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Agro-economic Potential of Agroforestry Practices in the Imphal Valley of Manipur, Northeast India

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Abstract

Agroforestry underpins the traditional and emerging farming systems of the Imphal Valley of Manipur, a landlocked, densely populated floodplain in Northeast India where indigenous diets and smallholder livelihoods depend heavily on home-grown crops, trees, and livestock. Despite this reliance, no integrated agro-economic assessment has previously compared agroforestry performance across the valley's two constituent districts. A multistage random sampling survey was conducted across seven Community Development blocks and 24 villages of Imphal East and Imphal West districts, covering 120 farm households (60 per district). Structured interviews, field verification, and GPS-referenced photo-documentation were used to record agroforestry types, species composition, land area, and household economics. Tangible economic performance was evaluated using the benefit–cost ratio (BCR). Farmers practiced eight agroforestry models in Imphal East and six in Imphal West, together spanning home gardens, agri-horticulture, agri-silviculture, agri-horti-pastoral, and pisciculture-integrated systems. Home garden was the most widely adopted model in both districts (31.7% and 41.7% of respondents, respectively), while pisciculture-integrated models occupied the smallest land area but returned the highest benefit–cost ratios (1.42–1.84). A total of 60 and 71 tree/woody species and 53 and 46 crop species were recorded in Imphal East and Imphal West, respectively, with agri-horti-silviculture and agri-horti-pastoral systems supporting the greatest species richness. Across all 14 model–district combinations, species richness was significantly and negatively correlated with benefit–cost ratio (Spearman $\rho = -0.665$, $p = 0.009$), and pisciculture-integrated models returned significantly higher benefit–cost ratios than plant-based models (Mann–Whitney $U = 0$, $p = 0.006$), confirming a genuine, statistically supported trade-off between on-farm biodiversity and short-term profitability. Home gardens dominate adoption due to low investment and direct food-security value, whereas fish- and livestock-integrated agroforestry models deliver superior tangible returns. Combining the biodiversity strength of tree-crop-dominated systems with the profitability of pisciculture-integrated systems offers a practical, scalable pathway for sustainable livelihood support in the Imphal Valley and comparable landlocked floodplain landscapes of Northeast India.

1. Introduction

Agroforestry is a well-established practice of the deliberate integration of trees, crops, and livestock on the same land unit and is widely recognized as a nature-based strategy that reconciles food production with ecosystem service delivery, income diversification, and climate resilience (Bhandari et al. 2026; Lehmann et al. 2020). In India, agroforestry already occupies a substantial share of agricultural land, and the National Agroforestry Policy of 2014 formally identified it as a low-cost, low-risk avenue for raising farm income while easing pressure on natural forests (Chavan et al. 2015). The policy's emphasis on region-specific documentation is particularly relevant to Northeast India, where centuries-old tree–crop–livestock combinations remain embedded in indigenous farming culture but are seldom quantified in economic terms (Debta 2025; Rangappa et al. 2025).

Manipur, one of the eight states of Northeast India, is dominated topographically by hill forests that encircle a small, densely settled valley. While more than 77% of the state's land area is forest, only 3% is recorded as agricultural land, mainly in the valley. Imphal Valley, comprising Imphal East and Imphal West districts, is the agricultural and demographic core of the state, yet its landlocked geography and seasonal road disruptions routinely constrain the inward flow of food commodities (Konsam et al. 2016). Under these conditions, household-level agroforestry is not a peripheral activity but a primary safeguard of food and nutritional security, supplying the vegetables, fruits, timber, fodder, and animal protein that sustain the largely rice-based Meitei diet. Because ethnic food preferences in the valley favor a wide range of indigenous plants, ethnobotanical surveys have documented over 100 wild and semi-domesticated food-plant taxa consumed by Manipur's ethnic communities, many of which are maintained in home gardens (Konsam et al. 2016; Yaipharembi et al. 2023; Leisembi 2024). Farmers have historically maintained diverse home gardens and multi-tier tree–crop systems alongside fish farming, poultry, and piggery.

Elsewhere in India, agroforestry systems have consistently outperformed monocropping in benefit–cost terms, with reported ratios ranging from 1.01 to more than 4, depending on system type and region (Katariya et al. 2025; Singh et al. 2022; Rathore et al. 2022). Comparable studies in the Eastern Himalayas and adjoining hill states have linked tree-integrated home gardens to both higher agrobiodiversity conservation and improved household food security (Singh and Sahoo 2021; Sharma et al. 2024, 2026; Singh et al. 2023), while fish-integrated homestead systems in the flood-prone wetlands of neighboring Bangladesh, an agro-ecological analog of the Imphal Valley, have returned some of the highest benefit–cost ratios among all integrated farming configurations tested (Akter et al. 2025; Jahan et al. 2022). However, the applicability of these findings to the intensively cultivated, land-scarce floodplain setting of the Imphal Valley, distinct from the surrounding hill agro-ecosystems typically studied in Northeast India (Ao 2026; Pandey et al. 2022), remains untested. Furthermore, literature on adoption-barriers and gender-participation suggests that the most profitable models are not always those most widely adopted by farmers (Bhandari et al. 2026; Kiptot and Franzel 2012).

Despite this long tradition, the agro-economic potential of agroforestry in Manipur Valley has never been assessed in an integrated manner. Therefore, this study combines household-level data to (i) document the traditional and modern agroforestry models practiced by farmers of the Imphal Valley; (ii) evaluate the tangible (economic) and intangible (species-diversity) potential of each model; and (iii) identify the agroforestry model(s) best suited for promotion as sustainable livelihood-support systems across the valley. Through surveys in Imphal East and Imphal West districts of the Imphal valley of Manipur, the primary household-level data have been generated on the types, species composition, and benefit–cost performance of locally practiced agroforestry models, classified according to the widely used structural framework of Nair (1985). Because both districts share the same valley agro-ecology, market access, and cultural context, analyzing their results together offers a more complete, statistically stronger picture of the Manipur valley's agroforestry economy than either survey alone, and allows economically superior models identified in one district to be evaluated for wider replication across the valley. The findings are

intended to guide extension agencies and policymakers in prioritizing agroforestry investments in the most land- and capital-constrained agricultural landscape in Manipur.

2. Materials and methods

2.1 Study area

The study was conducted in the Imphal Valley of Manipur, Northeast India, comprising Imphal East and Imphal West districts (Fig. 1) between November 2023 and May 2024. Imphal East lies between 24.73 N and 25.87 N latitude and 93.94 E and 94.05 E longitude, covers about 497 km², and is bounded by the Nongmaijing hill range to the north-east; elevation ranges from 790 m above mean sea level, and temperature ranges from winter and summer extremes of 0.6°C and 41°C, respectively (as recorded from the Worldclim.org). The district comprises four Community Development (CD) blocks — Sawombung, Heingang, Khetrigao, and Keirao. Imphal West lies between 24.70 N and 24.85 N latitude and 93.81 E and 94.91 E longitude, covers about 519 km² (449.8 km² rural and 69.2 km² urban), and is drained by the Imphal and Nambul rivers over fertile alluvial soil; it comprises four CD blocks — Lamphelpat, Lamsang, Patsoi and Wangoi (Fig. 1). Both districts form part of the same low-lying, landlocked floodplain, share a common Meitei agrarian culture, and are subject to identical monsoon-driven transport disruption, making them agro-ecologically and logistically comparable units for a combined analysis.

2.2 Sampling design and sample size

A multistage random sampling procedure was adopted in both districts. In Imphal East, three of the four CD blocks (Kshetrigao, Heingang, and Keirao) were selected, four villages were randomly chosen from each block, and five agroforestry-practicing households were randomly selected from each village (1 district × 3 blocks × 4 villages × 5 households = 60 households across 12 villages). In Imphal West, all four CD blocks (Lamsang, Patsoi, Wangoi and Lamphel) were covered, three villages were selected from each block, and five households were surveyed per village (1 district × 4 blocks × 3 villages × 5 households = 60 households across 12 villages). In total, 120 farm households across seven blocks and 24 villages of the Imphal Valley were surveyed (Table 1); each household constituted the primary sampling unit.

Table 1
Community development blocks and villages surveyed in Imphal East and Imphal West districts, Imphal Valley, Manipur

District	Block	Villages surveyed	Latitude range (°N)	Longitude range (°E)
Imphal East	Kshetrigao	Bamon Kampu, Naharup, Uchekkon, Bashikhong	24.74–24.79	93.94–93.98
	Heingang	Moirangkampu, Kongpal Ningthoubung, Heingang, Khabam	24.82–24.87	93.94–93.99
	Keirao	Keirao, Langdum, Kiyamgei, Andro	24.73–24.75	93.95–94.04
Imphal West	Lamsang	Mayang Langjing, Maklang, Kachikhul	24.81–24.85	93.81–93.86
	Patsoi	Patsoi Part 3, Langjing Achouba, Khaidem	24.76–24.79	93.83–93.87
	Wangoi	Kodompokpi, Haoreibi, Hiyangthang	24.70–24.74	93.89–93.91
	Lamphel	Iroishemba, Meitei Langol, Naoremthong Laishram Leirak	24.81–24.82	93.89–93.91

2.3 Data collection

Primary data were collected through structured questionnaire interviews administered to the head of each sampled household, supplemented by direct farm observation. Information was gathered on household demography (gender, age, literacy, family size), land area under each agroforestry model, the full inventory of crop, tree, and livestock/fish components, and the physical output and market returns obtained from each component during the reference cropping season/year.

2.4. Identification and documentation of agroforestry systems

Agroforestry types were identified and classified in the field on the basis of component structure (the woody, herbaceous and livestock/fish elements present) and functional role, following Nair's (1985) structural classification framework, under which systems are grouped by the composition and spatial arrangement of their dominant tree–crop–animal (or tree–crop–fish) combination (e.g., agri-horticulture, agri-silviculture, home garden, pisciculture-integrated systems). For each household, data were recorded on land-holding size under agroforestry, farmer age, family size, literacy status, the component species present (timber, non-timber/medicinal, fruit/horticultural, and crop/vegetable), livestock and fish components, and the plantation and management pattern. GPS-referenced photographs of each agroforestry plot were taken to verify species composition and spatial arrangement.

2.5 Economic analysis

Economic performance was evaluated using the benefit–cost ratio (BCR), and calculated separately for each agroforestry model as the ratio of total discounted benefit (gross output value in INR ha^{-1}) to total discounted cost (total input value in INR ha^{-1}):

BCR = Total output (benefit) ÷ Total input (cost)

Total input (production cost) included establishment cost, planting material, hired labor, land preparation, manures and fertilizers, plant-protection chemicals, irrigation, and livestock/fish feed and management costs. Total output (benefit) was the aggregate seasonal sale/consumption value of the crop, tree/horticultural, and livestock/fish components of each model. A BCR greater than 1 indicates that a model is economically viable.

2.6 Data processing and statistical analysis

Field data were compiled, cross-checked, and tabulated in MS Excel and summarised using descriptive statistics (frequencies, percentages, means). Results from the two districts were subsequently pooled and cross-tabulated to allow direct comparison of adoption pattern, species richness, area coverage, and benefit–cost performance across the Imphal Valley as a whole. In addition to these descriptive summaries, the model-level dataset (14 agroforestry models × district combinations, each characterized by area, dependent family size, tree/crop species richness, input cost, output value, and BCR) was subjected to the following inferential and multivariate analyses using Python 3 (SciPy v1.x and scikit-learn v1.x):

1. A component (tree:crop) diversity index (H') and its associated evenness (J' = H'/ln 2) were computed for each model from the proportional split between tree/woody and crop/vegetable richness, following the Shannon–Wiener formulation $H' = -\Sigma\, p_i \ln p_i$; this index is a proxy for structural (woody-versus-herbaceous) balance rather than a full species-abundance diversity measure, since farm-level abundance data for individual species were not recorded in the source surveys.
2. Pearson product-moment and Spearman rank correlations were used to test the association between total species richness (tree + crop) and BCR, and between land area and total output value, across the 14 model–district combinations.
3. Ordinary least-squares linear regression was used to model total output value as a function of total input cost.

4. Models were grouped into two functional categories - ‘plant-based’ (home garden, agri-horticulture, agri-silviculture, agri-horti-silviculture, agri-horti-pastoral, agri-horti-silvi-pastoral; n = 10) and ‘pisciculture-integrated’ (agri-horti-pisciculture, horti-pisciculture, horti-silvi-pisciculture, agri-horti-silvi-pisciculture; n = 4), and the Mann–Whitney U test (with Welch's t-test as a parametric cross-check) was used to test for a significant difference in BCR between groups. The same non-parametric approach, together with the Kruskal–Wallis test, was used to compare BCR and species richness between Imphal East and Imphal West.
5. Principal component analysis (PCA) was performed on six standardized model-level variables (area, family size, total species richness, total input, total output, and BCR) to identify the main axes of variation among the 14 models, followed by agglomerative hierarchical clustering (Ward's method, Euclidean distance) to group models with similar structural–economic profiles.

Because the model-level dataset comprises only 14 units, these analyses are necessarily exploratory and are interpreted with due caution regarding statistical power; results are reported with exact p-values throughout, and a significance threshold of $p < 0.05$ was adopted. Analyses that would have required data beyond the scope of the original household surveys including Land Equivalent Ratio (which requires sole-crop yield baselines), multi-year Net Present Value/Internal Rate of Return (which requires time-structured cash-flow records), and logistic regression of model choice on household-head gender (which requires household-level linkage between respondent gender and specific model adopted, not retained in the source data), were not performed and are identified as priorities for future primary data collection (Section 4.6).

3. Results

3.1 Study area and sample profile

Of the 120 sampled households, 70 (58.3%) were male-headed and 50 (41.7%) female-headed. Overall literacy across the valley was 55.8%, with male literacy (65.7%) exceeding female literacy (42.0%) in both districts (Table 2). Heingang block recorded the highest literacy in Imphal East, and Lamphel block recorded the highest in Imphal West.

Table 2
Socio-demographic profile of the sampled farm households (n) in the Imphal Valley

Parameter	Imphal East (n = 60)	Imphal West (n = 60)	Overall (Imphal Valley) (n = 120)
Male-headed households	34 (56.7%)	36 (60.0%)	70 (58.3%)
Female-headed households	26 (43.3%)	24 (40.0%)	50 (41.7%)
Overall literacy rate	53.3%	58.3%	55.8%
Male literacy rate	70.6%	61.1%	65.7%
Female literacy rate	30.8%	54.2%	42.0%
Block with the highest literacy	Heingang	Lamphel	—

3.2 Agroforestry models practiced in the Imphal Valley

Farmers of the Imphal Valley practiced a total of ten distinct agroforestry models, of which eight were recorded in Imphal East and six in Imphal West district; four models, home garden, agri-horti-silviculture, agri-horticulture, and agri-horti-silvi-pastoral/pisciculture combination, were common to both districts, while horti-pisciculture, horti-silvi-pisciculture, and agri-horti-pastoral were recorded only in Imphal East, and agri-silviculture and agri-horti-silvi-pisciculture only in Imphal West (Table 3). The home garden was the single most preferred model in both districts, adopted by 31.7% of farmers in Imphal East and 41.7% in Imphal West, reflecting its low capital requirements and direct contribution to household food supply. Agri-horti-silviculture (18.3% East; 23.3% West) and agri-horticulture (18.3% East; 18.3% West) were the next most widely adopted models in both districts, while pisciculture-integrated systems (horti-pisciculture, horti-silvi-pisciculture, agri-horti-pisciculture, agri-horti-silvi-pisciculture) together accounted for the smallest share of adopting farmers, reflecting the higher capital and water-resource requirements of fish integration.

Table 3
Agroforestry models practiced by farmers of the Imphal Valley, Manipur (n = 60 households per district)

District	Agroforestry model		Farmers (n)	Adoption (%)
Imphal East	1	Home garden	19	31.7
	2	Agri-horti-silviculture	11	18.3
	3	Agri-horticulture	11	18.3
	4	Agri-horti-pastoral	10	16.7
	5	Agri-horti-silvi-pastoral	3	5.0
	6	Agri-horti-pisciculture	3	5.0
	7	Horti-pisciculture	2	3.3
	8	Horti-silvi-pisciculture	1	1.7
Imphal West	1	Home garden	25	41.7
	2	Agri-horti-silviculture	14	23.3
	3	Agri-horticulture	11	18.3
	4	Agri-silviculture	4	6.7
	5	Agri-horti-silvi-pastoral	3	5.0
	6	Agri-horti-silvi-pisciculture	3	5.0

3.3 Area coverage and dependent population

In Imphal East, the agroforestry model area ranged from 0.33 ha (agri-horti-silvi-pastoral) to 2.44 ha (agri-horti-silviculture), the latter also supporting the second-largest number of dependent family members (66) after agri-horti-pastoral (73) (Table 4). In Imphal West, agri-horti-silvi-pisciculture occupied the single largest area of any model in the valley (3.08 ha) despite being adopted by only three households, while agri-horti-silvi-pastoral occupied the smallest area (0.75 ha). Home garden, notwithstanding its modest land requirement, supported the largest dependent population in both districts (87 people in Imphal East; 115 people in Imphal West), underscoring its role as a low-land, high-dependency subsistence system.

Table 4
Area coverage and dependent family members of different agroforestry models in the Imphal Valley

District	Agroforestry model	Area (ha)	Family members (n)
Imphal East	Home garden	0.695	87
	Agri-horti-silviculture	2.441	66
	Agri-horticulture	1.672	56
	Agri-horti-pastoral	0.628	73
	Agri-horti-silvi-pastoral	0.330	18
	Agri-horti-pisciculture	1.500	15
	Horti-pisciculture	1.000	8
	Horti-silvi-pisciculture	0.759	8
Imphal West	Home garden	1.560	115
	Agri-horti-silviculture	2.863	65
	Agri-horticulture	0.865	72
	Agri-silviculture	0.840	18
	Agri-horti-silvi-pastoral	0.749	19
	Agri-horti-silvi-pisciculture	3.082	25

3.4 Species diversity and intangible potential

A cumulative 60 tree/woody species and 53 crop/vegetable species were recorded across the eight agroforestry models of Imphal East, while 71 tree/woody species and 46 crop species were recorded across the six models of Imphal West, together representing well over 100 unique tree and crop taxa documented across the Imphal Valley (Table 5; Fig. 2). Species richness was highest in tree-crop-dominated models: agri-horti-pastoral (38 tree, 31 crop species) and agri-horticulture (36 tree, 31 crop species) in Imphal East, and home garden (30 tree, 39 crop species) and agri-horti-silviculture (27 tree, 38 crop species) in Imphal West. Pisciculture-dominated models (horti-pisciculture, horti-silvi-pisciculture, agri-horti-silvi-pisciculture) supported markedly fewer plant species but incorporated additional fish components (4–6 species), indicating a trade-off between plant-species richness and aquatic-component diversification. Livestock components — principally duck, hen and pig — were recorded predominantly in home garden, agri-horti-pastoral and agri-horti-silvi-pastoral models in both districts, reinforcing the multifunctional, subsistence-oriented character of these systems.

Table 5
Species richness of tree/woody and crop/vegetable components across agroforestry models of the Imphal Valley

District	Agroforestry model	Tree/woody species (n)	Crop/vegetable species (n)	Other components
Imphal East	Home garden	19	39	Duck (25), hen (15)
	Agri-horti-silviculture	20	33	—
	Agri-horticulture	36	31	—
	Agri-horti-pastoral	38	31	Cow, duck, hen, pig
	Agri-horti-silvi-pastoral	18	11	Duck, hen, pig
	Agri-horti-pisciculture	24	24	5 fish species
	Horti-pisciculture	7	—	6 fish species
	Horti-silvi-pisciculture	14	—	4 fish species
Imphal West	Home garden	30	39	Poultry
	Agri-horti-silviculture	27	38	—
	Agri-horticulture	2	33	—
	Agri-silviculture	5	17	—
	Agri-horti-silvi-pastoral	11	10	Poultry
	Agri-horti-silvi-pisciculture	8	—	Fish

3.5 Tangible (economic) potential

Total seasonal economic output varied widely across models and income components (Table 6). In Imphal East, agri-horti-silviculture generated the highest total system output (₹14,63,190), driven overwhelmingly by crop sales (₹13,77,380), while horti-pisciculture (₹9,92,100) and agri-horti-pastoral (₹10,02,970) derived most of their output from livestock and fish. In Imphal West, agri-horti-silvi-pisciculture produced by far the largest total output of any model in the valley (₹34,53,530), overwhelmingly from its fish component (₹34,00,500), underscoring the high value that pisciculture integration can add even where crop and tree output remain comparatively modest.

Table 6
Total seasonal economic output (INR) of crop, tree/horticultural, and livestock/fish components under different agroforestry models of the Imphal Valley

District	Model	Crop output (INR)	Tree/horti output (INR)	Livestock/fish output (INR)	Total output (INR)
Imphal East	Home garden	22,800	58,200	44,750	1,25,750
	Agri-horti-silviculture	13,77,380	85,810	—	14,63,190
	Agri-horticulture	7,17,160	52,720	—	7,69,880
	Agri-horti-pastoral	52,600	1,07,320	8,43,050	10,02,970
	Agri-horti-silvi-pastoral	9,200	12,370	4,45,000	4,66,570
	Agri-horti-pisciculture	57,050	16,880	6,41,800	7,15,730
	Horti-pisciculture	—	26,300	9,65,800	9,92,100
	Horti-silvi-pisciculture	—	12,150	4,15,200	4,27,350
Imphal West	Home garden	65,760	51,470	15,500	1,32,730
	Agri-horti-silviculture	76,900	69,210	—	1,46,110
	Agri-horticulture	39,880	46,740	—	86,620
	Agri-silviculture	49,800	—	—	49,800
	Agri-horti-silvi-pastoral	27,550	13,200	59,000	99,750
	Agri-horti-silvi-pisciculture	15,600	37,430	34,00,500	34,53,530

3.6 Benefit–cost ratio and economically efficient models

Every agroforestry model recorded in the Imphal Valley returned a benefit–cost ratio above unity, confirming that agroforestry investment is economically viable across the full range of models practiced (Table 7; Fig. 3). In Imphal East, agri-horti-pisciculture returned the highest BCR (1.84), followed by horti-pisciculture (1.53) and horti-silvi-pisciculture (1.42); home garden (1.05) and agri-horti-pastoral (1.05) returned the lowest, if still positive, ratios. In Imphal West, agri-horti-silvi-pisciculture again recorded the highest BCR (1.41), followed by agri-horti-silvi-pastoral (1.27); agri-silviculture recorded the lowest (1.09). Pooling both districts, pisciculture-integrated models consistently outperformed purely plant-based models on a per-rupee-invested basis, even though several of these models (e.g., home garden) were far

more widely adopted, indicating that farmer adoption in the Imphal Valley is currently driven more by access to capital and subsistence value than by relative profitability.

Table 7
Total input, total output, and benefit–cost (B:C) ratio of agroforestry models practiced in the Imphal Valley, Manipur

District	Model	Total input (INR)	Total output (INR)	B:C ratio
Imphal East	Home garden	1,20,000	1,25,750	1.05
	Agri-horti-silviculture	12,50,000	14,62,990	1.17
	Agri-horticulture	6,90,000	8,00,880	1.12
	Agri-horti-pastoral	9,57,000	10,02,970	1.05
	Agri-horti-silvi-pastoral	3,95,000	4,66,570	1.18
	Agri-horti-pisciculture	3,90,000	7,15,730	1.84
	Horti-pisciculture	6,50,000	9,92,100	1.53
	Horti-silvi-pisciculture	3,00,000	4,27,350	1.42
Imphal West	Home garden	1,15,000	1,32,730	1.15
	Agri-horti-silviculture	1,25,200	1,46,110	1.17
	Agri-horticulture	74,750	86,620	1.16
	Agri-silviculture	45,500	49,800	1.09
	Agri-horti-silvi-pastoral	78,850	99,750	1.27
	Agri-horti-silvi-pisciculture	24,53,500	34,53,530	1.41

3.7 Statistical relationships among model attributes

Treating each of the 14 agroforestry model–district combinations as an analytical unit, species richness and BCR were negatively and significantly correlated (Spearman ρ = −0.665, $p = 0.009$; Pearson r = −0.436, $p = 0.120$; Fig. 4): models with fewer tree and crop species tended to return higher benefit–cost ratios, and vice versa. This provides direct statistical support for the biodiversity–economy trade-off described qualitatively in Section 3.6. Land area and total output value were positively and significantly correlated (Pearson r = 0.595, p = 0.025), confirming that larger-area models generated proportionately higher gross output, whereas the number of dependent family members was not significantly associated with total output (r = − 0.207, p = 0.479), indicating that household size was driven by subsistence dependency rather than by the productive scale of the model itself. Total output was very strongly and significantly predicted by total input (OLS regression: Output = − 28,421 + 1.351 × Input; $R^2 = 0.979$, p < 0.001), confirming that, on average, every additional rupee (INR) invested returned approximately INR 1.35 in gross output across the valley.

When models were grouped into the two functional categories defined in Section 2.6, pisciculture-integrated models returned a significantly higher mean BCR (1.549 ± SD 0.19, n = 4) than plant-based models (1.140 ± SD 0.06, n = 10) (Mann–Whitney U = 0, p = 0.006; Welch's t = − 4.04, p = 0.023; Fig. 5). This result is notable, given the small sample size, and the fact that the two groups' BCR distributions did not overlap at all (U = 0) indicates a consistent, not incidental, economic advantage of fish integration across every pisciculture-integrated model recorded in the valley. By contrast, neither BCR nor total species richness differed significantly between the two districts (Mann–Whitney U = 26.5, p = 0.796 for BCR; Kruskal–Wallis H = 0.104, p = 0.747 for richness), indicating that the economic and biodiversity patterns reported here are consistent features of the Imphal Valley as a whole rather than artefacts of either individual district survey.

Principal component analysis of the six model-level variables (area, family size, species richness, input, output, and BCR) resolved 80.1% of total variance in the first two components (PC1 = 46.6%, PC2 = 33.5%; Fig. 6; Table 8). PC1 was most strongly loaded by total output (0.915) and total input (0.853), representing an overall ‘scale of production’ axis, while PC2 separated models with high family size and species richness (positive loadings of 0.763 and 0.673, respectively) from models with high BCR (negative loading of − 0.450), reproducing the biodiversity–profitability trade-off as an independent axis of variation. Agglomerative hierarchical clustering (Ward's method) of the same standardised variables produced two broad clusters: a larger cluster of species-rich, moderate-BCR models (predominantly home garden, agri-horticulture and agri-horti-silviculture combinations in both districts) and a smaller cluster combining all four pisciculture-integrated models together with the lowest-richness plant-based models (agri-horti-silvi-pastoral in both districts and agri-silviculture in Imphal West), indicating that the trade-off identified by correlation and PCA is not confined strictly to the plant-based/pisciculture-integrated classification but reflects a more general richness–profitability continuum across the valley's agroforestry portfolio.

Table 8
Summary of inferential statistical tests applied to the model-level dataset (n = 14 agroforestry model–district combinations)

Test	Variables	Statistic	p-value	Interpretation
Spearman correlation	Species richness × BCR	ρ = −0.665	0.009	Significant negative association
Pearson correlation	Species richness × BCR	r = −0.436	0.120	Not significant (linear)
Pearson correlation	Area × Total output	r = 0.595	0.025	Significant positive association
Pearson correlation	Family size × Total output	r = −0.207	0.479	Not significant
OLS regression	Total output ~ Total input	R^2 = 0.979	< 0.001	Strong, significant predictive relationship
Mann-Whitney U	BCR: plant-based vs pisciculture-integrated	U = 0.0	0.006	Significant difference (pisciculture higher)
Welch's t-test	BCR: plant-based vs pisciculture-integrated	t = − 4.04	0.023	Confirms Mann–Whitney result
Mann–Whitney U	BCR: Imphal East vs Imphal West	U = 26.5	0.796	No significant district difference
Kruskal–Wallis	Species richness: Imphal East vs Imphal West	H = 0.104	0.747	No significant district difference

4. Discussion

4.1 Structural diversity and farmer preference of agroforestry models

Following Nair's (1985) foundational structural classification, the ten agroforestry models recorded across the Imphal Valley span three of the four principal structural categories, agrisilvicultural (e.g., agri-silviculture), agrosilvopastoral (e.g., agri-horti-silvi-pastoral), and mixed agri-silvi-aquacultural configurations that extend the classical scheme to incorporate fish as a fourth production component. This structural range indicates a locally elaborated, multi-component adaptation of globally recognized agroforestry archetypes rather than a simplified subsistence system, and is broadly consistent with the diversification strategy through which farmers across Northeast India layer trees, seasonal crops, and animal husbandry to buffer subsistence risk under fragmented, hill-constrained landholdings (Rangappa et al. 2025; Ao 2026).

The overwhelming preference for home gardens (31.7% of respondents in Imphal East; 41.7% in Imphal West) mirrors findings from the Mizoram hills, where home gardens likewise emerged as the dominant tree-species reservoir and soil-carbon store among shifting-cultivation-adjacent land uses (Singh and Sahoo 2021), and from the Brahmaputra Valley of neighbouring Assam, where homegardens surveyed across diverse socio-ecological zones supported over 100 tree species and were present in the great majority of sampled households (Sharma et al. 2024). It is also consistent with global reviews concluding that home gardens are the most capital-light and food-security-oriented of all agroforestry configurations, combining vegetable, fruit, spice, medicinal, and, frequently, small-livestock components within the residential compound itself (Korpelainen 2023; Bardhan et al. 2012). That home gardens supported the largest dependent population in both districts of the Imphal Valley, despite occupying comparatively modest land area, is therefore not an anomaly but a structural feature shared with home garden systems across South and Southeast Asia, and it reinforces their status as the valley's primary subsistence safety-net rather than a commercial enterprise.

The clear district-level divergence in the less common models, pisciculture-integrated systems concentrated in Imphal East and agri-silviculture/agri-horti-silvi-pisciculture unique to Imphal West, most plausibly reflects micro-variation in water-body access, soil drainage class, and market proximity within the valley floor rather than any fundamental agro-ecological difference between the two districts, both of which share the same alluvial floodplain, monsoon regime, and Meitei agrarian culture. This heterogeneity is nonetheless informative for extension planning: it indicates that a single, valley-wide agroforestry template would be less effective than a portfolio approach in which extension agencies match specific models to the resource endowments of individual blocks, an approach increasingly advocated in narrative policy reviews of agroforestry scale-up in India (Debta 2025).

4.2 Economic performance in the context of Indian and South Asian agroforestry

All fourteen agroforestry model–district combinations returned benefit–cost ratios above unity (1.05–1.84), confirming that agroforestry investment is economically rational across the full range of models practiced in the Imphal Valley. This places valley agroforestry within (albeit toward the lower-to-middle end of) the profitable range documented across Indian agroforestry systems generally (BCR 1.01–4.17 across diverse agro-ecologies; Katariya et al. 2025) and is broadly comparable to tree-crop combinations reported from Eastern Uttar Pradesh (BCR up to 1.9; Singh et al. 2022) and semi-arid central India, where karonda (*Carissa carandas*) and moringa-based agri-horticultural systems returned BCRs as high as 3.85 alongside substantial soil-carbon co-benefits (Rathore et al. 2022). The comparatively modest ceiling on BCR observed in the Imphal Valley (a maximum of 1.84, versus BCRs exceeding 3 reported for some semi-arid and plateau systems) may reflect the valley's already intensive land use system, smaller per-household land holdings, and correspondingly higher relative input costs, rather than any inherent inefficiency of the models themselves.

The consistently higher BCRs recorded for pisciculture-integrated models (1.41–1.84) relative to purely plant-based systems (1.05–1.27) is the study's most economically consequential finding, and the statistical analysis reported in Section 3.7 confirms that this difference is unlikely to be due to chance despite the small number of models available for comparison (Mann–Whitney U = 0, p = 0.006; Fig. 6). It is corroborated by a substantial and geographically dispersed body of evidence on fish-integrated farming. Gamhar (*Gmelina arborea*) -based agrisilvicultural systems in the Eastern Plateau showed that adding a high-value component sharply raised system-level profitability relative to sole cropping (Kumar et al. 2026), while fish-integrated homestead–agroforestry systems in the flood-prone haor wetlands of Bangladesh (an agro-ecological analog of the landlocked, monsoon-flooded Imphal Valley) returned BCRs of 1.40 to 1.58, the highest among all integrated-farming combinations tested (Akter et al. 2025). Similarly, an agroforestry-based climate-mitigation investment analysis in Bangladesh found that agroforestry combinations consistently outperformed monocropping in BCR, net present value, and internal rate of return, particularly when diversified high-value components were included (Jahan et al. 2022). Taken together, this cross-regional convergence suggests that in the Imphal Valley, the marginal rupee of investment in fish integration currently earns a higher return than the marginal rupee invested in additional tree or crop diversification alone, and that this pattern is not an artifact of local data but reflects a more general economic property of aquaculture-integrated agroforestry in flood-prone, land-scarce settings. The strong linear relationship between input and output ($R^2 = 0.979$, $p < 0.001$; Section 3.7) further indicates that, within the range of investment levels observed, returns scaled predictably with capital outlay across all models, so that the higher profitability of pisciculture-integrated systems reflects a genuinely higher rate of return rather than simply higher absolute spending.

4.3 The biodiversity–economy trade-off

The combined inventory of well over 100 unique tree and crop taxa across the Imphal Valley (60 tree and 53 crop species in Imphal East; 71 tree and 46 crop species in Imphal West) illustrates the substantial *in-situ* agrobiodiversity conserved within farmer-managed agroforestry. This is comparable in scale to homegarden agrobiodiversity documented across the eastern Himalayan foothills of Assam, where 192 homegardens supported 101 tree species and high livestock diversity indices (Sharma et al. 2024, 2026), and to the broader recognition that homegardens and mixed agrisilvicultural systems function as informal, farmer-managed repositories of plant genetic resources that persist even where adjacent shifting-cultivation (jhum) landscapes are contracting under population pressure (Pandey et al. 2022; Penot 2023). It is also consistent with global syntheses that conclude that homegarden-type systems are among the most taxonomically diverse of all agroforestry configurations, routinely exceeding 100 plant species per landscape unit when tree, crop, spice, and medicinal components are combined (Korpelainen 2023; Bardhan et al. 2012).

However, within the Imphal Valley, species richness and economic return followed markedly different, and in places inverse, gradients: agri-horti-pastoral and agri-horticulture supported the greatest number of tree and crop species (up to 38 tree and 31 crop species per model) but returned only moderate BCRs (1.05–1.16), whereas pisciculture-dominated models supported far fewer plant species yet returned the

highest BCRs (1.41–1.84). This divergence was statistically confirmed by the significant negative Spearman correlation between total species richness and BCR across all 14 model–district combinations ($\rho = -0.665$, $p = 0.009$; Fig. 4; Section 3.7), and was further resolved as an independent axis of variation (PC2) in the principal component analysis, on which family size and richness loaded positively while BCR loaded negatively (Fig. 6). The pattern indicates a genuine, quantifiable trade-off in the valley between maximising on-farm agrobiodiversity and maximising short-term cash return, echoing similar tensions reported for tree-density and diversity effects on food security versus income variability in the semi-arid tropics of central India, where more diverse agroforestry portfolios reduced interannual income variability but did not necessarily maximise mean returns (Singh et al. 2023). The trade-off also carries a carbon-sequestration dimension: biomass- and soil-carbon reviews of Indian agroforestry systems consistently report that structurally complex, multi-species systems sequester more carbon per hectare than simpler tree-crop or tree-fish combinations (Ajit et al. 2017; Panwar et al. 2022), and hedge- and alder (*Alnus* species)-based systems in the Indian sub-Himalayas have been shown to combine carbon gains with improved crop productivity (Parmar et al. 2022), suggesting that the diversity-rich models of the Imphal Valley, although less immediately profitable, may be delivering environmental co-benefits not captured by the benefit–cost ratio alone. The ethnic food culture of Manipur is significantly influenced by a diverse array of indigenous vegetables, wild trees, food medicinal plants, spices & condiments, and fruits that are cultivated in home gardens and agri-horticultural plots. This is evidenced by ethnobotanical and home garden surveys conducted among the Meitei, Tangkhul, and Kuki communities, which document over 30 species of dietary wild trees and more than 100 taxa of wild plants consumed throughout Manipur (Konsam et al. 2016; Yaipharembi et al. 2023; Akoijam et al. 2025). Therefore, any policy initiatives aimed at promoting fish- or livestock-centric models should be crafted to enhance, rather than replace, these biodiversity-rich systems.

Most importantly, the major population of the valley maintains a home garden to grow plants, preferably vegetables, to fulfill their own domestic need, not for economic benefits. The valley's agroforestry portfolio is therefore best understood not as a set of competing alternatives but as a complementary production–conservation continuum, in which tree–crop-dominated models anchor dietary and genetic diversity while pisciculture-integrated models anchor cash income.

4.4 Determinants of the profitability–adoption gap

Notably, the models with the highest profitability (pisciculture-integrated systems) were not the models most widely adopted by farmers; home garden and agri-horti-silviculture, although returned comparatively modest BCRs, accounted for the majority of respondents in both districts. This profitability–adoption gap is a recurring and well-documented theme in the global agroforestry adoption literature. A recent systematic review of 148 peer-reviewed studies found that economic and social outcomes of agroforestry remain comparatively under-studied relative to environmental benefits, and that only a minority of studies examine adoption barriers explicitly, even though high initial capital cost, technical complexity, and weak market linkage are identified as the most persistent constraints across regions (Bhandari et al. 2026). Farm-level studies in Uttar Pradesh similarly report that landholding size,

access to quality planting material, weak financial incentives, and limited technical information are the principal barriers restricting uptake of more capital-intensive agroforestry configurations, rather than farmer skepticism about agroforestry's benefits. Comparable constraints have been documented in the wetland and homestead systems of Bangladesh, where despite two-thirds of surveyed farmers being aware of agroforestry's benefits, actual adoption of higher-return, more complex combinations lagged well behind awareness (Jahan et al. 2022), and in Ethiopia and Ireland, where farmer perception studies consistently identify financial risk, scheme inflexibility and lack of locally trusted technical advice as adoption bottlenecks even where farmers hold positive attitudes toward the practice (Gashu et al. 2025; Irwin et al. 2022).

A further, often under-recognized dimension of the adoption gap is gender. Reviews of agroforestry participation across Africa and, by extension, other smallholder-dominated regions find that women are frequently as actively engaged as men in day-to-day agroforestry management — particularly in home-garden and kitchen-garden components — but participate far less in the establishment and marketing of higher-investment, longer-payback systems such as fish ponds or timber plantations, owing to constrained access to land tenure, credit, and extension contact (Kiptot and Franzel 2012). The present survey found that 41.7% of sampled households in Imphal West and 43.3% in Imphal East were female-headed, a substantial proportion; if female-headed households face the same structural barriers to capital-intensive diversification documented elsewhere, this would help explain why home garden, which has resulted in the least capital-demanding model, was disproportionately preferred over pisciculture-integrated systems, independent of its lower relative profitability. This interpretation is necessarily tentative, since the present study did not disaggregate adoption decisions by household headship, but it points to gender-responsive extension design as a specific, testable lever for narrowing the profitability–adoption gap in future interventions.

4.5 Implications for sustainable livelihood-support models

Three practical implications follow from the combined Imphal Valley dataset, each grounded in the comparative evidence reviewed above. First, home garden systems, despite their comparatively low BCR, warrant continued and even expanded support because of their unmatched reach, supporting more dependent household members per unit area than any other model, and their central role in dietary diversity, the preservation of indigenous food culture, and household food security. Targeted interventions such as improved planting material, kitchen-garden micro-credit, and homestead nutrition-garden extension packages, of the kind shown to raise vegetable production and consumption in comparable South Asian home-garden systems (Bardhan et al. 2012; Korpelainen 2023), could raise home-garden productivity without requiring farmers to abandon a system they already trust and without eroding the wild and indigenous plant diversity documented among Manipur's ethnic communities (Yaipharembi et al. 2023).

Second, the demonstrably higher profitability of pisciculture-integrated models (agri-horti-pisciculture, horti-pisciculture, horti-silvi-pisciculture, and agri-horti-silvi-pisciculture) identifies these as the priority models for scaled promotion where water resources permit. Because their current adoption is limited

primarily by capital, technical, and, plausibly, gender-related barriers rather than agro-ecological unsuitability (Section 4.4), subsidized pond-excavation support, seed-fish supply chains, and structured, gender-inclusive farmer-field-school training, delivered through the same extension architecture that has driven agroforestry uptake nationally under the National Agroforestry Policy (Chavan et al. 2015), could convert a meaningful share of existing home-garden and agri-horticulture households into higher-return, fish-integrated systems over a multi-year transition. This is consistent with the broader case for policy-enabled agroforestry scale-up in India (Debta 2025) and with evidence that structured investment-planning support (covering discounted cash-flow indicators such as BCR, net present value, and internal rate of return, as applied in this study) measurably improves farmers' willingness to adopt more complex agroforestry combinations (Jahan et al. 2022).

Third, given the Imphal Valley's landlocked, flood- and road-disruption-prone geography, agroforestry diversification should be treated explicitly as a food-security and climate-resilience buffer, not merely an income strategy. Maintaining the species-rich, tree–crop-dominated models (agri-horti-pastoral, agri-horticulture, agri-horti-silviculture) alongside promoting higher-return pisciculture-integrated systems will together provide both the dietary breadth needed to withstand seasonal supply disruptions and the cash income needed to build household resilience. This dual strategy is consistent with the productivity, income-diversification and food-security functions increasingly documented for agroforestry systems in comparable Northeast Indian and wider South Asian floodplain and hill contexts (Rangappa et al. 2025; Singh et al. 2023; Lehmann et al. 2020), and it is reinforced by evidence that structurally diverse agroforestry systems in the Indian Himalayan and sub-Himalayan belt deliver measurable soil-carbon and productivity co-benefits alongside direct farm income (Ajit et al. 2017; Panwar et al. 2022; Saleem et al. 2023; Parmar et al. 2022), while not captured in the benefit–cost ratios reported here, strengthen the case for public investment in agroforestry as a climate-adaptive, multifunctional land-use strategy for the Imphal Valley.

4.6 Limitations and directions for further statistical analysis

The inferential analyses reported here (Section 3.7) treat each of the 14 agroforestry model–district combinations as the unit of analysis, which is appropriate for identifying valley-wide structural relationships but necessarily limits statistical power and precludes household-level inference; the significant results obtained despite this small n (notably the richness–BCR correlation and the plant-based/pisciculture-integrated BCR difference) should therefore be read as robust, valley-scale patterns rather than as precise effect-size estimates, and would benefit from replication with a larger number of independently surveyed model instances. Three further analyses were identified as valuable but could not be performed with the present dataset and are recommended for future primary data collection in the Imphal Valley. First, the Land Equivalent Ratio (LER) would allow the productivity advantage of each intercropped model to be benchmarked directly against sole-cropping yields, but requires paired sole-crop yield data that were not recorded in the source household surveys. Second, multi-year Net Present Value and Internal Rate of Return analysis would better capture the delayed returns characteristic of

timber- and fruit-dominated models (e.g., agri-horti-silviculture), whose benefits accrue over a period of years rather than within the single reference season used to compute the benefit–cost ratios reported here; this requires time-structured establishment-to-maturity cash-flow records. Third, a household-level logistic or multinomial regression of model choice on socio-demographic predictors, particularly household-head gender, literacy, land-holding size and access to credit, would allow the profitability–adoption gap discussed qualitatively in Section 4.4 to be tested formally; this requires linked household-level records connecting individual respondent characteristics to the specific agroforestry model adopted, a level of disaggregation not retained in the archived survey data used for this analysis. Addressing these three gaps in subsequent Imphal Valley surveys would substantially strengthen the evidence base for the livelihood recommendations advanced in Section 4.5.

5. Conclusion

This assessment of Imphal East and Imphal West districts shows that agroforestry is an economically viable, highly diversified, and widely practiced land-use strategy across the Imphal Valley of Manipur, with all fourteen documented model–district combinations returning positive benefit–cost ratios. Home gardens dominate adoption due to their low cost and direct contribution to food security, while pisciculture-integrated agroforestry models, though less widely adopted, consistently deliver the highest economic returns and represent the greatest under-exploited opportunity for livelihood enhancement in the valley. Reconciling the biodiversity strength of tree-crop-dominated systems with the profitability of fish- and livestock-integrated systems through targeted extension, credit, and infrastructure support offers a practical and scalable pathway toward sustainable, food-secure agroforestry-based livelihoods for the Imphal Valley and comparable landlocked floodplain landscapes in Northeast India.

Declarations

Funding This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The research was conducted in accordance with the Code of Ethics of the International Society of Ethnobiology. The research methods were approved by the Research Advisory Committee (RAC) of the Department of Forestry, Manipur University. The RAC ensures compliance with the Consortium for Academic Research and Ethics (CARE) guidelines of the University Grants Commission of India. The approved research proposal ensured full confidentiality and dignity of the human participants. Furthermore, this research caused no harm or deterioration to any organisms, including plant resources, animals, and human participants. There were no minor subjects under 18 years of age in the study.

Consent to participate All household interviews were conducted with respondents' informed verbal consent; no personally identifying information is reported. Approval was obtained from the village heads

for the household survey and the use of the questionnaire in the study area.

Consent to publish Not Applicable

Data availability The full species inventories from all agroforestry models, underlying Tables 5 and 6, and the household-level survey data, are attached in the Supplementary File.

Author contributions Y.D. prepared the initial draft and performed the initial data analysis. C.R.C. and M.M.D. conducted the field surveys and data collection. R.P. supervised the data collection and analysis. K.R.S prepared the initial and final draft of the manuscript. V.V. conceptualized and supervised the study and prepared the final draft of the manuscript. All authors read and approved the final manuscript.

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Figures

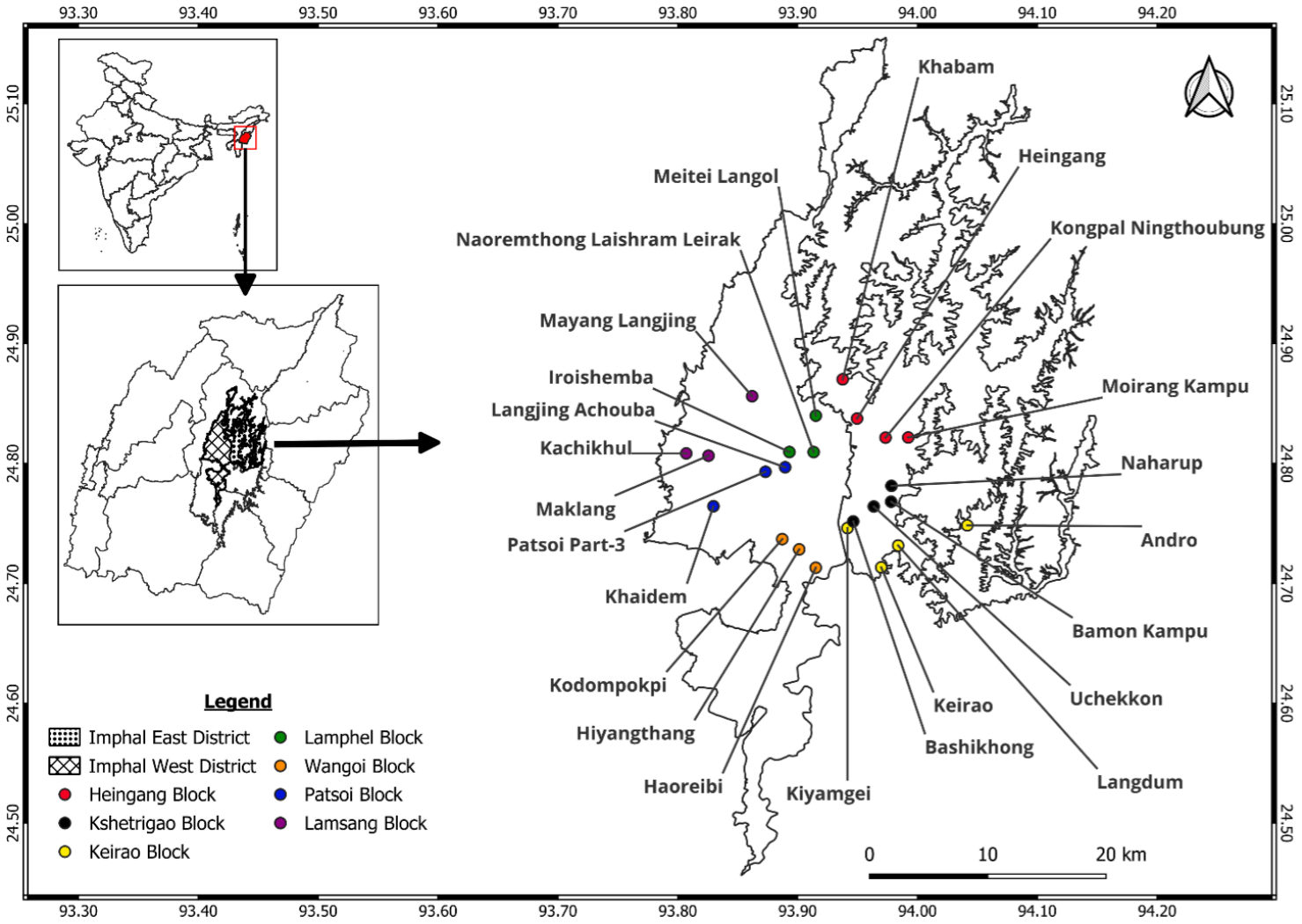


Figure 1

The map shows the studied Villages within the Imphal Valley of Manipur, a North-Eastern state of India

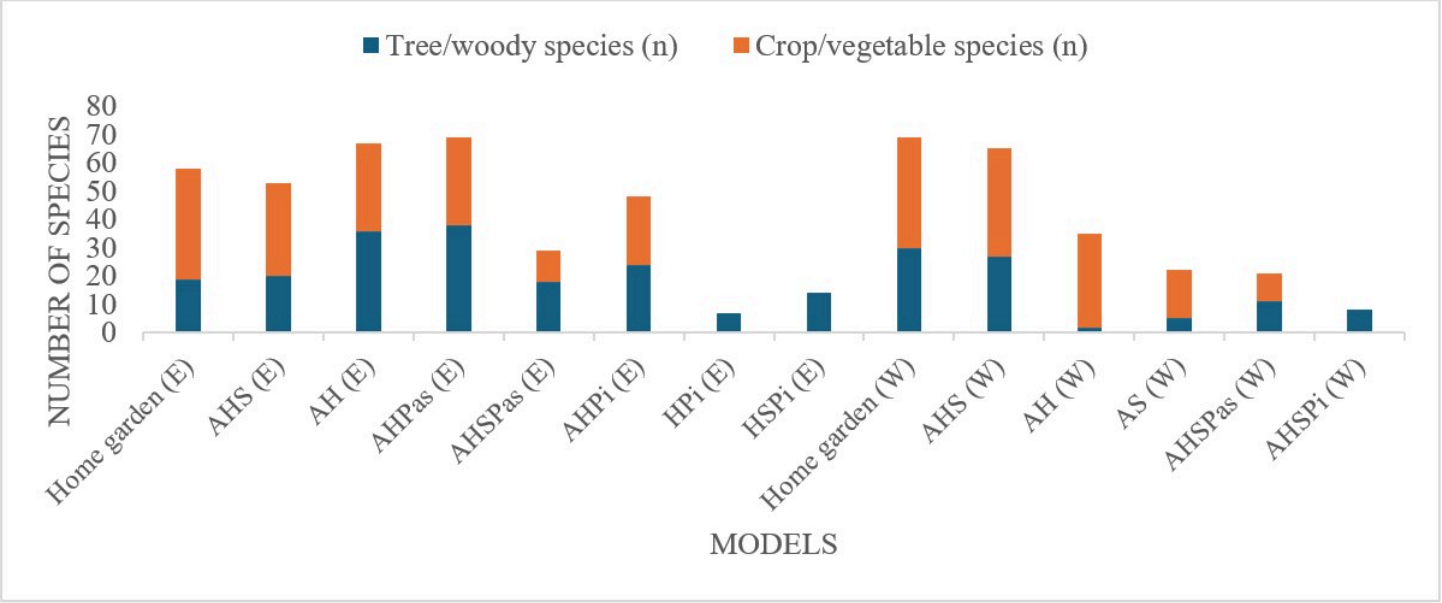


Figure 2

Species richness (tree/woody vs crop/vegetable) across agroforestry models of Imphal East (E) and Imphal West (W). AHS = agri-horti-silviculture; AH = agri-horticulture; AHPas = agri-horti-pastoral; AHSPas = agri-horti-silvi-pastoral; AHPi = agri-horti-pisciculture; HPi = horti-pisciculture; HSPi = horti-silvi-pisciculture; AS = agri-silviculture; AHSPi = agri-horti-silvi-pisciculture.

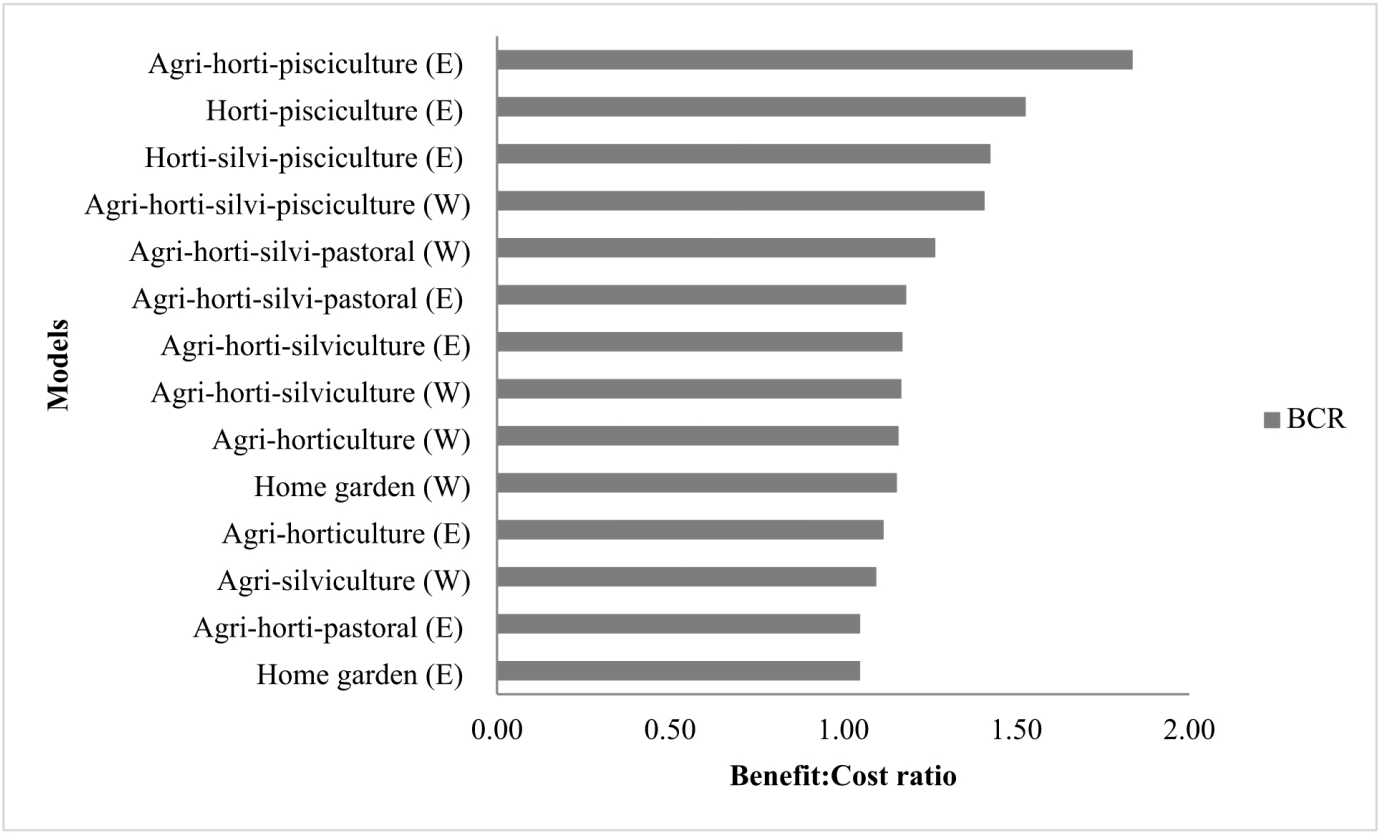


Figure 3

Benefit–cost ratio of agroforestry models practiced in Imphal East and Imphal West districts of the Imphal Valley, ranked from lowest to highest.

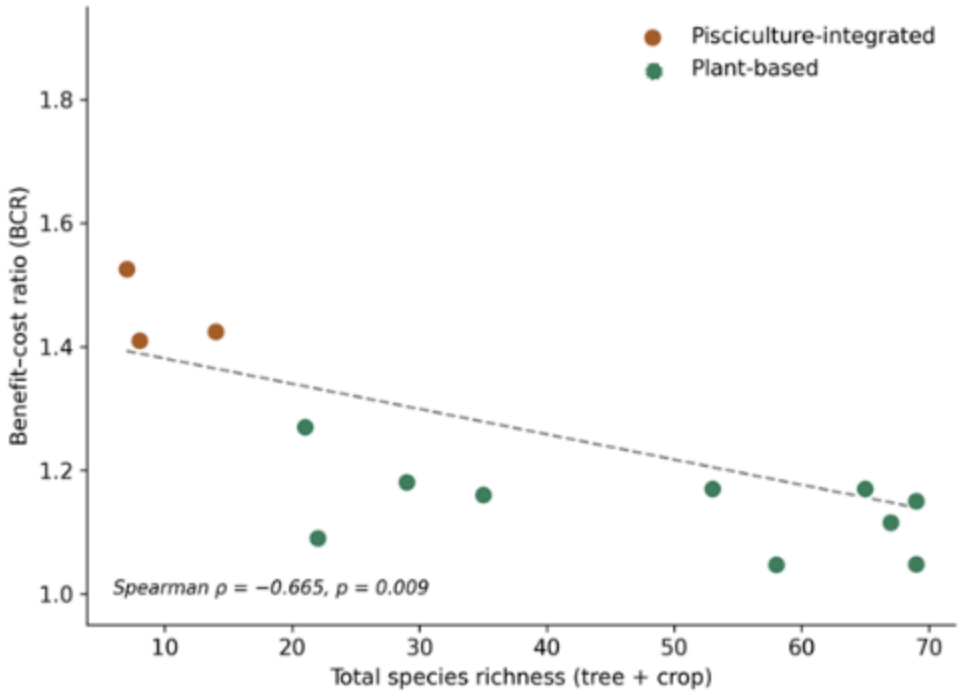


Figure 4

Relationship between total species richness (tree + crop) and benefit–cost ratio across the 14 agroforestry model–district combinations of the Imphal Valley. Dashed line shows the ordinary least-squares trend for reference; the reported correlation is the rank-based Spearman coefficient.

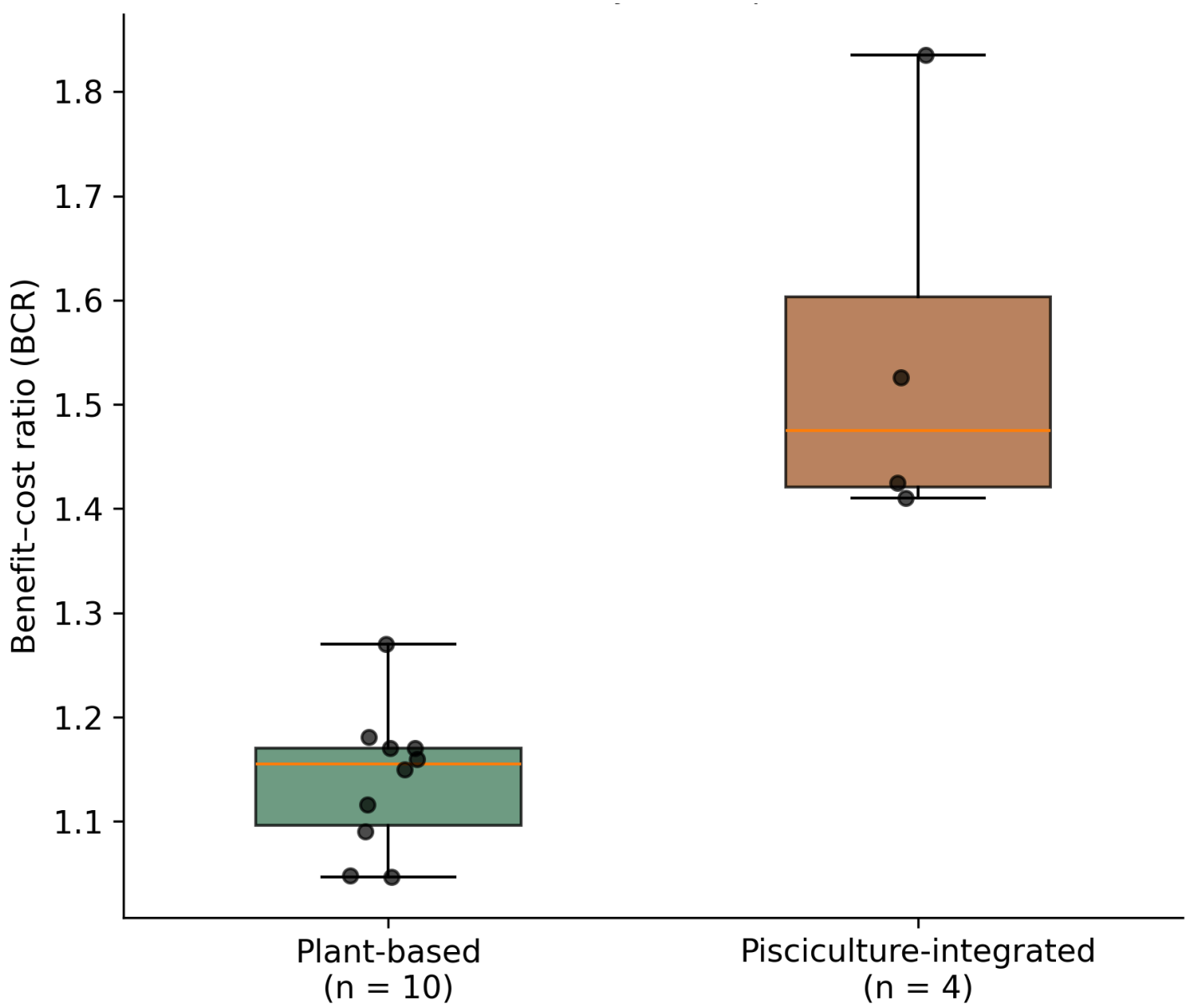


Figure 5

Benefit–cost ratio of plant-based versus pisciculture-integrated agroforestry models of the Imphal Valley (Mann–Whitney U = 0, p = 0.006). Black points show individual model–district values; box shows interquartile range with median (orange line).

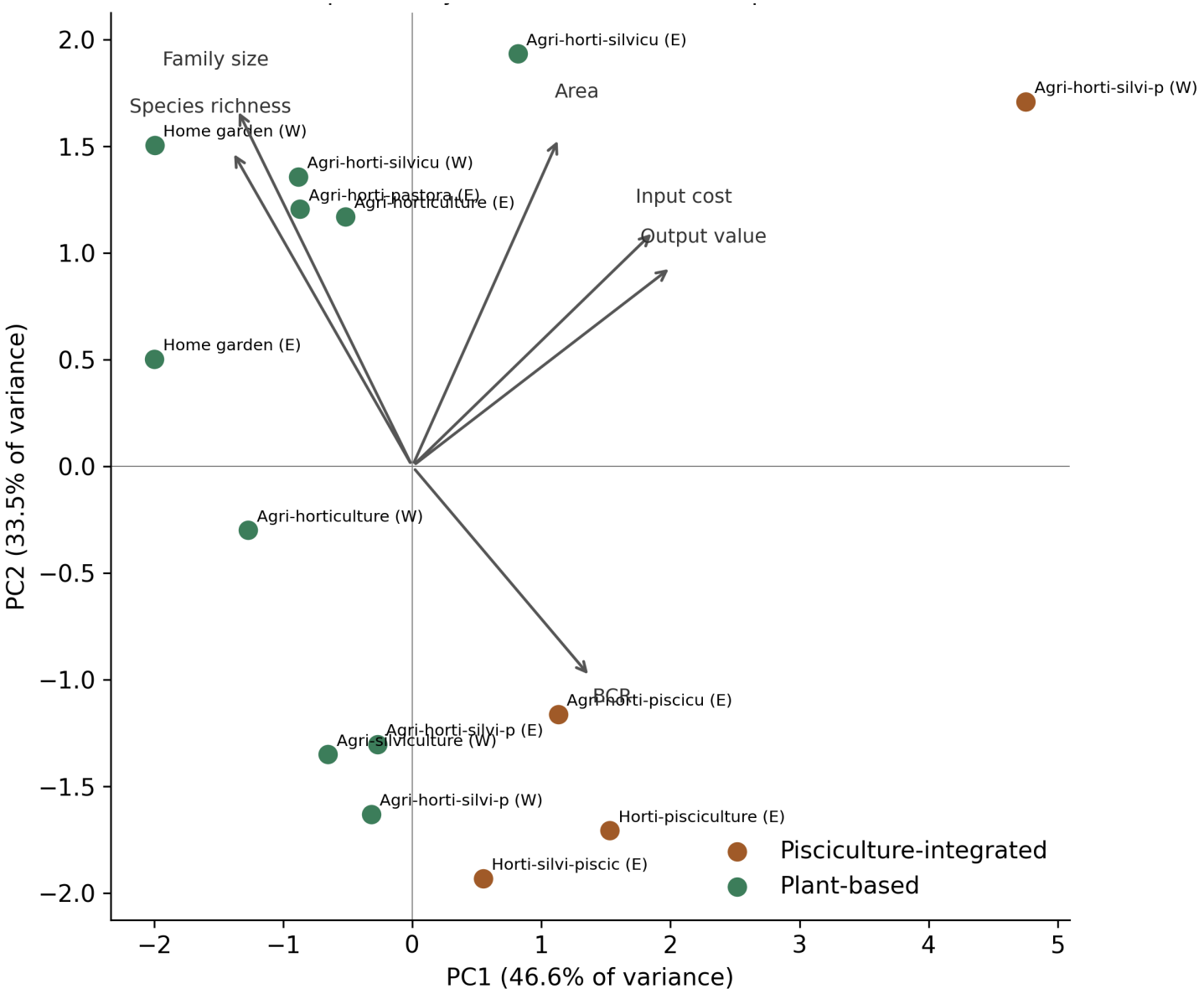


Figure 6

Principal component analysis biplot of the 14 agroforestry model–district combinations of the Imphal Valley, based on standardised area, family size, species richness, input cost, output value and BCR (cumulative variance explained = 80.1%). Arrows show variable loadings; points show model scores coloured by functional group.

Supplementary Files

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- ESM1.docx