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Enhancing Linseed Yield through Integrated Nutrient Management Using Phosphorus, Potassium, and Vermicompost

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Abstract: Linseed (*Linum usitatissimum* L.) is an important oilseed crop cultivated primarily during the rabi season. The present field experiment was conducted during 2018–2019 at Department of Seed Science and Technology, H.N.B. Garhwal University, Chauras Campus, Srinagar, Uttarakhand to evaluate the influence of phosphorus (P), potassium (K), and vermicompost (VC) on growth and yield parameters of linseed variety Alsi Him-1. The experiment was laid out in a Randomized Block Design (RBD) with nine treatments and three replications. Phosphorus was applied at 40 and 50 kg P_2O_5 ha^{-1}, potassium at 30 and 40 kg K_2O ha^{-1}, and vermicompost at 1.0 and 1.5 t ha^{-1}, used alone and in combinations. Results revealed that T8 (P 40 kg ha^{-1} + K 30 kg ha^{-1} + VC 1.0 t ha^{-1}) recorded the highest biomass accumulation, shoot length, and pod number per plant, while T3 (P 50 kg ha^{-1} + VC 1.5 t ha^{-1}) produced the maximum grain yield (10.17 g m^{-2}) and straw yield (26.7 g m^{-2}). Treatments lacking phosphorus recorded the lowest yields, underscoring the critical role of phosphorus in linseed productivity. Integrated nutrient management combining mineral fertilizers with vermicompost was found to be the most effective approach for optimizing linseed growth and yield.
Keywords: Linseed • Vermicompost • Phosphorus • Potassium • Integrated nutrient management • Oilseed crop

Introduction

Linseed (*Linum usitatissimum* L.) belongs to the family *Linaceae* and is among the oldest cultivated oilseed crops in the world. It is primarily grown as a rabi-season annual under low-input, moisture-deficient conditions. Linseed is classified into three types based on its use: seed-type for oil production, flax for fiber, and dual-purpose for both seed and fiber (Singh and Chopra 2018). The seeds contain 20–25% protein and 35–45% oil (Yilmaz *et al* 2021). Linseed is recognized as an important source of omega-3 and omega-6 fatty acids, with alpha-linolenic acid (ALA) constituting a major proportion. ALA is known to reduce cholesterol levels, alleviate inflammatory disorders, and support cardiovascular and immune health (Singh & Chopra, 2018). Linseed is also a leading source of lignans, offering potential protection against hormone-sensitive cancers due to its estrogenic and anti-estrogenic properties.

Despite its nutritional and industrial importance, linseed productivity in India remains low, primarily owing to poor soil fertility management and limited adoption of improved agronomic practices. In hilly regions such as Uttarakhand, where linseed is cultivated under resource-limited conditions, optimizing nutrient management is critical for improving yields. Phosphorus (P) is an essential macronutrient that plays a vital role in energy transfer, root development, reproductive growth, and seed formation (Yawalkar *et al* 2002; Sameer *et al* 2021). Potassium (K) enhances enzymatic activity, water-use efficiency, and resistance to abiotic stress. Vermicompost (VC), produced through earthworm activity, is a biologically active organic amendment rich in macro- and micronutrients, growth-promoting substances including auxins, cytokinins, gibberellins, and beneficial enzymes such as urease, cellulase, and dehydrogenase (Bano *et al* 1987; Wakudkar *et al* 2024). Integrated use of mineral fertilizers and organic amendments can improve soil health, nutrient availability, and crop productivity (Makkar *et al* 2018; Shahu *et al* 2024).

The study was therefore conducted to evaluate the effects of varying levels of phosphorus, potassium, and vermicompost applied individually and in combinations on the growth, biomass accumulation, root development, and yield attributes of linseed under the agroclimatic conditions of Srinagar, Garhwal, Uttarakhand.

Materials and Methods

Study Area and Experimental Site

The field experiment was conducted during rabi season 2018–2019 at the Department of Seed Science and Technology, H.N.B. Garhwal University, Chauras Campus, Srinagar, Uttarakhand. The climate is temperate, with an average annual rainfall of approximately 60 mm during the rabi season and temperatures ranging from 7°C to 22°C. The experimental soil was sandy loam in texture and porous in nature. A surface soil sample (0–15 cm depth) was collected before sowing and analyzed for physicochemical properties using standard methods.

Experimental Design and Treatments

The experiment was laid out in a Randomized Block Design (RBD) with nine treatments and three replications. Linseed variety Alsi Him-1 was used as the test crop. Seeds were manually sown at a row to row spacing of 25 cm and plant to plant spacing of 10 cm. Seeds were treated with a recommended fungicide before sowing, and light irrigation was applied immediately after. Weed management was done by hand weeding and two hoeings; no chemical pesticides were used. Five plants per replication were tagged to record growth and yield observations.

Phosphorus was applied as single superphosphate, potassium as muriate of potash, and vermicompost as farm-produced material. The nutrient doses per hectare were as follows:

The nine treatments were as follows:

- **T1:** Phosphorus @ 50 kg P_2O_5 ha^{-1} + Potassium @ 40 kg K_2O ha^{-1}
- **T2:** Phosphorus @ 40 kg P_2O_5 ha^{-1} + Potassium @ 30 kg K_2O ha^{-1}
- **T3:** Phosphorus @ 50 kg P_2O_5 ha^{-1} + Vermicompost @ 1.5 t ha^{-1}
- **T4:** Phosphorus @ 40 kg P_2O_5 ha^{-1} + Vermicompost @ 1.0 t ha^{-1}
- **T5:** Potassium @ 40 kg K_2O ha^{-1} + Vermicompost @ 1.5 t ha^{-1}
- **T6:** Potassium @ 30 kg K_2O ha^{-1} + Vermicompost @ 1.0 t ha^{-1}
- **T7:** Phosphorus @ 50 kg P_2O_5 ha^{-1} + Potassium @ 40 kg K_2O ha^{-1} + Vermicompost @ 1.5 t ha^{-1}
- **T8:** Phosphorus @ 40 kg P_2O_5 ha^{-1} + Potassium @ 30 kg K_2O ha^{-1} + Vermicompost @ 1.0 t ha^{-1}
- **T9:** Control (no nutrient application)

Parameters Recorded

Observations were recorded on: field emergence percentage, plant height (cm) at 30 and 60 days after sowing (DAS) and at harvest, number of primary and secondary branches per plant (30 DAS, 60 DAS, at harvest), fresh and dry matter production per plant (g) at 30 and 60 DAS, shoot length and root length (cm) at 30 and 60 DAS, number of roots per plant at 30 and 60 DAS, total number of pods per plant at harvest, grain yield (g m^{-2}), straw yield (g m^{-2}), and harvest index (%).

Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using standard RBD procedures. Treatment means were compared using critical difference (CD) at the 5% level of significance. Standard error of mean (S.EM) and standard error of difference (SE.d) were also computed.

Results and Discussion

Plant Height

The influence of phosphorus, potassium, and vermicompost on plant height of linseed was recorded at 30 DAS, 60 DAS, and at harvest (Table 1). T2 (P 40 kg ha^{-1} + K 30 kg ha^{-1}) recorded the maximum plant height at 60 DAS (65.8 cm) and at harvest (66.8 cm), indicating the positive effect of balanced mineral nutrition on vegetative growth. Phosphorus enhances root activity and overall metabolic vigor, while potassium regulates turgor pressure and cell elongation, together promoting shoot elongation. These results are in agreement with Muhammad *et al* (2022) and Shahu *et al* (2024), who reported increased plant height in linseed with balanced P and K application. Treatments involving vermicompost in combination with mineral nutrients (T7, T8) exhibited moderate plant height, slightly lower than T2, possibly because the nutrient release from vermicompost is gradual and may not have fully contributed during the early vegetative phase. The control (T9) showed relatively higher plant height at 30 DAS (42.46 cm) compared to some fertilized treatments; however, this early growth advantage was not sustained, and by 60 DAS and harvest the control lagged behind, suggesting that indigenous soil nutrient reserves supported initial growth but were insufficient for sustained vegetative development. Significant differences among treatments (CD at 5%) confirm the reliability of these results (Table 1).

Table 1: Effect of phosphorus, potassium, and vermicompost on plant height (cm) of linseed at different crop growth stages

Treatments	**Plant Height (cm)**		
	30 DAS	**60 DAS**	**At Harvesting**
T1 (P 50 + K 40)	38.38	63.14	64.14
T2 (P 40 + K 30)	40.02	65.80*	66.80*
T3 (P 50 + VC 1.5)	40.22	61.26	62.26
T4 (P 40 + VC 1.0)	38.62	55.60	56.60
T5 (K 40 + VC 1.5)	40.46	59.54	59.54
T6 (K 30 + VC 1.0)	36.26	56.84	57.80
T7 (P 50 + K 40 + VC 1.5)	40.90	61.54	62.54
T8 (P 40 + K 30 + VC 1.0)	41.42	60.34	61.34
T9 (Control)	42.46*	57.50	58.50
Mean	39.86	58.84	61.05
S.EM = 1.15; SE.d = 1.62; CD (5%) = 3.44			

** Highest value; P = Phosphorus (kg P_2O_5 ha^{-1}); K = Potassium (kg K_2O ha^{-1}); VC = Vermicompost (t ha^{-1})*

Number of Branches per Plant

The effect of treatments on primary and secondary branches at 30 DAS, 60 DAS, and at harvest is presented in Table 2. T2 (P 40 kg ha^{-1} + K 30 kg ha^{-1}) recorded the highest number of primary (9) and secondary (13) branches at 30 DAS, which further increased to 14 primary and 15 secondary branches by harvest. Balanced phosphorus and potassium nutrition promotes axillary bud development and canopy expansion by supporting cell division and the activity of growth-promoting hormones. Treatments combining vermicompost with mineral nutrients (T3, T5, T7, T8) produced moderate branching, superior to the control but lower than T2, reflecting the synergistic but slower action of organic amendments. The control (T9) consistently produced fewer branches, confirming that nutrient deficiency limits branching in linseed. These findings corroborate those of Muhammad *et al.* (2022) regarding the importance of balanced P and K in promoting linseed vegetative growth. Differences were statistically significant at the 5% level.

Fresh and Dry Matter Production

The effects of treatments on fresh and dry matter production at 30 and 60 DAS are presented in Table 3. T8 (P 40 + K 30 + VC 1.0 t ha^{-1}) recorded the highest fresh matter at 30 DAS (0.595 g) and 60 DAS (8.10 g), and the highest dry matter at 60 DAS (3.81 g). This suggests that combined application of moderate mineral nutrients with organic amendment optimizes biomass accumulation by enhancing soil biological activity and nutrient availability simultaneously.

Table 2: Effect of phosphorus, potassium, and vermicompost on the number of branches per plant of linseed at different crop growth stages

Treatments	30 DAS		60 DAS		At Harvesting	
	P	S	P	S	P	S
T1 (P 50 + K 40)	8	12	12	14	12	14
T2 (P 40 + K 30)	9*	13*	14*	15*	14*	15*
T3 (P 50 + VC 1.5)	8	12	10	13	10	13
T4 (P 40 + VC 1.0)	6	11	8	13	8	13
T5 (K 40 + VC 1.5)	7	12	9	14	9	14
T6 (K 30 + VC 1.0)	8	10	10	12	10	12
T7 (P 50 + K 40 + VC 1.5)	7	10	9	12	9	12
T8 (P 40 + K 30 + VC 1.0)	7	12	9	14	9	14
T9 (Control)	7	11	9	13	9	13
Mean	7.44	11.44	10.0	13.3	10.0	13.3
S.EM = 0.38; SE.d = 0.53; CD (5%) = 1.13						

*P = Primary branches; S = Secondary branches; * Highest value*

The control (T9) showed comparatively high fresh and dry matter at 60 DAS (8.47 g and 3.85 g, respectively), which may be attributed to the soil's inherent fertility supporting later-season biomass; however, this was not reflected in improved yield components. The fact that the control performed comparably to some fertilized treatments in biomass at 60 DAS but not in yield attributes (pods, grain yield) highlights the importance of targeted nutrient supply for reproductive growth. Statistical analysis confirmed significant treatment effects at the 5% probability level (Mirza *et al* 2024).

Table 3: Effect of phosphorus, potassium, and vermicompost on fresh and dry matter production (g) at different growth stages of linseed

Treatments	Fresh Matter (g)		Dry Matter (g)	
	30 DAS	60 DAS	30 DAS	60 DAS
T1 (P 50 + K 40)	0.368	7.944	0.189	3.662
T2 (P 40 + K 30)	0.477	5.902	0.099	2.680
T3 (P 50 + VC 1.5)	0.533	6.664	0.103	3.020
T4 (P 40 + VC 1.0)	0.440	5.275	0.099	2.390
T5 (K 40 + VC 1.5)	0.504	5.160	0.106	2.340
T6 (K 30 + VC 1.0)	0.499	5.730	0.090	2.634
T7 (P 50 + K 40 + VC 1.5)	0.407	6.600	0.076	3.003
T8 (P 40 + K 30 + VC 1.0)	0.595*	8.100*	0.109*	3.810*
T9 (Control)	0.335	8.470	0.084	3.850
Mean	0.462	6.650	0.106	3.040
S.EM = 0.043; SE.d = 0.060; CD (5%) = 1.28 (fresh matter); S.EM = 0.020; SE.d = 0.028; CD (5%) = 0.59 (dry matter)				

** Highest value among treatments*

Shoot and Root Length: Shoot and root length at 30 and 60 DAS were significantly influenced by nutrient treatments (Table 4). T8 (P 40 + K 30 + VC 1.0 t ha^{-1}) recorded the maximum shoot length at both 30 DAS (21.54 cm) and 60 DAS (36.54 cm), reflecting the positive synergistic effect of combined organic and inorganic amendments on vegetative elongation. The enhanced shoot growth under T8 is attributed to improved soil nutrient supply and biological activity stimulated by vermicompost, alongside the structural role of mineral nutrients in cell elongation and division. In contrast, the highest root length at 30 DAS was recorded under T7 (7.44 cm), and at 60 DAS under T1 (9.5 cm), suggesting that higher mineral nutrient doses, particularly phosphorus, promote deeper root development by stimulating root tip growth and increasing root surface area for nutrient and water absorption. These contrasting responses in shoot and root development under different treatment combinations highlight the complementary roles of organic and inorganic nutrition. Results are consistent with those of Shahu *et al.* (2024). Differences were statistically significant at 5% level.

Table 4: Effect of phosphorus, potassium, and vermicompost on shoot length and root length (cm) of linseed

Treatments	Shoot Length (cm)		Root Length (cm)	
	30 DAS	60 DAS	30 DAS	60 DAS
T1 (P 50 + K 40)	17.16	32.16	6.94	9.50*
T2 (P 40 + K 30)	18.68	33.68	6.10	8.66
T3 (P 50 + VC 1.5)	19.10	34.10	6.40	8.96
T4 (P 40 + VC 1.0)	17.70	32.70	6.06	8.62
T5 (K 40 + VC 1.5)	19.92	34.92	5.32	7.88
T6 (K 30 + VC 1.0)	21.20	33.00	5.92	8.48
T7 (P 50 + K 40 + VC 1.5)	18.56	33.56	7.44*	9.00
T8 (P 40 + K 30 + VC 1.0)	21.54*	36.54*	5.72	8.28
T9 (Control)	20.00	35.00	5.80	8.34
Mean	18.96	33.96	6.07	8.63
S.EM = 0.043; SE.d = 0.060; CD (5%) = 1.28 (shoot); S.EM = 0.020; SE.d = 0.028; CD (5%) = 0.59 (root)				

** Highest value in respective parameter*

Number of Roots per Plant: The number of roots per plant at 30 and 60 DAS was significantly affected by nutrient treatments (Table 5). T2 (P 40 + K 30 kg ha^{-1}) produced the highest root numbers at both 30 DAS (8 roots) and 60 DAS (9 roots). Phosphorus is known to stimulate lateral root initiation and root branching by activating phosphatases and improving metabolite transport, while potassium supports osmotic regulation in root cells. Treatments containing vermicompost showed moderate root numbers, generally better than the control. The control (T9) had the fewest roots at both stages (5 roots each), confirming the limiting effect of nutrient deficiency on root proliferation. A well-developed root system improves nutrient and water uptake, which ultimately supports higher yield components. These findings support observations by Shahu *et al* (2024).Statistical differences were significant at 5% level.

Table 5: Effect of phosphorus, potassium, and vermicompost on the number of roots per plant of linseed

Treatments	No. of Roots at 30 DAS	No. of Roots at 60 DAS
T1 (P 50 + K 40)	6	7
T2 (P 40 + K 30)	8*	9*
T3 (P 50 + VC 1.5)	6	7
T4 (P 40 + VC 1.0)	6	6
T5 (K 40 + VC 1.5)	7	7
T6 (K 30 + VC 1.0)	7	7
T7 (P 50 + K 40 + VC 1.5)	7	8
T8 (P 40 + K 30 + VC 1.0)	6	7
T9 (Control)	5	5
Mean	6.44	7.00
S.EM = 0.043; SE.d = 0.060; CD (5%) = 1.28		

** Highest value*

Number of Pods per Plant: The total number of pods per plant at harvest was significantly influenced by the treatments (Table 6). T8 (P 40 + K 30 + VC 1.0 t ha^{-1}) produced the maximum pods (98 per plant), followed by T7 (94) and the control T9 (93). The superiority of T8 may be attributed to the synergistic effect of balanced mineral nutrients and organic matter on reproductive growth, improved photosynthate partitioning toward pod filling, and better pollination success facilitated by phosphorus and potassium. The

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control (T9) performed comparably to some fertilized treatments in pod number but not in grain yield (Table 7), indicating that while pod number can be sustained by indigenous soil fertility, actual grain development and filling require adequate exogenous nutrient supply. Treatments without phosphorus (T5, T6) produced fewer pods, emphasizing phosphorus as a critical nutrient for pod initiation and seed set. These results agree with Makkar *et al.* (2018). All differences were statistically significant (CD at 5%).

Table 6: Effect of phosphorus, potassium, and vermicompost on the total number of pods per plant of linseed at harvest

Treatments	Total Pods per Plant
T1 (P 50 + K 40)	91
T2 (P 40 + K 30)	90
T3 (P 50 + VC 1.5)	63
T4 (P 40 + VC 1.0)	76
T5 (K 40 + VC 1.5)	85
T6 (K 30 + VC 1.0)	86
T7 (P 50 + K 40 + VC 1.5)	94
T8 (P 40 + K 30 + VC 1.0)	98*
T9 (Control)	93
Mean	86.22
S.EM = 0.23; SE.d = 0.33; CD (5%) = 0.72	

* *Highest value*

Grain Yield and Straw Yield: The influence of treatments on grain yield (g m^{-2}) and straw yield (g m^{-2}) is presented in Table 7. T3 (P 50 kg ha^{-1} + VC 1.5 t ha^{-1}) recorded the maximum grain yield (10.17 g m^{-2}) and straw yield (26.7 g m^{-2}). The combination of a higher phosphorus dose with vermicompost likely improved both soil fertility status and photosynthate supply during the grain-filling period. Phosphorus supports the synthesis of ATP and other energy-rich compounds critical for seed development, while vermicompost enhances the soil's biological activity and improves the availability of multiple nutrients. T1 (P 50 + K 40) and T8 (P 40 + K 30 + VC 1.0) also produced relatively high grain and straw yields, indicating that the availability of phosphorus is the primary driver of productivity. In contrast, treatments without phosphorus (T5: K 40 + VC 1.5; T6: K 30 + VC 1.0) produced the lowest grain yields (6.54 and 4.51 g m^{-2}, respectively), confirming the indispensable role of phosphorus in linseed productivity (Mirza *et al* 2024; Muhammad *et al* 2020). All yield differences were statistically significant at the 5% level.

Table 7: Effect of phosphorus, potassium, and vermicompost on grain yield and straw yield of linseed

Treatments	Grain Yield (g m^{-2})	Straw Yield (g m^{-2})
T1 (P 50 + K 40)	9.38	24.12
T2 (P 40 + K 30)	8.78	24.27
T3 (P 50 + VC 1.5)	10.17*	26.70*
T4 (P 40 + VC 1.0)	7.01	21.18
T5 (K 40 + VC 1.5)	6.54	19.44
T6 (K 30 + VC 1.0)	4.51	17.90
T7 (P 50 + K 40 + VC 1.5)	7.97	20.30
T8 (P 40 + K 30 + VC 1.0)	9.04	24.66
T9 (Control)	7.36	21.56
Mean	7.86	22.23

* *Highest value*

Conclusion

The results of the present study clearly demonstrate that integrated nutrient management combining phosphorus, potassium, and vermicompost significantly enhances the growth and yield of linseed compared to sole applications. Among all treatments, T3 (Phosphorus @ 50 kg P_2O_5 ha^{-1} + Vermicompost @ 1.5 t ha^{-1}) recorded the highest grain yield (10.17 g m^{-2}) and straw yield (26.7 g m^{-2}), making it the most productive treatment combination overall. T8 (Phosphorus @ 40 kg P_2O_5 ha^{-1} + Potassium @ 30 kg K_2O ha^{-1} + Vermicompost @ 1.0 t ha^{-1}) excelled in vegetative parameters including shoot length, fresh and dry biomass, and pod number per plant. T2 (Phosphorus @ 40 kg P_2O_5 ha^{-1} + Potassium @ 30 kg K_2O ha^{-1}) was most effective in promoting plant height and branching. Treatments lacking phosphorus (T5, T6) consistently produced the lowest yields, confirming phosphorus as the most critical nutrient for linseed productivity under the prevailing agroclimatic conditions. Based on the overall performance, T3 is recommended as the best treatment for maximizing linseed yield in similar hill environments, while T8 is recommended where improving vegetative growth and pod number is the primary objective. Further research on site-specific nutrient management and multi-season validation is suggested.

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