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Original Article

Comparative Carbon Stock Potential of Indigenous Agroforestry Systems in Silte Wereda, Southern Ethiopia

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ABSTRACT

Agroforestry system (AFS) is described as the best promising mitigation method for alarmingly changing climate through its adequate and proven carbon sequestration capacity. The present study was taken over in Silite District; Southern Ethiopia highly aiming to estimate unaccounted but recognized important capacity of AFS regarding its carbon lock potential. Biomass and soil organic carbon (SOC) were considered carbon pools in the present study. The samples were taken from temporary plots laid for this particular experiment each land use systems have standard sample plot size according to their nature. While taking the biomass samples Height (H) and diameter at breast height (DBH) of woody species were compulsory parameters considered for measurement to estimate the biomass. Proper and adequate number of soil samples was also taken for bulk density and SOC valuation. Non woody/herbaceous plats including grass was also sampled for total land use system biomass amount estimation. The samples were taken in1m^2 quadrant within the main plot. The finding from this estimation shows that the range for studied land use system found to be (1.28-7 Mg ha), while running the variance test between means of each land use system no substantial variation was observed. Whare as higher rate was attributed by parkland AFS has the higher rate. while the lowest was woodlot. A significantly higher amount of SOC was recorded in home garden AFS along the two depths (82.5 Mg ha -1) than the other two systems and the lowest was attributed to parkland (41.7 Mg ha -1). Therefore, this traditional AFS should be recognized and given enough attention for contribution in climate change mitigation schemes through significant amount of carbon in every available pool of the system.

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INTRODUCTION

High GHG concentration on the atmosphere due to forest degradation and deforestation can be major cause for the climate change. 25% of net annual CO_2 emission and 10% of N_2O emission is from tropical deforestation (IPCC, 2000). Forest deforestation, soil and nutrient deprivation due to anthropogenic undertakings like agricultural land expansion and land use change are the main source of CO_2 emission in tropical countries (Houghton,2012). Non-CO2 emission like CH4 and NO_2 are mainly triggered by livestock and as a result of artificial fertilizer application in the soil NO_2. Though most of the causes of GHG emissions are listed above fossil fuel burning attributes the largest present in the emission of GHG to the atmosphere resulting worst climate change impact (Heede & Oreskes, 2016). Different methods of exploiting land can also be potentially be sources of GHG emission whereas some of them can be a great source of carbon sink though land use change to agricultural lands leads to a giveaway in environmental carbon stocks other land use system like agroforestry contribute much to the change and continuing carbon lock in enduring storage of carbon in the ecosystem by stabilizing GHGs emissions (Kumar, 2011).

Most AFS incorporates trees in agricultural fields which pointedly lock up significant amount of carbon in different carbon pools available in the system there by acts as great carbon sink and contributes to dipping the amount of GHGs concentrations in the surrounding atmosphere (Rizvi et al.,2019). Comparing Agroforestry land use and bare agricultural lands without incorporated trees within, AFS resembles to have much greater carbon stock. The system also potentially balances immediate GHG emissions from deforestation/land use change (Nair, 2012).

Soil quality improvement through AFS has given a little attention but the actual truth about the contribution of the system through fixing available nitrogen under known tree species for their nitrogen fixing ability is very crucial. This will help small scale farmers to increase their livelihood income potential by increasing production level (Schlesinger & Andrews, 2000).

Though AFS also provide many ecosystem services and improves household income and nutrition most of the other livelihood sources which is agriculture have a direct impact on the economy and food security being a source of GHG emission thus, there is an urgent need to further develop and introduce climate resilient land use system like agroforestry systems considering of its prospects in the climate change adaptation and related mitigation options (Mbow, 2013).

The study site, Southern Ethiopia, Selete Wereda is prevalent in using different traditional AFS as a means of livelihood/income and house hold consumption. The land use system is also promising as a means of coping up measure for climate change hazards in the area specially flooding which is commonly occurring hazard in particular area. Though different studies are conducted in accounting ecological and socio-economic benefit gained from the land use system, particular studies in this study area are deficient thus, this study broadly aims to asses /estimate the environmental contribution of AFSs for climate change mitigation through their carbon sequestration potential. Knowledge and

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information gaps while applying the land use system highly affect the effectiveness sustainability of the system. (Nair, 2004) Thus, understand and identify which system is more resilient to climate change and is less source of GHG emission helps while introducing or scaling up the system, therefore, the present study aims to estimate and compair the carbon stock potential of selected AFS. The general objectives of the study were, therefore to compare and select more resilient AFS based on their carbon sequestration potential in the study area.

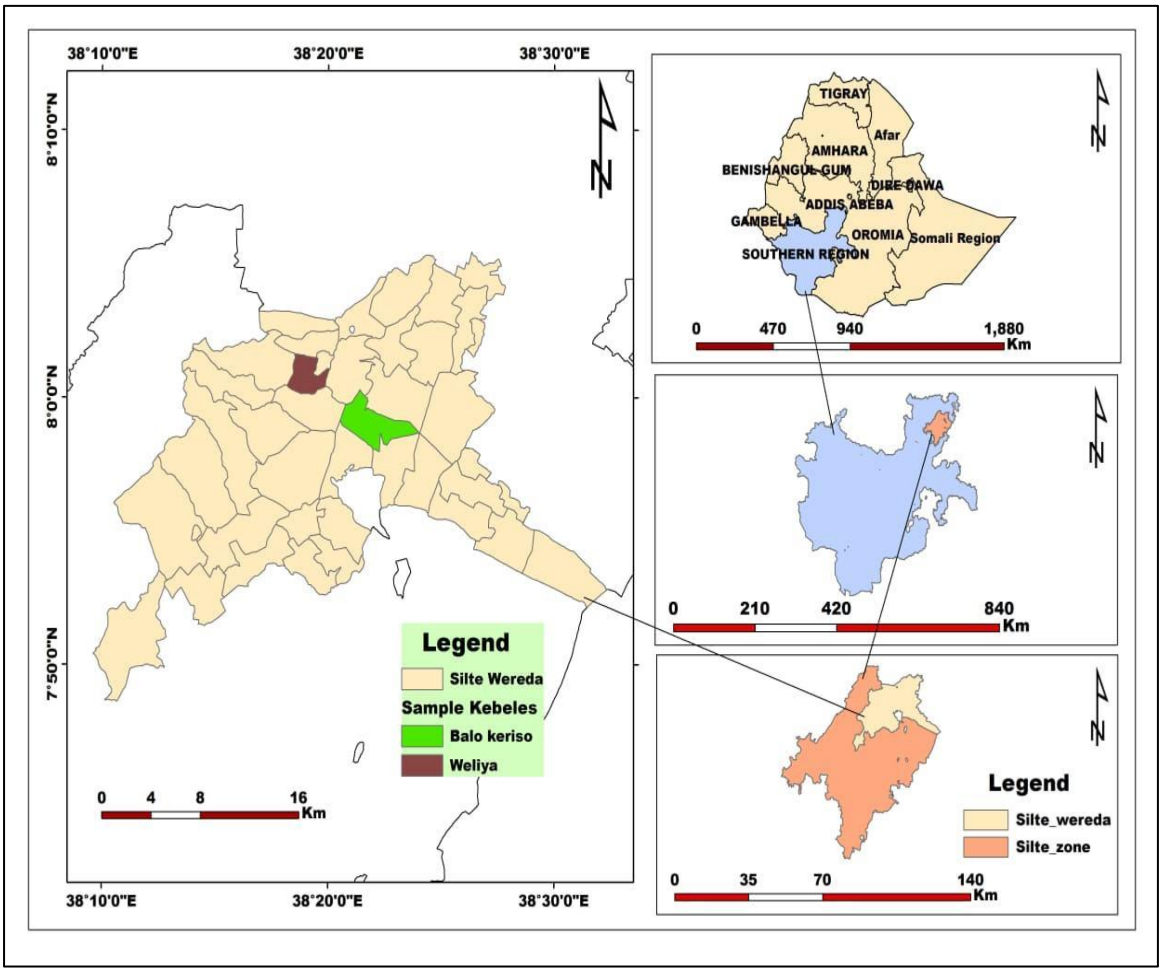
METHODOLOGY

Study Site Description

The present study site is located between 7°43' to 8°10'N latitude and 37° 86 'to 38° 86' E longitudes in SNNP, Southern Ethiopia. The total zone covers 3047.83 Km^2 , Balokeriso and Welay Sedest in Silite District, SNNP are small kebeles selected to conduct the practical study depending on their dominance and accessibility (*Figure 1*). The average yearly temperature and precipitation of the study site ranged from 10.1 °C to 22.5 °C and 650 mm to 1818 mm respectively with an altitude ranging from 501 m a.s.l. to 3500 m a.s.l.

The present study site which is purposely selected as AFS is common land use type in the area. The most common AFS include home garden, woodlot and parkland. In the home garden AFS enset, coffee, fruit tree, *Acacia Spps, Cordia africana* & *Croton macrostachyus*. Herbaceous crops were also incorporated in the system. While Eucalyptus species mainly *Eucalyptus viminalis* are the dominant species in woodlot AFS encompassing grass and herbs as understory layer. Parkland AFS includes mainly *Acacia albida* along with different crops like maize, teff, wheat and sorghum.

Figure 1: Map of the study site



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Sampling Procedures and Data Collection

The feedback from the reconnaissance survey offers the framework to select specific study areas and systems. The reconnaissance survey was conducted together with zonal and district agricultural experts. The selection of specific study area and AFS were done purposively based on the dominance. The selected kebeles have similarities in climate and soil conditions rainfall and temperature. Households representing the selected systems were randomly sampled.

Data Collection

Data were collected from biomass, litter, herb, grass and soil for carbon stock estimation for each component in the system. The specific variables considered during the data collection are as follows: -

Woody Species Inventory

Sampl plots were randomly placed for woody tree species data collection: for hight(H) and DBH in household farms. Every woody species found in the plot were considered and measured. In this study systematic random sampling was used to determine sample plots to be laid, accordingly, 120 farms were selected for biomass estimation and 60 plots for SOC determination. The selection criteria follow system dominance and resource both for sample size and sample selection.

Sample tree species found in selected AFS were collected within 50m × 100 m, 10m^2 and 20m^2 respectively for parkland, woodlot and home garden AFS. Sample plot sizes ware determined /adopted from similar studies with similar agroecology's which are standardized for AFS in tree density, component structure and management practices. The above adopted studies put standard sample sizes for the AFS selected in this study Hence, this study there by use this standard sampling as cited above. Measurement of required parameter took over within the plot considering hight and diameter at breast height to determine biomass composition of the given system. Accordingly,

Trees with more than one branch in the system treated by taking the equivalent diameter using the following formula. (Montagu et al.e ,2005).

$$d_e = \sqrt{\sum_i^n di^2} \quad (1)$$

Where d_e is Diameter (Stump height), d_i is diameter of the first stem at stump height (cm).

Litter Herb and Grass Sampling

Once the main plot is placed for each AFS each sample of litter, herb and grass were collected from 1m^2 mini plot that is found within the main plot. Samples were taken from the four corners and one in the centre. placed in plastic bags to measure the fresh weight (Pearson et al., 2013).

The samples for litter, herb and grass were taken from the four corners and centre of the main plot which is a total of five samples for each carbon pool

Soil Sampling

Bulk density and mineralized soil samples were considered parameter for soil organic carbon estimation accordingly, soil samples were collected from the same plots used for woody species inventory. Two depths i.e. (0-15 cm, 15-30 cm) were considered while sampling soil at four corner and centre of the main plot where the biomass samples were taken. 1m^2 quadrant ware laid to take composite sample of the soils. Soils samples were collected using the material auger and appropriate number of samples were taken back to the laboratory for further study (Roshetko *et al.*, 2002; Takimoto *et al.*, 2008). Soil bulk density sample were taken in same depth as the soil sample for SOC using standard core sampler material (Roshetko *et al.*, 2002; Lemenih *et al.*, 2005).

Data Analysis

Biomass carbon valuation

Biomass carbon potential of the studied AFS which comprises both above ground biomass (AGB) and below ground biomass (BGB) computed using allometric models which are selected based on the climate similarity and

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species matching for the sample land use system. Hence, lnY= -3.375+0.948 × ln (D2 × H) (2) equation were adopted for AFS in tropics (Steffan-Dewenter et al., 2007).

Where; Y=Biomass), D=DBH (cm) and H=Height (m).

The conversion factor for both AGB and BGB were 50% and 25% respectively (Kumar & Nair, 2011).

In addition to species specific equation some generic models were also considered for woody species types.

Coffea Arabica AGB=$0.147d^2_{40}$ (3) (Negash *et al*., 2013)

BGB= $0.490AGB^{0.923}$ (4) (Kuyah *et al*. 2012).

The above ground carbon stock was considered as 49% of above ground biomass (Negash et al. 2013).

Ensete venticosum AGB = -6.57 + 2.316ln (d10) + 0.124ln (h) (5) (Negash et al. 2013)

BGB=$7\times10^{-6} \times d_{10}^{4.083}$ (6) (Negash *et al*. 2013).

The above-ground carbon stock was considered as 47% of above-ground biomass (Negash et al. 2013).

Where; d40, diameter at 40 cm height (cm); d, diameter at breast height (cm); d10, diameter at 10 cm height (cm); h – total tree height.

Herb, Litter, and Grasses Carbon Stock Estimation

Sampled herbaceous species and grass available in the land use system were taken back to the laboratory and stayed in the oven until they samples become constants in their mass 70 ^{0}C (Pearson *et al*., 2005). The drymas content then computed as:

$$Dry-mass=\left[\frac{sub-sample-dry-mass}{sub-sample-fresh-mass}\right]*field-mass$$

$$Expansion-factor=\frac{10{,}000m^2}{Area-of-plot(m^2)} \quad (8)$$

Herbaceous /non woody species carbon fraction considered to be 50% (Pearson *et al*., 2005).

Soil Organic Carbon

Soil organic carbon analysis was carried out using Walkley-Black method which is the very accurate and common one. Soil samples from the filed were dried out in the air and sieved in 2 mm sieve to make it prepared for further chemical analysis (Pearson *et al.*, 2005: Meersmans et al., 2009) Bulk density samples were stayed in the oven at 105 ^{0}C and weight. Soil. The carbon stock density of soil organic carbon was calculated as (Pearson *et al.*, 2005): -

$$SOC = BD * d * \%C \quad (9)$$

Where, SOC = Soil organic carbon stock [Mg ha^{-1}], BD = Bulk density [g cm^{-3}], d = the total depth at which the sample was taken [cm], and %C = carbon concentration [%].

To estimate bulk density of the mineral soil :

$$\text{Bulk density } (g/m^3) = \frac{\text{oven dry mass } (g/m^3)}{\text{core volume } (m^3)\left[\frac{\text{Mass of coarse fragments } (g)}{\text{density of rock fragments } (g/m^3)}\right]} \quad (10)$$

Estimated Carbon

The current study considers all available carbon pools for the total carbon estimation accordingly, the ecosystem /total carbon stock for the studied system were computes as:

$$C_{Estimated} = C_{AGBc} + C_{BGBc} + C_{LHGc} + SOC \quad (11)$$

Where: $C_{Estimated}$ = Carbon estimated in [Mg C ha^{-1}], C_{AGBc} = Above ground carbon stock [Mg C ha^{-1}], C_{BGBc} = Below ground biomass [MG C ha^{-1}],

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C_{LHG} = Carbon in litter, herb & grass [Mg C ha^{-1}], and SOC= Organic carbon in soil [Mg C ha^{-1}].

Statistical Analysis

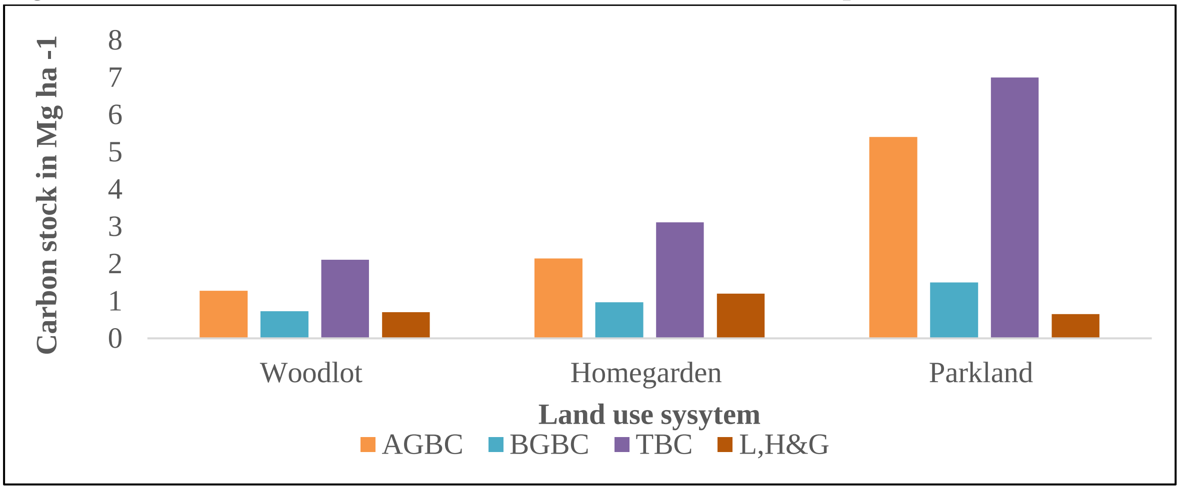
Statical analysis for intended samples were executed by considering latest and suitable software namely SPSS version 20 software. To compare the mean difference of results obtained from the adopted models and laboratory results One way ANOVA test was made. Based on the hypothesis sated, the current study opts to see if there is statistically significance difference among the studied system or not. Accordingly, we run post hoc test between mean value of the results.

RESULTS

Biomass Carbon Stock

Parkland AFS got highest biomass carbon both in AGB and BGB carbon (7 Mg ha^{-1}) and the list was recorded by woodlot AFS (2.11 Mg ha^{-1}) (Figure 1). Though there is an arithmetic difference among the results in biomass carbon stock there is no significant statistical difference α=0.05 as indicated as a result of one-way ANOVA. The amount of mean carbon by litter, herbs and grass estimated in studied agroforestry systems were 1.2, 0.7 and 0.65 $Mgha^{-1}$ for HG, WL and PL AFS respectively. The total biomass carbon in this study was supported by HG AFS which comprises the highest rate, though its proved that all land use systems considered in this study contain reasonable amount of biomass carbon the comparing the selected AFS in this study PL AFS contain the lowest rate. The mean difference in the studied land use system shows no significant difference at ($p > 0.05$).

Figure 2: Assessed biomass carbon in the studied land uses (Mean plus ±SD)



Soil Organic Carbon

Estimated amount of SOC in the present study highly comprised by HG AFS which accounted by the first layer i.e 64%. The above result works best in substantiating that soil organic carbon plays major role in contributing as prior a carbon pool. in the ecosystem. Meanwhile, parkland AFS holds the lowest SOC value in both soil depths. The contribution of SOC in both depths for each AFS estimated to be 43.7%, 34% and 22.3% for home garden, woodlot and parkland AFS respectively.

With the aim of accepting or rejecting the hypothesis and after a statistical tests, compared/studied land use systems differs insignificantly ($F = 8.65$ $p = 0.002$; *Table 2*) .

Table 1: SOC (Mg ha-1) across studied land use system. (Mean +SD)

Land use system	SOC (0-15 cm)	SOC (15-30)	Total SOC
Home garden	53±6.4	29.5±3.2	82.5±16.4
Woodlot	40±10.5	24.2±5.3	64.2±9.5
Parkland	23±4.2	18.7±4.9	41.7±5.5

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Total Carbon Stocks

Total carbon stock or ecosystem carbon of studied land use systems ranged from all of the components (1.2-82.5 Mg ha^{-1}) which includes biomass and soil components that exists in AFS. Though the contribution of each component diverge across the systems their difference was not statistically significant except the significant difference found between home garden and woodlot AFS in total carbon stock at α =0.05 significant level. Home garden AFS has significantly substantial amount of recorded for total carbon lock amount among the land uses. AFS total/ecosystem carbon recorded comprises 41 Mg ha^{-1} up to 82.7 Mg ha^{-1} (Table 2). The significant test performed to see mean difference among the carbon pools and components shows that no considerable difference was recorded among the systems. (F = 5.6 p= 0.001).

Table 2: ecosystem/total carbon lock amount of selected AFS (Mg ha-1).

	Agroforestry systems		
Carbon pools	**HG**	**WL**	**PL**
Biomass (AGBC+BGBC)	3.11±1.5	2.11±0.78	7±5.6
Herbs, grass and litter	1.2±0.3	0.7±0.56	0.65±0.2
SOC (0-15 cm)	53±16.4	40±9.5	23±4.2
SOC (15-30 cm)	29.5±5.5	24.2±6.3	18.7±7.9
Total SOC	82.5±16.4	64.2±9.5	41.7±5.5
Total carbon stock	86.8±10.2	67.01±6	49.35±5

DISCUSSION

Biomass Carbon Stock

Estimated biomass carbon (AGB+BGB) stock including litter, herb and grass accounts 4.31, 2.81 and 7.65 by HG, WL and PL respectively. As different related studies describes, reasonable amount of biomass carbon level could potentially relate with available tree stands in certain area and their common parameters and both negative and positive anthropogenic impacts on the stands to intensification of productivity while maintaining their livelihoods (Chave et al., 2004). Moreover, the arrangements of the stands, tree availability, species type and agroecology in a given land also be associated with difference in carbon stock potential among the studied AFS (Mosquera-Losada et al., 2011).

The results obtained in the present study was analogous with related researches in associated study area. Thus, comparing our results with the finding in Gununo Watershe Wolayitta Zone, Ethiopia, (Bajigo et al., 2015) which carried out in the same land use system with our study, it shows reasonably higher amount carbon available in the system.

The present results not only stay higher than other research findings but also found to be lower as compared to enset and enset based coffee agroforestry system in Southern escarpment of Ethiopia (Negash & Starr, 2015) and also still lower than tropical dry deciduous forests (14.7 - 43.2 Mg ha-1) (Chaiyo et al., 2011). There is a global report for AFS (10.1–100.9 t ha^{-1}) (Dixon 1995; Albrecht and Kandji 2003). provenly, our results fall in the range of the global average.

Incorporated trees in PLAS managed using different management practices like thinning and pruning to reduce the shading effect and competition for resources this could be associated with reduced biomass (Jandl et al. 2007). In addition, major climatic parameters like temperature and precipitation along with the impact of soil characteristics, topography and humidity can be directly or indirectly associated with differences in biomass among the studied AFS (Chen et al., 2014). Frequent litter collection for fuel, illegal grazing, cutting and collecting of grass and herbs for different household purposes could be associated with the reduced carbon stock amount stored in litter herb and grass carbon pool (Gebresamuel et al., 2010).

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Soil Organic Carbon Stock

Inputs and practices which are very common on AFS can be potential reasons for varying carbon stock amounts carried on it. Certain management practices such as organic mulch and manure particularly in home garden agroforestry system facilitate decomposition rate in the soil using microorganism as a catalyst and accelerating the decomposition rate in soil and SOC at the same time (Xu et al., 2016). Thus, above mentioned reasons positively associated with for substantial greatest record of carbon stock in the soil for the HG AFS.

Thus, the schemes in climate change mitigation can obtain great benefit from this land use systems as it locks noteworthy rate of carbon within the soil carbon pool. Furthermore, a collection of different species with high biomass assembly found in the system contributes a lot to facilitating high biomass decomposition which directly affects the soil carbon stock in the system (Wolle et al., 2021).

The amount of SOC in home garden and woodlot AFS recorded by this study was found to be greater than the research findings, particularly took over in Gununo Watershed, Wolayita Zone, Ethiopia which shares the same agroecology accounting. 61.6 t ha^{-1} and 48.6 Mg ha^{-1} of SOC respectively for HG and woodlot agroforestry (Bajogo et al., 2015). There are also some findings which appear to be greater in their carbon estimation than the present study (Lal, 2012) and (Negash *et al*., 2015) can be mentioned.

The study also reveals that the contribution of upper depth of the soil horizon (0-15cm) is higher than the lower depth (15-30 cm) this subordinate with greater decomposition rate in upper depth having the prodigious chance of biologically interacting with root biomass and rudiments in the ecology (Lal ,2005). Though ideal volume of carbon is locker in the studied AFS, comparing to each other PL AFS has the lowest rate of SOC this result can be comparable with findings in (Islam & Weil, 2000) in the same land use type.

Constant cultivation and disturbance of the soil which disable the system to fail on locking SOC may relate to the lower SOC in the system (Poudel & Thapa, 2001). In PL AFS its highly expected to loss reasonable amount of soil due to erosion which wash away the most important layer of the soil horizon which is the upper soil. Mostly the erosion occurs due as the system commonly involves ploughing and digging activities for production thus, this could be one of the reason for the reduced amount of SOC in the land use system (Bajigo et al., 2015).

Generally, the variation in the quantity of difference SOC within the studied AFS could be related with structure, land use history, and different management practices like thinning and pruning which can affect SOC by lowering the decomposition of litterfall naturally and due to the change in understory physiognomies (Laganière et al. 2010; Lorenz and Lal 2014).

Total Carbon Stock

AFS total ecosystem carbon which comprises both biomass and soil carbon falls in the range of (41 to 82.7 Mg ha^{-1}) showing considerable amount of carbon is locked by the land use system as compared to similar research findings (Dixon 1995). The current findings from this particular experimental study concludes that HG AFS contribute largely for the total carbon lock in considered land use systems this could be largely due to high species diversity, composition and structure and soil characteristics, local climate, density of woody per unit area, and disturbance in the system (Gelaw et al., 2014; Kumar, 2011).

Promising management practices applied in HG AFS can be reason for higher organic matter content in the system which results in high SOC amount in the soil (Negash & Starr, 2015). Since the tree stands in the study area are young the carbon accumulation stock are expected to increase due active growth performance until they attain maturity (Brakas & Aune, 2011).

CONCLUSION

The difference in management practice of AFS, available carbon pools and soil depth can affect emission reduction potential of land use system. Biomass and soil carbon stock found to be high in-home garden AFS with high application of natural manure and diverse component composition. SOC decrease down to the soil layer proving that most of organic matter found in upper part of the soil and organic carbon as well. Species diversity and composition in the system contribute a lot in high GHG emission reduction capacity. Hence, new and effective management options and recognition for traditional AFS is mandatory to distinguish and escalate the reduction capacity of the system.

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Competing of Interest

All authors declare that there is no conflict of interest.

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