RESEARCH ARTICLE

ESTIMATION OF CARBON STOCKS IN COFFEE BASED AGROFORESTRY AND ADJACENT *CUPRESSUS LUSITANICA* PLANTATION AT WONDO GENET COLLEGE, SOUTHEAST ETHIOPIA

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ABSTRACT

The purpose of this study was to estimate biomass and soil organic carbon (SOC) stock in coffee based Agroforestry and *Cupressus lusitanica* plantation. A total of 20 plots of 10 m x 10 m were established systematically in coffee based Agroforestry and *Cupressus lusitanica* plantation to sample soil and vegetation data. The biomass of shade tree, coffee shrubs and *Cupressus lusitanica* was estimated by previous allometric equations. Variation in biomass carbon and SOC between the two land use types were tested using analysis of variance. The average amount of biomass carbon stored in coffee based Agroforestry was 109.96 Mg C ha⁻¹. The proportion of total aboveground biomass carbon to the total biomass carbon stock was averaged 61.67% for coffee based Agroforestry. The average total biomass carbon was 74.24 Mg C ha⁻¹ in *Cupressus lusitanica* plantation. Coffee based Agroforestry had accounted more SOC than *Cupressus lusitanica* plantation in 0-40 cm soil depth. Our study concluded that coffee based Agroforestry, compared with *Cupressus lusitanica* plantation, had generally higher biomass carbon and SOC stocks.

KEYWORDS

Aboveground biomass, Shade trees, Soil organic carbon

1. INTRODUCTION

Agroforestry is a collective name for land use systems and technologies where woody perennials (trees, shrubs, and other perennials: palms, bamboos, etc.) are deliberately used on the same land management unit as agricultural crops and/or animals, either on the same form of spatial arrangement or temporal sequence (Nair et al., 2009; Nair et al., 2011). Agroforestry systems (AFS) have also a significant contribution to conserve native biodiversity (Richards & Mendez, 2014; Negash & Starr, 2015) and provide ecosystem services (Soto-Pinto et al., 2010; Richards & Mendez 2013). Carbon (C) sequestration potential of AFS is one of the recent recognitions of the environmental benefits of age old land management approach (Brown et al., 2018; Nair et al., 2010) and sequester carbon for climate change mitigation (Nair et al., 2009; Negash & Starr, 2015). Hence, Agroforestry distinguishes itself from the other systems as a sustainable land use system with a promising potential to sequester atmospheric carbon into biomass as well as soil (Abbas et al., 2017; Agevi et al., 2017; Bajigo et al., 2015). Globally, the C sequestration potential of Agroforestry systems is estimated between 12 and 228 Mg ha⁻¹ with a median value of 95 Mg ha⁻¹ (Agevi et al., 2017; Soto-Pinto et al., 2010).

According to empirical report by some authors (Oelbermann et al. 2004; De Stefano & Jacobson, 2017), the potential to sequester C in aboveground components in Agroforestry systems to be 2.1×10^9 megagram carbon per year (Mg C y⁻¹) in tropical and 1.9×10^9 Mg C y⁻¹ in temperate biomes. In

sub Saharan African, C sequestration in Agroforestry systems (park land, live fence, and homegardens) reported ranging from 0.2 to 0.8 Mg C ha⁻¹ y⁻¹, while in rotation woodlots, 2.2 to 5.8 Mg C ha⁻¹ y⁻¹ (Luedeling et al., 2011). The C sequestration potential in biomass and soil of Agroforestry systems in East and West Africa is also estimated to be 6-22 megagram carbon dioxide equivalent per hectare per year (Mg CO₂e ha⁻¹ y⁻¹) (Brown et al., 2008). In Ethiopia, a total biomass carbon stock average of 67 Mg ha⁻¹ and SOC of 109-253 megagram carbon per hectare (Mg ha⁻¹) have been recorded at Gedeo homegarden agroforestry (Negash & Starr 2015). According to Jose & Bardhan (2012), Agroforestry has a potential to sequester 30 to 322 Pg C yr⁻¹.

Agroforestry system are distinct from other forms of agriculture in their potential to store huge amounts of carbon in total biomass and soils (Mbow et al., 2014). In spite of this, greater than half of global species diversity is still under increasing human pressure, leading to the replacement of natural vegetation by monocultures (FOA, 2012; Meragiaw, 2017). Agroforestry is recognized as a win-win strategy to maintain a balance between environmental protection and human needs. In particular after the Kyoto Protocol (KP), stabilizing the CO₂ concentrations has received considerable scientific attention (Berhe & Retta, 2015; Mohammed & Bekele, 2014). Agroforestry is now become a focus of environmentalists and ecologists as a sustainable land management option over the globe because of its ecological, economic, and social values (Bajigo et al., 2015; Berhe & Retta, 2015).

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In addition to Agroforestry systems, plantations have also a significant role in reducing the atmospheric concentration of carbon dioxide. Carbon sequestration through afforestation and reforestation has already given priority in taking climate change (Nair et al., 2009; Zhang et al., 2016). For instance, in Ethiopia *Eucalyptus* species, *Cupressus lusitanica*, *Grevillea robusta* and *Pinus patula* are among common exotic plantation species that grow fast and hence, they remove more CO₂ from the atmosphere than they would release (Lemma, 2006; Demessie, 2009; Yirdaw, 2018). However, numerous studies on carbon stock assessment have been focusing on natural forests (Alemu, 2014; Belay et al., 2018; Gebeyehu et al., 2018) and carbon accounting in various Agroforestry systems and plantations is very rare. Therefore, the aim of a present study is aimed to (i) estimate stand biomass carbon of coffee based Agroforestry and adjacent *Cupressus lusitanica* plantation (ii) estimate soil organic carbon in the aforementioned ecosystems (iii) determine the effect of soil depth variation and land use on vertical distribution of soil organic carbon stock.

2. MATERIAL AND METHODS

2.1 Study area

The study was conducted in Wondo Genet College of Forestry and Natural Resource, which is located in south of Addis Ababa at about 263 km. It lies between 38°37' and 38°42' East longitude and 7°02' and 7°07' north latitude. The landscape of the study area varies with an altitude ranging between 1600 and 2580 meters above sea level (Figure 1).

The study area is categorized under Dega (cold) agro-ecological zone at the upper part and Woina Dega (temperate) agro-ecological zone at the lower part of the area. The rainfall distribution of the study area is bimodal, where short rain falls during spring and the major rain comes in summer and stays for the first two months of the autumn season. The annual temperature and rainfall range from 17°C to 19°C and from 700 mm to 1400 mm, respectively (Yirdaw, 2018).

Figure 1: Map of study area

2.2 Methods

2.2.1 Shade tree, coffee shrub and *Cupressus lusitanica* measurement

Field measurements were conducted in January, 2019. A total of 20 plots (Size = 10m x 10m) within each land use type was established to measure all shade tree species with a diameters of ≥ 2.5 cm and measured at breast height (dbh; measured at 1.3 m) and to monitor coffee plants. Systematically, plots were placed at 100 m apart from each other along the two transect lines. The first plot and transect line was selected randomly. In two perpendicular directions all stem diameter measurements (d₁ and d₂) were taken and the average value used in biomass estimation. The number of sapling trees (d < 2.5 cm) was small and have not been used in the estimation of biomass C stocks.

The diameter at stump height of all coffee shrubs (d at 40 cm) ≥ 2.5 cm in plots was counted. Multi-stemmed coffee plants (1 to 9 stems per plant), each stem were measured by caliper and the equivalent diameter of the plant calculated as the square root of the sum of the diameters of all stems per plant following Snowdon et al. (2002) as below:

$$d_e = \sqrt{\sum_{i=1}^n d_i^2}$$

where d_e is diameter equivalent (at breast or stump height), d is the diameter of the ith stem at the breast or stump height.

The height and diameter at breast height of all *Cupressus lusitanica* (d1 and d2 at 1.30 m) ≥ 2 cm was measured and the average value also used in biomass estimation. Diameter and height was measured using cliper and sunto clinometer, respectively.

2.2.2 Biomass and carbon stock estimation

The dry aboveground biomass of shade trees were estimated using allometric models developed by Kuyah et al., (2012).

$$AGB = 0.091 \cdot d^{2.472}$$

where AGB is above ground biomass; d is diameter at breast height

The above ground carbon stock of shade tree was estimated by multiplying AGB with 48%.

A belowground biomass component was estimated by shoot: root ratio. This ratios range from 20 to 45% and we use global average of 26% which is commonly used and the product was multiplied by 50% to calculate below ground biomass carbon stock (IPCC, 2003).

For each plot biomass C stocks (Mg C ha⁻¹) were calculated as the product of dry matter biomass and C content (Snowdon et al., 2002). The dry aboveground biomass of coffee shrubs (AGB) were estimated based on the model developed by Negash et al. (2013). We used this equation, because it was applicable for coffee plants using plant d as a single independent variable (Negash, 2013).

$$AGB_{coffee} = 0.147d^2; R^2 = 0.80, n = 31$$

where d is the diameter at stem height of coffee shrubs; AGB is aboveground biomass (kg dry matter/ plant).

The AGB were multiplied by 49% to calculate above ground biomass carbon stock of coffee shrubs (Negash et al., 2013) and the product was multiplied by 50% to calculate below ground biomass carbon stock.

The dry aboveground biomass of *Cupressus lusitanica* plantation were estimated using allometric models developed by Berhe et al. (2013).

$$AGB = 0.0319 \cdot D^{1.8903} \cdot H^{0.9194}$$

The above ground carbon stock of *Cupressus lusitanica* plantation was estimated as product of AGB multiplying 48% and the product were multiplied by 50% to calculate below ground biomass carbon stock.

2.3 Soil sampling and soil organic carbon estimation

A composite soil samples were collected from a nested plot of 1m x 1m sub-quadrat with three replications in a plot size of 20 cm x 20 cm and to a depth of 40 cm within each sub-quadrat. Soils were sampled in two increments of 0-20 cm and 20-40 cm using auger. Core sampler was used to take undisturbed soil sample for bulk density determination. A total of 80 soil samples (40 for carbon and 40 for bulk density determination) was collected. Bulk density was determined by calculating the total dry weight of the cores and dividing by the total core volume (Sistla et al., 2016), because study soil has no rock fragment. For bulk density determination samples were oven-dried at 105°C for 48 hours.

$$BD \text{ (g/cm}^3\text{)} = \frac{\text{Oven - dry mass (g)}}{\text{Core volume (cm}^3\text{)}}$$

Where Bd is bulk density

The soil samples for soil organic carbon (SOC) analysis were air dried and sieved by 2 mm sieve. The carbon content was determined by Walkley-Black method.

The soil carbon stocks (Mg c ha⁻¹) were calculated as follows:

$$C(t/h) = [(\text{Soil bulk density (gcm}^{-3}\text{)} \cdot \text{soil depth (cm)} \cdot \text{C contents (\%)})] \cdot 100$$

2.4 Statistical Analysis

Variation in biomass carbon and soil organic carbon between the two land uses was tested using ANOVA. Significant differences in mean values for biomass carbon and soil organic carbon across land use types were tested by t- test at $P < 0.05$. Prior to data analysis normality of data was checked by performing Bartlett's test of the null that the variances in each of the groups (samples) are the same. Multiple linear regression models were used to test the effect of vertical soil depth and land use on soil organic carbon. All statistical computations were made using R statistical Software version 3.5.3.

3. RESULTS

3.1 Biomass carbon stocks

The average amount of biomass carbon stored in CAFs was 109.96 Mg C ha⁻¹. Aboveground dry biomass of shade trees varied between 2.01 kg (*Celtis africana*) and 4607.65 kg (*Cordia africana*) per tree (dbh $\geq$ 2.5 cm). Aboveground biomass of coffee plants ranges from 0.72 kg-27.23 kg per plant.

Whereas, estimated total biomass carbon of coffee plants ranges from 0.45 kg to 13.34 kg per coffee plant. A total belowground biomass (tree and coffee) C stock ranged from 5.18 to 290.74 Mg ha⁻¹, averaging 66 Mg C ha⁻¹ (Table 1).

Trees accounted for 88.65 % of the total aboveground biomass in coffee based agroforestry, when compared to coffee plants for 11.35 % (Figure 2). The share of trees to the total belowground biomass C stocks was 23.7 %. The contribution of coffee to the total belowground C stock was 18.86%. The proportion of total aboveground biomass C to the total biomass C stock was averaged 61.67%.

The average amount of biomass carbon stored in *C. lusitânica* plantation was 74.24 Mg C ha⁻¹. In case of *C. lusitânica* plantation, aboveground biomass of plants ranges from 4.99 kg to 1946.83 kg per plant. The contribution of above ground biomass carbon to the total biomass carbon stock was 78.68%. However, there is no significance difference between means of total biomass carbon of the two land use types ($p > 0.05$) (Table1).

Figure 2: Percentage contribution of coffee and shade tree to total aboveground biomass stock.

Table 1: Means of total biomass carbon stock in coffee based agroforestry (CBAF) and <i>C.lusitânica</i> plantation (CL); TBC= Total biomass carbon		
Land use types	TBC (Mg C ha ⁻¹)	
	Mean	P value
CBAF	109.96 ^a	0.501
CL	74.24 ^a	

3.2 Soil organic carbon stocks

The result shows the upper soil layer accounted more soil organic carbon for both land uses. Across the all soil depth coffee based Agroforestry also accounted more soil carbon sock, when compared to *C.lusitânica* plantation (Figure 3). In other word, coffee based Agroforestry had accounted more SOC than *C.lusitânica* plantation in 0-40cm soil depth.

Figure 3: Soil organic carbon (SOC) under coffee based Agroforestry (CBAF) and *C.lusitânica* plantation (CL)

3.3 Effect of soil-vertical depth variation and land use types on SOC

The overall model showed that the independent variables included in the model had a significant effect on soil organic carbon ($P < 0.05$). The total variability of the SOC which explained by independent variable included in the model was 27.38% keeping other variables constant (Table 2).

Table 2: The effect of soil depth variation and land use types on SOC by multiple linear regression models.				
Sources of variation	Estimate	Std. Error	t value	Pr(> t)
Intercept	448.4	21.51	20.849	< 0.001 ***
Soil depth	-78.2	21.48	-3.641	0.00087 ***
LU	35.29	21.51	1.641	0.10979
Adj.R square	0.2738			
P-value	0.0014			

*** indicate significantly different at 99 CI

3.4 Ecosystems carbon stocks

A total carbon stock of the ecosystem was obtained, hereafter summed up the biomass carbon and soil organic carbon. Coffee based Agroforestry had accounted more total carbon stocks, when compared to *C.lusitânica* plantation (Figure 4). On the other hand, mean total carbon stock of coffee based agroforestry and *C.lusitânica* plantation was significantly different ($p < 0.05$).

Figure 4: Total carbon stocks of Ecosystem, TC = Total carbon; CBAF = Coffee based agroforestry; CL = *C. lusitânica* plantation

4. DISCUSSION

4.1 Biomass carbon stocks

The total biomass carbon stocks of the coffee based Agroforestry in our study were lie between the range for agroforestry systems reported globally (12–228 Mg ha⁻¹) (Bajigo et al., 2015; Soto-Pinto et al., 2010, Luedeling et al., 2011; Nair 2011; Zhang et al., 2018) and reported for Agroforestry systems (22 and 122 Mg ha⁻¹) of south eastern rift valley of Ethiopia (Negash & Starr, 2015), but higher than biomass carbon reviewed for West African Sahel countries (from arid Sahara desert to humid region Guinea) by Luedeling and Neufeldt (2012) and to be 9, 21,

50 and 63 Mg C ha⁻¹, reported for semiarid, sub-humid, humid and temperate regions, respectively (Montagnini & Nair, 2004). Abbas (2017) found that the amount of biomass C in Agroforestry systems differs with regions and climate. For instance, Lorenz & Lal (2014) point that Agroforestry systems on fertile humid regions have higher vegetation C sequestration rates than those on arid, semiarid, and degraded sites, and tropical Agroforestry systems have higher vegetation C sequestration rates than temperate Agroforestry systems.

The total aboveground biomass, 66 Mg C ha⁻¹ of coffee based Agroforestry, is revealed to be higher than average aboveground C reported for agroforestry systems in semiarid, sub-humid, humid and temperate regions (Montagnini & Nair, 2004), but lower than aboveground biomass (70 Mg C ha⁻¹) reported for Agroforestry systems in humid tropics (Mutuo et al., 2005). We found that high biomass C stocks in coffee based Agroforestry systems attributed to the high aboveground biomass of trees. Negash (2013); Kuyah & Rosenstock (2015) also confirmed that tree in agricultural land had large contribution to biomass carbon stock. The ecosystem carbon stocks of coffee based Agroforestry were high compared to *C. lusitanica* plantation. This difference attributed to the large amount of above ground biomass stock in our studied coffee based Agroforestry. Meta analysis by Shi et al. (2018) shows aboveground carbon to be correlated with tree density and growth rate, which is higher in AF systems.

4.2 Soil organic carbon stock

In our study for both land uses (i.e. Coffee based Agroforestry and *C. lusitanica* plantation) SOC was concentrated on top soil layer, 0-20 cm, where the largest C pools detected (Oelbermann & Voroney, 2007; Lorenz, 2014; Lorenz & Lal 2014). Similarly, Shi et al. (2018) reported the highest SOC stock is in topsoil (0-20 cm) for subtropical home-gardens. The SOC stock in our coffee based agroforestry system was noticeably high compared to the SOC stocks reported by Abbas et al., (2017) that is 1.3 Mg C ha⁻¹ in the top 40 cm soil layer with 13-year-old alley cropping practices in southern Canada, but lower than for agroforestry system reported from south eastern central rift valley encampment of Ethiopia in the topsoil 60 cm (Negash & Starr, 2015), 1 m depth to be 408 Mg C ha⁻¹ for silvopastoral systems (Nair et al., 2010) in Brazil. Negash (2013) also found that the amount of SOC in Agroforestry systems differs with regions, Agroforestry systems and soil depths.

Likewise, in our study SOC in coffee based Agroforestry was to be high compared to *C. lusitanica* plantation. This differences attribute to shade trees adding carbon transport into deeper soil layers through rhizodeposition and fine root turnover (Thakur et al., 2015), which is especially important for C sequestration considering long mean residence time of C in deep soil (Zang et al., 2018). Demessie (2009) also found that *cupressus* plantation at the harvesting stage may negatively influence the quantity and quality of the stand's litter production capability, which is manifested by the lower detritus mass and the corresponding SOC concentration along the depth.

4.3 Effect of soil depth and land use on soil organic carbon stock

The soil play an important role in carbon sequestration. The amount of carbon sequestered in the soil depends on a large number of factors, including the region, site quality, current land use, previous land use, and the portion of soil profile in case of land use changes (Lemenih et al., 2004; De stefano & Jacobson, 2017). In our study analysis of effect size revealed that soil depth had a significant effect on SOC, but the effect of land use was not statistically significant. Meta analysis by Shi et al., (2018) show that soil depth was an important factor for the differences in carbon stocks. From Ethiopia, Lemma (2006) and Demmessie (2009) confirmed that land use and soil depth have effect on soil carbon stocks.

4.4 Ecosystems carbon stocks

The distribution of carbon stocks between biomass and soil differs among ecosystems and with climate (Schmitt-Harsh et al., 2012; Shi et al., 2018). The total carbon stocks in our study, coffee based Agroforestry and *C. lusitanica* plantation, was found to be the sum of biomass and soil pools. The average coffee based Agroforestry ecosystem carbon stock (186 Mg C ha⁻¹) was lower than reported for south eastern rift valley encampment of Ethiopia (averaging 248 Mg C ha⁻¹; Negash & Starr, 2015). The published values of total carbon stocks for coffee Agroforestry plantations range from 82 to 198 Mg ha⁻¹, while soil carbon might reach over 89 % the total (Schmitt-Harsh et al., 2012). Our result for coffee based Agroforestry is between these ranges. In our study, the carbon stock of coffee Agroforestry was high compared to *C. lusitanica* plantation. Similarly, Ehrenbergerova

et al. (2016) found that aAgroforestry systems store more carbon than open space plantations.

5. CONCLUSIONS

Agroforestry systems play a significant role in storing carbon in agricultural landscapes. The amount of sequestered carbon depends on the tree species used for shading. Our study concluded that coffee based Agroforestry on the studied area, compared with *C.lusitanica* plantation, had generally higher biomass carbon and soil organic carbon. The result of this research suggested that Agroforestry systems have a crucial role in sequestering higher amount of carbon in plant biomass and soils than monoculture plantation.

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