

Effect of application of bioorganic nutrients on soil health and pea productivity in Entisols of North-western Himalayas

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Received: 09 October 2024

Revised: 09 January 2025

Accepted: 28 May 2025

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Abstract

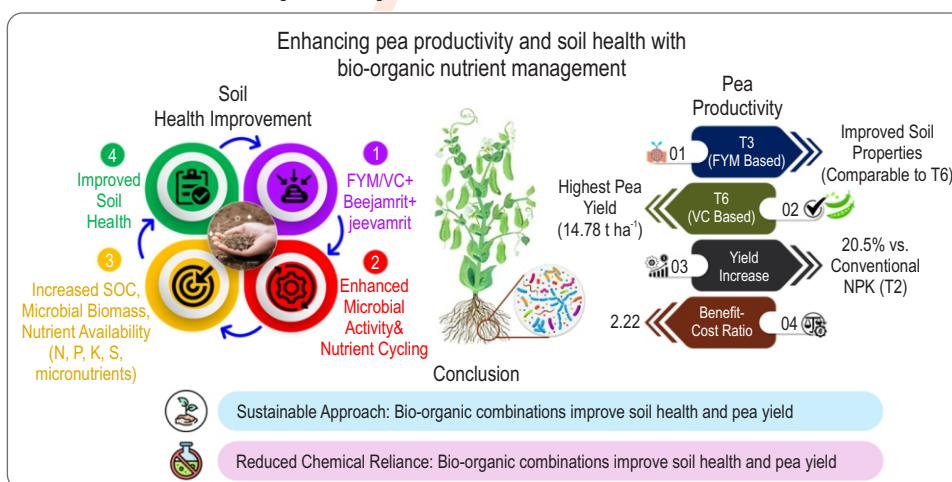
Aim: To evaluate the impact of integrating organic manures and fermented bio-formulations on soil health and pea (*Pisum sativum* L.) productivity as a sustainable alternative to inorganic fertilisers.

Methodology: The experiment evaluated nine treatments, which consisted of various combinations of fermented bio-formulations (jeevamrit, beejamrit, and ghanjeevamrit) and organic manures (FYM and vermicompost). The treatments were laid out in a randomised block design with three replications, using Pea (variety Punjab-89) as the test crop during the years 2021 and 2022.

Results: The results showed that integrating organic manures with bio-formulations significantly improved the soil properties and pea yield. Specifically, treatment T₃ enhanced the soil organic carbon, microbial count, and nutrient availability significantly. However, treatment T₆ achieved the highest pea yield of 14.78 t ha⁻¹, representing a 20.5% increase compared to the conventional NPK treatment (T₂), with a benefit-cost ratio of 2.22. T₆ treatment also demonstrated comparable improvements in the microbiological and biochemical activity to T₂.

Interpretation: The study concludes that the conjoint use of organic manure (FYM or vermicompost) with fermented nutrient sources (beejamrit and jeevamrit) offer a sustainable approach in enhancing the pea productivity and soil health, reducing reliance on chemical fertilisers.

Key words: Bioformulation, Entisols, Nutrient management, Organic manure, *Pisum sativum*



Introduction

The economy of India face challenges such as food and nutrient security, environmental issues, and supporting small farm production systems. Overreliance on fertilisers and pesticides for higher yields exacerbates these problems, impacting the environment and food security, deteriorating soil quality, disrupting plant-microflora relationships, and neglecting traditional farming practices. Agrochemical abuse is linked to reduced nutritional efficiency and increased risks of diseases, including cancers, liver and kidney damage, and cardio-neurotoxicity (Rathore *et al.*, 2023). Exploring alternative nutrient sources like fermented bio-organic formulations (beejamrit, jeevamrit, and ghanjeevamrit) combined with organic manures is essential. These formulations promote soil-plant health by producing biomolecules like growth regulators and enzymes. Organic manures (FYM and VC) and fermented formulations are key in natural farming systems. In hilly regions, organic materials like crop residues, cow dung, and cow urine are readily available for preparing nutrient-rich manures and formulations (Thakur *et al.*, 2025). Fermented formulations improve soil properties and nourish the rhizosphere, enhancing nutrient mobilisation and sustainable crop production (Sharma and Thakur, 2022).

Beejamrit protect seeds and promotes germination, producing plant growth regulators (Mukherjee *et al.*, 2022). Jeevamrit increases soil biochemistry and microbial activity, while ghanjeevamrit is its dried form. These products contain nutrients, amino acids, and microbes essential for crop growth (Sharma and Chadak, 2022). Combining these formulations with FYM and VC aids nutrient mineralisation, improves soil properties, and increases crop productivity. This integrated approach preserves soil microflora, enhancing fertility and nutrient availability. Jeevamrit and ghanjeevamrit, alone or with FYM or VC, provide chemical-free food and maintain soil health (Saharan *et al.*, 2023). In India, where vegetarianism is common, vegetables are crucial for a healthy diet, providing essential nutrients, minerals, and vitamins. Awareness of agrochemical health impacts has increased demand for naturally and organically grown vegetables (Willer *et al.*, 2024). Pea (*Pisum sativum* L.), a leguminous crop, is a good source of protein, carbohydrates, vitamins and minerals (McPhee, 2003; Sharma *et al.*, 2022b).

Pea fixes nitrogen, making it environmentally friendly and promoting sustainable agriculture. The agro-climatic conditions of the North-western Himalayas are favourable for off-season pea cultivation, yielding high premium prices for farmers (Sharma *et al.*, 2023). More farmers are adopting chemical-free farming (Sharma *et al.*, 2022a). There is no existing nutrient management module that combines organic manures and fermented formulations for pea cultivation and research on their combined effects on soil health and pea productivity is lacking. Developing a cost-effective, environmentally friendly nutrient management module is necessary. Considering the challenges mentioned, this study was conducted to assess the impact of organic and fermented nutrient sources on soil properties, enzyme activities, plant-available nutrients and pea productivity.

Materials and Methods

Site description: A field experiment was conducted at the experimental farm of the College of Horticulture and Forestry, Neri, Hamirpur (Himachal Pradesh), during the *rabi* (winter) seasons of 2021 and 2022. It is located at 31°41'43.9" N latitude and 76°27'58.2" E longitude 670 m above sea level. This area falls under the Sub-montane and low hills subtropical with a humid subtropical climate and dry winters (*Cwa*) and represents agroclimatic zone-1 of Himachal Pradesh. The average annual rainfall is 1248 mm. The average climatic normal of the *rabi* seasons of the year 2021 and 2022 are presented in Fig. 1. The soils are classified as *Entisols* with a sandy clay loam texture, pH 7.05, electrical conductivity (EC) of 0.18 dS m⁻¹, soil organic carbon (SOC) content of 5.9 g kg⁻¹, cation exchange capacity (CEC) of 9.15 cmol kg⁻¹, bulk density of 1.39 mg m⁻³, and maximum water holding capacity of 30.8%. Before the start of the experiment, the available nitrogen (N), phosphorus (P), potassium (K), and sulphur (S) content were 211.54, 14.22, 104.28, and 38.24 kg ha⁻¹, respectively. Microbiological and biochemical assessments of soil showed a total viable microbial count of 8.57×10⁵ cfu g⁻¹, nitrogen-fixing bacteria of 6.6×10⁴ cfu g⁻¹, and phosphate-solubilizing bacteria of 2.9×10⁴ cfu g⁻¹. Soil microbial biomass carbon was 21.54 µg C g⁻¹, and soil microbial biomass nitrogen was 11.8 µg N g⁻¹. Enzyme activities included alkaline phosphomonoesterase (140.54 µg nitrophenol g⁻¹ soil hr⁻¹), cellulase (0.107 µg p-nitrophenol released g⁻¹ soil hr⁻¹), urease (40.91 µg N hydrolysed g⁻¹ soil hr⁻¹), and dehydrogenase (21.4 µgtriphenyl formazan g⁻¹ soil day⁻¹).

Experimental design and crop management: The experiment included nine treatments viz. T₁-Beejamrit + Jeevamrit (100% N equivalence), T₂- FYM @ 20 t ha⁻¹ + 100% NPK (RDF; N:25; P:60; K:60 kg ha⁻¹), T₃- FYM @ 20 t ha⁻¹ + Beejamrit + Jeevamrit (100% N equivalence), T₄- FYM @ 20 t ha⁻¹ + Beejamrit + Jeevamrit (75% N equivalence), T₅- Vermicompost @ 5 t ha⁻¹ + 100% NPK (RDF; N:25; P:60; K:60 kg ha⁻¹), T₆- Vermicompost @ 5 t ha⁻¹ + Beejamrit + Jeevamrit (100% N equivalence), T₇- Vermicompost @ 5 t ha⁻¹ + Beejamrit + Jeevamrit (75% N equivalence), T₈- Ghanjeevamrit @ 1 t ha⁻¹ + Beejamrit + Jeevamrit (100% N equivalence), T₉- 100% NPK (RDF; N:25; P:60; K:60 kg ha⁻¹), in a randomised block design (RBD) with three replications. Pea (var. Punjab-89) seeds were sown on 24th November 2021 and 27th November 2022 at 60 cm × 10 cm spacing in 27 plots (6m² each). The site was free off inorganic fertilisers or synthetic agrochemicals for the last seven years. Various input combinations, including organic manures (vermicompost, FYM), fermented formulations (beejamrit, jeevamrit, and ghanjeevamrit), and the recommended fertiliser dose were applied uniformly as the treatment plan. For each treatment combination, the necessary amount of various input combinations, including organic manures (vermicompost, FYM), fermented formulations (beejamrit, jeevamrit, and ghanjeevamrit), and recommended fertiliser dose, was calculated and uniformly applied to each treatment plot. The fermented nutrient formulations (Beejamrit, jeevamrit and ghanjeevamrit) were prepared as per standard method (Palekar,

2006). Field preparation included ploughing to a depth of 0.15 m and planking. Organic manures were applied five days before sowing. Ghanjeevamrit was applied near the plant root zone, and jeevamrit was drenched with irrigation water. Table 1 details the nutrient composition and microbial count of FYM, vermicompost, ghanjeevamrit and jeevamrit. Pea seeds were bio-primed with beejamrit @ 1.0l 10 kg⁻¹ seeds. Nitrogen (N), phosphorus (P), and potassium (K) were applied through urea, SSP and MOP. Nitrogen was applied in two split doses: half during sowing and the remaining half as a top dressing at 30 and 55 days after sowing (DAS). Recommended practices for raising pea crop, viz. intercultural operations, weed control and root aeration, were followed, and irrigation was applied as per requirement. Uniform plant density was maintained through gap filling at 10 DAS and manual weeding was done at 20, 40 and 60 DAS. The weight of green pod was recorded from ten selected plants in each picking, and the average weight was computed as yield per plant and expressed in grams. The yield per plant was converted into yield per hectare (t ha⁻¹) based on the average plant population.

Collection and analysis of soil samples: Surface soil samples (0-0.15 m) were collected after the completion of a two-year experiment to assess treatment effects on soil properties. Soil samples were dried, sieved and stored for analysis. Soil bulk density and maximum water holding capacity (WHC) were quantified using standard procedures outlined by Singh (1980) and Piper (1950), respectively. Soil pH and EC were determined using potentiometric analysis with 1:2.5 soil-water suspensions (Jackson, 1973). Soil organic carbon (SOC) was estimated by the rapid titration method (Walkley and Black, 1934), and available nitrogen (N) was assessed through alkaline potassium permanganate (Subbiah and Asija, 1956). Available phosphorus (P), potassium (K), and sulphur (S) contents were determined by the sodium bicarbonate extraction method (Olsen *et al.*, 1954), flame photometry method (Pratt, 1965), and turbidimetric method (Chesnin and Yien, 1950), respectively. Micronutrient cations (Zn, Cu, Fe and Mn) were estimated by DTPA extraction method and an atomic absorption spectrophotometer (Lindsay and Norvell, 1978). Fresh soil samples were preserved under refrigerated conditions to estimate soil biological properties. Total culturable microbial count, nitrogen-fixing ability and phosphate-solubilizing bacteria were estimated by the spread plate technique and expressed as cfu g⁻¹ soil. The fumigation-extraction method was used to estimate the microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) content in soil. Soil respiration was determined by the carbon dioxide evolution method. Alkaline phosphomonoesterase (Tabatabai and Bremner, 1969), cellulase (Schinner and Mersi, 1990), urease (Kandeler and Gerber, 1988) and dehydrogenase (Casida *et al.*, 1964) activities were determined using standard methods.

Benefit-Cost ratio: The treatment-wise B: C ratio was calculated by dividing the net income (₹) by cultivation's total cost (₹).

Statistical analysis: The experimental data collected over two

growing seasons were pooled and statistically analysed using SPSS 16.0 statistical software. ANOVA and Duncan's multiple range test (DMRT) were employed to compare the least significant difference (LSD) at a probability level of p≤0.05 (Gomez and Gomez, 1984).

Results and Discussion

A significant variation was observed in the green pod yield of pea across different treatments (Fig. 2). The maximum pod yield (14.78 t ha⁻¹) was recorded under T6 treatment, whereas the minimum yield (8.75 t ha⁻¹) was registered under treatment T1. The combined use of organic manure and fermented liquid formulations significantly affected the green pod yield of peas. Treatment T6, resulted in the highest increase in green pod yield (20.5%) compared to the university-recommended practice of manure and fertilisers (RPMF), specifically treatment T2. This increase is attributed to improved nutrition from the continuous nutrient supply in the liquid formulations and vermicompost. Cow urine, a key component of beejamrit and jeevamrit, provides essential nitrogen (0.18%) for vegetative growth. As a result, this combination of bio-organics enhanced the formation of nucleic acids and amino acids in the meristematic tissues, thereby improving flowering, fruiting and pod formation (Suresh *et al.*, 2019; Thakur *et al.*, 2025). The integrated application of fermented formulations and organic manures significantly influenced the soil's water-holding capacity (WHC), cation exchange capacity (CEC), and organic carbon content compared to treatments that involved only application of fertilisers, fermented formulations, or manures combined with inorganic fertilisers (Table 2, 3). The soil pH, electrical conductivity (EC), and bulk density values across different treatment combinations ranged from 6.96 (T3) to 7.02 (T9), 0.12 dS m⁻¹ (T3) to 0.17 dS m⁻¹ (T9), and 1.35 Mg m⁻³ (T3 & T6) to 1.39 Mg m⁻³ (T9) after completion of the experiment. In this study, the highest WHC (34.2%), CEC (12.67 cmol kg⁻¹), and soil organic carbon (9.97 g kg⁻¹) were recorded under treatment T3. While no significant changes were observed on the soil bulk density, pH or electrical conductivity, a non-significant reduction in pH, EC and bulk density was noted under bioorganic treatments and could be attributed to microbial-driven mineralisation and decomposition, leading to the accumulation of humic and carbonic acids in the soil. Additionally, enhanced soil permeability facilitated ion leaching, contributing to reduced electrical conductivity (Sharma and Verma, 2011; Dhaliwal *et al.*, 2023).

Soil organic matter is crucial in enhancing soil quality and productivity through its interactions with biotic and abiotic elements within the soil matrix. Notably, a substantial enhancement in soil organic carbon levels was noted in the experimental plots that received applications of cow-based solid and fermented liquid nutrient inputs. In this study, a noteworthy 20.1% rise in soil organic carbon content with treatment T3 was observed, surpassing the recommended practice of manure and fertiliser application (T2) in post-harvest soil samples. The rise in SOC levels in T3, T6, T4, T7 and T8 treatments could be attributed to

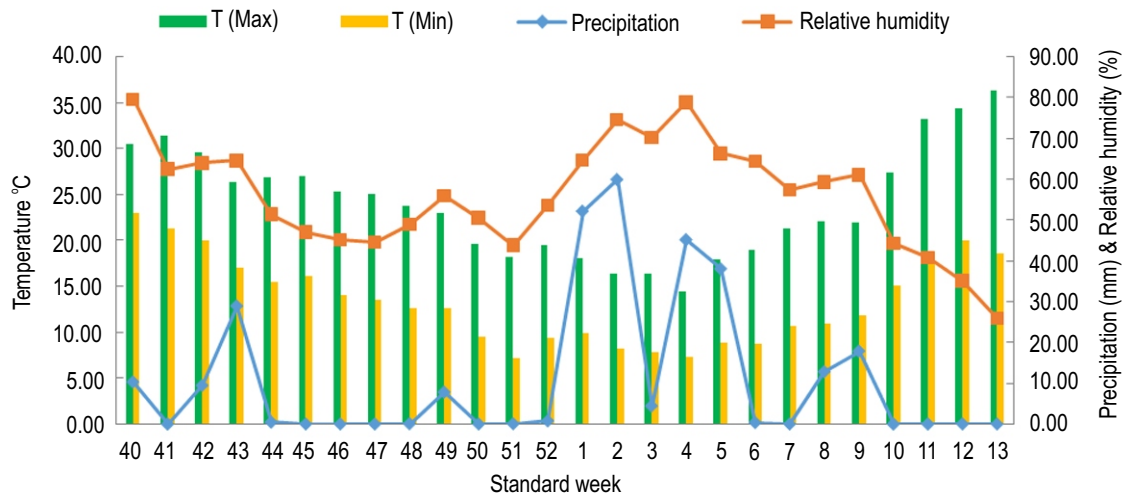


Fig. 1: Average climatic normal during the crop period.

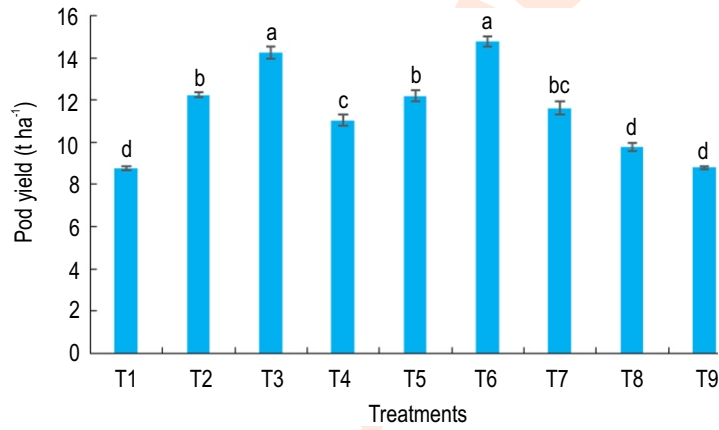


Fig. 2: Effect of organic manures and fermented bio-formulations on green pod yield of pea. Different letters (a, b, c, d) indicate significant differences between treatment means at p ≤ 0.05.

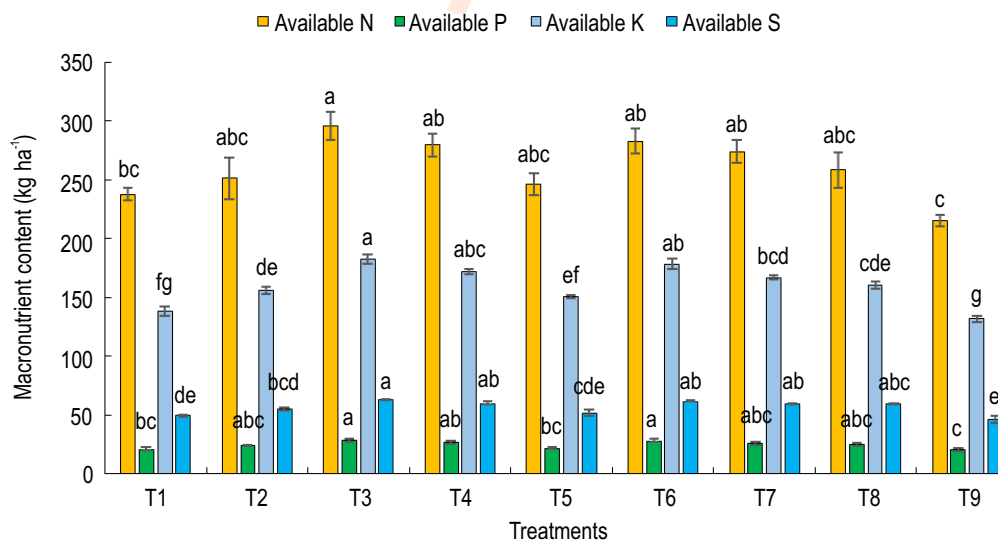


Fig. 3: Effect of organic and fermented nutrient sources on the post-harvest macronutrient content of soil. Different letters (a, b, c, d, e, f, g) indicate significant differences between treatment means at p ≤ 0.05.

Table 1: Nutrient composition and microbial count in organic manures and fermented bio-formulations

Parameters	Organic and fermented inputs			
	Jeevamrit	Ghanjeevamrit	FYM	Vermicompost
N (%)	0.32	1.72	0.39	1.64
P (%)	0.22	0.60	0.22	0.54
K (%)	0.24	0.82	0.35	0.84
S (%)	0.10	0.32	0.24	0.29
Total culturable microbial count (cfu g ⁻¹ cfu ml ⁻¹)	2.68×10 ⁷	2.23×10 ⁸	2.14×10 ⁷	2.01×10 ⁶
N-fixers (cfu g ⁻¹ cfu ml ⁻¹)	21.8×10 ⁶	25.1×10 ⁶	20.1×10 ⁶	19.5×10 ⁶
PSB (cfu g ⁻¹ cfu ml ⁻¹)	9.5×10 ⁶	8.9×10 ⁶	6.7×10 ⁶	7.1×10 ⁶
Alkaline phosphomonoesters (µg nitrophenol g hr ⁻¹)	1.818	1.739	1.252	0.898
Cellulase (µgp NP released g hr ⁻¹)	0.560	0.410	0.223	0.307
Urease (µg N hydrolysed g hr ⁻¹)	264.70	228.40	203.80	212.30
Dehydrogenase (µg TPF g day ⁻¹)	174.20	164.90	102.00	115.00

Table 2: Effect of organic manures and fermented bio-formulations on some physical properties of soil

Treatments	Bulk density (mg m ⁻³)	Maximum water holding capacity (%)
T ₁	1.38 ± 0.07	32.28 ^{bc} ± 0.10
T ₂	1.37 ± 0.05	32.97 ^{abc} ± 0.38
T ₃	1.35 ± 0.05	34.16 ^a ± 0.03
T ₄	1.36 ± 0.06	33.66 ^{ab} ± 0.53
T ₅	1.36 ± 0.05	32.70 ^{abc} ± 0.08
T ₆	1.35 ± 0.05	33.91 ^a ± 0.14
T ₇	1.36 ± 0.05	33.54 ^{ab} ± 0.15
T ₈	1.37 ± 0.06	33.23 ^{ab} ± 0.53
T ₉	1.39 ± 0.05	31.57 ^c ± 0.17
C.D. _(0.05)	NS	0.85
S.E.(m)	0.05	0.28

Data represent the mean of three replications over two seasons. Different letters in the superscript (a, b, c) indicate a significant difference between treatment means at $p \leq 0.05$

the synergistic effects of farmyard manure, vermicompost, ghanjeevamrit, beejamrit, and jeevamrit, and the increased favourable microbial population and stimulated enzymatic activities in the soil, thereby creating an ideal environment for the synthesis of organic substrates like fulvic and humic acids. This, in turn, contributed to an increased soil organic carbon pool (Jaggi and Sharma, 1999; Kumar *et al.*, 2015). Similar results were also reported in French bean and okra crops by Sharma and Thakur (2022) and Sharma and Chadak (2022), respectively. Furthermore, treatment T₃ resulted in a 3.61% increase in WHC over treatment T₂, likely due to enhanced soil organic matter and improved soil aggregation. The combined application of organic manure and liquid-fermented formulations positively influenced the residual fertility of the soil, as shown in Fig. 3,4. Treatment T₃, significantly increased the plant-available nitrogen (295.86 kg ha⁻¹), phosphorus (28.29 kg ha⁻¹), potassium (182.35 kg ha⁻¹), sulphur (62.64 kg ha⁻¹), and DTPA-extractable micronutrient cations such as Fe (13.65 mg kg⁻¹), Mn (8.99 mg kg⁻¹), Cu (2.90 mg kg⁻¹) and Zn

(2.09 mg kg⁻¹) after completion of two-season experiment.

Combining organic manures and liquid fermented formulations promoted beneficial microbial populations, enhancing mineralisation of organically bound nutrients and improving their bioavailability to plants. Treatment T₃ led to 18.0% increase in plant-available nitrogen compared to T₂ (Fig. 3). This could be attributed to accelerated decomposition under plots treated with organic manures and liquid fermented formulations, driven by microbial activity and nitrogen fixation by legume crops (Kimi *et al.*, 2021). Furthermore, the increase in phosphorus availability by 26.28% in treatment T₃ could be ascribed to microbial-mediated solubilisation of native phosphorus, facilitated due to generation of organic acids that form complexes with iron and aluminium, mobilising indigenous phosphorus (Sharma and Chadak, 2022). Enhanced microbial activity, particularly phosphorus-solubilizing bacteria (PSB), was more pronounced in organic and fermented treatments (Sharma and

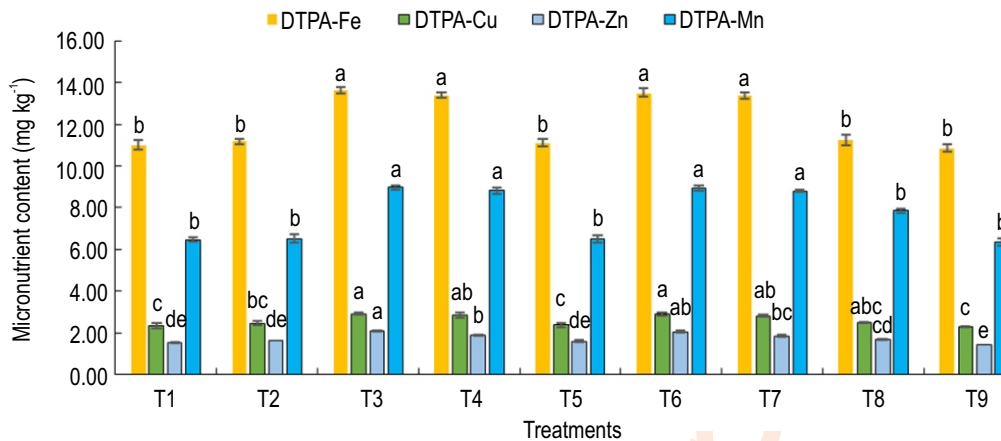


Fig. 4: Effect of organic manures and fermented bio-formulations on post-harvest DTPA extractable soil micronutrients. Different letters (a, b, c, d, e) indicate significant differences between treatment means at $p \leq 0.05$.

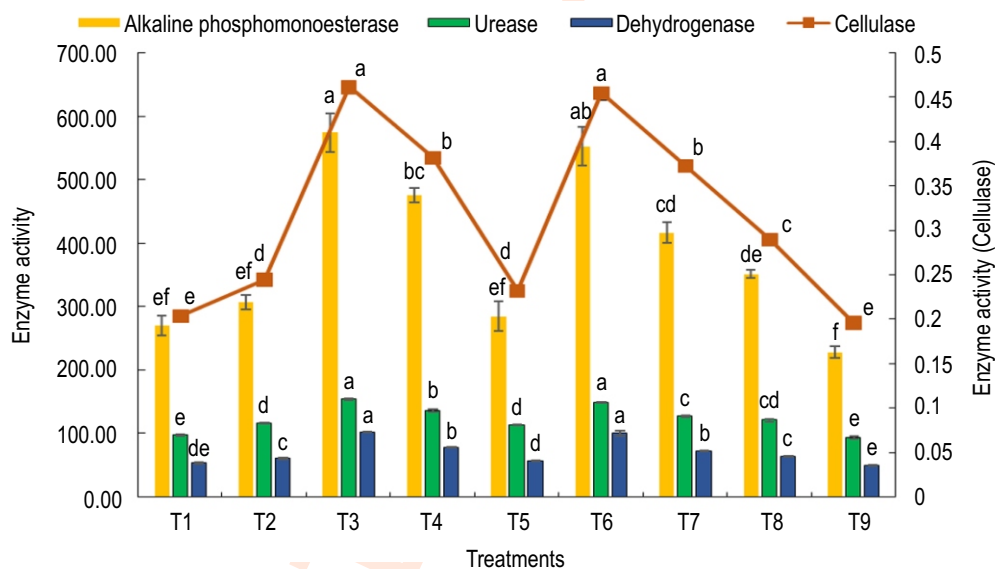


Fig. 5: Effect of organic and fermented nutrient sources on post-harvest biochemical properties of soil. Alkaline phosphomonoesterase is expressed as $\mu\text{g p-nitrophenol g}^{-1}\text{hr}^{-1}$, urease as $\mu\text{g N hydrolysed g}^{-1}\text{hr}^{-1}$, dehydrogenase as $\mu\text{g TPF g}^{-1}\text{day}^{-1}$ and cellulase as $\mu\text{g glucose equivalents g hr}^{-1}$. Different letters (a, b, c, d, e) indicate significant differences between treatment means at $p \leq 0.05$.

Thakur, 2022). In addition, treatment T_3 demonstrated significant increase in potassium (6.19%) and sulphur (10.35%) levels, which could be linked to improved CEC, promoting better retention and release of basic cations (Chatterjee and Bandyopadhyay, 2014). The decomposition of organic manures also enhanced the release of potassium ions and sulphur content, contributing to improved nutrient cycling (Bader et al., 2021).

The study found that plots treated with organic manure and liquid-fermented formulations showed increased micronutrient availability, likely due to chelating agents released by microbes during decomposition of organic matter, which prevent micronutrients from precipitating, oxidising, or leaching

(Fig. 4). The narrow carbon-to-nitrogen (C: N) ratio in farmyard manure (FYM) and vermicompost may contribute to higher levels of micronutrient cations. Furthermore, beejamrit and jeevamrit applications enhance the mineralisation of native nutrients, releasing trace elements into the rhizosphere. Previous research also supports the benefits of organic nutrient sources on DTPA-extractable micronutrients in soils for bell pepper and okra cultivation (Sharma et al., 2020; Sharma and Chadak, 2022). The use of diverse nutrient sources significantly impacted various microbiological properties of post-harvest soil (Table 4). Treatment T_3 , demonstrated the highest values for total microbial count (2.11×10^7 CFU g^{-1} soil), nitrogen-fixing bacteria (12.35×10^5 CFU g^{-1} soil), phosphate-solubilizing bacteria (6.80×10^5 CFU g^{-1}

Table 3: Effect of organic manures and fermented nutrient sources on some important chemical properties of soil

Treatments	pH	EC (dSm ⁻¹)	Soil organic carbon (g kg ⁻¹)	CEC (cmol p ⁺ kg ⁻¹)
T ₁	7.01	0.16 ± 0.02	6.80 ^b ± 0.29	10.37 ^c ± 0.32
T ₂	7.00	0.15 ± 0.02	8.30 ^{ab} ± 0.49	10.90 ^a ± 0.53
T ₃	6.96	0.12 ± 0.03	9.97 ^a ± 0.12	12.67 ^a ± 0.50
T ₄	7.00	0.14 ± 0.02	9.08 ^a ± 0.72	11.83 ^{abc} ± 0.26
T ₅	7.01	0.16 ± 0.03	7.97 ^{ab} ± 0.09	10.57 ^{bc} ± 0.29
T ₆	6.98	0.13 ± 0.04	9.65 ^a ± 0.27	12.37 ^{abc} ± 0.32
T ₇	6.99	0.14 ± 0.03	8.73 ^{ab} ± 0.60	11.67 ^{abc} ± 0.43
T ₈	7.00	0.16 ± 0.02	8.42 ^{ab} ± 0.31	11.20 ^a ± 0.27
T ₉	7.02	0.16 ± 0.04	6.53 ^b ± 0.67	10.13 ^c ± 0.26
C.D. _(0.05)	-	NS	1.44	1.17
S.E.(m)	-	0.02	0.48	0.39

Data represent mean of three replications over two seasons. Different letters in the superscript (a, b, c) indicate a significant difference between treatment means at $p \leq 0.05$.

Table 4: Microbiological parameters of soil as affected by organic and fermented nutrient sources

Treatments	Total microbial population (cfu g ⁻¹ soil × 10 ⁷)	Nitrogen fixing bacteria (cfu g ⁻¹ soil × 10 ⁵)	Phosphate solubilizing bacteria (cfu g ⁻¹ soil × 10 ⁵)	Microbial biomass Carbon (µg C g ⁻¹ dry soil)	Microbial biomass nitrogen (µg N g ⁻¹ dry soil)	Soil respiration (µg CO ₂ g ⁻¹ soil 24 hr ⁻¹)
T ₁	1.52 ^{cd} ± 0.04	9.90 ^{cd} ± 0.2	4.50 ^{cd} ± 0.30	57.54 ^{de} ± 0.67	24.90 ^{bc} ± 2.07	318.17 ^{de} ± 16.33
T ₂	1.70 ^{bc} ± 0.03	10.80 ^{abcd} ± 0.3	5.50 ^{abcd} ± 0.30	59.05 ^{cde} ± 0.27	29.77 ^{abc} ± 2.11	345.43 ^{bcd} ± 20.46
T ₃	2.11 ^a ± 0.07	12.35 ^a ± 0.25	6.80 ^a ± 0.40	67.84 ^a ± 0.53	38.97 ^a ± 2.29	423.67 ^a ± 9.92
T ₄	1.85 ^b ± 0.03	11.95 ^{ab} ± 0.45	6.15 ^{abc} ± 0.35	62.84 ^{bc} ± 0.53	32.23 ^{ab} ± 1.36	393.67 ^{abc} ± 18.65
T ₅	1.69 ^{bcd} ± 0.02	10.30 ^{bcd} ± 0.10	5.05 ^{bcd} ± 0.15	59.15 ^{cde} ± 0.24	29.23 ^{abc} ± 1.94	327.13 ^{cde} ± 14.16
T ₆	2.08 ^a ± 0.05	12.15 ^a ± 0.35	6.60 ^{ab} ± 0.50	65.06 ^{ab} ± 0.42	35.97 ^a ± 1.63	413.67 ^{ab} ± 9.92
T ₇	1.84 ^b ± 0.04	11.85 ^{ab} ± 0.45	6.00 ^{abc} ± 0.20	62.04 ^{bcd} ± 0.44	31.70 ^{abc} ± 0.61	380.77 ^{abcd} ± 9.02
T ₈	1.74 ^b ± 0.03	11.20 ^{abc} ± 0.40	5.85 ^{abc} ± 0.25	60.98 ^{bcd} ± 0.19	31.57 ^{abc} ± 3.31	366.37 ^{abcde} ± 10.25
T ₉	1.48 ^d ± 0.04	9.40 ^d ± 0.10	4.10 ^d ± 0.10	54.98 ^e ± 0.19	21.70 ^c ± 2.28	298.10 ^e ± 11.31
C.D. _(0.05)	0.13	0.89	0.94	2.71	6.62	42.57
S.E.(m)	0.04	0.27	0.28	0.90	2.19	14.08

Data represent mean of three replications over two seasons. Different letters in the superscript (a, b, c, d, e) indicate significant differences between treatment means at $p \leq 0.05$.

soil), microbial biomass carbon (67.84 µg C g⁻¹ dry soil), microbial biomass nitrogen (38.97 µg N g⁻¹ dry soil), and soil respiration rate (423.66 µg CO₂ g⁻¹ soil per 24 hr).

Notably, treatment T₃ exhibited significant increase in the microbial counts and activity, with 23.5% improvement in total microbial count, 14.3% for nitrogen-fixing bacteria, 23.6% for phosphate-solubilizing bacteria, 14.9% for microbial biomass carbon, 30.9% for microbial biomass nitrogen, and 22.6% for soil respiration, when compared to treatment T₂. These findings align with the previous studies indicating that organic amendments enhance soil microbial populations, thereby promoting soil health and nutrient cycling (Hicks *et al.*, 2021; Sharma and Chadak, 2022). Soil enzymatic activity, a key indicator of soil health, significantly increased under different treatments. The activities of alkaline phosphomonoesterase (574.67 µg p-nitrophenol g⁻¹

hr⁻¹), cellulase (0.462 µg glucose equivalents g⁻¹ hr⁻¹), urease (153.99 µg N hydrolysed g⁻¹ hr⁻¹), and dehydrogenase (102.33 µg TPF g⁻¹ day⁻¹) were highest in treatment T₃ compared to other treatments (Fig. 5). These enzymatic activities were elevated by 88.6%, 32.5%, 67.8% and 87.0%, respectively, over T₂. Higher enzymatic activity is crucial for nutrient cycling and soil health, as it supports organic matter decomposition and nutrient release (Ghosh *et al.*, 2020). A positive association between soil microbial biomass and enzymatic activity has also been previously reported by Choudhary *et al.* (2022) in wheat+ gram intercropping systems.

Economic analysis is crucial for evaluating farmers' performance and adopting new technologies, which must be economically efficient to gain widespread use. Table 5 shows different treatments' benefit-cost (B: C) ratios. Treatment T₆ had the highest gross returns of ₹162300/- and a B: C ratio of 2.22,

Table 5: Effect of organic manures and fermented nutrient sources on cultivation economics of pea

Treatments	Value of marketable produce (₹)	Total cost of inputs (₹)	Gross returns (₹)	B:C ratio
T ₁	175000	112100	62900	1.56
T ₂	245200	122292	122908	2.01
T ₃	285000	144500	140500	1.97
T ₄	221000	130750	90250	1.70
T ₅	246400	116092	130308	2.12
T ₆	295600	133300	162300	2.22
T ₇	232200	119550	112650	1.94
T ₈	195000	102750	92250	1.90
T ₉	176000	89892	86108	1.97
C.D. (0.05)		0.31		

while treatment T₁ had the lowest (1.58). The assessment revealed that various bio-organic nutrient sources positively affected the pea plant growth and productivity. Treatment T₆, achieved a B: C ratio of 2.22 due to higher yield and lower cultivation cost. These results are consistent with the findings of Sharma and Thakur (2022) and Vikash *et al.* (2022), which indicated improved benefit-cost ratios for French bean and green pea when using combined organic nutrient sources.

The findings of this study revealed an effective combination of organic manures and fermented nutrient formulations to boost pea productivity and improve post-harvest soil health. The optimal combination was farmyard manure (FYM) @ 20 t ha⁻¹ with beejamrit and jeevamrit (100% N equivalence), which maintained soil health over time. For pea productivity, the best combination was T₆, using vermicompost @ 5 t ha⁻¹ along with beejamrit and jeevamrit (100% N equivalence), resulting in a 20.5% increase in yield compared to treatment T₂ (RPMF) and a benefit-cost ratio of 2.22. Overall, the use of beejamrit and jeevamrit with FYM or vermicompost effectively replaced chemical fertilisers, promoting sustainable pea production without compromising yield.

Acknowledgment

The authors are thankful to the College of Horticulture and Forestry, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Hamirpur, H.P., India, for assistance received during research work.

Authors' contribution: **R. Sharma:** Conceptualization of research idea, Methodology, Resources, Writing -revision and editing; **K. Jasrotia:** Execution of field experiment and data collection, Laboratory analysis, Writing-original draft; **V. Sharma:** Analysis of data, Interpretation of results and manuscript editing; **S. Sharma:** Data analysis of data and interpretation; **M. Thakur:** Laboratory analysis and data curation; **A. Sharma:** Contribution of experimental materials; **Ojaswini:** Data analysis and interpretation.

Funding: Not applicable.

Research content: The research presented in this manuscript is original and has not been published elsewhere.

Ethical approval: Not applicable.

Conflict of interest: The authors declare no conflicts of interest.

Data availability: Not applicable.

Consent to publish: All authors agree to publish the paper in *Journal of Environmental Biology*.

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