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Agroforestry systems *vis-a-vis* socio-economic dynamics of the farmers: A case study of Baijnath tehsil, Himachal Pradesh

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ABSTRACT

India, despite its significant agricultural advancements, faces challenges such as food insecurity and land degradation, particularly due to climate change. Agroforestry has the potential to enhance the resilience and sustainability of cropping systems necessary to meet the projected food grain demands of 311 million tonnes (mt) by 2030 and 350 mt by 2050. Policies must be tailored to suit regional socio-economic contexts to promote agroforestry effectively. This study explored traditional agroforestry systems and the socio-economic conditions of farmers in Baijnath tehsil, Himachal Pradesh, assessing 150 households across marginal, small, and medium farm categories. Data regarding family structure, educational qualifications, and land use were collected through questionnaires and interviews. The findings revealed a predominance of nuclear families, with an average size of 5.26 members, a high literacy rate of 89.3% and a preference for cattle. Average landholdings were 0.73 ha for marginal farmers, 1.74 ha for small farmers, and 2.57 ha for medium farmers, with agriculture being the primary land use. Factors such as farm size, family size, literacy rate, and livestock numbers significantly influenced agroforestry practices. The identified agroforestry systems included agri-silviculture (AS), agri-silvi-horticulture (ASH) and others. Notably, the agri-silvi-horticulture (ASH) system exhibited the highest biomass production potential of 25.3 t ha^{-1}, whereas the pastoral-silviculture (PS) system had the lowest, at 13.8 t ha^{-1}. There was a significant positive relationship between income from agroforestry and variables like farm size, household size, literacy rate, and livestock holdings. These findings are crucial for developing sustainable agricultural practices and enhancing the livelihoods of farmers in the region.

1 | INTRODUCTION

India is home to approximately 18% of the global human population and 15% of the world's livestock, all sustained on just 2.4% of the Earth's geographical area (Bhattacharyya *et al*., 2015). Since gaining independence, India has achieved significant agricultural growth, evolving from a net importer to a net exporter of food grains. However, despite increased agricultural output, food security remains a pressing global challenge, compounded by issues such as climate change, land degradation, deforestation, intensive cropping, biodiversity loss, population growth, urbanization and substantial food wastage (Kumar and Sharma, 2020). To meet the demands of its growing population, India will require approx. 311 mt of food grains by 2030 and an estimated 350 mt by 2050. The sustainability of the rice-wheat cropping system in the Indo-Gangetic plains is under threat, as evidenced by stagnating yields and declining factor productivity over the past three decades (Aggarwal *et al*., 2004; Kumar *et al*., 2016). To ensure national food security, efforts must focus on expanding agricultural areas and enhancing crop productivity, with technological interventions playing a crucial role in reducing farmers' vulnerability to food security disruptions.

Agroforestry, the practice of integrating trees and crops on the same land, has emerged as a promising solution (Paul, 2024). SP systems combine trees with pastures or cattle within a single production unit and can augment short and long-term productivity. These systems are biodiversityfriendly and confer social and economic advantages to farmers. By reducing farmers' vulnerability and bolstering food security, agroforestry positively impacts all sustainable development goals, including zero hunger, food security, improved nutrition and sustainable agriculture (Kamesh *et al*., 2024). Globally, agroforestry extends over an estimated 823 m ha, with India's current agroforestry practice covering 28.427 m ha nationally (Nair *et al*., 2009; Ahmad *et al*., 2021; Arunachalam *et al*., 2022).

Historically, agroforestry has been integral to Indian livelihoods, capturing the interest of scientists and development planners for its ability to deliver diverse products, mitigate weather-related risks, prevent erosion and sustain intercrops. It enhances rural livelihoods and socio-economic status by providing resources such as fuelwood, fodder, timber, food grains, fiber, fruits, grasses and raw materials for forest-based industries. Agroforestry practices present opportunities for efficient use of natural resources, increased production, improved food quality and maintenance of diverse trees and shrubs, benefiting farmers by offering livelihood and environmental services (Akter *et al*., 2022). In the Himalayan region, agroforestry is essential for the livelihood security of agrarian hill communities, with 12.4% (4.1 m ha) of the North Himalayan agri-ecological zone dedicated to agroforestry practices (Arunachalam *et al*., 2022). This underscores its vital role in supporting local economies and preserving ecological balance.

Despite its numerous advantages, agroforestry adoption has not progressed at the desired pace globally, with mixed responses from farming communities in developing countries. The existing agroforestry literature identifies four broad categories of determinants influencing farmers' adoption decisions: farmers' preferences, resource endowments, institutional barriers and risk/uncertainty (Dhakal and Rai, 2021; Galabuzi *et al*., 2021). However, the influence of these determinants varies across different regions, highlighting the importance of regional studies on the extent of socio-economic factors. Studies conducted globally (Mwase *et al*., 2015; Tiwari *et al*., 2018; Dhakal and Rai, 2021) indicate that socio-economic and institutional factors, such as education level, household size, access to credit and formal training, significantly influence agroforestry adoption in specific regions. Policy interventions should encourage farmer participation in agroforestry projects to foster knowledge and experience sharing. The absence of agroforestry in public policy has limited its recognition as a solution for addressing both the climate crisis and rural livelihoods, likely due to a lack of comprehensive evidence highlighting its socio-economic and environmental benefits for rural communities (Beddington *et al*., 2012; Bishaw *et al*., 2013; Mukhlis *et al*., 2022). Addressing this challenge necessitates comprehensively examining farmers' socioeconomic attributes and agricultural practices in the Himalayan region.

HIGHLIGHTS

- Socio-economic dynamics significantly influence land use and livelihood patterns in Baijnath tehsil of Kangra district of Himachal Pradesh.
- Agri-silviculture (AS) was the most widely adopted system across all the farmer categories.
- Farmers with larger landholdings have more flexibility and resources to diversify their agroforestry practices.
- The agri-silvi-horticulture (ASH) system showed the highest biomass production potential.

This study aims to elucidate the socio-economic status of farmers, identify prevalent agroforestry systems and assess their biological productivity. The investigation aids in the identification of location-specific land-use technologies based on their productivity and suitability for agricultural adoption. Additionally, the study offers an exhaustive evaluation of the socio-economic profile of farmers, which is crucial for addressing food security challenges, augmenting land productivity and ultimately ensuring the sustainable livelihoods of farmers.

2 | MATERIALS AND METHODS

2.1 | Experimental Area

The investigation was conducted during the 2022-2023 period in Baijnath tehsil, located in the Kangra district of Himachal Pradesh, India. The tehsil is situated between 32°04'24” to 32°05'52"N latitude and 76°63'68" to 76°72'60"E longitude, with elevations ranging from 998 to 1525 m above mean sea level (amsl). Baijnath tehsil covers a total area of 296 sq km and includes 199 villages and 51 panchayats (Fig. 1). The region experiences a climate that varies from subtropical to sub-temperate, with an average annual rainfall of approximately 1751 mm. Average temperatures range from 6°C to 36°C, reflecting the diverse climatic conditions suitable for various agricultural practices.

2.2 | Survey and Identification of Agroforestry Systems

The study area, Baijnath tehsil, was purposely selected for its representativeness of the region's agroforestry practices. Within the tehsil, ten panchayats were randomly chosen for the investigation. From each selected panchayat, farmers were categorized based on their landholdings into three groups: marginal (<1 ha), small (1-2 ha) and medium (2-5 ha). A random sample of five farmers from each category was selected, resulting in 150 farmers (5 farmers × 3 categories × 10 panchayats) as the ultimate units of study. Data collection, encompassing variables such as family structure, family type, educational qualifications, land use,

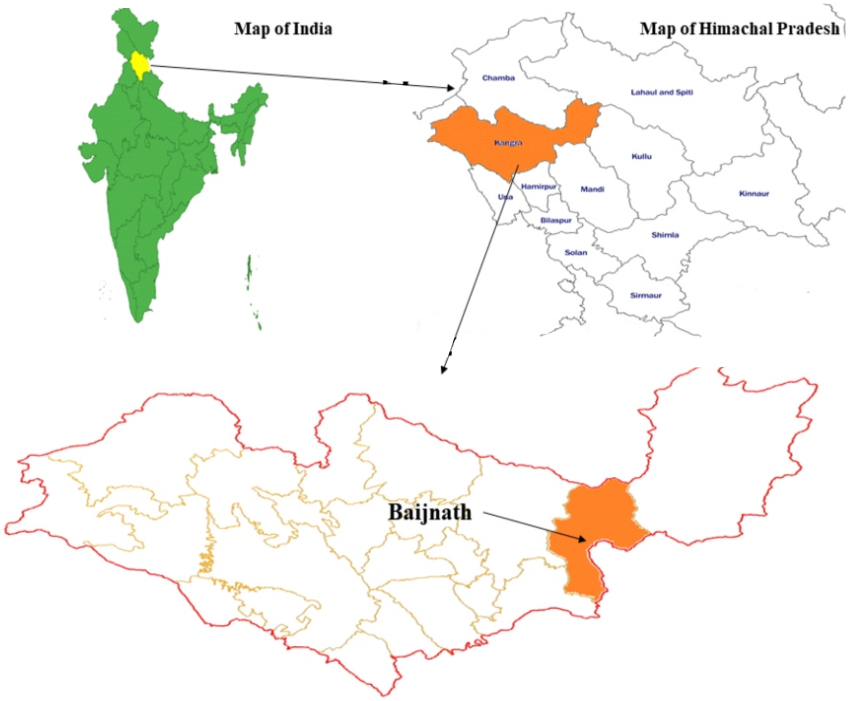

FIGURE 1 Location of the study area

employment status, livestock holdings and survey data, was carried out through questionnaires, personal interviews with household heads and direct field observations (Tiwari *et al*., 2018). Agroforestry land-use systems were identified based on their structure and function. Each system type was analyzed to determine its primary and secondary components. The primary component was defined as occupying a larger area of the total unit area and serving the primary function (Goswami *et al*., 2014). In contrast, the secondary component occupied a relatively smaller area and provided the secondary output needed by the farmer.

2.3 | Sampling and Estimation of Biomass and Carbon Stock

Biomass production of crops was assessed using 1 × 1 m random quadrants for both *kharif* and *rabi* crops. The entire plant, including its roots, was harvested, cleaned, and separated into roots and shoots. Samples were then oven-dried at 70°C until a constant weight was achieved, allowing for the determination of both aboveground and belowground biomass. A non-destructive method used species-specific volume equations to estimate above-ground tree biomass. In a 30 × 10 m sample plot, each tree's diameter at breast height (DBH) was measured to calculate stem volume. The species-specific wood density was multiplied by the stem volume to obtain stem biomass, which was subsequently multiplied by a biomass expansion factor (BEF) to determine the total above-ground tree biomass. The belowground tree biomass was estimated using a root-to-shoot ratio; default values of 0.25 for hardwood species and 0.21 for softwood species were used without specific ratios (IPCC, 2006; Simon *et al*., 2006). The total tree biomass was calculated by summing both aboveground and belowground biomass. Pasture biomass was measured in 50 × 50 cm random quadrants. Entire grass plants, including roots, were harvested, cleaned and oven-dried at 70°C until a constant weight was reached. The dried root and shoot portions were weighed to determine the above-ground, below-ground and total biomass.

2.4 | Statistical Analysis

The collected data were systematically arranged into tables and subjected to statistical analysis by standard procedures. Pearson's correlation coefficients among socio-economic variables were calculated using OPSTAT software.

3 | RESULTS AND DISCUSSION

3.1 | Family Size

Family size denotes the aggregate number of individuals within a household, encompassing adults and children and their distribution. The average family size was highest in the medium farmer category (5.94), followed by small (5.14) and marginal (4.72) farmer categories. The average family size in the region was 5.26, which aligns with the broader socio-economic context where the family serves as the cornerstone of social security and support (Table 1). This variation in family size can be attributed to the economic stability and resource availability associated with larger

TABLE 1 Family structure of different categories of farmers in the study area

Farmers category	Adult			Children			Average family size	Sex ratio	Type of families	
	Male	Female	Total	Male	Female	Total			Nuclear	Joint
Marginal	1.96 (41.53)	1.74 (36.86)	3.70 (78.39)	0.56 (11.86)	0.46 (9.75)	1.02 (21.61)	4.72 (100)	873	31 (62.00)	19 (38.00)
Small	2.10 (40.86)	2.02 (39.30)	4.12 (80.16)	0.58 (11.28)	0.44 (8.56)	1.02 (19.84)	5.14 (100)	917	26 (52.00)	24 (48.00)
Medium	2.36 (39.73)	2.46 (41.41)	4.82 (81.14)	0.72 (12.12)	0.40 (6.73)	1.12 (18.86)	5.94 (100)	928	21 (42.00)	29 (58.00)
Overall	2.14 (40.68)	2.07 (39.35)	4.21 (80.04)	0.62 (11.79)	0.43 (8.17)	1.05 (19.96)	5.26 (100)	910	78 (52.00)	72 (48.00)

Figures in the parenthesis are percentages of the total

landholdings, which may support larger families (Kumar and Sharma, 2020). The prevalence of nuclear and joint families differed significantly across farmer categories. Nuclear families were most common among marginal farmers (62%), while joint families were most prevalent among medium farmers (58%). Overall, nuclear families dominated the study area, reflecting broader societal trends toward smaller, more independent family units (Galabuzi *et al*., 2021). This shift has implications for agricultural practices, as nuclear families may have different resource management and decision-making dynamics than joint families.

3.2 | Type of Family

In most societies, the family has been the cornerstone of socio-economic life and the primary source of social security and support for its members. Two types of families, namely nuclear and joint, were identified (Table 1). The highest proportion of nuclear families was found in the marginal farmer category (62%), followed by small (52%) and medium (42%) farmer categories. Conversely, joint families were most prevalent in the medium farmer category (58%), followed by small (48%) and marginal (38%) farmer categories. Overall, nuclear families dominate the study area compared to joint families. This is supported by Chandra (2024), who noted that Indian families are transforming from traditional joint structures to modern nuclear setups, along with changing gender roles and increasing educational, career and technological influences. Thakur (2020) also observed comparable results in the Chuhar valley of Mandi district, Himachal Pradesh.

3.3 | Sex Ratio

The sex ratio among marginal, small and medium categories of farmers was 873, 917 and 928, respectively (Table 1). However, the overall sex ratio was 910, lower than the state and national averages of 972 and 940, respectively (Census, 2011). The lower sex ratio in the study area suggests a potential gender imbalance, which could be influenced by various socio-economic factors rather than a cultural preference for a specific gender. Addressing this imbalance is crucial for achieving gender equity and enhancing the region's overall socio-economic development. Kaler *et al.* (2017) reported sex ratios ranging from 844 to 913 across different altitudinal zones in the Kangra valley of the north-western Himalayas, which was approximately similar to the results.

3.4 | Educational Status

The educational status of different categories of farmers in the study area is presented in Table 2. Among farmer categories, the medium category exhibited the highest literacy rate (91.8%), followed by small (88.8%) and marginal (87.3%) categories. The overall average literacy rate in the study area was 89.3%, indicating a higher literacy rate than the overall state literacy rate of 82.8% in Himachal

TABLE 2 Education status of different categories of farmers in the study area

Education level	Farmers category			
	Marginal	Small	Medium	Overall
Primary	0.46 (9.75)	0.54 (10.51)	0.64 (10.77)	0.55 (10.34)
Middle	0.50 (10.59)	0.68 (13.23)	0.92 (15.49)	0.70 (13.10)
Matriculation	0.92 (19.49)	1.02 (19.84)	1.28 (21.55)	1.07 (20.29)
Senior secondary	1.06 (22.46)	0.96 (18.68)	1.14 (19.19)	1.05 (20.11)
Graduation and above	0.76 (16.10)	0.92 (17.89)	0.98 (16.50)	0.87 (16.83)
Literate	3.70 (78.39)	4.12 (80.15)	4.96 (83.50)	4.26 (82.09)
Illiterate	0.54 (11.44)	0.52 (10.12)	0.44 (7.41)	0.50 (9.03)
Non-school	0.48 (10.17)	0.50 (9.73)	0.54 (9.09)	0.51 (8.82)
Total	4.72 (100)	5.14 (100)	5.94 (100)	5.26 (100)
Literacy rate	(87.26)	(88.79)	(91.85)	(89.30)

Figures in the parenthesis are percentages of the total

Pradesh (Census, 2011). Most individuals had education up to the matriculation and senior secondary levels, with some being graduates. This higher educational attainment suggests a potential for greater adoption of modern technologies in agroforestry systems, as educated farmers are more likely to be receptive to new ideas and practices (Dhakal and Rai, 2021). The literacy rate was higher than that of Kaler *et al.* (2017), who reported that the literacy rate in the Kangra district of Himachal Pradesh ranged from 82.50% to 85.00%. The higher literacy rates and educational attainment among farmers in the study area bode well for adopting agroforestry systems. Education can enhance farmers' understanding of the benefits of agroforestry, such as improved soil health, increased biodiversity and better economic returns (Nair and Toth, 2016). Moreover, educated farmers are more likely to participate in training programs and knowledge-sharing initiatives, essential for successfully implementing agroforestry practices (Mwase *et al.*, 2015).

3.5 | Livestock Status

Livestock holds a vital position in rural livelihoods and the economies of developing nations. Within livestock-based agroforestry systems, a symbiotic relationship exists between crops and animals: crops are utilized as fodder for livestock. In return, livestock provide farmyard manure to enhance crop productivity. Livestock also yields milk, meat, wool and manure, improving income and crop productivity. The livestock reared by farmers in the study area included cows, buffaloes, bullocks, sheep and goats. Table 3 illustrates the livestock status among different households. It was observed that the average -number of livestock per family was highest

TABLE 3 Livestock status of different categories of farmers in the study area

Farmers category	No. of families possessing livestock	Livestock species	Adult livestock						Young livestock
			Total no. of livestock	Average no. of livestock/family	Local breed	Improved breed	Dry	Milking	
Marginal	39	Cow	40	1.02 (51.78)	9 (22.50)	31 (77.50)	11 (23.91)	29 (76.09)	9 (23.08)
		Buffalo	9	0.23 (11.68)	6 (66.67)	3 (33.33)	4 (44.44)	5 (55.56)	6 (15.38)
		Bullock	5	0.13 (6.60)	5 (100)	-	-	-	-
		Goat	14	0.36 (18.27)	14 (100)	-	-	-	7 (17.95)
		Sheep	9	0.23 (11.67)	9 (100)	-	-	-	3 (7.69)
		Total	77	1.97 (100)	-	-	-	-	25 (64.10)
Small	43	Cow	51	1.18 (52.91)	11 (21.57)	40 (78.43)	12 (23.53)	39 (76.47)	13 (30.23)
		Buffalo	11	0.25 (11.21)	7 (63.64)	4 (36.36)	3 (27.27)	8 (72.73)	7 (16.28)
		Bullock	8	0.19 (8.52)	8 (100)	-	-	-	-
		Goat	15	0.35 (15.70)	15 (100)	-	11 (73.33)	4 (26.67)	8 (18.60)
		Sheep	11	0.26 (11.66)	11 (100)	-	-	-	6 (13.95)
		Total	96	2.23 (100)	-	-	-	-	34 (79.07)
Medium	46	Cow	59	1.28 (53.56)	14 (23.73)	45 (76.27)	11 (19.30)	46 (80.70)	15 (32.61)
		Buffalo	14	0.30 (12.55)	10 (71.43)	4 (28.57)	5 (35.71)	9 (64.29)	10 (15.22)
		Bullock	5	0.11 (4.60)	5 (100)	-	-	-	-
		Goat	20	0.43 (17.99)	20 (100)	-	16 (80.00)	4 (20.00)	9 (19.57)
		Sheep	12	0.27 (11.30)	12 (100)	-	-	-	5 (10.87)
		Total	110	2.39 (100)	-	-	-	-	39 (84.78)

Figures in the parenthesis are percentages of the total

among medium (2.39) category farmers, followed by small (2.23) and marginal (1.97) farmers. Cows were the most preferred livestock due to their milk production capabilities, which aligns with the findings that cows outnumber buffaloes in Himachal Pradesh's hill areas (Singh and Vaidya, 2002). Notably, farmers in the study area tended to rear improved cattle breeds, likely due to their higher productivity and consequent economic benefits. Hence, it can be interpreted that livestock substantially enhances farm sector endeavours, augmenting overall agricultural revenue, especially within the Himalayan region. Comparable findings on livestock status were also reported by Thakur (2020) in the Chuhar Valley of Mandi district, Himachal Pradesh. Our study also supports the findings of Tiwari *et al*. (2018), who reported that bovines were pivotal domesticated livestock in the north-western Himalayas.

3.6 | Livestock Management Practices

Livestock management encompasses the rearing and care of farm animals, focusing on developing their genetic qualities and behaviour to generate profit. Livestock management practices of different categories of farmers in the study area are provided in Table 4. The study revealed that traditional milking methods predominated, but some farmers adopted scientific breeding and health management practices, indicating a shift towards improved livestock quality (Singh and Vaidya, 2002). Using animal dung for crop production underscores sustainable farming practices, recycling nutrients back into the soil (Shrestha and Vaidya, 2014). Integrating livestock within agroforestry systems enhances economic resilience by diversifying income sources and improving soil fertility through manure application (Nair and Toth, 2016). As consumer demand for sustainable food rises, effective livestock management becomes increasingly important for promoting productivity and environmental sustainability (Dhakal and Rai, 2021). Similar practices in livestock management were observed by Tiwari *et al*. (2018) in the Sirmaur district of Himachal Pradesh, highlighting the consistency in livestock management approaches.

3.7 | Land Use Pattern

Land is a fundamental resource in agrarian economies, with landholding size directly affecting household income, consumption and profits. There is a notable positive correlation between landholding size and farmer categories. On average, marginal, small and medium farmers had landholding sizes of 0.73 ha, 1.74 ha and 2.57 ha, respectively. These findings are consistent with those of Tiwari *et al.* (2018), who also reported a positive correlation between landholding size and farmer categories in the Sirmaur district of Himachal Pradesh. Most agricultural land was rainfed (43.2%), while a smaller portion was irrigated, as shown in Table 5. This highlights the need for improved irrigation infrastructure to enhance crop yields and food security (Rosegrant *et al*., 2002). Kaler *et al*. (2017) also observed that 73.34% of the Himalayan farming area is rainfed and managed traditionally. Enhanced irrigation infrastructure can signifi-

TABLE 4 Livestock management practices of different categories of farmers in the study area

Farmers category	No. of families possessing animals	Milking method traditional	Disease management			Breeding method		Animal dung utilization		Washing / Cleaning	Sanitation / Disinfection
			Regular de-worming	Disease pest management	Both	Scientific	Traditional	Crop production	Crop production + Fuel purpose		
Marginal	39	39	11	23	5	35	4	36	3	37	34
	(78.00)	(100)	(28.20)	(58.97)	(12.82)	(89.74)	(10.25)	(92.30)	(7.69)	(94.87)	(87.17)
Small	43	43	10	26	7	37	6	36	7	32	39
	(86.00)	(100)	(23.25)	(60.46)	(16.27)	(86.04)	(13.95)	(83.72)	(16.27)	(95.34)	(90.69)
Medium	46	46	12	29	5	41	5	38	8	45	42
	(92.00)	(100)	(26.08)	(63.04)	(10.86)	(89.13)	(10.86)	(82.60)	(17.39)	(97.82)	(91.30)
Overall	128	128	33	78	17	113	15	110	18	123	115
	(85.33)	(100)	(25.84)	(60.82)	(13.31)	(88.30)	(11.68)	(86.20)	(13.78)	(96.09)	(89.72)

Figures in the parenthesis are percentages of the total

TABLE 5 Land use pattern of different categories of farmers in the study area

Particulars	Landholding (ha)			Overall average
	Marginal	Small	Medium	
Agriculture	0.54 (73.97)	1.42 (81.61)	2.16 (84.04)	1.37 (79.87)
Irrigated	0.26 (35.62)	0.64 (36.78)	0.97 (37.74)	0.62 (36.71)
Rainfed	0.28 (38.35)	0.78 (44.83)	1.19 (46.30)	0.75 (43.16)
Pasture land	0.19 (26.03)	0.31 (17.82)	0.38 (14.79)	0.29 (19.55)
Orchard	-	0.01 (0.57)	0.03 (1.17)	0.02 (0.58)
Total land holding (ha)	0.73 (100)	1.74 (100)	2.57 (100)	1.68 (100)

Figures in the parenthesis are percentages of the total

cantly boost crop productivity and farmers' income (Kalli *et al*., 2024), highlighting the need to expand farmland irrigation systems in the study area to optimize agricultural output further.

3.8 | Status of Off-Farm Employment

Off-farm employment is crucial for farmers and their spouses to mitigate economic challenges during crop failure while supplementing their income. In the study area, farmers pursued livelihood opportunities through government services, private employment and entrepreneurial ventures, as illustrated in Table 6. On average, marginal, small and medium farmers had 1.18, 1.52 and 1.68 members engaged in off-farm employment. Across all categories, the average number of individuals involved in government services was 0.54, while in private services and entrepreneurship, it was 0.56 and 0.36, respectively. Employment in private services was the most prevalent, with farmers frequently working as laborers in private enterprises or government programs, while entrepreneurship was the least represented, with few individuals engaged in ventures such as poultry farming, retailing and contracting. The average annual income per person from government services, private employment and entrepreneurship was ₹ 376954, ₹ 231926 and ₹ 317414, respectively. The findings underscore the need for targeted interventions to improve access to irrigation facilities and encourage off-farm employment opportunities, including entrepreneurial ventures. Comprehensive rural development strategies should integrate agricultural improvements with off-farm employment initiatives to create sustainable and resilient livelihoods for farmers (Ruben and Van den Berg, 2001). Sharma *et al*. (2009) conducted a similar investigation on off-farm employment. They discovered that farmers were involved in diverse sectors, *viz.,* agriculture, dairy production, labour, poultry operations, government services and other sectors.

3.9 | Agroforestry in the Study Area

Agroforestry systems practised by different categories of farmers in the study area are detailed in Table 7. In the study area, primarily six types of agroforestry systems (Fig. 2 a-f) were identified: agri-silviculture (AS), agri-silvi-horticulture (ASH), agri-horticulture (AH), agri-silvi-pastoral (ASP), silvi-pastoral (SP) and pastoral-silviculture (PS). Among these, AS was the most widely adopted system in all three farmer categories (43.5% marginal farmers, 29.2% small farmers and 25.7% medium farmers adopted AS), followed by ASH, AS, AH, SP and PS being the least adopted. AS, ASH, AH and ASP systems were present across all farmer categories. In contrast, SP systems were found in small and medium categories but absent in the marginal farmer category. On the other hand, PS was only present in the medium category and absent in both marginal and minor categories. This distribution suggests that farmers with larger land holdings have more flexibility and resources to diversify their agroforestry practices, aligning with findings from other studies (Dhakal and Rai, 2021; Galabuzi *et al*., 2021).

The dominance of agriculture-based agroforestry systems in the region highlights the importance of these systems in meeting the diverse needs of farmers. The income

TABLE 6 Status of off-farm employment of different categories of farmers in the study area

Farmers category	Total average no. of members	Government service		Private service		Entrepreneur	
		Average no. of members	Average annual income ₹	Average no. of members	Average annual income ₹	Average no. of members	Average annual income ₹
Marginal	1.18 (100)	0.48 (40.68)	424137.00	0.42 (35.59)	220615.00	0.28 (23.73)	309724.50
Small	1.52 (100)	0.62 (40.79)	429333.50	0.56 (36.84)	239769.50	0.34 (22.37)	315204.00
Medium	1.68 (100)	0.52 (30.95)	477392.50	0.70 (41.67)	235392.50	0.46 (27.38)	327312.00
Overall	1.46 (100)	0.54 (36.98)	376954.33	0.56 (38.36)	231925.67	0.36 (24.66)	317413.50

Figures in the parenthesis are percentages of the total

TABLE 7 Agroforestry systems practised by different categories of farmers in the study area

Farmer categories	Agroforestry systems	Farmers (%)	Functional component			
			Major agricultural crops	Major forest trees	Major fruit trees	Major grasses
Marginal	Agri-silviculture	43.55	*Allium sativum, Zea mays, Oryza sativa, Solanum tuberosum, Triticum aestivum, Pisum sativum, Brassica rapa, Abelmoschus esculentus, Curcuma longa*	*Celtis australis, Ficus palmata, Grewia optiva, Morus alba, Bauhinia variegata, Melia azedarach, Populus deltiodes*	*Mangifera indica, Juglans regia, Prunus persica, Psidium guajava, Citrus limon*	*Agrostis spp., Cynodon dactylon, Arundinella nepalensis*
	Agri-silvi-horticulture	27.42				
	Agri-horticulture	11.29				
	Agri-silvi-pastoral	17.74				
Small	Agri-silviculture	29.17	*Allium sativum, Triticum aestivum, Oryza sativa, Brassica rapa, Abelmoschus esculentus, Curcuma longa, Solanum tuberosum, Pisum sativum, Zea mays, Glycine max*	*Celtis australis, Ficus palmata, Morus alba, Acacia catechu, Grewia optiva, Bauhinia variegata, Toona ciliata, Melia azedarach, Populus deltiodes*	*Prunus persica, Juglan sregia, Punica granatum, Psidium guajava, Citrus limon, Carica papaya*	*Arundinella nepalensis, Cynodon dactylon, Themeda anathera, Pennisetum purpureum, Trifolium alexandrinum, Agrostis spp.*
	Agri-silvi-horticulture	26.39				
	Agri-horticulture	12.50				
	Agri-silvipastoral	20.83				
	Silvi-pastoral	11.11				
Medium	Agri-silviculture	25.66	*Oryza sativa, Brassica rapa, Abelmoschus esculentus, Curcuma longa, Zea mays, Triticum aestivum, Solanum tuberosum, Pisumsativum, Brassica rapa, Brassica oleracea var. botrytis, Allium sativum, Capsicum annuum*	*Melia azedarach, Toona ciliata, Morus alba, Ficus palmata, Celtis australis, Grewia optiva, Bauhinia variegata, Acacia catechu, Prunus cerasoides, Albizzia chinensis, Populus deltiodes*	*Mangifera indica, Psidium guajava, Litchi chinensis, Punica granatum, Citrus limon, Prunus persica, Juglans regia, Carica papaya*	*Agrostis spp., Cenchrus ciliaris, Trifolium alexandrinum, Arundinella nepalensis, Cynodon dactylon, Pennisetum purpureum, Themeda anathera*
	Agri-silvi-horticulture	22.12				
	Agri-horticulture	17.70				
	Agri-silvipastoral	18.58				
	Silvi-pastoral	9.73				
	Pastoral-silviculture	6.19				

shares from agriculture, achieved via agroforestry adoption, demonstrated a significant correlation with farm size, family size, literacy levels and livestock numbers, as delineated in Table 8. This aligns with global studies indicating that socio-economic and institutional factors, such as education level, household size, access to credit and formal training, significantly influence agroforestry adoption (Mwase *et al*., 2015; Tiwari *et al*., 2018; Dhakal and Rai, 2021). However, sex ratio and non-farm employment exhibited no significant relation, suggesting that these factors may not be critical determinants in this context. The adaptability and productivity of these agroforestry systems make them predominantly adopted by most of the population in specific regions. This underscores the importance of regional studies on the extent of socio-economic factors influencing agroforestry adoption. Policy interventions should encourage farmer participation in agroforestry projects to foster knowledge and experience sharing, addressing the climate crisis and rural livelihoods (Beddington *et al*., 2012; Bishaw *et al*., 2013; Mukhlis *et al*., 2022).

The specific functional units under crops were cereals- *Triticum aestivum*, *Zea mays* and *Oryza sativa*; oilseeds and pulses- *Brassica rapa* and *Glycine max*; vegetables- *Solanum tuberosum*, *Pisum sativum*, *Brassica oleracea*, *Abelmoschus esculentus*, *Allium sativum*, *Curcuma longa*, *Solanum tuberosum* and *Capsicum annuum*, etc. The silviculture components were *Celtis australis*, *Grewia optiva*, *Bauhinia variegata*, *Morus alba*, *Albizzia chinensis*, *Populus deltiodes*, *Toona ciliata*, *Melia azedarach, Prunus cerasoides etc*. *Mangifera indica, Citrus limon, Litchi chinensis, Psidium guajava, Juglans regia* and *Carica papaya* were the fruit trees included. Various edaphic factors, climate and topography, influence the higher plant biodiversity and diverse agroforestry systems in Baijnath tehsil. These factors drive farmers to optimize their practices for varied outputs and greater profitability, aligning with the need-based composition of farming practices prevalent in the region (Akter *et al*., 2022; Arunachalam *et al*., 2022). The higher plant biodiversity and diverse agroforestry systems in Baijnath tehsil resulted from various edaphic factors, climate and topography, which drove farmers to optimize their practices for varied outputs and greater profitability (Sharma *et al*., 2023). Also, farming practices, characterized by their need-based composition, are predominantly adopted by the majority of the population in a specific region due to their adaptability and productivity. Sharma *et al*. (2023) reported varying agroforestry systems along altitude in the northwestern Himalayan region, differing in structural and functional composition based on ecological conditions, edaphic factors, economic considerations, topographical features and the needs and preferences of farming communities. Almost similar results have been reported by Kaler *et al.* (2017) and Thakur (2020) where

TABLE 8 Pearson's correlation coefficients between various parameters of the study area

Variables	Farm size	Family size	Sex ratio	Literacy	No. of livestock	Non-farm workers	Engaged in agriculture
Farm size	1.000	-	-	-	-	-	-
Family size	0.973*	1.000	-	-	-	-	-
Sex ratio	0.958*	0.868^{NS}	1.000		-	-	-
Literacy	0.998**	0.984*	0.942^{NS}	1.000	-	-	-
No. of livestock	0.997**	0.951*	0.978*	0.991**	1.000	-	-
Non-farm workers	0.989*	0.928^{NS}	0.988*	0.979*	0.998**	1.000	-
Engaged in agriculture	0.976*	0.992**	0.875^{NS}	0.984*	0.957*	0.938^{NS}	1.000

***(P<0.05); *(P<0.10); NS: Non-significant*

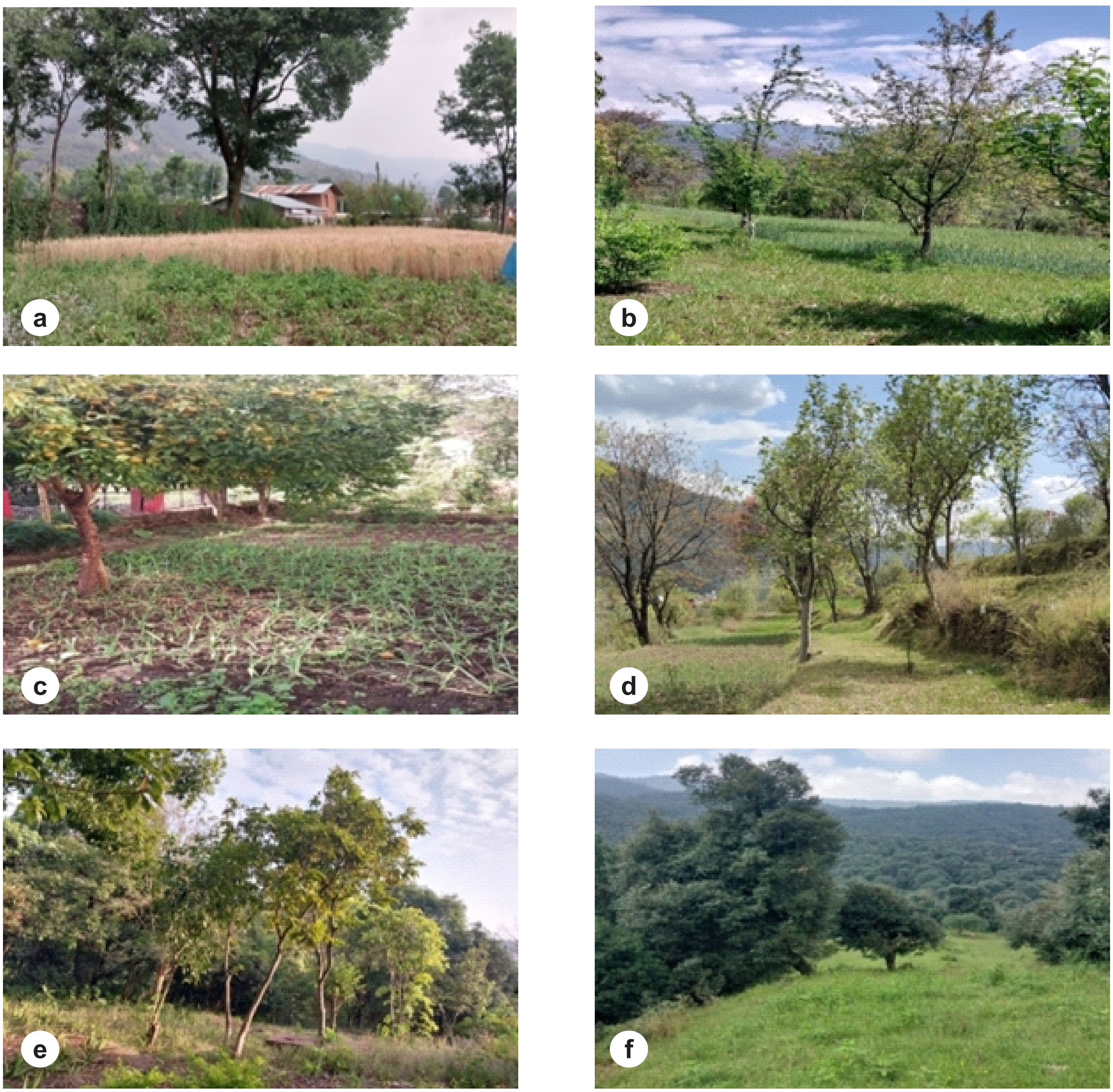

FIGURE 2 Agri-silviculture (a), agri-silvi-horticulture (b), agri-horticulture (c), agri-silvipastoral (d), silvi-pastoral (e), pastoral-silviculture (f) system in the study area

they observed six agroforestry systems namely, AS, ASH, AH, ASP, PS and SP in Kangra and Mandi district of Himachal Pradesh. Tiwari *et al.* (2018) also identified AS, AH, ASH, ASP, SP, PS and PSH systems in all altitudinal zones of Shimla district. They suggested that ecological variability was the driving factor in promoting plant biodiversity and system differentiation in this region.

3.10 | Biomass Production from various Agroforestry Systems

Biological yield encompasses the total dry matter produced from plants and crops in a particular area, including above ground and belowground biomass. The interaction between agroforestry systems and farmer categories significantly influenced biomass production in the region. The highest aboveground biomass (Fig. 3 a) was observed in the ASH system (19.31 t ha^{-1}) and the lowest in the PS system (10.94 t ha^{-1}), both under the medium farmer category, as PS system were absent among marginal and small farmers. Belowground biomass (Fig. 3 b) also followed the same trend, with the highest in the ASH system (5.97 t ha^{-1}) and the lowest in the PS system (2.86 t ha^{-1}), both under the medium farmer category. The variation in below-ground biomass is attributed to plant characteristics, root systems and ecological conditions. These findings align with Thakur (2020), who recorded the highest aboveground biomass in the ASH system (21.72 t ha^{-1}) and the lowest in the PS system (9.45 t ha^{-1}) in the Chuhar valley of Mandi district, Himachal Pradesh. Table 9 presents variations of total biomass production across different farmer categories. Total biomass production was observed highest in the ASH system under the medium farmer category (25.28 t ha^{-1}) and lowest in the PS system (13.80 t ha^{-1}) under the same category. Overall, biomass production followed the trend: ASH > AS > SP > AS > AH > PS. This variation can be influenced by species density, type, management practices, size and age (Dixon *et al.*, 1994). The high biomass in the ASH system was attributed to better space utilization, large fodder trees and a higher canopy of fruit trees. Various researchers (Yadav *et al.*, 2019; Sharma *et al.*, 2023) have

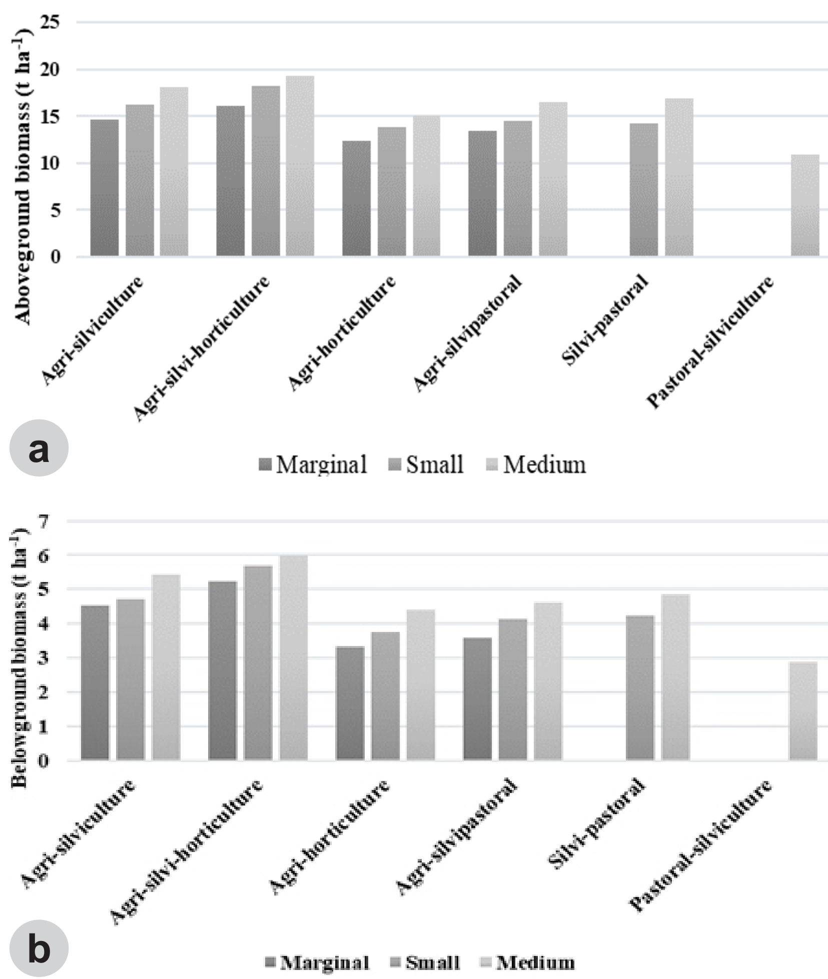

FIGURE 3 Variations in aboveground (a) and belowground (b) biomass of different agroforestry systems based on land ownership

TABLE 9 Total biomass (t ha^{-1}) production of agroforestry systems under different categories of farmers

Agroforestry systems (S)	Total biomass (t ha^{-1}) Category of farmers (F)		
	Marginal	Small	Medium
Agri-silviculture	19.14	20.92	23.56
Agri-silvi-horticulture	21.38	23.91	25.28
Agri-horticulture	15.63	17.54	19.39
Agri-silvipastoral	16.97	18.64	21.05
Silvi-pastoral	-	18.42	21.76
Pastoral-silviculture	-	-	13.80
	F*S	$CD_{0.05}$	0.19

also suggested that biomass production in agroforestry systems depends on various factors such as species richness, wood component density, dominant species number and their components. The findings align with previous studies that highlight the potential of agroforestry systems to enhance biomass production and ecosystem services. For instance, Nair *et al*. (2009) emphasized the role of agroforestry in improving soil health, nutrient cycling and overall ecosystem productivity. Similarly, Duffy *et al*. (2021) demonstrated that well-planned and implemented agroforestry systems can positively impact food production and income generation, particularly in regions with diverse ecological conditions. The significant differences in biomass production across various agroforestry systems and farmer categories underscore the importance of tailoring agroforestry practices to specific local conditions and farmer needs. With their larger landholdings, medium farmers benefit more from complex agroforestry systems like ASH, which require more space and resources (Sharma *et al*., 2023). In contrast, marginal and small farmers may need to focus on simpler systems more suited to their limited resources.

4 | CONCLUSIONS

The study demonstrated that the socio-economic dynamics of farmers in Baijnath tehsil, such as family size, family type, sex ratio, and educational status, significantly influence the adoption and sustainability of agroforestry systems. By addressing gender imbalances and promoting higher educational attainment, agroforestry practices can be enhanced, contributing to food security and sustainable livelihoods. Effective livestock management is also crucial for increasing agricultural productivity and supporting rural livelihoods. It is essential to tackle challenges related to land holding size and off-farm employment to achieve sustainable development. The study highlights the importance of agroforestry systems. It emphasizes the need for comprehensive strategies to optimize their benefits, especially through approaches like ASH, which can enhance biomass production and improve farmer livelihoods. Future research should aim to overcome challenges related to adoption and ensure long-term sustainability.

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DATA AVAILABILITY STATEMENT

The data supporting this study's findings are available from the corresponding author upon reasonable request.

CONFLICT OF INTEREST

The authors declare there is no conflict.

AUTHOR'S CONTRIBUTION

PK: writing-original draft, NSK: writing-original draft, review and correspondence, PS: writing - review and editing, SDS: writing - review and editing, AS: writing - review and editing, CN: writing - review and editing and RKD: writing - review and editing.

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