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Adaptive agroforestry—mitigating climate change impacts by farmers' perception in different climate conditions in Iran

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Introduction: Developing countries are particularly vulnerable to climate change (CC), thereby impacting food production and altering the species composition to deliver essential services. Sustainable land-use systems, such as agroforestry, have emerged as adaptive solutions to climate change. Agroforestry, which integrates trees and shrubs with crops or livestock, offers multiple benefits, including enhanced production, improved soil and water conservation, and increased carbon sequestration. A study assessing the impact of CC on agroforestry was carried out in Iran, spanning across semi-arid, semi-humid, and humid climates.

Methods: Data were collected from 204 households using surveys to understand the socioeconomic characteristics, land use, and agroforestry.

Results and discussion: The results indicated significant differences in farming experience and land holdings ($p < 0.01$) across regions. Agroforestry was more prevalent in semi-arid regions, with alley cropping being the most common practice. Farmers' attitudes toward continuing agroforestry were positive, although there was a general lack of information about the practice. The primary sources of information were other farmers and extension experts. Species diversity in agroforestry varied by region, with apples, walnuts, and poplars being the most common in semi-arid regions, while species diversity was generally lower in humid regions. To mitigate the impacts of climate change, adaptation strategies, such as altering crop and tree species to those more resilient to climate change, have been employed. The farm size assigned for the agroforestry systems in the semi-arid region was 0.86 ha, which was higher than that assigned in other regions. Farmers in the semi-arid regions rely on a greater diversity of species to mitigate CC impacts than those in other regions. This approach enhances the sustainability of agroforestry by optimizing resource use and maintaining agricultural productivity.

KEYWORDS

agroforestry, climate change (CC), semi-arid region, species diversity, Iran

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Introduction

Climate change (CC) refers to long-term shifts in temperature and weather patterns, primarily driven by human activities such as burning fossil fuels, which release greenhouse gases and contribute to global warming. This poses serious threats to agriculture, potentially reducing productivity on a global scale. While agriculture contributes 14% of human-caused greenhouse gas emissions, it also holds potential for mitigating CC through practices that enhance carbon sequestration in soil and biomass (Reppin et al., 2020). CC poses a serious threat to developing countries, impacting both food production and the capacity of natural ecosystems to provide products and services (Manaye et al., 2021). changes in temperature and precipitation patterns are projected to reduce crop yields, increase the prevalence of agricultural pests and diseases, and lower the quality of animal fodder (Skendžić et al., 2021; Alotaibi, 2023). These impacts are significantly concerning since agriculture is the main livelihood for many impoverished people in rural areas of developing countries. These populations typically have limited access to financial or biophysical resources for adapting to CC.

In light of these challenges, there has been an increasing recognition of the need for sustainable land-use systems that can help address both the economic and ecological impacts of CC. This is particularly urgent in arid and semi-arid regions, where droughts and famines have been aggravated by climate shifts in recent decades (Kumar et al., 2022b; Rathore et al., 2023; Motaghed et al., 2024). These systems must respond flexibly to rapid changes in economic and ecological conditions while preserving or restoring soil and water resources. An agroforestry system is a solution to reduce and adapt to the effects of CC (Reppin et al., 2020). Globally, agroforestry offers a sustainable and potential solution by increasing carbon reserves and potentially improving agricultural productivity. This approach can help countries like Ethiopia fulfill their commitments to forest restoration and smart agriculture, meeting the needs of vulnerable populations in changing climatic conditions (Manaye et al., 2021). Climate change also exacerbates its own effects. For instance, in the East Usambara Mountains of Tanzania, farmers used to have two growing seasons per year for crops, but recently, they have only one. Farmers report that decreasing humidity and increasing temperatures in mountainous areas are changing species compositions, with mango and citrus trees currently thriving in areas where they previously could not (Reyes, 2008). Such changes highlight the need for adaptive strategies to integrate agroforestry into broader land management practices.

Agroforestry is a form of sustainable land use that combines trees and shrubs with crops or livestock, enhancing and diversifying production while preserving natural resources (Molua, 2005; Rathore et al., 2023). Agroforestry, characterized by the growth of various woody perennials associated with crops, is a suitable alternative in areas where traditional land-use practices involve periodic clearing and cultivation. It helps control soil erosion, reduces environmental degradation through biological interactions among trees, crops, and livestock, and increases income from agricultural land (Rasul and Thapa, 2006; Kumar et al., 2022a). The multifunctional nature of agroforestry can address several problems simultaneously (Reyes, 2008; Mbow et al., 2014a). Agroforestry species improve microclimatic conditions and reduce the risk of food shortages due to reduced yields and low production for smallholder farmers. In various regions, agroforestry has been shown to increase farmers' income by growing multipurpose tree species alongside crops. Perennial woody plants help reduce global warming through carbon sequestration and improve aesthetic values (Rasul and Thapa, 2006; Babu et al., 2023). Due to the numerous benefits of agroforestry, many landowners in temperate regions have adopted these systems, achieving notable success in North America and Europe. Common agroforestry methods in the temperate regions include mixed cultivation, pasture forestry, forest understory agriculture, windbreaks, and riparian buffer strips (Molua, 2005). Common agroforestry systems in the temperate regions and Iran include alley cropping, silvopasture, forest farming, windbreaks, riparian buffers, and traditional home gardens. These systems enhance productivity, biodiversity, and resilience in temperate areas by integrating trees with crops and/or livestock. Similarly, in Iran's temperate and mountainous regions—such as the Caspian forests and Arasbaran—the use of fruit and nut trees (such as walnut, apple, and hazelnut) alongside annual crops, livestock grazing under forest cover, and the maintenance of windbreaks and shelterbelts are widespread. Traditional agroforestry practices in Iran, including orchard-based farming, garden-forests (Baq-e-Estan), and mixed tree-crop systems, reflect deep-rooted ecological knowledge and play a vital role in supporting rural livelihoods, conserving biodiversity, and adapting to climate variability.

While agroforestry has proven beneficial in many regions, the extent and nature of its impacts can vary depending on the system components and regional conditions. A variety of researchers have focused on the services provided by other systems of agroforestry (Newaj et al., 2013; Gomes et al., 2020; Niether et al., 2020; Papa et al., 2020; Reppin et al., 2020; Duffy et al., 2021; Manaye et al., 2021; Ariza-Salamanca et al., 2023). For example, Gomes et al. (2020) discussed the potential of agroforestry to mitigate these effects, maintaining approximately 75% of the area suitable for coffee production. In addition, Niether et al. (2020) confirmed that agroforestry contributed significantly to food security and diversified income sources. The strategic use of mixed cropping and marginal planting can enhance tree diversity in the arid ecosystems of Ethiopia (Manaye et al., 2021). Ariza-Salamanca et al. (2023) found that considering only available land use that does not contribute to deforestation would significantly reduce the suitable area by 14.5%. Regarding shade trees, their models indicate that 50% of the 37 shade tree species studied will experience a reduction in geographic range by 2040, and this reduction may reach 60% by 2060 in West Africa.

In recent decades, human activities due to industrialization and urbanization have accelerated CC, affecting all aspects of human life. These activities have also impacted agriculture, natural resources, and forests. Currently, to combat the negative effects of CC, many initiatives based on the knowledge of rural communities are being implemented. In Iran, agroforestry has been practiced since ancient times as an important economic and ecological solution to mitigate and adapt to CC. However, due to the diversity in agroforestry system components, it is essential to identify optimal systems. The role of different agroforestry systems in protecting plant diversity and forest structure has not been directly compared in many cases with high agricultural activity. Different land uses impose various costs and benefits on society through positive and negative externalities, such as soil erosion and environmental degradation. Therefore, policymakers need to understand which land-use systems best improve the livelihoods of rural people while reducing adverse environmental impacts. It is also crucial to identify what motivates farmers to transition from unsustainable to sustainable land-use activities (Rasul and Thapa, 2006). Understanding farmers' motivations to transition from unsustainable to sustainable practices, as well as the costs and benefits associated with different land-use systems, is crucial for informing policy decisions aimed at enhancing rural livelihoods and environmental resilience.

While extensive research has highlighted the potential of agroforestry as a sustainable land-use system to mitigate and adapt to climate change (CC), there remains a significant gap in understanding the optimal components and regional variations of agroforestry systems, especially in regions with high agricultural activity such as Iran (Nemati and Ghanbari, 2025). While agroforestry has been proven effective in temperate regions and some tropical areas, its applicability in arid and semi-arid regions, such as parts of Iran, remains underexplored, particularly in terms of how specific agroforestry practices can be tailored to local climatic and socioeconomic conditions. Furthermore, there is a lack of comprehensive studies comparing the role of different agroforestry systems in ecological and economic outcomes, particularly concerning the protection of plant diversity and forest structure. Although some studies have examined the economic and environmental benefits of agroforestry, little attention has been given to the motivations and challenges that farmers face when transitioning from unsustainable to sustainable land-use practices. This gap is critical, as understanding these drivers is essential for designing policies and interventions that encourage agroforestry adoption at a larger scale. Additionally, the long-term impact of agroforestry on local food security, especially in the face of CC-induced challenges such as reduced crop yields and increased pest prevalence, has not been sufficiently explored. The interaction between climatic changes, adaptation strategies, and agroforestry adoption also requires deeper investigation, particularly regarding how farmers in different regions of Iran have adapted their practices over the past three decades. To fill these gaps, future research should focus on identifying regional variations in agroforestry knowledge, understanding the socioeconomic motivations of farmers, and evaluating the effectiveness of various agroforestry components in addressing ecological and economic challenges in climate change.

Therefore, the primary objective is to investigate the role of agroforestry in mitigating and adapting to the effects of CC. In addition, in this research, we aim to (i) identify various agroforestry systems and their components, (ii) analyze regional variations in agroforestry knowledge sources, (iii) eventually evaluate farmers' motivations and challenges in agroforestry adoption, and finally (iv) analyze climatic changes over the past 30 years and adaptation strategies of farmers with CC. These objectives collectively address key issues of food security, rural livelihoods, and sustainable land use in Iran, while also providing a framework for promoting agroforestry as a climate-resilient strategy applicable in broader contexts.

Methods and materials

Study area

The present study was conducted in three climates: semi-arid, semi-humid, and humid to show the effects of climate change on agroforestry. For this purpose, the three provinces of East Azerbaijan (Ahar County and Varzaqan County) in the semi-arid region of Azerbaijan, Kermanshah (Paveh County) in the semi-humid climate of Zagros, and Mazandaran (Kalardasht County) in the humid environment of the Hyrcanian region were selected (Table 1; Figure 1). In East Azerbaijan, located in a semi-arid zone, the climate is characterized by hot, dry summers and cold winters, with annual precipitation ranging from 300 to 400 mm. The soils in this region are predominantly lithosols and regosols, which are nutrient-poor and prone to salinity in the absence of irrigation. In contrast, Kermanshah, specifically Paveh County in the semi-humid Zagros region, experiences cooler temperatures, with annual precipitation ranging between 600 and 800 mm. This region supports more fertile soils such as luvisols and cambisols, which retain moisture and are suitable for a wider variety of crops. Finally, Kalardasht in Mazandaran, located in the humid Hyrcanian region, enjoys mild temperatures and abundant rainfall (1,200–2,000 mm annually), resulting in highly fertile cambisols and fluvisols enriched with organic matter, making it ideal for agriculture such as rice and citrus cultivation. Each region's soil and climate distinctly influence their agricultural potential and vegetation types, ranging from arid, sparse vegetation in East Azerbaijan to lush, forested areas in Mazandaran.

Data collection

This research was conducted in several stages. Initially, a rapid preliminary assessment was conducted to identify farms with various agroforestry systems in each region. Based on the diversity of agroforestry systems in each region, a specific number of households were randomly selected from each system for evaluation.

TABLE 1 Climatic information of the three selected regions.

Region	Precipitation (mm)	Elevation (m)	Average temperature (°C)	Main activity	Main product	Sample size
SA – Azerbaijan	310–450	1,360	21.9	Farming and animal husbandry	Wheat and apple	78
SH – Kermanshah	670	1,540	15	Farming and animal husbandry	Pomegranate, walnut, mulberry, and pea	70
HU – Mazandaran	450	1,250	12	Farming, tourism, and gardening	Wheat, hazel, and walnut	56

SA, semi-arid; SH, semi-humid; HU, humid.

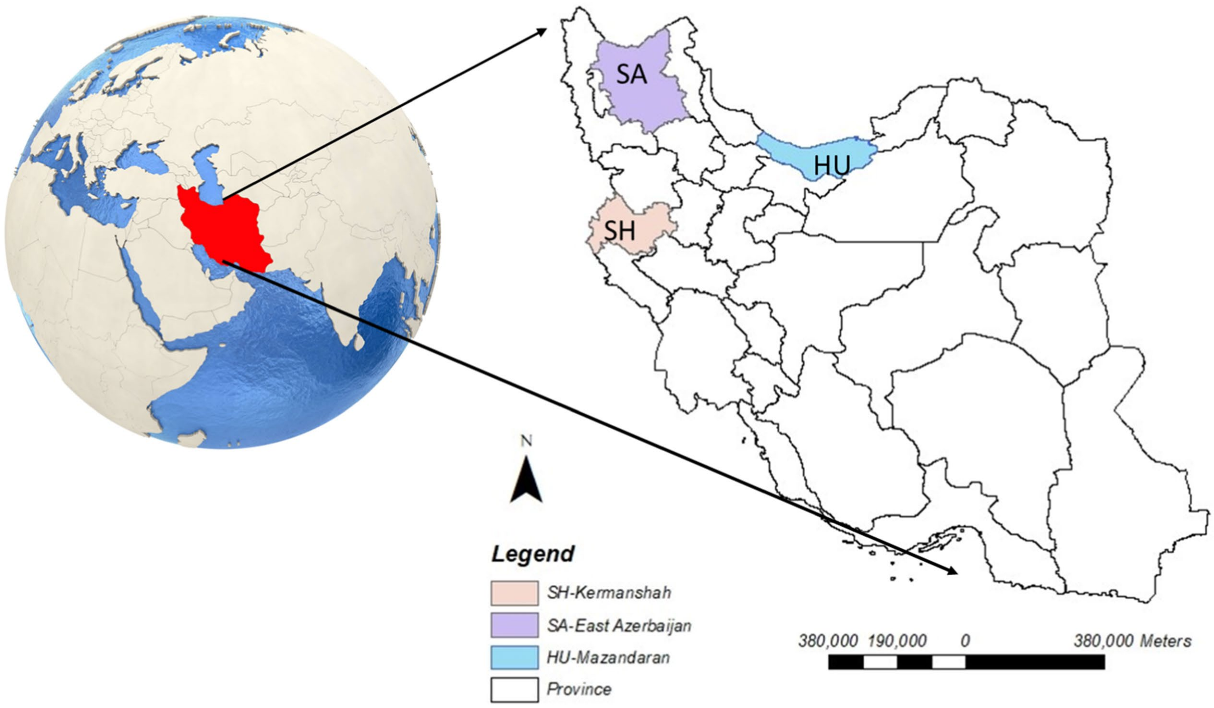

FIGURE 1
Location of the study area in three selected regions.

In the next step, a survey was conducted among households. Before beginning the interviews, farmers were informed about the objectives of the study. After obtaining their consent to participate, the interviews proceeded. Fourteen interviews were conducted using a pretested questionnaire to refine unbiased questions; however, after explaining the research aims, 14 farmers declined to participate. In total, we filled out 204 questionnaires from farmers. The interviews focused on gathering information on household use and benefits of on-farm trees and their role as a source of livelihood in household use and commercialization. Both quantitative and qualitative questions were used to collect information from the sample households (Bukomeko et al., 2019; Reppin et al., 2020). The average time of a face-to-face interview was between 45 and 65 min. The content validity of the questionnaire was confirmed by a panel of academic and executive specialists, who provided feedback regarding the suitability of each question. The questionnaire's reliability was assessed using the Cronbach's alpha coefficient for related criteria, which was 0.78. A five-point Likert scale (answer scale: 1: very low, 2: low, 3: average, 4: high, and 5: very high) was used to quantify the responses.

The main questions addressed personal characteristics, occupation, farm details, types of species, costs, incomes, types of harvested products, methods of selling, changes in species and products over time, and factors affecting production levels. Each farmer was also asked to prepare a list of most important tree species regarding each climate. The research instrument was divided into demographic and socioeconomic characteristics, agroforestry activities, motivations, problems, and climate change adaptation strategies. These sections addressed key research questions by linking farmers' demographic profiles to their agroforestry practices and the socioeconomic factors influencing these practices. For instance, farmer's average age and experience, along with educational background and landholding size, were analyzed to determine their impact on agroforestry adoption and management. Each section of the instrument was designed to collect data directly related to the research questions concerning the demographic and socioeconomic influences on farmers' activities. For instance, differences in farmers' age, experience, and education were associated with variations in agroforestry management and decision-making. Information on land holdings and cooperative membership provided context for analyzing economic resilience and resource access. Over time, information on shifts in species and products showed how farmers adapted their practices to cope with environmental and market changes, highlighting the constantly evolving nature of agroforestry systems. Overall, the comprehensive design of the instrument enabled a nuanced analysis of how various factors impact agroforestry practices, ensuring that the results reflect a broad spectrum of influences and outcomes (Figure 2).

Data analysis

Descriptive statistics were employed to analyze household data, revealing the uses and benefits of different tree species. To test differences between groups based on various farm and household characteristics, tests such as the Chi-squared and analysis of variance (ANOVA) tests were performed at a significance level of 5%. After the ANOVA test, we carried out a *post-hoc* test to determine which region is different from the other. Statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS) software version 20 IBM (Reppin et al., 2020).

Results

Demographic and socioeconomic characteristics of farmers

The socioeconomic characteristics of the respondents were identified as key factors influencing farmers' activities. Specifically, variables such as age, experience, and household size significantly impact the management of agroforestry systems. In this section, we provided some information about these factors. The mean age of household-head farmers was 52.3 years; the youngest household head interviewed was 24 years of age, and the oldest was 81 years of age. The maximum years of farming experience of farmers were approximately 65 years, with an average of 26 years (Table 2). There was a significant difference among farmers in age and farming experience ($p < 0.01$).

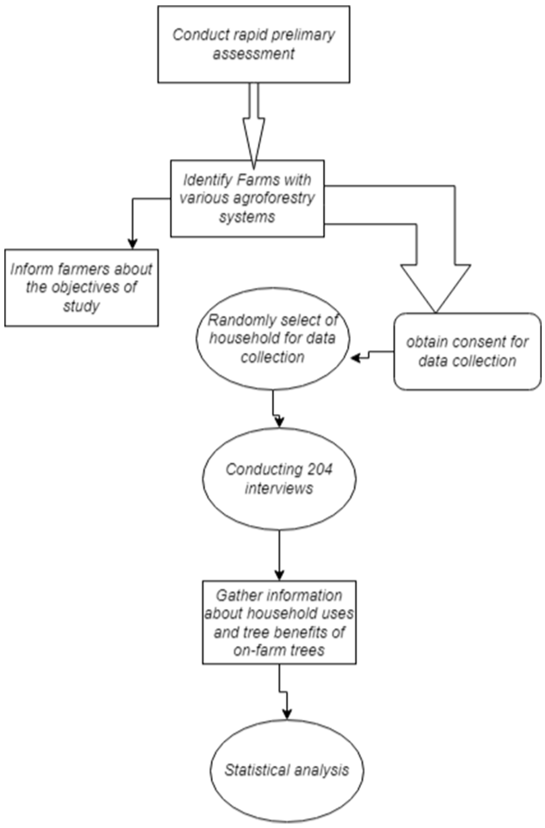

FIGURE 2
Flowchart for the research steps.

Nearly 91% of farmers were male-headed and 9% female-headed; 90% of respondents were married; and 10% of them were single. In addition, 72% of respondents had other income sources in addition to farming. Just 28% were active in farming. Furthermore, 66% of farmers had permanent residency status in the villages, and the remaining 34% had seasonal residency (Table 3).

The average length of schooling for farmers was 9–12 years. However, the level of education varied across different regions, ranging from no formal education in the SA and SH regions to the highest level of education with 18–22 years of schooling. The results showed that 46% of farmers in the SA region had 1–5 years schooling, approximately 40% of those in the SH region had 16–18 years of school education, and 31% in the HU region had 9–12 years of school education (Table 4).

The average household's land holding for irrigation farming land was 1.6 ha (standard deviation [SD] = 2.5), ranging from zero to 15 ha. The average rain-fed farming land was 3.5 ha. The average distance to the farming area from respondents' residences was 1.7 km (Table 5). All types of land holding were significantly different among regions. All items differed significantly ($p < 0.01$) across climate regions.

Only 15% of respondents were members of cooperatives, with membership rates ranged from 22% in the SH region to 7% in the HU region (Table 6).

Different irrigation methods were used by farmers in different climate regions. Almost all farmers did not use modern irrigation methods for farming in the SA and SH regions, whereas nearly one-third (29.6%) of farmers irrigated with sprinkler irrigation (Table 7).

TABLE 2 Descriptive statistics of respondents in different climate regions using Duncan's test.

Factor	Region	*N*	Min.	Max.	Mean	SD	*F*	Sig.
Age (year)	SA	78	32	81	51.6^{b}	12.9	9.24	<0.01**
	SH	66	24	68	48.4^{b}	10.2		
	HU	56	30	80	57.8^{a}	13.3		
	Total	200	24	81	52.3	12.7		
Household size (individual)	SA	76	1	11	4.2	1.9	0.26	0.770^{ns}
	SH	68	2	6	4.1	1.0		
	HU	56	0	8	4.0	2.0		
	Total	200	0	11	4.1	1.7		
Farming experience (year)	SA	78	7	65	33.3^{a}	15.7	18.02	<0.01**
	SH	64	2	45	23.4^{b}	14.3		
	HU	44	3	60	17.0^{c}	14.7		
	Total	186	2	65	26.0	16.3		

^{ns}Non-significant difference. **Significant difference at α = 0.01. *N*, number; Min, minimum; Max, maximum; SD, standard deviation; Sig, significant level; SA, semi-arid; SH, semi-humid; HU, humid. Alphabet a and b shows significant difference between two regions.

TABLE 3 Socioeconomic characteristics of respondents in different climate regions.

Factor		Frequency mean (%)		
Marital status	Region	Single	Married	Total
	SA	8 (10)	70 (90)	78
	SH	10 (15)	58 (85)	68
	HU	2 (4)	48 (96)	50
	Total	20 (10)	176 (90)	196
Gender	Region	Male	Female	Total
	SA	78 (100)	0 (0)	78
	SH	50 (76)	16 (24)	66
	HU	48 (96)	2 (4)	50
	Total	176 (91)	18 (9)	194
Main job	Region	Farming	Non-farming	Total
	SA	56 (72)	22 (28)	78
	SH	22 (34)	42 (66)	64
	HU	8 (14)	48 (86)	56
	Total	86 (43)	112 (57)	198
Other income source	Region	Yes	No	Total
	SA	44 (56)	34 (44)	78
	SH	50 (75)	16 (25)	66
	HU	48 (92)	4 (8)	52
	Total	142 (72)	54 (28)	196
Residence status	Region	Permanent	Seasonal	Total
	SA	56 (74)	20 (26)	76
	SH	32 (53)	28 (47)	60
	HU	38 (70)	16 (30)	54
	Total	126 (66)	64 (34)	190

SA, semi-arid; SH, semi-humid; HU, humid.

TABLE 4 Educational level of respondents in different climate regions.

Region	Education level (year)							
	No literacy	1–5	5–9	9–12	14–16	16–18	18–22	Total
SA	0 (0)	34 (46)	12 (16.2)	12 (16.2)	12 (16.2)	4 (5.4)	0 (0)	74 (100)
SH	0 (0)	12 (17.1)	6 (8.5)	4 (5.7)	18 (25.7)	28 (40)	2 (2.8)	70 (100)
HU	10 (19)	4 (8)	8 (15)	16 (31)	10 (19)	4 (8)	0 (0)	52 (100)
Total	10 (5.1)	50 (25.5)	26 (13.3)	32 (16.3)	40 (20.4)	36 (18.4)	2 (1)	196 (100)

Data in parentheses show the frequency percentage. SA, semi-arid; SH, semi-humid; HU, humid.

Agroforestry activities

Nearly half of the farmers (46%) did agroforestry in their lands in the SA region. This ratio was 31% in the SH region and 22.5% in the HU region. There was a decreasing trend with challenging climate conditions (Figure 3). The results showed that the average farm size assigned to the agroforestry system was 0.6 ha, varying from 0–3 ha. The highest farm size of agroforestry was observed in the SA region with 0.86 ha (Table 8). Agroforestry farm size (ha) per farmer was significantly different across climate regions ($F = 23.27$, $p < 0.001$).

Alley cropping was the most common form of agroforestry in all three climate regions. Aquaforestry had the lowest representation among agroforestry and was not practiced in the SA and SH regions (Figure 4). There was a significant difference in the types of agroforestry practiced among the different climate regions ($p < 0.01$).

Nearly all farmers expressed an intention to continue practicing agroforestry. However, there was a significant difference in their willingness to recommend agroforestry to other farmers ($p < 0.001$). The results showed that farmers did not have much information on agroforestry (3.5 ± 1.24) (Table 9).

TABLE 5 Access to farm land among farmers in different climate regions using Duncan's test.

Capital	Region	*N*	Min.	Max.	Mean	SD	*F*	Sig.
Irrigation farm land (ha)	SA	78	0	15	2.5[a]	3.1	14.64	<0.01**
	SH	24	0	2	0.7[b]	0.6		
	HU	36	0.03	0.35	0.2 [b]	0.1		
	Total	138	0	15	1.6	2.5		
Rainfed farming land (ha)	SA	78	0.5	16	4.6[a]	3.8	15.4	<0.01**
	SH	18	0.2	5	1.3[b]	1.4		
	HU	14	0.02	1	0.3 [b]	0.3		
	Total	110	0.02	16	3.5	3.7		
Garden lands (ha)	SA	74	0.1	10	1.3[a]	1.9	10.53	<0.01**
	SH	60	0.02	3	0.7[b]	0.7		
	HU	46	0.02	1	0.2[b]	0.2		
	Total	180	0.02	10	0.8	1.4		
Number piece of land	SA	76	1	30	10.7[a]	7.3	63.25	<0.01**
	SH	36	1	5	1.8[b]	1.1		
	HU	46	0.02	6	1.3[b]	1.1		
	Total	158	0.02	30	6.0	6.9		
Barren land (ha)	SA	58	0	10	3.1[a]	2.3	6.49	<0.01**
	SH	8	0	1.5	0.6[b]	0.6		
	HU	4	0.5	1	0.8[b]	0.3		
	Total	70	0	10	2.6	2.3		
Distance farming with village (km)	SA	76	0.5	5	2.3[a]	1.0	37.7	<0.01**
	SH	52	0.8	5	1.9[a]	1.2		
	HU	52	0	3	0.7[b]	0.8		
	Total	180	0	5	1.7	1.2		

**Significant difference at α = 0.01. *N*, number; Min, minimum; Max, maximum; SD, standard deviation; Sig, significant level; SA, semi-arid; SH, semi-humid; HU, humid. Alphabet a and b shows significant difference between two regions.

TABLE 6 The cooperative membership of farmers in different climate regions.

Region	Yes	No	Total
SA	10 (14)	60 (86)	70 (100)
SH	14 (22)	48 (78)	62 (100)
HU	4 (7)	50 (93)	54 (100)
Total	28 (15)	158 (85)	186 (100)

Data in parentheses show the frequency percentage. SA, semi-arid; SH, semi-humid; HU, humid.

TABLE 7 Irrigation method by farmers in different climate regions.

Region	Traditional/flooded	Sprinkler irrigation*	Dripped system	Other	Total
SA	74 (44)	0 (0)	4 (40)	0 (0)	78 (100)
SH	60 (35.7)	2 (11.12)	4 (40)	0 (0)	66 (100)
HU	34 (20.3)	16 (88.88)	2 (20)	2 (100)	54 (100)
Total	168 (100)	18 (100)	10 (100)	2 (100)	198 (100)

Data in parentheses show the frequency percentage. *Sprinkler irrigation is a method of applying irrigation water, which is similar to natural rainfall. SA, semi-arid; SH, semi-humid; HU, humid.

Farmers had access to information from different sources (Figure 5). Other farmers (39.5%) in the SA and HU regions were the primary sources of information, and in the SH regions, farmers got their information on agroforestry from extenders and experts (69%). In total, extenders and experts (46%) and other farmers (41%) were two important sources of information.

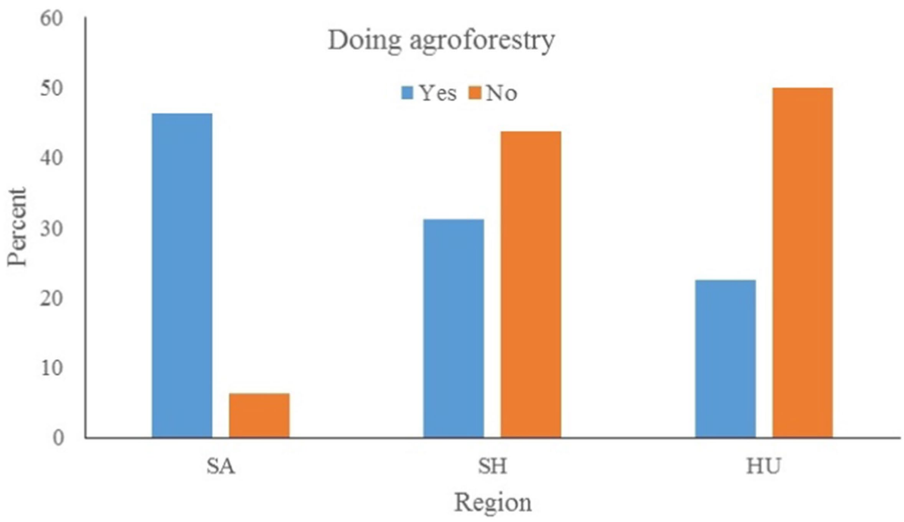

FIGURE 3
The distribution of agroforestry systems across climate regions. SA, semi-arid; SH, semi-humid; HU, humid.

TABLE 8 Agroforestry farm size (ha) per farmer across climate regions using Duncan's test.

Region	*N*	Min.	Max.	Mean	SD	*F*	Sig.
SA	74	0	3	0.86[a]	0.56	23.27	<0.01**
SH	28	0.1	2	0.41[b]	0.5		
HU	36	0.03	1	0.22[b]	0.22		
Total	138	0	3	0.6	0.56		

**Significant difference at α = 0.01. *N*, number; Min, minimum; Max, maximum; SD, standard deviation; Sig, significant level; SA, semi-arid; SH, semi-humid; HU, humid. Alphabet a and b shows significant difference between two regions.

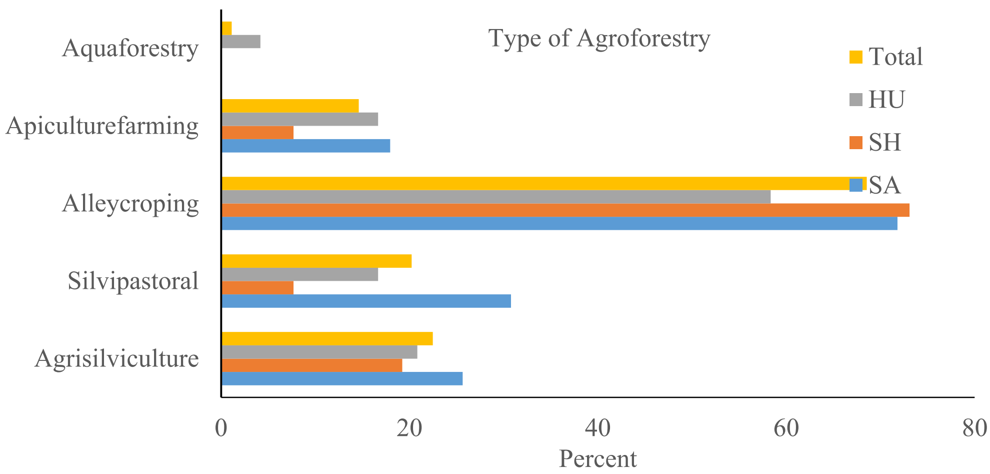

FIGURE 4
Type of agroforestry systems in different climate regions. SA, semi-arid; SH, semi-humid; HU, humid.

Notably, 17 and 14 tree species were planted in the agroforestry systems of the SA and SH regions, respectively. In the SA region, three species, apple, walnut, and poplar, were the primary species cultivated, while in the SH region, walnut, fig, and pomegranate were the three main species planted by farmers. The diversity of species planted in the HU region was very low. Of the five species planted in the HU region, poplar, walnut, and peach were three planted (Table 10).

Farmers followed a different purpose by planting trees in agroforestry. In all regions, the priority for farmers was providing food (70%) for their subsistence. The following preferences were selling timber (27.7%) and shading (23%) (Figure 6).

TABLE 9 Farmers' attitudes to agroforestry in different climate regions using Duncan's test.

Factor	Region	*N*	Mean	SD	*F*	Sig.
Tending to continue agroforestry	SA	78	4.6	0.75	3.86	0.023^{ns}
	SH	52	4.2	1.25		
	HU	48	4.7	1.03		
	Total	178	4.5	1.01		
Recommend to other farmers to use agroforestry	SA	78	4.5^{b}	0.79	10.2	<0.01**
	SH	52	4.3^{b}	1.21		
	HU	44	5.1^{a}	0.82		
	Total	174	4.6	0.99		
Information about agroforestry	SA	78	3.7^{a}	0.98	20.73	<0.01**
	SH	52	3.9^{a}	1.08		
	HU	52	2.6^{b}	1.34		
	Total	182	3.5	1.24		

[ns]Non-significant difference. **Significant difference at α = 0.01. Answer scale: 1: never, 2: very low, 3: low, 4: average, 5: high, and 6: very high). *N*, number; Min, minimum; Max, maximum; SD, standard deviation; Sig, significant level; SA, semi-arid; SH, semi-humid; HU, humid. Alphabet a and b shows significant difference between two regions.

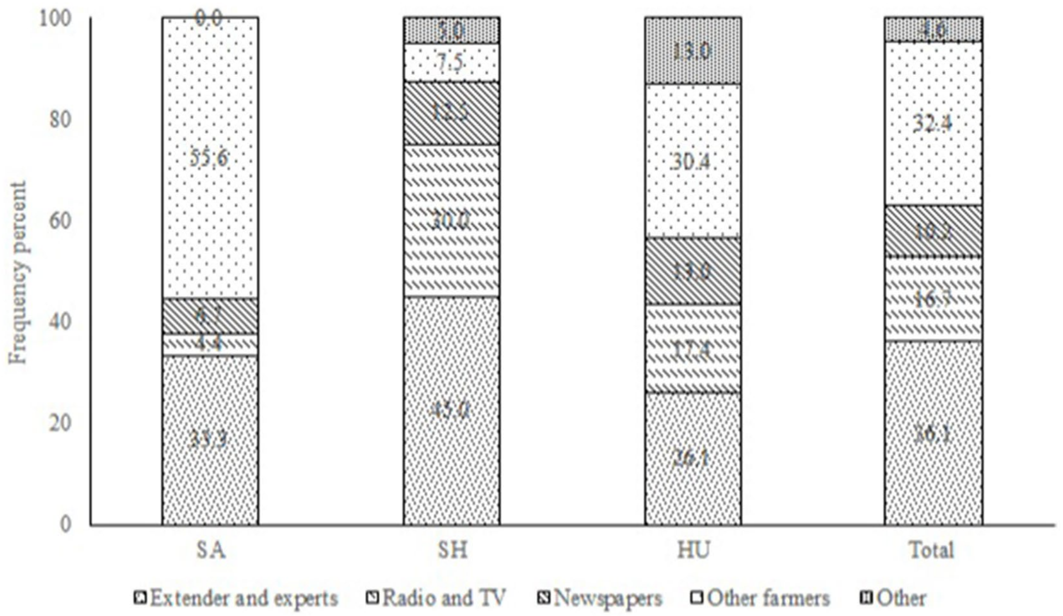

FIGURE 5
Source of information on agroforestry across climate regions. SA, semi-arid; SH, semi-humid; HU, humid.

Farmer's motivations

Farmers had different motivations for doing farming based on the agroforestry system. Although they had multiple purposes of doing agroforestry, increasing income (3.7 ± 1.1) and employment (3.3 ± 1.1) were two main motivating factors among farmers to do agroforestry. Wood (2.4 ± 1.2) and manure (2.3 ± 1) production were two other less important motivating factors of farmers (see Supplementary materials). Some motivational factors were significantly different among the studied regions. Water storage, creating employment, manure production, medicinal uses, and wood production significantly differed among the three climate regions. Similar to all production activities, farmers face some problems and obstacles in agroforestry. Governmental support (4.1 ± 1.1) and lack of efficient budget (4 ± 1.2) were the two main problems and obstacles in agroforestry. Lack of efficient land, lack of efficient information, and lack of education for farmers were three other factors among the challenges faced by farmers (Table 11).

Climate change adaptation

Climate change affects all dimensions of farmers' lives, and they experience its impacts in various ways. Increasing temperature

TABLE 10 Type of planted species at the agroforestry systems across climate regions.

Row	Species	Average per ha (%)*			
		SA	SH	HU	Total
1	Sour cherry (*Prunus cerasus*)	12 (7.32)	0 (0)	2 (7.14)	14 (5.43)
2	Peach (*Prunus persica*)	4 (2.44)	0 (0)	4 (14.28)	8 (3.1)
3	Almond (*Prunus amygdalus*)	4 (2.44)	4 (6.06)	0 (0)	8 (3.1)
4	Apple (*Malus domestica*)	44 (26.83)	0 (0)	0 (0)	44 (17.05)
5	Cherry (*Prunus avium*)	10 (6.1)	0 (0)	0 (0)	10 (3.87)
6	Plum (*Prunus domestica*)	4 (2.44)	0 (0)	0 (0)	4 (1.55)
7	Mulberry (*Morus alba*)	2 (1.22)	10 (15.15)	0 (0)	12 (4.65)
8	Nectarine (*P. persica* var. *nucipersica*)	2 (1.22)	0 (0)	0 (0)	2 (0.77)
9	Walnut (*Juglans regia*)	32 (19.51)	10 (15.15)	4 (14.28)	46 (17.82)
10	Pear (*Pyrus communis*)	4 (2.44)	4 (6.06)	0	8 (3.1)
11	Apricot (*Prunus armeniaca*)	12 (7.31)	0 (0)	0 (0)	12 (4.65)
12	Poplar (*Populus* sp.)	16 (9.75)	2 (3.03)	16 (57.14)	34 (13.18)
13	Ash (*Fraxinus excelsior*)	4 (2.44)	2 (3.03)	0 (0)	6 (2.32)
14	Elm (*Ulmus glabra*)	2 (1.22)	0 (0)	0 (0)	2 (0.77)
15	Willow (*Salix alba*)	8 (4.87)	0 (0)	0 (0)	8 (3.1)
16	Fig (*Ficus cariaria*)	0 (0)	10 (15.15)	0 (0)	10 (3.87)
17	Ailantus (*Ailanthus altissima*)	0 (0)	2 (3.03)	0 (0)	2 (0.77)
18	Persimmon (*Diospyros kaki*)	0 (0)	2 (3.03)	0 (0)	2 (0.77)
19	Olive (*Olea europaea*)	0 (0)	4 (6.06)	0 (0)	4 (1.55)
20	Orange (*Citrus sinensis*)	0 (0)	2 (3.03)	0 (0)	2 (0.77)
21	Lemon (*Citrus limon*)	0 (0)	2 (3.03)	0 (0)	2 (0.77)
22	Pomegranate (*Punica granatum*)	0 (0)	10 (15.15)	0 (0)	10 (3.87)
23	Grape (*Vitis vinifera*)	0 (0)	2 (3.03)	0 (0)	2 (0.77)
24	Pine (*Pinus eldarica*)	0 (0)	0 (0)	2 (7.14)	2 (0.77)
25	Rose (*Rosa* sp.)	2 (1.22)	0 (0)	0 (0)	2 (0.77)
26	Quince (*Cydonia oblonga*)	2 (1.22)	0 (0)	0 (0)	2 (0.77)
–	Total	164 (100)	66 (100)	28 (100)	258 (100)

*Data in parentheses show the frequency percentage of species rather than the total frequency of species in the region. SA, semi-arid; SH, semi humid; HU, humid.

(4 ± 1.7) and droughtiness (4 ± 1) were the two primarily perceived impacts, as reported by farmers (Table 12).

One adaptation strategy to coping with and mitigating climate change impacts was changing species. Farmers have changed crop species for several reasons, including low water demand, better adaptation, and improved efficiency. Traditional species cultivated in the past are replaced with new species (see Supplementary materials). For example, Barley has been replaced with alfalfa, pea, modified barley and wheat, and medicinal plants because of low water demand, adaptation, and change in efficiency. A similar strategy has been implemented for tree species planted in agroforestry. Some regions have replaced some high water demand species such as apple with walnut. Some farmers have changed grape species to fig, pomegranate, and pear for their adaptability and low water demand. Farmers have used other species, such as mulberry, olive, and pomegranate due to their adaptation, change in efficiency, and low water demand (Table 13).

Discussion

The findings from our study reveal significant regional variations in the sources of information that farmers rely on for agroforestry. In the SA and HU regions, 39.5% of farmers reported that other farmers were their primary source of information. This reliance on peer networks highlights the importance of social interactions and community-based learning in agricultural settings. Peer-to-peer knowledge exchange is often perceived as more practical and trustworthy, as it involves sharing firsthand experiences and locally adapted practices (Hermans et al., 2017). Such informal networks can play a crucial role in spreading innovative practices and encouraging the adoption of agroforestry among farmers who might be skeptical of external advice (Franzel et al., 2014).

In contrast, in the SH region, 69% of farmers obtained their information from extenders and experts, highlighting the essential role of formal agricultural extension services in this region. Extenders

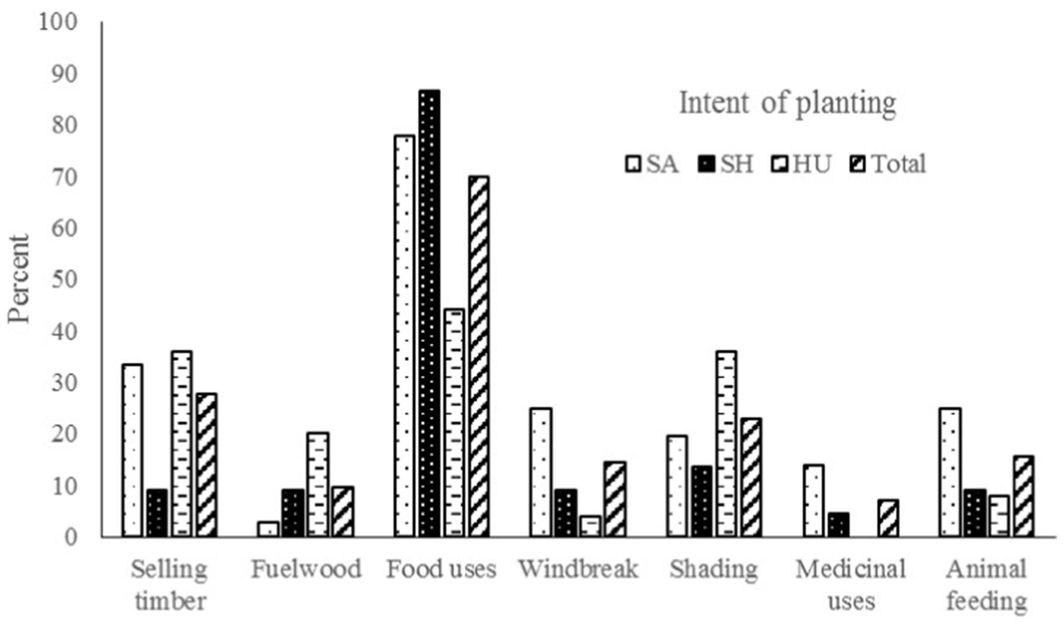

FIGURE 6
Intent of planting tree species based on the agroforestry systems across climate regions. SA, semi-arid; SH, semi-humid; HU, humid.

and experts accounted for 46% of the overall information sources, indicating their significant influence across the study areas. These professionals provide scientifically validated and comprehensive information, which is essential for addressing complex agroforestry issues and promoting sustainable practices (David and Asamoah, 2011). The regional difference suggests that, where extension services are well-established and accessible, farmers are more likely to trust and rely on these sources. These insights emphasize the need for a balanced approach to agricultural extension that integrates both informal peer networks and formal expert advice to address the various informational needs of farmers across different regions (Davis et al., 2012).

In the agroforestry systems of the SA, SH, and HU regions of Iran, 17, 14, and 5 species have been planted, respectively. All trees planted in the agroforestry have a special benefit and function. Although farmers had multiple purposes for practicing agroforestry, increasing income and employment emerged as the primary motivation factors for doing agroforestry. The ecological benefits of agroforestry activities such as ecosystem fixation, water storage, and soil quality were categorized as the second priorities of farmers. Some other researchers have mentioned similar benefits to the farmer communities (Lasco et al., 2016; Swamy and Tewari, 2017). Lasco et al. (2016) identified seven tree species planted in the agroforestry in Bohol, Philippines. In addition, Swamy and Tewari (2017) have stated that farmers are exploiting the benefits of agroforestry, providing a buffering effect against climate change in the arid and semiarid regions. In agroforestry, the species and diversity of tree species are critical in not only determining the income but also adapting to climate variability. This finding aligns with our results of planting more species in the SA and SH regions rather than the HU region. The potential of agroforestry can only be realized when the barriers to its implementation are addressed through the most efficient solutions. The recognition of agroforestry as a mitigation strategy under the Kyoto Protocol has enhanced its credibility as an adaptation strategy among local communities (Hernández-Morcillo et al., 2018).

The results of this study highlight that farmers have diverse purposes for planting trees in agroforestry, with primary focus on subsistence needs. Across all surveyed regions, the primary priority for farmers was to provide food (70%), highlighting the vital role of agroforestry in enhancing food security. This finding aligns with existing research indicating that agroforestry can significantly contribute to household food supplies by integrating tree crops with food crops and livestock (Mbow et al., 2014a). The secondary preferences of selling timber (27.7%) and providing shade (23%) reveal that farmers also recognize the economic benefits and the microclimate regulation that trees offer. Selling timber presents a valuable income source, while shade is crucial for protecting crops and livestock from extreme weather, thereby supporting overall farm productivity and resilience (Garrity, 2004; Yadav et al., 2024).

Farmers' motivations

The results revealed insightful findings regarding the motivations and challenges faced by farmers engaged in agroforestry. Farmers' motivations for adopting agroforestry were multifaceted, with income generation (3.7 ± 1.1) and employment opportunities (3.3 ± 1.1) being the primary driving forces. These motivations align with common expectations in agroforestry adoption, as the practice often offers economic benefits and improved livelihoods for rural communities. In particular, income and employment creation are often emphasized in studies like those by Arimi and Omoare (2021), highlighting the potential of agroforestry to help farmers combat climate change while also providing a reliable income source. However, wood (2.4 ± 1.2) and manure (2.3 ± 1) production, though beneficial, were reported as

TABLE 11 Problems and obstacles in implementing agroforestry systems across different climate regions using Duncan's test.

Problem	Region	*N*	Mean	SD	*F*	Sig.
Lack of governmental support	SA	78	3.8[a]	1.2	16.65	<0.01**
	SH	52	3.8[b]	1.2		
	HU	52	4.8[a]	0.5		
	Total	182	4.1	1.1		
Lack of education for farmers	SA	78	3.7	1.1	4.35	0.016[ns]
	SH	52	3.4	0.8		
	HU	50	3.2	1.0		
	Total	180	3.5	1.0		
Lack of efficient information	SA	76	3.7[a]	1.0	13.12	<0.01**
	SH	52	3.4[b]	1.0		
	HU	50	2.8[c]	0.9		
	Total	178	3.4	1.0		
Lack of efficient land	SA	74	3.1[c]	1.3	43.46	<0.01**
	SH	52	3.9[b]	1.2		
	HU	54	4.9[a]	0.5		
	Total	180	3.9	1.3		
Lack of an efficient budget	SA	78	3.4[c]	1.1	22.66	<0.01**
	SH	52	4.1[b]	1.4		
	HU	54	4.7[a]	0.7		
	Total	184	4.0	1.2		
Lack of information from the composition of the tree plus crops	SA	78	3.6[a]	1.1	17.54	<0.01**
	SH	52	3.3[a]	1.0		
	HU	50	2.5[b]	0.6		
	Total	180	3.2	1.1		
Not using updated research	SA	74	3.7[a]	1.1	19.63	<0.01**
	SH	52	3.2[b]	1.0		
	HU	46	2.6[c]	0.6		
	Total	172	3.2	1.1		

[ns]Non-significant difference. **Significant difference at $\alpha = 0.01$. Answer scale: 1: very low; 2: low, 3: average, 4: high, and 5: very high. N, number; SD, standard deviation; Sig, significant level. SA, semi-arid, SH, semi-humid, HU, humid. Alphabet a and b shows significant difference between two regions.

less important motivating factors. This could suggest that farmers prioritize immediate financial returns and livelihood benefits over secondary benefits like wood or manure, which might not be as directly associated with their economic survival. This finding could be contextualized by the study by Felton et al. (2023), which indicates that, while agroforestry offers multiple benefits, some are viewed as secondary or long-term benefits that may not outweigh the immediate need for income and job creation. On the flip side, farmers also face significant challenges in agroforestry. The two biggest obstacles were government support (4.1 ± 1.1) and the lack of an efficient budget (4 ± 1.2). This finding resonates with broader challenges in agroforestry adoption, as governmental support is often crucial in terms of policy frameworks, financial incentives, and technical assistance. The economic barriers, including insufficient budget allocation, were echoed in studies such as Schaffer et al. (2024), which suggest that the success of agroforestry depends on substantial government investment and support for farmers to overcome the costs of transitioning to these systems. Furthermore, the lack of efficient land, the lack of efficient information, and the lack of efficient education were significant hurdles. Farmers may not have access to land suitable for agroforestry or the information needed to implement these systems effectively. This finding reflects a common challenge in promoting agroforestry, as highlighted in the study by Arimi and Omoare (2021), where insufficient knowledge and lack of technical support hinder farmers' ability to maximize agroforestry's potential. Understanding these multifaceted motivations is crucial for developing tailored extension services and policies that support farmers' immediate and long-term goals, ensuring the success and sustainability of agroforestry.

Governmental support

Farmers involved in agroforestry, such as those in other agricultural activities, encounter various challenges that hinder their productivity and sustainability. The most significant

TABLE 12 The impacts of climate change perceived by farmers during the recent years across climate regions using Duncan's test.

Impact	Region	*N*	Mean	SD	*F*	Sig.
Increasing temperature	SA	76	3.9[b]	0.9	6.729	<0.01**
	SH	54	4.7[b]	1.07		
	HU	40	3.2[a]	1.2		
	Total	170	4.0	1.7		
Change of precipitation type	SA	78	3.6[b]	1.1	5.029	<0.01**
	SH	54	3.8[b]	0.8		
	HU	26	3.0[a]	1.1		
	Total	158	3.5	1.1		
Change of precipitation amount	SA	78	4.1[a]	0.9	21.18	<0.01**
	SH	52	3.8[a]	1.0		
	HU	20	2.6[b]	0.7		
	Total	150	3.8	1.0		
Changing of the season time	SA	76	3.5[a]	1.1	8.27	<0.01**
	SH	54	3.3[a]	0.9		
	HU	24	2.6[b]	0.7		
	Total	154	3.3	1.0		
Frostbite	SA	78	4.0[a]	0.9	12.91	<0.01**
	SH	54	3.8[a]	1.1		
	HU	28	2.8[b]	1.4		
	Total	160	3.7	1.1		
Droughtiness	SA	74	4.3[a]	0.7	28.22	<0.01**
	SH	54	4.0[a]	1.0		
	HU	22	2.7[b]	0.9		
	Total	150	4.0	1.0		

[ns]Non-significant difference. **Significant difference at α = 0.01. Answer scale: 1: very low, 2: low, 3: average, 4: high, and 5: very high. *N*, number; SD, standard deviation; Sig, significant level; SA, semi-arid, SH, semi-humid, HU, humid. Alphabet a and b shows significant difference between two regions.

obstacles identified in this study were the need for more governmental support (4.1 ± 1.1) and a lack of efficient budget (4 ± 1.2). This finding is consistent with previous research, which highlights that inadequate financial backing and policy support are significant constraints in the successful implementation and scaling up of agroforestry (Mbow et al., 2014a). Governmental support is crucial for providing the necessary resources, subsidies, and incentives to encourage farmers to adopt and sustain agroforestry. Without sufficient budget allocation, farmers struggle to invest in essential inputs and technologies, which can severely limit the potential benefits of agroforestry (Garrity, 2004).

In addition to financial and policy-related challenges, farmers face practical obstacles such as a lack of efficient land, a lack of information, and a lack of education. These factors are necessary to enable farmers to implement and manage agroforestry effectively. Limited access to suitable land restricts the extent to which farmers can engage in agroforestry, especially in densely populated areas or regions with land tenure issues (Franzel, 1999). Moreover, the lack of efficient information and education indicates a gap in knowledge transfer and capacity building. Farmers need comprehensive and accessible information on best practices, benefits, and management techniques of agroforestry to make informed decisions (Ajayi et al., 2006). Extension services and educational programs play a vital role in addressing this gap by providing tailored training and resources to equip farmers with the necessary skills and knowledge (Scherr and Sthapit, 2010). The reliance on extension services in the SH region can be mitigated by further elaboration upon improvements in these services, such as increasing their accessibility in remote areas, improving the quality of training, or tailoring advice to local agroecological conditions. Addressing these obstacles through targeted interventions can enhance the adoption and effectiveness of agroforestry, contributing to improved livelihoods and environmental sustainability.

In addition, climate change education can be incorporated into school and university curricula to help people understand this issue and also teach people how to cope with climate change (Hossain et al., 2016; Ghanbari et al., 2019). This information is essential for planners, extensionists, and NGOs to improve responses to further incidences of climate change and thus reduce the resulting difficulties. Finally, the adaptation projects should be contextualized according to the communities and ecosystems around them. Training programs for agroforestry managers and developing safe economic routes are key solutions to promote sustainable agroforestry.

TABLE 13 Changing tree species and climate change by farmers across climate regions.

Tree planted past	How many years ago	Tree planted recently	Reason for change
Plum	4	Cherry	Adaptation and low water demand
Apple	3	Walnut	low water demand, adaptation, and change in efficiency
Cherry	13	Persimmon	Adaptation
Grape	5	Fig	Adaptation and low water demand
Grape	5	Pomegranate	Adaptation and low water demand
Grape	5	Pear	Adaptation and low water demand
Poplar	17	Modified poplar	Change in efficiency
Native walnut	10	Modified walnut	Adaptation and change in efficiency
Plum	5	Poplar	Change in efficiency
Plum	15	Poplar	Adaptation and change in efficiency
Pomegranate	20	Olive	Adaptation and change in efficiency
Pomegranate	20	Mulberry	Adaptation and low water demand
Poplar	11	fruit trees	Change in efficiency
Poplar	15	Walnut	Adaptation and change in efficiency
Walnut	4	Mulberry	Adaptation and change in efficiency
Walnut	4	Orange	Adaptation and change in efficiency
Walnut	4	Lemon	Adaptation and change in efficiency
Walnut	14	Mulberry	Change in efficiency and low water demand
Walnut	14	Pomegranate	Change in efficiency and low water demand
Walnut	15	Pomegranate	Adaptation and change in efficiency
Walnut	15	Mulberry	Adaptation
Walnut	15	Mulberry	Change in efficiency
Walnut	15	Pomegranate	Adaptation and change in efficiency
Walnut	30	Pomegranate	Adaptation
Willow	5	Poplar	Change in efficiency

Climate change adaptation

As other researchers stated over the last decade, however, there has been a recognition that increasing temperatures, carbon dioxide levels, and changes in humidity and rainfall could affect agroforestry systems (Mbow et al., 2014b; Hariyanto et al., 2025). Climate change may shift ecological zones in tropical mountains and affect tree species distributions. Additionally, higher temperatures and increasing rainfall would increase the prevalence of coffee tree pests (Watts et al., 2022). Drought could decrease cacao yields by reducing the production of cacao pods per tree (Jaramillo et al., 2013). Due to the mentioned effects of CC, farmers attempt to adapt themselves to it. Besides, drought is considered another sign of climate change. Gateau-Rey et al. (2018) found that drought conditions could increase mortality rates in both cacao trees and their shade trees in Brazil, implying that tree shading may not be effective against drought. Adaptation to climate change is a two-step process that requires rural communities to first perceive climate change and then respond to the changes in the second step (Asrat and Simane, 2018; Rodríguez-Barillas et al., 2024). Changing cropping species by planting drought-resistant crop varieties was a vital adaptation strategy. As found in a study by Watts et al. (2022), agroforestry was mainly negatively affected by climate change. Climate change, manifested through increased temperature, changes in rainfall amounts and intensity, and drought, may hinder agroforestry farmers' climate resilience in dealing with declining ecosystem services. Emphasis on more drought-resistant crops in arid and semi-arid regions could help in reducing vulnerability to climate change (Rodríguez-Barillas et al., 2024). Generally, there is a shift from water-intensive to less water-intensive crops. A similar practice has been followed by farmers of the Barind region of Bangladesh who have cultivated a drought-tolerant rice variety to combat climate changes (Hossain et al., 2016). Furthermore, the shift in cropping practices was primarily from low economic yield and high water demand crops to crops with higher efficiency and low water demand. Changing cropping patterns has been noted as an adaptation strategy in Isfahan, Iran, and the Barind region of Bangladesh (Morid and Massah Bavani, 2010; Hossain et al., 2016). In addition, Kattumuri et al. (2017) reported that farmers in the semi-arid regions of Karnataka in India adopted shifting cropping pattern practices to cope with current climate risks. It was found to be the best possible strategy to mitigate the negative impacts of climate change (Morid and Massah Bavani, 2010). Saffron plantation has been expanded across Iran, especially the semi-arid region of Iran and Azerbaijan, as their response to water deficiency that villages face (Ghanbari et al., 2021).

In addition to changes in crop products, changes in tree species have been implemented to mitigate the climate change impacts. Swamy and Tewari (2017) mentioned that local communities had developed tree-based systems to reduce climate change risks. The tree component in agroforestry serves an important role in the conservation of fauna diversity, provision of ecosystem services (e.g., provision of food, fuel wood, improving crop productivity, increasing cash income, etc.), and inclusion of climate regulation services (Mulatu and Hunde, 2019). The functional diversity of trees led to planting and replacing different species in the agroforestry. In other parts of arid regions of the World, tree diversity can enhance food security and income in the arid ecosystems of Ethiopia (Manaye et al., 2021). We found similar results in this research, where the number of tree species in the agroforestry systems in the semi-arid region was higher than that in semi-humid and humid regions. Greater diverse species provide higher income sources, which will lead to an increase in their adaptability and the financial sustainability of farmers. As Santos et al. (2022) stated, Mediterranean agriculture urges alternatives, and agroforestry could be a key element among the tools to fight contemporary environmental challenges, such as climate change, water scarcity, and food security (Tramblay et al., 2020). Concerning biodiversity, trees in agricultural landscapes appear particularly efficient in contributing to biodiversity conservation, while environmentally valuable and economically profitable (Kay et al., 2019; Santos et al., 2022). Interestingly, our findings revealed that the number of tree species in agroforestry systems within the semi-arid region was higher than those observed in semi-humid and humid regions, indicating that more diverse species may contribute to a broader range of income sources. This result contrasts with many previous studies, which typically report greater species richness in more humid environments due to more favorable growing conditions and higher ecological productivity (Jose, 2012; Nair, 2012). In contrast, our results suggest that, in semi-arid regions, farmers may intentionally cultivate a wider array of drought-tolerant and multipurpose tree species to diversify income and mitigate environmental risks such as drought and soil degradation. This adaptive strategy may reflect a response to harsher climatic conditions, where species diversity becomes a form of livelihood insurance rather than a product of ecological abundance. Similar findings were reported in some case studies from dry regions of sub-Saharan Africa and Central Asia, where agroforestry diversity was driven more by the socioeconomic necessity and traditional knowledge than by climatic potential (Garrity, 2004). Therefore, the relationship between climate conditions and agroforestry diversity appears to be context-dependent, influenced not only by biophysical factors but also by farmers' strategies, cultural practices, and resource needs.

Farmers have employed various adaptation strategies to cope with and mitigate the impacts of climate change, with one notable strategy being the alteration of crop and tree species. This approach involves replacing traditional species with those that are more resilient to changing climatic conditions. For example, barley, which was historically cultivated, has been replaced by alfalfa, pea, bred barley, wheat, and medicinal plants. These replacements were driven by factors such as low water demand, better adaptation to the changing climate, and increased efficiency (Palombi and Sessa, 2013). This strategic shift not only helps in conserving water but also ensures that the crops can thrive under new environmental conditions, thereby maintaining agricultural productivity and sustainability.

Similarly, a comparable strategy has been adopted for tree species within agroforestry. Species with high water demand such as apple have been replaced with walnut in certain regions, reflecting a shift toward species that require less water and are better adapted to the prevailing climate (Nair, 2012). Additionally, some farmers have transitioned from grape cultivation to fig, pomegranate, and pear due to adaptability and lower water requirements. Other species, such as mulberry, olive, and pomegranate, have also been favored for their efficiency and adaptation to the new climatic conditions. These changes are indicative of farmers' proactive measures to ensure the sustainability of their agroforestry in the face of climate change (Lin, 2011). By selecting species that are better suited to the evolving environment, farmers can mitigate the adverse effects of climate change, optimize resource use, and sustain their livelihoods.

Conclusion

The study highlights significant regional differences in the sources of information that farmers in Iran rely on for agroforestry. In the semi-arid (SA) and humid (HU) regions, farmers primarily depend on peer networks (39.5%), emphasizing community-based learning. In contrast, in the semi-humid (SH) region, 69% of farmers rely on agricultural extension services and experts, reflecting the role of formal sources in areas with well-established services. The research also shows that agroforestry practices in Iran vary by region, with semi-arid areas exhibiting the highest species diversity. Farmers' motivations for agroforestry are driven by economic, ecological, and subsistence needs, with food security being the top priority, followed by income and employment benefits. However, challenges such as lack of government support, lack of an efficient budget, and lack of efficient land, lack of information, and lack of education hinder agroforestry adoption. Addressing these issues through targeted interventions, including better government support, budget allocation, and educational programs, is essential for successful agroforestry implementation. The study also emphasizes the need for integrating both informal peer networks and formal expert advice to meet the diverse informational needs of farmers.

Adaptation strategies, such as using climate-resilient crop and tree species, help mitigate climate change impacts and ensure agroforestry sustainability. The research highlights agroforestry's potential in enhancing food security, combating climate change, and improving rural livelihoods. To scale agroforestry, overcoming barriers to information, financial resources, and education is crucial, alongside incorporating these systems into national policies for sustainable land use and climate mitigation.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Dr. Rasoul Zavareghi, University of Tabriz; Dr. Attaollah Nadiri, University of Tabriz; and Dr. Jalal Shiri, University of Tabriz. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required from the participants or the participants' legal guardians/next of kin because we got permission from people orally before asking questions.

Author contributions

SG: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Software, Writing – original draft, Writing – review & editing. MJ: Conceptualization, Methodology, Writing – review & editing. JG: Conceptualization, Data curation, Writing – review & editing. IE: Conceptualization, Formal analysis, Methodology, Writing – review & editing. PÁ-Á: Conceptualization, Formal analysis, Supervision, Writing – original draft. SS: Conceptualization, Data curation, Investigation, Methodology, Writing – original draft. MA: Data curation, Methodology, Writing – original draft. LE: Data curation, Formal analysis, Writing – original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/ffgc.2025.1473355/full#supplementary-material

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