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Growth, Yield, Soil Properties, and Economic Performance of Pea under Integrated Nutrient Management in a Plum-Based Agroforestry System in Kullu Valley, India

Abhijeet Singh [a*], Manoj Kumar Thakur [a], K. S. Pant [b], Prem Prakash Sharma [a], Nisha Thakur [a] and Prakash [c]

[a] Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India.
[b] VCSG Uttarakhand University of Horticulture and Forestry, Bharsar, UK, India.
[c] Indian Institute of Forest Management, Bhopal, Madhya Pradesh, India.

Authors' contributions

This work was carried out in collaboration among all authors. Authors AS, MKT, KSP, PPS and NT contributed to the study conception and design, manuscript draft preparation, data collection and analysis, reviewing and editing. Authors MKT, KSP, PPS and NT framed the methodology and designed the experiment. Authors AS and Prakash wrote the manuscript. All authors read and approved the final manuscript.

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Abstract

Integrated nutrient management may improve the productivity and soil performance of fruit-tree-based agroforestry, but crop responses depend on resource availability beneath the tree canopy. A field experiment was conducted during the winter 2021–2022 season at Diyar, Kullu, Himachal Pradesh, India, to evaluate pea

**Corresponding author: E-mail: abhijeetsinghforester@gmail.com;*

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(*Pisum sativum* L.) under a plum (*Prunus salicina* Lindl. 'Mariposa')-based agroforestry system and sole cropping. Twelve nutrient treatments were evaluated in a factorial randomized block design with three replications. The treatments comprised the recommended dose of fertiliser (RDF), farmyard manure (FYM), vermicompost (VC), goat manure, Jeevamrut, combinations of organic sources with 50% RDF, and an unfertilised control. Sole cropping produced higher mean plant height, pod length, pod width, pods per plant, pod yield, and biological yield than the plum-based system. Across planting conditions, 50% RDF + 50% VC produced the highest pod yield (18.5 t ha^{-1}) and biological yield (45.1 t ha^{-1}), whereas the control produced the lowest values. Post-harvest soil means under the agroforestry system showed slightly lower bulk and particle density and slightly higher soil organic carbon and available nitrogen, phosphorus, and potassium than the sole-cropping system. Despite lower pea yield beneath plum, the agroforestry system recorded a higher mean net return (US$4,535$ha^{-1}$) and benefit:cost ratio (3.39) because the whole-system appraisal included the tree component. The results indicate a trade-off between understory pea yield and whole-system economic performance. Under the conditions of this experiment, integrating 50% RDF with 50% VC provided the most favourable combination of pea growth, yield, and economic return.

Keywords: Agri-horticulture; farmyard manure; garden pea; soil fertility; vermicompost; whole-system profitability.

1. Introduction

Agroforestry integrates woody perennials with crops or livestock on the same land-management unit and can diversify production while improving nutrient cycling and soil protection. Its performance, however, depends on the balance between facilitative processes and competition for light, water, and nutrients. Nutrient acquisition in agroforestry is influenced by root distribution, litter inputs, microbial processes, and the spatial arrangement of trees and crops (Isaac & Borden, 2019). In temperate and subtropical systems, the yield response of an intercrop varies with tree age, canopy structure, distance from the tree row, crop species, and management intensity (Pardon et al., 2018). Recent temperate agroforestry evidence further indicates that crop responses to shading depend on the severity of light reduction and the concurrent availability of water and nutrients, reinforcing the importance of evaluating these resources together (Vaccaro et al., 2022).

Fruit-tree-based agroforestry is particularly relevant in the Himalayan region because it combines annual crop production with perennial fruit output. Such systems may increase whole-farm value and diversify income, although the associated reduction in subcanopy light can constrain understory crop productivity (Kumar et al., 2024). Studies in temperate fruit-tree systems have similarly shown that resource competition can reduce crop growth near trees, while the economic value of the perennial component may compensate for lower annual-crop yield (Gao et al., 2013; Xia et al., 2020). Himalayan agroforestry systems also contribute biomass, carbon storage, and livelihood benefits, but responses are strongly site-specific (Zahoor et al., 2021). Field measurements at a fruit tree–crop interface have also shown that spatial variation in incident light can be associated with corresponding differences in intercrop growth and yield, highlighting the value of canopy-aware system design (Pham et al., 2024).

Garden pea (*Pisum sativum* L.) is an important cool-season legume and vegetable crop in the north-western Himalayas. Its short duration and market value make it a potentially suitable intercrop in deciduous fruit orchards. Previous work under *Grewia optiva*-based agrisilviculture showed that pea growth and yield were affected by tree spacing and manure management (Kar et al., 2019). These observations indicate that both canopy environment and nutrient supply must be considered when pea is introduced beneath fruit trees. Recent field research in garden pea confirms that crop productivity, nutrient uptake, and soil health respond to nutrient level, although the magnitude of response depends on the agronomic context (Chandel et al., 2023).

Integrated nutrient management combines mineral fertilisers with organic nutrient sources to maintain crop productivity and improve soil function. Meta-analytic evidence from Indian cropping systems indicates that integrated nutrient management can improve crop yield, microbial activity, and soil carbon relative to mineral fertiliser or organic sources used alone, although the magnitude of response varies among crops and environments (Padbhushan et al., 2021). Organic amendments may improve aggregation and soil organic matter, whereas mineral fertilisers provide nutrients in readily available forms (Abiven et al., 2009; Kaur et al., 2008). Recent syntheses likewise emphasise that balanced combinations of nutrient sources can support yield and soil quality while reducing reliance on a single input pathway (Paramesh et al., 2023; Haque et al. 2015, 2018). A recent systematic review likewise concluded that combining vermicompost with mineral nutrient sources can support crop performance and soil health, while outcomes remain dependent on formulation and application context (Sande et al., 2024).

Within fruit-based agroforestry, nutrient management must address both crop demand and tree–crop interactions. Organic manure and integrated nutrient treatments have improved soil properties and crop performance in several Himalayan agroforestry systems (Garima et al., 2021; Kumar et al., 2023; Saakshi et al., 2025). However, evidence for pea under plum in the mid-hills of Himachal Pradesh remains limited. The present study therefore evaluated the effects of planting condition and twelve nutrient treatments on pea growth and yield, post-harvest soil properties, and whole-system economic performance. It was hypothesised that sole cropping would produce greater pea yield, that a combined mineral–organic nutrient treatment would outperform single sources, and that the plum-based system would provide superior whole-system economic returns despite reduced understory yield.

2. Materials and Methods

2.1 Study Site and Experimental Season

The experiment was conducted during the winter 2021–2022 crop season in a plum orchard at Diyar village, Kullu district, Himachal Pradesh, India (31°51′05″ N, 77°12′17″ E; approximately 1,200 m above mean sea level). The site has a sub-humid, sub-temperate climate with cool winters and a monsoon-dominated annual rainfall of approximately 1,100–1,200 mm. The plum orchard had been established in January 2014.

The agroforestry component consisted of Japanese plum (*Prunus salicina* Lindl. ‘Mariposa’) planted at 4.5 m × 3.5 m in east–west-oriented rows. Pea was cultivated either beneath the plum-based system (S1) or as a sole crop in an open field (S2).

2.2 Experimental Design and Nutrient Treatments

The experiment was arranged as a 2 × 12 factorial randomized block design with three replications, giving 72 treatment plots. The two planting conditions were S1, plum-based agroforestry, and S2, sole pea cropping. Each plot measured 4 m × 3 m. The nutrient treatments were as follows:

T1: 100% recommended dose of fertiliser (RDF)
T2: FYM supplying 100% of the recommended nitrogen on an equivalence basis
T3: vermicompost supplying 100% of the recommended nitrogen on an equivalence basis
T4: goat manure supplying 100% of the recommended nitrogen on an equivalence basis
T5: Jeevamrut at 500 L ha^{-1}
T6: 50% RDF + 50% FYM
T7: 50% RDF + 50% vermicompost
T8: 50% RDF + 50% goat manure
T9: 50% RDF + 50% Jeevamrut
T10: 50% RDF + 25% FYM + 25% vermicompost
T11: 50% RDF + 25% goat manure + 25% Jeevamrut
T12: unfertilised control

The recommended fertiliser dose for pea was 25:60:60 kg $N:P_2O_5:K_2O$ ha^{-1}. On the basis of measured nitrogen concentrations, the quantities used to supply the recommended nitrogen were 5.00 t ha^{-1} FYM (0.5% N), 1.67 t ha^{-1} vermicompost (1.5% N), and 0.83 t ha^{-1} goat manure (3.0% N). The equivalence calculation standardised nitrogen input; the accompanying phosphorus, potassium, and micronutrient inputs from the organic materials were not separately standardised.

2.3 Preparation and Application of Nutrient Sources

Jeevamrut was prepared by mixing 1.25 kg cow dung, 1.25 L cow urine, 250 g jaggery, 250 g pulse flour, and 100 g field soil in 25 L water. The container was covered with a permeable cloth and the mixture was stirred two to three times daily. Before soil drenching, 5 L Jeevamrut was diluted in 100 L water. Jeevamrut was applied 15 and 30 days after sowing.

FYM, vermicompost, and goat manure were applied according to treatment and incorporated into the upper 10–15 cm soil layer before sowing. For RDF-containing treatments, half of the nitrogen and the full phosphorus and potassium doses were applied at sowing; the remaining nitrogen was top-dressed at the pre-flowering stage. Urea, single superphosphate, and muriate of potash were used as mineral nutrient sources.

2.4 Crop Management and Observations

The field was ploughed, cleared of stones and crop residues, levelled, and divided into 4 m × 3 m plots. Pea was sown in December 2021 at 30 cm × 7.5 cm spacing. Thinning and manual weeding were undertaken as required, and the crop was harvested manually.

At harvest, ten plants were selected randomly from each plot. Plant height (cm), pod length (cm), pod width (mm), number of pods per plant, pod yield (t ha^{-1}), and biological yield (t ha^{-1}) were recorded. The ten plant observations were averaged to represent the corresponding experimental plot. Biological yield represented the harvested above-ground plant mass, including pods.

2.5 Soil Sampling and Analysis

Soil was sampled before sowing in November 2021 and after harvest in March 2022. Three cores were collected from each plot at 0–30 cm depth and combined to form one composite sample per plot. Samples were shade-dried, gently ground, and passed through a 2-mm sieve. Bulk density, particle density, soil organic carbon, available nitrogen, available phosphorus, and available potassium were determined in the Department of Silviculture and Agroforestry soil laboratory using the laboratory's routine validated procedures. Post-harvest values are reported in the present manuscript.

2.6 Economic Analysis

Economic performance was calculated on a per-hectare basis for the plum–pea agroforestry system and the sole pea crop. Costs included land preparation, seed, fertilisers and organic inputs, labour, weeding, harvesting, and system maintenance. For the agroforestry treatment, plum establishment and maintenance expenses were annualised and the value of the plum component was included in whole-system returns. Gross return was calculated from marketable output and the prevailing market prices during the study period. Net return was calculated as gross return minus total cultivation cost, and the benefit:cost ratio was calculated as gross return divided by total cultivation cost. Economic values are presented in US dollars per hectare as recorded in the study accounts.

2.7 Statistical Analysis

Plot-level data were analysed in R version 4.3.2 (R Core Team, 2023). The factorial analysis of variance included planting system, nutrient treatment, their interaction, and block. Residual normality was evaluated using the Shapiro–Wilk test. Treatment means were separated using the least significant difference procedure at $p \leq .05$, following the principles described by Gomez and Gomez (1984). The tables report the critical difference at the 5% probability level for planting system (S), nutrient treatment (T), and the S × T interaction.

3. Results

3.1 Growth and Yield of Pea

Planting system, nutrient treatment, and their interaction affected the recorded growth and yield variables (Tables 1 and 2). Across nutrient treatments, sole cropping produced greater plant height (74.0 cm), pod length (8.184 cm), pod width (15.847 mm), number of pods per plant (10.453), pod yield (15.9 t ha^{-1}), and biological yield (44.6 t ha^{-1}) than the corresponding means under the plum-based system. Mean pod yield beneath plum was 9.666 t ha^{-1}, representing a 39.4% reduction relative to sole cropping.

Table 1. Effects of planting system and integrated nutrient management on plant height, pod length, and pod width of pea

Treatment	Plant height (cm)			Pod length (cm)			Pod width (mm)		
	S1	**S2**	**Mean**	**S1**	**S2**	**Mean**	**S1**	**S2**	**Mean**
T1	70.2^{g}	74.703^{b}	72.446^{b}	8.043^{cde}	8.559^{ab}	8.301^{ab}	16.553^{bcdef}	17.428^{abc}	16.991^{bc}
T2	69.087^{jk}	73.526^{de}	71.306^{de}	7.457^{fgh}	7.935^{cde}	7.696^{def}	13.817^{hij}	14.550^{ghi}	14.183^{gh}
T3	69.377^{hijk}	73.836^{cde}	71.607^{d}	7.523^{fgh}	8.006^{cde}	7.765^{de}	14.587^{fghi}	15.358^{defgh}	14.973^{efgh}
T4	69.203^{ijk}	73.649^{de}	71.426^{de}	7.470^{fgh}	7.954^{cde}	7.712^{def}	14.003^{hi}	14.744^{efghi}	14.374^{fgh}
T5	68.697^{k}	73.112^{e}	70.904^{e}	7.340^{gh}	7.812^{def}	7.576^{ef}	13.233^{ijk}	13.936^{hij}	13.585^{h}
T6	71.110^{f}	75.679^{a}	73.395^{a}	8.250^{bc}	8.688^{a}	8.469^{a}	17.103^{abcd}	18.010^{ab}	17.556^{ab}
T7	71.307^{f}	75.893^{a}	73.600^{a}	8.297^{abc}	8.701^{a}	8.499^{a}	17.917^{ab}	18.867^{a}	18.392^{a}
T8	69.930^{ghi}	74.425^{bc}	72.177^{bc}	7.720^{efg}	8.219^{bcd}	7.970^{cd}	15.753^{cdefgh}	16.587^{bcde}	16.170^{bcde}
T9	69.380^{hijk}	73.840^{cde}	71.610^{d}	7.657^{efg}	8.151^{bcd}	7.904^{cd}	14.830^{efghi}	15.617^{cdefgh}	15.223^{defg}
T10	70.007^{gh}	74.506^{bc}	72.256^{b}	7.837^{def}	8.339^{abc}	8.088^{bc}	16.120^{bcdefg}	16.975^{abcd}	16.547^{bcd}
T11	69.460^{ghij}	73.924^{cd}	71.692^{cd}	7.663^{efg}	8.158^{bcd}	7.911^{cd}	15.323^{defgh}	16.134^{bcdefg}	15.729^{cdef}
T12	67.237^{l}	71.557^{f}	69.397^{f}	7.220^{h}	7.686^{efg}	7.453^{f}	11.363^{k}	11.963^{jk}	11.663^{i}
Mean	**69.582^{b}**	**74.054^{a}**		**7.706^{b}**	**8.184^{a}**		**15.050^{b}**	**15.847^{a}**	
CD0.05	**S**	**0.22**		**S**	**0.12**		**S**	**0.57**	
	T	**0.53**		**T**	**0.29**		**T**	**1.40**	
	S×T	**0.74**		**S×T**	**0.41**		**S×T**	**1.98**	

Note. S1 = plum-based agroforestry; S2 = sole pea cropping. RDF = recommended dose of fertiliser. FYM = farmyard manure. VC = vermicompost. GM = goat manure. $CD_{0.05}$ = critical difference at p ≤ .05. Within a response column, means bearing different superscript letters differ according to the reported mean-separation procedure

Table 2. Effects of planting system and integrated nutrient management on pods per plant, pod yield, and biological yield of pea

Treatment	Pods per plant (number)			Pod yield (t ha^{-1})			Biological yield (t ha^{-1})		
	S1	S2	Mean	S1	S2	Mean	S1	S2	Mean
T1	11.547^{bcde}	12.160^{abcd}	11.853^{bc}	11.707^{ghijk}	19.163^{bc}	15.435^{bc}	36.163^{hij}	47.934^{bc}	42.049^{bc}
T2	8.200^{jklm}	8.640^{ijkl}	8.420^{g}	7.397^{op}	12.352^{ghij}	9.874^{fg}	31.853^{lmn}	41.123^{fg}	36.488^{f}
T3	8.810^{ijk}	9.280^{ghijk}	9.045^{fg}	8.460^{mno}	13.989^{fgh}	11.225^{ef}	32.917^{klm}	42.761^{ef}	37.839^{ef}
T4	8.503^{jkl}	8.960^{hijk}	8.732^{g}	8.050^{no}	13.345^{fghi}	10.697^{efg}	32.510^{lmn}	42.116^{ef}	37.313^{ef}
T5	7.897^{klm}	8.320^{jklm}	8.108^{g}	6.897^{op}	11.578^{ghijk}	9.237^{g}	31.357^{mn}	40.349^{fg}	35.853^{f}
T6	12.457^{abc}	13.120^{ab}	12.788^{ab}	12.433^{ghij}	21.033^{ab}	16.733^{ab}	36.893^{hi}	49.805^{ab}	43.349^{ab}
T7	13.063^{ab}	13.760^{a}	13.412^{a}	14.133^{efg}	22.928^{a}	18.531^{a}	38.590^{gh}	51.699^{a}	45.145^{a}
T8	10.637^{defgh}	11.200^{cdef}	10.918^{cde}	10.980^{ijklm}	17.387^{cd}	14.183^{cd}	35.440^{ijk}	46.158^{cd}	40.799^{cd}
T9	9.723^{fghij}	10.240^{efghi}	9.982^{ef}	9.520^{klmno}	15.735^{def}	12.627^{de}	33.977^{jklm}	44.506^{de}	39.241^{de}
T10	11.243^{cdef}	11.840^{bcde}	11.542^{cd}	11.300^{hijkl}	18.606^{bc}	14.953^{bc}	35.757^{ij}	47.377^{bc}	41.567^{bc}
T11	10.333^{efghi}	10.880^{cdefg}	10.607^{de}	10.177^{jklmn}	16.806^{cde}	13.491^{cd}	34.637^{ijkl}	45.577^{cd}	40.107^{cd}
T12	6.683^{m}	7.040^{lm}	6.862^{h}	4.943^{p}	8.571^{lmno}	6.757^{h}	30.027^{n}	36.987^{hi}	33.507^{g}
Mean	**9.925^{b}**	**10.453^{a}**		**9.666^{b}**	**15.958^{a}**		**34.177^{b}**	**44.699^{a}**	
CD0.05	**S**	**0.50**		**S**	**0.80**		**S**	**0.81**	
	T	**1.23**		**T**	**1.97**		**T**	**1.99**	
	S×T	**1.74**		**S×T**	**2.78**		**S×T**	**2.82**	

Note. S1 = plum-based agroforestry; S2 = sole pea cropping. RDF = recommended dose of fertiliser. FYM = farmyard manure. VC = vermicompost. GM = goat manure. $CD_{0.05}$ = critical difference at p ≤ .05. Within a response column, means bearing different superscript letters differ according to the reported mean-separation procedure

Across planting conditions, T7 (50% RDF + 50% vermicompost) produced the greatest plant height (73.600 cm), pod length (8.499 cm), pod width (18.3 mm), number of pods per plant (13.412), pod yield (18.5 t ha⁻¹), and biological yield (45.1 t ha⁻¹). T6 (50% RDF + 50% FYM) generally ranked next. The unfertilised control produced the lowest mean values for all six variables. The highest individual pod yield was recorded for T7 under sole cropping (22.928 t ha⁻¹), whereas the lowest was recorded for the control under the agroforestry system (4.943 t ha⁻¹).

3.2 Post-harvest Soil Properties

Post-harvest soil means showed modest differences between the two planting systems (Table 3). The plum-based agroforestry system had slightly lower bulk density (1.27 g cm⁻³) and particle density (2.55 g cm⁻³) than sole cropping (1.28 and 2.57 g cm⁻³, respectively). Soil organic carbon and available nitrogen, phosphorus, and potassium were slightly higher under agroforestry than under sole cropping.

Across nutrient treatments, the lowest bulk density and particle density and the highest soil organic carbon were recorded with T2 (100% FYM). The largest available nitrogen, phosphorus, and potassium values were recorded with T3 (100% vermicompost), whereas the unfertilised control produced the highest density values and the lowest organic carbon and available nutrient values.

Table 3. Summary of post-harvest soil properties under the two planting systems and the nutrient-treatment extremes

Soil property	S1: agroforestry	S2: sole crop	Highest treatment mean	Lowest treatment mean
Bulk density (g cm⁻³)	1.27	1.28	T12: 1.35	T2: 1.23
Particle density (g cm⁻³)	2.55	2.57	T12: 2.62	T2: 2.51
Soil organic carbon (%)	1.47	1.44	T2: 1.59	T12: 1.26
Available nitrogen (kg ha⁻¹)	327.09	322.51	T3: 358.49	T12: 258.78
Available phosphorus (kg ha⁻¹)	56.45	55.26	T3: 62.62	T12: 48.95
Available potassium (kg ha⁻¹)	355.28	351.49	T3: 362.353	T12: 343.64

Note. Values are post-harvest means reported from the experiment. T2 = FYM supplying 100% of the recommended nitrogen; T3 = vermicompost supplying 100% of the recommended nitrogen; T12 = unfertilised control. The table summarises the available treatment extremes; full plot-level uncertainty estimates were not included in the source dataset

3.3 Economic Performance

The whole-system economic appraisal favoured the plum-based agroforestry system (Table 4). Mean net return was US$4,535.52 ha⁻¹ under agroforestry and US$2,149.58 ha⁻¹ under sole pea cropping. The corresponding benefit:cost ratios were 3.39 and 2.72.

Across nutrient treatments, T7 produced the highest mean net return (US$4,615.78 ha⁻¹) and benefit:cost ratio (3.86). T6 ranked second for both variables. The control produced the lowest mean net return (US$2,042.47 ha⁻¹) and benefit:cost ratio (2.23). The highest system × treatment net return was recorded for T7 under agroforestry (US$5,600.20 ha⁻¹).

Table 4. Reported net returns and benefit:cost ratios for the plum–pea agroforestry and sole pea systems

Treatment	Net return (US$ ha⁻¹)			Benefit:cost ratio		
	S1	S2	Mean	S1	S2	Mean
T1	5065.73	2861.89	3963.81	3.69	3.34	3.52
T2	3894.66	1303.56	2599.11	2.98	1.99	2.49
T3	4127.62	1633.48	2880.55	3.07	2.22	2.64
T4	4118.12	1587.13	2852.62	3.16	2.27	2.72
T5	3918.70	1282.07	2600.39	3.15	2.10	2.63
T6	5312.77	3156.62	4234.69	3.76	3.49	3.62
T7	5600.20	3631.37	4615.78	3.89	3.84	3.86
T8	4767.27	2535.18	3651.23	3.52	3.05	3.29

Treatment	Net return (US$ ha⁻¹)			Benefit:cost ratio		
	S1	S2	Mean	S1	S2	Mean
T9	4546.12	2144.69	3345.40	3.45	2.80	3.13
T10	4924.41	2676.33	3800.37	3.55	3.10	3.32
T11	4698.61	2349.73	3524.17	3.51	2.94	3.22
T12	3452.07	632.88	2042.47	2.91	1.55	2.23
Mean	**4535.52**	**2149.58**		**3.39**	**2.72**	

Note. S1 = plum–pea agroforestry; S2 = sole pea cropping. Net returns for S1 represent the whole-system appraisal, including the annualised plum component. Values are reported from the study accounts and were not subjected to inferential statistical testing

4. Discussion

4.1 Effects of the Plum-Based System on Pea Growth and Yield

Pea growth and yield were consistently lower beneath plum than in the open sole-crop condition. The result is consistent with the general observation that annual-crop performance in temperate agroforestry is sensitive to canopy structure and the spatial distribution of resources (Pardon et al., 2018). A systematic review of shaded tropical cropping systems similarly found that crop yield commonly declines as subcanopy light availability decreases, although responses differ among crop species and management regimes (Kumar et al., 2024).

The present experiment did not directly measure photosynthetically active radiation, soil moisture, or root competition. Consequently, the lower pea yield cannot be assigned to a single mechanism. It may reflect a combination of reduced radiation beneath the tree canopy and competition for water or nutrients, as reported in other fruit-tree–crop systems (Gao et al., 2013). The magnitude of the reduction also depends on tree age, pruning, crop position, and seasonal weather. Future work should therefore relate pea response to canopy openness, distance from tree rows, and soil-water dynamics rather than treating the agroforestry environment as spatially uniform.

4.2 Response to Integrated Nutrient Management

The best crop performance was obtained with 50% RDF + 50% vermicompost. This response is agronomically plausible because mineral fertiliser supplies readily available nutrients during early growth, whereas vermicompost contributes organic matter and a more gradual nutrient release. The treatment may therefore improve nutrient synchrony without relying exclusively on either mineral or organic inputs. The second-ranked treatment, 50% RDF + 50% FYM, supports the broader conclusion that combining nutrient sources was more effective than using the corresponding organic materials alone.

The finding agrees with meta-analytic evidence that integrated nutrient management can increase crop yield and soil biological activity in Indian production systems (Padbhushan et al., 2021). Broader syntheses likewise identify balanced mineral–organic nutrient supply as a practical approach to sustaining yield and soil properties (Paramesh et al., 2023). In pea, organic manure and biofertiliser treatments have improved growth, yield, and quality relative to untreated controls, although the optimal source and rate depend on local soil and management conditions (Kumari et al., 2022).

The organic treatments were standardised on a nitrogen-equivalence basis rather than on total nitrogen, phosphorus, and potassium supply. Vermicompost, FYM, and goat manure therefore contributed different amounts of non-nitrogen nutrients and organic carbon. The superior response to T7 should consequently be interpreted as the performance of the complete treatment package rather than as an isolated vermicompost effect.

4.3 Soil-Property Responses

Post-harvest soil means under the plum-based system showed slightly lower bulk and particle density and slightly higher organic carbon and available nutrients than the sole-crop means. Agroforestry can influence soil fertility through litter deposition, rhizosphere processes, nutrient redistribution, and protection of the soil surface (Isaac & Borden, 2019; Prasad et al., 2023). Studies in Himalayan bamboo and fruit-based systems have also reported improved soil carbon and nutrient status under tree-based management (Garima et al., 2021; Zahoor et al., 2021).

The greatest soil organic carbon and the lowest density values were recorded with FYM, whereas vermicompost produced the largest available nitrogen, phosphorus, and potassium values. Long-term organic inputs can improve aggregation and soil organic matter, which may reduce bulk density and increase nutrient retention (Abiven et al., 2009; Kaur et al., 2008). Positive changes in soil properties following manure application have also been reported in coarse-textured soils and integrated manure–fertiliser systems (Azuka & Idu, 2022; Biratu et al., 2019).

The small difference in particle density between systems should be interpreted cautiously. Unlike bulk density, particle density is determined mainly by the composition of the solid mineral and organic fractions and is less directly affected by pore volume. The observed variation may reflect differences in organic-matter content or analytical variability rather than rapid structural change. Similarly, the post-harvest nutrient means cannot establish treatment-induced change without a full baseline-adjusted analysis.

The higher available potassium under vermicompost may have supported water regulation and physiological activity in pea. Potassium contributes to stomatal regulation, photosynthetic function, and plant water relations (Erel et al., 2015). However, nutrient uptake, microbial activity, and mineralisation were not measured, and the proposed mechanisms should be regarded as explanations supported by prior evidence rather than direct observations in the present experiment. Soil carbon stabilisation also depends on aggregate protection and interactions with the mineral matrix, processes that occur over longer periods than a single crop season (Six et al., 2002).

Comparable Himalayan research has shown that integrated nutrient management beneath fodder trees can improve both crop performance and soil fertility (Kumar et al., 2023), while common bean responses beneath mulberry have depended on canopy management and organic inputs (Saakshi et al., 2025). These studies reinforce the need to evaluate tree management and nutrient management jointly.

4.4 Economic Implications

Although sole cropping produced more pea, the plum-based system generated the greater whole-system net return and benefit:cost ratio. This distinction is important because crop yield alone does not represent the productivity of an agroforestry enterprise. The tree component can compensate economically for lower intercrop yield and can distribute income across products and seasons. Similar whole-system advantages have been reported for harar–soybean and wild-pomegranate–black-gram systems in Himachal Pradesh (Bhatia et al., 2024, 2025).

The economic advantage was greatest with 50% RDF + 50% vermicompost, which combined high pea yield with the value of the plum component. Land-use assessments of fruit-tree systems have likewise shown that perennial output can substantially influence net land-use benefits (Xia et al., 2020). Agroforestry may also contribute to broader sustainability objectives through production diversification and improved resource use, although these benefits depend on local markets, management capacity, and institutional conditions (Mbow et al., 2014).

The reported economic values are specific to the prices, labour requirements, orchard condition, and accounting assumptions used during the study. They should not be extrapolated directly to other locations without sensitivity analysis. Future economic evaluations should present separate crop and fruit revenues, itemised costs, the annuity or discount assumptions used for the tree component, and alternative price scenarios.

5. Conclusions

Sole cropping produced greater pea growth and yield than cultivation beneath plum. Across the two planting systems, 50% RDF + 50% vermicompost was the most productive nutrient treatment, followed closely by 50% RDF + 50% FYM. The unfertilised control consistently produced the lowest crop performance.

Post-harvest soil means suggested modest advantages of the plum-based system for soil organic carbon and available nitrogen, phosphorus, and potassium, while FYM and vermicompost produced the most favourable treatment-level soil values. These soil responses should be interpreted as short-term post-harvest observations rather than evidence of long-term change.

The whole-system economic appraisal favoured plum–pea agroforestry despite the reduction in pea yield. Under the study conditions, combining 50% RDF with 50% vermicompost provided the best balance of crop productivity and economic return. The findings support the use of integrated nutrient management in plum-based systems while also demonstrating the need to manage canopy and below-ground competition if understory pea yield is to be improved.

Data Availability

The plot-level data supporting the findings are available from the corresponding author upon reasonable request.

Ethics Statement

This agronomic field experiment did not involve human participants, personal data, or vertebrate animals; institutional human- or animal-research ethics approval was therefore not applicable.

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Declaration of AI Use

This manuscript was prepared through the combined contributions of all author(s), including contributions to the study design, data, content development, results, interpretation, and related scholarly work. The author(s) acknowledge the use of Grammarly and ChatGPT to assist with grammar checking, language refinement, reference formatting. These AI-assisted tools were not used as authors and did not replace the intellectual contributions or scholarly judgment of the author(s). All AI-assisted outputs, including content, references, and interpretations, were carefully reviewed, revised, verified, and approved by the author(s). The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

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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