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Comparative Economic Analysis of Agroforestry Systems in Kinnaur, Himachal Pradesh

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ABSTRACT: The study was conducted in the Kinnaur district of Himachal Pradesh during 2021–2023 to evaluate the economic productivity of prevalent agroforestry systems across different altitudinal zones. The district was stratified into three altitudinal zones: Zone-I (1500–2000 m amsl), Zone-II (2000–2500 m amsl), and Zone-III (above 2500 m amsl). From each zone, three Gram Panchayats were selected, and within each Panchayat, 15 farmers were categorized as marginal, small and semi-medium, with five from each category. The agroforestry practices in the region were classified into six land-use systems: agrihorticulture, hortiagriculture, agrihortisilviculture, hortiagrisilviculture, hortipastoral, and pastoralsilviculture. The findings revealed that economic productivity varied significantly across farmer categories, land-use systems, and altitudinal zones. Semi-medium farmers recorded the highest cost of cultivation, net returns, and benefit-cost ratio, while marginal farmers showed the lowest values. Among the agroforestry systems, the hortiagriculture system in altitudinal Zone-III exhibited the highest cost of cultivation (Rs 8,20,765 ha^{-1} yr^{-1}), gross returns (Rs 37,79,403 ha^{-1} yr^{-1}), and net returns (Rs 29,54,442 ha^{-1} yr^{-1}). The pastoralsilviculture system in the same zone recorded the highest benefit-cost ratio (4.68). This study provides valuable insights for selecting suitable agroforestry systems to enhance profitability and improve the socio-economic conditions of farmers in Himachal Pradesh.

Keywords: Agroforestry, Economic Productivity, Altitudinal Zones, Himachal Pradesh.

INTRODUCTION

Agroforestry, a sustainable land-use system that integrates trees with crops and/or livestock, has gained global recognition for its potential to enhance productivity, biodiversity, and rural livelihoods, especially in ecologically sensitive and mountainous regions (Nair, 2019, FAO, 2020; Pattanaik and Priyadarshini 2023). In the Indian Himalayan region, where conventional agriculture is often constrained by steep slopes, poor soil fertility, and climatic variability, agroforestry offers an adaptive strategy that balances ecological health with economic returns (Dhyani *et al.*, 2022). Kinnaur district in Himachal Pradesh, with its diverse topography and altitudinal variation (ranging from 1500 m to over 2500 m above mean sea level), supports a wide array of agroforestry systems adapted to local agro-climatic conditions. Farmers in the region adopt combinations of agrihorticulture, hortiagriculture, agrihortisilviculture, hortiagrisilviculture, hortipastoral, and pastoralsilviculture systems to meet their food, fodder, fuel, and income needs. These systems vary significantly in their resource requirements, output levels, and profitability depending on altitude, landholding size, and farmer category (Negi and Dhyani 2021). While the ecological benefits of agroforestry are well documented, economic evaluation remains crucial to assess the viability and scalability of different models. A comparative economic analysis that includes key parameters such as cost of cultivation, gross and net returns, and benefit-cost ratio can provide deeper insights into the most profitable and sustainable systems for different agro-ecological zones and socio-economic groups (Bhusal *et al.*, 2021; Dhillon *et al.*, 2023).

This study aims to conduct a comparative economic analysis of prevalent agroforestry systems across altitudinal zones in Kinnaur district. By evaluating their economic performance, the study seeks to identify high-return systems that can guide farmers, planners, and policymakers in optimizing land use, enhancing rural incomes, and promoting climate-resilient agriculture in Himalayan regions.

MATERIAL AND METHODS

The present study was conducted during 2021–2023 in Kinnaur district of Himachal Pradesh, covering an altitudinal range from 1500 meters above mean sea level (amsl) to elevations exceeding 2500 meters amsl. Geographically, Kinnaur is situated in the western part of Himachal Pradesh, lying between latitudes 31°05' to 32°05' N and longitudes 77°45' to 79°00' E. The district falls under the high hill dry temperate agro-climatic zone and is characterized by a cold and dry climate. It experiences significant seasonal temperature variations, with maximum temperatures reaching 22.8 °C in July and 5.2 °C in January. Minimum temperatures vary from 12.8 °C in July to as low as -3.8 °C in January. Most parts of the district experience heavy snowfall during the winter season, while the average annual rainfall is recorded at approximately 682.24 mm.

A. Cost of cultivation

Cost of cultivation is the total amount of expenditure (variable and fixed cost) done on producing yield.

B. Gross return

The utilizable biomass of each functional unit in a system was given the current market value for estimating total return from a system.

C. Net returns

Net Return = Gross return – Production cost

D. Benefit: Cost ratio

Benefit: cost ratio of the system was calculated by dividing total discounted benefits with total discounted costs of the system.

$$\text{Benefit : Cost Ratio} = \frac{\text{Total discounted benefits}}{\text{Total discounted costs}}$$

RESULTS AND DISCUSSION

A. Cost of cultivation (Rs ha $^{-1}$yr $^{-1}$)

(i) Altitudinal Zone-I. Data on effect of farmers categories on the cost of cultivation incurred for various prevalent agroforestry systems in altitudinal zone-I of Kinnaur district of Himachal Pradesh has been presented in Table 1. Considering the different farmers categories, cost of cultivation for different farmers categories were observed highest semi-medium farmers category (Rs 4,05,131 ha^{-1}yr^{-1}) followed by small farmers category (Rs 3,84,898 ha $^{-1}$yr $^{-1}$) and marginal farmers category (Rs 3,42,896 ha $^{-1}$yr^{-1}). Within agroforestry systems, the highest cost of cultivation (Rs 5,62,466 ha^{-1}yr $^{-1}$) were incurred for the hortiagriculture system, while the minimum (Rs 25,743 ha $^{-1}$yr $^{-1}$) cost of cultivation were observed for pastoralsilviculture system. In terms of interaction, the cost of cultivation was highest (Rs 6,22,447 ha^{-1}yr^{-1}) for the hortiagriculture system under the small farmers category and the minimum (Rs 22,180 ha^{-1}yr $^{-1}$) was observed for the pastoralsilviculture system under the marginal farmers category.

Table 1: Cost of cultivation (Rs ha $^{-1}$yr $^{-1}$) of prevalent agroforestry systems among different farmers categories in Kinnaur district (H.P.)

Cost of cultivation (Rs ha $^{-1}$yr $^{-1}$)				
Altitudinal Zone-I				
Agroforestry Systems (AFS)	**Farmers Category (FC)**			**Mean**
	Marginal	**Small**	**Semi-medium**	
AH	211320	241118	331025	261154
HA	522450	622447	542500	562466
AHS	312780	327785	402770	347778
HAS	461318	491328	581360	511335
HP	527330	602340	542450	557373
PS	22180	24370	30680	25743
Mean	342896	384898	405131	
Altitudinal Zone-II				
Agroforestry Systems (AFS)	**Farmers Category (FC)**			**Mean**
	Marginal	**Small**	**Semi-medium**	
AH	307220	337010	427025	357085
HA	617340	716233	637227	656933
AHS	507970	522865	597825	542887
HAS	557110	587621	677326	607352
HP	625450	700450	640450	655450
PS	33260	35370	41640	36757
Mean	441392	483258	503582	
Altitudinal Zone-III				
Agroforestry Systems (AFS)	**Farmers Category (FC)**			**Mean**
	Marginal	**Small**	**Semi-medium**	
AH	476480	505360	596220	526020
HA	785590	883585	805710	824962
AHS	727360	742380	817032	762257
HAS	726480	756250	846340	776357
HP	790650	865610	806035	820765
PS	37070	39150	45560	40593
Mean	590605	632056	652816	

Where, AH-Agrihorticulture, HA-Hortiagriculture, AHS-Agrihortisilviculture, HAS-Hortiagrisilviculture, HP- Hortipastoral, PS-Pastoralsilviculture

(ii) Altitudinal Zone-II. The information presented in Table 1 indicates the cost of cultivation incurred for various prevalent agroforestry systems in altitudinal zone-II. Among the different farmers categories, the maximum cost of cultivation (Rs 5,03,582 $ha^{-1}yr^{-1}$) were observed under the semi-medium farmers category and the minimum (Rs 4,41,392 $ha^{-1}yr^{-1}$) were found for the marginal farmers category. For the different agroforestry systems, the highest cost of cultivation (Rs 6,56,933 $ha^{-1}yr^{-1}$) were incurred for the hortiagriculture system, which was statistically at par with the cost of cultivation for hortipastoral system (Rs 6,55,450 $ha^{-1}yr^{-1}$) while the minimum cost of cultivation (Rs 36,757 $ha^{-1}yr^{-1}$) were observed for pastoralsilviculture system. For the interaction, the cost of cultivation was highest (Rs 7,16,233 $ha^{-1}yr^{-1}$) for the hortiagriculture system practiced by small farmers category and the minimum (Rs 33,260 $ha^{-1}yr^{-1}$) were found for the pastoralsilviculture system under the marginal farmers category.

(iii) Altitudinal Zone-III. The data presented in Table 1 revealed the cost of cultivation incurred for various prevalent agroforestry systems in altitudinal zone-III. Within the different farmers categories, the highest cost of cultivation (Rs 6,52,816 $ha^{-1}yr^{-1}$) were observed under the semi-medium farmers category and the lowest (Rs 5,90,605 $ha^{-1}yr^{-1}$) were found for the marginal farmers category. Midst of different agroforestry systems, the highest cost of cultivation (Rs 8,24,962 $ha^{-1}yr^{-1}$) were incurred for the hortiagriculture system which was statistically at par with the cost of cultivation for hortipastoral system (Rs 8,20,765 $ha^{-1}yr^{-1}$) and the minimum cost of cultivation was found for pastoralsilviculture system (Rs 40,593 $ha^{-1}yr^{-1}$). For the interaction, the cost of cultivation was highest (Rs 8,83,585 $ha^{-1}yr^{-1}$) for the hortiagriculture system under the small farmers category and the minimum (Rs 37,070 $ha^{-1}yr^{-1}$) were found for the pastoralsilviculture system under the marginal farmers category.

B. Gross Returns (Rs $ha^{-1}yr^{-1}$)

(i) Altitudinal Zone-I. Upon reviewing the data presented in Table 2 showed the gross returns obtained from the various prevalent agroforestry systems in altitudinal zone-I in Kinnaur district of Himachal Pradesh. Among the different farmers categories, the highest gross returns (Rs 12,27,972 $ha^{-1}yr^{-1}$) were found under the semi-medium farmers category and the minimum (Rs 10,41,830 $ha^{-1}yr^{-1}$) were found for the marginal farmers category. For the different agroforestry systems, the maximum gross returns (Rs 19,64,438 $ha^{-1}yr^{-1}$) were obtained for the hortiagriculture system which was statistically at par with gross return for hortipastoral system (Rs 19,09,160 $ha^{-1}yr^{-1}$) while the minimum gross returns (Rs 97,430 $ha^{-1}yr^{-1}$) were found for pastoralsilviculture system. In terms of interaction, gross returns were highest (Rs 21,17,565 $ha^{-1}yr^{-1}$) for the hortiagriculture system under the small farmers category which was statistically at par with gross return for hortipastoral system (Rs 21,26,438 $ha^{-1}yr^{-1}$) under same farmers category whereas the minimum (Rs 82,731 $ha^{-1}yr^{-1}$) were found for the pastoralsilviculture system under the marginal farmers category.

Table 2: Gross Returns (Rs $ha^{-1}yr^{-1}$) of prevalent agroforestry systems among different farmers categories in Kinnaur district (H.P.)

Gross Returns (Rs $ha^{-1}yr^{-1}$)				
Altitudinal Zone-I				
Agroforestry Systems (AFS)	**Farmers Category (FC)**			**Mean**
	Marginal	**Small**	**Semi-medium**	
AH	345212	388489	514810	416171
HA	1839024	2117565	1936725	1964438
AHS	686737	768944	901613	785765
HAS	1571354	1584577	2022367	1726099
HP	1725919	2126438	1875122	1909160
PS	82731	92362	117198	97430
Mean	1041830	1179729	1227972	
Altitudinal Zone-II				
Agroforestry Systems (AFS)	**Farmers Category (FC)**			**Mean**
	Marginal	**Small**	**Semi-medium**	
AH	680131	725001	851872	752335
HA	2444666	2907906	2612631	2655068
AHS	1459817	1469917	1587166	1505633
HAS	2109483	2249898	2665075	2341485
HP	2389219	2738760	2645059	2591012
PS	136366	147493	180718	154859
Mean	1536614	1706496	1757087	
Altitudinal Zone-III				
Agroforestry Systems (AFS)	**Farmers Category (FC)**			**Mean**
	Marginal	**Small**	**Semi-medium**	
AH	1210259	1310368	1627681	1382769
HA	3565620	4074135	3698455	3779403
AHS	2327552	2414918	2769738	2504069
HAS	3138394	3304813	3797172	3413459
HP	3486767	3843308	3643278	3657784
PS	174182	180290	215779	190084
Mean	2317129	2521305	2625351	

Where, AH-Agrihorticulture, HA-Hortiagriculture, AHS-Agrihortisilviculture, HAS-Hortiagrisilviculture, HP- Hortipastoral, PS-Pastoralsilviculture

(ii) Altitudinal Zone-II. The information presented in Table 2 regarding the gross returns obtained from various prevalent agroforestry systems in altitudinal zone-II. Considering the different farmers categories, the maximum gross returns (Rs 17,57,087 $ha^{-1}yr^{-1}$) were found under the semi-medium farmers category which was statistically at par with small farmers category (Rs 17,06,496 $ha^{-1}yr^{-1}$) while the minimum (Rs 15,36,614 $ha^{-1}yr^{-1}$) were observed for the marginal farmers category. Among the different agroforestry systems, the maximum gross returns (Rs 26,55,068 $ha^{-1}yr^{-1}$) were obtained for the hortiagriculture system and the minimum gross returns (Rs 1,54,859 $ha^{-1}yr^{-1}$) were found for pastoralsilviculture system. In terms of interaction, gross returns were found maximum (Rs 29,07,906 $ha^{-1}yr^{-1}$) for the hortiagriculture system practiced by small category farmerss and the minimum (Rs 1,36,366 $ha^{-1}yr^{-1}$) were found for the pastoralsilviculture system under the marginal category farmerss.

(iii) Altitudinal Zone-III. The data presented in Table 2 indicates the gross returns obtained from various prevalent agroforestry systems in altitudinal zone-III. Among the different farmers categories, the gross returns were found highest in semi-medium (Rs 26,25,351 $ha^{-1}yr^{-1}$) followed by small (Rs 25,21,305 $ha^{-1}yr^{-1}$) and marginal (Rs 23,17,129 $ha^{-1}yr^{-1}$) farmers categories. Midst of the different agroforestry systems, the highest gross returns (Rs 37,79,403 $ha^{-1}yr^{-1}$) were recorded for the hortiagriculture system and the lowest gross returns were recorded for pastoralsilviculture (Rs 1,90,084 $ha^{-1}yr^{-1}$). In terms of interaction, gross returns were maximum (Rs 40,74,135 $ha^{-1}yr^{-1}$) for the hortiagriculture system under the small farmers category and the minimum (Rs 1,74,182 $ha^{-1}yr^{-1}$) were found for the pastoralsilviculture system under the marginal farmers category.

C. Net Returns (Rs $ha^{-1}yr^{-1}$)

(i) Altitudinal Zone-I. The analysis of the data presented in Table 3 revealed the net returns obtained from various prevalent agroforestry systems in altitudinal zone-I in Kinnaur district of Himachal Pradesh. Within the different farmers categories, the semi-medium farmers category resulted in maximum net returns (Rs 8,22,842 $ha^{-1}yr^{-1}$) and the minimum (Rs 6,98,933 $ha^{-1}yr^{-1}$) was observed for the marginal farmers category. Considering the different agroforestry systems, the maximum net returns (Rs 14,01,972 $ha^{-1}yr^{-1}$) were obtained for hortiagriculture system and minimum net return (Rs 71,687 $ha^{-1}yr^{-1}$) were obtained for pastoralsilviculture system. For the interaction, net returns were maximum (Rs 15,24,098 $ha^{-1}yr^{-1}$) for the hortiagriculture system practiced by small farmers and the minimum (Rs 60,551 $ha^{-1}yr^{-1}$) were found for the pastoralsilviculture system in the marginal farmers category.

Table 3: Net Returns (Rs $ha^{-1}yr^{-1}$) of prevalent agroforestry systems among different farmers categories in Kinnaur district (H.P.).

Net Returns (Rs $ha^{-1}yr^{-1}$)				
Altitudinal Zone-I				
Agroforestry Systems (AFS)	**Farmers Category (FC)**			**Mean**
	Marginal	**Small**	**Semi-medium**	
AH	133892	147371	183785	155016
HA	1316574	1495118	1394225	1401972
AHS	373957	441159	498843	437986
HAS	1110036	1093249	1441007	1214764
HP	1198589	1524098	1332672	1351787
PS	60551	67992	86518	71687
Mean	698933	794831	822842	
Altitudinal Zone-II				
Agroforestry Systems (AFS)	**Farmers Category (FC)**			**Mean**
	Marginal	**Small**	**Semi-medium**	
AH	372911	387991	424847	395250
HA	1827326	2191673	1975404	1998134
AHS	951847	947052	989341	962747
HAS	1552373	1662277	1987749	1734133
HP	1763769	2038310	2004609	1935562
PS	103106	112123	139078	118102
Mean	1095222	1223238	1253504	
Altitudinal Zone-III				
Agroforestry Systems (AFS)	**Farmers Category (FC)**			**Mean**
	Marginal	**Small**	**Semi-medium**	
AH	733779	805008	1031461	856749
HA	2780030	3190550	2892745	2954442
AHS	1600192	1672538	1952706	1741812
HAS	2411914	2548563	2950832	2637103
HP	2696117	2977698	2837243	2837019
PS	137112	141140	170219	149490
Mean	1726524	1889250	1972534	

Where, AH-Agrihorticulture, HA-Hortiagriculture, AHS-Agrihortisilviculture, HAS-Hortiagrisilviculture, HP- Hortipastoral, PS-Pastoralsilviculture

(ii) Altitudinal Zone-II. The information presented in Table 3 indicates the net returns obtained from various prevalent agroforestry systems in altitudinal zone-II. Among the different farmers categories, net returns were found highest semi-medium farmers category (Rs 12,53,504 $ha^{-1}yr^{-1}$) which was statistically at par with small farmers category (Rs 12,23,238 $ha^{-1}yr^{-1}$), and lowest was found in marginal farmers category (Rs 10,95,222 $ha^{-1}yr^{-1}$). Taking into consideration the different agroforestry systems, the maximum net returns (Rs 19,98,134 $ha^{-1}yr^{-1}$) were obtained for the hortiagriculture system which was statistically at par with hortipastoral system (Rs 19,35,562 $ha^{-1}yr^{-1}$) and the minimum net returns (Rs 1,18,102 $ha^{-1}yr^{-1}$) were found for pastoralsilviculture system In terms of interaction, net returns were found highest (Rs 21,91,673 $ha^{-1}yr^{-1}$) for the hortiagriculture system practiced by small category farmers and the lowest (Rs 1,03,106 $ha^{-1}yr^{-1}$) was found for the pastoralsilviculture system under the marginal farmers category.

(iii) Altitudinal Zone-III. The data presented in Table 3 showed the net returns obtained from various prevalent agroforestry systems in altitudinal zone-III. Midst of the different farmers categories, net returns were found highest in semi-medium (Rs 19,72,534 $ha^{-1}yr^{-1}$) followed by small (Rs 18,89,250 $ha^{-1}yr^{-1}$) and marginal (Rs 17,26,524 $ha^{-1}yr^{-1}$) farmers categories. Within the different agroforestry systems, the maximum net returns (Rs 29,54,442 $ha^{-1}yr^{-1}$) were recorded for the hortiagriculture system and the minimum net returns (Rs 1,49,490 $ha^{-1}yr^{-1}$) were recorded for pastoralsilviculture system. For the interaction, net returns were found maximum (Rs 31,90,550 $ha^{-1}yr^{-1}$) for the hortiagriculture system under the small farmers category, whereas the minimum (Rs 1,37,112 $ha^{-1}yr^{-1}$) was found for the pastoralsilviculture system under the marginal farmers category.

D. Benefit: Cost Ratio

(i) Altitudinal Zone-I. Upon reviewing the data presented in Table 4 revealed the benefit: cost ratio for various prevalent agroforestry systems in altitudinal zone-I in Kinnaur district of Himachal Pradesh. Among the different farmers categories, the highest benefit: cost ratio was recorded for the semi-medium farmers category (3.02) and lowest was recorded for the marginal farmers category (2.96). Considering the different agroforestry systems, the highest benefit: cost ratio (3.78) was found for the pastoralsilviculture system, and the lowest benefit: cost ratio was found for agrihorticulture system (1.60). For interaction effects, the benefit: cost ratio was found maximum (3.82) for the pastoralsilviculture system practiced by semi-medium farmers category and the minimum benefit: cost ratio (1.56) was observed for the agrihorticulture system by semi-medium farmers category.

Table 4: Benefit: Cost ratio (BCR) of prevalent agroforestry systems among different farmers categories in Kinnaur district (H.P.).

Benefit: Cost ratio (BCR)				
Altitudinal Zone-I				
Agroforestry Systems (AFS)	**Farmers Category (FC)**			**Mean**
	Marginal	**Small**	**Semi-medium**	
AH	1.63	1.61	1.56	1.60
HA	3.52	3.40	3.57	3.50
AHS	2.20	2.35	2.24	2.26
HAS	3.41	3.23	3.48	3.37
HP	3.27	3.53	3.46	3.42
PS	3.73	3.79	3.82	3.78
Mean	2.96	2.98	3.02	
Altitudinal Zone-II				
Agroforestry Systems (AFS)	**Farmers Category (FC)**			**Mean**
	Marginal	**Small**	**Semi-medium**	
AH	2.21	2.15	1.99	2.12
HA	3.96	4.06	4.10	4.04
AHS	2.87	2.81	2.65	2.78
HAS	3.79	3.83	3.93	3.85
HP	3.82	3.91	4.13	3.95
PS	4.10	4.17	4.34	4.20
Mean	3.46	3.49	3.53	
Altitudinal Zone-III				
Agroforestry Systems (AFS)	**Farmers Category (FC)**			**Mean**
	Marginal	**Small**	**Semi-medium**	
AH	2.54	2.59	2.73	2.62
HA	4.54	4.61	4.59	4.58
AHS	3.20	3.25	3.39	3.28
HAS	4.32	4.37	4.49	4.39
HP	4.41	4.44	4.52	4.46
PS	4.70	4.61	4.74	4.68
Mean	3.95	3.98	4.08	

Where, AH-Agrihorticulture, HA-Hortiagriculture, AHS-Agrihortisilviculture, HAS-Hortiagrisilviculture, HP- Hortipastoral, PS-Pastoralsilviculture

(ii) Altitudinal Zone-II. The information presented in Table 4 showed the benefit: cost ratio for various prevalent agroforestry systems in altitudinal zone-II. The benefit: cost ratio varied among different farmers categories, with the maximum ratio of 3.53 observed under the semi-medium farmers category, and the minimum ratio of 3.46 found for the marginal farmers category. Among the different agroforestry systems, the maximum ratio of 4.20 was observed for pastoralsilviculture system and the minimum benefit: cost ratio of 2.12 was found for agrihorticulture system. For interaction, the maximum benefit: cost ratio (4.34) was found in the pastoralsilviculture system practiced by semi-medium farmers category and the minimum ratio (1.99) was observed in the agrihorticulture system under the semi-medium farmers category.

(iii) Altitudinal Zone-III. Table 4 data revealed the benefit: cost ratio for various prevalent agroforestry systems in altitudinal zone-III. Within the different farmers categories, the highest benefit: cost ratio was found for the semi-medium farmers category (4.08) followed by the small farmers category (3.98) and the marginal farmers category (3.95). Considering the different agroforestry systems, the maximum benefit: cost ratio (4.68) was obtained for the pastoralsilviculture system and the minimum benefit: cost ratio was found for agrihorticulture system (2.62). For interaction, the benefit: cost ratio was found highest (4.74) for the pastoralsilviculture system under the semi-medium farmers category and the lowest (2.54) was found for the agrihorticulture system under the marginal farmers category.

The cost of cultivation of the prevalent agroforestry systems among the different farmers categories along the altitudinal zones of Kinnaur district of Himachal Pradesh was recorded the highest under the semi-medium farmers category (Rs 6,52,816 $ha^{-1}yr^{-1}$) in altitudinal zone-III and lowest under the marginal farmers category (Rs 3,42,896 $ha^{-1}yr^{-1}$) in altitudinal zone-I (Table 1). The semi-medium farmers often invest in modern agricultural technologies and machinery to improve productivity and efficiency.

These investments come with higher upfront costs, including purchasing or leasing machinery, maintaining equipment, and investing in irrigation systems. Where, the marginal farmers may rely more on traditional farming methods and manual labor, which can be less costly initially but may lead to lower yields and productivity in the long run. The semi- medium farmers may benefit from economics of scale in certain aspects of production, such as bulk purchasing of inputs or more efficient use of machinery, these benefits may be outweighed by the higher overall costs associated with operating a larger farm. Singh (2019); Janju (2021) also reported that the highest cost of cultivation incurred by the semi-medium farmers category than the small and marginal farmers category. Similarly, Sharma (2022) also reported the total expenses incurred by the medium farmers in temperate zones of Himachal Pradesh. The cost of cultivation was recorded highest (Rs 8,20,765 $ha^{-1}yr^{-1}$) recorded under hortiagriculture system in altitudinal zone-III and lowest (Rs 25,743 $ha^{-1}yr^{-1}$) under the pastoralsilviculture system in altitudinal zone-I. The horticultural crop mainly the apple orchards typically take several years to reach full production capacity after planting. During this gestation period, growers incur costs for land preparation, tree planting, irrigation infrastructure, and other inputs without receiving significant returns. This long waiting period increases the overall cost of cultivation. Establishing an apple orchard requires a substantial initial investment in land, trees, infrastructure (such as trellises, irrigation systems, and fencing), and labor. High-quality apple trees are often grafted on rootstocks, which can be expensive. Additionally, specialized equipment for orchard management and harvesting adds to the initial investment. The apple orchards require intensive labor throughout the year for tasks such as pruning, thinning, pest and disease management, irrigation, and harvesting. Labor costs can be significant, especially during peak seasons such as bloom thinning and harvest. The labor-intensive nature of orchard management contributes to the overall cost of cultivation (Kireeti *et al*., 2014). Establishing an apple orchard require inputs such as fertilizers, pesticides, herbicides, and fungicides to maintain tree health and productivity. Additionally, orchardists may invest in specialized equipment for pest and disease monitoring, as well as equipment for frost protection and irrigation. These input costs contribute to the overall expense of apple orchard cultivation. Apple orchards are susceptible to weather-related risks such as late frosts, hailstorms, and drought, which can damage trees and reduce yields. Growers may need to invest in protective measures such as frost fans, hail nets, and irrigation systems to mitigate these risks, adding to the cost of cultivation. The apple market often demands high-quality fruit that meets specific size, color, and taste standards. Achieving and maintaining these standards may require additional investments in orchard management practices, such as thinning and pruning, to optimize fruit quality. Packaging and storage facilities may also be necessary to meet market requirements, further increasing costs. After harvest, apples require careful handling and storage to maintain quality and extend shelf life. Investments in packing facilities, cold storage, and transportation infrastructure are necessary to preserve fruit quality and meet market demand, adding to the overall cost of cultivation. The findings are consistent with those reported by Chisanga *et al.* (2013); Singh (2019) in temperate zones of Himachal Pradesh. However, among all the agroforestry systems, pastoralsilviculture system resulted in minimum cost of cultivation (Rs 23,654 $ha^{-1}yr^{-1}$) due to pastoralsilviculture system often rely on natural processes and ecosystem services to maintain soil fertility, control pests, and regulate microclimates. As a result, the need for synthetic fertilizers, pesticides, and herbicides is minimized, leading to reduced input costs. Additionally, the presence of trees in the system can enhance soil health and water retention, further reducing the need for irrigation and soil amendments. Integrating trees with livestock grazing can diversify income streams for farmers. In addition to revenue from livestock production, farmers may derive additional income from the sale of timber, non-timber forest products (such as fruits, nuts, and medicinal plants), carbon credits, and eco-tourism activities. This diversification of income sources can help offset the cost of cultivation and improve overall profitability. The cost of cultivation increased as altitude increased across the various altitudinal zones. Several research (Chisanga *et al.,* 2013; Singh, 2019; Sharma, 2022) found that the expense of farming increased with altitude in Himachal Pradesh. Cultivating crops at higher altitudes often requires extensive land terracing, slope stabilization measures, and construction of infrastructure such as roads and irrigation channels. The rugged terrain makes it difficult to access agricultural land, necessitating additional investments in land preparation and infrastructure, which increases cultivation costs. The climate varies significantly with altitude and the higher altitudes experience cooler temperatures, shorter growing seasons, and more variable weather patterns. The frost, snowfall, and hailstorms are common at higher elevations, posing risks to crops and requiring protective measures such as frost protection systems and hail nets. The farmers may need to invest in specialized crop varieties, irrigation systems, and soil conservation practices to adapt to the harsh climate, leading to higher cultivation costs. Cultivable land at higher altitudes in Himachal Pradesh is limited due to steep slopes, rocky terrain, and conservation regulations aimed at protecting fragile mountain ecosystems. Farmers may need to reclaim land through terracing or soil conservation measures, which requires significant investment in labor and resources. The scarcity of land increases land acquisition costs and reduces economics of scale, contributing to higher cultivation costs. Agricultural inputs such as plants, seeds, fertilizers, pesticides, and machinery may be more expensive and less accessible at higher altitudes due to transportation costs and logistical challenges. Farmers may need to import inputs from lower altitudes or neighboring states, leading to higher input costs. Cultivating crops at higher altitudes is labor-intensive due to the rugged terrain, terracing requirements, and limited mechanization options. Farmers rely heavily on manual labor for tasks such as land preparation, planting, and harvesting. Labor costs may be higher due to the scarcity of skilled labor and the need for specialized skills in terrace construction and hillside farming practices, adding to cultivation costs. Cultivating crops at higher altitudes exposes farmers to additional risks such as soil erosion, landslides, and altitude-related pests and diseases. Managing these risks requires investments in erosion control measures, land stabilization techniques, pest and disease management practices, and insurance coverage, which increase cultivation costs. The farmers face challenges in accessing markets and agricultural services due to remoteness, inadequate infrastructure, and poor connectivity. The transportation costs are higher at higher altitudes due to difficult terrain and longer distances to markets. Lack of storage facilities and processing infrastructure further limits market access and increases post-harvest losses, leading to higher overall cultivation costs.

Gross returns data showed in Table 2 revealed that the prevalent agroforestry systems among the different farmers categories along the altitudinal zones of Kinnaur district of Himachal Pradesh was recorded the highest under the semi-medium farmers category (Rs 26,25,351 $ha^{-1}yr^{-1}$) in altitudinal zone-III and lowest under the marginal farmers category (Rs 10,41,830 $ha^{-1}yr^{-1}$) in altitudinal zone-I. Similarly, Net returns was recorded the highest under the semi-medium farmers category (Rs 19,72,534 $ha^{-1}yr^{-1}$) in altitudinal zone-III and lowest under the marginal farmers category (Rs 6,98,933 $ha^{-1}yr^{-1}$) in altitudinal zone-I (Table 3). These results are consistent with those of the researchers (Singh, 2019; Janju 2021), who also found the highest gross and net returns under the medium farmers category in Himachal Pradesh. The semi-medium category farmers often have better access to resources such as land, credit, technology, and inputs compared to marginal category farmers. They may have larger landholdings and access to formal financial institutions, allowing them to invest in higher-quality inputs, machinery, and infrastructure. This enables semi-medium farmers to improve productivity and achieve higher gross returns as well as net returns (Sinha *et al*., 2021). The semi-medium category farmers often have better access to resources such as land, credit, technology, and inputs compared to marginal category farmers. They may have larger landholdings and access to formal financial institutions, allowing them to invest in higher-quality inputs, machinery, and infrastructure. This enables semi-medium farmers to improve productivity and achieve higher gross returns as well as net returns. In the semi-medium category farmers often invest in infrastructure such as irrigation systems, storage facilities, processing units, and transportation networks to add value to their produce and access higher-value markets. They may also adopt technology and innovation to improve efficiency, reduce waste, and enhance product quality. These investments enable semi-medium category farmers to add value to their products, reduce post-harvest losses, and increase profitability, leading to higher net returns. The gross returns were found maximum (Rs 37,79,403 $ha^{-1}yr^{-1}$) under hortiagriculture system in altitudinal zone-III and minimum (Rs 97,430 $ha^{-1}yr^{-1}$) under the pastoralsilviculture system in altitudinal zone-I. Likewise, highest net returns (Rs 29,54,442 $ha^{-1}yr^{-1}$) recorded under hortiagriculture system in altitudinal zone-III and minimum (Rs 71,687 $ha^{-1}yr^{-1}$) under pastoralsilviculture system in altitudinal zone-I. of Kinnaur district of Himachal Pradesh. The maximum area occupied by the apple plants in the hortiagricultue system, which is higher than other horticulture-based systems might be the reason for the highest gross and net returns. In addition to income from apple production, farmers may derive revenue from intercropped crops, such as vegetables, agricultural crops in orchard alleys. The diversification of income sources can help spread risk and increase overall gross and net returns. The hortiagriculture system provide various ecosystem services that benefit apple production and overall farm productivity. The apple trees in the system contribute to soil fertility, water retention, and biodiversity conservation. They also help control soil erosion, regulate microclimates, and provide habitat for beneficial insects and pollinators. By enhancing ecosystem services, hortiagriculture systems can improve apple yields and quality, leading to higher gross returns. The hortiagriculture systems promote soil health and fertility through the addition of organic matter, nutrient cycling, and improved soil structure. Trees in the system contribute to the accumulation of organic matter through leaf litter and root exudates, which enhances soil fertility and microbial activity. Healthy soils support vigorous apple tree growth and reduce the need for synthetic fertilizers, leading to cost savings and higher gross returns. The hortiagriculture systems are often more sustainable and resilient to environmental stresses compared to monoculture orchards. By diversifying plant species and creating ecological niches, agroforestry systems can buffer against pests, diseases, and extreme weather events. This resilience helps maintain consistent apple yields and quality over time, ensuring stable gross as well as net returns for farmers. Gross and net returns increase with altitude across the various altitudinal zones of Kinnaur district of Himachal Pradesh. Several researches (Chisanga *et al.,* 2013; Singh, 2019; Sharma, 2022) have also reported an increase in gross and net returns as altitude increases in Himachal Pradesh.

As altitude increases, temperatures generally decrease and the apples require a certain number of chilling hours during the dormant season to break dormancy and set fruit. Higher altitudes provide cooler temperatures, extending the duration of chilling hours (González-Martínez *et al*., 2025). This can lead to better fruit set and overall yield. The higher altitudes often receive more direct sunlight due to reduced atmospheric interference. This can result in better fruit coloring, flavor development, and overall fruit quality, which can command higher prices in the market. Some pests and diseases that affect apple trees thrive at lower altitudes. The higher altitudes may have fewer pest and disease pressures, reducing the need for costly interventions such as pesticides and fungicides. In some cases, higher altitudes may have soils more conducive to apple cultivation, resulting in healthier trees and better yields. The apples grown at higher altitudes may be perceived as higher quality or more unique due to their specific growing conditions. This can result in increased demand and potentially higher prices for the apples produced at these altitudes. The certain apple varieties may perform better at higher altitudes due to their specific requirements for chilling hours, sunlight, or soil conditions. The growers at higher altitudes may choose varieties that are better suited to their environmental conditions, leading to improved yields and returns.

Benefit: Cost Ratio data showed in the Table 4 revealed that the prevalent agroforestry systems among the different farmers categories along the altitudinal zones was recorded the highest under the semi-medium farmers category (4.08) in altitudinal zone-III and lowest under the marginal farmers category (2.96) in altitudinal zone-I of Kinnaur district of Himachal Pradesh. These results are consistent with those of the other researchers (Singh, 2019; Janju, 2021) who also reported the highest benefit: cost ratio under medium farmers category as compared to small and marginal category farmers in Himachal Pradesh. The semi-medium farmers typically operate on a larger scale than marginal farmers. In the semi-medium category farmers may have better access to resources such as land, finance, technology, and inputs compared to marginal farmers. This improved access allows them to adopt modern agricultural practices, invest in high-yielding varieties, and use advanced machinery, resulting in higher productivity and profitability. The semi-medium category farmers may have more diversified income sources and assets compared to marginal farmers. This diversification helps spread risk and buffers against losses from crop failures or market fluctuations, thereby contributing to a higher BCR. In the semi-medium category farmers often have better market linkages and bargaining power compared to marginal farmers. They may be able to access higher-value markets, negotiate better prices for their produce, and reduce post-harvest losses through improved storage and transportation facilities, resulting in higher net returns. The semi-medium category farmers typically have a higher level of education, training, and experience compared to marginal farmers. This enables them to make more informed decisions regarding crop management, resource allocation, and marketing strategies, leading to improved efficiency and profitability (Yadav and Rao 2024). The semi-medium category farmers may have more diversified income sources and assets compared to marginal farmers. This diversification helps spread risk and buffers against losses from crop failures or market fluctuations, thereby contributing to a higher BCR. In the semi-medium category farmers often have better market linkages and bargaining power compared to marginal farmers. They may be able to access higher-value markets, negotiate better prices for their produce, and reduce post-harvest losses through improved storage and transportation facilities, resulting in higher net returns. The semi-medium category farmers typically have a higher level of education, training, and experience compared to marginal farmers. This enables them to make more informed decisions regarding crop management, resource allocation, and marketing strategies, leading to improved efficiency and profitability. The semi-medium category farmers may have greater capacity to invest in climate-smart agricultural practices and technologies to mitigate the impacts of climate change on their farming operations. This resilience can help maintain or increase yields and incomes, resulting in a higher BCR compared to less resilient farming systems. The Benefit: Cost Ratio were found to be significantly affected by the different agroforestry systems being practiced with maximum (4.68) recorded under pastoralsilviculture system in altitudinal zone-III and minimum (1.60) was recored under agrihorticulture system in altitudinal zone-I of Kinnaur district of Himachal Pradesh. The pastoralsilviculture system involves integrating livestock grazing with tree plantation. This diversification of income sources allows farmers to derive benefits from livestock rearing; timber production and non-timber forest produce mainly the chilgoza from *Pinus gerardiana* tree hereby increasing overall profitability. Trees planted in pastoralsilviculture systems help prevent soil erosion, improve water infiltration, and reduce runoff. This leads to better moisture retention in the soil, which is particularly beneficial in dryland areas like Kinnaur district. Improved soil and water conservation contribute to increased agricultural productivity and resilience to drought, ultimately enhancing the BCR. Pastoralsilviculture systems are often more sustainable than monoculture systems as they promote ecological balance and enhance ecosystem resilience. By integrating trees with livestock grazing, farmers in Kinnaur district can maintain the health and productivity of their land over the long term, ensuring continued benefits and higher BCRs in the future. The findings of Chisanga *et al.* (2013); Singh (2019) support the observation that silvipastoral systems tend to have higher benefit: cost ratio in the temperate zone of Himachal Pradesh. Additionally, the reported order of benefit: cost ratio align with the economic efficiency of different agroforestry systems in the mentioned region: silvipastoral, horticulture, agrihorticulture, agrihortisilviculture, agriculture systems. Benefit: Cost Ratio was found increased with altitude across the various altitudinal zones of Kinnaur district of Himachal Pradesh.

CONCLUSIONS

The present study was undertaken to conduct a comparative economic analysis of agroforestry systems practiced across different altitudinal zones in the Kinnaur district of Himachal Pradesh. The systems analyzed included agrihorticulture, hortiagriculture, agrihortisilviculture, hortiagrisilviculture, hortipastoral, and pastoralsilviculture. Data were collected from marginal, small, and semi-medium farmers to evaluate the cost of cultivation, gross and net returns, and benefit-cost ratios associated with each system. The results revealed significant variation in economic performance across systems and farmer categories. Among all systems, hortiagriculture practiced at higher altitudes (above 2500 m amsl) recorded the highest gross and net returns, marking it as the most economically profitable model. However, this system also incurred the highest cost of cultivation. In contrast, the pastoralsilviculture system, though lower in gross income, exhibited the highest benefit-cost ratio, making it more economically efficient and suitable for resource-constrained farmers. Semi-medium farmers consistently achieved better economic outcomes compared to marginal and small farmers. This was largely due to better access to land, capital, and improved management practices. These findings highlight that altitude, landholding size, and the choice of agroforestry system are key determinants of economic viability in mountain farming contexts.

Agroforestry systems in Kinnaur district hold significant promise for enhancing farm income and improving rural livelihoods. When tailored to local agro-climatic conditions and the socio-economic profile of farmers, these systems can offer high returns and sustainable land use options. Promoting location-specific models—such as hortiagriculture in higher altitudes and pastoralsilviculture in low-input settings—can optimize resource use, increase profitability, and strengthen livelihood resilience. The outcomes of this study provide a scientific basis for policy formulation, extension support, and capacity building aimed at scaling up agroforestry adoption in hill agriculture for enhanced economic and ecological sustainability in Himachal Pradesh.

FUTURE SCOPE

The study opens avenues for long-term monitoring of agroforestry systems to evaluate their economic and ecological sustainability under changing climatic and market conditions. Future research can explore the role of policy support, carbon credit valuation, and improved market linkages in enhancing profitability. Comparative studies across similar agro-ecological zones and the inclusion of technological interventions can further refine agroforestry models suited to the Himalayan region, supporting both livelihood improvement and environmental conservation.

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Conflict of Interest. None.

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