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Original Article

Diversity of Shade Tree Species and Carbon Stock in Smallholder Coffee-Based Agroforestry System in Southwest Ethiopia

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What is already known on this topic?

- *This coffee-based agroforestry system well- practiced at farm level and home garden in Gomma woreda for long period by local community. In this system, farmer manage and use different multipurpose shade trees species for coffee production. Local community manage different multipurpose shade tree it is not only for shade purpose their also use ecosystem services like expansion of household income, fiber, food, and energy. Even if, local community use this multipurpose there is limited scientifically information on diversity of shade tree species, and role of coffee-based agroforestry for climate change mitigation at Gomma Woreda.*

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ABSTRACT

Coffee agroecosystems are essential for preserving woody species diversity and sequestering carbon. In a smallholder coffee-based agroforestry system, various shade tree species were identified, and the carbon stock was measured along an altitude gradient in the Gomma district. Two villages were selected randomly from each category after the elevation gradients were separated into upper, middle, and lower categories. Sixty sample plots with a coffee-based agroforestry system were used to gather soil samples and data on the number, diameter, and height of various shade tree species. According to the results, a total of 24 species of shade trees belonging to 17 families were found, and the diversity of tree species was higher at lower elevations (2 ± 0.04), medium at middle elevations (1.73 ± 0.029), and lower at upper elevations (1.63 ± 0.02), according to the elevation categories. Coffee-based agroforestry systems are crucial for preserving wood species diversity and carbon sequestration at the farmer level in the Gomma district.

Keywords: Biomass, shade tree, smallholder, soil organic carbon

Introduction

Nowadays, biodiversity loss, and climate change are major worldwide challenges that have a greater influence preceding the livelihoods of society living in the tropics, including plant and animal species (Thornton et al., 2009). These biodiversity loss and climate change are the outcomes of global human activity, including industrialization, urbanization, and the expansion of agricultural land. Human activities increase greenhouse gas emissions, habitat fragmentation, the introduction of non-native species, and the overexploitation of existing species, all contribute to biodiversity loss and global warming, respectively.

Ethiopia's rapid population growth degrades natural resources and raises vulnerability to climate change and biodiversity loss. According to Bekele and Lakew (2014), Ethiopia's population grew gradually from 83.7 million in 2012 to 133.5 million in 2032 and 171.8 million in 2050, with a doubling time of 83 years in 2050. Today, various native multipurpose tree species in Ethiopia are endangered due to the expansion of agricultural land and the introduction of exotic tree species to meet human needs. *Juniperus procera, Hagenia abyssinica, and Boswellia papyrifera* are examples of endangered tree species in Ethiopia that provide both economic and ecological benefits.

There are several ways to reduce the effects of climate change and biodiversity loss, one of that is the agroforestry system. Agroforestry is a dynamic, ecologically based system for managing natural assets that incorporate trees on farms to diversify agricultural landscapes. Agroforestry practices include home gardens, woodlands, farm boundary practices, coffee shade tree systems, and trees on grazing lands (Sanchez, 1999).

Additionally, it is a land-use system that offers cultural services like agro-tourism, appealing values, and education in addition to a variety of ecosystem services like the expansion of income for families, roughage, food, and energy to local communities (Negash et al., 2013). Agroforestry systems have historically been used extensively as a means of attaining agricultural sustainability and reducing the detrimental consequences of agriculture, such as soil erosion and desertification (Gupta et al., 2020). Adopting agroforestry-related practices is one of the management strategies that has the potential to increase biomass and, as

What this study adds on this topic?

- *Therefore, study's goals were to measure carbon stocks and investigate the diversity of woody species in a coffee-based agroforestry system in Goma woreda along three gradients. These were the study area's lower, middle, and upper elevation gradients. Smallholder coffee-based agroforestry systems were included in this study to help mitigate climate change along elevation and conserve wood species diversity in the study area. Additionally, this study shows no relationship between the carbon stock in the study area and the diversity of wood species. In light of this, this study adds to the body of knowledge by demonstrating that small-holder coffee-based agroforestry systems have a significant role in mitigating the effects of climate change and woody species conservation. A total of 24 woody species, belonging to 17 families, that are used as shade have been identified and documented in coffee-based agroforestry systems.*

a result, higher carbon storage. This is because tree-based systems have a higher biomass lifespan than grass-based systems.

Agroforestry systems as a mitigation strategy for greenhouse gas emissions (Nair et al., 2009). Geographic location, previous land use system, species composition in agroforestry systems, climate, soil characteristics, and species management practices are a few of the variables that affect these systems' ability to sequester carbon (Dossa et al., 2008). In semi-arid, sub-humid, humid, and temperate regions, the potential carbon storage capacity of agroforestry is estimated to be 9, 21, 50, and 63 t C/ha, respectively (Montagnini & Nair, 2004). Luedeling and Neufeldt (2012) also carried out extensive reviews for West African Sahel countries and showed that biomass carbon stocks range from 22.2 to 70.8 t C/ha.

Coffee-based agroforestry systems, which combines trees and coffee shrubs to produce economic benefits for the surrounding people, are an example of an agroforestry system. To expand the possibilities for land use and diversify rural livelihood income, certain Ethiopian regions have embraced agroforestry techniques (Vanderhaegen et al., 2015). This coffee-based agroforestry scheme, which has been around for a while, helps to mitigate climate change and preserve the richness of woody species in the south and southwest of Ethiopia. Ethiopia specifically uses coffee-based agroforestry systems on farmlands, in home gardens, and in homesteads. In these systems, where shade tree species dominate at the upper strata, coffee shrubs occupy the middle strata, and extra food crops are predominantly grown under the coffee.

This coffee-based agroforestry system has been implemented at the farm level and in home gardens in Gomma Woreda by the local people. In this system, coffee production is not only beneficial for benefiting from coffee itself but also it is for cultivating different crops on the same land management unit, for better utilization of the land's potential, and contributing to mitigating climate change and conserving diversity. Even if the local community manages different multipurpose shade trees, there is limited scientific information on the diversity of shade tree species and the role of coffee-based agroforestry in climate change mitigation in the Gomma district. Furthermore, factors influencing wood species variety and carbon storage in agroforestry systems, such as site quality, prior land use, and environmental characteristics such as elevation, slope, and gradient aspect (Fahey et al., 2010), were not addressed in the research region. Therefore, the goal of this study was to measure carbon stocks and evaluate the diversity of woody species in coffee-based agroforestry systems along the elevation in Gomma district, Jimma Zone, Southwest Ethiopia.

Objective of This Study

Woody species diversity was assessed in coffee-based agroforestry system along the elevation at the farm level.

Carbon stocks were quantified in a coffee-based agroforestry system along the elevation in the Gomma district.

Procedures of Study

Research Area Description

The research was conducted in the Gomma district, Jimma zone, Oromia Region, Southwest of Ethiopia. Gomma district is one of the 17 Woredas in the Jimma Zone known for growing coffee. It is situated approximately 50 km west of Jimma town and 403 km southwest of Addis Ababa. Geographically, it is located between 34°30′ and 38°E and 6°49′ and 9°10′N (Figure 1). Gomma district is bordered by Seka Chekorsa to the south, Gera to the southwest, Setema to the northwest, the Didessa River to the north, which divides it from the Illubabor Zone, Limmu Kosa to the northeast, and Mana district to the east. This district contains one of Ethiopia's biodiversity hubs for coffee (IMPS, 2007).

The Study Area's Topography and Climate

The district lies between 1387 and 2870 m above sea level. The majority of the district is situated between 1849 and 2067 m, and between 1387 and 1643 m above sea level. However, there are not many places in the Woreda that are higher than 2229 m above sea level. Three agro-ecological zones make up this Woreda: 8% is highland (dega), 88% is mid-highland (woina dega), and 4% is lowland (kola) (Productivity & Success, 2007). The area receives between 800 and 2000 mm of rainfall on an average year, and the mean lowest and maximum temperatures range from 7°C to 12°C and 25°C to 30°C, respectively (JZARDO, 2008). With sporadic showers in March and April, the primary rainy season spans from June to October.

Soil

The most dominant soil type is nitisols, which make up about 90% of the Woreda. These soils are also young and acidic. Consequently, farmers grow crops that can withstand acidity. Gomma soils have a pH range

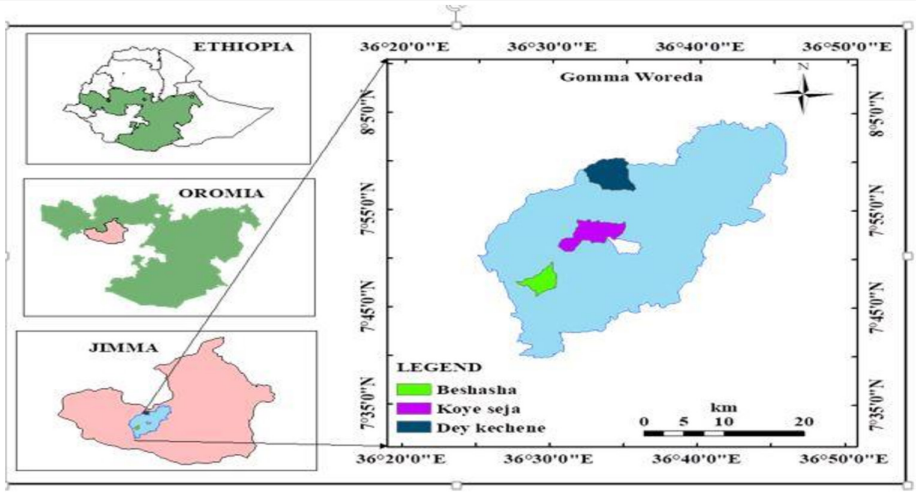

Figure 1.
Map of the Research Area.

of 4.5-5.5. Nonetheless, poisoning from aluminum and magnesium is uncommon (IPMS, 2007).

Land Use Type

The district has four land use types: grazing land, agriculture, and forest. A total of 60.7% of the district's land is considered arable or cultivable; 8.1% is pasture, 4.6% is forest, and 20.1% is deemed unusable (GMWO, 2021). Fruits and spices are significant cash crops (IPMS, 2007). Coffee is the most important cash crop in Gomma, with over 50 km^2 under cultivation. Farmers grow coffee under a variety of shade trees and with sorghum, haricot beans, and maize as the three main crops are farmed in the woreda (JZARDO, 2008).

Means of Livelihood

Coffee production provides a livelihood for woreda communities and a significant portion of the producers' income. For this reason, about 86.7% of communities earn their income from coffee production as a primary source (GMWO, 2021). The selling of honeybuns, *Catha edulis*, cereals, fruit trees, livestock, wood, and other non-timber forest products also helps the local community by providing extra revenue and support for their way of life. These products can be used for revenue generation, domestic consumption, or both.

Technique of Sample and Data Collection

A multiple-stage sampling method was used to gather soil and vegetation samples. During the initial stage, the Gomma district, known as the coffee-growing area, was purposefully selected. To create homogenous units, the research area was divided into three elevational categories at the second stage: lower (1300–1643 m), intermediate (1849–2067 m), and higher (2229 m above). Kebele in each elevation category was classified into non-coffee producers and coffee producers at the third level (GAO, 2021). Following stratification, two hamlets (villages) from each kebele were randomly chosen at the fourth stage, and three kebeles, namely Dey Kechene from the lower, Koye Seja from the intermediate, and Beshasha from the higher were chosen at random as coffee-growing kebeles (Table 1). The farms were selected randomly per selected village categories for wood species and soil samples, respectively. Overall, 60 farmers' farms were randomly selected for soil sampling and wood species inventory in the study area. Sampling quadrats of 20 m × 20 m were established in the selected farms' coffee farm for woody species inventory.

Vegetation Sampling

Inventory of woody species with a diameter of 5 cm and above was carried out in each quadrat as described in Haretche et al. (2012). By means of a caliper or diameter tape, the diameters of all woody species in the 20 × 20 m^2 plot with diameter at breast height (DBH) (1.3 m above the ground) >5 cm were measured. For coffee, the diameters were taken at 40 cm plant height (Negash et al., 2013). Plant species below 5 cm DBH was not considered in this study because they were continuously removed from the system through farm management activities. A clinometer (Suunto PM-5/360 Pc, Finland) was used to measure the height of woody species, and gobal positioning system (GPS) was used to record the elevation of each sampling plot. For the purpose of the woody species inventory and soil sample collection, a total of 60 farmers were chosen from each hamlet. Using the flora of Ethiopia and Eritrea and shrubs of Ethiopia, the woody species were identified (Hedberg, 1996).

Design for Soil Sampling

Soil samples for soil organic carbon (SOC) measurement were collected at depths of 0–30 cm and 30–60 cm in each plot using an "X" configuration. Using an auger in the center of each quadrat, trials were collected from five locations within a 1 m ×1 m area (Negash et al., 2013). The five soil samples were mixed within every plot (Takimoto et al., 2008). Soil organic carbon was determined using 120 composite soil samples. A 5 cm long and 5 cm wide core sampler was used to collect 120 bulk density (BD) soil samples (Roshetko et al., 2002).

Table 1.
Kebele Chosen for Sample in the Gomma District Along Slopes in Elevation

Altitude Gradient	Kebele	Village
Upper	Beshasha	Tabba Kollo
		Echemo Kararo
Middle	Koye seja	Koye Sayyoo
		Cida Bero
Lower	Dey kechene	Gota Misoma
		Hunda Oli

Estimation of Carbon and Biomass Stocks

To calculate the plant species' above- and below-ground biomass in the agroforestry systems, a generic multi-species allometric equation was used. Kuyah et al. (2012) developed an equation in Western Kenya that was used to calculate both above-ground and below ground biomass of all trees and shrubs, respectively (Table 2). This may be attributed to the formulation of equations for trees growing in Western Kenyan agroforestry systems, which have the lowest error of prediction values and the greatest R^2 values. In addition, allometric equations developed in Southern Ethiopia by Negash et al. (2013) were used to evaluate the biomass of coffee above as well as below ground. As per Kuyah et al. (2012), it was calculated that the biomass carbon stock for woody species was 48%, while the biomass stock for coffee was predicted to be 49% (Negash et al., 2013).

In order to determine the amount of carbon in the soil, soil samples were air-dried and then run through a 2 mm filter. The Walkley–Black method and established procedures (Walkley & Black, 1934) were utilized to compute the soil organic carbon. The soil BD was computed using the core sample method (Blake, 1965). The soil samples were dried at 105°C for a whole day in an oven.

With splitting the bulk of the oven-dried debris by the core's overall volume, the BD was calculated. Utilizing (Pearson et al., 2013), soil organic matter was computed. Soil organic carbon (mg/ha) = (% of organic carbon content × bulk density of soil (gm/cm^3) × horizon thickness (cm) × 100. By adding the carbon stock values for the two layers (0–30 cm and 30–60 cm), the carbon stock for the 0–60 cm layer was determined (Negash and Starr, 2015). The total above ground biomass carbon (AGBC), below ground biomass carbon (BGBC), and SOC stock were determined at the farmer level as the overall carbon stock of the coffee-based agroforestry system.

Statistical Analysis

The species richness, evenness index, and Shannon diversity index were used to analyze the diversity of woody species. The overall number of species in the community is known as species richness (Krebs, 1999). To describe species diversity, the Shannon–Wiener diversity index, species richness, and evenness were computed (Shannon & Weaver, 1949). Additionally, the Sorensen coefficient of similarity was used to determine how similar certain groups were to one another. The important value index (IVI) was developed by summing relative density, relative frequency, and relative basal area.

Table 2.
Allometric Equations for Woody Species and Coffee

Species	Equation	R^2	*D* (cm)	*C*%	Source
Wood species	$AGB = 0.225 \times d^{2.341} \times p^{0.73}$	0.98	≥2.5	48	Kuyah et al. (2012)
	$BGB = 0.490 \times AGB^{0.923}$	0.95	>10	48	Kuyah et al. (2012)
	$BGB = 0.28 \times AGB$	_	≤10	48	Kuyah et al. (2012)
Coffee	$AGB = 0.147 \times d40^2$	0.80	≥3.8	49	Negash et al. (2013)

Note: AGB, above ground biomass kg/plant; BGB, below ground biomass kg/plant; D, diameter at breast height (cm); d40, diameter of coffee at 40 in (cm); R^2, coefficient of determination; p, wood density.

Shannon diversity index was calculated as below:

$$H' = -\Sigma_1^s \, pilnpi \quad (1)$$

Where, H' = Shannon diversity index.

pi = the proportion of individuals found in the ith species.

S = the number of species.

Ln = natural logarithm.

Value of the index (H') usually lies between 1.5 and 3.5, although, in exceptional cases, the value can exceed 4.5 (Burrage et al., 1993). The higher the diversity, the higher the H' value. The variety in the relative abundance of species is referred to as evenness. The evenness index describes the equality of species abundance in a community. Evenness (E) was determined and used to evaluate the homogeneous distribution of tree species on farms (Burrage et al., 1993).

$$E = \frac{H'}{\ln S} \quad (2)$$

Where, E = species evenness and H' = Shannon diversity index.

According to Burrage et al. (1993), E has values between 0 and 1, with 1 denoting complete evenness.

Similarity Indices

Similarity indexes assess how similar the species compositions of different systems are. There are numerous methods for determining the similarity or dissimilarity of vegetation samples or quadrats. The Sorensen similarity coefficient is frequently used in qualitative data because it gives more weight to species that are found in both samples rather than those that are found only in one (Kent et al., 1997).

The Sorensen coefficient of similarity (*Ss*) is given by the following formula:

$$S = \frac{2a}{2a + b + c} \quad (3)$$

Where *Ss* is Sorensen's similarity coefficient, *a* is the number of species common to both samples, *b* is the number of species distinctive in sample 1, and *c* is the number of species distinctive in sample 2

Population Structure

The significant value index (IVI), frequency, density,DBH, and basal area were used to characterize the population organization. The biophysical data from the study were used to identify and categorize woody species into different structural distributions. Mekonen et al. (2015) categorized DBHs based on their thickness. A formula was used to determine the basal area:

$$BA = \frac{(DBH)^2}{4} \quad (4)$$

Where BA = basal area (m^2), D = diameter at breast height, and $\pi = 3.14$.

Density is defined as the number of individuals of a species within a given area. The total number of individuals observed in plots was converted to hectares to assess the density of woody species. The frequency of identifying a species in a certain sample location or quadrat is defined (Kent & Coker, 1992). As a result, it shows the presence or absence of a certain species within each sample plot. The significance value index (Kent and Coker, 1992) is a composite indicator based on species frequency, abundance, and dominance relative measurements. It denotes the importance or structural importance of a species in the system.

Significant value index was calculated as follows:

IVI = Relative Frequency + Relative Density + Relative Dominance

$$\text{Relative density (RD)} = \frac{\text{Number of individual of one shade tree species}}{\text{Total number of individuals}} \times 100 \quad (5)$$

$$\text{Relative dominance (Rd)} = \frac{\text{Dominance of a shade tree species}}{\text{Dominance of all species}} \times 100 \quad (6)$$

$$\text{Relative frequency (RF)} = \frac{\text{Frequency of a shade tree species}}{\text{Frequency of all species}} \times 100 \quad (7)$$

Statistic Evaluation

One-way analysis of variance (ANOVA) was used to look for important causes of differences in above and below-ground biomass carbon, soil organic carbon stock, diversity index, and IVI. The normal probability plot was used to determine if the data on biomass carbon and total carbon stock fulfilled the normal distribution requirements.

Mean separation was carried out using the least significant difference (LSD). The correlation between the diversity of woody species and the carbon stock was examined using Pearson's correlation test. Statistical package for social science (SPSS) software version 20 and SAS software version 9.3 were used for all statistical calculations.

Results

Woody Species Composition

An overall of 24 woody species used as shade that belong to 17 families were identified and recorded in coffee-based agroforestry systems. Only nine of the tree species recorded were exotic, with 15 being indigenous. Five species were found in the Fabaceae family, while two species were found in the Moraceae and Oleaceae families, respectively.

Diversity of Wood Species

In the study area, Shannon index and evenness showed statistically significant variations observed along the elevation gradient. The lowest site (Table 3) had the greatest mean Shannon–Wiener and Shannon evenness indices, suggesting that it was more diversified than the top locations. Compared to the upper elevation, the lower site had a

Table 3.
Woody Species Diversity Indices in Coffee-based Agroforestry System in Gomma District

	Diversity Indice	
Elevation Gradient	Shannon (*H'*)	Evenness (*E*)
Lower	2 ± 0.04a	0.84 ± 0.017a
Middle	1.72 ± 0.029b	0.83 ± 0.014a
Upper	1.63 ± 0.02b	0.79 ± 0.011b
F	40	3.69
p	.0001	.0265

Note: The unlike letters across a column on the mean values determine a statistically significant ($p < .05$) difference between elevation gradients.

Table 4.
Sorensen's Similarity Index (%) Among Elevation Gradients in Gomma Woreda

Altitude Category	Lower	Middle	Upper
Lower	100	24	24
Middle	–	100	71
Upper	–		100

Table 5.
(Means) Richness and Abundance of Woody Species Per Plot of the Gomma Woreda Agroforestry System in Southwest Ethiopia

No	Kebele	Richness	Abundance
1	Lower	9.5 ± 1.2a	14 ± 2.9a
2	Middle	4 ± 0.8b	27 ± 4.6b
3	Upper	4 ± 0.8b	29 ± 4.5b
4	*p*	6.39	4.9
5	*p*	0.005	0.015

Note: The different letters across a column on the mean values demonstrate a statistically significant ($p < .05$) difference between elevation gradients.

Table 6.
The Species Found in This Coffee-Based Agroforestry System Varied in IVI for Each Category of Elevation

Elevation Class	Scientific Name of the Species	Importance Value Index (%)
Upper	*Croton macrostachyus*	43.76
	Albizia gummifera	30.64
	Cordia africana	13.06
	Milicia excels	13.00
	Grevillea robusta	12.18
Middle	*A. gummifera*	27.98
	C. africana	22.86
	C. macrostachyus	16.39
	G. robusta	12.02
	Millettia ferruginea	15.28
Lower	*A. gummifera*	19.53
	C. macrostachyus	12.52
	C. africana	10.09
	Ficus vasta	10.3
	Ficus sur	9.29

Table 7.
The Above- and Belowground Biomass Carbon Store (Mg/ha) Along Elevation Gradients (mean ± SE)

Elevation gradient	AGBC	BGBC
Upper	31 ± 4a	11.6 ± 1.3a
Middle	14 ± 3b	5.54 ± 1.1b
Lower	12 ± 3b	5.07 ± 1.1b
F	4.13	4.26
p	.027	.024

Note: AGBC, aboveground biomass carbon, BGBC, belowground biomass carbon.
The unalike letters across a column on the mean values indicate that there are significant differences between the elevation gradients at ($p < .05$).

Table 8.
Contribution of Trees and Coffee to Total Biomass Carbon (mg/ha) in Each Elevation Gradient

Elevation Gradient	Habitat	AGBC	BGBC	Total Biomass C
Lower	Tree	13.38	4.5	17.88
	Coffee	0.08	0.05	0.13
Middle	Tree	22.10	6.13	28.13
	Coffee	0.14	0.08	0.22
Upper	Tree	36.33	10.66	46.99
	Coffee	0.22	0.14	0.36

Note: AGBC, above-ground biomass carbon; BGB, below ground biomass carbon.

Table 9.
The Soil Organic Carbon Stock Along Altitude Gradients (mean ± SE) in Gomma Southwest of Ethiopia

Elevation Gradient	SOC
Lower	64 ± 3^{b}
Middle	75 ± 4^{b}
Upper	89 ± 4^{a}
F	8.39
p	.001

Note: SOC, soil organic carbon.

Table 10.
Over All Carbon Stocks (mean ± SE) (mg/ha) Along the Altitude Gradient in Gomma District

Elevation Gradient	Total Carbon Stock
Lower	82 ± 5b
Middle	95 ± 7b
Upper	132 ± 7a
F	16.35
p	.0001

Note: Different letters ordered on mean values along the column show a significant difference.

Table 11.
Pearson Correlation of Woody Species Diversity Index and C Stock (Mg/ha)

Correlation coefficient (*r*)	AGBC	BGBC	SOC	TCs
Shannon (*H'*)	−0.29	−0.23	−0.3	−0.34
Evenness (*E*)	−0.121	−0.12	−0.12	−0.16

Note: AGBC, above-ground biomass carbon; BGB, below-ground biomass carbon; SOC, soil organic carbon. TCs: Total carbon stock

noticeably greater variety. There was no significant difference ($p > .05$) in the variety of woody species found in the higher and intermediate sites.

Sorensen's Similarity Index

Sorensen's similarity index (Table 4) was used to characterize the similarities of woody species utilized as a shade in three altitudinal groups. The similarity index was computed based on the presence or absence of woody species in the plots that were sampled. The woody species composition likeness index is strongest at upper and middle elevations. The percentage of species in the middle and upper elevation groups is remarkably similar (71%).

Woody Species Richness and Abundance

The higher mean values in woody species abundance were recorded at upper and middle, and low woody species abundance was recorded at lower (Table 5).

Carbon Stock in Biomass Alongside Altitude

Along the gradients, the carbon stock changed significantly. Higher AGBC and BGBC were recorded at the top site, suggesting that as elevation climbed, the carbon stock rose, while lower AGBC and BGBC were found at the lower location (Table 6).

Trees at higher elevations had aboveground biomass carbon stocks that were 2.7 times higher than those at lower elevations, and coffee at higher elevations had aboveground biomass carbon stocks that were 2.4 times higher than those at lower elevations (Table 8).

Soil Organic Carbon Stock Along Elevation Gradient

As depicted in Table 10 the coffee-based agroforestry system at the upper elevation had noticeably higher (89 ± 4 Mg/ha) SOC than the lower elevation (64 ± 3 Mg) (Table 9).

The overall carbon stock of the upper was significantly higher than that of the middle and lower altitudes (Table 10).

Association Between Carbon Stock and Woody Species Diversity

There was no correlation between carbon stocks and the diversity of woody species (Table 11).

Discussion

The lowest numbers of species were found at the upper and middle elevations, while the highest numbers of woody species were found at the lower elevation. This could be because farmers may prefer to grow domestic plant varieties, especially fruit trees, which are the primary source of food and income, at lower altitudes compared to other plants. Environmental variables such as altitude, soils, terrain, species adaptation, and management techniques may explain variations in woody species composition and richness between locations (Negash, 2010).

There is a lot more diversity at the lower level than at the greater height. The number of woody species found in the top and intermediate sites did not differ significantly ($p > .05$). According to Tolera et al. (2008), the evenness, Simpson index, and Shannon diversity index were 2.22, 0.83, and 0.64, respectively. The woody species' Shannon diversity index ranged from 1.12 to 3 in the coffee-based agroforestry systems in Kerala Gardens, India, where this study was conducted (Mohan Kumar et al., 1994). The proportion of species was very similar (71%) between the medium and upper elevation categories. The findings of the study agree with those of Birhane et al. (2020) who found that there was a significant similarity between the elite and middle classes when it came to the home garden agroforestry practice.

The higher mean values in woody species abundance were recorded at the upper and middle, and low woody species abundance was recorded at the lower (Table 5). According to reports from Sidama's home gardens, the planting patterns of the woody species have a significant impact on their abundance. This could explain why there are more woody species per plot in the current study (Abebe et al., 2010). The lower elevation's abundance of woody species differed significantly ($p < .05$) from the higher and intermediate elevations. Lower elevation had the highest woody species richness found anywhere, and it differed significantly ($p <.05$) from both top and intermediate elevations. According to Abebe et al. (2010), socioeconomic factors, site characteristics, and farmers' preferences for tree species and functions in various locales could all contribute to the variation in woody species richness.

The species found in this coffee-based agroforestry system varied in IVI for each category of elevation. At lower and middle elevation categories, *Albizia gummifera* had the highest IVI, whereas *Croton macrostachyus* had the highest IVI in the upper altitudinal category. The IVI variation between altitudes in the coffee-based agroforestry systems was due to the variation in woody species density, DBH, and frequency. This finding is in line with the findings of Abebe et al. (2010), who reported four tree species with the highest IVI. Inferring that the despicable ABG and BGB indicate that the carbon stock increased with increasing elevation, with higher AGBC and BGBC recorded at the upper site, while lower AGBC and BGBC were recorded at the lower site.

Because coffee shade trees at intermediate and lower elevations are commonly used for other purposes, this rise was related to a higher frequency of people in higher DBH classes. Along the elevation gradient, there were significant changes in both above- and below-ground biomass carbon. The difference in upper elevation categories between AGBC and BGBC was significant ($p <.005$). This finding is congruent with the findings of Birhane et al. (2020), who discovered that the AGB and BGBC stock were highest at higher elevations in the Hawassa Zuria woreda home garden agroforestry system. Total mean AGBC and BGBC levels were 31 and 11.6 Mg ha^{-1}, respectively (Table 7).

Trees at higher elevations had 2.7 times the aboveground biomass carbon stores of those at lower elevations, while coffee at higher elevations had 2.4 times the aboveground biomass carbon stocks of those at lower elevations (Table 8). This could be attributed to the large overall number of people (Wang et al., 2011). As a result, a large number of tree plantations are required to boost the carbon stock of the research region, particularly in lower and middle elevations. Both tree and coffee species variety was high at lower elevations, but biomass carbon stock was low. This discovery was consistent with the findings of Birhane et al. (2020), who found increased species diversity and lower aboveground carbon at lower elevations in the forest.

Along an elevation gradient, the study area's overall SOC rose (Table 9). This is perhaps due to the felling old tree leaves, which had a slow rate of decomposition and mineralization in the cooler uplands than in the lowlands. Negash & Starr (2015) assert that the change in SOC along elevation is caused by the top elevation (lower temperature) of the Enset system in the southeast Rift Valley escarpment, Ethiopia, and lower mineralization rates as a result of those characteristics.

In various ecosystems, the distribution of carbon stocks between biomass and soil might change depending on the climate, and the total carbon stored at the upper was much larger than that of the medium and lower elevations (Table 10) (Negash and Starr, 2015). Furthermore, the average carbon stock of a coffee-based agroforestry system (103 Mg C ha^{-1}) was lower than that reported for Ethiopia's southeastern rift valley escarpment, where the average was 248 Mg C ha^{-1} (Negash & Starr, 2015). Total carbon stocks for coffee agroforestry plantations have been reported to range from 82 to 198 Mg ha^{-1}, with soil carbon accounting for up to 89% of the total (Schmidt et al., 2012).

Conclusion and Recommendations

The coffee-based agroforestry system, the primary land-use system in the Gomma district, is essential to land-use management and the provision of essential rural livelihoods. In addition to producing coffee, this agroforestry system contributes to the preservation of woody species diversity, sequestering carbon in biomass and soils, and producing other ecosystem services and products. Coffee shade trees provided farmers with valuable ecosystem services and goods, such as fruit, lumber, building wood, soil fertility management, feed, and soil and water conservation. Significant differences existed between altitudinal classes in terms of the species diversity index, evenness, richness, and density. Although lower elevations had the greatest diversity of woody species, higher elevation categories had higher biomass carbon and SOC than the lower elevations. The study's findings revealed no conclusive relationship between the diversity of woody species and carbon stock in an agroforestry system based on coffee. This indicates that differences in tree size more adequately account for carbon variation and that the diversity of woody species was not necessary.

Availability of Data and Materials: The data that support the findings of this study are available on request from the corresponding author.

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