

# COMPARATIVE ANALYSIS OF FRUIT TREE-BASED AGROFORESTRY AND MONOCULTURE IN TACKLING CLIMATE CHANGE CHALLENGES: EVIDENCE FROM SOFI DISTRICT, ETHIOPIA

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## Abstract

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The effects of climate change have hit the agriculture sector in Africa hard. Making adjustments to adapt to the changing environment is critical for countries like Ethiopia, whose primary source of income is subsistence agriculture, which is heavily reliant on rainfall. As a result, establishing context-specific adaptation approaches is crucial for reducing the adverse effects of climate change. This study was conducted at Sofi district, Harari Regional State, Ethiopia, to compare the contribution of fruit tree-based agroforestry and monoculture in tackling climate change challenges. To choose two kebeles and 102 household heads, multistage random sampling was used. Soil and biomass measurements were used to collect soil samples and biomass samples. According to the findings of the study, there are significant differences in how agroforestry and monoculture smallholder farmers deal with climate change challenges in terms of livelihood strategies, with agroforestry smallholders being more resilient. Carbon stock accumulation was estimated to be 453.32 mg ha<sup>-1</sup> in agroforestry and 124.7 mg ha<sup>-1</sup> in monoculture, where no trees were found on monoculture land. The findings of the study demonstrated that carbon stock accumulation was statistically significant between the mean of soil organic carbon agroforestry land use. Agroforestry systems, in general, contribute significantly more to smallholder livelihoods, as well as the socioeconomic system, in the face of climate change concerns. Incorporating smallholders into an agroforestry system for long-term livelihood sustainability requires support in the form of resources, training, and research. In the face of climate change threats, local, regional, and national governments, as well as financial institutions and other agricultural credit providers, must support smallholders.

**Key words:** land use, agroforestry, smallholders' livelihoods, climate change, adaptation, mitigation.

## Introduction

Climate is an important factor in agricultural productivity. The agricultural sector both contributes to climate change and is being affected by climate change. The agricultural sector now accounts for 16–27% of global greenhouse gas emissions and is a major cause of freshwater pollution, soil degradation, and loss of biodiversity (Khan et al., 2014). The global food system falls far short of achieving global goals for both health and the environment. In the 21st century, the most critical obstacle for agriculture is the need to feed increasing numbers of people – most of them in developing countries – while at the same time preserving the local and global environment in the face of limited land and water resources and increasing pressures associated with socioeconomic development and climate change (Mbow et al., 2014). Rural farmers in sub-Saharan Africa are more likely to be affected by

climate change owing to the combination of poverty, a lack of infrastructure and technological progress, and a heavy reliance on rain-fed agriculture (Lipper et al., 2014). More than 95% of agricultural production in sub-Saharan Africa is rain fed (Simelton et al., 2013).

Climate projections indicate that Africa will be subjected to substantial climate shifts (Adebisi-Adelani, Oyesola, 2014). Furthermore, many communities can no longer easily access natural stands of fruits, nuts, and other edible non-timber forest products (NTFPs) that they once collected to supplement their diets, due to continued deforestation, which is currently estimated to be 3.4 million ha per year for Africa as a whole (Thornton, 2010). In Ethiopia, deforestation accelerated soil erosion, and land degradation is a serious problem. There is a scarcity of precise data on the rate of deforestation and the area of previous forest cover in Ethiopia. In 2010, Ethiopia had 12.4 million hacter of tree cover, extending over 11% of its land area. In 2021, it lost 19.8 kha of

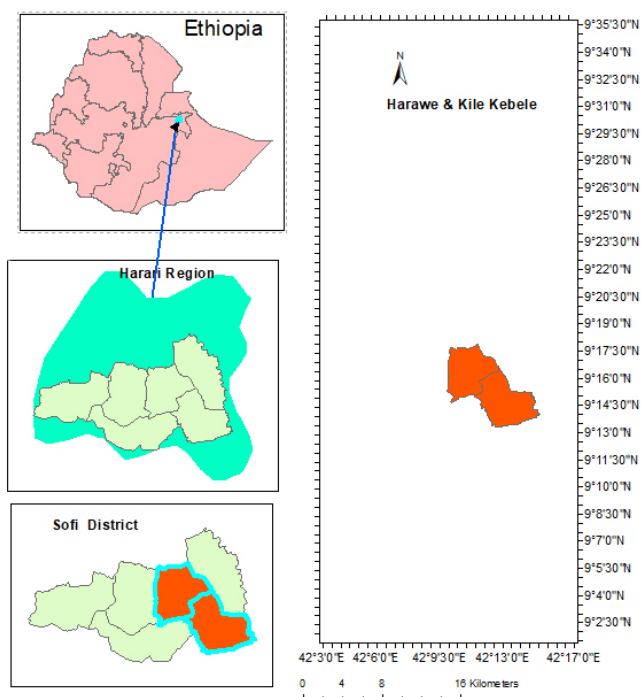


**Fig. 1.** Location map of the study area in Sofi district.

tree cover, equivalent to 9.33 Mt of CO<sub>2</sub> emissions (<https://www.globalforestwatch.org/>).

Consequently, rural communities have returned to using natural resources as a source of income, albeit in an unsustainable manner (Deressa et al., 2009). Since agricultural output is still the primary source of income for most rural people, adapting the agricultural sector to the negative consequences of climate change will be critical in protecting the poor's livelihoods and ensuring food security.

To ensure food security, there is a greater need for more efficient, climate-resistant agricultural production systems. Unfortunately, in many instances, smallholder farmers who depend on agriculture as their primary source of livelihood are among the most insecure and least able to respond to climate change (Pachauri et al., 2014). The contributions of agroforestry practices to the livelihoods of farmers are determined by local biophysical and socioeconomic factors and need to be examined from their perspective (Dumont et al., 2017).

Agroforestry potential relies on its contribution toward strengthening of the five pillars of food and nutrition security (FNS): availability, access, utilization, stability, and sovereignty. Examples in the local contexts are as follows: first, the presence of perennial staple food species in the system, like *Ensete ventricosum*, *Musa* spp., *Moringa stenopetala*, or *Manihot* esculenta, which ensure the availability of food (Sida, 2018); second, the existence of species that provide cash to farming households which directly boosts their access to market-based foods, such as *Coffea arabica* or *Theobroma cacao* (Dawson et al., 2013); third, The diversity of species offering limited nutrients, such as fruits, leaves, nuts, and the use of cooking fuel, expands the range of dimensions in culinary practices. (Dawson et al., 2013); fourth,

contributing agroforestry to food access, these species tend to become the primary source of income for farmers' livelihoods in cash crop-dominated areas, which are ultimately used to buy food from markets that sustain farmers' livelihoods (Munyua, Wagara, 2015); and lastly, increased resilience and reduced vulnerability of the household to the social and ecological character (Mbow et al., 2014). By making more effective use of water, improving the micro-climate, raising soil productivity, and improving farm productivity and diversifying their health, nutrition, and increasing the farm income while simultaneously sequestering carbon, agroforestry systems boost the resilience of smallholder farmers (Torquebiau, 2000).

The majority of agroforestry research findings in Ethiopia focus primarily on the structure and diversity of species and the role of agroforestry in the food and nutrition system (Elbakidze et al., 2017). No wide and systematic studies have attempted to understand the role of this land-use activity in providing livelihood assets/capitals and the challenges of its ability to reduce vulnerability and preserve sustainability for rural smallholders while potentially sequestering carbon for rising biomass.

Due to unpredictable climate change factors such as long droughts and flood severity, in the Harari region, crops experience frequent total yield drops, putting smallholder farmers at risk of food insecurity. Sofi, the district selected for this study, has encountered the aforementioned problems. Therefore, it is very important to formulate adaptation strategies that can maximize productivity and resilience and minimize the costs that would lead to sustainable agriculture development. Thus, the study is aimed to justify the significance of agroforestry systems to address the climate challenges, compared to monocultures.

Therefore, the livelihood strategies of farmers practicing fruit tree-based agroforestry and monoculture under changing climate conditions in the Sofi district of Harari Regional State were compared.

## Material and methods

### Description of the study area

#### Geographic location

This research was conducted in Sofi district of Harari Regional State, which is one of the upstream micro-watersheds of the Wabi Shebelle river basin (HPRS, 2011). Sofi district is located between 090 21' 0" N to 090 9' 30" N and 420 11' 0" E to 420 15' 0" E, with an elevation range of 800–2920 m above sea level (m.a.s.l.). Sofi lies in the south-western part of Harari Regional State in the southern edge of the south-eastern plateau dividing the Great Rift Valley from the plains of the Ogaden lowlands (HPRS, 2011) (Fig. 1).

#### Climate

The average annual temperature ranges from 10 °C in highlands to 26 °C in lowlands. The mean annual maximum temperature of the area is 22 °C in highlands and 28 °C in lowlands. In Sofi district, the rainfall ranges from 850 to 870 mm and is bimodal with peaks in April and August (CSA, 2013-2014).

## Geology

According to the geological map of Ethiopia, first published in 1973 and edited in 1996 at a scale of 1:2,000,000, the geology of Harari region is dominantly covered by the Adigrat formation constituted by sandstones and the Hamanlei formation that contains Oxfordian limestone and shale formed during the early Triassic to middle Jurassic periods (Hadgu et al., 2014). The Harari highlands, on the other hand, appear to be built on the crystalline bedrock of the prehistoric Gondwana continent, which was later broken, according to Mohr (1964). The geomorphology of the site is defined by a gently sloping landform at the western face of Abubeker hill draining to the easterly direction. The site relatively gently slopes to the north and is covered with mango trees and shrubs (Bezu et al., 2015).

## Soil

The major soil types of the Harari region include nitisols, luvisols, arnosols, and aerosols. Nitisols (distinguished by their shiny pad surface) occupy 2792.5 ha and luvisols (soils which have cation exchange capacity [CEC] equal to or greater than 24 mol clay) occupy 2440 ha. Regosols (medium and fine textured) occupy 6017.5 ha, and aerosols (coarse textured with weak pedogenic characteristics in the B-horizon) occupy 4575 ha (HPRS, 2011). The major soil types which occur in Sofi are the limestone plateau with limestone hills to the east, vertisols on a plateau, and lithosols on hills. The site is covered with a reddish clay residual soil of thickness ranging from 2 to 4 m above the weathered limestone and with gypsum–marl interlaying (HPRS, 2011).

## Land use

Agriculture is a fundamental practice that provides adequate food to the needy Harari. The largest land-use type in the region is cultivated land, with an area of 19,985 ha, covering 64.5% of the total land area in Sofi. This indicates that agriculture is the primary land-use activity in the region and it is the main source of livelihood for the local community. The second largest land-use type in the region is forest, shrub, and bush land, covering an area of 9155 ha, which is 18.1% of the total land area in Sofi. The percentage of this type of land use in the region is relatively low compared to the cultivated land, indicating that the area may have experienced deforestation due to agricultural expansion or other human activities. The third land use type in the region consists of other land uses, covering an area of 8810 ha, which is 17.4% of the total land

area. This land-use type may include residential areas, commercial activities, and other land-use activities (Table 1).

Most small-scale farmers in the Harari Region grow grain crops such as cereals, pulses, and oilseeds. Despite this, cereals and oilseeds are the primary food crops cultivated in the region, with only a small portion of land allocated to the cultivation of pulses, fruits, and vegetables, as stated by Central Statistical Agency (2013–2014). In terms of agroforestry practices, the Harari Region's fruit tree, root crop, and stimulant crop cultivation mainly consists of khat (*Catha edulis*) and coffee (*C. arabica*), alongside vegetables (such as potatoes, tomatoes, and onions) and root crops (CSA, 2013–2014).

## Sampling design and research design

This research employed a combination of qualitative and quantitative data from primary and secondary sources. The primary data was obtained from selected households, as well as soil and tree biomass samples. To gather primary socioeconomic data, researcher's utilized structured questionnaires and conducted in-depth interviews. The study focused on comparing carbon stock, income generation sources, and resilience to climate variability effects between two land uses.

## Data collection for livelihood aspect

Two kebeles (the smallest administrative units in the administrative structure of the country) within cluster villages (villages predominantly practicing fruit tree–based agroforestry) were selected purposively based on the intensity and potential of fruit tree–based agroforestry practices in the areas and adjacent monoculture. A list of household members of the kebele was taken from kebele administration (KA). Then, key informants (KIs) was used to categorize households into fruit tree–based agroforestry practitioners and monoculture practitioners.

**Table 1.** Land use types in Sofi the Harari region.

| Land use                     | Area in ha     | In percent |
|------------------------------|----------------|------------|
| Cultivated land              | 19,985         | 64.5       |
| Forest, shrub, and bush land | 9155           | 18.1       |
| Others                       | 8810           | 17.4       |
| <b>Total</b>                 | <b>50702.5</b> | <b>100</b> |

Note: Harari Bureau of Agriculture and Rural Development, 2009.

**Table 2.** Total and sampled households in the study sites.

| Kebele                      | THHs | AFHHs |        |            | MOHHs |        |            |
|-----------------------------|------|-------|--------|------------|-------|--------|------------|
|                             |      | Poor  | Medium | Better-off | Poor  | Medium | Better-off |
| From Kile (3 villages)      | 326  | 13    | 54     | 93         | 53    | 78     | 35         |
| From Harawe(3 villages)     | 354  | 17    | 57     | 96         | 84    | 71     | 29         |
| Total                       | 680  | 30    | 111    | 189        | 137   | 149    | 64         |
| Selected 15% of respondents |      | 5     | 17     | 28         | 20    | 22     | 10         |
| Total                       |      |       |        | 50         |       |        | 50         |

Notes: THHs – total household; AFHHs – agroforestry household; MOHHs – monoculture household.

Snowball approaches were used to select KIs (Noy, 2008) to generate 10 KIs from the two kebeles. For each category, KI further classified the households into poor, medium, and better-off wealthy classes. Then, KIs were given a wealth ranking based on local standard of wealth classification (rich, medium, poor) for smallholders. Each stratum was separated into farmers practicing fruit tree-based agroforestry and monoculture. A proportional sample of 15% of the total households (102 households) from each wealth class was chosen at random for qualitative data collection, with 52 monoculture smallholders and 50 fruit tree-based agroforestry smallholders participating (Table 2). Structured and semi-structured methods were employed to create a questionnaire focused on annual incomes and the production of products and services resulting from the practices. Eventually, focus group discussion (FGD) and KI interviews were undertaken and the data was triangulated.

### *Analysis for livelihood strategies*

Structured interviews were conducted orally using a list of pre-determined questions to be answered (Bryman, 2006). The interview covered the personal histories of individual household families, respondent-owned resources, major household expenditures, and main source of annual incomes. KI interviews were conducted to triangulate with smallholders' views on fruit tree-based agroforestry and monoculture agricultural practices for climate adaptations. Furthermore, six FGDs were held, each of which was led by a skilled moderator with five to eight group members who were randomly selected from KA, elders, women, different age groups, smallholders, and development agents. The questions about farmers' livelihood assets identified during the household interview and KI interviews were brought up to initiate the discussion.

### *Data collection for carbon determination*

In total, nine plots from agroforestry were randomly placed from three selected villages, yielding a total of 27 soil organic carbon (SOC) composite samples. A similar approach was followed for monoculture from three selected villages, each with three random plots, totaling nine plots for a total of 27 SOC composite samples. Fieldwork was conducted over a period spanning February 2020 to May 2021, involving two rounds of data collection, including a reconnaissance survey. Soil samples were collected from plots of area  $20 \times 20$  m, and the collection was made from three depths for each (land-use system): 0–20, 20–40, and 40–60 cm. This was done by the following procedure: soil samples were taken from three horizontal distances, that is, close under the canopy of tree, at the margin of the canopy from the trunk, and at an open area (outside the crown area), and from four directions (north, south, east, and west) around a randomly selected tree in a plot and combined to acquire a composite sample for agroforestry.

For monoculture farm depths, soil samples were taken from 0–20, 20–40, and 40–60 cm around the field at the center and corner of the plot of area  $20 \times 20$  m along the transect line direction adjacent to fruit tree agroforestry farms to acquire a composite sample for each depth. One hundred and eight composite soil samples were collected from two land-use systems and placed

in appropriately labeled sample bags. These samples were then transported to the Soil Chemistry Laboratory at Haramaya University for analysis of selected physical, chemical, and biological properties using standard procedures. The soil samples were dried at room temperature and passed through a 2-mm sieve screen before analysis. The SOC content was determined using the chromate wet oxidation method (Walkey-Black, 1934), while soil bulk density (BD) was measured using a pycnometer.

To estimate BD, three individual soil samples of approximately  $300 \text{ cm}^3$ , one each from three depths (0–20, 20–40, and 40–60 cm), were collected with the help of a standardized  $500\text{-cm}^3$  soil core sampler. This process involved obtaining soil samples in a sequential manner. Initially, a sample was collected from the top 20 cm, then shifted horizontally by 5 cm to gather soil from the 20–40 cm depth. This horizontal movement was repeated to minimize soil disruption. Finally, samples were collected from the 40–60 cm depth. In total, three layers of soil samples were gathered from each plot to analyze organic carbon concentrations, as described by. (Al-Shammari et al., 2018).

A plot of size  $20 \times 20$  m was specified in each sampled farm to inventory both the agroforestry and monoculture agriculture study areas following Osuri et al. (2016). All woody species with a diameter at breast height (DBH) greater than 2.5 cm and of height greater than 1.3 m were measured and recorded, including fruit trees, non-fruit trees, and shrub trees at a height of greater than 40 cm (Negash et al., 2013).

For this study, the aboveground biomass (AGB) was estimated by using generalized allometric equations developed for a similar biophysical environment (Chave, 2013). The equation originally formulated by Kuyah et al. (2012), designed for calculating carbon stocks in woody species, including fruit trees within the agroforestry system, was adjusted by applying a 49% conversion factor.

The accumulation of belowground biomass (BGB) is closely tied to the changes in aboveground biomass, and any disruption to the topsoil can result in a reduction in BGB. Given that BGB can represent a substantial portion of the total biomass, ranging from 20% to 26%, it is typically estimated using a global average value of 26% of the aboveground biomass, as suggested by (Cairns et al., 1997), while applying a 49% conversion factor for carbon stock, as recommended by (Negash et al., 2013).

### *Data analysis*

#### *Livelihood strategies*

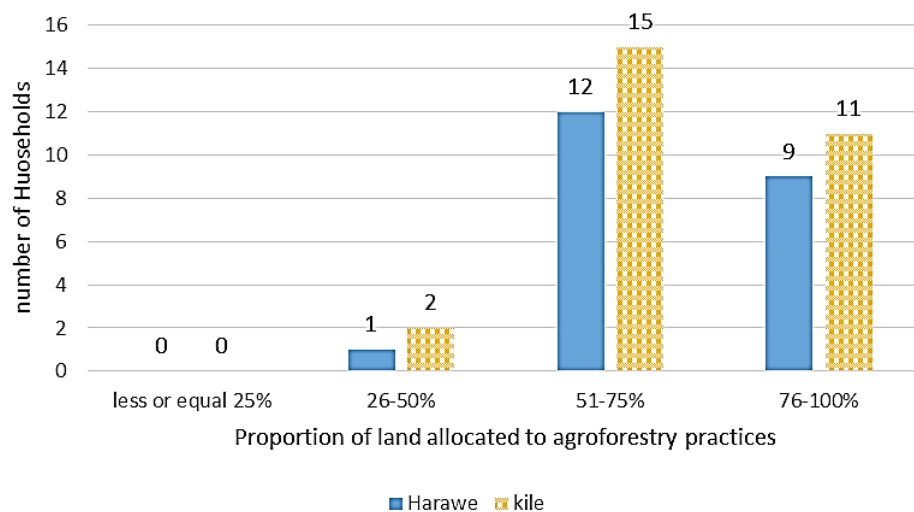
For quantitative survey data, Statistical Package for the Social Sciences (SPSS) version 20 software program was used for data analysis, while R software and Microsoft Excel were used for graphical comparisons of livelihood-coping strategies of fruit tree-based agroforestry and monoculture practicing smallholders while facing climate change challenges.

#### *Carbon inventory*

An independent *t*-test and Chi-square were used in statistical analysis to examine the mean statistical differences between the two systems (agroforestry system and monoculture).

**Table 3.** Demographic characteristics.

| Demographic characteristics        |         |         | Classes | Frequency      |         |
|------------------------------------|---------|---------|---------|----------------|---------|
| Gender of respondent               |         |         | Male    | 84             |         |
|                                    |         |         | Female  | 16             |         |
| education status of the respondent |         |         |         |                |         |
| Cannot read and write              |         |         |         | 32             |         |
| Can write and read                 |         |         |         | 35             |         |
| First cycle (grade 1-4)            |         |         |         | 26             |         |
| High school (grade 9-12)           |         |         |         | 5              |         |
| Any special training in Forestry   |         |         |         | 4              |         |
|                                    | Minimum | Maximum | Mean    | Std. Deviation |         |
| Age of respondent                  | 102     | 27.00   | 60.00   | 39.9608        | 8.53638 |
| HH size of the respondent          | 102     | 2.00    | 9.00    | 5.4314         | 1.97765 |
| Valid N (listwise)                 |         |         | 102     |                |         |

**Fig. 2.** Overall number of respondent's practicing agroforestry and proportion of their land allocated to agroforestry.

## Results and discussion

### Demographic characteristics of Sofi district

The majority (84.4%) of households which participated in the survey were headed by males, with an average family size of approximately five individuals, ranging from four to six. The respondents' average age was 40 years, and age was found to be the determining factor for selecting suitable land-use activities. In terms of education, the majority of respondents (34.3%) were able to read and write, while 25.5% had completed the first cycle of schooling (grades 1–8), 4.9% had finished secondary school (grades 9–12), and 3.9% had received specialized training in forestry (Table 3). The average landholding size for households in the study area was between 0.5 and 1 ha. In total, out of the 50 respondents who practiced agroforestry, 84% of households allocated more than half of their landholdings to various agroforestry practices (Fig. 2).

### Household livelihood strategies at Sofi district

#### Source of income and livelihood strategies at Sofi district

In Figure 3, it is evident that all 102 respondents identified crops as a crucial means of livelihood for both agroforestry and monoculture. However, for households of agroforestry practitioners, fruit, cattle, and vegetables were the most prevalent sources of income, with forest resources and vegetables being the most significant income sources for agroforestry-practicing smallholders in the area. In contrast, monoculture farmers in Sofi use crops for both income and consumption, while agroforestry farmers primarily use crops for consumption purposes. In the Sofi district of *Mangifera indica* L., *Carica papaya* L., and *Casimiroa edulis* L., are the primary tree and shrub species that thrive and are actively tended to by the local communities (Appendix 1).

In a study carried out in Malawi by Kamanga et al. (2009), it was discovered that impoverished households generated less

income from forests compared to other demographic groups. The income generated from forests, including both cash and subsistence income, primarily stemmed from fuelwood and accounted for a significant share, ranging from 66.4 to 77.9%. Meanwhile, other studies, such as Tesfaye et al. (2011), revealed that forest resource income is a significant source of cash income for low-income individuals, enabling them to diversify their livelihoods. In the Sofi district, most monoculture small households experience food insecurity. This is in line with the findings of Duguma (2013), who indicated that the economic benefits of agroforestry accrue to smallholders through improved farm profitability and higher and more diversified income flows from the selling of agroforestry goods and services. The study also confirmed that crop production and private business are the two most valuable household income sources, as found by Tesfaye et al. (2011). However, the livestock-based strategy does not correspond to higher income or consumption, contrary to the findings of Dercon and Krishnan (1996).

### Monthly availability of ripe fruit trees, food security, and nutrition in Sofi district

Agroforestry practitioners benefit from the fact that different fruits ripen at various times of the year, enabling them to harvest throughout the year. As a result, farmers always have at least one type of fruit tree available for market and consumption each month, and the peak harvest times for each fruit vary by tree. For example, respondents reported harvesting *Mangifera indica* trees (mango) twice per season. According to Maroyi (2009), agrofor-

estry inherently provides one ripe product per month, which can singlehandedly fulfill the food security pillars. Smallholders in Sofi district who practiced agroforestry provided evidence of monthly availability of ripe fruit trees and crops for harvest during questioning and focus groups. Furthermore, Nair (2007) observed that agroforestry offers continuous food production throughout the year and an abundance of crops available for harvest for families almost all year-round, as shown in Figure 4. Therefore, agroforestry has the potential to buffer household food supplies during times of instability such as drought. In addition, Elbakidze et al. (2017) stated that agroforestry's ability to provide harvests at various times of the year can reduce household income variability.

### Food production at Sofi district

As shown in Table 4, the majority of farmers who practice agroforestry (88%) are able to provide their families with food for more than 6 months, while only a small percentage (19.19%) of smallholders who practice monoculture can do the same. Farmers who practiced agroforestry reported that their family's food security was enhanced by the income generated from the sale of agroforestry products, vegetables, and animal products. On the other hand, the majority of smallholders who practiced monoculture (80.72%) expressed concerns about increasing food insecurity as they were only able to feed their families for less than 6 months. A study used the Chi-square test to examine the relationship between agroforestry and monoculture and having enough food year-round. The results indicated that there is a connection between land use and food sufficiency, with agroforestry being significantly associated with the ability to have sufficient food throughout the year (Table 5). Moreover, Koohafkan et al. (2012) underscored the perception that agroforestry is frequently regarded as a cost-efficient approach to enhancing agricultural practices sustainably and bolstering food security.

### Mean income differences in smallholders of Sofi district with the respective practices

As per sources, adopting fruit tree-based agroforestry can lead to higher average revenues for farmers compared to monoculture in Sofi district. Based on responses from 50 respondents, smallholders practicing agroforestry earned an average of 11,529.3920 birr net earnings per year, while as per the responses of 52 respondents, monoculture farmers earned an average of 4566.38 birr net income per year (Table 6). An independent *t*-test was conducted to assess the mean difference in net income

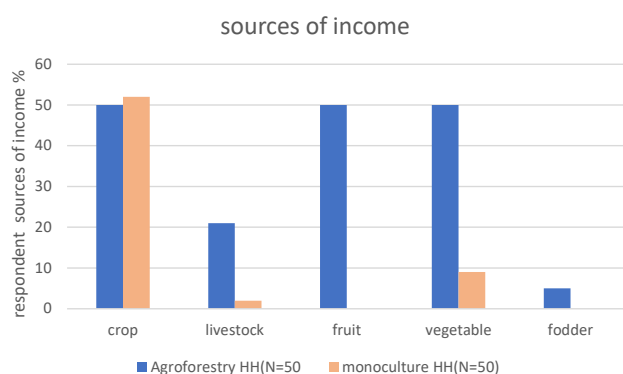


Fig. 3. Sources of incomes for the smallholder farmers in Sofi district. Note: HH - household.

| Fruit trees                | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII |
|----------------------------|---|----|-----|----|---|----|-----|------|----|---|----|-----|
| <i>Mangifera indica</i> L. |   |    |     |    |   |    |     |      |    |   |    |     |
| <i>Carioca papaya</i> L.   |   |    |     |    |   |    |     |      |    |   |    |     |
| <i>Citrus lemon</i> L.     |   |    |     |    |   |    |     |      |    |   |    |     |
| <i>Psidium guajava</i> L.  |   |    |     |    |   |    |     |      |    |   |    |     |
| <i>Casimiroa edulis</i> L. |   |    |     |    |   |    |     |      |    |   |    |     |

Fig. 4. Monthly availability of ripe fruit in Sofi district over year.

between smallholders practicing agroforestry and monoculture. All reported incomes comprise the annual cash and subsistence activities. The study found that the mean net earnings of smallholders practicing agroforestry and monoculture were statistically significant, indicating that agroforestry-practicing smallholders have significantly higher average net income compared to those practicing monoculture (Table 7).

Furthermore, incorporating trees on farms can enhance the diversification and range of livelihood sets for smallholder farming households in Sofi (Appendix 2). Studies conducted by Akinnifesi et al. (2008) and Mithöfer and Waibel (2003) focused on the financial analysis of fodder crops, rotational woodlots, and fruit trees, revealing that these agroforestry businesses were profitable and provided income at a crucial time of year, which is beneficial to households that do not receive remittances.

### *Overall contribution of agroforestry and monoculture to smallholder farmers' livelihoods*

#### Contribution of agroforestry for enhancing natural capital

Natural capital includes accessibility and quality of natural resources (Neelakantan et al., 2020). Conserving these resources from overexploitation is necessary to guarantee that the natural capital continues to provide ecosystem services that sustain livelihoods. Major fruit trees' diversity and density have increased significantly over time according to KIs. The findings show that the practice of agroforestry for various purposes on private land has increased significantly over time. Keating et al. (2010) found that efficient agroforestry systems can fully utilize renewable resources, minimize local emissions and pollution, conserve biodiversity for ecological stability, ensure predictable production, and adapt swiftly to changes in social, economic, and environmental conditions.

#### Contribution of agroforestry in improving social and financial capital

Teamwork led to the creation of rules and procedures that boosted social capital among Sofi's agroforestry smallholders. In focus group discussions (FGDs), farmers mentioned that due to declining productivity and the absence of wage-earning opportunities in their villages, many family members who practiced monoculture crops left for nearby cities such as Harar, Dire Dawa, and Jigjiga. These results align with those reported by Dix et al. (1999). Many agroforestry systems provide more than two livelihood assets at the same time, like the indica tree, which serves as a multipurpose tree that provides fruit, shade, organic matter for soil modification, and livestock feed. Furthermore, Sofi district smallholder farmers who practice agroforestry earn more money by selling a wide range of fruits and vegetables than the smallholder farmers who practice monoculture (Appendix 3). The majority of agroforestry households in the study area used their income from fruit, vegetable, and livestock product sales to improve other livelihood capital assets. For example, income from fruit, vegetable, and livestock products was used to purchase production inputs such as fertilizer, pesticide and herbicide, and fruit tree seedlings from nurseries, which improve human capital by which school fees can be paid and healthy food options for

**Table 4.** Sufficient food to feed all their members in Sofi.

| Month  | Fruit tree based AF percent | Monoculture percent |
|--------|-----------------------------|---------------------|
| Two    | -                           | 1.9                 |
| Three  |                             | 17.3                |
| Four   | 2                           | 21.15               |
| Five   | 2                           | 9.61                |
| Six    | 8                           | 30.76               |
| Seven  | 4                           | 1.9                 |
| Eight  | 12                          | 1.9                 |
| Nine   | 4                           | -                   |
| Ten    | 10                          | 7.69                |
| Eleven | 18                          | 3.85                |
| Twelve | 40                          | 3.85                |
| Total  | 100                         | 100                 |

**Table 5.** Test statistics for having sufficient food/year.

| Chi-Square Tests             |         |    |                       |
|------------------------------|---------|----|-----------------------|
|                              | Value   | Df | Asymp. Sig. (2-sided) |
| Pearson Chi-Square           | 56.469a | 10 | .000                  |
| Likelihood Ratio             | 69.584  | 10 | .000                  |
| Linear-by-Linear Association | 45.398  | 1  | .000                  |
| N of Valid Cases             | 102     |    |                       |

**Table 6.** Mean income comparison of the two land uses.

|                   | Practice of HH | N  | Mean (birr) | Std. dev. | Std. error mean |
|-------------------|----------------|----|-------------|-----------|-----------------|
| Av. net income HH | AF             | 50 | 11529.39    | 6747.07   | 954.18          |
|                   | MO             | 52 | 4566.38     | 3338.93   | 463.02          |

**Table 7.** Test statistics for income difference within agricultural practice.

| Independent Samples Test                |                 |       |           | average net income HH |
|-----------------------------------------|-----------------|-------|-----------|-----------------------|
|                                         |                 |       | Equal V.a | Equal v. not assumed  |
| Levene's test for equality of variances | F               |       | 3.861     |                       |
|                                         | Sig.            | .052  |           |                       |
| T-test for equality of means            |                 |       | T         | 6.565                 |
|                                         |                 |       | Df        | 100                   |
|                                         | Sig. (2-tailed) |       | .000      | .000                  |
|                                         | MD              |       | 6963.01   |                       |
|                                         | Std. E.D        |       | 1047.9    |                       |
|                                         | 95percent CI    | Lower | 4883.95   | 4848.25               |
|                                         |                 | Upper | 9042.06   | 9077.76               |

**Table 8.** BD, C percent, and SOC of different land uses at different soil depths.

|                                                       | LU                        | 0-20cm                    | 20-40 cm                    | 40-60cm                     | Overall      |
|-------------------------------------------------------|---------------------------|---------------------------|-----------------------------|-----------------------------|--------------|
| <b>BD<sub>t</sub></b>                                 | AF                        | .88±.26                   | .97±.25                     | .85±.08                     | .90±.21      |
|                                                       | MO                        | .43±.24                   | .45±.20                     | .40±.24                     | .43±.22      |
| <b>SC</b>                                             | AF                        | 1.54±.39                  | .95±.43                     | .81±.35                     | 1.10±.49     |
|                                                       | MO                        | .18±.10                   | .19±.15                     | .23±.17                     | .2057±.1     |
| <b>SOC t ha<sup>-1</sup></b>                          | AF                        | 204.16 ± 7.62             | 116.45± 4.95                | 81.69± 6.81                 | 402.32±6.46  |
|                                                       | MO                        | 33.08± 6.5                | 36.95± 8.43                 | 54.74± 5.69                 | 124.77±6.87  |
| <b>BAF<sub>LU</sub> C<sub>t</sub> ha<sup>-1</sup></b> | <b>AGB<sub>tree</sub></b> | <b>BGB<sub>tree</sub></b> | <b>AGB<sub>shrubs</sub></b> | <b>BGB<sub>shrubs</sub></b> | <b>Total</b> |
|                                                       | 81.87                     | 21.29                     | 0.78                        | 0.2                         | 104.14       |

Notes: BD<sub>total</sub> - bulk density; SC - soil carbon; SOC<sub>t</sub> - total soil organic carbon; BAF<sub>LU</sub> -Biomass Agroforestry land use; AGB - above ground biomass; BGB - below ground biomass.

**Table 9.** Carbon stock of land use of agroforestry.

| Biomass                           | generalized allometric equation                             | Author                                              |
|-----------------------------------|-------------------------------------------------------------|-----------------------------------------------------|
| <b>AGB</b>                        | $0.091 * d^{2.472}$ $R^2 = 0.95$ ; $n = 72$                 | (Kuyah et al., 2012, Chave et al., 2013 equation 1) |
| <b>BGB</b>                        | $0.26AGB$                                                   | (Mesele Negash et al., 2013).                       |
| <b>AGB<sub>shrubs</sub></b>       | $0.147 * d^2$ $R^2 = 0.80$ ; $n = 31$                       | (Kuyah et al. 2012a equation 2)                     |
| <b>BGB<sub>shrubs</sub></b>       | $0.490AGB^{0.923}$ $R^2 = 0.95$ ; $n = 72$                  | (Kuyah et al. 2012b )                               |
| <b>TAGBC</b>                      | Biomass carbon stock of tress + shrubs biomass              |                                                     |
| <b>AGC OR BGC</b>                 | $AGB \text{ or } BGB \cdot 0.5$                             | Eq. 2 (MacDicken 1997; Brown 2002)                  |
| <b>TBGB</b>                       | Biomass carbon stock of trees + shrubs biomass              |                                                     |
| <b>TBC</b>                        | $TAGBC + TBGB$                                              |                                                     |
| <b>BD (g cm<sup>-3</sup>)</b>     | $ODS (g) / \text{Volume of core sample (cm)}$               |                                                     |
| <b>SOC (Mg C ha<sup>-1</sup>)</b> | $BD (g cm^{-3}) \%C * \text{Soil depth (cm)} * 1\text{-cf}$ |                                                     |
| <b>C<sub>Total</sub></b>          | $C_{AGTB} + C_{BGB} + SOC$                                  |                                                     |

Notes: AGB - is the aboveground biomass (kg dry matter/ plant); d - Breast height diameter (cm); AGBshrub - trees is aboveground biomass for shrubs; d40 - Stem diameter (cm) of the shrubs plant at 40 cm height; BGB - is the aboveground biomass (kg dry matter/ plant); TAGBC - Total Above ground biomass carbon; TBGB - Total below ground biomass carbon; TBC - total biomass of carbon; BD - Bulk density; ODS - Oven dried soil; SOC - Soil organic carbon; cf - course fraction; C<sub>total</sub> - total carbon stock accumulated.

the family are provided. This is in line with a financial analysis by Franzel (2004), which revealed that agroforestry based on fruit trees is a more profitable land-use scheme than monoculture.

### Contribution of agroforestry for improving physical capital

Test statistics for income differences within agricultural practices in Sofi district focus on the contribution of agroforestry to physical capital improvement. Table 7 gives a comparison of the average net income of households engaged in agroforestry with those engaged in monoculture farming. An independent samples test was used to compare the two groups, with equal variance assumed and not assumed. The Levene's test for equality of variances indicated that the assumption of equal variances between the two groups was reasonable, with a significance level of 0.052. The *t*-test for equality of means showed that the average net income of households engaged in agroforestry was significantly higher than that of those engaged in monoculture farming, with a two-tailed significance level of 0.000 for both equal variances assumed and not assumed. Households en-

gaged in agroforestry in Sofi district have significantly higher average net income compared to those engaged in monoculture farming. This suggests that agroforestry can contribute to improving physical capital, specifically by reducing fertilizer costs and addressing soil erosion and fertility issues. Trees on farms could offset direct climatic impacts, such as erosion prevention, or minimize grain production losses during dry years (Kimaro et al., 2011). Fixing the problem of food and nutritional security requires a variety of interconnected agricultural approaches (Martinez et al., 2021).

### Agroforestry and monoculture carbon stock estimation

#### Carbon stock estimation for agroforestry and monoculture

The results of this study show that in agroforestry land use, SOC dropped as soil depth increased (Table 8). The SOC content percent was found to be higher in the upper layers, which could be due to higher soil organic matter content and lesser parent material effect. In a similar investigation conducted in Nepal by

Lawrence et al. (2019) for four land uses, there was a gradual increase in BD with increasing soil depth.

The topsoil layer had a lower BD than the other soil depths, indicating that the soil was better for plant growth. It suggests that land-use practices have had a major impact on SOC stock overall. With increasing soil depths, SOC showed a decreasing trend in agroforestry, while it showed an increasing trend in monoculture. Accordingly SOC stocks for the 0–60 cm layer ranged between 81.69 and 204.16 Mg C ha<sup>-1</sup> with the 0–20 cm layer in agroforestry totally layer 402.32 Mg C ha<sup>-1</sup> whereas in monoculture ranging 33.08 and 54.74 Mg C ha<sup>-1</sup> averaging layer 124.77 Mg C ha<sup>-1</sup> (Table 8). In summary, carbon stock accumulation was significantly greater in agroforestry systems, totaling (453.32 Mg C ha<sup>-1</sup>) with contributions from soil organic carbon (SOC) at (402.32 Mg C ha<sup>-1</sup>) and aboveground tree and shrub biomass as well as belowground biomass (BGB) at (104.1 Mg C ha<sup>-1</sup>). In contrast, monoculture soil had a lower SOC content of (124.77 Mg C ha<sup>-1</sup>) as indicated in (Table 8).

The topsoil layer had a lower BD than the other soil depths, indicating that the soil was better for plant growth. It suggests that land-use practices have had a major impact on SOC stock overall. With increasing soil depths, agroforestry showed a decreasing trend in SOC, while monoculture showed an increase. This could be due to the greater SOC content percent in the top layer of soil. Carbon accumulation in agroforestry was significantly higher than in monoculture (Table 9). This study showed that agroforestry is an interesting option for sequestering carbon on agricultural soils because it absorbs significant amounts of carbon while keeping the majority of the land in agricultural use. At the same time, it can help smallholders with a range of other issues, such as economic diversification, biodiversity, and water quality.

This is consistent with the findings of Montagnini and Nair (2004), which revealed that agroforestry systems differ from other land-use systems in their ability to accumulate higher concentrations of carbon (C) in AGB, BGB, and soil. Nair et al. (2009) compared the soil carbon sequestration in agroforestry system to other land-use systems and found a general trend of rising SOC, an indication of soil carbon sequestration, in agroforestry, and ranked the land-use systems in terms of their SOC content in the following order: forests and agroforestry greater than tree plantations greater than arable crops. The study assessed natural forest, coffee agroforestry, grazing land, and cropland in the Hades sub-watershed of eastern Ethiopia, using samples from four carbon pools: aboveground, belowground, litter, and soil. SOC levels were found to be high in natural and coffee-based agroforestry (Toru, Kibret, 2019). An independent *t*-test was conducted to see if the mean difference found between the carbon stock accumulated by agroforestry and monoculture was statistically significantly different or not. The result indicated that there were statistically significant differences between the mean of SOC.

## Conclusion

This study conducted in Sofi district, Harari Regional State, Ethiopia, highlights the significant impact of climate change on agriculture, especially on subsistence agriculture heavily reliant on rainfall. The study compared the contribution of fruit tree-based agroforestry and monoculture in tackling climate change

challenges and found that agroforestry smallholders were more resilient and contributed significantly more to smallholder livelihoods as well as the socioeconomic system. The study also found that carbon stock accumulation was statistically significant between the mean of SOC agroforestry land use. Incorporating smallholders into an agroforestry system for long-term livelihood sustainability requires support in the form of resources, training, and research. Therefore, the study recommends that local, regional, and national governments, as well as financial institutions and other agricultural credit providers, must support smallholders to mitigate the adverse effects of climate change.

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**Appendix 1.** Major Tree, shrubs, the crop grew and managed by local communities in the study site.

| Botanical Name                               | Local name   | kile | harawe | No of individuals species |
|----------------------------------------------|--------------|------|--------|---------------------------|
| <i>Mangifera indica</i> L.                   | Mango        | ✓    | ✓      | 173                       |
| <i>Casimiroa edulis</i> L.                   | Ambuka       | ✓    | ✓      | 45                        |
| <i>Catha edulis</i> (Vahl.) Forssk. ex Endl. | Chat         | ✓    | ✓      | -                         |
| <i>Moringa oleifera</i>                      | Shifera      | ✓    | ✓      | 37                        |
| <i>Carica papaya</i> L.                      | Papaya       | ✓    | ✓      | 112                       |
| <i>Cajanus cajan</i> (L.) Mill. sp.          | Atara looni  | ✓    | ✓      | 45                        |
| <i>Grevillea robusta</i> A. Cunn. ex. R. Br. | Grevillea    | ✓    | ✓      | 22                        |
| <i>Pennisetum purpureum</i> S.               | Nyaata arbaa | ✓    | ✓      | 32                        |
| <i>Psidium guajava</i> L.                    | Zeyitunaa    | ✓    | ✓      | -                         |

**Appendix 2.** Comparison between agroforestry and monoculture.

| Factor                     | Agroforestry  | Monoculture   |
|----------------------------|---------------|---------------|
| Carbon sequestration       | High          | Low           |
| Income generation          | Moderate-High | Moderate-High |
| Land use sustainability    | High          | Low           |
| Fruit tree diversity       | High          | Low           |
| Soil fertility improvement | High          | Low           |
| Microclimate improvement   | High          | Low           |
| Livelihood improvement     | High          | Low           |

**Appendix 3.** Major Tree, shrubs, the crop grew and managed by local communities in the study site.

|                                | practice of HH               |         |
|--------------------------------|------------------------------|---------|
| Agroforestry mean income/ year | Monoculture mean income/year |         |
| Mango and apple mango tree     | 4210.3                       | 0       |
| Papaya                         | 1459.84                      | 39.23   |
| Lemon                          | 372.24                       | 18      |
| Zayituna                       | 1056.92                      | 0       |
| Ambuka                         | 937.06                       | 16.83   |
| Potato                         | 1231.6                       | 422.81  |
| Tomato                         | 1325.42                      | 17.4646 |
| Vegetables                     | 744                          | 9.42    |
| Sorghum                        | 63.96                        | 1382.25 |
| Maize                          | 12.6                         | 1166.31 |
| Groundnut                      | 82.2                         | 1259.62 |
| Salita                         | 32.9                         |         |