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Tree Diversity, Carbon Stock, and Factors Influencing the Adoption of Agroforestry Systems in Dugda District, Ethiopia

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Abstract: The Dugda district's, Ethiopia farmers have employed the agroforestry system for millennia. However, farmers usually ignore the agroforestry system in favor of an intensive farming that grows a monocrop because they are unaware of its conservation and climate change mitigation benefits. This study's goal was to assess the impact of agroforestry on the plant diversity, carbon stock and to identify factors governing its adoption. From a total of 242 sampling points, tree species identification, height and diameter at breast height measurements were all done simultaneously. Complete measurements were taken in the home garden, 50 m x 100 m, 10 m x 10 m, and 10 m x 5 m quadrat were used for farmland, woodlot and grazing land, and line planting, respectively. From 0 to 30 cm depths, at each corner and in the middle, composite soil samples were collected from 50 sites (25 in agroforestry adopters and 25 in non-adopter). The outcome demonstrates that adopter sites store more carbon in their biomass and soil than the non-adopter sites. The one-way ANOVA and Fisher's LSD test findings revealed a significant difference in the mean biomass between adopters' and non-adopters sites. The highest plant diversity was recorded at the adopter site (H'), 2.25, while the maximum diversity (H'), at the non-adopter site was 1.95. Age, education, and family size are factors influencing farmers' decision to adopt agroforestry practices. The results of the study showed how agroforestry reduces climate change and protects biodiversity. Therefore, encouraging non-adopters to engage in agroforestry practices is essential.

Keywords: Agroforestry, Carbon stock, Adoption; Biodiversity.

INTRODUCTION

Out of the 121 nations with sufficient data to compute 2022 GHI ratings, Ethiopia comes in at position 104 on the index. Ethiopia's hunger level is severe with a score of 27.6 (GHI 2022). Climate change coupled with land degradation has exacerbated the threat of food insecurity. Therefore, it is critical to look for indigenous knowledge-based sustainable agricultural systems that increase socioeconomic benefits while reducing the impact of climate change and land degradation. Agroforestry is a sustainable production system that provides a range of benefits and services, including greater carbon storage, biodiversity conservation, improved soil fertility, increased infiltration, and enhanced climate change resilience (Sanchez et al. 1997; Garrity et al. 2010; Tanga et al. 2014). In line with this, studies conducted in agroforestry of various areas have shown a remarkable richness of plant species that provide an additional food supply and cash income for the people (Gemeda, 2016; Gebrehiwot, 2017; Olango et al., 2014). For instance, the agroforestry system is used to grow food and cash crops like enset (Ensete ventricosum (Welw.) Cheesman), khat (Catha edulis Forsk), and coffee (Coffea arabica L.), among others. Hence, agroforestry enhances rural livelihood and relieves pressure on the natural forest while preserving a sizable percentage of biodiversity (Bhagwat et al., 2008).

The agroforestry system is an ancient agronomy embedded in the culture of smallholder farmers in Ethiopia (Lelamo 2021; Manaye et al 2021; Jiru 2019). Its arrangement and design are distinctive in that species in the upper, middle, and lower stories are integrated in such a way that it provides multiple economic and ecosystem services. Especially the home garden agroforestry has a complex multi-strata configuration of the herbaceous layers near the ground, a tree layer at upper level, and intermediate layer perennials in between (Degefa 2016). Different plant species with varied growth forms are compacted in small parcels in the backyard of smallholder farmers. The temporal and spatial design is based on the indigenous ecological knowledge inherited from generations to the next (Kura, 2013; Negash and Achalu, 2008). In the country, there are a number of distinct agroforestry types in addition to the home garden agroforestry system. The agroecology and location factors mainly determine the agroforestry types. For example, the central highlands, southwestern and western regions of the country are characterized by a high density of home gardens, parkland, line planting and cash crop-based agroforestry systems, and woodlots agroforestry on the boundaries of agricultural fields (Manaye et al 2021; Tadesse et al 2019; Gebru et al 2019). In addition, there are also agroforestry methods based on fruit plants (Adane et al 2019).

In Ethiopia, agricultural activities are carried out on small tracts of land dispersed over plateau and hills. Due to the scarcity of land, segregating shade trees, fruit trees, annuals, and perennial crops is impossible in the central highlands of the country. In the same way, the land is scarce to spare from production for biodiversity conservation. The only option available for the farmers in the context of Ethiopia is to share the land for production and for conservation. Because of this, farmers design a resilient agroforestry system using their indigenous knowledge so that the systems consistently produce multiple goods and services while conserving genetic resources. Agroforestry system ensures the optimal use of land for both agricultural and forestry production on a sustainable basis (Alao and Shuaibu 2013). Because of this, policies that institutionally divide agriculture from forestry miss chances for synergy (Mbow et al 2014).

Similar to other regions of the world, a number of factors hinder all farmers in the study area from adopting agroforestry practices. Agroforestry system acceptance and uptake in Europe for example is hindered by factors, such as high implementation costs, a dearth of financial incentives, and a dearth of agroforestry system product marketing, a lack of education, awareness, and field demonstrations (Sollen-Norrlin et al 2020). Agroforestry systems have thrived in Africa despite the adoption being limited and despite persistent efforts to promote the monoculture production system. The adoption of agroforestry hasn't been widespread, though, for a number of reasons, including the systems' efficacy, farmers' perceptions, and political and economic factors (Mbow et al 2014). Although Mehari et al (2019) argued tenure right and small land size as a barrier to the adoption of the agroforestry system in Ethiopia agroforestry is practices in many parts of the country regardless of the tenure right and land size. Many agreed that the absence of support for such systems in public policies is a major barrier to the adoption of agroforestry strategies. Regardless of the multiple benefits of the agroforestry farmers are abandoning the agroforestry, which arguably has been the source of sustenance in rural Ethiopia since time immemorial (Bishaw and Abdelkadir, 2003). The rich indigenous knowledge linked with agroforestry that has been passed down through generations is in danger of being lost with the abandonment of agroforestry, in addition to the economic and social benefits that are lost.

The composition of the AFS biodiversity, their use, and carbon sequestration have all been extensively studied in various regions of Ethiopia (Linger et al., 2014; Jiru et al., 2017; Endale et al., 2017; Yusuf et al., 2020; Amare et al., 2019; Gebrehiwot et al., 2016; Negash, 2013; Tesfaye et al., 2022); however, no studies have been conducted to evaluate the diversity and composition of woody species and their role in carbon sequestration in the rift valley region. As a result, the area is degrading, even more, putting the community at risk, especially the women who have the responsibility to provide food for their families and collect firewood for cooking. The goal of this study was therefore to identify the different tree species that are part of the agroforestry system in the Dugda district as well as how much carbon they store in their biomass and soil and to identify whether the woody species diversity and carbon stock varied between agroforestry adopter and non-adopter lands. While there may be trees on the fields of non-adopters, the majority of them were not purposefully planted or managed, whereas the adopters are smallholder farmers who are intentionally grown or retained and managed trees in their lands.

MATERIALS AND METHODS

Description of the study area

The Dugda District is located in the East Shoa Zone of the Oromia Regional State. The district is situated between $38^0$31'E and $38^0$57'E longitudes, while its latitudes are between 8^0 01'N and 8^0 10'N (figure 1). The district's total area is 959.45 km^2. The two major rivers in the district are Meki and Kata. The largest and shallowest lake in the midst of the Rift Valley, Lake Ziway occupies 434 km^2 and has a maximum depth of 8 meters and a minimum depth of 2.5 meters.

Agro-ecologically the region is categorized as a semi-arid region. The rainy season primarily lasts from July through August, followed by a protracted dry season. The region is distinguished by a unimodal pattern of rainfall distribution. The economy of the district is based on agriculture which is characterized as a mixed farming system (DWFEDO, 2010). From the nearest weather station, the district's yearly rainfall is typically between 700 and 800 mm. The main cropping season is the wet summer months of July and August. The study area experiences average annual low and high temperatures of 15ºC and 28ºC, respectively (DWOA, 2014). Sandy loam and clay loam are the two major soil types in the district.

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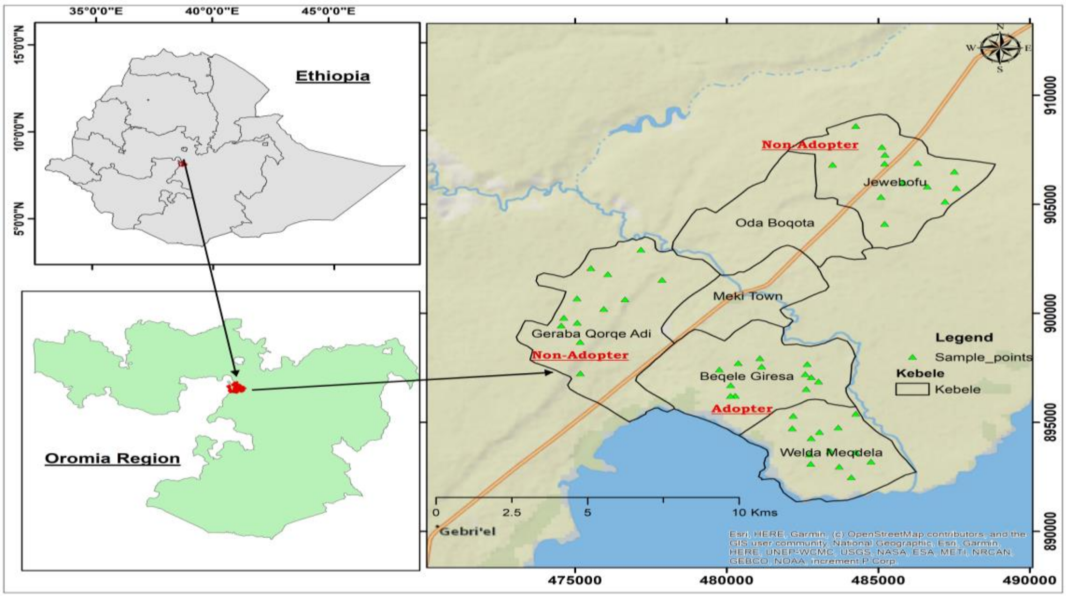

Figure 1. The study area map

Selection of study area

During field survey, contact was initially made with the Dugda District Agricultural and Rural Development Office and with different kebeles' heads which are situated at Meki to collect the necessary information about the target region and to choose good agroforestry adopters and non-adopter kebeles. The Dugda District Agricultural Office assisted in the selection process by suggesting Welda Meqdela, Giraba Qorqe Adi, Beqele Giresa, and Jewebofu. For the agroforestry adopters Welda Meqdela and Beqele Giresa and for the non-adopter kebeles Giraba Qorqe Adi and Jewebofu were chosen.

Methods of carbon stock estimation

Aboveground tree biomass, belowground biomass, and SOC measurement were the main carbon measurement operations throughout the field data collection. The pools of litter and dead wood were excluded from the carbon calculation process because households collect the dead wood for firewood.

Complete measurements were employed in home gardens as in (Motuma et al., 2008) and to estimate the carbon stored in the woody part. Data on woody species were gathered from quadrates with a sample size of 50 m by 100 m in farmland as in (Nikiema, 2005), and from quadrates with a sample size of 10 m by 10 m in woodlots and grazing areas as in (Feyera et al., 2002). Each sample plot's woody species that are less than 1 m tall are referred to as "seedlings," those that are between 1 and 2 m tall are referred to as "saplings," and those that are more than 2 m tall were handled as "trees" (Jiangshan et al, 2009). Woody plants with multiple stems at 1.3m from the ground or above that were treated as a single individual and DBH of the largest stem was taken. Woody plants with multiple stems or forks below 1.3m from the ground were considered as single individuals.

On the properties of 100 smallholders (50 agroforestry adapters and 50 non-adopters), an estimation of the above- and below-ground biomass of woody species was made. We examined various allometric equations, such as those proposed by Brown, 1997; Chave et al., 2005; Henry et al., 2009; and Kuyah et al., 2012a, in order to calculate the aboveground biomass of trees and shrubs. The aboveground biomass estimation results from the various equations show no discernible differences. The Kuyah et al. (2012) allometric equation was chosen because it had the lowest prediction error and could be used to estimate a wide range of factors, including DBH, height, and aboveground biomass. Agroforestry trees with DBH of more than 2.5 cm are also included in the development of this equation. Besides, this equation was developed in areas having similar environmental conditions to the current study area. The equations are as follows:

$$AGB = 0.091xd^{2.472} \ldots\ldots\ldots \text{Equation 1}$$

R2= 0.98 where AGB= aboveground biomass, d= diameter at breast height

Quantifying belowground biomass can be expensive and no practical standard techniques yet exist (Brown, 2002). Below ground biomass of the tree and coffee plants was estimated using the generic equation (Kuyah et al., 2012b).

$$BGB = 0.490AGB^{0.923}; R^2 = 0.95 \ldots\ldots \text{Equation 2}$$

AGB stands for aboveground biomass and BGB for belowground biomass, both measured in kg of dry matter per plant. The biomass was estimated on a hectare basis.

$$AGC \text{ or } BGC = AGB \text{ or } BGB * 0.5 \ldots\ldots \text{Equation 3}$$

While AGB (kg dry matter/plant/ plant) stands for

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aboveground biomass, and d (cm) refers to the diameter at breast height.

Species-specific allometric equations were also used to estimate above-ground biomasses for trees and shrubs on farmland.

$$AGB\ (coffee) = 0.147x + d(40)^2 \ldots \ldots Equation\ 4$$

$$ln(AGBenset) = -6.57 + 2.316 ln(d10) + 0.124 ln(h) \ldots \ldots equation\ 5$$

While d10 (cm) is the basal diameter of the enset pseudostem at 10 cm height and h (m) is the overall height, d40 (cm) is the diameter of the stem of the coffee plant at a height of 40 cm.

$$BGBenset = 7 \times 10^{-6} x d10^{4.083} \ldots \ldots Equation\ 6$$

Enset belowground biomass is represented by BGB (enset) (kg dry matter/plant), while the basal diameter of the enset pseudo-stem at 10 cm height is represented by d10 (cm).

Soil Organic Carbon (SOC)

Three different types of variables were measured: (1) soil depth, (2) bulk density, and (3) the concentrations of organic carbon inside the sample to get an accurate inventory of organic carbon stocks in mineral or organic soil (Pearson et al., 2005). A 1m ×1m square plot was taken at each sampling point of the chosen agroforestry practices for each plot, with soil samples being collected from the corners and the plot's center. With the aid of an auger, 1 kg of a composite sample was taken from one plot at one depth (0–30 cm). After combining the samples to create the composite sample, 1 kg of soil samples were gathered from each plot to create a single representative sample. A total of 50 soil samples were taken 25 from adopters and 25 from non-adopter. The soil samples were analyzed at National Soil Testing Center.

Following (Equation 7) created by Pearson et al., (2007), the soil organic carbon stock (SOC) was calculated. SOC was determined via the Walkley-Black oxidation technique (Chesworth 2008). The bulk density was determined via the gravimetric approach (Grossman and Reinsch 2002). The samples were then put through a 2 mm mesh screen, and the chunky pieces (greater than 2 mm) were weighed. Gravimetric water content and bulk density were estimated using cumulative sub-samples.

$$SOC\ (MgC/ha) = (C100) * \rho * d * (1 - frag100) * 10 \ldots \ldots Equation\ 7$$

C is the amount of soil organic carbon found in one kilogram of soil (g kg^{-1}), ρ is the bulk density (g cm^{-3}), d is the depth of the soil layer being sampled (cm), and frag is the volume of coarse fragments as a percentage of the total volume.

Total carbon stock estimate

The total carbon stock was determined by adding each of the carbon pools according to Eq (Pearson et al., 2005). The study area's carbon stock density:

$$TC = AGC + BGC + SOC \ldots \ldots equation\ 8$$

AGC, BGC, and SOC stand for aboveground, belowground, and soil organic carbon, respectively, while TC stands for total carbon.

Statistical Analyses

The information gathered during the field inventory was arranged, entered into a Microsoft Excel 2021 datasheet, and copied to SPSS. To satisfy the assumption of normal distribution, the estimated AGB, AGC, BGB, and BGC data were transformed using the logarithm [log (n)] before statistical analysis. R software for Windows versions was used to compare the variables using a one-way analysis of variance (ANOVA) at α= 0.05.

RESULTS AND DISCUSSIONS

Characterization of the agroforestry

Geographical and local factors affect the agroforestry model in Ethiopia. It may just be done on farmer homesteads or the entire agricultural landscape (Degefa 2016). In the research areas, agroforestry in backyard gardens is typical. Additionally, farmers in the Dugda district plant multifunctional trees in farms (farmland agroforestry), intentionally leave on grazing grounds (grazing land agroforestry), plant in line as a fence around homesteads (line planting), and plant by mixing with commercial trees (woodlot agroforestry).

Biodiversity Composition

The study's findings revealed that there were 105 different plant species, 74 of which were woody plants from 43 different families, spread across all 242 parcels. This is more in line with Endale et al (2017)'s analysis, which found 77 distinct species of trees in semi-arid East Shoa. Our findings outperform those of Motuma (2006), who identified 32 tree species on farmlands in Arsi Negelle, and Jiru et al., (2020), who noted 46 woody plant species diversity in Jimma, southern Ethiopia. 4 species of climbers, 27 species of herbs, and 74 species of woody plants (trees/shrubs) were among the plant species that were reported. The Fabaceae family, which included 11 species, dominated the list of families. The line planting, home garden, cropland, grazing land, and woodlot of adopter sites contained 61, 60, 35, 25, 30, and 30 woody plant species, respectively. In non-adopter sites, line planting, household gardens, croplands, grazing lands, and woodlots, respectively, contained 40, 21, 15, 15, and 7 plant species. In total, 74 species of woody plants of various agroforestry types were discovered in the adopters' sites, and 46 species of woody plants were discovered inside the non-adopter sites (Table 1).

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Table 1. Tree density, abundance, and richness in the various agroforestry types of agroforestry adopter and non-adopter

	Adopter				*Non-adopter*			
Land use	Abundance	Sampled area (ha)	No tree/ha	Richness	Abundance	Sampled area (ha)	No tree/ha	Richness
Line planting	1318	1.12	1176	61	990	1.19	831.9	40
Home garden	1037	15	69.13	60	236	6	39.33	21
Cropland	523	33.5	15.61	35	428	50.3	8.5	15
Grazing land	432	0.52	830.2	25	83	0.9	92.22	15
Woodlot	313	0.33	948	30	152	1	152	7
Total	3623	50.47	71.78	74	1889	59.39	31.83	46

Figure 2. Partial view of home garden

Table 2. List of woody species

Botanical name	Family	Local Name	Origin
Acacia abyssinica	Fabaceae	Lafto	Indigenous
Acacia brevispica	Fabaceae	Qwentr (Gora)	Indigenous
Acacia Senegal	fabaceae	sabansa(Kerteta)	Indigenous
Acacia tortilis	Fabaceae	Tedecha	Indigenous
Acokanthera schimperi	Apocyanceae	Qararo	Indigenous
Acacia seyal	Fabaceae	Wachu	Indigenous
Anethum graveolens L.	Apiaceae	Insilale/Kamuni	Indigenous
Annona muricata L	Annonaceae	Hambeshok	Exotic
Annona senegalensis	Annonaceae	Gishta	Indigenous
Azadirachta indica A. Juss.	Meliaceae	Nimi	Exotic
Balanites aegyptiaca	Balanitaceae	Bedena	Indigenous
Brassica carinata A. Br.	Brassicaceae	Midhan-Rafu	Indigenous
Brassica oleracea L.	Brassicaceae	Rafu marama	Indigenous
Bascia senegalensis	cappalidaceae	Lanquata	Indigenous
Borleria eronthemoides R.Br.ex	Asteraceae	Yeset melas	Indigenous
Capppparis tomentosa	Capparidaceae	Gumero/Gora	Indigenous
Capsicum annum L.	Solanaceae	Qara/berbare	Exotic
Carica papaya L.	Carricaceae	Papaya	Exotic
Catha edulis (Vahl.)	Celastraceae	Chat	Indigenous
Casimiroa edulis	Rutaceae	Kasmir	Exotic
Casuarina equise folia L.	Casuarinaceae	Shewshewe	Indigenous
Citrus aurantifolium (L.) Burn. f.	Rutaceae	Loomii/Lomi	Exotic
Citrus sinensis (L.) Osb.	Rutaceae	Burtukana	Exotic
Coffea arabica (L.)	Rubiaceae	Buna	Indigenous
Cordia africana (Lam.)	Boraginaceae	Wadessa	Indigenous
Croton macrostachyus Hochst. ex Del	Euphorbiaceae	Bakkannisa	Indigenous

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Cupressus lusitanica Mill.	Cupressaceae	Yeferenji-tid	Exotic
Defonix regia(Boj.ex.Hook)ref	Fabaceae	Diredewa zaf	Exotic
Dodonaea viscosa (L.F.)	Sapindaceae	Itecha	Indigenous
Dovyalis abyssinica (A. Rich)	Flacourtiaceae	Koshim/Ankekute	Indigenous
Dregea schimperi(Decne.) Bullock	Asclepiadaceae	Hida/Yeregna missa	Indigenous
Ehretia cymosa Thonn.	Boraginaceae	Ulaga	Indigenous
sAbyssinica steudel ex A. Rich.	Fabaceae	Kontir/Amazaze	Indigenous
Erythrina abyssinica Lam. ex DC.	Fabaceae	Wolensu	Indigenous
Eucalyptus camaldulensis Dehnh	Myrtaceae	Bergamo-dima	Exotic
Euphorbia abyssinica Gmel.	Euphorbiaceae	Adami/kulkual	Indigenous
Euphorbia tirucalli L.	Euphorbiaceae	Kinchib/anno	Indigenous
Faidherbia albida (Delile) A.Chev.	Fabaceae	Gerbi	Indigenous
Ficus sycomorus	Moraceae	Oda	Indigenous
Gossypium arboretum	Manaceae	Tit	Indigenous
Grevillea robusta (A.Cunn.Ex.R.Br.)	Proteaceae	Giravila	Exotic
Grewia bicolor Juss.	Tiliacea	Haroresa	Indigenous
Hibiscus rosa-sinensis L.	Malvaceae	Yechayna tsegereda	Exotic
Jacaranda mimosifolia	Bignoniaceae	Jacaranda	Exotic
Juniperus procera	Cupressaceae	Yehabesha Tid	Indigenous
Justicia schimperiana Hochst. Ex Nees) T.Anders	Acanthaceae	Tumuga	Indigenous
Lagenaria siceraria (Molina) Standi	Cucurbitaceae	Buke/kil	Indigenous
Lantana camara L.	Verbenaceae	Yewof kolo	Indigenous
Leucaena leucocephala (Lam.)	Fabaceae	Lucina	Exotic
Lippia adoensis var adoensis Hochst.exWalp	Verbenaceae	Kessie	Indigenous
Malus sylvestris	Rosaceae	Apili	Exotic
Maerua angolensis	Capparidaceae	Dergu	Indigenous
Mangifera indica L.	Anacardiaceae	Mango	Exotic
Maytenus arbutifolia	Celastraceae	Kombolcha	Indigenous
Millettia ferruginea (Hochyst, Baker)	Fabaceae	Birbira	Indigenous
Moringa oleifera Lam.	Moringaceae	Shiferaw	Exotic
Musa paradisiaca L.	Musaceae	Muza	Indigenous
Myrtus communis L.	Myrtaceae	Ades	Indigenous
Ocimum basilicum L.	Lamiaceae	Bosobila	Indigenous
Ocimum lamiifolium Hochst.ex Benths	Lamiaceae	Dama-kase	Indigenous
Olea europea	Oleaceae	Weira	Indigenous
Persea americana Mill.	Lauraceae	Avocado	Indigenous
Prunus persica	Rosacea	Kock	Exotic
Psidium guajava L.	Myrtaceae	Zeyituna	Exotic
Rhamnus prinoides L" Herit.	Rhamnaceae	Gesho	Indigenous
Ricinus communis (L.)	Euphorbiaceae	Kobo	Indigenous
Rosa abyssinics	Rosaceae	Gora	Indigenous
Rosa richardii Hart. Shrub	Rosaceae	Tsgereda	Indigenous
Rosmarinus officinalis L	Lamiaceae	Siga metibesha	Indigenous
Rumex abyssinicus Jacq.	Polygonaceae	Meqmeqo	Indigenous
Ruta chalepensis L.	Rutaceae	Xalasan/(Tenadam)	Indigenous
Sesbania sesban	Fabaceae	Suspania	Indigenous
Vernonia amygdalina (Del.)	Asteraceae	Obicha (Ebicha)	Indigenous
Ziziphus hamur	Rhamnaceae	Bulecha	Indigenous

Table 3. List of climber and herbs

Botanical name	Family	Local Name	Habit
Achyranthes aspera L.	Amaranthaceae	Derguu/Etse-tekeze	H
Allium cepa L. A.	Alliaceae	Key shinkurt	H
Allium sativum L.	Alliaceae	Nech shinkurt	H
Aloe gilbertii Reynolds	Aloaceae	Argisaa	H

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Aloe vera (L.) Burm.f.	Aloaceae	Ret	H
Artemisia absinthium L.	Asteraceae	Ariti	H
Bidens pilosa L.	Asteraceae	Chogogitii/Chogogit	H
Brassica carinata A. Br.	Brassicaceae	Gomen	H
Brassica integrifolia L.	Brassicaceae	Yegurage gomen	H
Brassica oleracea L.	Brassicaceae	Tikilgomen	H
Brassica rapa L.	Brassicaceae	Kosta	H
Canna indica L.	Cannaceae	Siet-akuri	H
Capsicum annuum L.	Solanaceae	Karia	H
Capsicum frutescens L.	Solanaceae	Mitimita	H
Clematis simensis Fresen	Ranunculaceae	Hareg	Cl
Cucurbito pepo L.	Cucurbitaceae	Duba	Cl
Cyathula cylindrica Moq.	Amaranthaceae	Derguu/Yemogne Fikir	H
Cymbopogon citralus (DC) Stapf	Poaceae	Tej-sar	H
Daucus carota L.	Apiaceae	Carrot	H
Ipomoea batatas (L.) Lam.	Convolvulaceae	Sikuwar dinich	H
Ipomoea purpurea (L.)	Convolvulaceae	Abeba	Cl
Lactuca sativa L.	Asteraceae	Selata	H
Lactuca sativa L.	Solanaceae	Timatim	H
Mirabilis jalapa L.	Nyctaginaceae	Abeba	H
Nicotiana tabacum L.	Solanaceae	Timbaho	H
Ocimum basilicum L.	Lamiaceae	Besobila	H
Phaseolus vulgaris L.	Fabaceae	Boloqqie	Cl
Pennisetum violaceum (Lam.) L. Rich	Poaceae	Zihone sar	H
Saccharum officinarum L.	Poaceae	Shonkora	H
Solanum tuberosum L.	Solanaceae	Dinich	H
Urtica simensis Steudel	Urticaceae	Sama	H

The total number of tree species between farmer category and across land types was statistically significant ($p \leq 0.05$). *Acacia tortilis* and *Faidherbia albida* were well-known trees in the cropland in both the adopter and non-adopter sites. The most common trees in adopter sites were *Carica papaya* and *Mangifera indica*. The fruit trees were typically the most dominant plant in the home garden, and farmers used the fruit for a variety of things. This outcome is consistent with Jiru et al., (2020); Kebebew and Urgessa (2011), who claimed that home garden land use is primarily known by fruit tree species, which aids the farmer in Southwestern Ethiopia for food/fruit and cash. The three most prevalent woody plant families were Fabaceae (14%), Rutaceae (6%), and Euphorbiaceae (3%). Only 22.9% of the total number of species was foreign, with 77.0% being native. As previously mentioned, a large diversity of tree species (i.e., a total of 74 species) was seen in line planting across both the adopter and non-adopter sites. Subsequently, more trees were discovered in the home gardens of adopter sites and the cropland of non-adopters. The average tree density was 69.13 trees per ha for the adopter and 15 trees per ha for non-adopter but it varied across the land uses.

Diversity, Richness, and Evenness of Woody Species

The Shannon-Wiener diversity index (H'), 2.25, Pielou's evenness index (J'), 0.54, and Simpson diversity index (d), 0.96 in LP of the adopter revealed a high level of plant diversity. In the GL of non-adopter during the course of the study, the least value for plant diversity (H' 0.65, J' 0.15, and Simpson diversity index 0.74) was recorded in contrast to the other land use type (table 4). Adopters have higher species richness than non-adopters. However, the values of species diversity and evenness varied greatly across all land-use types. The Shannon diversity index value of LP was much higher than all other land use types, and at the adopter's location, HG diversity was higher next to LP. The adopter household line planting had the largest mean Shannon diversity. The line planting and backyard gardens of the adopter and non-adopter households had the most Shannon diversity, according to the data. This study's Shannon diversity index for home gardens and line planting was lower than that reported by Endale et al. (2017), who reported values of 3.1 and 3.05, respectively, and higher than that published by Legesse and Negash (2021). In comparison to Endale et al., the species richness in the home garden of the current study was lower (2017).

As well as selective defoliation and crushing by grazing animals, people using the wood lots as fire sources may be contributing to the loss of species diversity in the GL and WL (Belaynesh, 2006). A low mean evenness rating in WL and GL in both adopter's and non-adopters sites suggests that only a few species dominate in the community. While high evenness means LP and HG of adopters; LP and CL of the non-adopter site indicate that there are constant dispersals of the species in a given ecological community (Cavalcanti and Larrazabal, 2004).

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Table 4. Tree species abundance, richness, evenness, and diversity of each land type in decreasing order of diversity

Niche type	Simpson diversity	Shannon diversity	Richness	Evenness
		Adopter		
HG	0.92	2.00	60	0.48
LP	0.96	2.25	61	0.54
CL	0.75	1.46	35	0.41
GL	0.76	1.17	25	0.36
WL	0.75	1.10	30	0.32
Total	0.94	1.85	73	0.43
		Non-adopter		
HG	0.88	0.65	19	0.22
LP	0.92	1.95	46	0.52
CL	0.75	1.14	10	0.49
GL	0.74	0.66	15	0.24
WL	0.66	0.91	7	0.46
Total	0.79	0.74	46	0.19

Assessing carbon pools of agroforestry systems

Above and below-ground biomass

All AF systems' above- and below-ground standing biomass, as well as their biomass carbon stock, was calculated using allometric equations created by Kuyah et al. (2012a); Kuyah et al. (2012b); Negash et al. (2013a); and Negash et al (2013b). The average aboveground woody species biomass of the adopter ranged from 26.09 t ha^{-1} (grazing land AF system) to 119.51 t ha^{-1} (woodlots AF system), and the average below ground tree biomass carbon ranged from 9.60 t ha^{-1} (grazing land AF system) to 37.97 t ha^{-1} (woodlots AF system). The mean aboveground biomass of non-adopter species ranged from 23.23 t ha^{-1} in the grazing land AF system to 58.97t ha^{-1} in the cropland AF system. The below-ground biomass of non-adopter trees ranged from 8.36 t ha^{-1} in the grazing land AF system to 12.30t ha^{-1} in the cropland AF system (Table 5). The findings of the one-way ANOVA and post-hoc testing (Fisher's LSD test) revealed that there was a significant difference in the mean above-ground, below-ground, and total (above plus below-ground) biomass farmer category at (P<0.05) (Table 5).

Table 5. Mean±SD; above, belowground biomass and total (above- plus belowground) biomass (t ha^{-1}) for agroforestry adopters and non-adopters in each niche type

Farmers category	Nich type	DBH	AGB	BGB	Total
Adopter	HG	25.05±14.88	45.40±52.00	15.87±17.18	61.27±6917
	LP	21.82±16.34	40.20±55.85	13.96±18.37	54.16±7421
	CL	29.21±17.48	66.15±9737	22.31±29.88	88.47±127.22
	WL	35.10±25.66	119.51±190	37.97±56.58	157.48±246
	GL	20.00±10.88	26.09±86	9.60±10.19	35.70±43
	Total	25.63±16.93	52.63±79.58	17.98±24.83	70.62±104.39
Non-adopter	HG	19.66±9.49	22.24±20.49	8.35±7.09	30.59±27.58
	LP	20.01±13.31	28.92±34.28	10.42±11.74	39.34±46.02
	CL	23.41±14.81	40.22±42.41	14.19±14.41	54.42±56.82
	WL	28.07±17.02	58.97±62.04	20.28±20.30	79.26±82.33
	GL	17.40±13.23	23.23±37.63	8.36±12.80	31.60±50.43
	Total	21.93±13.73	34.51±40.47	12.30±13.61	46.81±54.08
	Sig	*	**	**	**

**, * indicate significance at p ≤0.01 and p≤0.05respectivilly

The mean above- and below-ground biomass values of adopters in the research region were more comparable to those reported in indigenous AF systems of the south-eastern rift-valley escarpment of Ethiopia by Negash (2013). The Coffee-Albizia association AF in Southwestern Togo, which had a mean value of 140t ha^{-1} in its aboveground and 32t ha^{-1} belowground, provided more comparable results (Dossa et al., 2007).

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Soil organic carbon

At adopter sites, the mean SOC stocks ranged from 34 mg/ha (grazing land) to 60 mg/ha (woodlots), while at non-adopter sites, it ranged from 30.15 mg/ha (home garden) to 35.13 mg/ha (woodlots). Because trees and shrubs in the AF system play a significant role in nutrient recycling and soil organic carbon enhancement, AF adopters have greater soil organic carbon levels than non-adopters (Lehmann et al., 1998; Sarvade et al., 2014, Kaur et al., 2000). In comparison to the nearby non-adopter systems, the mean total soil organic carbon stock of the AF adopter systems under study was greater. The SOC stock of the grazing land AF system and its nearby adopter and non-adopter smallholdings showed no noticeable variation, according to a post-hock test, although all AF practices were statistically different from the corresponding adopter smallholdings (Table 6). The various soil management techniques employed by these adopter farms may be the reason for this difference in SOC stock. The total SOC of adopters being higher than non-adopters may be attributed to farmers spreading compost, ashes, and livestock waste on their fields. The presence of lignified cells in the litter, branches, bark, roots, and other structures that are contributed to the soil might be the cause of the high amounts of SOC stock at the agroforestry adopters site (Six et al., 2002). The slower rate of oxidation of organic matter in the shadow of trees (Gill and Burman, 2002), the addition of root exudates from trees in the rhizosphere (Bertin et al., 2003), and fine root degradation in the soil, the high soil organic carbon could be attributed to these factors (Komicha et al., 2018).

Table 6. Mean±SD; soil organic carbon and results of 1-way ANOVA (at α=0.05)

Niche type	Adopter	Non-adopter	Sig
HG	54.3±16.05	30.15±2.45	**
LP	54.3±16.05	32.61±1.4	**
CL	51.08±26.79	30.7±0.88	**
WL	60±16.95	35.13±6.3	**
GL	34.40±23.90	30.63±16.8	NS
Total	46.45±21.82	31.83±8.06	***

***, ** and NS indicate significance at p= 0.00at P≤0.01 and non-significant respectively.

Ecosystem carbon stock

The adopter site's mean aboveground biomass ranged from 24.53t ha^{-1} (at the grazing land AF system) to 104.12t ha^{-1} (at the woodlots AF system). For comparison, the corresponding below-ground tree biomass carbon ranges from 6.73t ha^{-1} (at the grazing land AF system) to 22.5t ha^{-1} (in the woodlots AF system). The mean aboveground biomass of non-adopter species sites ranged from 19.38t ha^{-1} (at the grazing land AF system) to 43.54t ha^{-1} (at the cropland AF system), and the below-ground carbon content of trees ranged from 2.3 t ha^{-1} (grazing land AF system) to 15.45 t ha^{-1} (cropland AF system). The below-ground biomass ranged from 8.36 t ha^{-1} for grazing land to 12.30t ha^{-1} for cropland (Table 7). The findings of the one-way ANOVA and post-hoc testing (Fisher's LSD test) revealed that there was a significant difference in the mean above-ground, below-ground, and total (above plus below-ground) biomass between kebele at (P<0.05) (Table 7). Adopter sites' mean total carbon ranged from 50.02t ha^{-1} (grazing land AF system) to 116.43t ha^{-1} (woodlots AF system). Non-adopter sites' mean total carbon ranged from 43.82t ha^{-1} (grazing land AF system) to 59.73t ha^{-1} (cropland AF system). The carbon content of aboveground tree biomass ranged from 12.26 t ha^{-1} (grazing land AF system) to 45.15t ha^{-1} (woodlot AF system). The below-ground carbon ranges from 3.36t ha-1 (grazing land AF system) to 11.28t ha^{-1} (woodlots AF system). Aboveground carbon concentrations ranged from 9.69t ha^{-1} (grazing land AF system) to 21.77t ha^{-1} (cropland AF system). The amount of carbon below ground ranged from 2.3t ha^{-1} (grazing land AF system) to 5.35t ha^{-1} (cropland AF system) at non-adopter sites.

Table 7. Mean±SD; above and belowground biomass total (above- plus belowground) biomass carbon (t ha^{-1}) for each of the studied AF systems) and results of one-way ANOVAs (at α=0.05).

Farmer category	Biomass	HG	LP	CL	WL	GL
Adopter	AGB	42.77±65	33.44±47.44	48.11±63.69	104.12±8.56	24.53±10.78
	BGB	15.88±23.55	11.73±15.76	16.54±21.79	22.57±32.34	6.73±2.16
	AGC	23.33±37.03	16.75±23.72	25.15±35.2	45.15±66.53	12.26±5.39
	BGC	7.94±11.77	5.86±7.88	8.27±10.89	11.28±16.7	3.36±1.08
	SOC	54.3±16.05	54.3±16.05	51.08±26.79	60±16.95	34.40±23.90
	TC	85.47±76.1	76.91±54.23	84.5±45.54	116.43±105	50.02±23.6
Non-adopter						
	AGB	20.23±22.99	27.39±36.5	43.54±99.28	30.81±24.13	19.38±30.34

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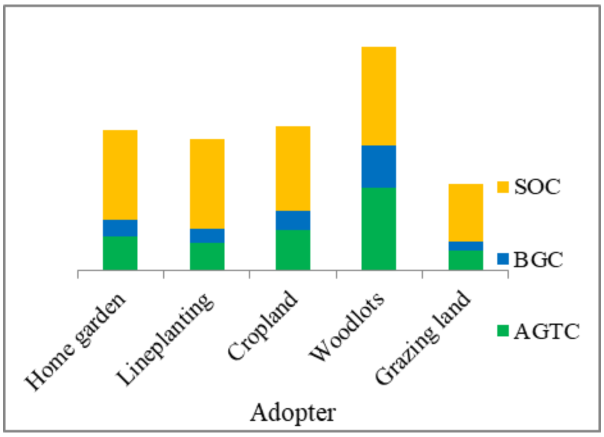
	BGB	4.95±5.63	6.71±8.85	10.71±24.3	6.19±3.53	4.75±7.43
	AGC	10.11±11.49	13.69±18.07	21.77±49.64	12.6±7.22	9.69±15.17
	BGC	2.47±2.81	3.35±4.42	5.35±12.15	3.05±1.76	2.3±73.71
	SOC	30.15±2.45	32.61±1.4	30.75±1.8	35.13±16.8	30.63±8.06
	TC	43.82±32.45	49.65±51.45	59.73±32.34	55.75±21.34	42.73±31.23

The total biomass values in the study site were within range of the global average values (12 -149t ha^{-1}) reported for forest biomass and some tropical forest types FAO (2010). The result of non-adopter was more similar to Manaye et al., (2021), who report the result of above ground biomass carbon stock ranged from 2.78 to 21.43 Mg ha^{-1} in the four smallholdings agroforestry practices. While for belowground biomass carbon stock ranged from 1.26 to 9.70 Mg ha^{-1} but the result of adopter was higher than Manaye et al., (2021). The adopter sites store more carbon dioxide in their biomass and soil than non-adopter sites, which might be attributed to perennial trees that help to boost carbon sequestration (Mulhollem, 2018). Additionally, good environmental conditions, good management, and a long agroforestry life span might have helped the high carbon sequestration (Albrecht and Kandji, 2003). A large number of trees on the adopter sites could be another factor for the high carbon stock on the adopter site than that of the non-adopters. Longer-aged AF systems with no land degradation, favorable environmental conditions, and high biomass output are likely to be present in the adopter sites; the systems were seen as permanent systems and a long lifespan.



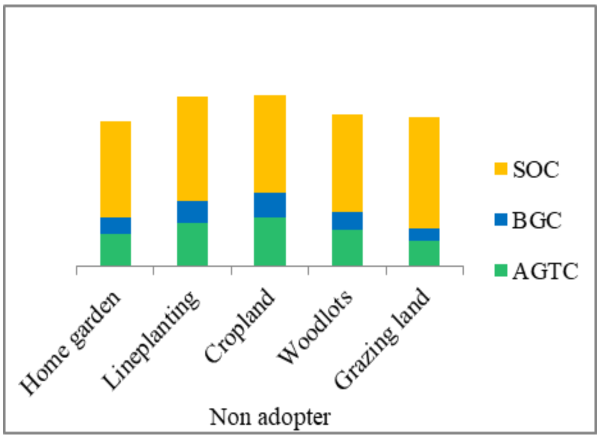


Figure 3. Soil Organic Carbon (SOC) (0–30 cm), aboveground and belowground carbon stocks (t ha^{-1}) for each agroforestry types

The relationship between the SOC stocks of AF systems and the biomass carbon stock was positively correlated. Studies carried out in various tropical regions demonstrated that the continual addition of tree/shrub trimming and root turnover over the years has contributed to the buildup of SOC (Lehmann et al., 1998; Rao et al., 1997).

Factors governing the adoption of the agroforestry system

Farmers' decisions to adopt agroforestry practices were largely influenced by their age, level of education, and the size of their families. The study also showed that sex, land size, presence/absence of additional livelihood sources, and wealth status had no significant impact on their decision to adopt/not to adopt agroforestry.

Table 8. Factors determining the adoption of agroforestry

	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta		
Sex	.307	.170	.157	1.802	.075
Age	.117	.036	.280	3.268	.002**
Education	-.131	.057	-.208	-2.284	.025*
Family size	-.169	.038	-.393	-4.390	.000**
Marital status	-.165	.145	-.115	-1.142	.256
Land size	.075	.067	.097	1.126	.263
Livelihood source	.211	.160	.114	1.320	.190
Wealth status	-.006	.090	-.007	-.063	.950

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CONCLUSIONS AND RECOMMENDATIONS

Agroforestry is a traditional conservation practice in Ethiopia. However, being unaware of the contributions of agroforestry to soil fertility, biodiversity, and livelihood diversification, farmers have recently reduced their agroforestry practices. The study's findings revealed that agroforestry adopters' farmland had more carbon stock than nearby non-adopter sites. Furthermore, the adopters' land had more plant diversity than the non-adopters land, implying that agroforestry adopters earn more than their non-adopter counterparts because soil fertility and biodiversity increase farmers' productivity. As a result, policymakers should encourage non-adopters to participate in agroforestry projects and learn from their peers.

Declaration of competing interests

The authors declare that no commercial or financial relationship existed that could be taken as a potential conflict of interest during the research.

Data Availability Statement

The authors affirm that there were no business or financial ties that might have been seen as posing a conflict of interest during the research.

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