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REVIEW PAPER

Economic Viability of Agrisilviculture and Agrihortisilviculture Systems for *Rabi* Crops in Garhwal Himalayas

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ABSTRACT

Agroforestry systems play a crucial role in enhancing farm income and sustainability in hill regions. The present study evaluated the economic viability of agrisilviculture (AS) and agrihortisilviculture (AHS) systems for selected *rabi* and vegetable crops in the Garhwal Himalayas, Uttarakhand. Cost-return analysis was conducted using data on input costs and market-based returns from grain, vegetable produce, and crop residues. Economic indicators such as gross return, net return, and benefit-cost (B:C) ratio were used to assess system performance. Results revealed considerable variation among crops and systems. Under AS, lentil and vegetable-based models exhibited higher net returns and B:C ratios compared to wheat and barley. Vegetable crops, particularly garlic and pea, recorded superior economic performance in both AS and AHS systems. In AHS, integration of horticultural species influenced crop profitability, with vegetable-based models showing higher economic returns than *rabi* cereals. Overall, vegetable-based agroforestry models were moswre economically viable than cereal-based systems, highlighting their potential for income enhancement in hill agroecosystems. The study underscores the importance of crop selection and system design for improving farm profitability in Himalayan agroforestry systems.

HIGHLIGHTS

- Evaluated economic viability of AS and AHS systems in the Garhwal Himalayas.
- Vegetable-based models outperformed *rabi* cereals in net returns and B:C ratio.
- Garlic and pea showed highest profitability across systems.
- Agroforestry offers income diversification opportunities in hill farming systems.

Keywords: Agroforestry systems, Benefit-cost ratio, Agrisilviculture, Agrihortisilviculture, Hill agriculture

The Indian Himalayan Region (IHR) represents a dominant geographical unit of the country and is characterized by high ecological fragility and rich biological diversity. The region serves as a major source of freshwater, supporting river systems that sustain millions of people both within and beyond the Himalayas. Agroforestry practices in the Himalayan region are deeply rooted in traditional hill agriculture and have been practiced for centuries. Farmers traditionally integrate agricultural crops with tree species to meet multiple livelihood needs, commonly referred to as the '6Fs' - food, fodder, fuel, fibre, fertilizer, and fruits along with livestock rearing. A wide range of socially accepted agroforestry systems exists in the region; wherein woody perennials are deliberately retained or planted alongside crops and/or livestock to optimize both economic returns and ecological functions. These traditional mountain agroforestry

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systems closely resemble natural forest ecosystems, as they provide a range of tangible and intangible ecosystem services and contribute significantly to sustainable livelihoods of hill farmers (Arunachalam *et al.* 2019).

Agroforestry is an integrated land-use system that combines crops, trees, livestock, and other biotic and abiotic components to enhance land-use efficiency. In the Northwestern Himalayan region, the integration of agricultural crops with tree species and livestock has been practiced for centuries to improve farm productivity and income. Increasing population pressure and rapid industrialization have intensified demands on agricultural land and contributed to the depletion of forest resources. Owing to its distinct topography, the Garhwal Himalaya is dominated by permanent agroforestry systems, which provide multiple outputs such as fuelwood, fodder, livestock feed, animal products, and medicinal and aromatic plants - benefits that are difficult to achieve under monocropping systems (Prakash *et al.* 2023).

Farmers in the hilly regions largely depend on tree resources to supplement farm income, particularly for fuelwood and fodder. The Northwestern Himalayan region is predominantly rainfed, which results in low crop productivity and inferior produce quality (Bhatt, 2002). Owing to limited options for tree species selection, farmers traditionally continue cultivating locally available species to meet their subsistence needs (Bhatt *et al.* 2010). Conventional agroforestry practices in the region mainly involve the retention of multipurpose tree species along field boundaries. However, with increasing scientific interest in agroforestry, research efforts are now directed toward developing and refining diversified agroforestry systems that enhance farm income while maintaining ecological balance.

Agroforestry systems have been widely reported to enhance sustainability by improving soil biological activity, physico-chemical properties, and overall ecological balance. Tree components play a crucial role in formation of surface organic ('O') horizon of the soil profile through continuous litter deposition. The inclusion of multipurpose tree species is therefore integral to agroforestry systems, as they improve soil conditions for crop growth while simultaneously supplying fuelwood and fodder (Prakash *et al.* 2023). In addition, trees stimulate soil microbial activity, leading to increased availability of essential nutrients. Owing to these combined effects, crop productivity under agroforestry systems is generally higher than that under sole cropping or intercropping systems. Considering these advantages and the dependence of nearly 120 million people on the Northwestern Himalayan region, there is a pressing need to promote sustainable and ecologically balanced agroforestry systems in the region (Rao *et al.* 2003).

Traditional agroforestry systems of Garhwal

Himalayan communities cultivate plants for food, fodder, medicinal, religious, and aesthetic uses. Traditional agroforestry systems effectively integrate agricultural and forest components, supporting soil health and efficient cropping practices. The inclusion of multipurpose tree species enhances productivity while providing environmental benefits (Prakash *et al.*2023).

Monsoon rainfall plays a major role in the cultivation of medicinal herbs in Himalayan region, where precipitation strongly influences crop growth. Districts such as Chamoli and Dehradun receive higher rainfall and are recognized for their diversity of medicinal plants. Monsoonal rains expand the cultivated area and improve crop productivity (Shiva, 1996), thereby supporting livelihoods through efficient utilization of natural resources (Gautam and Singh, 2005).

Rainfed agriculture accounts for nearly 75% of India's cropped area. The Western Himalayas largely fall under rainfed conditions, where local communities depend primarily on rainfall for agricultural activities. Agroforestry systems in Uttarakhand are similarly rainfall-dependent, and adequate precipitation promotes greater forest species diversity (Kala, 2007; Kaur *et al.* 2009).

In this context, understanding the nature of agroforestry is essential due to its influence on regional agricultural enterprises (Maikhuri *et al.* 2000). Cereals, grasslands, pastures, and related land uses are closely linked to agriculture, highlighting the urgent need for studies on agroforestry systems and their utilization (Iqbal *et al.* 2014).

Present agroforestry status

The data indicate that the studied villages follow rainfed cropping systems. Three major land-use categories were identified: settled agriculture, forest land, and barren land. The dominant cropping pattern comprises rice and wheat. Major kharif crops include rice (*Oryza sativa*), finger millet locally known as mandua (*Eleusine coracana*), soybean (*Glycine max*), and jhangora (*Echinochloa frumentacea*), while wheat (*Triticum aestivum*) is the principal *rabi* crop. Overall, farmers primarily cultivate *Triticum aestivum*, *Oryza sativa*, *Echinochloa frumentacea*, *Eleusine coracana*, and mixed pulses (Prakash *et al.* 2023).

Among the various agroforestry systems prevalent in the mid-hill regions of the Himalayas, agrisilviculture (AS) and agrihortisilviculture (AHS) are commonly practiced due to their adaptability to diverse agro-ecological conditions. These systems enable efficient utilization of land resources and offer both short-term returns from annual crops and long-term benefits from perennial components.

Rabi crops play an important role in ensuring food security as well as income for hill farmers in the Garhwal Himalayas. Crops such as wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), mustard (*Brassica juncea* L.), pulses, and fodder crops are widely cultivated during the *rabi* season under rainfed or limited-irrigation conditions. However, the performance of *rabi* crops under tree-based systems is influenced by factors such as shading, below-ground competition for moisture and nutrients, and tree-induced microclimatic modifications, which may affect crop productivity and economic returns (Jose, 2009; Singh *et al.* 2020).

In view of the above, the present study was undertaken to assess and compare the economic viability of agrisilviculture (AS) and agrihortisilviculture (AHS) systems for *rabi* crops in the Garhwal Himalayan region of Uttarakhand. The findings are expected to provide scientific evidence to support the promotion of suitable agroforestry systems for enhancing farm income and sustainability in hill agriculture.

MATERIALS AND METHODS

The study was carried out in Pauri block of Pauri Garhwal district, Uttarakhand, India, situated in the mid-hill zone of the Garhwal Himalayas at an elevation of approximately 1650 m above mean sea level (29°45′–30°15′ N latitude and 78°24′–79°23′ E longitude). The region represents typical hill farming conditions, where agroforestry-based cropping systems are widely practiced.

Agroforestry systems

Two dominant land-use systems prevalent in the region were selected i.e. Agrisilviculture (AS) system, involving annual crops grown in association with forest tree species, and Agrihortisilviculture (AHS) system, comprising annual crops integrated with horticultural and forest tree species.

Crops and tree components

The analysis focused on *rabi* season crops, namely wheat, barley, gram, lentil, mustard, pea, and selected vegetables such as potato, onion, garlic, and ginger. Common tree components included *Cedrus deodara*, *Pinus roxburghii*, *Quercus spp*., and horticultural species such as apple, pear, plum, and walnut.

Productivity estimation and economic analysis

Crop productivity was measured in terms of grain and straw yield (kg ha^{-1}). Biological yield was computed as the combined grain and straw yield. Economic viability was evaluated using standard farm economic indicators, including gross return (₹ ha^{-1}) based on prevailing market prices, net return (₹ ha^{-1}) calculated as gross return minus cost of cultivation, and the benefit–cost (B:C) ratio expressed as the ratio of gross return to cost of cultivation.

Data collection and data analysis

Primary data were collected through field surveys during the *rabi* season from representative farmers practicing the selected agroforestry systems. Data recorded included crop yield, straw yield, and input use. Costs of cultivation were estimated based on expenditures for land preparation, seed, fertilizers, plant protection, labour, irrigation, and harvesting. The data were summarized using mean values to compare productivity and economic returns between AS and AHS systems.

RESULTS AND DISCUSSION

The economic performance of *rabi* and vegetable crops under AS and AHS systems was evaluated using a cost-return analysis based on prevailing local market prices. Total cost of cultivation included expenses on land preparation, seed or planting material, farmyard manure and fertilizers, labour for intercultural operations, harvesting, and transportation. Gross return was estimated from the combined value of marketable produce and straw where applicable, while net return was calculated by deducting total cost of cultivation from gross return. The B:C ratio was used as a uniform indicator to compare the economic viability of different crop-tree combinations across AS and AHS models.

Economic analysis of *rabi* crops under AS system

Triticum aestivum + *Celtis australis* + *Grewia optiva* (Wheat + Khadik + Bhimal) based model

In this model, tree density ranged from 90-100 trees ha^{-1}. The total cost of wheat cultivation was ₹ 26,215.71 ha^{-1}, while the gross return obtained was ₹ 21,437.86 ha^{-1} (Table 1). This resulted in a net return of ₹ 4,777.85 ha^{-1} with a B:C ratio of 0.81. Although wheat grain and straw contributed to farm income, the low B:C ratio indicates that wheat cultivation under this AS configuration was economically less viable, possibly due to higher input costs and yield reduction under tree canopy.

Lens culinaris + *Celtis australis* + *Grewia optiva* (Lentils + Khadik + Bhimal) based model

The lentil-based AS model had a similar tree density of 90-100 trees ha^{-1}. Total cost of cultivation was ₹ 21,528.99 ha^{-1}, whereas gross return reached ₹ 32,349.60 ha^{-1} (Table 1), resulting in a net return of ₹ 10,820.61 ha^{-1}. The B:C ratio of 1.50 clearly indicated superior economic performance of lentil compared to wheat and barley under AS system. Higher market price of lentil grain and comparatively lower input cost contributed significantly to enhanced profitability, making this model economically most viable among the evaluated AS systems.

Hordeum vulgare + *Celtis australis* + *Grewia optiva* (Barley + Khadik + Bhimal) based model

In the barley-based model, tree density ranged from 120-130 trees ha^{-1}. The total cultivation cost was ₹ 19,296.28 ha^{-1}, while gross return was ₹ 13,971.40 ha^{-1} (Table 1), resulting in a net return of ₹ 5,324.80 ha^{-1} and a B:C ratio of 0.72. Despite relatively lower cultivation cost, barley exhibited poor economic returns under the AS system, likely due to lower grain price and reduced productivity under higher tree density.

Comparative interaction

Among the *rabi* crops evaluated under the AS system, lentil proved to be the most economically viable option, followed by wheat and barley. The differences in profitability were primarily governed

Table 1: Economic analysis of *rabi* crops in different models of AS system

Economic variables recorded	Wheat + Khadik + Bhimal	Lentils + Khadik + Bhimal	Barley + Khadik + Bhimal
Variable cost	**Total amount (in ₹) for one hectare**		
Establishment cost			
Site preparation	1549.89	1310.50	1149.88
FYM	1868.60	1868.60	2180.00
Seed	3114.37	3488.10	2491.50
Labour	5979.60	5979.60	4983.00
Harvesting	3986.40	3986.40	3238.90
Post-harvesting	4733.85	4235.55	3537.90
Transportation	4983.00	660.24	1715.10
Fixed cost	—	—	—
Total	26215.71	21528.99	19296.80
Revenues			
Crop	13191.90	32249.60	9955.50
Straw	8247.30	—	4016.29
Gross return	21437.86	32349.60	13971.40
Net return	4777.85	10820.61	5324.00
BCR	0.81	1.50	0.72

by crop market value, input costs, and crop response to tree competition. The results suggest that pulse crops such as lentil are better suited for integration under tree-based systems in the Garhwal Himalayan region, whereas cereal crops, particularly barley, show limited economic advantage under similar conditions.

Economic analysis of vegetable crops in different models of AS system

Pisum sativum + *Celtis australis* + *Grewia optiva* (Pea + Khadik + Bhimal) based model

This model had a tree density of 90-100 trees ha^{-1}. Due to multiple harvests, total pea yield was computed cumulatively. The total cost of cultivation was ₹ 45,842.53 ha^{-1}, while gross return amounted to ₹ 105,240.96 ha^{-1} (Table 2), resulting in a net return of ₹ 59,398.43 ha$_{-1}$. The B:C ratio of 2.29 indicates high economic viability of pea under the AS system, attributable to frequent harvesting and favourable market prices.

Solanum tuberosum + *Celtis australis* + *Grewia optiva* (Potato + Khadik + Bhimal) based model

In this model, tree density ranged from 120-130 trees ha^{-1}. Potato cultivation incurred a total cost of ₹ 22,564.40 ha^{-1} and generated a gross return of ₹ 48,813.46 ha^{-1} (Table 2). The resulting net return was ₹ 26,249.06 ha^{-1} with a B:C ratio of 2.16. Despite higher tree density, potato showed good economic performance, likely due to moderate input costs and stable market demand.

Allium sativum + *Celtis australis* + *Grewia optiva* (Garlic + Khadik + Bhimal) based model

The garlic-based AS model had a tree density of 90-100 trees ha^{-1}. The total cost of cultivation was ₹ 43,317.90 ha^{-1}, while gross return reached ₹ 111,160.76 ha^{-1} (Table 2). This resulted in the highest net return of ₹ 67,842.86 ha^{-1} among all vegetable crops, with a B:C ratio of 2.56. The superior economic performance of garlic can be attributed to its high market price and relatively strong yield under partial shade conditions.

Allium cepa + *Celtis australis* + *Grewia optiva* (Onion + Khadik + Bhimal) based model

In the onion-based model, tree density varied from 120-130 trees ha^{-1}. The total cultivation cost was ₹ 24,776.90 ha^{-1}, and gross return was ₹ 38,456.30 ha^{-1} (Table 2), resulting in a net return of ₹ 13,679.40 ha^{-1}. The B:C ratio of 1.55 indicates moderate profitability of onion under the AS system, lower than pea, potato, and garlic, possibly due to comparatively lower yield and higher sensitivity to tree competition.

Table 2: Economic analysis of vegetable crops in different models of AS system

Economic variables recorded	Pea + Khadik + Bhimal	Potato + Khadik + Bhimal	Garlic + Khadik + Bhimal	Onion + Khadik + Bhimal
Variable cost	**Total amount (in ₹) for one hectare**			
	Establishment cost			
Site preparation	2765.56	1699.70	2880.90	1840.23
FYM	1868.20	1868.60	3737.50	1868.62
DAP	5979.60	—	—	—
Urea	3737.25	2491.50	4983.00	2491.50
Seed	4983.00	3986.40	13952.40	5481.30
Labour	7972.80	4983.00	7474.50	4983.00
Harvesting	11959.20	4484.70	7972.80	5979.60
Transportation	6577.50	3050.50	2316.80	2132.72
Fixed cost	—	—	—	—
Total	45842.53	22564.40	43317.90	24776.00
	Revenues			
Crop	105240.96	48813.46	111160.76	38456.30
Gross return	105240.96	48813.46	111160.76	38456.30
Net return	59398.43	26249.06	67842.86	13679.40
BCR	2.29	2.16	2.56	1.55

Comparative interpretation

Among vegetable crops evaluated under AS system, garlic recorded the highest economic returns followed by pea, potato, and onion. Higher profitability of garlic and pea highlights the suitability of high-value and multi-harvest vegetable crops for integration under tree-based systems in the Garhwal Himalayan region. These findings suggest that careful crop selection can substantially enhance farm income under this system.

Economic analysis of *rabi* crops under AHS system

Triticum aestivum + *Citrus sinensis* + *Grewia optiva* (Wheat + Malta + Bhimal) based model

This AHS model recorded a relatively high tree density of 150-160 trees ha^{-1}. The total cost of wheat cultivation was ₹ 23,888.66 ha^{-1}, whereas the gross return obtained was ₹ 10,618.10 ha^{-1} (Table 3). This resulted in a net loss of ₹ 13,270.56 ha^{-1} with a low B:C ratio of 0.44, indicating poor economic performance of wheat under this system. The reduced profitability can be attributed to increased tree competition and shading effects under dense horticultural and silvicultural components.

Lens culinaris + *Celtis australis* + *Citrus sinensis* (Lentils + Khadik + Malta) based model

In this model, tree density ranged from 90-100 trees ha^{-1}. Lentil cultivation incurred a total cost of ₹ 22,099.47 ha^{-1} and generated a gross return of ₹ 24,456.50 ha^{-1} (Table 3), resulting in a modest net return of ₹ 2,357.03 ha^{-1}. The B:C ratio of 1.10 indicates marginal profitability of lentil under the AHS system, suggesting better adaptability of pulse crops compared to cereals under combined tree-horticulture interactions.

Hordeum vulgare + *Citrus aurentifolia* + *Grewia optiva* (Barley + Nimbu + Bhimal) based model

This system had a tree density of 120-130 trees ha^{-1}. The total cost of barley cultivation was ₹ 16,729.13 ha^{-1}, while the gross return was ₹ 9,756.60 ha^{-1} (Table 3), resulting in a net loss of ₹ 6,972.53 ha^{-1} and a B:C ratio of 0.58. Despite lower input costs, barley cultivation under this AHS configuration was economically unviable, likely due to yield suppression under higher tree density and lower market value of the produce.

Comparative interaction

Overall, *rabi* crops under the AHS system exhibited lower economic returns compared to AS systems. Lentil showed relatively better performance, while wheat and barley resulted in economic losses. High tree density and increased competition for light and nutrients appear to be the major factors

Table 3: Economics of cereal/*rabi* crops in different models of AHS system

Economic variables recorded	Wheat + Malta + Bhimal	Lentils + Malta + Khadik	Barley + Nimbu + Bhimal
Variable cost	**Total amount (in ₹) for one hectare**		
	Establishment cost		
Site preparation	1310.70	1195.80	1011.80
FYM	2491.50	934.31	1245.75
Seed	4360.12	5232.15	3737.25
Labour	5979.60	5979.60	3039.63
Harvesting	4983.00	4262.95	2740.65
Post-harvesting	3986.40	3986.40	3238.95
Transportation	777.34	508.26	1715.10
Fixed cost	—	—	—
Total	23888.66	22099.47	16729.13
	Revenues		
Crop	9238.10	24456.50	6173.90
Straw	1290.00	—	3582.77
Gross return	10618.10	24456.50	9756.60
Net return	13270.50	2357.03	6972.53
BCR	0.44	1.10	0.58

limiting crop productivity and profitability under AHS conditions in the Garhwal Himalayan region.

Economic analysis of vegetable crops in different models of AHS system

Pisum sativum + Citrus sinensis + Grewia optiva (Pea + Malta + Bhimal) based model

This AHS model recorded a tree density of 180-190 trees ha^{-1}. Due to multiple harvests, pea yield was calculated cumulatively. The total cost of cultivation was ₹ 35,940.19 ha^{-1}, while gross return amounted to ₹ 73,569.00 ha^{-1} (Table 4), resulting in a net return of ₹ 37,628.81 ha^{-1}. The B:C ratio of 2.04 indicates good economic viability of pea under AHS system, despite higher tree density.

Solanum tuberosum + Citrus aurentifolia + Grewia optiva (Potato + Nimbu + Bhimal) based model

In this model, tree density ranged from 120-130 trees ha^{-1}. Potato cultivation incurred a total cost of ₹ 19,638.10 ha^{-1} and generated a gross return of ₹ 35,758.00 ha^{-1} (Table 4), resulting in a net return of ₹ 16,119.90 ha^{-1} with a B:C ratio of 1.82. The results indicate that potato remains economically viable under moderate tree density in AHS systems.

Allium sativum + Citrus sinensis + Grewia optiva (Garlic + Malta/Nimbu + Bhimal) based model

This model had a tree density of 140-150 trees ha^{-1}. The total cost of garlic cultivation was ₹ 37,232.46 ha^{-1}, while gross return reached ₹ 121,924.00 ha^{-1} (Table 4), resulting in the highest net return of ₹ 84,691.54 ha^{-1} among all vegetable-based AHS models. The B:C ratio of 3.27 highlights the superior economic performance of garlic, attributable to its high market value and better tolerance to partial shade conditions.

Allium cepa + Citrus sinensis + Celtis australis (Onion + Malta + Khadik) based model

In the onion-based AHS model, tree density ranged from 180-190 trees ha^{-1}. The total cost of cultivation was ₹ 30,952.90 ha^{-1}, and gross return was ₹ 35,204.80 ha^{-1} (Table 4), resulting in a net return of ₹ 4,251.90 ha^{-1} with a B:C ratio of 1.13. The relatively lower profitability of onion suggests higher sensitivity to tree competition under dense AHS configurations.

Comparative interpretation

Among vegetable crops evaluated under the AHS system, garlic emerged as the most profitable crop, followed by pea, potato, and onion. High-value vegetable crops demonstrated better economic resilience under combined horticultural–silvicultural systems, even at higher tree densities. These results emphasize the importance of crop selection in

Table 4: Economic analysis of vegetable crops in different models of AHS system

Economic variables recorded	Pea + Malta + Bhimal	Potato + Nimbu + Bhimal	Garlic + Malta + Bhimal	Onion + Malta + Khadik
Variable cost	**Total amount (in ₹) for one hectare**			
	Establishment cost			
Site preparation	2565.56	1830.80	2116.30	1750.80
FYM	3114.37	1868.60	3425.81	3114.37
DAP	4484.70	—	—	—
Urea	2491.50	996.60	3737.25	1245.75
Seed	4983.00	3488.10	8720.25	4983.00
Labour	7723.65	4235.55	6727.05	5979.60
Harvesting	5979.60	4983.00	9966.00	4982.00
Transportation	4597.81	2235.50	2539.80	1955.80
Fixed cost	—	—	—	—
Total	35940.19	19638.10	37232.46	30952.90
	Revenues			
Crop	73569.00	35758.00	121924.00	35204.80
Gross return	73569.00	35758.00	121924.00	35204.80
Net return	37628.81	16119.90	84691.54	4251.90
BCR	2.04	1.82	3.27	1.13

Table 5: Total cost, gross return, net return and benefit cost ratio of all models under selected agroforestry system

Agroforestry system	Model	Total cost	Gross return	Net return	BCR
AS	Wheat + Khadik + Bhimal	26215.71	21437.86	4777.85	0.81
	Lentils + Khadik + Bhimal	21528.99	32349.60	10820.61	1.50
	Barley + Khadik + Bhimal	19296.28	13971.40	5324.88	0.72
	Pea + Khadik + Bhimal	45842.53	105240.96	59398.43	2.29
	Potato + Khadik + Bhimal	22564.40	48813.46	26249.06	2.16
	Garlic + Khadik + Bhimal	43317.90	111160.76	67842.86	2.56
	Onion + Khadik + Bhimal	24776.90	38456.30	13679.40	1.55
AHS	Wheat + Bhimal + Malta	23888.66	10618.10	13270.50	0.44
	Lentils + Khadik + Malta	22099.66	24456.50	2357.03	1.10
	Barley + Bhimal + Nimbu	16729.13	9756.60	6972.53	0.58
	Pea + Bhimal + Malta	35940.19	73569.00	37628.81	2.04
	Potato + Bhimal + Nimbu	19638.10	35758.00	16119.90	1.82
	Garlic + Bhimal + Malta/Nimbu	37232.46	121924.00	84691.54	3.27
	Onion + Khadik + Malta	30952.90	35204.80	4251.90	1.13

enhancing farm income under AHS systems in the Garhwal Himalayan region.

Comparative analysis of BCR in different models of AS vs AHS system

The comparative benefit-cost ratios, along with total cost, gross return, and net return across different AS and AHS models, are presented in Table 5, clearly illustrating the variation in economic performance among crop-tree combinations. Sharma *et al.* 2021 have reported that AS systems often provide higher economic returns for selected crops due to more efficient resource use and improved management practices. This may explain the comparatively higher benefit-cost ratio observed for wheat under the AS system in the present study. Joshi *et al.* 2022 reported marginal differences in the economic performance of barley between AS and AHS systems, suggesting that although overall returns may remain comparable, AS can facilitate slightly better resource allocation under certain conditions. Similar observations were reported by Patel *et al.* 2024, who attributed variations in B:C ratio across agroforestry systems to differences in management practices and tree-crop interactions. Comparable economic returns under different systems further indicate the role of effective system management in sustaining profitability (Sharma and Gupta, 2023). Moreover, earlier studies have highlighted that AS systems enhance profitability of high-value crops through improvements in soil health and microclimatic conditions (Sharma *et al.* 2021). In addition, integration of horticultural components in agroforestry systems has been shown to positively influence crop productivity and economic returns by optimizing land use and diversifying farm income (Singh and Kumar, 2020).

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