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# Linseed response to nutrient management: A review

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**Abstract**
*Linum usitatissimum* L., commonly known as linseed or flax, is an economically important oilseed crop valued for its dual-purpose utility: the oil, renowned for its high omega-3 fatty acid content and the fiber, widely utilized in diverse industrial applications. Despite India's considerable area under linseed cultivation, productivity remains below global averages, largely due to suboptimal nutrient management practices. Studies highlight the critical role of nutrient management in improving growth parameters, yield attributes and quality traits of linseed. Integration of 75% RDF and 2.5 tonnes vermicompost ha$^{-1}$ resulted in the highest plant height, leaf area index, and primary branches, while 100% RDF combined with 30 kg S ha$^{-1}$ or bio-inoculants (Azotobacter and PSB) enhanced growth, seed yield and stover yield. Foliar applications of nano-N (0.4%) and urea (2%) further boosted growth rates and nutrient use efficiency. Nutrient management practices like 75% NPK + 5 t FYM + biofertilizers demonstrated superior productivity, highlighting the synergy between organic and inorganic inputs. Oil yield and quality traits were maximized with 100% RDN supplemented by FYM, sulfur, and zinc, enhancing protein and oil content. Incremental nitrogen levels improved fiber and oil yields but reduced total unsaturated fatty acids beyond 45 kg N ha$^{-1}$. Correlation analysis indicated a significant positive relationship between seed yield and growth parameters such as plant height, branches, capsules, and test weight. This review underscores the necessity of adopting balanced nutrient management strategies, including integrated nutrient management (INM), to bridge the yield gap, enhance productivity, and maintain soil health. Optimized practices, such as the application of RDF with biofertilizers and organic inputs, hold potential for sustainable linseed production in India.

**Keywords:** Linseed productivity, nutrient management, integrated nutrient management (INM), oilseed crop, soil health, biofertilizers

## Introduction

Linseed (*Linum usitatissimum* L.), also known as flaxseed, is an ancient oilseed crop that holds significant economic importance due to its multifaceted uses. Globally, linseed is cultivated in temperate regions for its oil, which is rich in omega-3 fatty acids and its fiber, which has applications in textiles and industry. Linseed is cultivated on an area of 32.23 lakh hectares globally, producing 30.68 lakh tonnes, with an average productivity of 952 kg ha$^{-1}$. Linseed occupies an area of 1.96 lakh ha, yielding 1.26 lakh tonnes with an average productivity of 642 kg ha$^{-1}$ in India (FAO STAT., 2022). India ranks fifth in area under linseed cultivation, following Kazakhstan, the Russian Federation, Canada, and China, but holds the sixth position in production, behind Kazakhstan, Canada, the Russian Federation, China, and the USA (FAO STAT., 2019). Although there has been a modest improvement in average productivity in recent years, it remains significantly below the experimental yields (1400-1800 kg ha$^{-1}$) or the potential yields (2000-2200 kg ha$^{-1}$) achievable with improved linseed varieties and agro techniques. In major linseed-producing countries such as Canada (1432 kg ha$^{-1}$), China (1308 kg ha$^{-1}$) and USA (1258 kg ha$^{-1}$) higher productivity highlights the need to scale up both production and productivity in India. A 2-3 fold increase in current linseed production is possible through the adoption of improved varieties and the implementation of recommended agronomic and protection practices.

In India, the primary linseed-producing states *viz.* Madhya Pradesh, Chhattisgarh, Uttar Pradesh, Maharashtra, Bihar, Odisha, Jharkhand, West Bengal, Nagaland, and Assam account for around

97% of the country's total cultivation area. Madhya Pradesh leads both in area and production, followed by Jharkhand and Uttar Pradesh. Despite having considerable area under cultivation, the productivity of linseed in India lags behind the global average, impacting its potential contribution to the economy. Linseed is crucial for its oil content used in industrial applications, nutritional supplements, and biodiesel production, further enhancing its economic relevance.

However, the productivity of linseed in India remains low, raising concerns about the factors limiting its yield. Several reasons contribute to this low productivity, including suboptimal agronomic practices, poor-quality seeds, and most critically, improper nutrient management. Nutrient deficiencies, especially of macronutrients like nitrogen (N), phosphorus (P), and potassium (K), along with micronutrients, have been identified as key constraints. Linseed is often grown on marginal soils with inadequate fertilization, leading to suboptimal plant growth and development. In this context, addressing nutrient management becomes crucial. Proper and balanced nutrient application can enhance the yield potential by ensuring better crop establishment, improved growth, and higher oil content. Hence, nutrient management practices tailored for linseed cultivation could play a pivotal role in addressing the current yield gap in India.

Effective nutrient management not only improves the productivity of linseed but also contributes to maintaining soil health. Excessive or imbalanced use of fertilizers can lead to soil degradation, while appropriate nutrient management practices, such as integrated nutrient management (INM), can enhance soil fertility and sustainability. By adopting proper nutrient management strategies, farmers can optimize the nutrient supply to crops, ensuring better yields without compromising long-term soil health. This review aims to examine the current understanding of linseed's response to nutrient management and provide insights into how improved practices can boost productivity while preserving the integrity of agricultural soils.

**Effect of nutrient management on crop growth parameters**

Nutrient management is a cornerstone of sustainable crop production, directly impacting plant growth parameters such as height, leaf area index, branching, and dry matter accumulation. Various studies have demonstrated the profound influence of nutrient management approaches on enhancing these traits in linseed. Among the integrated nutrient management, Kumar *et al.* 2019) [11] found the highest values of plant height along with technical height (cm), leaf area index (LAI) and primary branches plant$^{-1}$ at flowering stage with the integration of 75% RDF (recommended dose of fertilizer) and 2.5 tonnes VC (vermicompost) ha$^{-1}$. Similarly, Mahammad *et al.* (2013) [14] reported that various growth characters (*viz.*, height of plant, number of branches plant$^{-1}$ and dry matter accumulation plant$^{-1}$) were found highest in treatment receiving 100% RDF + Azotobactor + PSB, but remained at par with treatments 100% RDF + Azotobactor, 100% RDF and 75% RDF + Azotobactor + PSB. Patel *et al.* (2017) [20] also revealed that application of RDF + FYM placement in rows @ 5 t ha$^{-1}$ recorded significantly higher growth parameters *viz.* plant height, primary branches plant$^{-1}$, secondary branches plant$^{-1}$, dry matter accumulation (g plant$^{-1}$). With regard to inorganic nutrient management, Saryam *et al.* (2024) [24] reported maximum plant height and number of branches plant$^{-1}$ at maximum crop growth stage with the application of 60:30:40 kg ha$^{-1}$ NPK (100% RDF). Similarly, Singh *et al.* (2023) [28] found that pre-harvest observations *viz.*, plant height (cm), number of branches plant$^{-1}$ were significantly higher under treatment 100% RDF + 30 kg sulphur ha$^{-1}$ in linseed crop cultivated in Chhattisgarh plain. In case of soil + foliar applications, Khule *et al.* (2023) [9] reported the highest plant height, fresh and dry weight (g plant$^{-1}$) and total chlorophyll content under the application of 50% RDN (recommended dose of nitrogen) and 100% P and K through soil + two foliar sprays of 0.4% nano-N at 20 and 40 DAS (day after sowing) and found statistically similar with the application of 25% RDN and 100% P and K + three spray of 0.4% nano-N at 20, 40 and 60 day after sowing. Findings of Abo-Marzoka *et al.* 2018 [1] indicated that increasing fertilizer from 25 up to 45 kg N ha$^{-1}$gradually, increased values of plant height, fruiting zone length, technical length, as well as, leaf area plant$^{-1}$ and dry matter accumulation (g m$^{-2}$) at 80 & 95 DAS and crop growth rate (CGR) and net assimilation rate (NAR) at 80-95 DAS period were obtained maximum when plants received 35 kg N ha$^{-1}$ and foliar spray with urea 2% + 200 ppm micronutrients mixture of (Fe + Zn + Mn). The findings highlight the crucial role of nutrient management in enhancing the growth parameters of linseed. The integration of chemical fertilizers, organic amendments, biofertilizers, and foliar nutrient applications optimizes plant growth and physiological processes by ensuring efficient nutrient uptake, maximizes physiological processes, and supports robust crop development. Such tailored nutrient management strategies ensure better crop productivity and sustainability, emphasize their importance in linseed cultivation.

**Effect of nutrient management on yield attributes and yield**

Adopting a balanced and integrated nutrient management strategy tailored to crop and soil requirements can sustainably maximize linseed yield and its contributing traits, ensuring both agricultural productivity and environmental stewardship. Several studies have highlighted the impact of various nutrient management strategies on linseed yield and its attributing characters. Among the integrated nutrient management practices, Sarmah *et al.* (2024) [23] reported the highest seed yield and stover yield (during 2019 & 2020) of succeeding relay sown linseed were recorded with the N @ 30 kg ha$^{-1}$ through vermicompost along with pre-season green manuring with *Sesbania bispinosa* and root dip treatment of rice seedlings with azospirillium and phosphorus solubilising bacteria (PSB) @ 3.5 kg ha$^{-1}$ each. Similarly, Husain *et al.* (2017) [29] found that in maize-linseed cropping system, grain yield of maize and seed yield of linseed were recorded the highest when the system was fed @ 75% NPK + 5 t FYM + Azotobacter + PSB to maize and 75% NPK +Azotobacter + PSB to linseed. Mahammad *et al.* (2013) [14] also reported that yield contributing characters (*viz.*, number of capsules plant$^{-1}$ and grain weight plant$^{-1}$), seed yield (q ha$^{-1}$) were the highest in treatments receiving 100% RDF + Azotobactor + PSB. Patel *et al.* (2017) [20] observed that the application of recommended dose of fertilizer (RDF) (60:30:30 kg ha$^{-1}$ NPK) + FYM placement in rows @ 5 t ha$^{-1}$ gave significantly highest no. of capsules plant$^{-1}$, seeds capsule$^{-1}$, seeds plant$^{-1}$, test weight and seed yield (kg ha$^{-1}$) of linseed. While Singh *et al.* (2023) [28] found that seed yield (kg ha$^{-1}$) and total biomass (kg ha$^{-1}$) under 100% organic nutrient management of linseed were significantly higher over integrated (75% organic + 25% inorganic, 50% organic + 50% inorganic) and inorganic treatment (100% inorganic, state recommendation). Among the inorganic source of nutrient management, Saryam *et al.* (2024) [24] observed the highest number of capsules plant$^{-1}$, test weight, seed yield and stover yield at maximum crop growth stage in plots treated with the application of 60:30:40 kg ha$^{-1}$ NPK (100% RDF). Similarly, Kikon *et al.* (2024) [10] reported that among the different soil application treatments, significantly highest NUE (Agronomic Efficiency), seed yield and stover yield were recorded with soil application of 100% N and Kumar *et al.* (2011) [12] found significantly higher seed yield (kg ha$^{-1}$) with the application of 60 kg N ha$^{-1}$ over control and 30 kg N ha$^{-1}$. Singh *et al.* (2023) [28] reveals that post harvest observations *viz.*, number of capsule plant$^{-1}$, seed yield, stover yield, harvest index (%) were observed significantly higher under treatment 100% RDF + 30 kg sulphur ha$^{-1}$ in linseed crop cultivated in Chhattisgarh plain. Tiwari *et al.* (2017) [29] also found the highest grain yield and stover yield with the application of 100% RDN + 30 kg S ha$^{-1}$ + 5 kg Zn ha$^{-1}$, which was 98.8 and 85.0 percent higher than control. Durgeshwari *et al.* (2023) [3] also found a significant increase in capsule number, test weight, seed yield and stover yield with the 200% N treatment relative to the 100% N treatment. The 150% N treatment produced non-significantly different seed and stover yields compared to the 200% N treatment, but it was significantly lower in terms of capsule number and test weight (Table 1). Similarly, Gaikwad (2020) [6] reported that application of 150% recommended dose of fertilizer produced significantly higher seed yield, straw yield and biological yield over 50% recommended dose of fertilizer and found at par with application of 100% recommended dose of fertilizer. In case of foliar applications, Khule *et al.* (2023) [9] found that the application of 50% N (recommended dose of nitrogen) and 100% P and K through soil + two foliar sprays of 0.4% nano-N at 20 and 40 DAS recorded the highest grain yield (kg ha$^{-1}$) and straw yield (kg ha$^{-1}$) among the treatments. Similarly, Reddy *et al.* (2023) found that soil application of 100% N and supplemental nitrogen management with foliar application of two sprays of Nano-urea @ 3 ml lit$^{-1}$ at flowering stage and capsule developmental stage was recorded significantly highest linseed yield attributes, seed and stover yield compare to the rest of the treatments. Mamdi *et al.* (2023) [16] also reported that application of 2% urea recorded significantly higher seed yield, straw yield and biological yield of linseed. Patel *et al.* (2017) [20] studied correlation between seed yield and several morphological and physiological traits in linseed and revealed a strong positive association: Specifically, plant height, number of primary and secondary branches, dry matter accumulation, number of capsules and seeds capsule$^{-1}$, 1000-seed weight exhibited significant positive correlations with seed yield at the 1% level of significance (Table 2).

**Table 1:** Yield attributes, yield and quality parameter of linseed as influenced by nitrogen management practices

| Treatment | No. of Capsules Plant$^{-1}$ | Seeds Capsule$^{-1}$ | 1000-Seed Weight (g) | Seed yield (q ha$^{-1}$) | Stover yield (q ha$^{-1}$) | Harvest index (%) | Fibre length (in cm) | Fibre yield (kg ha$^{-1}$) | Oil Content (%) | Oil Yield (kg ha$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| N1: 100% N | 50.07 | 8.23 | 7.24 | 17.12 | 24.43 | 41.34 | 58.36 | 321 | 37.44 | 641 |
| N2: 150% N | 54.32 | 8.27 | 7.43 | 18.57 | 26.34 | 41.4 | 61.09 | 352 | 36.83 | 687 |
| N3: 200% N | 57.93 | 8.31 | 7.57 | 18.83 | 26.95 | 41.22 | 61.95 | 356 | 35.22 | 666 |
| S.Em± | 0.45 | 0.07 | 0.05 | 0.12 | 0.24 | 0.22 | 0.31 | 1.85 | 0.5 | 11.82 |
| CD (P=0.05) | 1.31 | NS | 0.15 | 0.36 | 0.79 | NS | 0.92 | 5.4 | 1.47 | 34.53 |

(***Source***: Durgeshwari *et al*, 2023) [3]

**Table 2:** Correlation coefficients of seed yield of linseed crop with respect to growth parameters and yield attributes

| Parameter | SY | PH | NPB | NSB | DMAP | NCPP | NSPC | NSPP | TSW |
|---|---|---|---|---|---|---|---|---|---|
| Seed Yield (SY) | 1.000** | 0.998** | 0.942** | 0.982** | 0.971** | 0.933** | 0.950** | 0.930** | 0.927** |
| Plant Height (PH) | | 1.000** | 0.932** | 0.977** | 0.958** | 0.923** | 0.933** | 0.921** | 0.909** |
| No. of Primary Branches per Plant (NPB) | | | 1.000** | 0.970** | 0.936** | 0.903** | 0.962** | 0.898** | 0.902** |
| No. of Secondary Branches per Plant (NSB) | | | | 1.000** | 0.963** | 0.962** | 0.970** | 0.958** | 0.944** |
| Dry Matter Accumulation per Plant (DMAP) | | | | | 1.000** | 0.953** | 0.970** | 0.952** | 0.974** |
| No. of Capsules per Plant (NCPP) | | | | | | 1.000** | 0.952** | 0.999** | 0.985** |
| No. of Seeds per Capsule (NSPC) | | | | | | | 1.000** | 0.946** | 0.971** |
| No. of Seeds per Plant (NSPP) | | | | | | | | 1.000** | 0.983** |
| Thousand Seed Weight (TSW) | | | | | | | | | 1.000** |

** indicates significant at 1% probability level (Source: Patel *et al.*, 2017) [20]

**Effect of nutrient management on quality parameters**

Nutrient management plays a pivotal role in improving the oil, fiber yield and quality of linseed by optimizing nutrient availability and uptake. Proper fertilization strategies enhance oil content, oil yield, fiber percentage, and fiber yield while maintaining essential quality parameters like iodine value and fatty acid composition. In these contexts, Mahammad *et al.* (2013) [14] reported that oil yield was significantly influenced by the application of 100% RDF + Azotobactor + PSB and recorded significantly maximum oil yield and was at par with treatment 100% RDF + Azotobacter. Tiwari *et al.* (2017) [29] found that oil content, oil yield and protein content were recorded maximum with 100% RDN + 25% N through FYM + 30 kg S ha$^{-1}$ and 5 kg Zn ha$^{-1}$. While, Abo-Marzoka *et al.* (2018) [1] revealed that straw, seed yields and its components, fiber (%), fiber yield, total chlorophyll of leaves at 95 day after sowing, oil (%), oil yield, total saturated fatty acids of flax oil were gradually increased with increasing nitrogen fertilizer rate from 25 to 45 kg N ha$^{-1}$, whereas, the total unsaturated fatty acids were decreased. Similarly, Singh *et al.* (2013) [27] reported that the highest oil content was found with lowest dose of NPK level while, progressive increase in oil yield was obtained with successive increment of NPK up to the highest level, but increment beyond 90:45:45 kg N:P:K ha$^{-1}$ was not significant. However, incremental levels of NPK significantly delayed maturity of the crop. Meena *et al.* (2011) [18] also found that the oil content of linseed increased significantly due to the application of N, P, K and S over control and it was maximum with fertility level of 60:30:30:30 kg N, P, K and S ha$^{-1}$. Rahimi *et al.* (2011) [21] revealed that seed protein percent and linolenic acid percent in linseed increased significantly up to 120 kg N ha$^{-1}$. Increasing in N level decreased oil seed content, however oil seed yield increased with applying fertilizer, due to increase in seed yield. Haldar (2011) [7] observed that the treatment receiving N:P ratio of 1.50 (60 kg N, 40 kg $P_2O_5$ and 30 kg $K_2O$ ha$^{-1}$) produced oil yield (kg ha$^{-1}$) as compared to the recommended N:P ratio of 0.75 with 60 kg N, 80 kg $P_2O_5$ and 30 kg $K_2O$ $ha^{-1}$ fertilizer level and control. Further increase in N: P ratio there was no significant increase in the oil yield. Singh *et al.* (2013) [27] also reported that the maximum oil content and minimum iodine value of linseed under 60-30-30 kg and 120-60-60 kg NPK $ha^{-1}$, respectively. Durgeshwari *et al.* (2023) [3] reported a significant increase in fiber length and fiber yield was observed with the 200% N treatment relative to the 100% N treatment. The 100% N treatment resulted in the highest oil content, while the 150% N treatment yielded the highest oil yield (Table 1). Adopting scientifically proven nutrient management practices and balanced application of nitrogen, phosphorus, potassium, sulfur, and micronutrients ensures better chlorophyll content, protein levels, and crop maturity, contributing to superior oil and fiber quality.

## Effect of nutrient management on soil properties

Soils under organic and integrated nutrient management practices demonstrated elevated levels of soil organic carbon (SOC) compared to those employing inorganic fertilizers. The increased carbon input from organic manure was identified as the primary driver of this enhancement (Singh *et al.* 2022) [6]. Panwar *et al.* (2010) [19] and Lakaria *et al.* (2012) [13] similarly underscored the substantial influence of regular organic additions, including manures and root biomass, on soil organic carbon. Adekiya *et al.* (2020) [2] further corroborated these findings, reporting elevated SOC content in organic and/or integrated management systems in comparison to chemical management practices. Organic management practices thus emerge as a pivotal strategy for soil restoration, optimizing the retention and recycling of organic matter and plant nutrients.

Singh *et al.* (2022) [6] also reported that soil-available N did not found significantly across the treatments, whereas available P and K were found significantly higher in organic nutrient-management practice than either inorganic or integrated management practice. Meena *et al.*, (2020) [17] revealed that the elevated levels of available phosphorus (P) in organic treatments are likely attributable to the release of organic acids during microbial decomposition of organic matter, which enhances the solubility of native phosphate. Adekiya *et al.* (2020) [2] also found that organic systems improve soil fertility, characterized by increased organic matter content and available N, P, K, Ca, and Mg levels. Shirale *et al.* (2018) [25] observed that organic management practices also resulted in higher available potassium (K) levels (kg $ha^{-1}$) compared to the inorganic management practices. The positive influence of organic matter on available K is primarily attributed to the release of K to organic colloids, which possess greater cation-exchange sites capable of attracting K from the non-exchangeable pool and applied K, ultimately favoring the availability of K. Similarly, Majumdar *et al.* (2005) [15] observed that K concentrations in soils amended with organic wastes exceeded those supplied with chemical fertilizers. Panwar *et al.* (2010) [19] also reported maximum soil-available N, P and K in cattle dung manure applied treatments on nitrogen-equivalent basis. Sarmah *et al.* (2024) [23] observed highest available N (kg $ha^{-1}$), $P_2O_5$ (kg $ha^{-1}$) and $K_2O$ (kg $ha^{-1}$), organic C, soil organic carbon (SOC) stock (t $ha^{-1}$), soil microbial biomass carbon (SMBC) (μg $g^{-1}$ of soil) in soil with the N @ 30 kg $ha^{-1}$ through vermicompost along with pre-season green manuring with *Sesbania bispinosa* and root dip treatment of rice seedlings with Azospirillium and phosphorus solubilising bacteria (PSB) @ 3.5 kg $ha^{-1}$ each after harvest of linseed (Table 3). Organic and integrated nutrient management practices significantly enhance soil health by increasing soil organic carbon, microbial biomass and the availability of essential nutrients like N, P and K. These practices not only restore soil fertility but also promote sustainable nutrient cycling, making them pivotal for long-term agricultural productivity and environmental conservation.

**Table 3:** Soil properties at harvest of linseed as influenced by organic nutrient sources in aromatic rice cultivars in rice-linseed (relay) sequence

| Treatment | Available N (kg $ha^{-1}$) | | Available $P_2O_5$ (kg $ha^{-1}$) | | Available $K_2O$ (kg $ha^{-1}$) | | Organic C (%) | | SMBC (μg $g^{-1}$ of soil) | | SOC stock (t $ha^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Organic nutrient sources (N) | 2019 | 2020 | 2019 | 2020 | 2019 | 2020 | 2019 | 2020 | 2019 | 2020 | 2019 | 2020 |
| N0 | 228.89 | 206.43 | 13.53 | 11.52 | 119.76 | 115.97 | 0.61 | 0.60 | 137.96 | 140.13 | 12.50 | 12.56 |
| N1 | 242.69 | 245.67 | 16.56 | 18.69 | 132.10 | 135.43 | 0.64 | 0.64 | 167.48 | 174.56 | 12.75 | 13.14 |
| N2 | 245.04 | 249.48 | 18.46 | 20.08 | 134.78 | 138.34 | 0.64 | 0.65 | 176.27 | 180.64 | 12.95 | 13.22 |
| N3 | 245.48 | 250.10 | 18.58 | 20.40 | 136.09 | 140.06 | 0.64 | 0.65 | 179.19 | 183.43 | 12.98 | 13.29 |
| N4 | 243.30 | 247.37 | 17.02 | 18.49 | 131.47 | 135.53 | 0.63 | 0.64 | 169.57 | 175.14 | 12.89 | 12.99 |
| Sem± | 0.97 | 2.36 | 0.43 | 0.98 | 1.65 | 2.02 | 0.00 | 0.00 | 1.26 | 2.53 | 0.10 | 0.11 |
| CD ($P<0.05$) | 2.82 | 6.85 | 1.25 | 2.84 | 4.79 | 5.87 | 0.01 | 0.01 | 3.66 | 7.35 | NS | 0.34 |

SOC, Soil organic carbon; SMBC, Soil microbial biomass carbon. (Source: Sarmah *et al.* 2024) [23]

## Effect of nutrient management on economics

Nutrient management plays a crucial role in maximizing the gross return, net profit and benefit-cost (B:C) ratio in linseed cultivation. Several findings emphasize the importance of tailored nutrient strategies to achieve superior economic outcomes in linseed farming. Results demonstrated that organic management practices led to significantly higher economic returns, including increased gross return, net profit, and B:C ratio as compared to chemical treatment (Singh *et al,* (2022) [6]. Similarly, Ramesh *et al.* (2010) [19] found that under soybean-wheat cropping system in *Vertisols,* the combined application of cattle dung manure, vermicompost and poultry manure yielded the highest gross returns, net returns and B:C ratio as compared to either chemical fertilizers or the control. Kikon *et al.* (2024) [10] reported that soil application of 100% N and two sprays of Nano urea @ 3 ml $l^{-1}$, among foliar treatments ultimately recorded the highest net return and IBCR. Saryam *et al.* (2024) [24] also found the highest gross return, net returns and B:C ratio at maximum crop growth stage in plots treated with application of 60:30:40 kg $ha^{-1}$ NPK (100% RDF). Husain *et al.* (2017) [29] observed that, application of nutrients @ 75% NPK+ 5 t $ha^{-1}$ FYM+ Azotobacter + PSB to maize and 75% NPK + Azotobacter + PSB to linseed brought significant increase net monetary return and B:C ratio. Singh *et al.* (2023) found significantly maximum gross return, net return and B: C ratio under treatment 100% RDF + 30 kg sulphur $ha^{-1}$) in linseed crop cultivated in Chhattisgarh plain. Mahammad *et al.* (2013) [14] reported that application of 100% RDF + Azotobacter + PSB recorded maximum and significantly more gross monetary returns, net return and B:C ratio. Patel *et al.* (2017) [20] found that the treatment RDF + FYM placement in rows gave the highest gross return and net return, however the application of RDF 60:30:30 N: P: K kg $ha^{-1}$ fetched high B:C ratio. Tiwari *et al.* (2017) [29] reported the highest gross return, net return and B: C ratio with 100% RDN+25% N through FYM+30 kg S ha$^{-1}$ +5 kg Zn ha$^{-1}$. Mamdi *et al.* (2023) [16] reported that the foliar application of 2% urea proved to be most remunerative with net monetary returns and gross monetary returns with highest B: C ratio. Durgeshwari *et al.* (2024) [4] also found that nitrogen application at the 200% N resulted in the highest gross and net returns, followed by the 150% N. The 100% N produced the lowest gross and net returns. The highest benefit-cost ratio was achieved with the 150% N rate, followed by the 200% N. The 100% N had the lowest benefit-cost ratio (Table 4). Nutrient management plays a crucial role in maximizing the gross return, net profit, and benefit-cost (B: C) ratio in linseed cultivation. Integrated practices combining organic and inorganic inputs, such as FYM, vermicompost, Azotobacter, PSB, and foliar sprays of nano-urea or urea, significantly enhance economic returns by improving crop productivity and nutrient use efficiency. Effective nutrient management, combining organic inputs like FYM and vermicompost with inorganic fertilizers, Azotobacter, PSB, and micronutrients, enhances linseed productivity by improving soil fertility and nutrient availability. This integrated approach boosts seed yield and stover production, leading to higher gross returns, net profits, and benefit-cost ratios. Tailored nutrient strategies optimize resource use, reduce costs, and ensure sustainable farming practices, resulting in long-term profitability.

**Table 4:** Economics of linseed as influenced by nitrogen management practices

| Treatment | Seed-Stover | | | | Seed-fiber | | | |
|---|---|---|---|---|---|---|---|---|
| | Cost of Cultivation (Rs. ha$^{-1}$) | Gross Return (Rs. ha$^{-1}$) | Net Return (Rs. ha$^{-1}$) | B:C Ratio | Cost of Cultivation (Rs. ha$^{-1}$) | Gross Return (Rs. ha$^{-1}$) | Net Return (Rs. ha$^{-1}$) | B:C Ratio |
| N1: 100% N | 22879 | 88058 | 65179 | 2.85 | 58240 | 246361 | 196430 | 3.94 |
| N2: 150% N | 23264 | 95471 | 72207 | 3.11 | 61430 | 266675 | 214331 | 4.09 |
| N3: 200% N | 23969 | 96854 | 72885 | 3.04 | 62794 | 271990 | 218279 | 4.06 |

(***Source***: Durgeshwari *et al.*, 2024) [4]

**Cost of fibre extraction:** Rs. 1084 and 1040 quintal$^{-1}$ during 2021-22 & 2022-23, respectively.

**Price of fibre:** Rs. 500 kg$^{-1}$.

## Conclusion

Optimized nutrient management is pivotal for enhancing the growth, yield, quality, and sustainability of linseed cultivation. Integrated approaches, such as combining 75-150% RDF with organic amendments like vermicompost (2.5 t ha$^{-1}$), FYM (5 t ha$^{-1}$), and biofertilizers (Azotobacter and PSB), significantly improved plant growth parameters, yield attributes, and nutrient use efficiency. Foliar applications of nano-nitrogen (0.4%) and urea (2%) further boosted growth rates, seed yield, and stover yield. Superior oil yield, protein content, and fatty acid quality were achieved with a combination of 100% RDN, FYM, sulfur (30 kg ha$^{-1}$), and zinc (5 kg ha$^{-1}$), emphasizing the synergistic benefits of balanced macro- and micronutrient management. Integrated nutrient management practices not only enhanced productivity but also improved soil health by increasing soil organic carbon, microbial biomass, and nutrient availability. Economic analysis demonstrated that tailored nutrient strategies yielded the highest gross returns, net profits, and benefit-cost ratios, ensuring economic viability. These findings emphasize the importance of adopting balanced, site-specific nutrient management strategies to bridge the yield gap, enhance sustainability, and improve the economic and ecological viability of linseed production in India.

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