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Research Article

Effects of wealth status on home-garden's biomass and soil carbon stocks: The case of midland kebeles of Ofa district, Wolaita Zone, Southern Ethiopia

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Article Info

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Abstract

Home garden agroforestry has been practiced in various parts of the tropics, and is known to provide a wider ecosystem services for smallholder farmers. Several studies have been conducted on the biodiversity and socio-economic importance of home garden agroforestry in different parts of Ethiopia, however, empirical studies are limited on home garden's carbon stocks storage in reference to socioeconomic factors. The objective of this study was, therefore, to identify the effects of household's wealth status on the home garden's biomass and soil organic carbon stocks at midland kebeles of Ofa district, Wolaita Zone, Southern Ethiopia. Three kebeles were purposively selected from the district based on the existence and extensive practice of home garden agroforestry. A total of 73 sample plots with 10m×10m were established on home gardens of randomly selected households across wealth classes, representing 14 for rich, 27 for medium, and 32 for poor. In each main plot, all woody species above 2.5 cm dbh were inventoried. Also, three nested 1m×1m subplots were used to collect litter and soil samples. Already developed allometric equations were used for estimation of above and belowground biomass. A total of 146 soil samples for soil physicochemical analysis, and the same size samples were collected separately for bulk density determination, and 73 samples for litter. The mean total carbon stocks (biomass plus soil, 0-60cm) was significantly higher in home gardens of the rich and medium households (respectively 232 ± 22 Mg C ha^{-1} and 207±19Mg C ha^{-1}) than poor households (130 ± 13 Mg C ha^{-1}). The soil organic carbon (SOC) accounted for 68%, 71% and 82% of the total carbon stock in rich, medium and poor households' home gardens. SOC stock was positively correlated (Spearman R^2=0.65) with total biomass carbon stock. This study revealed that wealth status of households affects carbon stocks in home garden agroforestry in Southern Ethiopia..

Keywords: carbon stocks, climate change mitigation, home garden, wealth status, woody species

1 Introduction

Global warming is real and there is a growing interest in the role of different land use systems in stabilizing atmospheric carbon dioxide (CO2) concentration (IPCC 2014). Increasing the size of the global terrestrial sink is one of the strategies for reduction of CO2 in the atmosphere. Currently, agroforestry system is more attracting attention to achieve higher amount of carbon stock in the biomass than grasslands, agricultural fallows, and permanent shrub (Roshetko et al. 2002). There has been growing interest in agroforestry systems owing to their large potential for climate change mitigation and their roles to mitigate household food security (Minang et al. 2012; Nair 2012). It has a potential to sequester greater amount of carbon to offset emissions caused by deforestation and forest degradation (Takimoto et al. 2008; Gupta et al. 2009).[1] Different studies in tropics and subtropics revealed that agroforestry practices stored significant amount of carbon in their biomass and soil (e.g., Montagnini and Nair 2004).

A home garden is one of agroforestry practices with various ecosystem services. It is defined as “a complex sustainable land use system that combines multiple farming components, such as annual and perennial crops and invariably livestock of the homestead and provides environmental services, household needs, and employment and income generation opportunities to the households, the whole tree- crop-animal unit being intensively managed by family labor” (Weerahewa et al. 2012). Home garden is most commonly practiced throughout the tropics and named differently to different places such as household or homestead farms, multi-strata tree gardens, compound farms, backyard gardens, village forest gardens, dooryard gardens, and house gardens (Mattson et al. 2013).

The most common agroforestry practices that are practiced in different parts of Ethiopia include: scattered trees in croplands or parkland agroforestry practiced in large parts of the Ethiopian agricultural landscapes (Hoekstra et al. 1990; Mahari Alebachew 2012), home gardens are practiced in many parts of the southern and south western regions of Ethiopia (Tesfaye Abebe 2000; Mesele Negash et al. 2005), Coffee based agroforestry systems practiced in southern, southwestern and eastern regions of Ethiopia (Demel Teketay and Assefa Tegineh 1991; Mesele Negash et al. 2005; Diriba Muleta et al. 2008).

Agroforestry practices contributed to the sustainable development of Agriculture and promoted economic progress in Ethiopia. It is also believed to contribute for the sustainable Development Goals of the United Nations in various ways. Home garden have a potential to provide productive functions including fuel wood, pole, fodder for animals, improve soil fertility (Poschen 1986; Tesfaye Abebe 2000). Additionally, agroforestry practices also play important roles in adaptation and mitigation of climate change (Tesfaye Feyera 2011; Abiot Molla 2013; Mesele Negash 2013).

The adaptation and mitigation of climate change roles of agroforestry depends on socio- economic factors such as wealth status (Winnas et al. 2015). Wealth status impact is mainly depicted due to the fact that its influence on farm size, tree density and diversity and management of agroforestry practices in different parts of Ethiopia (Zemede Asfaw and Zerihun Woldu 1997; Zebene Asfaw 2003; Abebaw Zeleke 2006). Besides, the amount of carbon stored in the agroforestry practices depend on climatic and edaphic factors (Islam et al. 2015; Unruh et al. 1993), size and age of the holding (Saha et al. 2009).

Home garden agroforestry practice stores higher amounts of carbon than other agricultural systems in the above and belowground biomass and soils (Schroth et al. 2011; Mattsson et al. 2013). The enhanced soil organic carbon sequestration in these systems was attributed to the carbon assimilated by the woody perennial plants, which is transported below-ground to support root growth and organic matter turnover processes (Kumar 2006; Makumba et al. 2007; Beedy et al. 2010). However, such a huge benefits of home garden agroforestry are not addressed well, and the system face problem of changing in to monoculture system in southern Ethiopia (Mersha Gebrehiwot 2013; Tesfaye Abebe et al. 2013).

Previous studies on home garden agroforestry of Wolaita zone, southern Ethiopia assessed the structure, diversity and income contribution of home garden agroforestry for the smallholder farmers (Talamos Seta et al.2013; Mathewos Agize et al. 2016). However, the empirical scientific evidence is lacking regarding how socio-economic factors such as households' wealth status influence biomass and soil organic carbon stocks in agroforestry system. The overall objective of this study was therefore to evaluate the effect of households’ wealth status on the home garden’s biomass and soil organic carbon stocks and the relationship between them in the midland kebeles of Ofa district, Wolaita zone, southern Ethiopia. We hypothesized that both biomass carbon and soil organic carbon (SOC) stocks would differ among the wealth status of households because of the difference in tree/shrub density; that soil organic carbon stock is significantly related to biomass carbon stocks in home garden because of the high inputs of tree/shrub litter fall.

2 Materials and Methods

2.1 Description of the study area

The study was carried out in the Ofa district, Wolaita Zone, Southern Ethiopia geographically located between 6°42' and 6°49' N latitude and 37°28' and 37°34' E longitude (Figure 1). The total land area of the district is 38,537 ha, comprising cultivated land (44.8%), agroforestry (23.4%), forest land (1.9%), grazing land (13.4%), settlement (11.0%) and other lands (5.4%) (Elias Bojago et al. 2022). Ofa district is one of the most densely populated areas in Ethiopia, with an average density of 450 person’s km^{-2} (Elias Bojago et al. 2022). The elevation ranges from 1450 to 2800 ma.s.l. The annual rainfall ranges between 660-1549 mm and temperature ranges from 14 to 34°c (Figure 2).

Ranges of soil types are found in Woliata Zone, but the dominant soil type of the study sites are Nitisols. According to Ethiopian Agro climatic zone classification, the selected district has three major Agro climatic zones, kolla (lowland), Weyna dega (midland) and Dega (highland), accounting for 31%, 48%, and 21% of the district's area, respectively (Elias Bojago et al. 2022). The selected kebeles (Galako, Okoto Sere and Zamo) for this study are located in the mid land (woyna dega) of the district.

The home garden of the present study site is *Tree-enset-coffee* based and woody species such as *Millettia ferruginea, Persea americana*, *Croton macrostachyus*, and *Cordia africana* are mainly dominated the upper story while *Enset ventricosum* (*Enset* or *Uta*) and *Coffea arabica* dominate the middle story.

2.2 Specific sites selection

Reconnaissance survey was conducted before the actual survey to have an impression and obtain basic information of the study sites. From the study district, three kebeles (smallest administrative unit) were purposively selected for this research based on extensive existence of home garden system. Then, nine villages, three from each selected kebele were selected randomly for this study. In all selected kebeles, *Tree-enset-coffee* based home garden agroforestry was commonly practiced

2.3 Key informants selection and wealth status classification

Key informants (KIs) were used to stratify the wealth classes in the study site. In the current study, key informants (KIs) are persons who have lived in the study sites for at least 50 years and are knowledgeable about their localities. To select key informants snowball method was employed. In this method, to select individual farmers who could identify key informants, village tour was made. During village walk, five farmers were randomly asked to give the name of five key informants whom they know best in the study sites. At each village, out of 25 key informants suggested, five top ranking or the most frequently appeared were selected to categorize households (HHs) into different wealth categories. Therefore, in total 45 key informants were selected from the 9 villages.

The purpose of key informant selection was to stratify the households into different wealth categories (poor, medium and rich) based on their own local criteria. The list of required farmers of each village was collected from the Kebele administrative offices. Key informants then set the wealth criteria to categorized households in to different wealth classes. Finally, key informants categorized HHs living in each village into three wealth classes of rich, medium and poor according to the set criteria (see Table 1).

2.4 Sampling techniques

Stratified random sampling technique was employed to collect data from the study sites. Stratification was based on the wealth status of households. Accordingly, three wealth statuses were identified (poor, medium and rich) based on their own local criteria (Table 1). The total of 14, 27 and 32 sample plots were inventoried in rich, medium and poor household farms respectively. The numbers of sample plots required for this study were determined by the pragmatic approach as a result; 10% farmers from each wealth class at each village were randomly selected using lottery method based on their relative proportion. A total of 73 households/farmers across the three wealth classes were selected, comprising 14 rich, 27 medium and 32 poor households (see Table 2).

3 Species inventory

An inventory of all trees/shrubs including coffee and enset (*Ensete ventricosum)* grown on the home garden agroforestry within 10m x 10m plot was conducted. The sample plots were located randomly within selected home garden agroforestry. Trees/shrubs with diameter at breast height (d, at 1.3 m aboveground)) ≥2.5cm, and total height and dominant height in the case of enset (h) ≥1.5 m were measured. For coffee plants, stem diameter at stump height (at 40cm aboveground) and for enset, the basal diameter of the pseudo stem (at 10cm height, d10) were measured (Mesele Negash and Starr 2015). All stem diameter measurements were taken in two perpendicular directions and the average value was used in subsequent calculations. In the case of multi-stemmed plants, each stem was measured and the equivalent diameter of the plant calculated by equation (1) as the square root of the sum of diameters of all stems per plant (Snowdon et al. 2002). Local name of the plants were recorded in field and identification was done using published volumes of Flora of Ethiopia and Eritrea. The summary of biometric characteristics inventoried are shown in Table 3.

$$= \quad {}^{2}$$

Where: de is diameter equivalent (at breast or stump Height) (cm) and di is diameter of the i$^{\text{th}}$ stem at the measurement height (cm).

A total number of 2718 individuals were recorded in the survey. The variation in diameter and height among the wealth status was not significant (Table 3).

Different letters show significant differences among groups at 5% level of significance D10= diameter at 10 cm height for enset, D40=diameter at 40 cm height for coffee, D=diameter at breast height, H=height (dominant height in the case of enset).

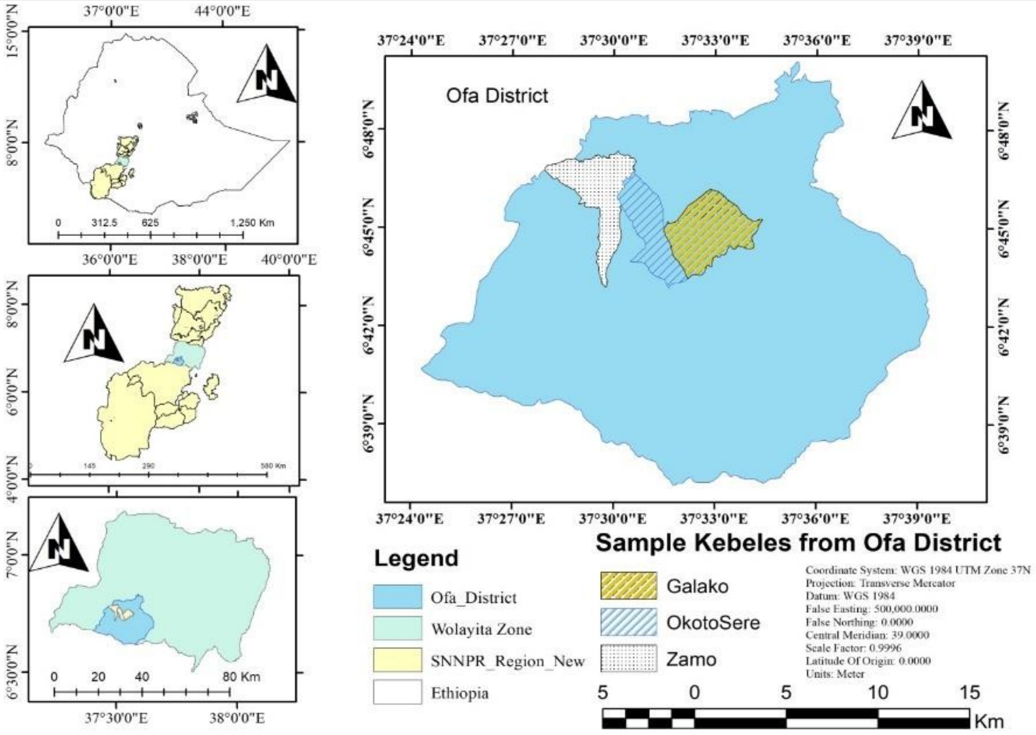

Figure 1: Map of the study Area

Table 1: Local criteria for wealth ranking based on key informants

Criteria	Poor	Medium	Rich
Land holding (ha)	up to 0.5	up to 1	up to 2 and more
Ox	no ox	1 or a pair of oxen	¿ a pair of oxen
Cow	no cow	2 cows	¿ 3 cows
Goat and sheep	0-1	2-4	¿ 5 goats or sheep
Donkey	0 donkey	1 donkey	≥1 donkey
Mule	no mule	no mule	1 mule
Chicken	1-4	5-10	¿11
Mature enset	20-30	80-100	200-1000
No of corrugated iron sheets of the house	0	1	¿1

3.1 Litter and soil sampling

Litter and soil samples were collected from three 1m x 1m sub-plots selected randomly from the four corners and the center of each 10m x 10m plots using a lottery method. Litter sub-samples from each plot were composited and fresh weights were measured on the site using spring balance. Then, a 100 g sub-samples were sun- dried and taken to laboratory to oven-dry at 70 °C for 24 h and determined fresh to dry weight ratio. A total of composited 146 samples were collected from 0-30 cm and 30-60 cm depths using soil augur with 7.5 cm diameter for SOC determination and the same amount of soil samples were separately collected for bulk density determination with 5 cm core samplers. The samples for SOC were dried, ground and then sieved with a 2 mm sieve. The bulk density samples were oven-dried at 105 °C for 48 h and

Biomass carbon stocks for each plot (Mg ha^1) were calculated as the product of dry matter biomass and carbon content. For trees, coffee and enset plants the biomass was calculated using the plot inventory data (d, d40, d10 and h) and allometric biomass functions. For the aboveground biomass of trees, the allometric equation (2) developed by Kuyah et al. (2012a) was used.

$$AGB = 0.091 \times d^{2.472};\ R^2 = 0.98,\ n = 72$$

Where AGB is the aboveground biomass (kg dry matter/plant) and d is diameter at breast height (cm). This equation was developed for trees in agroforestry systems in western Kenya having similar climatic and soil condition as those in our study area. For estimating the aboveground biomass of coffee and enset plants the allometric equations (3 and 4) developed in the Gedeo agroforestry system, southern Ethiopia by Mesele Negash et al. (2013a) were used.

$AGB\ coffee,\ kg/plant = 0.147d^2$; $R^2 = 0.80$; $n = 31$ Where d40 is stem diameter (cm) of the coffee plant at 40 cm height.

$\ln(AGBenset) = 6.57 + 2.316\ln(d10) + 0.124\ln(h);\ R^2 = 0.91,\ n =$

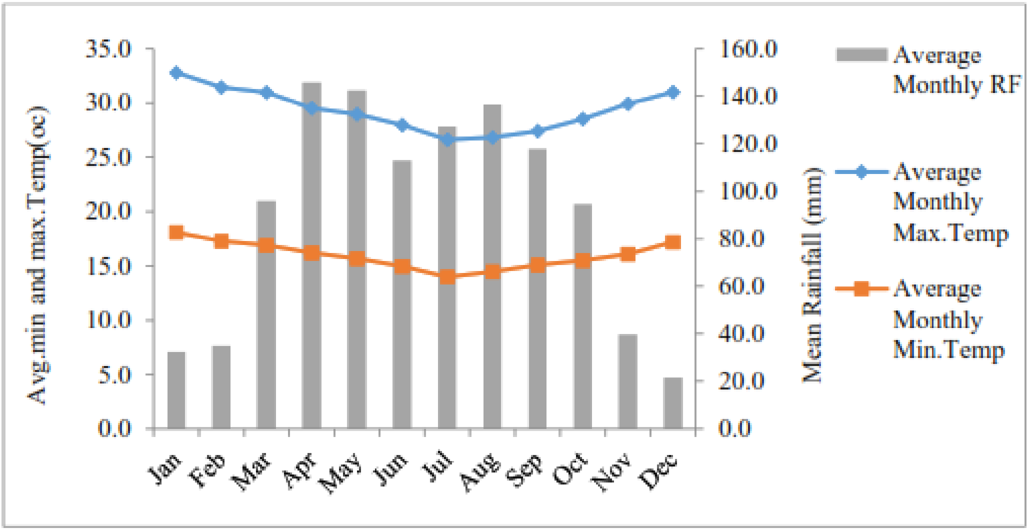

Figure 2: Climate diagram on mean monthly rainfall (mm), mean monthly minimum and maximum temperature (°C) of the Ofa district during the period of 1988-2015 (Source: National Meteorological Agency SNNPR Metrological Center, Hawassa, 2017)

Table 2: Summary of kebeles, villages, and HHs at each wealth class selected for this study

Kebeles	No of Selected Villages	Total HHs	Rich	Medium	Poor	Sampled HHs	Total
Zamo	10	60	10	20	30	1	6
Zogisa	10	76	10	28	38	1	8
Chana	9	71	9	26	36	1	8
Okoto Sere	11	82	18	28	36	2	9
Shoya	8	63	8	25	30	1	7
Kanko	17	82	17	37	28	2	9
Galako	8	72	18	27	27	2	8
Ambe	20	86	20	29	37	2	9
Manisa	19	84	19	28	37	2	9
Total	29	676	129	248	299	14	73

40

Where d10 is the basal diameter (cm) of the enset pseudo stem at 10 cm height and h is total height (m).

Belowground biomass of the tree and coffee plants were calculated using the generic equation

(5) developed by Kuyah et al. (2012b) $BGB = 0.490AGB^{0.923}$; $R^2=0.95$; $n = 72$

Where BGB is the belowground biomass (kg dry matter/plant) and AGB is aboveground

biomass (kg dry matter/ plant).

Below ground biomass of enset was calculated using the allometric equation (6) developed by Mesele Negash et al. (2013a)

weighed, and the weight of >2 mm and <2 mm fractions were recorded

BGB

enset

$= 7(x10^{6})$ d

$^{4.083}$; $R^2= 0.68$, $n = 40$

3.2 Determination of biomass

Where d10 is the basal diameter (cm) of the enset pseudo stem at 10 cm height.

The dry biomass of litter was calculated using the equation of Pearson et al. (2005)

LB = W Field × W subsample (dry) × 1

A W subsample (fresh) 10000

Where: LB is Litter biomass (Mg ha^{1}), W field is weight of wet field sample of litter sampled within an area of size 1 m^{2} (g), A is size of the area in which litter was collected (ha), W sub- sample (dry) is

Table 3: Statistical summary of studied home garden agroforestry practice across wealth categories in midland kebeles of Ofa district, Wolaita Zone, Southern Ethiopia

Stand characteristics	Rich (n=14)	Medium (n=27)	Poor (n=32)
D10, cm	32.6 ± 6.6^a	29.4 ± 4.6^a	31.7 ± 5^a
D40, cm	8.0 ± 1.1^a	6.5 ± 0.7^a	6.9 ± 2.3^a
D, cm	18.5 ± 4.6^a	19.6 ± 3.0^a	16 ± 4.6^a
H, m	7.8 ± 1.5^a	7.37 ± 0.5^a	7.23 ± 0.9^a

Different letters show significant differences among groups at 5% level of significance. D10 = diameter at 10 cm height for enset, D40 = diameter at 40 cm height for coffee, D = diameter at breast height, H = height (dominant height in the case of enset).

weight of the oven-dry sub- sample of litter was taken to the laboratory to determine moisture content (g), and W sub- sample (fresh) is weight of the fresh sub-sample of litter was taken to the laboratory to determine moisture content (g).

SOC stocks (Mg ha^{1}) were calculated as the product of C content (%), bulk density (g<2 mm cm^{3}) and soil depth (cm). To estimate SOC, first the bulk density was determined. The presence of rock fragments over or underestimate the SOC stock (Throop et al. 2012). This requires accurate estimation of the amount of rock fragments for SOC stock calculation. The estimation was made following Pearson et al. (2005).

ODW

BDsoil = Mcoarsefrag CV ( )

Densrock frag

where: BD soil is soil bulk density (g cm$^{-3,}$ $>$ 2 mm coarse fragments), ODW is oven dry weight of soil (<2mm fraction) (g), CV is soil core volume (cm^{3}), Mcoarse frag is mass of coarse fragments (g), and Densrock frag is density of rock fragments (g cm^{-3}) = 2.65 g cm^{-3}.

The SOC stock values for the two depths (0–30 cm and 30–60 cm) were summed to give the SOC stock for the entire 0–60 cm depth. Home garden total C stocks are defined as the sum of the total biomass carbon and SOC stocks (0–60 cm).

3.3 Determination of biomass, litter and soil carbon content

The carbon content in the tree biomass was calculated by multiplying tree biomass by 48% C content, which was determined for trees grown in agroforestry systems in Kenya (Kuyah et al. 2012a). The C contents of 49% for coffee and 47% for enset biomass were used (Mesele Negash et al. 2013a). The C content (%) of the litter samples were calculated from organic matter contents determined through loss-on- ignition (LOI; ignition at 550°C for 2 h) and litter organic matter fraction was calculated according to Allen et al. (1986). While the carbon content of the soil samples was determined using the Walkley-Black method in soil laboratory (Walkley-Black 1934).

3.4 Statistical analyses

Evaluation of normality (Shapiro-Wilk test) and equality of variance (Levene's test) assumptions were done to check the data prior to further statistical analysis. The size and variation in the carbon stocks for each home garden were described by the mean and standard deviation. To test for differences in biomass carbon and SOC stocks among the three wealth categories, one- way ANOVA was performed (α = 0.05). To find out the effect of wealth status and soil depths on soil organic carbon stock two-way ANOVA was performed. Spearman correlation test was conducted to examine the relationship between biomass and soil organic carbon stocks. All statistical tests were performed by using Statistical Package for Social Science (SPSS) software version 16.0.

4 Results

4.1 Biomass carbon stocks

The above and belowground carbon stocks in the studied home garden among the three wealth categories are shown in Table 4. The above ground biomass carbon accounted for 75%, 72% and 74% of the total biomass carbon stocks for rich, medium and poor households, respectively. The total biomass carbon stock in the home gardens of poor household was lower than the rich and medium households by 69% and 62%, respectively. Trees contributed 85-94% of the total biomass carbon stocks across the wealth categories. Coffee accounted for 8.3%, 7% and 3.7% of total biomass for home gardens of rich, medium and poor households, respectively.

While enset contributed 6%, 4% and 2% to the total biomass of rich, medium and poor households, respectively. Litter shared 2.6%, 3.2% and 3.3% to the total above ground biomass carbon stock for rich, medium and poor households, respectively.

4.2 Soil organic carbon stocks

The soil organic carbon stock (Mg ha^{-1}, 0-60cm) did not differ between the home gardens of rich and medium households, but both of them significantly varied from poor households (p<0.05) (Table 5). The total soil organic carbon stock in the home gardens of poor household was lower than rich and medium households by 32% and

Table 4: Mean (±SD) above and belowground biomass carbon stocks (Mg ha^{-1}) among the three wealth categories of the studied home gardens

Biomass component	Rich (n=14)	Medium (n=27)	Poor (n=32)
AGBC	56 ± 16.0^b	43 ± 11.0^b	17 ± 1.0^a
BGBC	19 ± 5.7^b	17 ± 2.0^b	6 ± 3.4^a
TBC	75 ± 18.0^b	60 ± 17.0^b	23 ± 9.0^a

Different letters indicate significant differences and similar letters among wealth categories groups non-significantly different at 5% level of significance; AGBC = Aboveground biomass carbon stock, BGBC = Belowground biomass carbon stock, TBC = total biomass carbon stock.

27%, respectively. The soil organic carbon stock was highest for rich households and least for the poor households. Higher SOC stock was found in surface soil (depth 0-30cm) than sub- surface layer (30-60 cm) in all wealth categories, and the difference was significant along the soil depths (Table 5). The surface soil layer contributed 53% of the total SOC in home garden of rich household, 56% for the medium and 58% for the poor. The SOC stocks of the sub-surface followed similar trend that of the surface layers across the wealth categories.

Within each soil layer, different small letter superscripts show significant differences among groups in row at 5 % level of significance and between soil depths (0-30 and 30-60cm) different capital letter superscripts show significant differences among groups in column at 5 % level of significance.

The SOC showed significant variation within soil depths and among wealth categories ($p < 0.05$) but the interaction effect did not differ ($p > 0.05$) (Table 6).

4.3 Home garden total carbon stock

The total carbon stock (in biomass and soil) did not significantly differ between home gardens of rich and medium households, but both of them significantly varied from the poor households ($p<0.05$). The highest home garden total carbon stocks was recorded for rich (232±22 Mg C ha^{-1}), followed by medium (207±19Mg C ha^{-1}) and poor households (130±13Mg C ha^{-1}) (Figure 3). The total carbon stock in the home gardens of poor household was lower than the rich and medium households, by 43% and 37% respectively. The highest variation in total C stock was observed in the home gardens of rich (ranged 120–357.4 Mg C ha^{-1}), followed by medium (83.5–314.8 Mg ha^{-1}), and the poor households (43.9–225.3 Mg ha^{-1}). The soil

As we hypothesized, the results of the correlation analysis revealed a significant and positive relationship between biomass components and SOC stocks. The total biomass carbon stock explained 65% of the total variation in SOC stock while aboveground and belowground biomass carbon stocks explained 80% and 74% of the total variations in SOC stocks, respectively (Figure 4 a-c).

5 Discussion

5.1 Biomass carbon stocks

This study revealed that wealth status of households affect biomass carbon stocks in the home garden agroforestry in southern Ethiopia. We attribute high total biomass carbon stock in the home garden of rich and medium households to the high plant biomass and basal area. In our study, trees accounted for most of the total biomass C stocks (89 % on average). Study conducted in different parts of Ethiopia confirmed that wealth status of households affect tree density in agroforestry practices (Zebene Asfaw 2003; Worku Belayhun 2011; Getahun Yakob et al. 2014; Getahun Haile et al. 2017). Poor farmers in the studied area focus only on a few selected species which provide direct benefits such as fruit trees and coffee. If the farmers have small size of land holding then, they do not prepare to plant large numbers of tree in their farm since their available land is reserved for corps for home consumption. This tree density may affect the biomass carbon stocks. Study conducted by Wang *et al.* (2011) showed that stand structural parameters have significant positive relationship with aboveground carbon stocks. The high biomass carbon stocks across the three wealth status suggest the significant potential of the systems to store and enhance terrestrial carbon content. The total biomass C stocks across the three wealth status were within the range reported for tropical agroforestry systems (12–228 Mg C ha^{1}) (Albrecht and Kandji 2003).

5.2 Soil organic carbon stocks

The amount of SOC in the studied home garden agroforestry was significantly affected by difference in the wealth status of households. The high SOC stocks for rich and medium households could be related to high litter inputs from high number of perennial components such as tree, coffee and enset. Litterfall contributes to the return of organic matter to the soil (Liang et al. 2011). This was in agreement with studies in Kerala, where home garden's with high number of stems resulted high soil organic carbon than home gardens with low number of stems (Saha et al. 2009). James et al. (2009) asserts that number of stem is an important factor for soil organic carbon stock in home garden as it is directly related to the carbon sequestration. Other studies elsewhere showed similar results (e.g., Fernandez et al. 2010). Strong correlation between total biomass and SOC stocks were also shown in our study.

Soil organic carbon plays a great role in the global carbon cycle and C pools (Sundarapandian et al. 2015). We attribute the high SOC stocks in present home garden agroforestry to the high proportion of tree and shrubs in the system. The SOC stock of the present study

Table 5: Mean (±SD) soil organic carbon stock (Mg ha^{-1}) of the studied home gardens among wealth categories

Depth, cm	Rich (n=14)	Medium (n=27)	Poor (n=32)
0-30	84 ± 12^b	83 ± 11^b	63 ± 13^a
30-60	73 ± 10^A	64 ± 14^A	44 ± 12^A
Total (0-60)	157 ± 21^b	147 ± 19^b	107 ± 11^a

Within each soil layer, different small letter superscripts show significant differences among groups in row at 5% level of significance and between soil depths (0-30 and 30-60 cm) different capital letter superscripts show significant differences among groups in column at 5% level of significance.

Table 6: Mixed model effects of soil depth and wealth categories on SOC stock in the study sites

Source of variation	Df	MS	p-value
Depth	1	8236.680	0.00
Wealth status	2	8941.265	0.00
Depth*Wealth status	2	210.123	0.635
Error	140	461.237	

MS = mean square, df = degree of freedom.

was lower than indigenous agroforestry systems of the south- eastern Rift Valley escarpment of Ethiopia (Mesele Negash and Mike Starr 2015). However, it was higher than those reported in home garden of Rangpur district, in Bangladesh (Jaman et al. 2016). The 0-30 cm depth SOC stocks in the current agroforestry system was higher than the ones reported for coffee agroforestry systems elsewhere in the tropics (Ekwe Dossa et al. 2008; van Noordwijk et al. 2002). Soil organic carbon content decreased with increase in the soil depth. This might be due to the higher presence of organic matter on the surface soil layer than the sub-surface layer (Yimer et al. 2015). The result was consistent with other studies conducted in the different parts of Ethiopia (e.g., Aklilu Bajigo et al. 2015; Mesele Negash and Mike Starr 2015) and elsewhere in tropics (e.g. Ekwe Dossa et al. 2008; van Noordwijk et al. 2002).

5.3 Home garden total carbon stock

Home garden agroforestry across the three wealth status of study site had a high potential to store carbon both in biomass and soil. A high proportion of the total C stock in home garden agroforestry system in the present study is in the soil. The SOC (060 cm) to total biomass C ratio for the studied home garden agroforestry was 2:1 for rich households, 2.5:1 for medium households and 4.6:1 for the poor households. The total carbon stock in the studied home garden across the three wealth status was higher than the reports of home garden agroforestry practice of Gunnuno watershed (Aklilu Bajigo et al. 2015) and lower than Gedeo agroforestry in South- eastern Rift Valley escarpment of Ethiopia (Mesele Negash and Mike Starr 2015). Maintaining of higher carbon stock levels of home garden agroforestry also ensures the productivity of the system.

5.4 Relationship between biomass and soil organic carbon

There was significant and positive relationship between biomass and soil organic carbon stocks in the studied home garden agroforestry. We attribute this to home garden with the high number of stems, which accumulate high organic matter from root, litter and aboveground biomass have a high potential to store carbon in the soil. This was in line with study conducted by Mekuria Wolde et al. (2009), reported that soil organic carbon stock increases in ecosystems as aboveground biomass increases. A study conducted in Rangpur district, in Bangladesh showed a positive and significant relationship between tree biomass and soil organic carbon (R^2=0.94) (Jaman et al. 2016). This finding was also in conformity with studies conducted in Kerala, India that revealed home gardens with higher biomass had higher soil organic carbon than home gardens with lower biomass (Saha et al. 2009). Moreover, Joneidi (2013), reported that belowground biomass was positively correlated with soil organic carbon in his study (r=0.84, $p<0.05$). Therefore, climate change mitigation efforts on smallholder farms should also be considered the socio-economic factors affecting carbon accumulation of the system.

6 Conclusions

The home garden agroforestry of the study area is not only providing productive and protective services for smallholders, but also important for serving as carbon sinks to help in climate change mitigation. The result of this study confirms that wealth status of households in the study area affected home garden's biomass and soil organic carbon stocks. The home gardens of rich and medium households had higher biomass and soil organic carbon stock than poor households. The variation in carbon stocks (biomass and soil) between rich and medium households is not significant, but poor households are significantly different from both rich and medium households. This is in association with high number of stems, which results in high litter fall production and biomass in the home gardens of rich and medium households. Biomass carbon stocks were found to be strongly correlated with soil organic carbons. Thus, climate change mitigation efforts on smallholder farms should also consider the socioeconomic factors such as wealth status for enhancing climate change mitigation role of the agroforestry system.

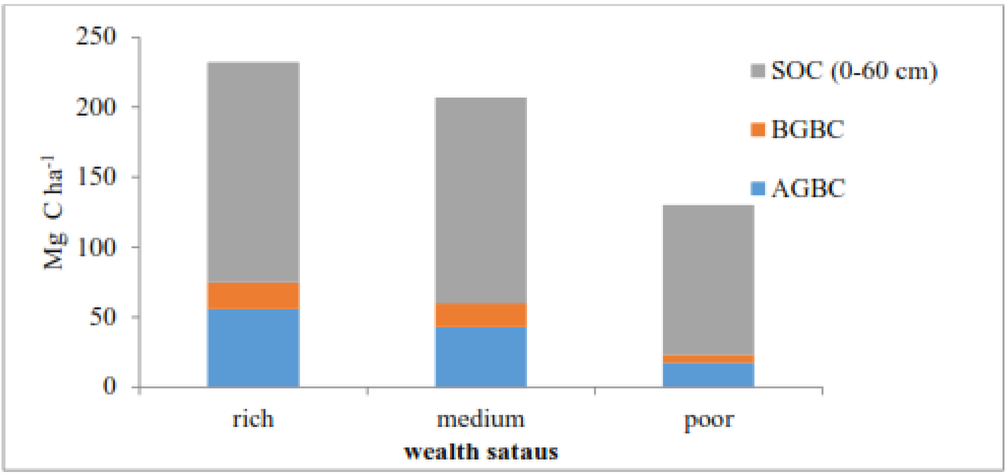

Figure 3: Total home garden carbon stocks across wealth categories. AGBC= aboveground biomass carbon stock, BGBC= belowground biomass carbon stock

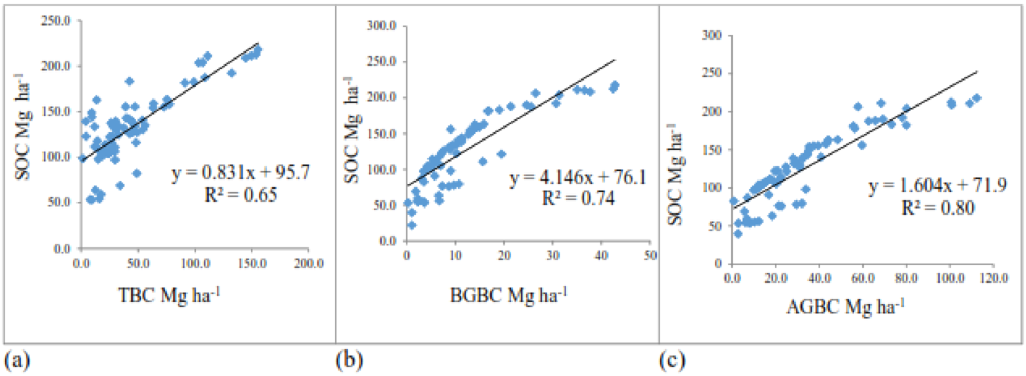

Figure 4: Spearman correlation between (a) total biomass, (b) belowground biomass and (c) aboveground biomass carbon stocks with SOC stocks for the studied home garden

7 Recommendations

Based on this study, the following points have been forwarded as recommendations

- The high carbon stocks of the system indicates that it has a significant carbon sequestration and climate change mitigation role so, farmers should be benefited from carbon credit schemes to maintain this agroforestry system through the implementation of payment for environmental services.
- Further research should be conducted on other socioeconomic factors other than wealth status that may affect the carbon stocks in home garden agroforestry system.
- The policy makers, stakeholders, researchers and extension practitioners should further work on enhancing the awareness about the role of home garden agroforestry on climate change adaptation and mitigation.

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Competing interest

The authors declare that they have no competing interests

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