https://doi.org/10.17221/151/2021-JFS

Climate resilient traditional agroforestry systems in Silite district, Southern Ethiopia

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Citation: Semere M., Cherinet A., Gebreyesus M. (2022): Climate resilient traditional agroforestry systems in Silite district, Southern Ethiopia. J. For. Sci., 68: 136–144.

Abstract: Agroforestry is recognized as one of the strategies for climate change mitigation and adaptation under the Kyoto protocol. The system has been practiced in Ethiopia for a while by smallholder farmers by incorporating crops with trees providing extensive socio-economic and environmental benefits. This unaccounted benefit of the system needs further and specific study. Thus, this study aimed to examine the resilience of three (homegardens, woodlots, and parkland) traditional agroforestry systems (TAFS) on the basis of biomass carbon accumulation and socio-economic characteristics in Silite district, Southern Ethiopia. Systematic random sampling was employed to collect social and biological data. Height and diameter at breast height (*DBH*) were measured to determine the biomass carbon stock and a questionnaire was performed for the socio-economic data. The mean differences across the system were analyzed using a post hoc test. Socioeconomic data were analyzed using descriptive statistics and the chi-square test. Climate change awareness was perceived almost by half of the respondents, thus the contribution of TAFS to climate change adaptation and mitigation was revealed socio-economically and ecologically. Carbon stock and socio-economic benefits gained from agroforestry systems consist in a great sink of carbon and food security.

Keywords: adaptation; biomass carbon stock; climate change; mitigation

Agroforestry practice is a long-standing land use practice which incorporates woody perennials, trees, crops, herbaceous plants and/or animals either on spatial or on rotational basis (Doyle et al. 1986). Agroforestry is used in greenhouse gas (GHG) mitigation and adaptation strategies. The use of agroforestry should not create gap that would result in the conversion of forest land into agricultural land. Additionally, in agroforestry agricultural land use will remain the landowner's primary intent (Dixon 1995). Agroforestry can play a vital role in enhancing productivity and sustainability, and agroforestry systems are believed to have a high potential to contribute to climate change adaptation and mitigation. Integration of trees on farmlands minimizes environmental degradation and enhances productivity. Other than the economic contribution, carbon stock estimation in agroforestry systems (AFS) ensures the significance of the system for global carbon balance and enhances the potential of farmers in AFS expansion (Nair 2012).

Agroforestry (AF) is one of the most important land use systems since it has multiple advantages of mitigating and adapting to change. Smallholder farmers are the most vulnerable to the effect of climate change and variability. Environmental degradation and deforestation through the poor land use system and high demand for fuel wood are the major causes for the changing climate. Ethiopia has a good system of homegarden agroforestry as compared to other tropical African countries, especially grain-based cultivation and enset-based mixed cultivation are the major agricultural systems in Ethiopia. The latter system occurs in the southern part while the former is found in northern and northwestern parts of the country (Negash et al. 2013).

This study was carried out in Silite district in the southern part of Ethiopia, which was selected because of its popular and widely held agroforestry system application for a long period of time. The area dominantly includes woodlots, homegarden and parkland agroforestry systems. A homegarden agroforestry system provides the year round production of food and saleable products which are very common practices in the present study area. Enset- and coffee-based homegarden agroforestry systems are the most common ones. *Eucalyptus* dominated woodlot agroforestry is the most dominant system in the study area with high wood product provision for market and for domestic consumption as a source of fuel wood and construction material. The parkland agroforestry system is defined as areas where scattered multipurpose trees occur on farmlands as a result of farmer selection and protection. *Federbiya albida* is the most common tree species that is incorporated into parkland AFS in this study site. The species mostly takes over an inverted phenology with physiological dormancy and sheds its nitrogen rich leaves during the early rainy season (Nair 1989; ICRAF 2000). Furthermore, the shed leaves improve the soil fertility (Dangasuk et al. 2006). Thus, this study was aimed to evaluate the unaccounted contribution of agroforestry system by assessing the carbon stock amount stored on the three selected AFS in Silite district.

MATERIAL AND METHODS

Site description. The study was conducted in two selected rural kebeles, namely Balokeriso and Welay Sedest of Silite district, SNNP (Figure 1). They have a total area of 3 047.83 km^2 and are geographically located between 7°43' to 8°10'N latitude and 37°86' to 38°86'E longitude with the mean annual temperature ranging from 10.1 °C to 22.5 °C while the annual precipitation ranged from 650 mm to 1 818 mm. The targeted wereda has the altitude from 1 501 m a.s.l. to 3 500 m a.s.l. (CSA 2007).

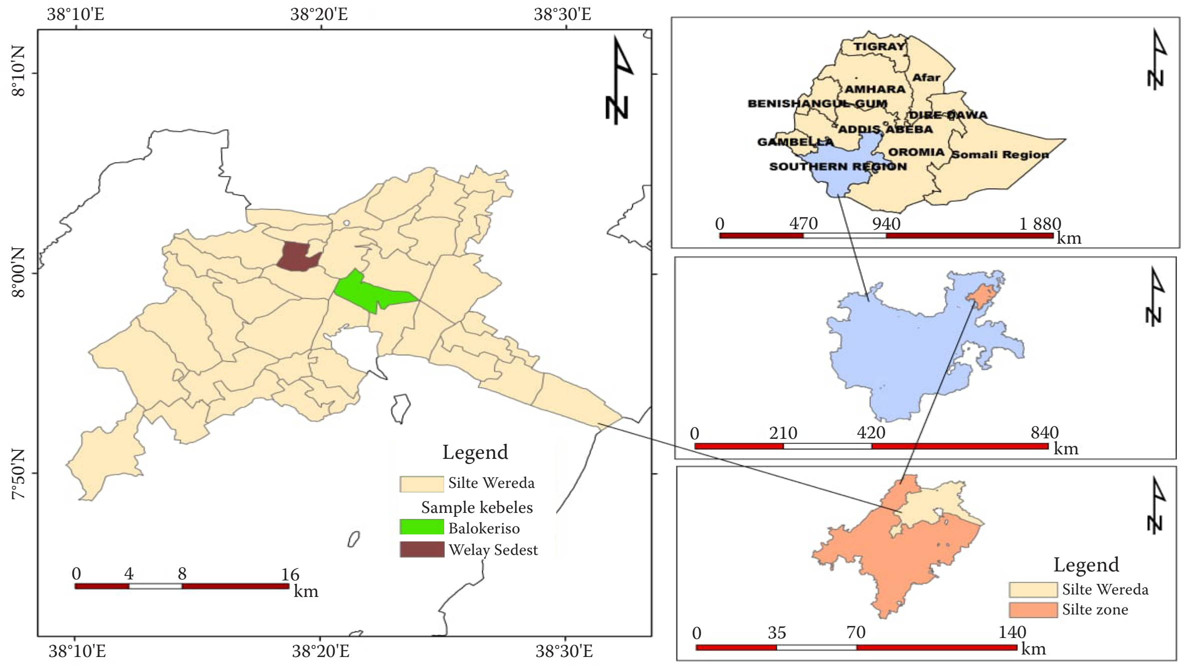

Figure 1. Map of the study site

Landscape characteristics of the studied land use system. The selected AFSs are composed of components like staple foods, crops, fruit trees, coffee and other woody species such as *Federbiya albida* and *Eucalyptus viminalis* for parkland and homegarden AFS, respectively. Coffee, enset, fruit trees and other woody species are incorporated into homegarden AFS.

Selection of study sites and sampling size. Prior to further studies, a reconnaissance survey was done to identify a suitable study site and agroforestry system. The survey was conducted through the collection of information about agroforestry types of the targeted zone in spatial distribution, and on a rotational basis. Then Silite district in Silite zone was selected based on the aforementioned parameters. Accordingly, homegarden, parkland and woodlot AFS were identified. Two potential kebeles Welay Sedest and Balokeriso were selected. Twenty households for each AFS were selected randomly. A total of 60 farms consisting of 20 farms for each land use were randomly selected.

Data collection. Socioeconomic data were collected using systematic random sampling and the sample households were selected following the procedures of Kothari (2004) [Equation (1)]:

$$n = \frac{Z^2 \times N \times \sigma^2}{(N-1) \times e^2 + z^2 \times \sigma^2} \tag{1}$$

where:

n – sample size;
N – population size;
e – acceptable error (the precision);
σ – population standard deviation;
Z – standardized normal deviation;
z – standard variant at a given confidence level.

For the sake of uniformity the following values will be used for calculations: $e = 0.5$, $\sigma = 3$ and $z = 1.96$ (95% confidence level).

For woody biomass inventory, sample plots were randomly laid down of 20 × 20 m in size for homegardens (Molla, Kewessa 2015), 50 × 100 m for parklands and 10 × 10 m for woodlots (Bajigo et al. 2015). Each tree within the plot was identified and recorded. Data on life forms (tree, shrub, etc.) are shown. All trees in the sample plot with diameter at breast height (*DBH* at 1.3 m) ≥ 5 cm and total tree height (*TH*) ≥ 1.5 m were measured and recorded (MacDicken 1997).

For coffee plants, stem diameter at stump height (40 cm, d_{40}) was measured in two times perpendicular to each other. For enset-based homegarden agroforestry systems, the basal diameter of the enset (at 10 cm height, d_{10}) in all enset plants one year old or older was measured and recorded (Negash et al. 2013). In the case of multi-stemmed woody species, each stem was measured separately and DBH was squared (Snowdon et al. 2002) [Equation (2)].

$$d_e = \sqrt{\sum_i^n d_i^2} \tag{2}$$

where:

d_e – equivalent diameter (at breast or stump height);
d_i – diameter of the i^{th} stem at breast or stump height (cm).

Woody species and fruit trees incorporated within homegarden agroforestry (aboveground biomass; *AGB*) were estimated using an allometric equation [Equation (3)] developed by Kuyah et al. (2012) and 48% were used for carbon stock conversion.

Table 1. Adopted allometric models for biomass

Species	Allometric model		Carbon equivalent (%)
	AGB	*BGB*	
Federbiya albida	$AGB = 7.985 \times W \times 32.277$ (Larwanou 2010)	26% of *AGB* (Cairns et al. 1997)	50% (MacDicken 1997)
Eucalyptus viminalis	$AGB = 0.45X^{3.41}$ (Zewdi et al. 2009)		
Coffea arabica	$AGB = 0.147d_{40}^2$ (Negash et al. 2013)	$BGB = 0.490AGB^{0.923}$ (Kuyah et al. 2012)	49% (Negash et al. 2013)
Ensete venticosum	$\ln(AGB_{\text{enset}}) = -6.57 + 2.316\ln(d_{10}) + 0.124\ln(h)$ (Negash et al. 2013)	$BGB = 7 \times 10^{-6} \times d_{10}^{4.083}$ (Negash et al. 2013)	47% (Negash et al. 2013)

AGB – above ground biomass; *BGB* – below ground biomass; *W* – wood density; *X* – predictor variable; *d* – diameter at breast height; *h* – total tree height

$$AGB = 0.091 \times d^{2.472} \quad (3)$$

Belowground biomass (BGB) was estimated using the global average value of 26% of aboveground biomass (Cairns et al. 1997) and 50% (default values) was used for carbon stock conversion (MacDicken 1997).

The total carbon stored in the system was estimated by Equation (4):

$$T_{BC} = T_{AGBC} + T_{BGBC} \quad (4)$$

where:

T_{BC} – total biomass carbon [Mg(C)·ha^{-1}];
T_{AGBC} – total aboveground biomass carbon [Mg(C)·ha^{-1}];
T_{BGBC} – total belowground biomass carbon [Mg(C)·ha^{-1}].

For the adopted allometric models for biomass, see Table 1.

Data analysis. The collected data was analysed using SPSS software (Version 20, 2020). The variations in biomass carbon stock among the selected agroforestry systems were examined by one-way analysis of variance (ANOVA). The mean differences across the system were analysed using a post hoc test. Socioeconomic data were analysed using descriptive statistics and chi-square test.

RESULTS

Socioeconomic characteristics of respondents. The socioeconomic characteristics of respondents included gender, age, farm size, occupation and educational level. A high proportion of male respondents was involved in the sample (73%) and the remaining respondents were females. The average age, family and land holding size of the respondents ranged between 40–42 years, 5–6 members and 0.5–0.7 ha, respectively. About 35.2% of the respondents were illiterate and the rest completed the first and second cycle. The most popular income source of the respondents is crop production; 58% of them depend only on crop production, more than 90% of them practice multiple cropping and the rest of the respondents are engaged in crop production, livestock production and agroforestry. Fertilizer application in crop production is the most certain activity which is practiced almost by all of the respondent farmers. Respondents had an average of USD 1 098.79 annual income. The majority of the farmers (40%) get their farming materials from natural forests and the rest get them from their own farmlands (25.3%) and from the local market (28.5%), the remainder obtain the materials from both the market and their own farmlands (Table 2).

Table 2. Household characteristics of the two selected kebeles

Variable	Balokeriso	Welay Sedest
No. of respondents	81	47
No. of male respondents	56 (69%)	36 (76.5%)
No. of female respondents	25 (31%)	11 (23.5%)
Average age of the respondent	40	42
Average family size	5	6
Average land holding size (ha)	0.65	0.55
Average annual family income (USD)	1 568.73	706.85

Topologies of traditional agroforestry system. The homegarden agroforestry system was the most dominant which comprises 49.3% followed by parkland and woodlot agroforestry systems which account for 43.2% and 7.5%, respectively, in Balokeriso kebele. The same trend was followed in Welay Sedest kebele which is encompassed by 44.4% of homegarden agroforestry and 37.7% and 18% of parkland and woodlot agroforestry system, respectively (Figure 2).

Importance of trees incorporated into agroforestry system. The results found that the contributions of products from trees were significantly different ($P < 0.05$) between the two kebeles. Fuel wood and tree fruit were the main products of agroforestry in the targeted kebeles for livelihood sources and household consumption. Fuel wood and fruit trees accounted for about 42% and 25% and 32% and 20% for Balokeriso and Welay Sedest kebeles, respectively (Figure 3).

Importance of trees incorporated into agroforestry system for livelihood. The farmers sustain and expand their livelihood according to climate change adaptation strategies other than AF prod-

Figure 2. Types of traditional agroforestry system in two selected kebeles

https://doi.org/10.17221/151/2021-JFS

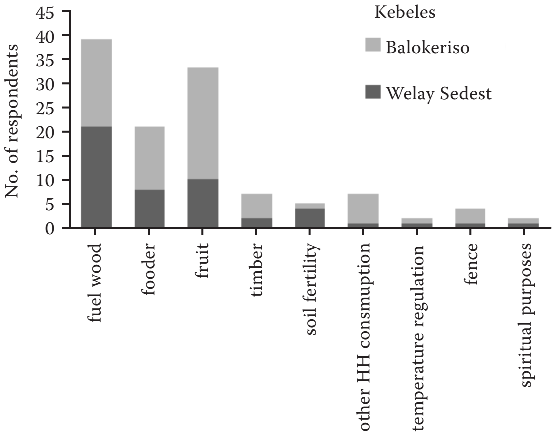

Figure 3. Importance of trees incorporated in agroforestry system for livelihood

HH – household

ucts. The farmers practiced about 8 major adaptation techniques (Figure 4). Livestock sale was amongst the first followed by off-farm activities and government aid. Others such as remittance, migration, product from AF saving are also coping mechanisms. This study also makes sure that the livelihood sources/adaptation methods listed below are basically followed by climate related hazards.

Farmer's perception of climate change. The respondents claimed that drought and flood were the natural hazards that widely occurred in the study areas. 62% and 93% of the respondents in the above-mentioned kebeles, respectively, had perceived the prevalence of climate change ($\chi^2 = 15.7$, $P < 0.001$). In line with this, 56% and 83% of the respondents claimed that agroforestry could increase crop productivity and coping climate change effect ($\chi^2 = 9.1$, $P < 0.01$) (Table 3).

Table 3. Farmer's perception on climate change in the two selected kebeles; $\chi^2 = 15.7$; $P = 0.001$

Perception	Balokeriso		Welay Sedest	
	frequency	%	frequency	%
Perceived	51	62	40	93
Not perceived	4	5	2	4.7
Not sure	27	33	1	2.3
Total	82	100	43	100

Perception on agricultural productivity. The statistical descriptive analysis indicated that out of the total respondents from Balokeriso kebele 56% of the respondents were positive about increasing crop productivity with tree incorporation in farmland and 33% of them perceived decreasing productivity of crops after incorporation of trees in farmland while the rest 11% perceived no change. The same trend was observed in Welay Sedest kebele, 83% of the respondents were positive about increasing crop productivity with tree incorporation in farmland and 12% of them perceived the opposite and the remainder 5% perceived no change. According to the chi-squared statistic test the difference in perception of climate change in the two studied kebeles was significant ($\chi^2 = 9.1$ and $P < 0.05$) (Table 4).

Climate hazards observed in the study area. In both studied kebeles drought was the most frequently observed climate threat; in Balokeriso kebele the threats were ranked as drought followed by heat wave, flood and strong wind while the most important threats observed in Welay Sedest kebele were flood followed by drought, strong wind and heat wave (Table 5).

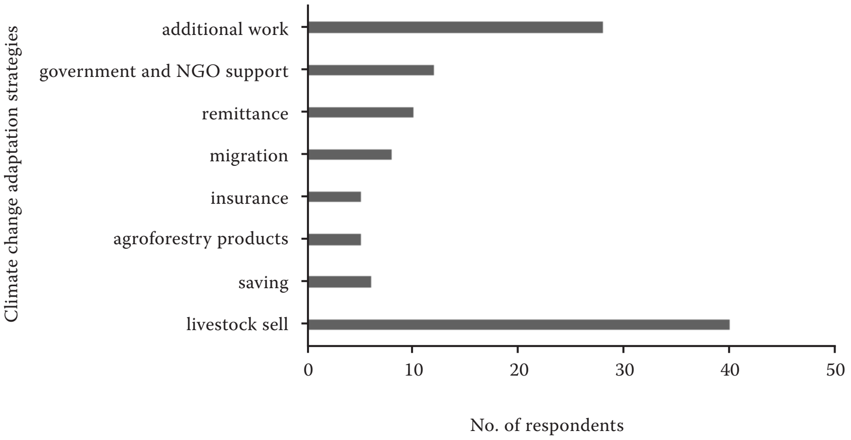

Figure 4. Climate change adaptation strategies of farmers in Silite district, Ethiopia

Table 4. Farmers perception on agricultural productivity in the two selected kebeles; $\chi^2 = 9.1$; $P = 0.01$

Perception	Balo Keriso		Welay Sedest	
	frequency	%	frequency	%
Increasing	46	56	35	83
Decreasing	27	33	5	12
No change	9	11	2	5
Total	82	100	42	100

Biomass carbon stock. The mean total biomass (*AGB* and *BGB*) carbon stock of studied agroforestry, i.e. parkland, homegarden and woodlot AFS systems, ranged from 2–7 Mg·ha^{-1} across the systems. The result showed that *AGBC* (above ground biomass carbon) and *TBC* (total biomass carbon) among all the AFS was significant at a 5% level of significance and parkland AFS accounts significantly for a higher amount of *TBC* among all studied AFS (Table 6).

Share of carbon stock in homegarden AFS components. Homegarden AFS incorporates trees, coffee plants and enset at once. The tree component (including fruit trees such as papaya, avocado and mango) has taken the major share in the total carbon stock (Figure 5).

Table 5. Climate hazards observed in the study area

Climate threats observed	Number of respondents	
	Balokeriso (total = 79)	Welay Sedest (total = 50)
Drought	28	12
Flood	15	22
Heat wave	22	6
Strong wind	14	10

Table 6. The mean (± SD) carbon stocks in different agroforestry systems

Biomass components	Land use systems		
	woodlot	homegarden	parkland
AGBC	1.28 ± 1.0^{a}	2.14 ± 0.85^{b}	5.40 ± 1.24^{c}
BGBC	0.73 ± 0.8^{a}	0.97 ± 1.74^{a}	1.50 ± 0.78^{b}
TBC	2.01 ± 2.1^{a}	3.11 ± 2.40^{b}	7.01 ± 1.40^{c}

a, b, c – significant difference among *ABGC*, *BGBC* and *TBC*; *AGBC* – above ground biomass carbon; *BGBC* – below ground biomass carbon; *TBC* – total biomass carbon

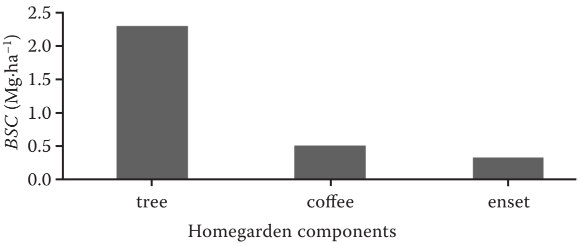

Figure 5. Homegarden AFS components' carbon stock share

BSC – biomass carbon stock; AFS – agroforestry system

DISCUSSION

Biomass carbon stock. This study documented that minimum aboveground biomass carbon stock was estimated in woodlot and homegarden AFS whereas maximum aboveground carbon stock was exhibited by parkland AFS, which can be attributed to continuous biomass accumulation in the woody component. The carbon stock of aboveground biomass is higher compared to belowground biomass (*BGB*) in all studied plots. The average frequency of aboveground biomass (*AGB*) was more important compared to belowground biomass (*BGB*) in the studied sites. Aboveground, belowground carbon and total biomass carbon in general followed virtually the same trend.

The number of planted trees tends to increase the biomass carbon stock of a given area. However, the result in this study was opposite to the above claim proving that parkland AFS accounts for a high amount of carbon stock compared to the other studied AFS having a lower number of individual trees with less diversity. Therefore, the result indicated that the stand structure and number of individual trees in the study area have a greater impact on increasing the carbon stock than the species diversity (Baul et al. 2021). This study also indicated that the species diversity has a significant positive relationship with aboveground carbon. Therefore, the lowest carbon stock recorded for woodlot AFS could be due to the single species-based woodlot agroforestry system.

The biomass carbon stock in a particular land use system depends to a great extent upon its age, structure, functional component and its number and intensity of management. Additionally, the high carbon stock of parkland AFS could be potentially due to its natural reserve of flora and to being a less disturbed AFS. This study also proves that the carbon stock potential highly depends on *DBH* and height rather than on the number of trees.

The mean total biomass carbon stock of selected AFS observed in this study was comparable with the findings in Vietnam coffee-based AFS (Pham et al. 2018) in Gununo watershed in the Wolayita zone, Ethiopia (Bajigo et al. 2015) and it is also analogous in the range of African tropical dry forest [10–34 Mg(C)·ha^{-1}] (Henry 2010). The biomass carbon storage capacity estimated in our study is lower than in fruit tree-based agroforestry [60 Mg(C)·ha^{-1}] studied in Costa Rica and in other fruit-based agroforestry systems [51.85 Mg(C)·ha^{-1}] in the Northwestern Himalayas (Sanneh 2007). The aboveground tree carbon of the study area was also smaller than in smallholder farms of Vihiga district [36.9 Mg(C)·ha^{-1}] in Western Kenya and smallholder farms of Siaya district [115.9 Mg(C)·ha^{-1}] in Western Kenya (De Stefano et al. 2017). Our study shows higher results than the latest study carried out in Adulala Watershed, Ethiopia, where the mean aboveground total dry biomass of trees was estimated at 844 kg·tree^{-1}, tree density was 5.80 trees·ha^{-1} and 2.45 Mg(C)·ha^{-1} in aboveground biomass and 0.76 Mg(C)·ha^{-1} in belowground biomass (Dilla et al. 2019).

The higher biomass carbon stock recorded in parkland AFS could be due to the species (*F. albida*) morphological characteristics. This species undergoes physiological dormancy and sheds its nitrogen-rich leaves during the early rainy season, which makes it very suitable to be incorporated under parkland AFS and for the growth of crops under the tree canopy. This suggests that agroforestry systems sequester a considerable amount of carbon stock, which makes it appropriate for climate change mitigation in addition to its socio-economic contribution by being a means of income generation for smallholder farmers.

Perception of climate change. The results further showed that the perceived effect of agroforestry on soil fertility, perceived effect of agroforestry on drought control, farm size, and association membership were the positive determinants of agroforestry technique adoption among respondents in the study area.

This study shows that the majority (more than 50%) of the respondents perceived some abnormal changes in their local climatic changes in both studied kebeles; this is in line with the study by Adesina and Baidu-Forson (1995), Hitayezu et al. (2017) and Asrat and Simane (2018).

Climate change threats and adaptation strategies. The study of farmers' perceptions toward the most important climatic hazards reveals that drought and water shortages, when considering their occurrence, intensity, negative impact and severity to cope with, are the most important climatic hazards the future production system and livelihood are facing. Although climate change is a global issue, its impacts differ from one place to another. Rain and water shortage, pest and disease outbreaks (Niles et al. 2016), extreme temperatures and change in precipitation patterns and decreasing yields and erratic rain have already been considered as the most important impacts of climate change.

The hydrological cycle is intimately linked with changes in atmospheric temperature and radiation balance. Increased temperatures in the study area may increase precipitation intensity and variability, which are expected to increase the risks of flooding and drought. According to IPCC (2008), the frequency of intense precipitation events (or the proportion of total rainfall from intense falls) will likely increase over most areas during the 21st century, resulting in the risk of floods. At the same time, the proportion of land surface in extreme drought is also projected to increase. The same study was found in the Gedio zone in Ethiopia (Bishaw et al. 2013), in Burkina Faso (Callo-Conch 2018), tropical Africa (Paeth et al. 2008) and Africa (Sanchez 2002). The threats caused by changing climate hinder productivity, thus a simple solution could be to increase tree density within the AFS and carbon sequestration. Also the inclusion of trees for timber or wood production could increase the revenue and carbon sequestration potential without complementing maintenance costs significantly. These recommendations are an easy and possible solution to turn the AFS feasible without incurring further costs.

CONCLUSION

The selected indigenous agroforestry systems of this study area are very important carbon sinks which directly provide a climate change mitigation option in addition to their socio-economic contribution to smallholder farmers. This study shows that parkland AFS accounted for a significantly higher amount of biomass carbon stock than the other studied AFS which was considerably higher than in the same studies carried out in different parts of tropics. Generally, this study provides information about the carbon stock potential of AFP in the southern part of Ethiopia. This study also implies that incorporating trees into a daily cropping system supports the environment by being one means of the climate change mitigation option. Larger carbon projects need a higher amount of carbon and farmer participation than ever. Local small-scale farmers are less aware of environmental benefits of the system. But these days a very large number of parkland AFS have been re-established in different parts of the world; this could be a motivation factor for the carbon stock benefit gained from the system. The study as a whole supports the impression of the higher recognition of AFS as one of the best climate change mitigation options considering the fact that agroforestry can contribute to food security through the provision of edible products such as fruits, roots and seeds. Trees can also improve soil fertility by fixing nitrogen from the air and recycling nutrients, thereby helping to increase crop yields. Trees in the agroforestry system provide valuable supplemental fodder for animals to enhance livestock production and household energy for cooking, heating, and light.

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Received: December 14, 2021
Accepted: April 7, 2022