



Sustainable Cropping System and Nutrient Management to Enhance Linseed (*Linum usitatissimum* L.) Productivity and Profitability

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: <https://doi.org/10.9734/ijpss/2025/v37i75581>

Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://pr.sdiarticle5.com/review-history/139393>

Original Research Article

Received: 03/05/2025
Accepted: 06/07/2025
Published: 11/07/2025

ABSTRACT

Aims: To evaluate the effect of different cropping systems and nutrient management practices on growth, yield and economics of linseed (*Linum usitatissimum* L.) under *Vertisol* conditions of Chhattisgarh.

Study Design: Split plot design.

Place and Duration of Study: Research cum Instructional Farm, Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.) during the *kharif* & *rabi* seasons of 2023-24 & 2024-25.

Methodology: The experiment consisted four main plot treatments as cropping systems and four sub-plot treatments as nutrient management to linseed, replicated thrice using a split plot design.

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Cite as: Sahu, Himalay, Sanjay Kumar Dwivedi, and Rahul Raj. 2025. "Sustainable Cropping System and Nutrient Management to Enhance Linseed (*Linum Usitatissimum* L.) Productivity and Profitability". *International Journal of Plant & Soil Science* 37 (7):358-67. <https://doi.org/10.9734/ijpss/2025/v37i75581>.

Linseed variety RLC-92 was sown at 25 kg ha⁻¹ with 30 cm row spacing during *rabi* season of both years of study. Nutrient sources included DAP, urea, SSP, MOP, vermicompost, and nano urea as foliar spray. Growth parameters (plant height, number of primary and secondary branches plant⁻¹), Yield attributes (capsules plant⁻¹, seeds capsule⁻¹ and test weight), Yield (seed and stover yields), Economic indicators (cost of cultivation, GMR, NMR and B: C ratio) were recorded. Data were averaged over two years and analyzed using ANOVA with treatment means compared by LSD at 5% level of significance.

Results: Based on the mean data from two consecutive years (2023–24 & 2024–25), significant variations were observed in growth and yield parameters of linseed, including plant height, number of primary & secondary branches plant⁻¹ and number of capsules plant⁻¹ under different cropping systems and nutrient management practices. The linseed crop sown after soybean recorded the highest seed and stover yields, which was statistically at par with linseed grown after blackgram and greengram. Similarly, gross monetary return, net return and benefit-cost (B:C) ratio were also found to be highest in the soybean-linseed cropping sequence. Among nutrient management treatments, the Soil Test Crop Response (STCR)-based nutrient management significantly outperformed other treatments in terms of seed and stover yields and was statistically at par with the application of 75% Recommended Dose of Nutrients (RDN) through (75 % inorganic sources + 25% through organic source *i.e.* vermicompost), along with two foliar sprays of nano urea. The STCR-based treatment also led to the highest gross monetary return, net return and B:C ratio. The interaction between cropping systems and nutrient management practices exerted a significant synergistic effect on plant height, number of primary and secondary branches plant⁻¹, number of capsules plant⁻¹ and both seed & stover yields.

Conclusion: Legume-based cropping systems combined with STCR and integrated nutrient management significantly improved linseed growth, yield and economic returns, highlighting their potential for sustainable and efficient linseed production.

Keywords: *Linseed productivity; nutrient management; STCR approach; cropping system; economic analysis.*

1. INTRODUCTION

In the wake of globalization and rapid economic growth, Indian agriculture is confronted with complex second-generation challenges, such as declining soil fertility, nutrient imbalance, overexploitation of water resources, increasing pest and disease outbreaks, environmental pollution and stagnation in farm profitability (Reddy and Reddy, 2022). The wide spread adoption of cereal-based mono cropping systems, especially rice-wheat, since the green revolution has led to unsustainable production practices, contributing to declining factor productivity and deteriorating soil health (Lal, 2004). Crop diversification, especially with pulses and oilseeds, offers a sustainable pathway to restore soil health, stabilize incomes, improve nutritional security and ensure resilience to climate variability. According to Patel et al., (2022), crop diversification not only helps in efficient resource use and employment generation but also in mitigating weather-related risks and reducing dependency on chemical fertilizers and pesticides. Diversifying traditional rice-based systems with oilseeds and pulses has shown potential to enhance system productivity

and economic efficiency, while significantly improving soil nutrient availability, organic carbon content and microbial activity (Upadhaya et al., 2022).

Linseed is an ancient oilseed crop, cultivated globally for its oil, fiber and medicinal properties. It contains approximately 41% oil, rich in α -linolenic acid (ALA), an essential omega-3 fatty acid known to reduce cholesterol, inflammation and the risk of cardiovascular diseases (Morris, 2007). Linseed cultivated extensively in both temperate and tropical regions (Shakya et al., 2023). India ranks among the leading producers of linseed, with an area of 1.75 lakh ha and total production of 1.13 lakh ton in 2023–24, with an average productivity of 644 kg ha⁻¹ (DOD, 2024a). In Chhattisgarh, linseed is cultivated in 0.082 lakh ha and total production of 0.039 lakh ton, with an average productivity of just 473 kg ha⁻¹, indicating a wide yield gap that needs to be bridged (DOD, 2024b).

Low linseed productivity in India is mainly due to poor nutrient management. Nutrient management combining organic manures and chemical fertilizers improves nutrient efficiency

and soil health (Ali and Gupta, 2012). The soil test crop response (STCR) is a scientific approach to fertilizer recommendation that ensures efficient use, supporting higher crop production while protecting the environment and preserving resources (Murthy et al., 2024). Double cropping systems, particularly those integrating legumes and oilseeds, offer a sustainable strategy to mitigate moisture stress and soil degradation. These systems facilitate crop diversification, enhance soil nutrient cycling through biological nitrogen fixation and improve water-use efficiency by optimizing soil moisture retention and reducing evapotranspiration losses (Kumari et al., 2025). However, few studies have assessed the combined effects of cropping systems and nutrient management on linseed, especially in central and eastern India. Therefore, the present study was undertaken to evaluate the effect of different cropping systems in combination with nutrient management practices on the growth, yield attributes, yields and economics of linseed.

2. MATERIALS AND METHODS

The experiment was conducted during the *kharif* and *rabi* seasons of 2023–24 and 2024–25 at the Research cum Instructional Farm, IGKV, Raipur (C.G.), using a split plot design with four main plot treatments and four sub-plot treatments, replicated thrice. Details of the treatments can be found in Table 1 & 2. Linseed variety RLC 92 was sown at a rate of 25 kg ha⁻¹ with 30 cm inter-row spacing. Field preparation involved one ploughing and two harrowing. Irrigation was given just after sowing to ensure uniform germination. For nutrient management DAP, urea, Single Super Phosphate (SSP), Murate of Potash (MOP), Vermicompost (1.5:0.8:1.2 N: P₂O₅:K₂O) and for foliar spray IFFCO brand

nano urea were used. The full quantity SSP, MOP and vermicompost were applied as basal dose, while 50 % of urea was applied as basal and remaining 25 % was applied at branching and 25 % at capsule formation stage of linseed as top dressing. Nano urea (3 ml l⁻¹ of water) was applied as foliar application at branching and capsule formation stage of linseed as per the treatments. Growth parameters (plant population, plant height, number of primary and secondary branches plant⁻¹) and yield attributes (capsules plant⁻¹, seeds capsule⁻¹ and test weight) were recorded at harvest. Five plants per plot were randomly selected for measurements, and plot-level data were averaged across two years. Seed and stover yields were recorded from the net plot area, converted to kg ha⁻¹, and averaged over the two years to obtain final mean values for all parameters. Economic parameters were assessed by calculating the net return ha⁻¹, which was derived by subtracting the total cost of cultivation from the gross returns. The benefit-cost (B: C) ratio, an indicator of economic viability, was determined by dividing the gross return by the total cultivation cost. This provided a comprehensive evaluation of the economic efficiency of the treatments.

2.1 Statistical Analysis

The data obtained from various characters under study were analyzed by the method of analysis of variance as described by Gomez and Gomez (1984). Fisher's test of significance was employed to compare the differences between treatment means at a 5% probability level. Standard errors and critical differences at the 5% significance level were calculated to distinguish the treatment effects from those arising due to random variation.

Table 1. Treatment details

Main plots: Cropping Systems	
C ₁	Soybean-Linseed
C ₂	Greengram-Linseed
C ₃	Blackgram-Linseed
C ₄	Drilled Rice-Linseed
Sub plots: Nutrient management in linseed	
F ₁	Farmer's practice (40:28.70:00 N: P ₂ O ₅ : K ₂ O kg ha ⁻¹)
F ₂	100 % RDN (60:30:30 N: P ₂ O ₅ : K ₂ O kg ha ⁻¹)
F ₃	*STCR based nutrient management
F ₄	75 % RDN (45:22.5:22.5 N: P ₂ O ₅ : K ₂ O kg/ha- 75 % inorganic + 25 % organic i.e. vermicompost) + 2 foliar sprays of nano urea

Table 2. Soil test crop response (STCR) based nutrient management

Particulars	Nutrient req. as per STCR based equation (N: P2O5:K2O kg ha ⁻¹)	
	2023-24	2024-25
Soybean-Linseed	90:45:45	87:43:46
Greengram-Linseed	91:47:45	90:44:45
Blackgram-Linseed	92:48:46	90:45:46
Drilled Rice-Linseed	94:49:46	92:45:47
The equation for linseed under <i>Vertisol</i> condition (Puri and Dharudu 2007)-(target yield of linseed= 20 q ha ⁻¹)		
FN= 8.48 (T) -0.46 (SN)		
FP ₂ O ₅ = 7.38 (T) -5.08 (SP)		
FK ₂ O= 6.59 (T)-0.25 (SK)		

3. RESULTS AND DISCUSSION

3.1 Effect on Growth Parameters

Growth parameters such as plant height, number of primary and secondary branches plant⁻¹ were significantly influenced by both the cropping systems and nutrient management practices, except for plant population, which remained unaffected (Table 3). Among the different cropping systems, the soybean–linseed sequence (C₁) recorded the highest plant height (75.90 cm), primary branches (4.60) and secondary branches (17.57). These results were statistically at par with those obtained under the greengram–linseed (C₂) and blackgram–linseed (C₃) systems, indicating their comparable efficiency in promoting linseed growth. The observed improvement can be attributed to the residual benefits of preceding leguminous crops, particularly their ability to enhance soil fertility through biological nitrogen fixation, thereby creating a favorable environment for the succeeding linseed crop. These findings are supported by previous studies, wherein Singh et al., (2022), Meena et al., (2019) and Panwar et al., (2010) reported similar positive effects of legume-based cropping systems on subsequent crop performance. With respect to nutrient management, the STCR-based treatment (F₃) resulted in the highest plant height (76.14 cm), number of primary branches (4.71), and secondary branches (17.73), all of which were statistically at par with those recorded under the treatment (F₄), consisting of 75% RDN (75 % through inorganic sources, + 25 % through organic source) + two foliar sprays of nano urea. This highlights the effectiveness of integrated nutrient strategies that combine conventional, organic and nano-based inputs for optimizing crop growth. These results corroborate earlier

findings by Kumar et al., (2019), Mahammad et al., (2013), Saryam et al., (2024) and Khule et al., (2023), who reported similar benefits of integrated nutrient management approaches on crop growth and development.

3.2 Effect on Yield Attributes

Among the yield attributes of linseed, the number of capsules plant⁻¹ was significantly influenced by both cropping systems and nutrient management practices (Table 4). However, the number of seeds capsule⁻¹ and test weight did not exhibit significant variations, indicating their relative stability across treatments and these traits are largely governed by genetic factors and may be less responsive to agronomic interventions. The soybean–linseed cropping system (C₁) recorded the highest number of capsules plant⁻¹ (63.15), which was statistically at par with the blackgram–linseed (C₃) and greengram–linseed (C₂) systems. This suggests that legume-based preceding crops may enhance the microenvironment and soil fertility, thereby promoting better capsule formation in linseed. Similarly, with respect to nutrient management, the STCR-based treatment (F₃) resulted in the maximum number of capsules plant⁻¹ (62.90), which was statistically at par with the treatment (F₄), involving 75% RDN (75 % through inorganic sources, + 25 % through organic source) and two foliar sprays of nano urea. These results indicate that optimized nutrient supply through precision and integrated nutrient management can significantly improve reproductive development and yield potential in linseed by enhancing nutrient availability, uptake efficiency and physiological performance. These observations are consistent with findings reported by Mahammad et al., (2013) and Patel et al., (2017).

3.3 Effect on Yield

Seed and stover yields of linseed were significantly influenced by both cropping systems and nutrient management practices (Table 4). Among the evaluated cropping systems, the soybean–linseed sequence (C_1) recorded the highest seed yield ($1660.15 \text{ kg ha}^{-1}$) and stover yield ($2102.01 \text{ kg ha}^{-1}$). These values were statistically at par with those recorded under the blackgram–linseed (C_3) and greengram–linseed (C_2) systems, indicating the comparable efficacy of legume-based rotations in enhancing both biomass and reproductive yield. The observed benefits are likely due to improved soil fertility and nutrient availability resulting from the biological nitrogen fixation and organic matter contributions by the preceding legume crops. These observations are consistent with findings reported by Singh et al., (2022).

In terms of nutrient management, the STCR based approach (F_3) resulted in the highest seed yield ($1710.62 \text{ kg ha}^{-1}$) and stover yield ($2134.09 \text{ kg ha}^{-1}$), which were statistically at par with those achieved under the treatment (F_4), comprising 75% RDN (75 % through inorganic sources, + 25 % through organic source) and two foliar sprays of nano urea. This outcome underscores the advantage of precision and integrated nutrient application strategies in achieving enhanced productivity in linseed. These findings are in alignment with previous studies reported by Husain et al., (2017) and Khule et al., (2023).

3.4 Effect on Economics

The economic performance of linseed cultivation, in terms of cost of cultivation, gross monetary returns (GMR), net monetary returns (NMR) and benefit-cost (B:C) ratio, were significantly affected by both cropping systems and nutrient management strategies (Table 5). Among the cropping systems, the soybean–linseed sequence (C_1) recorded the highest gross monetary returns (Rs. 1, 03,098 ha^{-1}) and net monetary returns (Rs. 69,414 ha^{-1}), resulting in the maximum B:C ratio of 3.07. This was followed by the blackgram–linseed (C_3) and greengram–linseed (C_2) systems, with B:C ratios of 2.93 and 2.92, respectively, indicating their comparable economic viability. In contrast, the drilled rice–linseed system (C_4) showed the lowest economic returns, with a B:C ratio of 2.78, primarily due to lower yield returns, despite similar input costs. Among nutrient management practices, the STCR-based approach (F_3)

yielded the highest economic benefits, with gross monetary returns of Rs. 1,06,069 ha^{-1} and net returns of Rs. 72,470 ha^{-1} , resulting in a highest B:C ratio of 3.16. This was closely followed by the 100% RDN (F_2), which achieved a B:C ratio of 3.05. The farmer's practice (F_1), although economically inferior in comparison, still maintained a reasonably good B:C ratio of 2.84. Interestingly, while the treatment (F_4) comprising 75% RDN (75 % through inorganic sources, + 25 % through organic source) and two foliar sprays of nano urea recorded high gross returns (Rs. 1,02,672 ha^{-1}), the relatively elevated cost of cultivation (Rs. 38,736 ha^{-1}) substantially reduced its net returns and B:C ratio to 2.65, the lowest among all nutrient management treatments. This underscores the need for careful cost-benefit optimization when adopting advanced input strategies. These findings are consistent with the results reported by Singh et al., (2022), Kikon et al., (2024) and Saryam et al., (2024).

3.5 Interaction Effects of Cropping Systems and Nutrient Management Practices

The interaction between cropping systems and nutrient management practices showed a non-significant effect on the plant population, number of seeds capsule⁻¹ and test weight of linseed. However, a statistically significant interaction was observed for plant height, number of primary and secondary branches plant⁻¹, number of capsules plant⁻¹, as well as seed and stover yields. These findings indicate that while certain traits such as seeds capsule⁻¹ and test weight are predominantly governed by genetic factors, others are more responsive to the interactive influence of cropping systems and nutrient inputs. The significant interactions observed for plant height, branching, capsule formation and yield components suggest a synergistic effect of cropping sequence and nutrient management. Legume-based cropping systems, particularly the soybean–linseed sequence, when integrated with balanced nutrient management practices such as Soil Test Crop Response (STCR)-based recommendations or Integrated Nutrient Management (INM) involving nano urea, likely improve soil health, enhance root development, and optimize nutrient availability & uptake. These favorable conditions contribute to enhanced vegetative growth, branching and reproductive development, ultimately leading to improved seed and stover yields.

Table 3. Effect of different cropping systems and nutrient management practices on growth parameters at harvest of linseed (*Linum usitatissimum* L.) during 2023-24 & 2024-25

Treatment	Plant population (Number m ⁻²)	Plant height(cm)	Primary branches plant ⁻¹	Secondary branches plant ⁻¹
Main plots: Cropping systems				
C1:Soybean– Linseed	155	75.90	4.60	17.57
C2:Greengram– Linseed	154	74.68	4.34	16.92
C3:Blackgram– Linseed	152	74.27	4.32	16.49
C4:Drilled Rice– Linseed	145	73.07	4.10	15.02
SE(m) ±	2.87	0.61	0.10	0.31
CD (P=0.05)	NS	2.12	0.35	1.06
Sub plots: Nutrient management to linseed				
F1:Farmer's practice	150	72.78	4.03	14.92
F2: 100% RDF	150	73.85	4.20	16.31
F3: STCR based nutrient management	155	76.14	4.71	17.73
F4: 75% RDN (75% Inorganic + 25% organic) + 2 foliar sprays of nano urea	151	75.15	4.42	17.04
SE(m)±	2.75	0.53	0.12	0.30
CD (P=0.05)	NS	1.54	0.34	0.85
Interaction				
SE(m)±	5.31	1.05	0.23	0.58
CD at (P=0.05)	NS	S	S	S

NS and S means not significant, significant at 0.05 probability, respectively

Table 4. Effect of different cropping systems and nutrient management practices on yield attributes and yields of linseed (*Linum usitatissimum* L.) during 2023-24 & 2024-25

Treatment	Capsules plant ⁻¹ (At harvest)	Seeds capsule ⁻¹ (At harvest)	Test weight (g)	Seed yield (kg ha ⁻¹)	Stover yield (kg ha ⁻¹)
Main plots: Cropping systems					
C1: Soybean– Linseed	63.15	8.49	7.48	1660.15	2102.01
C2: Greengram– Linseed	58.19	8.30	7.33	1584.04	1993.11
C3: Blackgram– Linseed	58.71	8.32	7.35	1582.47	1996.92
C4: Drilled Rice – Linseed	54.80	8.13	7.18	1503.70	1874.02
SE(m)±	1.55	0.15	0.17	23.16	30.97
CD (P=0.05)	5.35	NS	NS	80.13	107.15
Sub plots: Nutrient management to linseed					
F1: Farmer's practice	54.41	8.13	7.10	1402.46	1750.17
F2: 100% RDF	57.12	8.25	7.26	1561.93	2010.42
F3: STCR based nutrient management	62.90	8.50	7.57	1710.62	2134.09
F4:75% RDN (75% Inorganic + 25% organic) + 2 foliar sprays of nano urea	60.43	8.37	7.42	1655.34	2071.39
SE(m)±	1.22	0.14	0.20	20.51	30.57
CD (P=0.05)	3.57	NS	NS	59.85	89.23
Interaction					
SE(m)±	2.44	0.28	0.39	41.01	61.15
CD at (P=0.05)	S	NS	NS	S	S

NS and S means not significant, significant at 0.05 probability, respectively

Table 5. Effect of different cropping systems and nutrient management practices on economics of linseed (*Linum usitatissimum* L.) during 2023-24 & 2024-25

Treatment	Cost of cultivation (Rs. ha⁻¹)	GMR (Rs. ha⁻¹)	NMR (Rs. ha⁻¹)	B:C ratio
Main plots: Cropping systems				
C1: Soybean– Linseed	33685	103098	69414	3.07
C2: Greengram– Linseed	33699	98295	64596	2.92
C3: Blackgram– Linseed	33718	98235	64516	2.93
C4: Drilled Rice – Linseed	33739	93213	59475	2.78
Sub plots: Nutrient management to linseed				
F1: Farmer's practice	30634	86956	56322	2.84
F2: 100% RDF	31872	97145	65273	3.05
F3: STCR based nutrient management	33598	106069	72470	3.16
F4: 75% RDN (75% Inorganic + 25% organic) + 2 foliar sprays of nano urea	38736	102672	63936	2.65

4. CONCLUSION

The present study clearly demonstrated that both cropping systems and nutrient management practices significantly influenced growth parameters, yield attributes, yields, and economic returns of linseed. Among the cropping systems, soybean–linseed consistently outperformed others in terms of plant height, branching, capsule development, seed & stover yields and economic returns highlighting the benefits of preceding legumes in improving soil fertility and biological activity. Compared to the drilled rice–linseed sequence, the soybean–linseed system enhanced seed yield and B:C ratio by 10.40% and 10.43%, respectively. Nutrient management practices based on the Soil Test Crop Response (STCR) approach recorded the highest yields and returns, with seed yield and B:C ratio improved by 21.97% and 11.26% over the farmer's practice. Integrated nutrient management 75% RDN (75 % through inorganic sources, + 25 % through organic source) and two foliar sprays of nano urea also produced comparable results, suggesting it as a viable sustainable alternative. The significant interaction effects for key traits emphasized the synergistic advantage of combining legume-based systems with balanced nutrient strategies, enhancing nutrient uptake, vegetative growth and reproductive efficiency.

Thus, integrating the soybean–linseed system with either STCR-based or INM-based nutrient management is recommended as an efficient and sustainable approach for improving linseed productivity and profitability under similar agro-ecological conditions.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author hereby declare that NO generative AI technologies such as large language models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

ACKNOWLEDGEMENTS

Funding received from AICRP-ICAR & IGKV, Raipur (C.G.) is duly acknowledged.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could

have appeared to influence the work reported in this paper.

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