



RESEARCH ARTICLE

Combined application of mineral fertilisers and farmyard manure improve the growth, yield and nutrient content of black gram and garden pea in mid hills of North-Western Himalayan region

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Abstract

This research investigates the effects of integrated nutrient management (INM) on the growth, yield and nutrient uptake of two important legume crops black gram (*Vigna mungo* (L.) Hepper) and garden pea (*Pisum sativum* L.) under mid-hill conditions. A field experiment was conducted using a randomized block design (RBD) with eight different treatments involving combinations of chemical fertilisers (NPK), organic inputs (FYM) and bio-enhancers. The observed increase in plant height was 30.8 % and 18.5 %, respectively while pod length improved by 5.8 % and 17.2 %, respectively when compared to the control treatment in black gram and garden pea. The number of pods per plant and grains per pod increased by 45.0 % and 33.3 % in black gram and 42.8 % and 29.3 % in garden pea, respectively. Grain yield of black gram and green pod yield of garden pea under Soil test-based NPK + FYM (T₅) increased by 71.0 % and 58.8 %, respectively, over control. Similarly, nutrient content was also higher with the application of NPK and farmyard manure treatment (T₅) over control. This highlights the superior efficacy of integrated nutrient systems over chemical-only or organic-only approaches. The findings suggest that integrating organic amendments like FYM with mineral fertilisers enhances crop productivity and contributes to sustainable soil fertility management. These results are especially relevant for farmers in hill regions, offering a practical and eco-friendly solution for enhancing legume production while maintaining long-term soil health.

Keywords: black gram; farmyard manure; garden pea; jeevamrit; natural farming; NPK

Introduction

Legume cropping systems play a crucial role in Indian agriculture, particularly in maintaining soil fertility and enhancing sustainable farming practices (1–3). Among these grain legumes, black gram and pea are the most sustainable crops grown in India in an area of 54.29 lakh ha and 540.5 thousand ha with an annual production of 35.62 lakh tonnes and 5422.1 thousand million tonnes, respectively (4). Leguminous crops, such as black gram and garden pea, are integral to Indian farming systems due to their ability to fix atmospheric nitrogen, thereby enriching the soil naturally and reducing the dependence on synthetic fertilisers (5). These crops not only contribute to soil health but also provide essential nutrients, particularly proteins, making them a staple in the diet of many rural communities. In the hilly regions of India, where agricultural activities face unique challenges like soil erosion, limited arable land and nutrient depletion, maintaining soil fertility is a constant

concern (6–7). The degradation of soil in these regions, often due to the steep slopes, poor organic content and excessive reliance on chemical fertilisers, leads to reduced productivity over time (8).

Nutrient management through fertilisers, therefore, adds one of the most critical management practices for agricultural productivity. Owing to their remarkable responsiveness to fertilisers, these nutrient-loving crops, like pulses and vegetables, have emerged as crops that thrive well when provided with an adequate and balanced supply of plant-essential nutrients. Nitrogen (N) promotes leaf and stem growth and enhances the overall size and greenness of plants. It is a crucial component of proteins, chlorophyll and other essential plant compounds (9, 10). Phosphorus (P) is essential for root development, flowering, fruiting, energy transfer and storage, as well as the production of DNA and other vital molecules in plants (11). Potassium (K) is a vital nutrient for plants and is involved in regulating water uptake, boosting

disease resistance, enhancing photosynthesis and promoting overall plant vigour by supporting various physiological processes (12). Different fertilisers have different chemical compositions and qualities, leading to diverse responses to soil applications. Their different responses affect soil chemical properties and overall crop quality. Therefore, for high production and food security, chemical fertilisers play a major role (13).

Organic manure, such as farmyard manure (FYM) acts as a storehouse of plant essential macro- and micronutrients, enriches the soil with organic matter and has the potential to support cropping systems by promoting nutrient cycling and enhancing soil physical properties (14, 15). A noteworthy demonstration revealed that applying 20 tonnes of FYM ha⁻¹ effectively alleviated the detrimental effects of drought stress by reducing evaporation, enhancing water retention and increasing water-holding capacity, as it acts as mulch (14). Jeevamrit, a fermented bio-organic input widely used in natural farming systems, functions primarily as a microbial inoculant that stimulates beneficial soil microorganisms, thereby enhancing nutrient availability and biological activity in the rhizosphere.

Increased nutrient use efficiency and reduced nutrient loss in agricultural systems, along with improving crop yield, are critical sustainability challenges in the present context. Inorganic or chemical fertilisers may provide immediate benefits, but overreliance on these fertilisers has detrimental consequences on soil fertility and long-term agricultural productivity. However, for many farmers (especially small and marginal) in Himalayan region, the purchase of chemical fertilisers and pesticides is and will continue to be constrained by their high costs and unavailability. They also have severe impacts on human health, including chemical residues in food and water contamination and they contribute significantly to environmental problems, such as excessive nutrient losses (16, 17). On the other hand, application of organic sources such as FYM or Jeevamrit alone may result in delayed nutrient release (18), which are associated with limiting root growth and ultimately decreased production (19). The sole application of animal manure (FYM) or jeevamrit is not sufficient to meet the nutrient demand because it contains relatively small amounts of nutrients and FYM is not available in the huge amounts that would be necessary (20). This is where integrated nutrient management (INM) comes in as a viable alternative. The INM combines both organic inputs, like farmyard manure (FYM) and Jeevamrit, with inorganic fertilisers such as nitrogen, phosphorus and potassium (NPK), to create a balanced and sustainable approach to nutrient supply (21, 22). By enhancing soil organic matter and improving nutrient cycling, INM promotes soil health, optimises nutrient use efficiency and reduces the reliance on synthetic inputs, making it an ideal solution for sustainable farming, particularly in hill agriculture (23, 24). The present research aims to explore the effects of different nutrient management strategies, including mineral fertilisation through (NPK), organic amendments such as FYM and bio-organic application in the form of Jeevamrit on the yield and growth of black gram and garden pea, providing insights into the benefits of integrated nutrient practices for farmers in these challenging agro-ecological zones.

Materials and Methods

Experimental site

The field experiment was carried out at the Hill Agricultural

Research and Extension Centre (HAREC), Bajaura, affiliated with CSK Himachal Pradesh Krishi Vishvavidyalaya, during the rabi and kharif seasons of 2018–2019 and 2019–2020. Situated in the mid-hills of Himachal Pradesh, the experimental site is geographically located at 31.8° N latitude and 77° E longitude, at an elevation of 1090 m above mean sea level. This agro-ecological zone is characterised by a temperate climate with distinct cold winters and moderately warm summers, making it suitable for leguminous crops like black gram and garden pea. The region receives an average annual rainfall of 900–1200 mm, predominantly during the monsoon period from July to September, which contributes significantly to soil moisture availability. The soil at the site is classified as silty clay loam, which provides a balanced texture favourable for root development and moisture retention. Chemical analysis of the soil revealed that it is slightly acidic in reaction (pH 6.43), deficient in available nitrogen (262 kg ha⁻¹), high in available phosphorus (34.6 kg ha⁻¹) and moderate in available potassium (180.2 kg ha⁻¹). These baseline soil fertility conditions provided an appropriate setting to assess the effect of different nutrient management practices on crop growth, yield and nutrient uptake under a sequential black gram-garden pea cropping system.

Experimental design

The experimental design employed for this study was the randomized block design (RBD), which is widely used in agricultural research to minimise the effects of variability within the field. The experiment consisted of eight distinct treatments (T₁ to T₈), each replicated three times, resulting in a total of 24 plots per crop for each cropping season. This layout ensured adequate statistical validity and allowed for effective comparison among treatments. The plot sizes were carefully standardised across all replications to maintain uniformity in the application of inputs and the collection of observational data. The primary objective of the study was to evaluate and compare the impacts of different nutrient management strategies specifically organic, inorganic, integrated and natural farming practices on the growth, yield and nutrient dynamics of black gram (*Vigna mungo* (L.) Hepper) and garden pea (*Pisum sativum* L.) grown in a sequential cropping system. This design facilitated a systematic and unbiased assessment of treatment effects under mid-hill agro-climatic conditions.

Crop and agronomic details

The cropping sequence comprised garden pea and black gram, selected for their suitability to the mid-hill agro-climatic conditions and their significance as leguminous crops. Garden pea (cv. Azad Pea-1) was sown during the rabi seasons on 31st October 2018 and 7th November 2019, using a row spacing of 45 cm and plant spacing of 7.5 cm, with a seed rate of 60 kg ha⁻¹ to ensure optimal plant population and uniform stand establishment. Black gram (Palampur-93) was sown in the kharif seasons on 18th July 2018 and 23rd July 2019, at a spacing of 45 × 10 cm and a seed rate of 18 kg ha⁻¹, aligning with regional agronomic guidelines. Based upon the adopted spacing, the plant population was approximately 465 plants for blackgram and 415 plants for garden pea per plot (14 m²). Throughout the cropping periods, standard cultural practices such as timely weeding, irrigation, pest control and disease management were implemented as per the recommendations of CSK Himachal Pradesh Krishi Vishvavidyalaya (25, 26). There was no disease and insect incidence on crops and hence no chemical plant protection measures were applied. Additionally, specific treatments like the application of Jeevamrit a fermented organic bio-stimulant were

administered in accordance with Subhash Palekar's Natural Farming protocols. These practices ensured that each treatment condition was precisely managed to assess its effect on crop performance accurately.

Treatment	Description
T ₁	Application of Jeevamrit at 15-day intervals
T ₂	Application of Jeevamrit at 30-day intervals
T ₃	Farmyard Manure (FYM) alone at 20 t ha ⁻¹ for pea, 10 t ha ⁻¹ for black gram
T ₄	Soil test-based NPK application
T ₅	Soil test-based NPK + FYM (recommended dose)
T ₆	Integrated application: 50 % NPK + 50 % FYM
T ₇	Farmer's practice: 40 % of recommended dose of fertilisers (RDF)
T ₈	Control (no fertiliser or manure applied)

Treatment details

The experiment comprised the following eight treatments, targeting various nutrient management strategies:

The RDF applied was N:P:K at 50:60:60 kg ha⁻¹ + 20 t ha⁻¹ FYM for garden pea and N:P:K at 20:40:20 kg ha⁻¹ + 10 t ha⁻¹ FYM for black gram. In soil test-based treatments, nitrogen was increased by 25 % and phosphorus reduced by 25 % to enhance nutrient use efficiency. FYM was incorporated one week before sowing to promote early mineralisation and improve nutrient availability to the crops.

Observations recorded

Growth attributes and yield

To evaluate the effect of different farming practices on crop development, key growth attributes were recorded at critical phenological stages flowering, pod formation, grain and straw harvest. For this purpose, five plants were randomly selected and tagged in each plot to ensure unbiased sampling. Measurements included plant height (cm) to assess vegetative growth, pod length (cm) as an indicator of reproductive development and the number of pods per plant and number of grains per pod, which directly influence yield potential. Additionally, shelling percentage (%), calculated as the ratio of grain weight to total pod weight, was determined to evaluate grain filling efficiency. These parameters collectively reflect the physiological response of black gram and garden pea to different nutrient management treatments and help in understanding how growth translates into yield under varying farming practices. The data on growth, yield and its attributes were recorded as per procedure given below.

Plant height: The plant height was measured at harvest from 5 marked black gram plants with the help of measuring scale. Height was measured from the ground base to the topmost leaves tip, then

the average height of the plant was worked out.

Pod length (cm): Pod length in cm was obtained by means of measuring scale by averaging the length of five pods tagged plants at harvest time. The length in cm of each pod was recorded from the base of the pod to the apex of the pod.

Number of pods per plant: Total number of pods was counted from the five tagged plants and the mean number of pods per plant was recorded by dividing the total number by 5.

Number of grains per pod: Number of grains per pod recorded from five tagged plants at maturity in each plot and the mean was calculated.

Shelling percentage: Ten pods selected from net plots were weighed and seeds from these pods were weighed separately.

$$\text{Shelling percentage} = \frac{\text{weight of seeds}}{\text{weight of pods}} \times 100$$

Green pod and straw yield of pea: The green pods of pea obtained at all pickings were recorded and summed up to determine total pod yield and expressed as q ha⁻¹. The dry straw yield was recorded after the final harvest.

Grain and straw yield of black gram: Yield of grain and straw from net plot was recorded after drying the bundles under sun to a standard moisture condition, the grain yield was recorded after the crop harvest. Further, straw yield of mash was recorded after crop harvest and yield was expressed in q ha⁻¹.

Nutrient content analysis

To assess the nutrient dynamics under different treatments, plant samples (leaves, grains and straw) were collected at three key growth stages: flowering, pod formation and harvest. The plant samples (leaves and grains) were oven dried at 60 °C, ground in a stainless-steel grinder. The samples were kept in paper bags for subsequent analysis. The analytical methods used for plant analysis have been given in Table 1.

Statistical analysis

The data obtained from field and laboratory experiments were analysed statistically using analysis of variance (ANOVA) appropriate for a RBD, following the method outlined by Gomez and Gomez (1984) and OPSTAT statistical software. Treatment differences were evaluated at the 5 % level of significance to determine statistical relevance.

Results

Yield attributes and productivity of black gram and pea under different farming practices

The results presented in Table 2 clearly indicate significant

Table 1. Analytical methods used for plant analysis

Sl. No.	Parameter	Method employed
1.	Nitrogen	Digestion with concentrated H ₂ SO ₄ in the presence of digestion mixture (K ₂ SO ₄ , CuSO ₄ and Selenium powder in 10:1:0.1 ratio) and further determination by micro-kjeldahl method (27).
2.	Phosphorus	Digestion in diacid mixture (HNO ₃ : HClO ₄ :: 9:4) and further determination following vanadomolybdate acid yellow colour method (27).
3.	Potassium	Digestion in diacid mixture (HNO ₃ : HClO ₄ :: 9:4) and estimation by Flame photometer (28).
4.	Calcium	Flame photometer method (27)
5.	Magnesium	AAS method (27)
6.	Sulphur	Turbidimetric method (29)

Table 2. Effect of different farming practices on yield attributes and yield of blackgram and garden pea

Treatment	Plant height (cm)		Pod length (cm)		Pods plant ⁻¹		Grains per pod		Shelling (%)		Yield (q ha ⁻¹)		Straw yield (q ha ⁻¹)	
	Black gram	Pea	Black gram	Pea	Black Gram	Pea	Black gram	Pea	Black gram	Pea	Black gram	Pea	Black gram	Pea
T ₁	42.4	61.1	4.87	9.83	24.5	28.5	4.5	6.4	51.2	53.9	6.77	100.1	18.5	39
T ₂	40.6	59.7	4.85	9.58	23.6	27.5	4.2	6.2	49.9	52.6	6.53	96.1	17.7	36.7
T ₃	43.3	61.9	4.91	10	25.5	29.4	4.6	6.7	51.9	54.3	7.26	103.3	20.2	40.5
T ₄	45.3	63.8	4.96	10.37	27.5	32.1	5	7.1	54.1	57.4	8.39	112.4	22.3	43.2
T ₅	47.1	66.6	5.09	10.82	31	35	5.2	7.6	56.3	59.8	9.61	120.2	25	47.1
T ₆	46.3	65.2	5.06	10.6	29.4	34	5.1	7.4	54.8	58.5	9.01	116.4	23.3	44.7
T ₇	44.6	62.7	4.93	10.22	27.2	31	4.8	6.9	53.3	55.9	7.82	107.9	21.1	41.9
T ₈	36.5	56.2	4.81	9.23	21.4	24.5	3.9	5.9	47.3	49.3	5.62	75.7	16.2	28.5
CD ($p = 0.05$)	1.4	1.2	0.01	0.12	1	1.2	0.1	0.13	1	1	0.27	4.15	0.66	0.82

variation in yield and yield attributes among treatments. The highest pod length in black gram (5.09 cm) and pea (10.82 cm) was observed in T₅, while the shortest was in T₈. Similarly, T₅ also recorded the highest number of pods per plant in black gram (31.0) and pea (35.0), grains per pod (5.2 in black gram, 7.6 in pea) and shelling percentage (56.3 % and 59.8 %, respectively). Notably, T₅ yielded the highest grain yield of 9.61 q ha⁻¹ (black gram) and 120.2 q ha⁻¹ (pea), as well as straw yield of 25.0 q ha⁻¹ and 47.1 q ha⁻¹, significantly outperforming all other treatments. Conversely, T₈ consistently recorded the lowest values for all traits evaluated. The critical difference (CD) at $p \leq 0.05$ confirmed the statistical significance of differences among treatments, especially for pod number, grain yield and shelling percentage in both crops. These results highlight T₅ as the most effective treatment for maximising productivity in black gram and pea intercropping.

Leaf nutrient content of black gram and pea at flowering stage under different farming practices

An insight into the data presented in Table 3 revealed that significant differences in leaf nutrient content at the flowering stage were observed among the treatments. Treatment T₅ recorded the highest nutrient concentrations in both black gram and pea, with nitrogen at 3.74 % and 3.89 %, phosphorus at 0.50 % and 0.60 % and potassium at 2.51 % and 2.67 %, respectively. Similarly, the highest levels of secondary nutrients calcium (0.87 % and 1.04 %), magnesium (0.74 % and 0.78 %) and sulphur (0.44 % and 0.47 %) were also noted in T₅, indicating enhanced nutrient uptake under this practice. In contrast, T₈ consistently showed the lowest nutrient levels across all elements in both crops. The CD values at $p \leq 0.05$ confirm that these differences are statistically significant, especially for phosphorus and sulphur content. Overall, T₅ demonstrated superior nutrient assimilation, aligning

with its higher productivity outcomes reported earlier

Leaf nutrient content of black gram and pea at pod formation stage under different farming practices

An appraisal of the data given in Table 4 led to an inference that different fertilisation treatments had significant effect on nutrient content of leaves at the pod formation stage. Treatment T₅ showed the highest nutrient levels in both black gram and pea, with nitrogen at 2.59 % and 2.73 %, phosphorus at 0.38 % and 0.44 % and potassium at 1.38 % and 1.42 %, respectively. It also had the highest levels of calcium (0.75 % and 0.85 %), magnesium (0.70 % and 0.73 %) and sulphur (0.40 % and 0.41 %), indicating efficient nutrient retention during reproductive growth. Conversely, T₈ recorded the lowest nutrient concentrations across all parameters. The differences observed were statistically significant, as supported by the CD values at $p = 0.05$. These findings confirm that improved farming practices under T₅ positively influenced nutrient accumulation in both crops during pod development.

Effect of farming practices on leaf nutrient content at grain harvest stage in black gram and pea

At the grain harvest stage, nutrient content in leaf tissues declined compared to earlier stages, but significant differences among treatments were still observed (Table 5). Treatment T₅ consistently recorded the highest levels of essential nutrients in both black gram and pea. Notably, nitrogen content was 1.93 % in black gram and 1.98 % in pea, while phosphorus reached 0.32 % and 0.38 % and potassium peaked at 0.80 % and 0.89 %, respectively. It also showed higher calcium (0.40 % and 0.43 %), magnesium (0.23 % and 0.27 %) and sulphur (0.30 % and 0.37 %) levels, indicating better nutrient retention under enhanced farming practices. In contrast, T₈ exhibited the lowest nutrient content

Table 3. Effect of different farming practices on leaf nutrient content at flowering stage

Treatment	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		%S	
	Black gram	Pea	Black gram	Pea	Black gram	Pea	Black gram	Pea	Black gram	Pea	Blackgram	Pea
T ₁	3.61	3.74	0.41	0.52	2.40	2.55	0.78	0.96	0.65	0.69	0.35	0.40
T ₂	3.59	3.72	0.38	0.49	2.37	2.52	0.77	0.94	0.63	0.67	0.33	0.38
T ₃	3.63	3.78	0.42	0.53	2.41	2.58	0.81	0.98	0.67	0.70	0.36	0.41
T ₄	3.70	3.85	0.45	0.56	2.46	2.62	0.85	1.01	0.68	0.73	0.40	0.44
T ₅	3.74	3.89	0.50	0.60	2.51	2.67	0.87	1.04	0.74	0.78	0.44	0.47
T ₆	3.71	3.87	0.48	0.59	2.48	2.64	0.86	1.03	0.72	0.75	0.42	0.45
T ₇	3.66	3.81	0.44	0.55	2.44	2.61	0.83	0.99	0.69	0.72	0.37	0.42
T ₈	3.40	3.41	0.26	0.40	2.24	2.41	0.66	0.80	0.54	0.57	0.25	0.28
CD ($p = 0.05$)	0.11	0.03	0.07	0.07	0.06	0.04	0.05	0.11	0.05	0.07	0.03	0.05

N: Nitrogen; P: Phosphorus; K: Potassium; Ca: Calcium; Mg: Magnesium; S: Sulphur; CD: Critical difference; p : Probability level.

Table 4. Effect of different farming practices on leaf nutrient content at pod formation

Treatment	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		%S	
	Black gram	Pea	Black gram	Pea	Black gram	Pea	Black gram	Pea	Black gram	Pea	Blackgram	Pea
T ₁	2.48	2.61	0.31	0.37	1.29	1.34	0.65	0.77	0.60	0.66	0.29	0.33
T ₂	2.44	2.59	0.30	0.35	1.28	1.32	0.63	0.75	0.58	0.64	0.27	0.30
T ₃	2.50	2.64	0.33	0.38	1.32	1.36	0.68	0.79	0.63	0.68	0.31	0.34
T ₄	2.55	2.68	0.35	0.42	1.35	1.40	0.72	0.82	0.67	0.71	0.37	0.39
T ₅	2.59	2.73	0.38	0.44	1.38	1.42	0.75	0.85	0.70	0.73	0.40	0.41
T ₆	2.57	2.71	0.37	0.43	1.36	1.41	0.73	0.84	0.68	0.72	0.38	0.40
T ₇	2.52	2.66	0.34	0.41	1.34	1.38	0.70	0.81	0.66	0.69	0.33	0.35
T ₈	2.32	2.44	0.22	0.27	1.14	1.17	0.50	0.59	0.48	0.52	0.19	0.21
CD ($p = 0.05$)	0.03	0.03	0.04	0.07	0.11	0.10	0.07	0.08	0.07	0.08	0.05	0.04

N: Nitrogen; P: Phosphorus; K: Potassium; Ca: Calcium; Mg: Magnesium; S: Sulphur; CD: Critical difference; p : Probability level.

Table 5. Effect of different farming practices on leaf nutrient content at grain harvest stage

Treatment	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		%S	
	Black gram	Pea	Black gram	Pea	Black gram	Pea	Black gram	Pea	Black gram	Pea	Blackgram	Pea
T ₁	1.82	1.86	0.26	0.31	0.71	0.81	0.31	0.35	0.14	0.19	0.22	0.28
T ₂	1.80	1.84	0.24	0.29	0.68	0.78	0.27	0.32	0.13	0.16	0.20	0.26
T ₃	1.84	1.89	0.28	0.32	0.74	0.83	0.32	0.36	0.15	0.20	0.23	0.29
T ₄	1.89	1.94	0.30	0.35	0.78	0.85	0.37	0.39	0.19	0.22	0.27	0.35
T ₅	1.93	1.98	0.32	0.38	0.80	0.89	0.40	0.43	0.23	0.27	0.30	0.37
T ₆	1.90	1.95	0.31	0.36	0.79	0.87	0.38	0.41	0.20	0.25	0.28	0.36
T ₇	1.87	1.92	0.29	0.34	0.76	0.84	0.35	0.38	0.18	0.21	0.24	0.30
T ₈	1.62	1.69	0.16	0.18	0.58	0.67	0.17	0.23	0.07	0.08	0.15	0.19
CD ($p = 0.05$)	0.04	0.03	0.03	0.09	0.08	0.09	0.05	0.06	0.03	0.05	0.04	0.04

N: Nitrogen; P: Phosphorus; K: Potassium; Ca: Calcium; Mg: Magnesium; S: Sulphur; CD: Critical difference; p : Probability level.

across all elements. The CD values confirmed that these variations were statistically significant at the 5 % level, emphasising the beneficial impact of improved management under T₅ on nutrient conservation at crop maturity.

Effect of farming practices on leaf nutrient content in straw at harvest stage in black gram and pea

The data presented in Table 6 demonstrated that at the straw harvest stage, leaf nutrient content showed considerable variation among different farming practices. Treatment T₅ recorded the highest nutrient concentrations in both black gram and pea straw, with nitrogen at 0.85 % and 1.08 %, phosphorus at 0.23 % and 0.28 % and potassium at 0.73 % and 0.77 %, respectively. Maximum concentrations of calcium (0.24 % and

0.27 %), magnesium (0.13 % and 0.17 %) and sulphur (0.23 % and 0.27 %) were also recorded under T₅ in black gram and pea, indicating enhanced nutrient recycling potential. Conversely, T₈ exhibited the lowest nutrient content across all parameters, reflecting the poorest nutrient retention. The differences were statistically significant (CD at $p \leq 0.05$), demonstrating that improved agronomic practices, particularly under T₅, positively influenced post-harvest straw nutrient composition, which could enhance soil fertility when residues are returned to the field.

Table 6. Effect of different farming practices on leaf nutrient content in straw at harvest stage

Treatment	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		%S	
	Black gram	Pea	Black gram	Pea	Black gram	Pea	Black gram	Pea	Black gram	Pea	Blackgram	Pea
T ₁	0.72	0.93	0.17	0.21	0.65	0.67	0.19	0.21	0.10	0.14	0.18	0.21
T ₂	0.68	0.89	0.15	0.18	0.63	0.64	0.17	0.20	0.09	0.13	0.17	0.20
T ₃	0.74	0.95	0.18	0.23	0.66	0.69	0.21	0.23	0.11	0.15	0.19	0.22
T ₄	0.80	1.02	0.21	0.25	0.69	0.73	0.24	0.27	0.13	0.17	0.23	0.27
T ₅	0.85	1.08	0.23	0.28	0.73	0.77	0.27	0.30	0.15	0.19	0.26	0.29
T ₆	0.82	1.05	0.22	0.27	0.71	0.75	0.25	0.29	0.14	0.18	0.24	0.28
T ₇	0.76	0.99	0.20	0.24	0.68	0.72	0.22	0.25	0.12	0.16	0.20	0.23
T ₈	0.56	0.75	0.08	0.10	0.53	0.55	0.10	0.12	0.05	0.06	0.11	0.12
CD ($p = 0.05$)	0.05	0.03	0.04	0.05	0.07	0.06	0.06	0.04	0.02	0.03	0.04	0.04

N: Nitrogen; P: Phosphorus; K: Potassium; Ca: Calcium; Mg: Magnesium; S: Sulphur; CD: Critical difference; p : Probability level.

Discussion

Long term sub-optimal applications of chemical fertilisers to soil in mid-hill regions resulted in the deterioration of soil health, environmental pollution and stagnation or decrease in crop productivity (30). Under such vulnerable and fragile agro-ecological conditions, reliance on either chemical fertilisers or organic inputs alone often fails to sustain crop performance and soil health in the long term (31). Therefore, identifying integrated nutrient management strategies is an ecologically, socially and economically viable approach that promote long-term soil fertility improvement is essential for sustainable hill agriculture. The findings of this study clearly demonstrate that INM, particularly the combination of NPK with FYM (T_5), significantly enhances growth parameters, yield components and nutrient content in both black gram and garden pea under mid-hill conditions. The increase in plant height might be due to integration of organic manure with inorganic fertilisers that increased the availability of nutrients are considered an important constituent of nucleotides, protein, chlorophyll and enzyme involved in various metabolic processes resulting better vegetative plant growth (32). The increase in numbers of pods per plant was directly related to reproduction, pollen tube growth and pollen germination. Hydroxyl-rich organic molecules, like sugars, which released through applied organic manure was involved in pollen tube wall formation (33, 34). Higher number of grains per pod due to conjunctive use of organic and inorganic fertilisers was due to more assimilation and utilisation of available nutrients by the plants during the entire growth period (35). The improvement in yield attributes due to applied NPK + FYM may be owing to maximum increase in dry matter production and its effective partitioning to the economic sink and increased supply of multi-nutrients might have increased multi-role activities in plant and soil which, in turn, resulted in greater accumulation of carbohydrates, protein and their translocation to the reproductive organs (36). The superior nitrogen, phosphorus and potassium uptake in T_5 treatment further validates the role of INM in enhancing nutrient assimilation due to better root proliferation and enzymatic activity stimulated by improved soil microbial conditions. Moreover, treatments relying solely on either organics or inorganics (such as T_1 and T_2) exhibited comparatively lower performance, indicating the limitations of single-input systems. These findings align with earlier studies by previous researchers, who highlighted that in black gram (*V. mungo*) grown under subtropical conditions of central India with integrated application of inorganic fertilisers (RDF) in combination with organic sources (FYM or vermicompost) and biofertiliser (*Rhizobium*) significantly improved growth, yield and nutrient content compared to the sole application of either chemical fertilisers or organic manures, thereby highlighting the limitations of exclusive nutrient input systems in sustaining crop productivity (37). Collectively, INM emerges as a sustainable and productive approach, especially for hill agriculture, by ensuring optimal crop performance while conserving the ecological integrity of the soil.

Conclusion

Based on the research findings, it can be concluded that different farming practices significantly influence the leaf nutrient content

and productivity of black gram and pea at the flowering stage. Among the treatments, T_5 consistently showed superior nutrient assimilation, recording the highest concentrations of essential macronutrients (nitrogen, phosphorus and potassium) and secondary nutrients (calcium, magnesium and sulphur) in both crops. This enhanced nutrient uptake under T_5 aligns with its superior yield and straw production, indicating that this farming practice optimises plant nutrition and productivity. Conversely, T_8 exhibited the lowest nutrient levels and yields, highlighting the impact of suboptimal practices. The statistical significance of these differences confirms the effectiveness of targeted nutrient management in improving crop performance. From a future perspective, the present findings gain particular importance in the context of the imbalanced use of chemical fertilisers, which poses long-term threats to crop productivity, soil health and environmental sustainability. The results provide wide scope for the adoption of integrated nutrient management practices, which can help farmers to achieve higher productivity while maintaining soil fertility and environmental health, especially under resource-constrained and hill agro-ecological conditions. Long-term adoption of such practices may further contribute to the sustainable intensification of legume-based cropping systems and enhance the resilience of agricultural production systems. Overall, the findings underscore the importance of adopting improved farming practices, such as those in T_5 , to maximise nutrient efficiency and crop yield in black gram and pea cultivation.

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Authors' contributions

M and DKP conceptualised and designed the experiment. M carried out the field experimentation and data collection. Laboratory analysis and data curation were performed by M and JT. Statistical analysis and interpretation of data were conducted by M, AS and MD. DKP provided supervision and overall guidance throughout the study. M prepared the original draft of the manuscript and DKP and AV reviewed and edited the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

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