg ha^{-1}) was recorded with two sprays of nano urea @ 3 ml 1^{-1} at flower initiation and capsule development stage and it was found on par with two sprays of 2% urea at flower initiation and capsule development stage (1635 kg ha^{-1}). However, significantly lower straw yield was recorded in control (no spray of nano urea) (1542 kg ha^{-1}).

The data on the harvest index of linseed as influenced by different levels of RDN, foliar spray of nano urea and their interactions are presented in Table 1.

There was non-significant effect of different levels of RDN on harvest index was observed. However numerically higher harvest index (0.35) was observed with application of 100% RDN and lower harvest index was observed in the plots that received 25% RDN (0.29).

Nano urea does not had any significant effect on harvest index. Numerically higher harvest index (0.33) was documented in two sprays of nano urea @ 3 ml 1^{-1} at flower initiation and capsule development stage and lower harvest index (0.32) was documented in control (no spray of nano urea).

Table 1: Growth and yield parameters of transplanted rice as influenced by the application different levels of conventional and nano fertilizers

Treatment	Capsules plant^{-1}	Seeds capsule^{-1}	1000 seed weight (g)	Seed yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Harvest index
Main plot (F)	**Nitrogen management through fertilizers (F)**					
F_1	48.70	8.75	8.14	914	1731	0.35
F_2	45.06	8.47	7.94	854	1679	0.34
F_3	36.51	8.00	7.47	716	1542	0.32
F_4	30.59	7.55	7.06	613	1443	0.29
S.Em.±	0.49	0.09	0.16	14	27	0.01
C.D. (P=0.05)	1.69	0.31	0.55	49	92	NS
Sub plot (N)	**Nitrogen management through nano urea and conventional urea (N)**					
N_1	35.49	7.78	7.43	708	1542	0.32
N_2	39.37	8.20	7.60	768	1584	0.32
N_3	45.30	8.53	7.94	838	1669	0.33
N_4	37.78	8.09	7.50	745	1563	0.32
N_5	43.15	8.39	7.81	810	1635	0.33
S.Em.±	0.76	0.07	0.13	11	13	0.02
C.D. (P=0.05)	2.20	0.21	0.37	31	37	NS
Interactions (F×N)						
$F_1 N_1$	42.77	8.41	7.85	862	1659	0.34
$F_1 N_2$	46.51	8.64	8.05	887	1692	0.34
$F_1 N_3$	56.07	9.24	8.58	984	1827	0.36
$F_1 N_4$	45.30	8.55	7.91	883	1687	0.34
$F_1 N_5$	52.87	8.92	8.31	952	1791	0.35
$F_2 N_1$	39.65	8.07	7.73	754	1605	0.33
$F_2 N_2$	42.59	8.41	7.80	849	1651	0.34
$F_2 N_3$	52.34	8.81	8.25	939	1770	0.35
$F_2 N_4$	41.25	8.32	7.77	830	1633	0.34
$F_2 N_5$	49.49	8.75	8.15	899	1736	0.34
$F_3 N_1$	33.58	7.60	7.32	642	1526	0.31
$F_3 N_2$	36.44	8.03	7.44	716	1536	0.32
$F_3 N_3$	39.47	8.24	7.65	781	1571	0.33
$F_3 N_4$	35.47	8.00	7.36	682	1532	0.32
$F_3 N_5$	37.59	8.15	7.59	757	1545	0.32
$F_4 N_1$	25.96	7.02	6.82	576	1379	0.28
$F_4 N_2$	31.92	7.71	7.11	620	1456	0.29
$F_4 N_3$	33.33	7.81	7.26	650	1508	0.30
$F_4 N_4$	29.10	7.48	6.94	587	1401	0.29
$F_4 N_5$	32.63	7.74	7.18	631	1469	0.29
S.Em.±	1.52	0.14	0.25	21	25	0.03
C.D. (P=0.05)	NS	NS	NS	NS	NS	NS

Note: NS-Non-significant, DAS-Days after sowing, F_1:100%N (Two Splits-50% as basal dose+50% as top dressing), F_2:75%N (Two Splits-50% as basal dose+50% as top dressing), F_3:50%N (Two Splits-50% as basal dose+50% as top dressing) & F_4:25%N (Two Splits-50% as basal dose+50% as top dressing), N_1:No spray of nanourea, N_2:One spray of nanourea @ 3 ml l^{-1} at flower initiation stage, N_3:Two sprays of nano urea @ 3ml l^{-1}at flower initiation stage and capsule development stage, N_4:One spray of 2% urea at flower initiation stage & N_5:Two sprays of 2% urea at flower initiation and capsule development stage

Economics of linseed as influenced by nitrogen management through fertilizers and foliar application of nano urea

The economic returns measure the profitability of a system. Farmers adopt only such practices that are more profitable. The price of inputs and farm produce change from time to time and place to place. Thus profitable nutrient management system in crop production also varies accordingly.

The data with respect to economics of linseed production as influenced by different RDN levels, nano urea, conventional urea and their interactions are presented in Fig. 2.

Significantly higher gross returns (₹ 45,684 ha^{-1}) were recorded with treatment which received 100% RDN over other RDN levels and significantly lower gross returns (₹ 30,644 ha^{-1}) were recorded with application of 25% RDN.

Among the foliar sprays of nano urea and conventional urea, two sprays of nano urea @ 3 ml 1^{-1} at flower initiation and capsule development stage recorded significantly higher gross returns (₹ 41,925 ha^{-1}) and it was found on par with two sprays of 2% urea at flower initiation and capsule development stage (₹ 40,492 ha^{-1}) and lower gross returns was observed in control (₹ 35,421 ha^{-1}).

Significantly higher net returns (₹ 29,863 ha^{-1}) were documented with treatment which received 100% RDN over other RDN levels and significantly lower net returns (₹ 16,393 ha^{-1}) were recorded in 25% RDN.

Among the different nano urea levels, two sprays of nano urea @ 3 ml 1^{-1} at flower initiation and capsule development stage recorded significantly higher net returns (₹ 25,894 ha^{-1}) and it was found on par with application of two sprays of 2% urea at flower initiation and capsule development stage **(**₹ 25,647 ha^{-1}). However, significantly lower net returns (₹ 20,990 ha^{-1}) was recorded in control.

The net returns were higher in the treatments receiving 100% RDN because the nutrient requirement of plant was met, as a result of this the plant produced higher yields and fetched higher returns. Similar results were confirmed by Goud *et al*. (2014) [8] Sujathamma *et al*. (2014) [17] and Bhutada *et al*. (2019) [2].

The foliar spray of nano urea provided greater amount of nutrients, particularly nitrogen to the plants. The combination of nutrient availability, efficient nutrient uptake, and improved physiological responses often leads to increased crop yield. Higher yield contributes to higher net returns. Similar results were also observed by Rajesh (2021) [13] and Chavan *et al*. (2023) [4] Foliar application of conventional nano urea fertilizer supplied the required amount of nutrients adequately and resulted in producing higher yields fetching higher returns. Similar results were also obtained by Rawat (2017) [14] Sankar *et al*. (2020) [15] and Rajesh (2021) [13].

Significantly higher benefit cost ratio (2.89) was recorded with application of 100% RDN level as compared to other RDN levels and significantly lower benefit cost ratio was recorded in the treatment which received 25% RDN level (2.15).

Among the foliar sprays of nano urea and conventional urea, two sprays of nano urea @ 3 ml 1^{-1} at flower initiation and capsule development stage recorded significantly higher benefit cost ratio (2.60) and it was found on par with application of two sprays of 2% urea at flower initiation and capsule development stage (2.71) and lower benefit cost ratio was observed in control (2.45).

The increase in B:C with the increase in RDN levels and foliar spray of nano urea can be attributed to the higher yield and gross returns. Due to increase in RDN levels and nano urea sprays, yield is increased, which resulted in better gross and net returns. Similar results were obtained by Charishma *et al*. (2022) [3] and Choudhary *et al*. (2022) [5] and Chavan *et al*. (2023) [4].

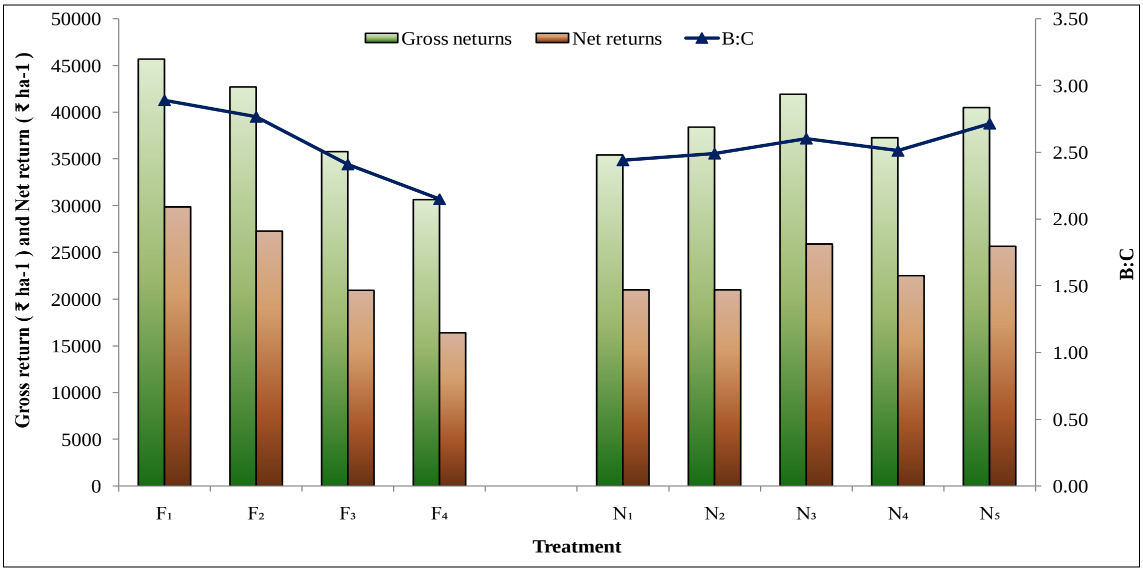


Fig 2: Economics of linseed as influenced by nitrogen management through fertilizers and foliar application of nano urea

Conclusion

Application of 100% RDN (50% basal + 50% top dressing) along with foliar application of nano urea @ 3 ml 1^{-1} at flower initiation and capsule development stage or foliar application of urea @ 2% at flower initiation and capsule development stage was found beneficial in getting the higher seed yield, net returns and benefit cost ratio.

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