Article

Assessing Carbon Pools of Three Indigenous Agroforestry Systems in the South-Eastern Rift-Valley Landscapes, Ethiopia

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Abstract: The role of agroforestry (AF) systems in providing ecosystem services is very crucial. The greatest considerable increase in carbon (C) storage is often attained by moving from lower biomass land-use systems to tree-based systems like AF. However, estimation of C stocks in indigenous AF systems of South-eastern Rift- valley landscapes, Ethiopia the data are scarce. The study was aimed to investigate the biomass, biomass carbon (BC), and soil organic carbon (SOC) stock of Enset based, Enset-Coffee based, and Coffee-Fruit tree-Enset based AF systems. Comparison of SOC stock of AF systems against their adjacent monocropping farms was also investigated. Research questions were initiated to answer whether C stocks among the three AF systems vary because of different management systems and how biomass C stock is influenced by species abundance, diversity, and richness in the AF systems. The study was carried out in three selected sites of the Dilla Zuria district of Gedeo zone. Twenty farms (total of 60) representative of each AF system were arbitrarily selected, inventoried and biomass C stocks estimated. Ten adjacent mono-cropping farms which were related to each AF system were selected in a purposive manner for comparison of SOC stock. Inventory and soil sampling were employed in the 10×10 m farm plot. The mean AGB ranged from 81.1 t ha^{-1} to 255.9 t ha^{-1} and for BGB from 26.9 t ha^{-1} to 72.2 t ha^{-1}. The highest C stock was found in Coffee-Fruit tree-Enset based (233.3±81.0 t ha^{-1}), and the lowest was in Coffee-Enset based AF system (190.1±29.8 t ha^{-1}). The result showed that SOC stocks were not statistically significant between the three AF systems, although they showed a significant difference in their BC stock. The C stocks of the investigated AF systems are considerably higher than those reported for some tropical forests and AF systems. The SOC of AF systems was significantly higher than the ones for the adjacent monocropped farms. Therefore, it could be understood that the studied AF systems are storing significant amount of C in their biomass as well as soil. Such considerable C storage by these systems might contribute to climate change mitigation.

Keywords: Biomass, Carbon pool, Indigenous agroforestry system, Coffee, Enset, South-eastern Ethiopia

1. Introduction

Agroforestry (AF) practices integrate trees and shrubs in the farmlands and the implementation of agroforestry in a given landscape plays a meaningful role in moderating the effects of climate change through sequestration of carbon (C) [50, 71, 26]. Agroforestry is recognized as one of the greenhouse gas lessening strategies under the Kyoto Protocol which was adopted in 1997. As a result, the sequestration potential of agroforestry systems has caught the attention of many countries throughout the world, prompting them to concentrate on it. Several authors have suggested that trees in agroforestry practices absorb and store larger quantities of atmospheric carbon dioxide (CO_2) than do the herbaceous seasonal or annual crops and pastures [74, 35, 54]. This is because incorporation of perennial trees and shrubs in croplands and pastures would result in higher C sequestration both in biomass and the soil [28, 54]. Therefore, improving C stock in farmlands by introducing AF practices could be potential option to mitigate climate change impacts [26]. Worldwide, the whole land area covered with various types of AF systems is projected to be around 1.6×10^9 hectares, with an aboveground biomass sequestration potential of 1.1–2.2 billion t C in the coming 50 years [45]. Furthermore, [87] reported that the earth's area that is appropriate for practicing agroforestry is approximately 222×10^7 hectare (ha) and if AF systems are turned into effect on these suitable areas more than 55.3 billion t C could be stored in the terrestrial ecosystems over the next 50 years. The amount of C sequestered in an AF system mainly depends on the species composition, arrangement, and role of components within the system, which in turn determined by the ecological and socio-economic aspects [4].

The capacity of AF systems to store C varies among different agro-ecological landscapes. As a result, the storage potential for semi-arid, sub-humid, humid, and temperate regions is estimated at 9, 21, 50, and 63 t C ha^{-1} respectively [49]. Extensive reviews by [46] for West African Sahel countries (extending from arid Sahara Desert to humid region Guinea) reported biomass C stocks ranging from 22.2 to 70.8 t C ha^{-1}. There are many similar studies conducted in various regions of the continents [21, 77, 22, 85]. As reports showed globally, the total biomass C stock for AF systems ranged between 12 and 228 t C ha^{-1} [20, 4]. Another study by [55] reported that AF practices stored C ranging from 0.29 to 15.21 t C ha^{-1} yr^{-1} in their aboveground biomass and can have from 30 to 300 t C ha^{-1} in their soil down to one-meter depth. Soil C stock for 0–60 cm soil layer differs among different land uses and regions. For instance, the C stock in the above-mentioned soil layer is 121-123 t ha^{-1} for tropical forests and 110-117 t ha^{-1} for tropical savannahs [42]. Some studies conducted in Southern Ethiopia by [73, 60, 14] showed that the indigenous AF systems have a great potential in sequestering a significant quantity of C. Species composition of the AF, age, geographical location [30], previous land use [52, 70], climate, soil characteristics, the way crop and tree combined, and handling method [65, 22, 72] are some of the factors which have a great influence upon variation in C sequestration potential of these systems.

The entire area covered by AF systems in Ethiopia is not well recorded, although according to some estimates based on satellite imagery for the base year 2006, roughly 2.32 million ha are classified AF land-use [18]. However, the figure did not include scattered trees on crop and grazing lands due to some reason. The latest estimate by [25] projected the AF area in the country to 16 million ha by 2020. Agroforestry practices in Gedeo zone of southern Ethiopia are known to have a long traditional and to be indigenous in nature. Gedeo agroforests are also a well-known land-use system, and it is believed to have self-sustaining and self-regulating attributes compared to other land-use systems in the area [32]. Studies have been conducted by different researchers in Ethiopia [59, 9, 57, 1] on the aspects of management of AF systems, component interaction in these systems, and determinants for diversity and composition in AF and additional ecosystems services in Gedeo zone and other locations. Some studies were already conducted by [58, 73] on C stocks in AF systems in Gedeo and nearby regions. However, the study and comparison of carbon stocks in three indigenous AF systems, such as Enset based, Coffee-Enset (C-E) based, and Coffee-Fruit tree-Enset (C-Ft-E) based agroforestry (AF) systems, is thought to be highly relevant and complimentary to the existing research findings. Furthermore, this study used C stocks for monocropping systems as a control, which was not done in a prior study at the same location [60].

The general objective of this study was to determine and compare the C stock of the three AF systems and relate them also to traditional field crop agriculture. The specific objectives were 1) to determine and compare the biomass of the fruit and non-fruit trees, coffee, enset and litter of the three AF systems, 2) to determine and compare the C stocks among the studied AF systems and, 3) to compare the C stock of AF and adjacent field crop agriculture as control. Research was initiated to answer the following questions: Could carbon stocks among the three indigenous AF systems vary because of different management systems? Is there a difference in soil organic carbon stock among the three AF systems and in relation to field crop agriculture? Is biomass carbon stock affected by the species abundance, diversity, and richness in the three AF systems?

2. Materials and Methods

2.1. Study area and sites

The research was carried out in Dilla Zuria district of Gedeo zone, Southern Nations', Nationalities' and Peoples' Regional State (SNNPRs), Ethiopia (Fig 1). Geographically, it is located between 5°50' 26'' and 6° 12' 48'' N latitude and 38° 03' 02'' and 38° 18' 59'' E longitude. Elevation in the study area ranges between 1300 and 3064 meters above sea level (masl). According to the meteorological data of 9 years, the annual rainfall ranged from 1127-1624 mm, and the mean monthly air temperature ranged from 13-28 0C [56]. The entire area of the Zone is 134700 ha, which is divided into different land-use types such as agricultural land and AF together which accounts (94.5%), grassland (1.4%), wetland (0.8%), natural forest (0.5%)

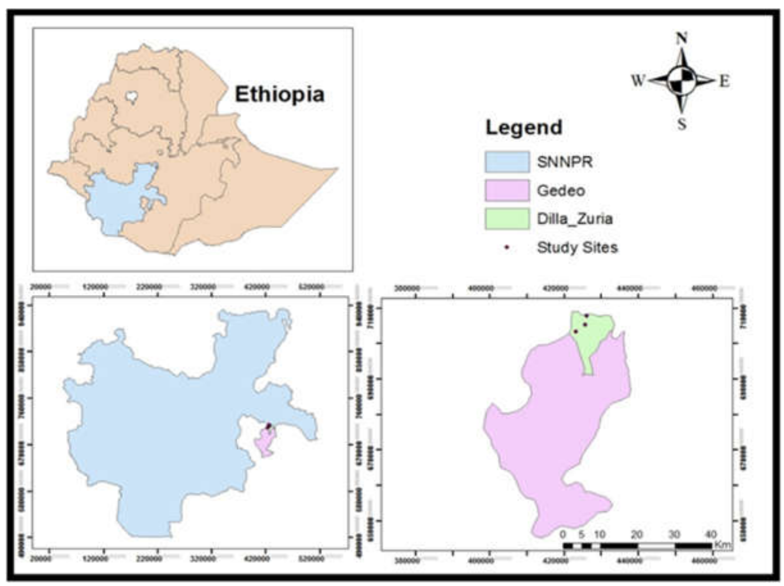


Figure 1. Map of the study site

plantations (0.1%) and others (2.7%) [48]. The soil type is Nitosol and the texture is predominantly clay. The livelihood of the community under this district is mainly dependent on AF practice. They used mixed farming, including non-fruit trees, fruit trees, crops, vegetables, spices production, and very limited animal husbandry focused on oxen, goats, and sheep fattening. Although there are several types of AF systems practiced by the farmers the main and most common are the following 1) Enset based AF system (mainly practiced in Sisota site), 2) Enset-Coffee based AF system (practiced in Golla site), and 3) C-Ft-E based AF system (practiced in Chichu site) see table 1 for detail information.

2.2 Characteristics of the three indigenous agroforestry systems which are concern of the study

A brief description about the above-mentioned AF systems is given in 2.2.1, 2.2.2, and 2.2.3 and a photograph of each AF system is shown in figure 2

Table 1 Characteristics of the research sites

Characterstics	Research sites		
	Sisota	Golla	Chichu
Location	Dilla zuria district, SNNPRS	Dilla zuria district, SNNPRs	Dilla zuria district, SNNPRS
Altitude	1760-1830 m asl	1665-1732 m asl	1544-1587 m asl
Topography	Steep slope land feature, azimuth: South-west facing	Slightly steep to medium, azimuth: South-west facing	Slithly Gentle slope, azimuth: South-west facing
Plant species coverage	Enset dominated	Coffee and enset dominated	Fruit tree, Coffee and Enset dominated
AF handling activity	Tree trimming, lopping, tightening, ripping of unwanted plants. Enset leaves and foliage of *Milletia sp.* used for manuring and floor covering	Trimming, lopping, pollarding, tightening, ripping of unwanted plants. Enset leaves, herbaceous plants and foliage of *Milletia sp.* used for manuring and floor covering	Tree trimming, pollarding. Farm house waste, ash and coffee peelings used as compost
Major food and cash crops, vegetables	Enset, taro, yam, kale	Coffee, enset, banana, taro, yam, sweet potatoes	Fruit, coffee, enset maize, haricot bean, sweet potatoes
Average distance from the next town (market)	10 km	8 km	5 km

2.2.1 Enset based agroforestry system

Enset based AF systems are common in central, south-western, and southern Ethiopia [8, 2, 12]. The areal coverage of enset in this system could be approximately within a range of 60-70% of the farm total depending on the presence of other plant species and their composition. Enset (*Ensete ventricosum*) is one of the species from the Musaceae family, which is also commonly known as false Banana. This perennial species is native and domesticated as one of the important crops in Ethiopia. The enset can be either cultivated in monospecific plantations or in mixture with a rotation period of 3 to 15 years [16, 86]. To bear flowers and then set seed the plant might took it 9 or more years [15]. Enset is among home garden crops known for its high energy content [3].

2.2.2 Coffee-Enset based agroforestry system

The Coffee-Enset based agroforestry (C-E based AF) system is one of the traditional AF home gardens in Southern Ethiopia [2]. The system is suitably practiced in an altitude range between 1,500 and 2,300 masl. In this altitude, moisture and temperature conditions are expected to be conducive for these AF practices. The two dominant native perennial crops in this AF are enset and coffee, and they comprised more over 60% in each farm [1]. Enset is a staple food crop, and coffee (*Coffea arabica*) serves as a cash crop. Coffee also contributes more than 60% of export income in Ethiopia and has been sold as organic [51, 41]. Owing to their great socio-economic and ecological benefits in the farming system of the study area the crops can be deemed as "keystone" species in south Ethiopian AF. Coffee-Enset based AF systems harbor several native woody species (*Cordia africana*, *Millettia forginea*, roots (Ginger, Sweet potato) and annual crops (Maize) favorably growing in intimate association with enset and coffee.

2.2.3 Coffee-Fruit tree-Enset based agroforestry system

Multipurpose tree/shrub species such as coffee, enset, several fruits, and annual crops, vegetables, medicinal plants, and livestock are components of Coffee-Fruit tree-Enset (C-Ft-E) based agroforestry system. Under this type of indigenous AF system, the coffee, fruit tree, and enset have the greater share, and the remaining components such as vegetables, spices, and livestock are still included [7]. The proportional area for coffee, fruit tree, and enset is approximately 20-25% for each component. In C-Ft-E based AF system fruit trees such as *Persea americana* Mill., *Mangifera indica* L. *Casimiroa edulis* Lal Llave and Lex. etc are in a mixture with coffee and enset. In addition, non-fruit trees for instance *Cordia africana*, *Milletia ferruginea*, *Ficus Vasta*, and *Ficus sur* are also incorporated and mainly used as a shade for coffee. Communities practicing this type of AF system are self-sufficient in fuel wood, and the fruit trees and coffee account for 47% and 45% of their annual income, respectively [7].

Figure 2. The three studied agroforestry systems

2.3 Sampling design and data collection

2.3.1. Inventory for biomass estimation

The agroforestry systems were selected at similar altitudinal locations gradient of the landscape to minimize variation in climatic variables and slope. Within each AF study site, 20 AF farms (60 farms in total) were randomly selected, and ten adjacent mono-cropping farms (30 farms in total) were selected in a purposive manner. The altitude, slope, GPS location, agroforestry type, age of each agroforestry, and mono-cropping farm and site history were also recorded.

A nested quadrat with 10×10 m size was established in each AF farm for the inventory of trees/shrubs, coffee and enset. The inventory was aimed to get data for the biomass estimation. The size of the quadrats and sampling size coincide with recommended practice in literature for similar AF farms by [58]. In some cases, the size of the quadrant might occupy the whole farm. Due to small size of some farms, cost and time-related issues, the size of the quadrant was limited to 100 m^2. Within each quadrant, three 50×50 cm small plots for litter sampling were laid out. In addition, five circular plots at four corners of the quadrant and one in the center were determined for soil sampling.

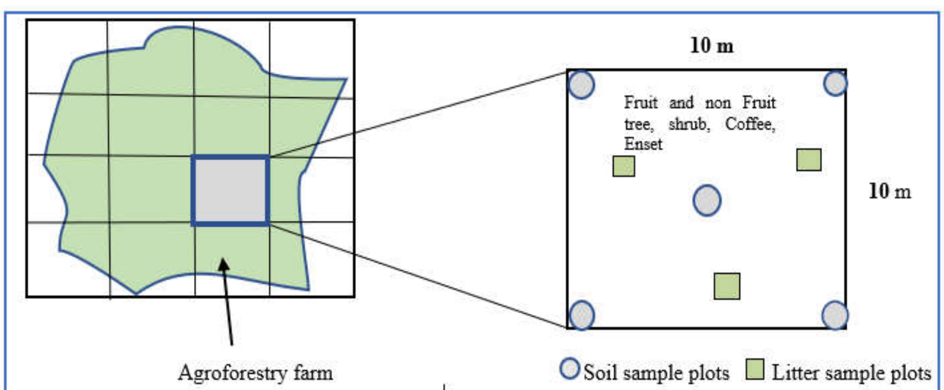


Figure 3. Sample plot layout for inventory of trees, shrubs, coffee and enset plants (10×10 m), soil sample points (circular points), and litter (50 × 50 cm squares).

Measurements such as diameter at breast height (DBH, cm ±0.1), total height (h, m ±0.1) of all trees and shrubs (single and multi-stemmed) having a breast height diameter ≥ 2.5 cm and height ≥ 1.5 m was made. For coffee plants (in C-E based and C-Ft-E based AF systems), the stem diameter at stump height (40 cm), d_{40}, was also measured. For Enset based AF systems, the basal diameter of the pseudostem (height of 10 cm, d_{10}) of plants one-year-old or older was measured. Stem diameter measurements (DBH, d_{10}, and d_{40}) were taken using a caliper in two vertical directions to minimize measuring error. The two values were averaged and later used in successive computations.

2.3.2. Biomass and determination of biomass C stocks

Estimation of total above-ground biomass (AGB) and belowground biomass (BGB) (t ha^{-1}) of fruit trees and non-fruit trees and shrubs, enset, and coffee plants were done for the 60 farms (20 farms from each AF). However, 30 farms (10 farms from each AF) were randomly selected, and the biomass C stocks (t C ha^{-1}) was estimated. Unlike the fine roots and herbs C stocks of the tree and shrub, enset, coffee, and litter were computed. For some reason fine roots and herbs were excluded from the computation. The biomass in natural forest/AF could be estimated by both destructive and non-destructive methods. In this study allometric equations (which are non-destructive) were used. This is because destructive tree harvesting is too costly, labor-intensive, and time-consuming for both AGB and BGB determination. Further on, farmers may demand compensating payments for the sampled trees because they may be harvested at the wrong time and/or production is less due to premature cutting.

To compute the AGB and BGB, and their respective C stocks, a plant species inventory followed by the application of allometric equations were performed. These equations were developed by [39, 40, 61, 62]. The reason for adopting these allometric equations is because the study site in which the equation was developed had alike environmental setting (climate and soils) to our research sites and showed the highest R^2, the smallest error of prediction values and used only DBH for trees [39, 40, 61, 62]. In addition, the similarity in type of plant, plant architecture and species could be a reason to adopt these equations to this study [61, 62]. For instance, [39] developed an equation to estimate AGB of trees grown in AF systems in western Kenya.

$$AGB = 0.225 \times d^{2.341} \times \varrho^{0.73} \qquad R^2 = 98;\ n=72 \ \ldots \ (1)$$

Where AGB (kg dry matter /plant) = aboveground biomass, d (cm) = diameter at breast height and ϱ is species wood density (g cm^{-3}).

But, to estimate the AGB (kg dry matter/plant) of the coffee and enset plants, an allometric equation which was developed by [62] and [61] respectively was adopted.

$$AGB_{coffee} = 0.147 \times d_{40}^{2} \qquad R^2 = 0.80,\ n = 31 \ \ldots \ (2)$$

$$\ln (AGB_{enset}) = -6.57 + 2.316\ln(d_{10}) + 0.124\ln(h);\ R^2 = 0.91,\ n=40 \ \ldots (3)$$

Where d_{40} (cm) = stem diameter of the coffee plant at 40 cm height, d_{10} (cm) = the basal diameter of the enset pseudo stem at 10 cm height and h (m) = total height

For estimating the BGB (stump plus coarse roots (>2 cm)) for trees and shrubs, including coffee, the following allometric equation by [40] was used.

$$BGB = 0.490\ AGB^{0.923} \qquad R^2 = 0.95,\ n = 72 \ \ldots \ (4)$$

Where BGB (kg dry matter/plant) = belowground biomass, d (cm) = diameter at breast height.

However, to estimate the BGB of enset (corm plus attached proximal roots), the allometric equation developed by [62] was used.

$$BGB_{enset} = 7 \times 10^{-6} \times d_{10}^{4.083};\ R^2 = 0.68,\ n = 40 \quad (5)$$

Where BGB_{enset} (kg dry matter/plant) = enset belowground biomass, d_{10} (cm) = the basal diameter of the enset pseudostem at 10 cm height

Note: n (in all the formulas) is the number of individual plants that were sampled the development of the allometric equation

The biomass of litter was determined from collected samples taken from the three 50×50 cm plots within the 10×10 m inventory quadrant. Three samples were taken from each quadrant, and later one composite sample was taken for C measurement and analysis.

The BGB and AGB C stocks were determined using content C% in each component. It was computed from organic matter contents determined as loss-on-ignition (LOI; ignition at 550 °C for 2 hours) and an assumed C content of organic matter of 44% [60]. Accordingly, C content of 48% for fruit and non-fruit trees and shrubs, 43% for coffee, 41% for enset, and 29% for litter were used [60]. The sum of above and belowground biomass C give us the total biomass C stocks for that specific farm or site.

2.3.3. Soil sampling and determination of soil organic carbon stocks

Soil samples were taken from the four corners and center of each 10 × 10 m inventory quadrant and then a composite soil was used to determine the SOC. This was done for soil depth from 0-20 cm and 20-40 cm. It was assumed that taking samples down to 40 cm soil depth might be sufficient. The total number of samples were 60 for the AF systems and 60 for the adjacent monocropping farms. The sampling depth was chosen with regard to cost for soil analysis and to have a uniform and complete sampling procedure since the method should be used for the selected AF farms and monocropping farms. The sampling was employed for all three AF systems as well as the adjacent mono-cropping farms. Both gravimetric and volumetric soil sampling methods were employed. The volumetric soil sampling was employed in the middle of each 10×10 m inventory quadrant. Volumetric sampling was carried out to get soil samples for determination of bulk density, and the gravimetric sampling for SOC determination. 200-250 mg soil from each of the 120 samples was weighed, and the SOC content was determined by a LECO TruSpec CN analyzer (ÖNORM L1080). The soil C stocks (t C ha^{-1}) were computed by multiplying the C content (%), bulk density (g cm^{-3}), and layer thickness (cm). The total SOC stock is the sum of the two layers' values (0-20 cm and 20-40 cm). AF C stocks in the study sites are calculated by adding total biomass C and SOC up to 40 cm depth

2.4. Statistical analysis

The biomass (t ha^{-1}) of the trees and shrubs, coffee and enset, was estimated for all 60 farms (smallholdings) using the allometric equations. However, the AF C stocks (t ha^{-1}) were calculated only for the 30 farms (smallholdings), implying ten farms from each AF system. This was because the soil and litter samples were only taken from randomly selected 30 AF farms. The biomass, biomass C stocks for each AF were expressed using the mean, minimum, maximum, and standard deviation statistics. To test for differences in the biomass, biomass C, and soil C between the three AF systems a one-way ANOVA followed by post-hoc testing (Fisher's LSD test) was used. Levene's test was conducted to check the homogeneity of variances. Linear regression analysis was also conducted to analyze the relationship between some parameters. Similarly, the soil C stocks for 30 monocropping farms adjacent to the AF farms were also calculated layer by layer and their means were compared. For the comparison, a pairwise 2-tailed t-test was conducted. The statistical analyses were done using Statistical Package for Social Sciences-IBM SPSS version 26 (SPSS Inc. 2019).

3. Results

3.1. Biomass and biomass carbon stocks

The above and belowground biomass and biomass C stock of three AF systems were estimated and the estimation was made for each plant species within the inventoried quadrant. AF system mean AGB and BGB t ha^{-1} and the biomass values of components of the AF are displayed in table 2 and table 3 respectively. The mean AGB ranged from 81.1 t ha^{-1} (Enset based AF) to 255.9 t ha^{-1} (C-Ft-E based AF system) and for BGB from 26.9 t ha^{-1} (Enset based AF system) to 72.2 t ha^{-1} (C-Ft-E based AF system) (Table 2). The AGB was by far higher than the BGB across all the AF systems. In C-Ft-E AF the AGB was even 3.5 fold compared to its respective BGB, which is extremely high. The total calculated biomass values in the studied three AF systems ranged from 108.0-328.1 t ha^{-1}. The one-way ANOVA followed by post-hoc testing (Fisher's LSD test) (n=20) results showed that the mean AGB, BGB and total (above plus below-ground) between the three AF systems was significant at ($P<0.05$) (Table 2). In general, the biomass t ha^{-1} is in the order of: C-Ft-E based AF > C-E based AF> Enset based AF.

Table 2. Mean(±SD); n=20), AGB, BGB and total (above- plus belowground) biomass (t ha^{-1}) for each of the three studied AF systems) and results of 1-way ANOVAs (at α=0.05, significant differences between AF systems were indicated)

Biomass	C-Ft-E AF	Enset AF	C-E AF	F	p
Aboveground biomass[a]	255.9 ±294.0	81.1±69.0	126.7±145.1	4.4	0.017
Belowground biomass[b]	72.2±69.9	26.9 ±21.1	39.4±39.4	4.8	0.012
Agroforestry total biomass	328.1±364	108.0±90.0	166.1±184.4	4.5	0.016

[a] trees, coffee, enset.

[b] stumps, coarse roots (Enset corm + proximal roots), and fine roots.

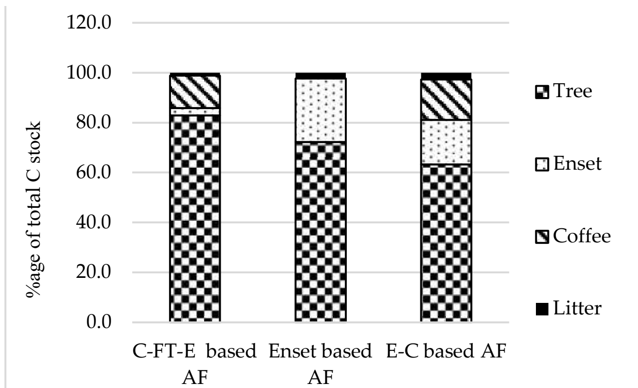
The biomass contribution from individual component (e.g. fruit tree, non-fruit tree, enset and coffee) to the each of the three AF systems was computed. As the results displayed in table 3, the contribution was higher from the woody fruits and non-fruits across all the AF systems. The contribution from non-fruits trees and shrubs was relatively higher in all AF systems except in C-Ft-E based. The result of one-way ANOVA followed by post-hoc testing (Fisher's LSD test) (n=20) showed that the total biomass of fruit trees and non-fruit trees in C-Ft-E based AF system was significantly different at ($P<0.05$) from both Enset based and C-E based AF systems, but Enset based and C-E based AF were not significantly different (Table 3).

Table 3. Mean (±SD) total biomass (t ha^{-1}) of woody, enset and coffee components grown in three AF systems. Within each AF system having the same letter are not significantly different at ($p<0.05$) from each other (Fisher LSD test; n=20 for each AF system).

Agroforestry system	Woody			Enset	Coffee	Agroforestry total biomass
	Fruit	Non-fruit	Total			
C-Ft-E based AF	154.1±158.8[a]	141.6±283[a]	295.7±372.0[a]	6.8±3.7[a]	25.6±41.5[a]	328.1±364[a]
Enset based AF	29.7±61.2[b]	45.3±67.2[a]	75.0±94.0[b]	29.0±15.6[ab]	-	108.0±90[b]
C-E based AF	31.7±132.4[b]	97.7±128.9[a]	129.4±186.4[b]	19.1±10.2[ac]	17.6±6.5[a]	166.1±184[b]

C-Ft-E based AF= Coffee-Fruit tree-Enset based agroforestry; Enset based AF = Enset based agroforestry; C-E based AF = Coffee-Enset based agroforestry system

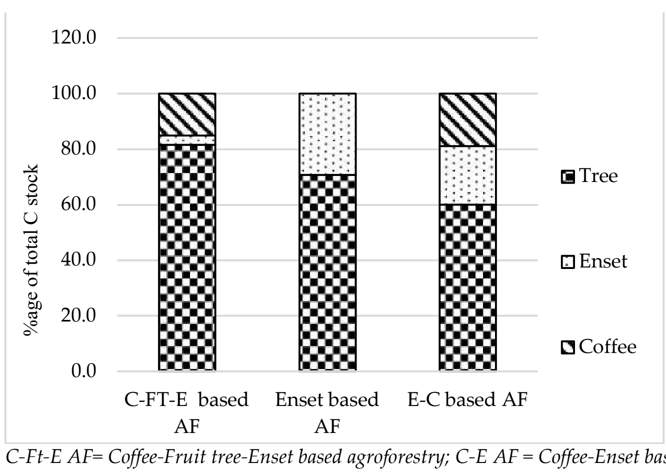
When it comes to the C stock, only 10 out of the 20 farms were randomly selected and computed their biomass C stocks. This is because the numbers of farms where we took soil and litter samples were only from the ten farms. In addition, soil sample collection from monocropping farms was only carried out on 30 smallholdings (10 for each) which are adjacent to the AF farms. Therefore, to estimate ecosystem C stock, a uniform representation of samples from all components (standing biomass, litter, and soil) is very important. The AGB carbon stock ranged from 10.2-212.9 t ha^{-1} across the three AF systems. While the average C stock in BGB ranged from 2.9-56.1 t ha^{-1}. In the case of individual AF



C-Ft-E AF= Coffee-Fruit tree-Enset based agroforestry; C-E based AF = Coffee-Enset based agroforestry

Figure 4. Proportion of C stock of each component in the above-ground biomass

farms, the highest total biomass C stock was recorded in C-Ft-E based AF system (269 t ha^{-1}), and the least was in an Enset based AF system (13 t ha^{-1}). The ratio of mean AGB to BGB carbon stock was 3.4, 3.1, and 3.0 for C-Ft-E based, Enset based, and C-E based AF systems, respectively. The share of fruit and non-fruit woody species in the total AGB carbon stock was estimated at 83%, 72%, and 63% for C-Ft-E based, Enset based, and E-C based AF systems, respectively (Figure 4). The share of trees (fruit trees and non-fruit



C-Ft-E AF= Coffee-Fruit tree-Enset based agroforestry; C-E AF = Coffee-Enset based agroforestry

Figure 5. Proportion of carbon stock of each component in the below-ground biomass

trees) in the total BGB C stock was estimated at 82%, 71%, and 60% in C-Ft-E, Enset based and E-C based AF systems, respectively (Figure 5). On average, trees accounted for 73% in AGB and 71% in BGB C stock across all smallholdings. The results of the statistical analysis showed that the total mean biomass C stock of C-Ft-E based AF was significantly different at (P<0.05) from both Enset based and C-E based but Enset based and C-E based AF were not significantly different. We hypothesized that biomass C stocks would differ significantly amongst AF systems, and our findings supported this hypothesis. In general, the total biomass C stock of the AF systems is in the order of C-Ft-E based AF > Enset based AF > C-E based AF (Table 3).

3.2. Soil organic carbon stock

In the current study considering all the individual farms, the greater SOC stock was found in C-E based AF which is 190 t ha^{-1} while the least was found in C-Ft-E based AF with a value of 86 t ha^{-1}. From the total SOC stock (0-40 cm), the upper soil layer (0-20 cm) contributed an average of 60.3%, 56%, and 55.1% for C-Ft-E based AF, Enset based AF, and C-E based AF, respectively. The highest total mean SOC stock for the AF systems was found in Enset based (146.1 t ha^{-1}) and the least was in C-Ft-E based AF (125.5 t ha^{-1}). The results of ANOVA analysis showed that the mean SOC stock was not significantly different between the AF systems at (P<0.05) (Table 4). In general, the total mean SOC stock of the AF systems is in the order of Enset based > C-E based > C-Ft-E based AF system.

3.3. Ecosystem carbon stocks

The mean AF total C stock for C-Ft-E based was relatively high and the least was recorded in C-E based AF (Table 4). The result of one-way ANOVA followed by post-hoc testing (Fisher's LSD test) (n=10), at (p<0.05) showed that the total AF C stock and SOC stock were not statistically significant between the three AF systems, although they showed a significant difference in their biomass carbon (BC) stock.

Table 4. Mean (±SD; n=10) BC, SOC (0-40 cm) and AF total C stock (t ha^{-1}) for the three AF systems) and results of 1-way ANOVAs (at α=0.05)

C stock	C-Ft-E AF	Enset AF	C-E AF	F	p
Aboveground C [a]	83.8 ±63.0	39.1±32.0	37.8±17.3	3.9	0.033
Belowground C [b]	24.4±16.2	12.6 ±9.7	12.7±5.8	3.6	0.042
Total biomass	108.2 ±79.2[a]	51.7 ±41.7[b]	50.5 ±23.1[b]	3.8	0.034
SOC 0-20	75.7±14.2	81.7 ±14.4	76.9 ±18.3	0.4	0.665
SOC 20-40	49.8±7.5	64.4 ±16.3	62.7 ±21.2	8.9	0.103
SOC 0-40	125.5±17.3[a]	146.1 ±26.5[a]	139.6 ±25.4[a]	14.7	0.152
Agroforestry total	233.3±81.0[a]	197.8 ±58.7[a]	190.1 ±29.8[a]	0.1	0.243

[a] *trees, coffee, enset and litter*

[b] *stumps, coarse roots enset corm + proximal roots), and fine roots*

Total AF C stock of individual AF smallholdings in this study ranged between 132.0 t ha^{-1} (Enset based AF) and 356.4 t ha^{-1} (C-Ft-E based AF). The mean biomass C stock fraction of the total AF C stock was 46%, 26% and 27% for C-Ft-E based AF, Enset based AF, and C-E-based AF, respectively. Except for C-Ft-E based the remaining two AF systems had a greater contribution from the SOC (about 2.8 times the biomass C) to their respective total AF carbon stock. The SOC exceeds the biomass C across all AF systems, and there was a difference in SOC to total biomass C stock ratio among the AF systems. The highest proportion of SOC (0-40 cm) to total biomass C stock was found in Enset based AF with a value of 2.82, and the least was in C-Ft-E based AF with a value of 1.16. The contribution of SOC to the total AF C stock was 54% for C-Ft-E based, 74% for Enset based, and 73% for C-E based AF.

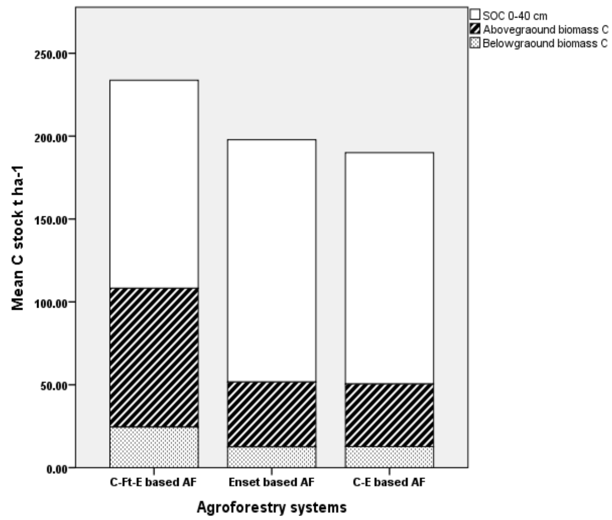


Figure 6. Agroforestry total carbon stocks (including trees, shrubs, coffee, enset, stumps, and large roots, SOC 0-40 cm) (t ha^{-1}) by AF system.

3.4. Correlation between biomass carbon and SOC of agroforestry systems

For the ten selected farms in all three AF systems, the result of Pearson correlation (2-tailed significance difference) showed that biomass C stock and SOC stocks had r-values of -0.005 for C-Ft-E based AF, 0.5 for Enset based AF, and -0.3 for C-E based AF (Appendix 1). The correlation under Enset based AF showed a positive and a bit higher value but it was not statistically significant. A correlation analysis of SOC stock with other factors such as slope percent and wealth status of the households (rich, medium, and poor) was conducted. In addition, a correlation of SOC stock and number of livestock units owned, and age of the AF farm were conducted. These factors were believed to act as proxy variables for the intensity of biomass extraction from the AF system and thus affect the SOC stock on each farm. Accordingly, the correlation results of SOC stock with the farm's age showed a positive correlation with r-values 0.7, 0.64, and 0.44 for Enset based, C-E based, and C-Ft-E based AF systems, respectively. The r-values under Enset based and C-E based AF systems were statistically significant. Most AF farms that have older age showed a higher amount of SOC stock. However, SOC stock was negatively correlated with slope percent and showed r-values -0.61, -0.55, and -0.21 for Enset based, C-E based, and C-Ft-E based AF systems, respectively.

The correlation results of SOC stock with the households' wealth status (rich, medium, and poor) showed that there is higher SOC stock on farms owned by wealthy farmers across the three AF systems. A positive correlation was observed with r-values of 0.37, 0.47 and 0.34 for Enset based, C-E based, and C-Ft-E based AF systems. However, SOC was negatively correlated with the number of livestock units owned by the practitioners. The correlation results showed that the relationship between SOC stock and the number of livestock under Enset based AF was statistically significant with an r-value of -0.66. However, the r-values for C-E based and C-Ft-E based AF systems were -0.49 and -0.31, respectively, and were not significant.

3.5. Relationship between biomass C and Abundance, Shannon diversity, Marglef's richness

The bivariate correlation analysis results showed that the quantity of biomass carbon (BC) stock was positively correlated with mean species richness, mean abundance, and diversity in all AF systems except in C-Ft-E-based AF. Under C-Ft-E based AF system, the relationship between total BC and diversity was negative. From all AF systems, the strongest correlation between BC and plant species richness was observed in C-E based

AF with an r-value of 0.52. A weak correlation was observed in BC stock with plant diversity (r=-0.32) for C-Ft-E-based AF system. The BC stock was more positively correlated with species richness (r =0.49, r =0.44, r =0.52) for C-Ft-E based, Enset based, and C-E based AF respectively than the other variables.

3.6 Soil organic carbon stocks of AF systems versus their adjacent monocropping farms

A pairwise comparison was conducted to see the SOC stocks of three AF systems and their adjacent monocropping farming systems. The mean total SOC stock of the three investigated AF systems were higher than in the adjacent monocropping. According to the results of paired 2-tailed t-test C-Ft-E based AF and C-E based AF showed a statistically highly significant difference compared to the respective monocropping smallholding. However, the SOC stock of Enset based AF system did not significantly differ from its adjacent monocropping plots (Table 5).

Table 5. Mean (±SD; n=10), SOC stock (0-40 cm, t ha^{-1}) for the three studied AF systems and their adjacent monocropping plot and results of paired samples two tailed t-test

	Land use type	N	Mean±SD	t	df	Sig. (2-tailed)
Pair 1	SOC Coffee-Ft-Enset AF	10	125.5±17.3	5.0	9	0.001**
	SOC monocropping plot	10	90.5±15.3			
Pair 2	SOC Enset based AF	10	146.1±26.5	0.4	9	0.688 NS
	SOC monocropping plot	10	141.8±28.1			
Pair 3	SOC Coffee-Enset AF	10	139.6±25.4	5.4	9	0.000**
	SOC monocropping plot	10	95.3±14.6			

** *Significant at the 0.01 level (2-tailed).*

* *Significant at the 0.05 level (2-tailed).*

NS-Not significant

4. Discussion

4.1. Biomass and biomass carbon stocks

For a mitigation of the rising CO_2 in the atmosphere C stores in biomass are only of major importance when they are deposited in longer-lived biomass such as the woody components of AF etc [4]. Another advantage of having these perennial systems is that C sequestration does not have to end after harvesting the wood component. Because the boles, stems, or branches can also store carbon if processed in any form of long-lasting products [67]. The mean above and belowground biomass values of the current study are higher than the values reported by [58] in indigenous AF systems. Both studies were conducted in the same Zone of the region but different specific research sites. The author reported values from 34.9-59.2 t ha^{-1} for AGB and 11.6-19.2 t ha-1 for BGB. Results of this study were also relatively higher than the Coffee-Albizia association AF in southwestern Togo, which had an average value of 140 t ha^{-1} in its aboveground and 32 t ha^{-1} in belowground [22]. The total calculated biomass values in the studied three AF systems ranged from 108.0-328.1 t ha^{-1} were for the two of the three AF systems lower than Cacao agroforests of Cameroon with value (304 t ha^{-1}) [23]. However, the total biomass values in our study are still greater than the global average values reported for forests, and some tropical AF practices (149 t ha^{-1}) as [24] has reported. The variation in biomass stock among different AF systems might be attributed to several factors, for instance, the types of trees and shrubs included, the environmental conditions, type of soil, the level of land degradation, and age of the AF system [4]. Very low land degradation, good environmental conditions, and longer aged AF systems probably showed high biomass production and storage. The studied AF systems as being permanent systems with very little land degradation and of older age exhibited larger biomass.

The total biomass of fruit trees and non-fruit trees in C-Ft-E based AF system was significantly different compared to the two remaining systems. This might be due to C-Ft-E based AF had quite higher number of fruit trees with vigorous growth and thus accumulated more biomass on its above and belowground. The contribution of enset, coffee, and litter to the mean above and below-ground biomass C stock of AF system was by far lower than the contribution from trees across all AF systems. Similar studies were conducted on the contribution of tree species to the total mean aboveground and belowground C stock and reported that trees had a greater share [73, 60].

When it comes to individual AF farms, the highest total biomass C stock recoded in the current study was substantially high as compared with shaded Coffee AF systems in south-western Togo reported by [22] with a value of 82 t ha^{-1}, tree-enset based home garden AF systems of Hawassa Zuria district (20-50 t ha^{-1}; [23]), and Enset based, Enset-Coffee based and Fruit-Coffee AF systems in similar region where our study was conducted (22-122 t ha^{-1}; [60]). Besides, [46] did extensive reviews on the biomass C stocks for West African Sahel countries. In their study areas that encompassed extremely arid and humid regions of Guinea they reported values ranging from 22.2 to 70.8 t ha^{-1}. These C values are lower than values reported in the current study of AF systems. In a review on biomass C stock of AF systems globally [20, 4] reported, ranges from 12-228 t ha^{-1}. Therefore, it is possible to summarize that the biomass C stocks of the studied AF systems fall within the global value range for AF systems and compare favorably to those of tropical forests and savannas in Brazil [75]. But the results of this study for Enset based, C-E based and C-Ft-E based AF systems are lower than tropical Cocoa-based AF systems (304 t ha-1) reported in Cameroon [23]. The high biomass C stock reported in this study, specifically in the C-Ft-E based AF system, is due to higher trees' density, a high number of fruit trees and non-fruit trees growing vigorously, and their considerable age. Similarly [19] and [10] pointed out that variance in the biomass C stock is influenced by a variety of factors, including tree age, species, density, and type and extent of management employed by the practitioner. Likewise, the sort of allometric equation utilized by different researchers to estimate biomass C stock could also cause discrepancies in the reported numbers [38].

4.2. Soil organic carbon stock

Agroforestry systems, as one of the tree-based land-use systems, can store more carbon in their soil system and thus come next to forest systems [54]. In general, the soil is considered a compartment of terrestrial ecosystems where the higher quantity of organic C is stored [11], and it is estimated at 2300 billion tonnes globally within one-meter soil depth [79]. This value is nearly 4.5 times the C stored in vegetation (610 billion tonnes). Higher SOC stocks are regularly observed in the upper most soil horizons because they get the first organic matter input from falling litter either by leaching or by biogenic activity. This is pattern is universally encouraged in most terrestrial ecosystems [78]. In this study, the greater share of SOC in the first layer (0-20 cm) might be also due to the abundant addition of litter and pruning biomass to the soil, thus enhancing the accumulation of more soil organic matter.

The highest total mean SOC stock for Enset based AF could be attributed to practitioners' efforts to trim down old enset leaves and mulch the ground, as well as slower mineralization rates due to the higher altitude (colder weather condition) [60]. From these results, AF which had the highest biomass showed lower SOC stock and vice-versa. The canopy closure and shading under C-Ft-E based AF is higher compared to Enset based AF system. But the average SOC stock under C-Ft-E based AF was lower due to high decomposition rate of the biomass assisted by high temperature and better nutrient recycling.

The average SOC stock value (137.1 t ha^{-1}) of all AF systems (0-40 cm) in this study was comparable with the global average 121-123 t C ha^{-1} and 110-117 t C ha^{-1} (0-60 cm soil depth) for tropical forests and tropical savannahs respectively [42]. However, the values were considerably higher than those reported for low land home gardens of southern Tigrai in Ethiopia (109.75 t C ha^{-1}, 0-60 cm soil depth; [77]), and semi-arid *Acacia etabica* woodland in southern Ethiopia (43 t C ha^{-1})[44]. AF systems in other tropical regions such as home garden AF systems of humid lowlands with a tree density of >750 stems ha^{-1} (70-120 t C ha^{-1}), Silvopastures (grazing and fodder) of humid lowlands with a tree density of >25 stems ha^{-1} (80-120 t C ha^{-1}), humid lowland and tropical highland wood lots >10 years old (80-100 t C ha^{-1}), humid lowland tree intercropping with a tree density of >100 stems ha^{-1} (50-120 t C ha^{-1}) [54] and for AF systems in central India (27 t C ha^{-1}) [81] were reported. The above reports showed a lower SOC stock than the AF systems of the current study. The mean SOC stock value for soil depth 0-20 cm under C-Ft-E, Enset based, and C-E based AF systems of this study was, however, lower than reported for Inga-shade organic coffee systems, Taungya systems, and polyculture-shade non-organic coffee systems in Chiapas, Mexico [78].

4.3. Ecosystem carbon stocks

Proper management of AF systems might help capture and store a significant fraction of the atmospheric C in plant biomass and soils [4]. Depending on the ecosystem type, the amount of AF total C stock fluctuates substantially from one AF practice to the next and from region to region. The insignificant difference in total AF C stock and SOC stock between the investigated AF systems was due to the fact that high biomass C stock do not mean it yields high SOC stock. Because the increase or decrease in SOC is highly affected by other factors such as management and extraction of biomass from the components of AF system, and soil management and land-use history [54]. These additional factors may play an important role in the SOC dynamics. The relation between biomass C stock and SOC stock is discussed in detail under 3.4.

These results are consistent with the study conducted on Enset based AF systems by [60] and reported greater contribution of SOC stock to the total ecosystem C stock. The type of ecosystem and latitude affects C stocks' distribution between biomass and soil. The biomass C and SOC stocks (for 1 m soil depth) showed variation among different forest ecosystems of the globe [21]. For instance, the highest SOC stocks were at high latitudes (343 t ha^{-1}), and the lowest was at low latitudes (121 t ha^{-1}). The highest biomass C stocks were in low latitudes, whereas the lowest was in high latitudes [21]. The author added the proportion of forest ecosystem C stock in biomass increased towards the tropics, from 16% at high latitudes to 50% at low latitudes. In general, majority of organic matter storage in tropical forests resides in biomass, which is followed by soil and litter with values of 58%, 41%, and 1%, respectively [17].

The average total AF C stock (biomass plus SOC) of the studied AF systems (207.1 t ha^{-1}) were higher than reported for lowland home gardens of southern Tigrai in Ethiopia, which have 148.3 t ha^{-1} for 60 cm soil depth [77]. They were 2.5 times higher than shaded coffee plantations of southwestern Togo [22]. It was also reported in a similar range in the shade-grown Coffee system of Indonesia 82 t ha^{-1} for 40 cm soil depth [85]. We could say that the studied AF systems sequester considerably more C from the above-reported C stock values than other tree-based ecosystems generally do in the tropics. However, it was lower than the tropical forest biomes (244 t ha^{-1}) [21].

4.4. Correlation between biomass carbon and SOC of agroforestry systems

The relationship between biomass carbon (BC) stock and soil organic carbon (SOC) stocks of AF systems could vary depending on different factors. Considering vegetation as one of the many factors influencing SOC stocks [64, 80], studies conducted in wide areas of the tropics showed that a consistent addition of tree/shrub prunings and their root turnover over the years have contributed to the accumulation of SOC [45]. Results that support the contribution of biomass C to the SOC were reported from different countries. For example, a trial of hedgerow intercropping that incorporated *Giliricidia sepium* and *Leucaena leucocephala* was done for 12 years in Nigerian Alfisol. As a result of incorporating the trees, the surface SOC was increased by 15% (2.38 t ha^{-1}); [31]. Likewise, after a five-year trial of hedgerow intercropping that incorporated *Inga edulis* on a Typic Paleudult soil in Peru, it also observed an increase of 12% (0.23 t ha^{-1}) SOC stock [5]. On the contrary, having more tree cover in a given land-use may not necessarily produce additional SOC stocks to the system. It is also affected by the existing extent of soil disturbances and other human interferences especially extraction of biomass or AF products [36]. This might be the reason why a very weak correlation between biomass and SOC under C-Ft-E based AF and C-E based AF was found. Other authors [34] also explained that SOC stock was influenced mainly by soil properties, but topography and vegetation had an insignificant impact. Also, [4] revealed that the contribution of biomass C stock to SOC stocks at farm and landscape level was attributed to factors such as soil types, precipitation and land-use, and land management.

In general, the relationship between the two variables might also be affected by other factors such as tree management (pruning, lopping, pollarding, etc.) and land-use history [54]. Besides, the age of the AF system, type and number of tree species included, and their rotation age [49], elevation and climate [4,78], soil type, and soil properties [34] might affect the relationship. The findings of the current study are consistent with several other studies where biomass C stock and SOC stocks showed a very weak relationship, even negatively correlated [63, 67, 59].

Higher SOC stock in older AF systems points toward a lasting accumulation of organic matter over the years and an aggradation of soils from AF practices. From the r-values, it could understand that most AF farms with less slope percent showed a higher SOC stock. This might be due to the biomass incorporation into the soil more pronounced in gentle slope AF farms as a result of the accumulation of biomass by gravity. In the upper slope position where loss of organic matter is more than in gentle lower slopes, which are typically accumulation sites. The r-value under C-Ft-E based AF system was very low. This implies farms that are situated in lower elevation and gentler slope are less affected by slope percent for their SOC stock.

From these results, it could be understood that the richer households have less tendency of using biomass from the trees and shrubs for the purpose of house construction, cooking, and other uses. In addition, the richer households have larger landholding and thus the extraction of biomass per unit area of the AF farm may be less than with poor households. However, the poor people are more or less dependent on biomass for different uses and thus lessen the biomass input to the soil. It was assumed that households with more livestock could utilize more biomass as a forage than those who have less livestock. This implies that if significant biomass is consumed by the livestock the biomass input returned as a litter to the soil could be dramatically decreased. As a result, the practitioners who have more livestock numbers showed comparatively less SOC stock under their AF farms than those with fewer livestock numbers. Therefore, in the current study SOC was negatively correlated with the number of livestock.

4.5. Relationship between biomass C and Abundance, Shannon diversity, Marglef's richness

The level of biomass carbon stock of AF systems could be also affected by structure and composition of the tree species. For instance, abundance, diversity, and rich ness of the tree/shrub species within the AF system. The relationship between BC and plant diversity observed in C-Ft-E-based AF of the current study is consistent with the home garden AF of southern Ethiopia in which they found a weak correlation between woody species diversity and biomass C stock [14]. This implies that high plant diversity might not be linked to greater BC stock. It may be rather due to the fact that these AF systems encounter more human interference and greater disturbance levels, which resulted in lower number of plants and lower biomass production [66]. Socio-economic factors may also play an important role.

The correlation between BC and species richness in C-E based AF was strong and positive. Similar results were reported by [73, 60], who conducted research in Enset-Coffee-tree agroforests. We had hypothesized in the current study that plant abundance would have a strong correlation with BC stock than with plant richness. However, a weaker correlation of plant abundance with BC stock was found compared to the correlation of BC stock with plant richness. [84] emphasized that C stock of AF systems depends more on their functional diversity than on woody and non-woody plant species diversity. [29] and [47] also pointed out the biomass increment is more likely dependent on tree richness than tree diversity thus AF systems which have greater richness are expected to produce more biomass and then greater biomass C.

The benefits of AF acquired from enhanced C sequestration is a promising incentive to introduce AF practices. This, in turn, contributes to sustainable land-use in tropical regions [82]. Considerably high C stocks in the studied AF systems can be a convincing argument that they make a significant contribution to C sequestration and climate change mitigation than some other land-uses. The upcoming success in C trading and payments through the operation of payment for ecosystem services and REDD+ programs could help local communities to maintain AF systems by utilizing these incentives [83]. In addition, the financial cost needed to sequester C through AF is expected to be much lower (approximately $1–69/t C, median $13/t C) than through other CO_2 mitigating options [83]. This is because some costs related to tree planting and management, land management, and planting material could be easily offset by the monetary gains from the multiple AF products and C trading incentives.

4.6 Soil organic carbon stocks of AF systems versus their adjacent monocropping farms

The higher litter input from tree and shrubs in AF systems adds more decayed plant material to the soil and thus has the capability to increase SOC through the decomposition process [43, 69, 33]. It is not surprising to see greater SOC stock in AF systems than the adjacent monocropping farms, but the aim was to investigate the extent of significant difference. The difference was highly significant except for Enset based AF. The reason for insignificant difference Enset based AF versus its adjacent monocropping farms might be due to soil management employed to these monocropping farms such as addition of livestock manure, ashes, and compost by farm owners. The high amount of SOC stock in the three AF systems might be due to the AF systems have more litterfall which contributes organic matter to the soil while in monocropped fields a smaller amount of crop residues might be left in the field. Another reason could be due to the lignified cells found in trees' litter, branches, bark, roots, etc., which could lead to C stabilization and slower mineralization in the soil [76]. The slower oxidation rate of organic matter under the tree shades [27], the addition of root exudates [13], and accumulation of more organic matter as a result of fine root degradation in the underground [37] might also initiate to higher SOC stock. Similar results were reported by [29], who found higher SOC stock in home-garden AF than food crops mono-culture land, [68] home-garden AF systems showed 114% greater SOC stock than rice paddies, and [33] observed increased soil organic C by 11-52% in AF systems compared to monocropping fields. Also, in a study which was conducted by [6] in central Amazonia of Brazil, similar levels of SOC under AF were reported. Therefore, we could understood that AF systems have higher SOC levels than monocropping fields, even sometimes similar level with forest areas depending on the plant mixture and management of the AF system.

5. Conclusion and recommendations

Higher C stores, either above or belowground, are achieved when the land-use systems are integrating perennial plant species, and an effective management is employed.

Agricultural techniques that integrate sufficient trees and shrubs, for example, AF systems, have a higher C repository. As several authors reported majority of the C sink in AF land-use systems happens in the soil. Similarly, the investigated AF systems showed a higher SOC stock. This is a good advantage to sequester more C in the system sustainably. Because soils have the capacity to maintain and store most C fractions for a longer period than biomass. From the findings of the current study, it could understood that the variation in biomass and total C stock among the AF systems is mainly influenced by altitude, silvicultural management, types of trees and shrubs included and density of the stand. Relatively higher C stock in the indigenous AF systems of the south-eastern rift-valley landscapes Ethiopia is an indicator of their potential to serve as large sinks for C. As a result, these land use systems might have a great role in sequestering significant amount of C and thus contributing to mitigate climate change. Quantifying the C stock and understanding the potential of the studied AF systems to store C may help to design and develop climate change mitigation strategies. It further contributes to develop a national policy concerning the mitigation of climate change and the implementation of international mechanisms such as $REDD^+$ (Reducing Emission from Deforestation and Forest Degradation) and CDM (Clean Development Mechanism).

To maintain and utilize the great potential of AF systems to sequester C sustainably, the government should think of ways to scale-up these practices to different parts of the country. A strategy that benefits AF practitioners from carbon trading should also be designed and planned. Because this would encourage farmers to conserve woody and non woody perennial plants for the long-term, thus fostering more C to be stored in the biomass and soil permanently. This could be done by linking with governmental or non-governmental projects working on carbon trading.

Author Contributions: Tesfay, HM. generated the idea and study design, collected data, carried out the laboratory work, data analysis, and write up. Negash, M. and Hager, H. supported in study design, read, reviewed, and shaped the manuscript to the present form. Godbold, D. L. also reviewed the manuscript. All authors have read and agreed to the manuscript.

F**unding**: Austrian Partnership Programme in Higher Education and Research Development (APPEAR) and International Foundation for Science (IFS Grant. #D/6183-1) this research as part of a Ph.D. study.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: This is not applicable to this article since no data sets were generated.

Acknowledgments: I am grateful to the Austrian Partnership Programme in Higher Education and Research Development (APPEAR) for giving me the scholarship award to pursue my study in Austria. I acknowledge financial support from International Foundation for Science (IFS Grant. #D/6183-1) and Federal Research and Training Centre for Forests, Natural Hazards and Landscape department of Biodiversity and Nature Conservation, Vienna, Austria. I am grateful to Prof. Herbert Hager and Dr. Mesele Negash for their indispensable support from the beginning to the end. I would like also to extend my gratitude to Prof. Douglas L. Godbold for his valuable review. The University of Natural Resource and Life Sciences (BOKU) institute of Forest Ecology, Austria, and Hawassa University, Wondo Genet College of Forestry and Natural Resources, Ethiopia, are also acknowledged for offering me the postgraduate study opportunity. We are also indebted to Gedeo zone experts and the farmers for allowing us to visit and carry out this study on their farms and for providing marvelous experiences.

Conflicts of interest: We declare that no conflicts of interest.

Appendix 1 Correlation between BC stock and SOC stock in the three AF systems

		BC stock of C-Ft-E based AF	SOC stock of C-Ft-E based AF	BC stock of Enset based AF	SOC stock of Enset based AF	BC stock of C-E based AF	SOC stock of C-E based AF
BC stock of C-Ft-E based AF	Pearson Correlation	1					
	Sig. (2-tailed)						
	N	10					
SOC stock of C-Ft-E based AF	Pearson Correlation	-.005	1				
	Sig. (2-tailed)	.989					
	N	10	10				
BC stock of Enset based AF	Pearson Correlation	.184	-.186	1			
	Sig. (2-tailed)	.612	.606				
	N	10	10	10			
SOC stock of Enset based AF	Pearson Correlation	.080	.055	.458	1		
	Sig. (2-tailed)	.825	.881	.183			
	N	10	10	10	10		
BC stock of C-E based AF	Pearson Correlation	-.088	-.069	.029	-.527	1	
	Sig. (2-tailed)	.810	.850	.937	.117		
	N	10	10	10	10	10	
SOC stock of C-E based AF	Pearson Correlation	-.552	.008	-.412	.415	-.246	1
	Sig. (2-tailed)	.098	.983	.237	.233	.493	
	N	10	10	10	10	10	10

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