Research Article

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Biodiversity and Carbon Stock Potential of Forest-Farm Interface in South-Central Highland of Ethiopia

Tamiru Kefalew[a*], Motuma Tolera[b] and Kefyalew Sahle[b]

[*a]*Madda Walabu University, P.O. Box: 247; Robe, Ethiopia.*

[b]*Hawassa University, Wondo Genet College of Forestry and Natural Resources; P.O. Box: 128; Shashemene*

[*]Corresponding Author
Kefalew T, Madda Walabu University, And P.O. Box: 247; Robe, Ethiopia.

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Abstract
Woody species diversity and carbon stocks of Forest-Farm interface (FFI) and adjacent natural forest (NF) and farm land (FL) were assessed in south-central highlands of Ethiopia. Vegetation and biomass carbon stock data were collected from a total of 30 plots from each land use. In each plot, diameter at breast height (DBH) of all woody species ≥ 2cm and height of ≥ 1.5m height was measured. A total of 15 soil sample were collected from every other plots of woody species inventory plots. Soil samples were collected from 0-30 cm and 30-60 cm depths from three diagonally established subplots containing (1m2). One-way analysis of variation (ANOVA) was used to compare variation of total carbon stocks and woody species diversity and two ways ANOVA was used for multiple comparison of soil organic carbon stock (SOC) among depth and land use. Pearson correlation was used to determine relationship between woody diversity and carbon stocks. The result showed that Fisher alpha diversity in FFI is 7.34 and that of NF and FL are 5.22 and 3.38 respectively and it is significantly different (F= 58.7; DF =2, 87; p < 0.05). The total carbon stock in FFI is 2044.05 (SE = ± 13.9) tons ha-1 while it is 348.5 (SE = ± 47.6) tons ha-1 in NF and 28.1 (SE = ± 12.5) tons ha-1 in FL. Similarly, the total carbon stock of FFI is significantly higher than FL ((F = 28.9; DF = 1, 28; P < 0.05) and is significantly lower than that of adjacent NF (F = 8.4; DF = 1, 28; P < 0.05). The result shows that the relationship gets stronger with increasing species diversity (r = 0.10, 0.21 and 0.40 for FL, FFI and NF respectively at P < 0.05). In every aspects assessed in this study, the FFI has proved to play significant role in conserving biodiversity and carbon stock as compared to the adjacent NF. Hence, sustainable management of the landscape under FFI is important to sustain its environmental and economic contributions.

Keywords: Biodiversity; Biomass; Soil organic carbon; Land use: Relationship.

1. Introduction

According to Pan et al., forest ecosystems are thought to be the primary carbon sinks and potentially lessen the effects of climate change [1]. Being the most diversified terrestrial ecosystem, it is also home to two-thirds of all land-dwelling plants and animals [2]. However, the natural forest (NF) and the associated biodiversity in the tropics are under growing threat from anthropogenic sources. According to FAO (2016), from 2000 to 2010, tropical nations saw an annual net loss of 7 million hectares of forest and an annual net increase of 6 million hectares of agricultural land. Low income nations reported the biggest net loss of forests and the highest net gain in agricultural land over the time period.

Like many other tropical countries, the forest cover of Ethiopia is shrinking at an alarming rate. Reported that Ethiopia's forest is declining at about 141,000 ha per annum. The deforestation and forest degradation in Ethiopia is mainly driven by expansion of farm land (FL), free livestock grazing, and extraction fuelwood [3]. This co-existence of trees and agricultural activities are more common at the Forest-Farm Interface (FFI) where trees are an integral part of many farm-households [4, 5]. FFI is an area created through encroachment into forests and it is found under intensive economic activities dominated by crop farming, grazing, and utilization of forest products [4, 5]. Trees in the FFI play an important role in maintaining woody species diversity and also would offer potential of C sequestration in developing countries [6, 7].

Nevertheless, the contribution of FFI in maintaining woody species diversity and carbon stocks is less studied and managed leading to declining environmental and economic services from trees in the FFI. For planning sustainable management of FFI, it would be important to generate quantitative information on environmental role of FFI. Such information will guide policy makers to make informed decision on its management. Hence, this study is initiated to assess woody species diversity and carbon stock of FFI in south-central Ethiopia.

2. Materials and Methods

2.1. Description of the study area: The study was conducted in south-central highlands of Ethiopia. The study site is geographically located between 8° 11'- 8° 41' N and 38° 45' - 39° 49'E. The average annual rainfall in the study area is 1200 mm while the average annual minimum and maximum temperatures are 10°C and 25°C, respectively [8]. The major agricultural activity in the study area is a mixed farming system which encompasses both crop production and livestock rearing [9]. The soil type of study area is Mollic Andosols [10].

2.2. Sampling techniques and method of data collection: Data for this study was collected from NF, FFI and FL which are adjacent to each other and also found on the same agro-ecology (same altitudinal range, soil type). Vegetation and biomass carbon stock was collected from a total of 30 systematically laid plots in each land use. The distance between transect lines and consecutive sample plots were 200m. The sample plot size was determined based on expected density of woody species in each land use [11]. Nested plot design of 400m2, 25m2 and 1m2 size was used to collect vegetation data in NF. In the 400m2, all woody species ≥ 5cm DBH and in the 25m2 all woody species from 2cm to 5cm DBH were recorded. In the third nested plot (i.e. 1m2), woody species with < 2 cm DBH were recoded. Since the woody species in FFI is scattered, 50 m x 50 m was used. Finally, plot size of 50 m x 100 m was used for all diameter class for FL. DBH in each plot was measured following the techniques described in various relevant literatures [12, 13, and 14]. The complete list of woody species was made for each sample plot throughout the entire area and recorded by local name. Species identification for common species was done in the field by using different plant identification keys. But for the less common species plant sample specimen were pressed and identified at the National Herbarium of Ethiopia (ETH), Addis Ababa University.

Litter samples were collected from a total of 30 sample plots placed in the main plot of each land use. The samples were collected from three diagonally placed 1m2 subplots in each main plot. Herbs and grasses were harvested from the three subplots. The litter samples collected from each main plot was mixed and homogenized [13]. The litter samples included dead leaves, branches, twigs, flowers, and dead wood (DBH < 2 cm). In this subplot litter, herbs and grasses (live above ground non-woody with DBH < 2 cm) samples were collected [15]. All the litter samples were weighed in the field and 100 gm of the composite samples were brought to laboratory to determine dry biomass and % C [13]. The litter samples which were brought to the laboratory were oven-dried at 700C for 24 hours and weighed for analysis of total carbon concentrations. The loss on ignition (LOI) method was used to determine % C in LHGs [15, 16].

The soil samples were collected from 15 plots (every other plot of the plots for vegetation sampling) for each land use. Two sets of soil samples were taken; one set for the determination of SOC contents and one set for the determination of soil bulk density. In each case, the samples were collected from the two depths (0–30 and 30–60 cm) within the main plot and composited by layer. The SOC samples were taken using a gouge-type auger and bulk density samples were taken from the middle of the sampling layer with a core sampler. Three equal weights of each sample from each sub-plot were taken and mixed homogenously while a composite sub sample of 500 gm from each plot were taken to laboratory for SOC determination. Fine roots of less than 2 mm diameter were excluded, because it often cannot be distinguished empirically from soil organic matter or litter [17]. The fine roots were extracted by hand and then the soil passed through a 2 mm sieve and the < 2 mm fraction was used for SOC determination. The weight of soil samples > 2 mm and < 2 mm fractions was recorded. SOC content was measured using the Walkley and Black titration method [18]. The bulk density samples were oven-dried at 105°C for 24 hours and weighed [15].

2.3. Data analysis: Shannon diversity index was used to determine diversity of woody species [19]. Additionally, Fisher's α (alpha) was also used to assess diversity of woody species. This additional diversity index was used owing to its less sensitivity to variations in sample size [20]. Woody species evenness was also assessed using Shannon evenness [19].

Sorensen similarity coefficient was used to assess similarity in composition of woody species among the three land uses [19]. This analysis was important to check the level of woody species similarity among the three land uses. Additionally, a multiple-site similarity index was used to overcome the problem of covariance between pairwise similarities in a multiple site study [21].

2.4 Biomass estimation: Considering soil type, elevation, vegetation type and climate, appropriate allometric equations were employed for biomass estimation. Accordingly [22]. Was employed for above ground biomass (AGB) estimation of NF (Eq. 1). In order to estimate biomass of woody species having between ≥ 2 and < 5cm DBH, an allometric equation developed for dry tropical woody species at juvenile stage [23]. Was used (Eq. 2). This model performed well across forest types and bioclimatic conditions [22, 24]. Was used for AGB estimation of FFI and FL for all diameter class (Eq. 3). This equation has lower AIC value, improved model fit and was developed from a study with similar environmental condition with this study site [24].

$$AGB = 0.0673\ x\ )(\rho D^2 H)^{0.976} \quad (1)$$

$$AGB = 3.428 + 0.310 \ln \rho D^2 H \quad (2)$$

$$AGB = 0.225\ x\ D^{2.341} x \rho^{0.730} \quad (3)$$

The below ground biomass (BGB) was calculated by multiplying AGB taking 0.26 as root to shoot ratio for NF. In FFI and FL, Belowground biomasses were 0.28 of AGB for woody species < 10 cm DBH; while BGB=0.048*$d^{2.303}$ was used for woody species > 10 cm DBH [25, 26].

$$BGB = 0.26 * AGB \quad (4)$$

$$BGB = 0.048 * d^{2.303} \quad (5)$$

Where AGB is the aboveground biomass (kg dry matter/woody species); BGB is the belowground biomass (kg dry matter/woody species); H: Height (m); D is diameter at breast height (cm) and ρ is wood density (g/cm^3) obtained from Ethiopia's forest reference level submitted to the [27]. Finally, biomass estimates obtained were converted to carbon stocks using the default IPCC carbon fraction value of 0.47 [28].

2.5 Estimation of carbon in leaf litter, herbs and grasses: Biomass of leaf litter, herbs and grasses was determined by using equation developed by [13]. Finally, carbon density of LHGs was then calculated by multiplying biomass of LHGs per unit area with the percentage of carbon determined for each sample [16].

2.6 Estimation of carbon in soil organic carbon (SOC): The carbon stock density of SOC was calculated as recommended by [13]. From the volume and bulk density of the soil.

$$CV = h \times \pi r^2 \quad (6)$$

$$BD = \frac{DM}{CV - \left(\frac{Mcoarse\,frag}{Densrock\,frag}\right)} \quad (7)$$

Where, CV is soil core volume (cm3); h: is the height of core sampler in cm, and r: is the radius of core sampler in cm; BD is bulk density (g/cm3), DM is dry mass (g/cm^3), Mcoarse frag is mass of coarse fragments (g), and Dens rock frag is density of rock fragments (g/cm3) = 2.65 g/cm^3. SOC can be calculated as recommended by [29]. Soil organic carbon stocks (g m^2) for each sampled depth in the NF were calculated using the following (Eq.8).

$$C = (z \times BD \times \%c) \times 100 \quad (8)$$

Where, C = SOC stock (g m^{-2}) of a sample depth, z = thickness of a sample depth (cm), BD=bulk density (g cm^{-3}) of NF at a sample depth, c = SOC content (g kg−1soil) of a sample depth.

SOC stocks (g/cm^{-2}) for each sampled depth in the FL and FFI were calculated using the following equation 9. The soil samples at a certain layer of the NF may not be comparable to those of the FL and FFI sites. Therefore, the following equation was applied to adjust the thickness of soil layers at the FL and FFI sites to avoid errors from the differences in bulk density between the soil layers of the FL, FFI and NF.

$$C = [(BDwl / BDy) \times z \times BDy \times c] \times 100 \quad (9)$$

Where, C = SOC stock (tons ha-1) of a sample depth, z = thickness of a sample depth (cm), BDwl = bulk density (g/cm^3) of NF at a sample depth, BDy =bulk density (g/cm^3) of FL and FFI at a sample depth and c = SOC content (g kg^{-1}soil) of a sample depth. Finally, the total carbon stock was calculated by adding the carbon stock of individual carbon pools [13].

2.4. Statistical analysis: Carbon stock of the three land uses were compared using one-way ANOVA. Two-way ANOVA was used for multiple comparisons of SOC means among land use and depth. Tukey test was used to check for the homogeneity of variances. The relationship between woody species diversity and carbon stocks were determined using Pearson correlation. All tests were conducted at 95% confidence level.

3. Results and Discussions

3.1. Woody species composition and diversity: The result shows that 40 woody species which belong to 30 families were recorded from the three land uses. The highest number of woody species (33) was recorded in NF followed by FFI (24) and FL (19). Myrsinaceae, and Fabaceae were families with relatively higher number of species in the study site. The result also showed that the Fisher alpha and evenness of FFI are significantly lower than NF and higher than FL at $p < 0.05$ (Table 1).

Land use	Species richness	Fisher alpha	Evenness (J)
NF	33	7.34 + 0.3 ^{a}	0.3 + 0.25 ^{a}
FFI	24	5.22 + 0.5 ^{b}	0.28 + 0.26 ^{b}
FL	19	3.38 + 0.2 ^{c}	0.22 + 0.01 ^{c}
P-value		< 0.001	< 0.01

Table 1: Table 1: Diversity and evenness of woody species among the three land uses (Mean ± SE) in in south-central Ethiopia (Means with different letters within column are significantly different (P < 0.05) with respect to the land use. NF = Natural forest; FFI = Forest farm interface and FL = Farm land).

Our result indicated that, diversity of woody species in agricultural landscape (FFI and FL) was lower than NF in the study area which is consistent with other studies in Ethiopia [33, 34]. This might be due to activities of farmers to enhance their land use efficiency and intensive thinning of woody species in order to get more space and reduce competition from agricultural crops. The result also showed higher species richness in NF as compared to agricultural landscapes. In contrary to this, it is disagreeing with results of [11]. In south western Ethiopia and in Northern Ethiopia which depicted that agricultural landscapes host higher woody species richness than NF.

Evenness in FFI was higher than NF which shows that there is better representation of all woody species. This show FFI has potential to conserve diverse woody species with intermediate values that lies between NF and FL. This could serve as a source of propagules for forest regeneration because they produce seed locally.

3.2. Woody Species Similarity

The highest similarity in woody species compositions (39.6 %) was recorded between NF and FFI, while lowest similarity (34.9 %) was recorded between NF and FL. Afro carpus falcatus, Croton macrostachyus and Schefflera abyssinica were some of the woody species common in all the studied land uses. From a total of 50 woody species, about 16 species were found to be common to all land uses (Table 2).

Land use type	Similarity (%)
Natural Forest vs Forest farm interface	39.6
Natural forest vs Farm land	34.9
Forest farm interface vs Farm land	38.1
Natural Forest vs Forest farm interface vs Farm land	47.8

Table 2: Similarity index of woody species among three land uses in south-central Ethiopia

The result shows that, woody species similarity between FL and NF is lower than similarity between FFI and NF. The less number of woody species (both in diversity and abundance) in FL is the result of exploitation, natural death and lack of recruitment. In general, the results from the diversity and similarity analysis indicate that FFI plays important role in preserving woody species which is of intermediate value as compared to NF and FL.

3.3. Total Carbon Stocks in three Land Uses

The total biomass carbon stock in FFI is 7.67 (SE = ± 10.9) tons ha^{-1} which is significantly lower than 167.8 (SE = ± 36.5) tons ha-1 of the adjacent NF, but higher than that of FL which is 18.98 (SE = ± 4.7) (One way ANOVA; F = 13.78; DF = (2, 87); $p < 0.05$)). This result indicates that the FFI maintains 46% of biomass carbon while FL has only 11.3% of the biomass carbon stock as compared to the adjacent NF. This is related to higher presence of larger number of trees with larger DBH in FFI as compared to FL.

Average mean of SOC stocks was significantly different among all land use (F = 59.9; DF = (2, 84); $p < 0.05$)) and also different per soil depth (F = 16; DF = (1, 84); $p < 0.05$)). The top surface layer accounted for 54.2%, 52.2% and 54% of the total SOC in NF and adjacent FFI and FL respectively. The total (0-60 cm depth) SOC stocks of FFI which is 146.21 (SE = ± 6.6 $t.ha^{-1}$) is significantly lower in relation to adjacent NF (196.8 ± 6.1 t ha-1), but significantly higher than FL (116.8 ± 7.12 t ha-1) (F = 37.4; DF = (2, 42); $p < 0.05$)). The result indicates that 25.4 % and 40.6 % of SOC stocks (0–60 cm) were lost in conversion of the NF to the FFI and FL respectively. This tells us FFI can maintain higher SOC in relation to the adjacent FL.

The total carbon stock in FFI is 244.05 (SE = ± 13.9) tons ha-1 and that of the adjacent NF and FL were 388.46 (SE = ± 47.6) and 143.14 (SE = ± 12.56) tons ha-1 respectively (Table 3). The average carbon stock (ton ha-1) is significantly different among the three land use (One way ANOVA; F = 17.4; df = (2, 42); $p < 0.05$)).This result shows that the FFI maintains 62.8% of total carbon while FL has only 36% of the total carbon stock as compared to the adjacent NF. This result also shows that the FFI maintains close to twice as higher total carbon as compared to the adjacent FL. This is related to higher presence of larger number of trees with larger DBH and low level of disturbance due to tillage in FFI as compared to FL.

Land use	Mean (±SE)				
	CAGB	CBGB	SOC	CLHGs	TCS
NF	2.1 ± 28.9^{a}	38.7 ±7.54^{a}	7.85 ± 6.1^{a}	0.47 ± 0.03	4.46 ± 47.62^{a}
FFI	6.2 ± 8.70^{b}	1.4 ± 2.19^{b}	2.21 ± 6.6^{b}	-	0.05 ± 13.9^{b}
FL	3.8 ± 3.76^{c}	5.14 ± 0.95^{c}	0.78 ± 7.12^{c}	-	28.14 ± 12.56^{c}
P-value	< 0.001	< 0.001	<0.001		<0.001

Where: CAGB: carbon stocks in above ground biomass, CBGB: carbon stocks in below ground biomass; CLHGs: Carbon in litter, herbs and grasses; SOC: Soil organic carbon; TCs: Total carbon stocks.

Table 3: Total carbon stocks of FFI and adjacent NF and FL (tons ha^{-1}) in south central highland of Ethiopia (Means with the different letters across column are significantly different ($P < 0.01$).

The biomass carbon stock of FFI 7.67 (SE = ± 10.9) reported in this study is greater than carbon values (50 –75 tons ha-1) reported for tropical agroforestry systems and within a range of 12–228 tons ha-1 reported for the total biomass C stocks of the smallholder agroforestry systems globally [37, 38]. It is also greater than 46 tons ha^{-1} reported for parklands agroforestry in the Sahel [39]. In agreement with our finding, a study conducted in Gera, Southwestern Ethiopia also showed that biomass carbon in NF is significantly higher than the adjacent parkland agroforestry practice and FL dominated by annual crops [40]. The difference in biomass carbon stock among the three land uses is related to number and size of trees per hectare which contribute to carbon sequestration [41]. In line with this, the result showed that FFI plays an important role in climate change mitigation while also serving provision of forest products and also supporting production of annual crops [42]. Reported similar finding which attested that crop fields with diverse woody species play important role in biodiversity conservation and mitigation of climate change [43, 44].

The result indicated that, SOC in the three land uses decreased with depth. It is consistent with findings of conducted in natural forest of Bangladesh [45]. This might be due to the accumulation and rapid decomposition of litter in the top soil. The result shows, SOC stocks of FFI was significantly lower in relation to adjacent NF, but significantly higher than FL. SOC in FFI had higher SOC than ranges for whole Africa (64–67) t•ha^{-1} and park land agroforestry in Jido Komolcha District, southern Ethiopia which is 64.8 t•ha^{-1} [46, 47]. This is associated to a larger density of woody species, which supplies more biomass to the soil in the form of litter and roots, increasing SOC. Additionally, under FFI, the breakdown of fine roots and litter increases soil carbon concentration [48, 49]. Feces of birds resting and nesting on trees, feces and urine of animals resting under trees, and deposition of organic dust are other possible sources of soil fertility improvement
[50].

3.4. Relationship between woody species diversity and carbon stock

The result showed that total carbon stock is positively correlated with woody species diversity in all land uses (Table 4). The result shows that the relationship gets stronger with increasing species diversity.

Land use	Carbon stocks	H'	Species richness	Evenness
		R	R	R
NF	TCS	0.40	0.55	0.45
FFI	TCS	0.21	0.30	0.23
FL	TCS	0.10	0.17	0.12

Where, H'; Shannon diversity; TCS; Total carbon stock; Correlation is significant at the 0.05 level.

Table 4: Pearson correlation among woody species diversity and total carbon stock (tons ha^{-1}) in three land uses of Arsi Negele site, Ethiopia

Despite many theoretical and experimental studies carried out to date, the relationship between species diversity and ecosystem productivity continues to be one of the most controversial subjects in Ecology [56]. The forests with more diversity maintain more biomass carbon stock was also reported [42, 57, 58]. A study from southern Ethiopia also showed that woody species richness in agroforestry systems is positively correlated with biomass carbon stock [59].

4. Conclusions

This study showed that the FFI in south-central highlands of Ethiopia play important role in maintaining diverse woody species as compared to FL. It also showed that the FFI maintain significantly higher carbon stock as compared to the adjacent FL. The higher contribution of FFI to climate change mitigation is mainly attributed to the higher abundance of larger woody species in the system as compared to the adjacent farmland. In addition to the environmental role through maintaining biodiversity and carbon stock, the provision service played by the on-farm trees of the FFI through supply of wood products and maintenance of environmental resilience is also important in marinating crop productivity at the FFI. However, the fact that the farmland found adjacent to the FFI showed lower role of biodiversity conservation and carbon stock shows that sustainability of the system is questionable. If the FFI is not sustainably managed, there will always be expansion of the FL into FFI and also FFI into the NF causing decline of environmental services in the FFI and also deforestation and forest degradation in the FFI. Hence, sustainable management of FFI is important to sustain its environmental and economic services.

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