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Agroforestry practices for climate change adaptation and livelihood resilience in drylands of Ethiopia

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ABSTRACT

Agroforestry practices have gained attention as a means to enhance the resilience of smallholder farmers to climate threats. However, their role in building resilient livelihoods and adapting to climate change is not well studied in Ethiopia. Through our study, we evaluated the significance of indigenous agroforestry practices for climate change adaptation and livelihood resilience in different agroecologies of Northern Ethiopia. We interviewed 197 households to gather insightful data, and statistical analyses, including Chi-square, Pearson's correlation, ANOVA, and multinomial regression, were employed to analyze the data. Our findings reveal that farmers are proactively responding to the impacts of a changing climate by making strategic shifts in crop varieties, livestock types, and tree species, which they believe strengthen their adaptive capacity. Indigenous agroforestry emerged as the third most preferred climate change adaptation option among farmers, following livestock and off-farm activities. Additionally, on-farm trees were identified as the third most significant livelihood asset for farming households, underscoring the pivotal role of indigenous agroforestry in bolstering livelihood resilience. Indigenous agroforestry practices offer a multitude of benefits, including wood, livestock fodder, and crucial ecosystem services, particularly during periods of climate shocks. This not only enhances farmers' adaptive capacity but also alleviates pressure on neighboring natural forests. Notably, on-farm trees exhibited a substantial positive impact on crop productivity, household income, and overall climate change adaptation capabilities. Despite variations observed across different agroecologies, on-farm trees accounted for an impressive 34.35% of the household's total income, further highlighting their significance in fostering long-term livelihood resilience. In conclusion, our study emphasizes the urgent need to scale up indigenous agroforestry practices as a means to enhance short-term adaptive capacity and foster long-term resilience.

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Climate shock; livelihood diversification; on-farm trees; smallholder farmers

1. Introduction

Climate change, evidenced by various climate indicators (IPCC, 2007) has been posing significant risks to ecosystems, livelihoods, cultures, and infrastructures (Gentle and Maraseni 2012; IPCC 2014). To address these negative impacts of climate change, the implementation of effective adaptation mechanisms is crucial (FAO 2013; IPCC, 2007), especially for those that are highly affected smallholder farmers in developing countries (Cannon 2013; FAO 2013; Lasco et al. 2013; Awazi and Quandt 2021; Awazi et al. 2022a; Awazi 2022b). The integration of adaptation and mitigation strategies is increasingly recognized as a necessity, particularly in sectors such as agriculture, forestry, and land use (Montagnini and Nair 2004). Within this context, agroforestry practices have gained attention as a means to enhance the resilience of smallholder farmers to climate risks (Lasco et al. 2013).

Agroforestry is an old land use approach (Leakey et al. 2005; Zomer et al. 2009), which has been widely practiced by subsistence farmers and has been promoted by various actors working in climate change and development sectors (Zomer et al. 2009). It offers a range of benefits, including diversification of production systems, enhanced sustainability, and increased farm profitability (Montagnini and Nair 2004; Verchot et al. 2007). By integrating trees with crops and livestock, agroforestry systems can maintain production levels during both wetter and drier years, reduce the damaging effects of wind and water flow, and provide additional income streams for farmers (Montagnini and Nair 2004). Furthermore, agroforestry plays a crucial role in environmental amelioration, food security, and climate

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change mitigation and adaptation (Torquebiau 2013). Microclimatic improvements resulting from agroforestry practices can buffer crops against extreme temperatures and create more favorable conditions for growth and yield (Montagnini and Nair 2004).

The IPCC asserts with high confidence that agroforestry is a viable adaptation strategy along with others (IPCC 2007). For instance, when the livelihoods of millions of Africans are threatened by climate change and land degradation, tree-based agriculture practices have provided a lifeline (Mbow et al. 2014) by boosting the community's resilience during times of drought, which significantly contributed to making it possible to cope with disaster (Alemu 2016). Furthermore, farmers in Cameroon (Nyong et al. 2019; Awazi 2022b), Bangladesh (Hanif et al. 2018), and Kenya (Kariuki et al. 2011) support their livelihood and resilience through agroforestry.

In Ethiopia, agroforestry is practiced by smallholder farmers throughout the country (Teketay and Tegineh 1991; Bekele Jiru 2019). Studies conducted in different regions of the country, such as Gedeo, Afar, and Tigray, have shown that agroforestry has the potential to enable farmers to adapt to and mitigate the effects of climate change and variability which is already being felt and resulting in declining crop and livestock productivity and impacting livelihoods (Bishaw and Abdelkadir 2003; Teka et al. 2012; Linger 2014; Weldearegay and Tedla 2018; Araro et al. 2020; Manaye et al. 2021). It improves farmland ecosystem resilience and sustainability capacity (Yang et al. 2023). While the importance of agroforestry for smallholding livelihoods has been recognized in various parts of Ethiopia (Teketay and Tegineh 1991; Bishaw and Abdelkadir 2003; Hassan et al. 2011; Kebede and Adane 2011; Rahman et al. 2012; Linger 2014; Alemu 2016; Bekele Jiru 2019; Manaye et al. 2021), there remains a research gap in understanding the role of indigenous agroforestry systems in diversifying livelihoods and enhancing adaptation capacities in specific geographic areas (Awazi, 2019; Muthee et al. 2022; Zada et al. 2022; Quandt et al. 2023). This study aims to address this research gap by examining how indigenous agroforestry is used for climate change adaptation by farmers, and how much it contributes for livelihood diversification and resilience in the Tigray region of Ethiopia. Our work offers important knowledge regarding the importance of indigenous agroforestry for coping with climate change and maintaining livelihoods, and is helpful to decision-makers in considering it for improved management and expansion.

2. Methods

2.1. Study site

Tigray regional state is located in the Northern part of Ethiopia at 12°-15° N latitude and 36° 30′ – 40° 30′ E longitude, in altitudinal range of 500 – 400 m.a.s.l. (Gufi et al. 2023); where the specific study sites, Endamekhoni, Kilteawlaelo, and Tanquaaberegele are located in its highland, lowland, and midland part respectively, representing three agro-ecologies (Figure 1). The three agroecologies were chosen in the context of an altitude-based agroecological zoning, assuming that the majority of the region and the study districts fall within these zones (Gorfu and Ahmed 2011). All districts practice a mixed type of farming by which livelihoods are dependent on crop, livestock, and tree cultivation systems. The study sites have a dominant soil type of Leptosol (Endamekhoni and Kilteawlealo) and Cambisol (Tnaquaberegele) (FAO 2006). The districts are among those whose communities

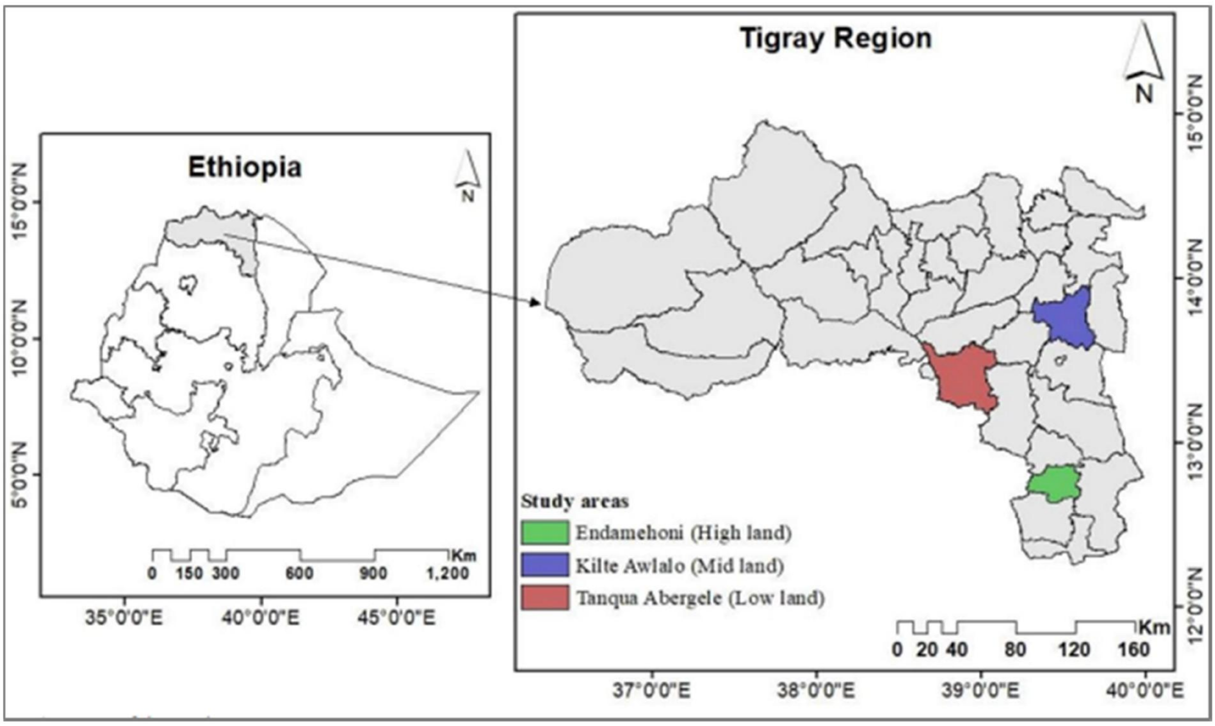

Figure 1. Location of the study area.

are vulnerable to and affected by climate change and variability (Kebede and Adane 2011; Sørhaug 2011; Teka et al. 2012; Weldearegay and Tedla 2018).

Endamekhoni district is found in the southern part of the region with an average altitude of 2622 m.a.s.l (ranging from 1752–3858 m.a.s.l), where it receives a bimodal type of rainfall ranging from 478 to 956 mm per year. It has an average mean minimum and maximum temperature of 10.2 and 22.5 °C respectively. *Eucalyptus globulus, Acacia abyssinica, Acacia saligna, Olea africana*, and *Psidium guajava* are the major dominant tree species in the area. Kilteawlealo district is located in the eastern part of the region with an average altitude of 2112 m.a.s.l. (ranging from 1757–2618 m.a.s.l.). It receives a bimodal type of rainfall that ranges from 397 to 953 mm per year. It has an average mean minimum and maximum temperature of 11.1 and 28.0 °C respectively. *Faidherbia albida, Eucalyptus camaldulensis*, and *Acacia saligna* are the major dominant tree species in the district. Apart from these, Tanquaabergele is found in central zone of the region and receives a unimodal type of rainfall extending from 400 to 600 mm per year. It has an average mean minimum and maximum temperature varying from 14.3 and 29.9 °C respectively and an average altitude of 1446 m.a.s.l. (ranging from 912-2277 m.a.s.l.). *Ziziphus spinachristi, Acacia etbaica,* and *Acacia seyal* are the major dominant tree species in the district (Manaye et al. 2021).

2.2. Sampling, data collection and Analysis methods

Sampling technique

The assessment considered different agroecologies of the study region, thinking agroecology might affect the benefits of agroforestry practices concerning climate change adaptation and livelihood resilience. Hence, a reconnaissance survey was made to understand the distribution of potential areas in agroforestry practices across different agroecologies. Based on the reconnaissance survey, one site was randomly selected from the potential agroforestry areas of each agroecology from Tigray region, Ethiopia. Endamekhoni, Kilte-Awlealo, and Tanqu-Abergele were selected representing highland, midland, and lowland areas respectively.

Since we couldn't find accurate sample population of the studied areas the sample size was determined using the following formula (Kothari, 2004; Yamane 1967)

$$n = \frac{z^2.p.q}{e^2}$$

Where n = Sample size
z = Standard variate at a given rate confidence level
p = Sample proportion
q = 1-p
e = precision

In our case we used 95% confidence level ($z = 1.96$), 7% (0.07) precision, 0.5 sample proportion and 0.5 q value. Based on that, a total of 197 respondents, 68 from Tanqua_Abergele, 64 from Kilte-Awlaelo, and 65 from Endamekhoni were selected randomly from a list of residents in each district of a particular village. Besides, key informants of forestry and agroforestry professionals, community leader and elders were purposely selected as key informants based on their forestry/agroforestry related profession and experience. A total of fifteen key informants, two professionals, one community leader and two elders from each study district were selected for this purpose.

Data collection

Data collection was conducted using a questionnaire, semi structured observation checklist and semi structured interview guideline prepared by the authors. The questionnaire was developed based on the prototype of the PEN (Poverty Environment Network) of the CIFOR (Center for International Forest Research) (Bakkegaard 2013). Extension agents were hired and trained to collect the required data from household heads using the questionnaires. Before proceeding to data collection, the questionnaire was validated and tested by five experts of Mekelle university, five experts of Bureau of agriculture and rural development of the Tigray region and five residents of the study area. Suggestion of the experts and response of the residents were used to improve and prepare finalized questionnaire. Data regarding household characteristics, benefits of agroforestry, climate change adaptation strategies, livelihood resilience, and income from agroforestry were collected through the questionnaire. Besides, field level observation and key informant interview was conducted using semi structured observation checklist and interview guidelines to triangulate the data collected *via* questionnaire. The authors conducted an in-depth interview with the key informants.

Data analysis

Analysis was done using IBM SPSS version 26. The rank-based inverse normal transformation was done to non-normal data to enable us to use Pearson's correlation and one-way ANOVA. Descriptive methods and inferential statistics like Chi-square, Pearson's correlation, and multinomial regression were used to analyze the data. Pearson's correlation test was used to identify the relationship between household income (income from farm trees and total household income) and on-farm trees; and its implication for livelihood resilience. One-way ANOVA was used to investigate the mean difference of income from trees, household income, and household main livelihood assets across agroecologies and wealth categories of households; and its implication to climate change adaptation and resilience. Multinomial regression was applied to examine the relationship between socioeconomic factors and the choice of climate change adaptation options. Furthermore, qualitative data obtained from respondents and key informants was explained and described systematically.

Table 1. Factors affecting adaptation to climate change option of farmers.

	Model Fitting Criteria	Likelihood Ratio Tests		
Effect	−2 Log Likelihood of Reduced Model	Chi-Square	df	Sig.
Intercept	409.294	3.702	3	0.296
Age	409.734	4.141	3	0.247
Family size	409.835	4.242	3	0.237
Gender	416.22	10.627	3	0.014
Literacy	407.142	1.55	3	0.671
Wealth	409.353	3.76	3	0.289
If Agroecology is Lowland	423.057	17.465	3	0.001

3. Results

3.1. Socioeconomic characteristics of respondents

Of the total 197 sampled respondents, majority of them were male, and many of them were categorized as illiterate and at elementary educational level, showing that most of them are not educated. Depending on the local wealth classification of each study area, the majority of them reported that their wealth status is medium; mentioning that they can cover their food demand throughout the year; regardless of the quality of the food. But, 28.9% of them belonged to the category of poor, indicating members of the household are highly dependent on governmental or non-governmental food aid. Only a few households (8.1%) were categorized as rich, having surplus production. The average family size and age of respondents were found to be 6 ± 2 and 48 ± 13 respectively (Appendix 1).

The farmers of all the study areas are highly dependent on rainfed agriculture mainly crop production and livestock rearing. They have been seen engaging in various agroforestry practices. The farmers in the highland area were engaged in woodlot, parkland, border planting, and home garden forms of agroforestry, with woodlots predominating. Boundary planting, home gardens, and parkland agroforestry practices were also practiced in the midland of the study area; by which parkland agroforestry is dominant. Parkland agroforestry practices are prevalent in the lowland. Boundary plantings, however, are also used in the area.

3.2. Agroforestry to climate change adaptation

Climate has been changing as perceived by 94% of respondents, evidenced by low precipitation, short rainfall duration, increased temperature, and occurrence of extreme climate events mainly drought, compared to the past thirty and more years. The farmers said that such climate change-related problems have been affecting their production systems and were exposed to loss of livestock and crop production. About 68.4%, 76.6%, and 89.7% of the respondents in the local community, respectively in the highland, midland, and lowland said drought was the most common climate hazard faced. In all the study areas drought (78.8%) and flood (11.7%) are the main climate hazard frequently manifesting. Only 9.5% of the respondents said they didn't perceive any of the climate hazards mentioned by the rest of the respondents.

This manifestation of climate change and climate hazards made the farmers shift crop varieties, livestock species, and tree species. For instance, 85.3% of the respondents shifted the species type to a new adaptive type. Most of them (80.1%) often change their previous crop variety to those introduced by agricultural extension/research systems. A few of them appeared to change their livestock species (13.3%), and tree species (6.6%) to another species they perceive as adaptive. Furthermore, farmers were found using livestock, off-farm activities, and agroforestry (ranked by respondents as a third adaptation choice) as their adaptation and coping mechanisms for climate change. Farmers also confirmed that they used trees in farmland as their main source of feed for their livestock in times of drought; because grasses and forage can't be harvested in drought times due to a shortage of moisture.

The results of our multinomial regression model indicated that gender and agroecology affected the choice of agroforestry as an adaptation option for farmers (Table 1). Male respondents tend to choose agroforestry over off-farm, nonfarm, and livestock adaptation options more than females. Females appeared to prefer off-farm, nonfarm, and livestock to agroforestry. In addition, the lowlanders' choice of climate change adaptation strategy relied less on agroforestry than the farmers of the other two agroecologies. The other variables, age, family size, literacy, and wealth, show no significant effect on a household's choice of agroforestry as an adaptation option (Table 1). Moreover, the chi-square test result exhibited that the adaptation strategy of farmers varied ($p < 0.05$) across agroecology.

3.3. Agroforestry in diversifying income and livelihood resilience

The findings of this research indicated that farmers in the study area used trees in farmland for construction purposes/timber (29.9%), fodder for their livestock (24.7%), firewood for domestic purposes (14.9%), and other functions. Most farmers in the lowland (38.2%) and highland (50.8%) use trees in farmland for timber/construction purposes. Whereas, farmers in the midlands (61.9%) used the trees mainly as a source of feed for their livestock (Figure 2).

The research found that most residents used tree products in their farmland for constructing living houses. Respondents confirmed more than two-third material of their house's wall is made up of tree products from their farmland. In the highland area, most farmers were using tree products from their farmland for constructing the wall of their houses. Whereas, in

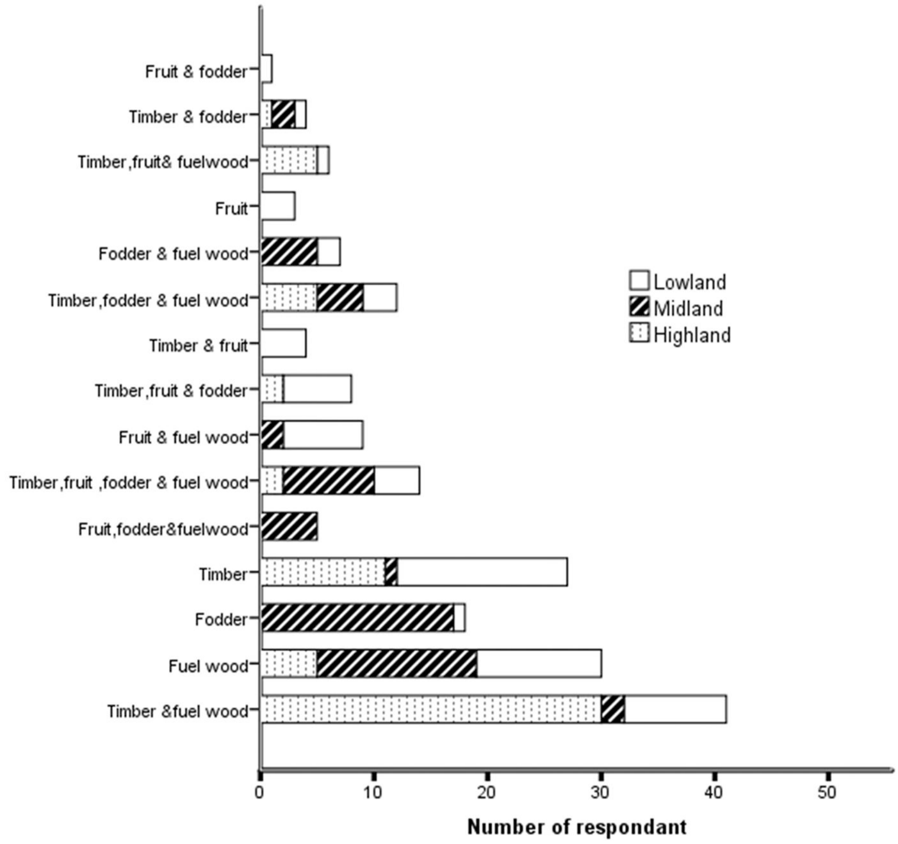

Figure 2. Benefits of trees in farmland.

Table 2. Type and source of material for house building and farm utilities.

		% of respondents			
Type of material	Source	Highland	Midland	Lowland	Overall
Farm utilities	Open forest	21.5	21.9	17.6	20.3
	Own farmland	78.5	78.1	82.4	79.7
Most material of wall of a house	Wooden (with mud)	79.7	21.9	13.2	37.8
	Bricks/Stone	20.3	78.1	86.8	62.2
Most material of roof of a house	Wooden (with mud)	9.4	59.4	61.8	43.9
	Iron sheet (with wood/timber)	90.6	40.6	38.2	56.1

the lowland and midland areas only 13.2% and 21.9% of them respectively used tree products for constructing a wall of their houses. This is because most materials wall of a house in the midland and lowland areas are stone/bricks. Using tree products for constructing a wall of a house is higher in the highland. Besides, of all the total respondents, 43.9% of them confirmed that most material of their house's roof is made up of wood products. Farmers in the highland (9.4%), midland (59.4%), and lowland (61.8%) areas used tree products for the roof of their houses. Using tree products for a house's roof is higher in lowland and midland areas. As is affirmed by the majority of respondents, most farmers obtain farm tools from their land. Many farmers in the highland, midland and lowlands gain farm tools from their farmland. Some other respondents also said they get farm equipment from the open forest (Table 2).

Most importantly, farmers proved such benefits of farm trees enabled them to save the money which they were supposed to pay for construction and farm tools; thereby enabling them to enhance their adaptive capacity indirectly. Results from our open-ended questions and from interviews of the elders indicated that the trees in their farmland tolerated drought (the most frequent climate manifestation) and were in less difficult situations when they need to build their shelter and needed farm tools, even during drought times. Besides they testified that not purchasing construction or farm materials enables them to save their money which was supposed to buy the materials and save their time from spending too much time wandering in open forests which are mostly far from where they live; and use their savings for difficult times. Except for the decline, farmers never had problem of harvesting tree products (farm tools, timber, forage) even in drought times.

As witnessed by 73.1% of respondents, the presence of trees in farmland improves crop production. The Pearson Correlation test also testified that an increase in the number of trees in farmland enabled the household to have an increased income from crop production and total household income. However, the chi-square test analysis result showed that there is a significant

Table 3. The relationship between trees in farmland and income (income from crop and total household income).

Variables	Crop income	Total income
Abundance	.374**	.552**
Richness	.213**	.169*

**Correlation is significant at $p < 0.01$ and *$p < 0.05$.

Table 4. Mean difference of on-farm trees and total household income in the three agro-ecologies.

Agroecology	Total household income (US dollars)	On-farm trees income
Highland	622.19 ± 434.99^{c}	202.63 ± 261.51^{c}
Midland	222.11 ± 236.82^{a}	86.73 ± 148.95^{a}
Lowland	304.54 ± 209.09^{b}	102.46 ± 127.59^{a}
p-Value	0.000	0.004

Similar letters indicate no significant difference and different letters indicate significant difference at $p < 0.05$. 1 US dollar = 55.40 Ethiopian Birr (ETB) (Exchange rate as of November 29, 2023).

difference in the tree stand asset in farmland among the agroecologies. Our study shows, having an increased number of tree species types (diversity) in farmland has a positive relationship with income from crop production and total household income (Table 3). With moderate strength of relationship, an increase in abundance of trees exhibited an increase both in income of crop and total income of households ($p < 0.01$). Similarly, an increased tree species richness showed us a week positive relationship with crop income and total income of the households (significant at $p < 0.01$ with crop income and $p < 0.05$ with total income). However, this positive relationship was found to be up to certain amount of optimum level of tree richness. The mean number of trees and number of types of tree species in farmland showed a significant difference between the wealth categories of the respondents. More particularly, the mean of these two variables has a significant difference between the poor and medium wealth categories.

The mean income of the households studied was higher in the highland (622.19 ± 434.99 US dollars), followed by the midland and lowland agroecologies, respectively. The households had a mean total income of 382.57 US dollars. The mean income from farm trees was 131.41 US dollars, with the highest mean income obtained in the highland (202.63 ± 261.51 US dollars), followed by the midland and lowland agroecologies. The contribution of on-farm trees in agroforestry was 32.57% in the highland, 39.05% in the midland, and 33.65% in the lowland of the total household income. Overall, the agroforestry practices of the studied agroecologies contributed 34.35% to the total household income (Table 4).

Furthermore, interviewees from our study indicated that in times of climate shock trees in farmland helped farmers to harvest tree products (timber, fuelwood, forage, and others) and serve them as source of income and compensation for the failed crop production. In such difficult times of climate shock (particularly drought) they sold timber and fuelwood to fulfill their food and other demands of their household. Moreover, the trees help the farmers to tackle shortage of forage for their cattle and sheep during drought, there by mitigate absence of food supply for the household. Besides, they said the income obtained in a time of out of climate problem from the trees contributed for the stability and better resilience when climate shock comes. This shows that trees in farmland, which are less affected by climate hazards significantly contribute to improving household income and livelihood resilience.

Table 5. Percentage of respondents who ranked the main livelihood products based on their importance to their livelihood.

		% of Respondents			
Agroecology	Rank	Crop	Livestock	Non-farm	Agroforestry
Highland	*First*	93.8	1.6	1.6	3.1
	Second	6.8	54.2	6.8	32.2
	Third	31.4	0	9.8	58.8
Midland	*First*	89.1	6.3	1.6	3.1
	Second	6.3	71.9	6.3	15.6
	Third	3.3	16.7	8.3	71.7
Lowland	*First*	92.6	5.9	1.5	0
	Second	5.9	89.7		4.4
	Third	1.5	1.5	8.8	88.2
Overall	*First*	91.8	4.6	1.5	2
	Second	6.3	72.8	4.2	16.8
	Third	1.7	15.1	8.9	74.3

The results of the study indicated that income from on-farm trees varies between agroecologies ($p < 0.05$). There is a significant difference between the mean income from trees in farmland between highland and midland, and highland and lowland (p = <0.05). However, the mean income difference was not significant (p = <0.05) between the midland and lowland agroecologies (Table 4).

Moreover, the study confirmed that on-farm trees are one of the main livelihood assets for households. Most of the respondents ranked crops, livestock, and trees as the first, second, and third important livelihood products respectively. This applies to all the three agro-ecologies, except in the highland agroecology, by which respondents ranking trees in farmland as their third livelihood asset were lower than the other two agroecologies. This testifies that trees in farmland were found as one of the top three important livelihood assets (Table 5).

In addition, the total mean household asset estimated in US dollars was found to be 690.85 ± 524.72. The mean score of trees in farmland asset was 132.73 US dollars; constituting 19.21% of the total household livelihood asset; which is third next to livestock (369.86 ± 271.34 US dollars) and crop production (189.09 ± 211.69 US dollars). The mean total livelihood asset was found higher in highland (795.86 ± 691.47 US dollars) than the other agroecologies. Likewise, the mean tree stands asset of the highlanders (283.15 ± 409.66 US dollars) was higher than the mid-landers and the lowlanders. There was a significant ($p < 0.05$) difference in mean in all the three main livelihood assets and total assets across the three agro-ecologies. However, the mean difference of the total main livelihood asset between highland and lowland was not significant at $p < 0.05$ (Table 6).

In our interview we found that increased income and productivity, resulted from the presence of trees in farmland, helped farmers for better adaptive capacity.

Table 6. Mean difference of main household livelihood assets in different agro-ecologies (estimated in USD)

Agroecology	Livestock asset	Crop production asset	Trees stand asset	Total main livelihood asset
Highland	284.80 ± 218.42[a]	238.39 ± 279.41[b]	283.15 ± 409.66[c]	795.86 ± 691.47[b]
Midland	375.77 ± 269.03[b]	120.28 ± 156.78[a]	55.51 ± 87.39[a]	555.59 ± 380.09[a]
Lowland	444.21 ± 298.07[b]	207.19 ± 160.43[b]	73.99 ± 72.16[b]	717.77 ± 428.92[b]
p-Value	0.003	0.000	0.000	0.033

Similar letters indicate no significant difference and different letters indicate significant difference at $p < 0.05$.

The low vulnerability to climate shock made trees to be considered as their main livelihood asset and source of income. The interviewee noted trees in farmland helped farmers as main livelihood asset, and main source of feed during drought times. This supported them to reduce the loss of livestock because of the climate shock and enabled to fulfill their food demand. Besides, they noted that the agroforestry trees asset accumulation out of climate shock time supported them to have less vulnerable asset in time of climate shock, which in turn will enhance their adaptive capacity.

4. Discussion

4.1. Contribution of agroforestry to climate change adaptation

Similar to our findings, other studies confirm the presence of climate change observed by low precipitation, short rainfall duration, increased temperature and happening of extreme climate events like drought (IPCC 2007) and its impact on ecosystems, livelihoods, cultures, and infrastructures (IPCC 2014). Studies in Cameroon (Awazi et al. 2020a, 2020b) and northern Ethiopia of Tigray region (Sørhaug 2011; Teka et al. 2012) attest the prevalence and impact of climate change.

As is noted in this study that climate hazards such as drought and flood have been threatening the production system of farmers, other researchers also explored how climate change affects the agriculture sector by which smallholder farmers are and will be the most affected (Verchot et al. 2007; Lasco et al. 2013; IPCC 2014). The IPCC confirms there is high confidence that smallholder farmers in developing countries will suffer more because of climate change impacts (Lasco et al. 2011; IPCC 2014). The adverse effect is also evident in Ethiopia in general, and in Tigray in particular (Teka et al. 2012).

In response to the climate change and its impacts farmers used different mechanisms to cope up and adapt. Their adaptation mechanisms range from changing agricultural species to changing production systems. Farmers in our study areas and farmers in Cameroon chose on-farm, off-farm and agroforestry practices to adapt to climate change (Awazi et al. 2019b). Farmers in Nepal considered agroforestry as a second measure for adaptation to climate change (Paudel et al. 2022), which is alike with those from our study areas, by which they ranked it as their third adaptation option. Whereas, for farmers in North-West region of Cameroon, agroforestry practice is the most prevalent adaptation measure to climate change (Awazi et al. 2019b). This indicates that there is perception difference toward using agroforestry practices as a means of climate change adaptation across communities.

This study and other findings assert tree-based agricultural practices have been providing a way of resilience for millions when their livelihoods are threatened by climate change and land degradation (Lasco et al. 2013; Mbow et al. 2014; Alemu 2016). Farmers in Kenya have been escaping from drought using mango, papaya, and banana products. This indicates agroforestry is a promising option for climate change adaptation (Quandt et al. 2017). Beside to using products of trees in farmland as source of food during drought, it was evident that trees in farmland are used as source of fodder during climate crisis (Awazi 2022a, 2022b).

A research from Cameroon affirmed that socioeconomic and institutional factors influenced farmers' decision of practicing agroforestry as a means of adaptation to climate change (Awazi et al. 2019b; 2020a, 2020b). Unlike to our study, access to land, household income and access to information of farmers in Cameroon determine the choice of agroforestry as an adaptation option for climate change (Awazi et al. 2021). Whereas, our study affirms that gender and agroecology had an impact on farmers' decisions to choose agroforestry as a form of adaptation. Farmers in other parts of the world and in our study areas seem being affected by different factors in choosing agroforestry as their adaptation option. This could be for a variety of causes, all of which call for the attention of authorities in agroforestry research and development projects (Mbow et al. 2013).

4.2. Agroforestry in diversifying income and livelihood resilience

The IPCC states that livelihood diversification enhances adaptive capacity of lives and livelihoods. It also argues with high confidence agroforestry along with others is an effective option of adaptation (IPCC, 2007). Our findings also indicate the significance of agroforestry trees for livelihood diversification and livelihood resilience.

Farmers harvest timber and fodder the trees in their farmland for construction, selling and feeding their livestock. Moreover, in times of climate shock, the farmers' main source of feed was found to be trees in farmland, which in turn helped them to replace their failed crop production by livestock and minimized their vulnerability. Besides, the tree products harvested out of time of climate shock helped them support their livelihood when the time of shock comes. This implies agroforestry minimizes the vulnerability of farmers to climate change and forest degradation by substituting timber, fodder, and fuelwood demand of farmers. Others also avowed that on-farm trees contributed to providing fuelwood (Ndayambaje and Mohren 2011; Rahman et al. 2012; Jamnadass et al. 2013; Ndalama et al. 2015; Anwar et al. 2017; Nyong et al. 2019; Awazi 2022a), fodder (Jamnadass et al. 2013; Mathukia et al. 2016; Anwar et al. 2017; Awazi 2022a), fruit (Bishaw and Abdelkadir 2003), food (Mukhlis & Rizaludin, 2022) and other benefits to smallholder farmers. Farmers' in Cameroon strengthen their resilience and attenuate vulnerability by agroforestry products and service of food, fuel wood, building materials and erosion control (Nyong et al. 2019; Awazi 2022b). Farmers in Bangladesh also plant trees on farmland for fruits, fuelwood, timber production (Hanif et al. 2018), and medicinal purposes (Jahan et al. 2022; Awazi et al. 2022a) which on the other hand improves their resilience. In Kenya, diversification of livelihood such as climate shock tolerant crops, tree for timber, multipurpose trees for sale, fodder trees, proper animal husbandry and soil management techniques; made farmers less reliant on crop production and less vulnerable to climate change (Kariuki et al. 2011). Another research in Kenya testified that agroforestry trees improve adaptive capacity by providing important tree products and financial benefits, such as fruit, food, firewood, timber, fodder, traditional medicines and money from tree products (Quandt 2020). Therefore, agroforestry has the potential to satisfy the human need for food, fuelwood (Nyong et al. 2019), fodder, timber, etc; there by serve as insurance against drought, flood, and other natural disasters (Kariuki et al. 2011; Anwar et al. 2017; Jahan et al. 2022).

Farmers in the study sites and other areas gained farm tools and construction materils for their houses from the trees in their farmland. Such benefits obtained from agroforestry have been key interventions to reduce deforestation of the protected natural forest (Quandt et al. 2019). Scholars found that tree-based agricultural practices are an important source of house construction materials by providing the required timber product for the local community (Anwar et al. 2017; Nyong et al. 2019). They produce commercial tree products, thereby diversifying production systems and improving livelihood resilience to climate change (Dawson et al. 2014).

Research revealed that farmers adaptive capacity to climate change is enhanced by household income, trees in farmland, and other factors (Awazi et al. 2022b). Scholars found that agroforestry diversifies the income of farmers thereby reducing farm risks coming from different reasons (Roshetko et al. 2013), such as climate change (Awazi et al. 2022a). Similarly, both farmers' responses and our Pearson's correlation test affirmed the importance of on-farm trees in enhancing crop productivity and household income. Similar findings indicating that there is a positive relationship between food security and agroforestry-based farming were found in southwestern Ethiopia (Kebebew and Urgessa 2011). In Cameroon and Pakistan, there was a positive relationship between climate change adaptation and practicing agroforestry; affirming the significance of agroforestry for resilience (Zada et al. 2022; Awazi et al. 2022b).

On-farm trees contributed as a source of income to the local community, which improved the livelihood resilience of farmers to climate and other shocks. Approximately one-third of a household's income comes from trees on farmland; from a source which is less affected by climate hazards like drought. Despite that, a significant ($p < 0.05$) mean variation of income from trees in farmland between agroecologies was noted. This could be due to farmers' level of awareness about the benefits of agroforestry. A similar study in Malawi indicated that agroforestry increased the income of farmers by 51.7% and crop production by 33.3% (Ndalama et al. 2015). Research in northwestern Ethiopia also presented that home-garden agroforestry significantly increased farmers' cash income more than non-tree-based farmland (Linger 2014). This enhances farmland ecosystem resilience of farming communities (Yang et al. 2023). Many agreed that agroforestry improved the income and food security of farmers thereby enhancing livelihood resilience to climate and other shocks (Kebebew and Urgessa 2011; Rahman et al. 2012; Jamnadass et al. 2013; Basu 2014; Linger 2014; Mbow et al. 2014; Nyong et al. 2019; Quandt et al. 2019).

Agroforestry is valued for its contribution to the development of sustainable livelihoods that help smallholder farmers in Africa adapt to climate change and variability (Quandt 2020). Studies in Ghana (Kabobah et al. 2018), Mexico (Meza 2015) and Kenya (Kariuki et al. 2011) declare that farmers with higher alternative livelihood assets and diverse income have high adaptation capacity.

Our study found out that agroforestry is one of the main livelihood assets of the farmers. These trees stand asset helped small holding farmers to be better adaptive to climate change. Farmers with low livelihood capital assets are not adaptive to climate change (Awazi et al. 2020b). The more the farmers get access to such resources the more adaptable to climate change are (Kabobah et al. 2018). Hence, practicing agroforestry as a livelihood asset enabled the smallholding communities to advance their livelihood resilience (Linger 2014; Quandt et al. 2017).

Adoption of agroforestry improved community livelihoods through sales of assets such as products and crop yield and allowed farmers to have better resilience (Bishaw and Abdelkadir 2003; Linger 2014; Ndalama et al. 2015; Anwar et al. 2017; Quandt et al. 2017). Farmers practicing agroforestry scored 10% higher livelihood assets in Kenya, indicating the possibility of more resilient livelihoods (Quandt et al. 2017). Therefore, agroforestry makes a significant contribution to household resilience if it is viewed as one of the livelihood assets of farmers.

5. Conclusion

The presence of climate change is evident and is threatening the community by disturbing its livelihood negatively. In a time of such difficulties, farmers come up with adaptation strategies such as agroforestry practices. Agroforestry practices along with livestock, non-farm activities, and off-farm activities serve as one of the main adaptation options to minimize the impacts of climate change. For instance, in drought times, farmers' main source of income is found from livestock by which the source of feed for their cattle, sheep, and goat is mainly from trees on farmland. How ever, there is variation among farmers of different gender and different agroecologies, which needs attention by concerned bodies to find a way that all from various social classes and geographic areas could be benefited from practicing agroforestry.

The study revealed that indigenous agroforestry enhances livelihood resilience by providing various benefits, boosting livestock production, improving crop production, and increasing household income. It serves as one of the main livelihood assets and diversifies income of farmers including in time of climate shock. Due to the fact that trees are less vulnerable to climate shock than crops, on farm trees prominently contribute in providing fodder, food and timber products in drought times. This helps small holder farmers to diversify income and enhance livelihood resilience in the face of climate change. However, there was variation of obtaining such benefits among famers of different agroecologies. This could give insight to researchers and practitioners of agroforestry on how to maximize the role of agroforestry practices for climate change adaptation and livelihood resilience. Hence, the study indicates that indigenous agroforestry significantly diversifies the income and livelihood of farmers in the face of climate change directly and indirectly.

This study recommends that responsible bodies need to put their effort into upscaling and modernizing agroforestry practices in the study areas.

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Appendix 1. Socioeconomic characteristics of sampled households.

Variables		Highland ($N = 65$)	Midland ($N = 64$)	Lowland ($N = 68$)	Overall ($N = 197$)
Gender	Male (%)	66.2	56.3	83.8	69
	Female (%)	33.8	43.8	16.2	31
Marital status	Married (%)	78.1	90.6	89.7	86.2
	Otherwise (%)	21.9	9.4	10.3	13.8
Education level	Illiterate (%)	49.2	57.8	39.4	48.7
	Elementary (%)	35.4	37.5	53	42.1
	Secondary and above (%)	15.4	4.7	7.6	9.2
Wealth	Poor (%)	24.6	34.4	27.9	28.9
	Medium (%)	64.6	62.5	61.8	62.9
	Rich (%)	10.8	3.1	10.3	8.1
Age	Mean ± SD	50 ± 13	49 ± 13	47 ± 14	48 ± 13
Family size	Mean ± SD	6 ± 2	6 ± 2	6 ± 2	6 ± 2