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Research Article

Litterfall-Associated Carbon Deposition and Vertical Profiles of Soil Organic Carbon in Different Land-Use Systems

Mengistu T. Teramage [1,2] Biruk Bassango [1] and Getachew Sime [2,3]

[1] *School of Plant and Horticultural Sciences, College of Agriculture, Hawassa University, Awasa, Ethiopia*
[2] *Center for Ethiopian Rift Valley Studies, Hawassa University, Awasa, Ethiopia*
[3] *Department of Biology, College of Natural and Computational Science, Hawassa University, Awasa, Ethiopia*

Correspondence should be addressed to Mengistu T. Teramage; teramaget@yahoo.com

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Litterfall is one of the major inputs for soil nutrients. Understanding the connection of litterfall and soil organic carbon (SOC) as the part of ecological processes is a key step towards carbon sequestration as a climate change mitigation strategy. Yet, it remains inadequate to support by empirical pieces of evidence particularly in tropical ecosystems. In this study, litter traps were used to monitor the monthly organic carbon deposition over a year through litterfall, and soil samples were collected vertically up to 30 cm depth to define the SOC depth distribution in three different land use types located at Wondo Genet district, southern Ethiopia. The results were interpreted by deploying both the carbon stratification ratio (CSR) and carbon flow balance ratio (CFBR) as ecological indicators. The results revealed that both the annual litterfall amount and associated organic carbon input in plantation forest ($958.4 \pm 112\,g{\cdot}m^{-2}{\cdot}yr^{-1}$; $391.4 \pm 112\,g{\cdot}C{\cdot}m^{-2}{\cdot}yr^{-1}$) were higher than those in the homegarden ($183.5.4 \pm 26\,g{\cdot}m^{-2}{\cdot}yr^{-1}$; $67.4 \pm 10\,g{\cdot}C{\cdot}m^{-2}{\cdot}yr^{-1}$), conceivably due to few litter contributors (trees) present in the homegarden. The CSR of the homegarden (1.3 ± 0.01) was found between the ratio obtained for crop (1.2 ± 0.01) and plantation forest (1.4 ± 0.01), indicating that it is definitely a combination of pure plantation forest and crop system. The CFBR was higher in plantation forest ($3.4\,yr^{-1}$) than in soil of homegarden ($0.77\,yr^{-1}$), implying the net accumulation of soil carbon over time in the latter system. Hence, homegardens could be considered as a system of climate-smart practice with multiple-biogeochemistry pathways, which simultaneously address the social-absolute needs. Given the current tendency of transforming homegarden agroforestry to monoculture types owing to economical drivers, such indicators can dictate of making rational decisions related to land use planning and soil fertility management.

1. Introduction

Litterfall and decomposition are among the important ecological processes which strongly affect the pools and fluxes of the soil in different terrestrial ecosystems. The soil stores a significantly large amount of carbon (C) as compared to vegetation and the atmosphere [1, 2]. Land use change from natural to modified ecosystems affects the pools and fluxes of terrestrial soil carbon pools, particularly in tropical regions, which in turn affect their ability to provide goods and services to mankind. Shedding of various plant components such as leaves, wood, and roots are responsible for altering the pools and fluxes of carbon in the soil, which are significantly affected by the changes in the land use patterns from one to other ecosystem types, i.e., forest to home garden and/or agriculture [3]. The ability of soil to store carbon is regulated by a number of factors, e.g., soil physicochemical properties, quality and quantity of soil organic matter, microflora, and fauna and their activities. In tropical ecosystems, the promotion of plantations by important tree species such as *Grevillea robusta* and agroforestry systems in these regions is considered important to improve the soil and environmental quality [4]. Despite this, little is known about tropical soil carbon covered under different land use types as compared to temperate regions.

In general terms, plantation forest, cropland, and agroforestry land use systems are the most common land use practices globally [5]. In tropical areas, the soils are commonly covered by seasonal food crop farming, which often does not involve a litterfall-derived carbon input continuum. However, still, considerable lands are also covered mostly by forest and with mixed systems of both crop and tree components, which is commonly called agroforestry. Obviously, both forest and agroforestry systems involve litterfall as nutrient input including carbon whose amount varies depending on the number of trees present. Litterfall is a year-round biophysical process and is considered as a key segment in the C cycle in which recognizable plant materials enter into the soil and undergo a series of biological, physical, and chemical breakdown processes [3].

Similarly, in Ethiopia for various reasons including food, fuel, construction of woods, local medicine, generating income, reducing soil erosion, and ritual purposes, considerable lands are covered by crop, forest, and agroforestry systems. Especially, in the southern part of Ethiopia including the Sidama region, agroforestry land use systems are the most common and widely practiced system dominated by the indigenous homegarden agroforestry practice [4, 6].

However, the ever-increasing population with expanding demands for food exerts a huge pressure on forest and indigenous homegarden practices. Shifting of homegarden agroforestry practices into cash (commercial) crop systems without due consideration of the effect it brings up on the soil properties is ecologically unwise. Therefore, there must be appropriate and quantified information on how the existing land use types influence the depth distribution of SOC as well as the contribution of litterfall in depositing the organic carbon particularly in homegardens and plantation forests compared to conventional cropland.

In response to SOC protection and improvement, empirical field evidence has to be summarized and understood before recommendations go out for wider policy applications. Hence, comparing the depth distribution of SOC in relation to the litter-derived carbon input in the most common land use types becomes a paramount importance. Therefore, this study hypothesized that the vertical arrangement of SOC in the most active soil horizon (0–30 cm) under crop, indigenous homegarden, and plantation forest land uses types (LUTs) is similar, and it is not affected by the contribution of carbon associated with litterfall process to the SOC stock in the last two LUTs located in Sidama region, southern Ethiopia.

2. Materials and Methods

2.1. Description of the Study Area. The study was conducted in the Wondo Genet district, which is located 24 km to northeast of Hawassa town and 297 km to south of Addis Ababa. It is characterized by a cool subhumid agroclimate (Figure 1), which is locally equivalent to "Woyina Dega." Based on the World Reference Base for Soil Resources (WRB), the soil type in the study area is dominated by nitosol. The general and detailed biophysical characteristics of the study site are given in Table 1.

Due to ever-increasing laboratory-associated costs, we carefully identified and selected well-representative sample land uses to well-represent the cropland, plantation forest, and indigenous homegarden of the study district for soil sampling. The plantation forest is composed of *Grevillea robusta* planted some 36 years ago. While the homegarden contains purposely either planted or retained diverse tree species including *Cordia africana, Croton macrostachyus,* and *Millettia ferruginea* which dominate the upper story in different arrangements while various biannual and annual plants including enset (false banana), coffee, maize, haricot, potato and the like dominate the middle and understory strata of the system. The sampled cropland is conventional agricultural land used to cultivate food crops every farming season including barley, wheat, potato, and maize (Table 1). Haricot beans and maize were harvested before and during sampling years, respectively.

2.2. Experimental Layout

2.2.1. Litterfall Samples. Litter traps (1 m^2 nylon net each) with three replications were installed at 1 m above the ground only in plantation forest and homegarden land uses to monitor the litterfall production and associated organic carbon deposition into the soil for one year (January 2021 to December 2021). At cropland, litterfall traps were not installed to collect litter due to the absence of trees. A schematic diagram indicating the experimental setups including litter traps and soil sampling patterns in the study area is shown in Figure 2. To make it more representative, the litter traps were installed as near as possible to the soil sampling points in a triangular pattern taking midway or rows of trees into consideration (Figure 2). The traps were emptied monthly by handpicking and litters were placed inside the labeled collecting bags and transported to the laboratory for subsequent processes.

2.2.2. Soil Sampling. At each LUT, 10 m × 10 m quadrats were deployed at the center of the sampling site to avoid any possible edge effects and three pits were opened in a triangle pattern of 1 m apart. This pattern was repeated at three points along the diagonal of the quadrat as clearly illustrated in Figure 2. Then, soil samples were collected using a steel core tube (with an internal diameter of 5 cm and a length of 5 cm, 9.83 cm^3) by manual percussion layer by layer vertically up to 30 cm for the six depth intervals (0–5 cm, 5–10 cm, 10–15 cm, 15–20 cm, 20–25 cm, and 25–30 cm). The sampling points were purposely selected based on similarity in land use and at the flat area along the diagonal of the quadrat to avoid any slope effect and associated morphological differences on the typological soil horizons. According to each sampling point, the soil samples were collected with three replications and then combined together at each respective depth section to well-represent the spatial variation of the sampling points [7], resulting in a total of 54 composite soil samples. The soil samples were then transferred into polyethylene bags, labeled and safely transported to the laboratory for analysis.

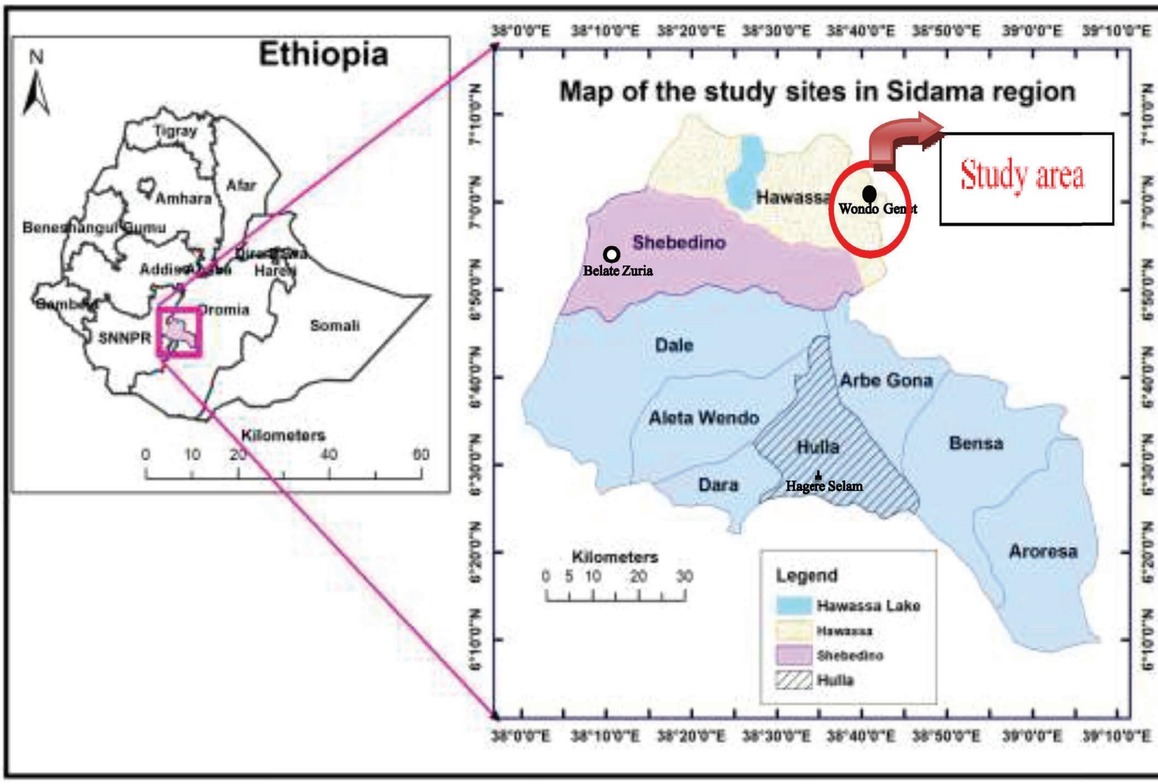

FIGURE 1: Map of the sampling site (indicated in circle) located in the Sidama region in the Southern part of Ethiopia.

TABLE 1: Biophysical characteristics of the study site.

Characteristics	Wondo Genet
Altitude (m a.s.l)	1844
Annual rainfall (mm)	1372–2062
Annual temperature (°C)	12–26
Geographically	7°14′ N and 38°36′ E
Major trees/fruit	
Home garden	*Ensete ventricosum*, chat (*Catha edulis* (Vahl) Forssk. ex Endl), garden coffee (*Coffea arabica* L.), avocado, and tree species such as *Cordia africana*, *Croton macrostachyus*, and *Millettia ferruginea* mixed with food crops such as peas, beans, maize, haricot bean, potato, and cabbage
Plantation forest	*Grevillea robusta* plantation with an approximate age of 36
Major food crops	
Cropland	Barley, wheat, peas, bean, maize, haricot bean, and potato

2.2.3. Laboratory Analysis Procedure. Litters were placed in paper bags and dried in an oven at 70°C until constant mass was reached. The rate of litterfall at dry mass base was calculated in $g{\cdot}m^{-2}{\cdot}y^{-1}$. The dry litter samples were pulverized into powder and homogenized for organic carbon analysis. The carbon content (%) of the litter was determined following the loss-on-ignition (LOI) at 550°C and corrected by its molecular proportion (44%) in plant organic matter ($C_65\ H_2O$) [8–10].

All soil samples were dried in an oven at 70°C until a constant mass was reached to determine the dry weight. Then, the soil samples were disaggregated by gentle grinding, passed through a 2 mm sieve, and well mixed to ensure a homogenous sample material for each respective sampling depth. The carbon content of the samples was determined using the Walkley–Black wet oxidation method and a correction factor of 1.33 was applied to account for the incomplete oxidation of organic carbon [8].

2.2.4. Carbon Stratification Ratio (CSR). To investigate the location of the majority of the SOC, we used the concept of CSR (equation (1)), which shows the proportion of the amount of carbon in the upper-half (0–15 cm) to lower-half

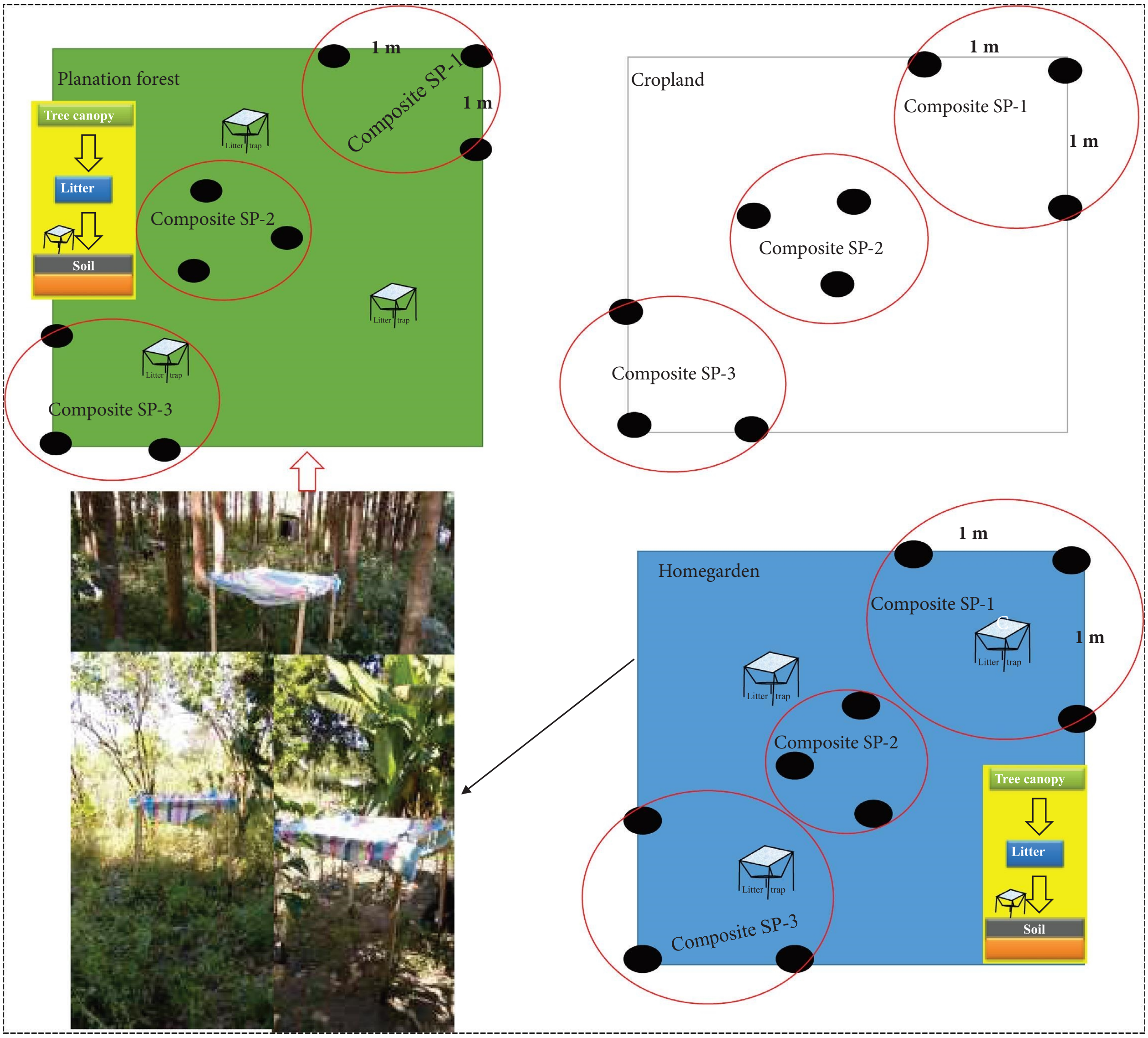

FIGURE 2: Schematic diagrams and photos showing the layout of litterfall traps and composite soil sampling points over the land use types.

(15–30 cm) of the sampling soil layer. This ratio is often used to study the selectiveness of soil erosion processes by taking the concentration or amount of the soil constituted in the eroded material to its concentration or amount in the topsoil of the original site [11–15]. To fit it to our purpose, the assumption is that in managed ecosystems the sources of the majority of soil constitutes such as carbon are often from aboveground active biophysical components. Depending on the magnitude of the ratio, it can help to infer the direction of the input sources of a specific soil element of interest (organic carbon in this case). Hence, to clearly visualize the carbon location in our studied soils at a specific time and location, we adapted and employed the carbon stratification ratio (CSR) by redefining it as the quantity sum (mass depth, kg·m^{-2}) of the specific element in the upper-half sampled soil depth (0–15 cm, kg·m^{-2}) to that of the lower-half sampled soil depth (15–30 cm, kg·m^{-2}) of the same soil profile as indicated in the following equation:

$$\text{CSR} = \frac{\text{Carbon amount in the upper} - \text{half sampling soil depth } (0 - 15\text{ cm}) \left(\text{kg/m}^2\right)}{\text{Carbon amount in lower} - \text{half sampling depth } (15 - 30\text{ cm})\left(\text{kg/m}^2\right)}, \quad (1)$$

where CSR is the carbon stratification ratio (unit less), which is sensitive to soil mass (<2.00 mm particles and carbon concentration). CSR values were evaluated if:

(i) CSR = 1: the element has nearly a uniform distribution between the upper-half sampled soil depth and lower-half sampled soil depth.

(ii) CSR >1: the element is inclined to concentrate on the upper-half sampled soil depth.

(iii) CSR <1: the element tends to concentrate in the lower-half sampled soil depth.

2.2.5. Carbon Flow Balance Ratio (CFBR). We introduced a new approach called carbon flow balance ratio (CFBR) by taking the annual litter carbon (ALC) inputs flowing into that of the SOC continuum via litterfall processes using the annual litterfall ($g{\cdot}m^{-2}$) to the existing SOC of the upper 30 cm ($g{\cdot}m^{-2}$) as indicated in the following equation:

$$\text{CFBR} = \frac{\text{ALC}\,(g/m2\ yr)}{\text{SOC}\,(g/m2)\ \text{in}\ 0-30\ \text{cm}}, \tag{2}$$

where CFBR is the carbon flow balance ratio (yr^{-1}), ALC is the annual litter carbon ($g{\cdot}m^{-2}{\cdot}yr^{-1}$) dry weight base, and SOC is the soil organic carbon ($g{\cdot}m^{-2}$) in the upper 30 cm CFBR values were evaluated if:

(i) CFBR = 1: the net carbon flow from tree canopy to soil is in equilibrium or balanced i.e., at least the input and output are the same so that the SOC remains the same.

(ii) CFBR >1: the litter carbon input is higher than to that of the expected SOC accumulated in the upper 30 cm over years. I.e. the soil is either losing carbon faster than the litter input or the litter remains in the litter form in the soil or it may imply that the carbon is staying in the biomass.

(iii) CFBR <1: net carbon accumulation in the soil system.

2.2.6. Statistical Analysis. The size and variation of SOC and litterfall were described by the mean and standard deviation. To test for differences in the carbon content in litter and soil among the studied land uses, one-way ANOVA was performed ($\alpha = 0.05$) using SPSS 26.0 (IBM Corp., USA) software.

3. Results and Discussion

3.1. Litterfall Rate and Associated Carbon Deposition in Homegarden and Plantation Forest Uses. The monthly distribution of litterfall (dry base) and associated organic carbon deposition over a year time period with cumulative values is illustrated in Figure 3. The annual dry litterfall amount and associated organic carbon (OC) input in plantation forest ($958.4 \pm 112\ g{\cdot}m^{-2}{\cdot}yr^{-1}$; $391.4 \pm 112\ g{\cdot}C{\cdot}m^{-2}{\cdot}yr^{-1}$) were found to be higher than those in the homegarden ($183.5.4 \pm 26\ g{\cdot}m^{-2}{\cdot}yr^{-1}$; $67.4 \pm 10\ g{\cdot}C{\cdot}m^{-2}{\cdot}yr^{-1}$), with the highest litterfall in autumn ($532\ g{\cdot}m^{-2}$) for plantation forest and winter ($65.4\ g{\cdot}m^{-2}$) for homegarden. Despite species type and site differences, Rubino et al. [16] have studied the carbon loss of *Populus nigra* leaf litter by decomposition. They demonstrated that the litter lost 80% of its original weight by the end of 11 months, in which the majority ($67 \pm 12\%$) of the litter carbon lost was as input into the soil carbon pool while nearly $30 \pm 3\%$ was lost in the form of CO_2 into the atmosphere. Taking these proportions into consideration, our finding implies that the litterfall pathway contributes a significant amount of carbon into the soil system in which obviously the highest is in plantation forests due to the presence of several trees. Most litterfall and associated nutrient inputs related studies have focused on individual multipurpose tree levels [17, 18] instead of homegardens as agroforestry practice, which made it difficult for comparison due to the difference in the nature of sampling methods. Despite this, a similar study from southern Japan reported that annual litterfall and associated OC inputs were about $220 \pm 9\ g{\cdot}m^{-2}$ and $117 \pm 5\ g{\cdot}C{\cdot}m^{-2}$ in coniferous forests, respectively [19]. In spite of incomparable site setup, compared to this particular study, the annual litterfall and OC were found to be higher in the tropics nearly by 77% and 70%, respectively. The observed difference between the two regions could be attributed to the difference in latitudinal specific climate [20] and associated variation in species composition, stand structure/density [21], and management activities with the entire suite of complexity of the forest ecosystem of interest [22]. This boldly highlights the difference between the tropical and temperate regional trends of litterfall and associated OC depositional patterns. In light of these, within the tropics (Gedo Zone, Ethiopia), researchers have reported that from the total measured aboveground biomass carbon, litter accounted for 10% in enset ($3500\ g{\cdot}C{\cdot}m^{-2}$), 4% in enset-coffee ($59\ g{\cdot}C{\cdot}m^{-2}$) and 6% in fruit-coffee ($5800\ g{\cdot}C{\cdot}m^{-2}$) agroforestry systems. In our study, the homegarden was a combination of the three (enset-coffee-fruit) and hence taking their average (7%) as a good comparison index, the mean contribution of litter to the total carbon became $357\ g{\cdot}C{\cdot}m^{-2}$ ($=5100\ g{\cdot}C{\cdot}m^{-2} * 0.07$), which is five-fold higher than our finding ($67\ g{\cdot}C{\cdot}m^{-2}$) from homegarden practice [8]. In addition to the propagation effects of a series of averaging during value conversion, the observed disparity is possibly due to the sampling difference in which the researchers collected the existing litter from the ground which was accumulated for several years in one visit in 50×50 cm ground plots unlike our annual-based litterfall monitoring scheme of 1×1 m suspended litter traps type.

Statistically (at $\alpha = 0.05$), both litterfall amount ($P = 0.008$) and its organic carbon ($P = 0.01$) contributions were significantly different between homegarden agroforestry and plantation forest. This could be attributed to the difference in the structure and associated species composition. For instance, reports indicated that tropical homegardens generally consist of at least three vegetation layers with different species [23] unlike our studied plantation forest of single tree layer.

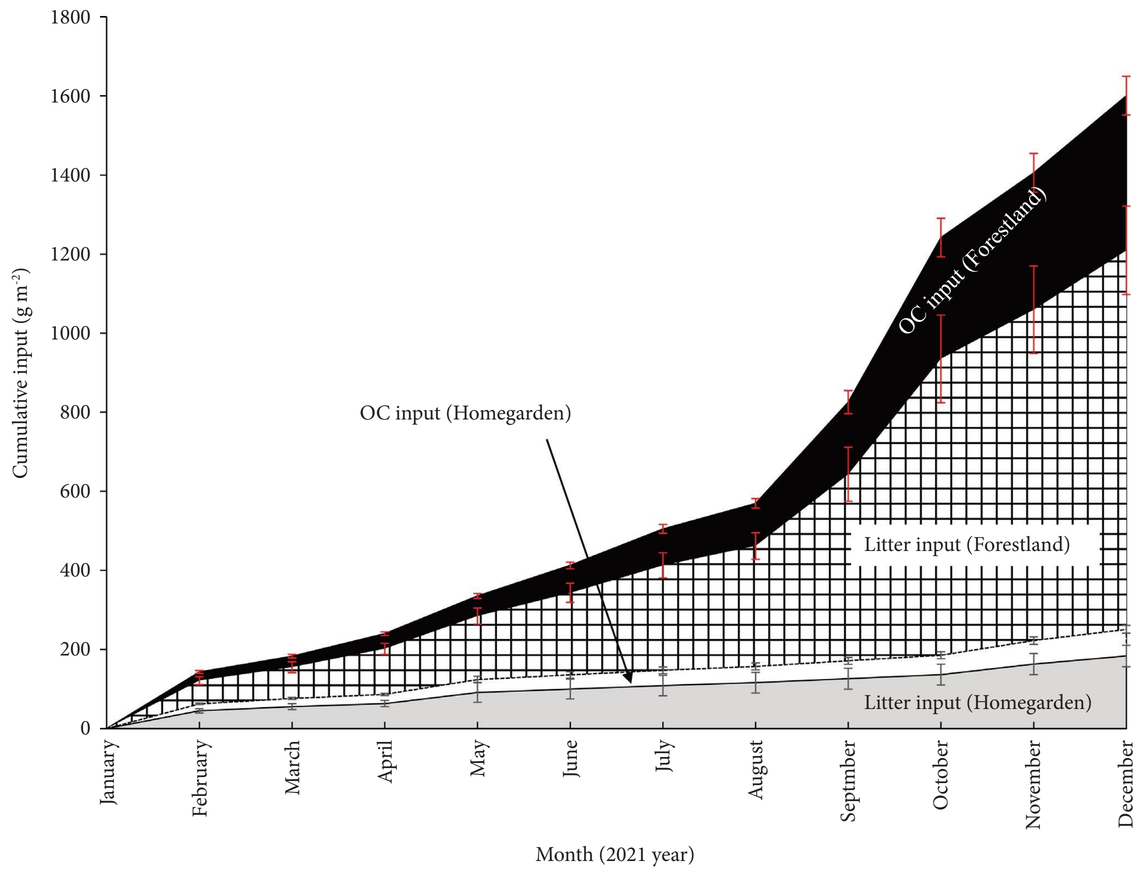

Figure 3: Cumulative deposition of litterfall and associated organic carbon (OC) in home garden and plantation forest (indicated as forestland) land uses in Wondo Genet. The cumulative amount of each parameter is equivalent to the net area under the curve.

3.2. The Depth Distribution of SOC, CSR, and SOC Stocks

3.2.1. The Depth Distribution of SOC. As similar trends of the depth distribution of SOC reported by Kome et al. [24] from the grassland system, SOC showed a decreasing trend along the depth in all studied land use types (Figure 4). SOC concentrations decreased along the depth from 3.39 mg kg^{-1} to 2.76 mg kg^{-1}, 5.36 mg kg^{-1} to 3.66 mg kg^{-1}, and 4.68 mg kg^{-1} to 3.19 mg kg^{-1} of the cropland, plantation, and homegarden, respectively. As compared to homegardens and plantation forests, SOC was uniformly distributed along the upper 10 cm in the soil of cropland, which is possibly attributed to frequent soil work and cultivation resulting in soil mix-up in the specific soil layer. Similar results have been reported by Scanlan and Davies [25] and Teramage et al. [26] that cultivation and tillage results in a high mixing index and uniform distribution in the upper 0–10 cm.

Unlike the findings in this study with a CSR of 1.3 (discussed later), Teramage et al. [26] have reported a reversed depth distribution of SOC in homegarden systems located in both highland (CSR = 0.7) and lowland (CSR = 0.8) settings. They further suggested that increasing the concentration of SOC along the depth has an advantage in terms of climate change as the carbon is buried far from the surface soil. Given the composition of species derived from the altitudinal differences, the depth distribution of SOC in the homegarden located in the middle altitude (this study) is unique in such a way that SOC is highly concentrated in the upper soil layer where active mineralization takes place (Figure 4).

Except for 10–15 cm in soil under plantation forest, higher SOC in the top upper soil layer in the homegarden and plantation forest than the cropland (Figure 4) was due to the presence of tree components in the different proportions which feeds the soil by falling litter and associated decomposition processes. In fact, this study acknowledges that applications of organic inputs (e.g., crop residue and animal dung) and chemical fertilizers are also other input pathways of SOC [20] in cropland. However, the observed lower SOC concentration in cropland soil revealed that either the supply of carbon from such sources was interrupted or harvest loss surpassed the inputs. Nevertheless, based on the SOC concentration in the top 5 cm layer, the following order of SOC can be identified: plantation forest > homegarden > cropland.

Despite showing a similar pattern of propagation along the depth, statistically (at $\alpha = 0.05$), the depth distributions of SOC were significantly different between plantation forest and cropland ($p < 0.05$) systems as well as between homegarden and cropland ($p < 0.05$) but indifferent between homegarden and plantation forest ($p = 0.116$). Moreover, within the same soil depth band except at depths 5–10 cm ($p = 0.182$) and 25–30 cm ($p = 0.104$), a significant difference in SOC concentration was obtained between soils

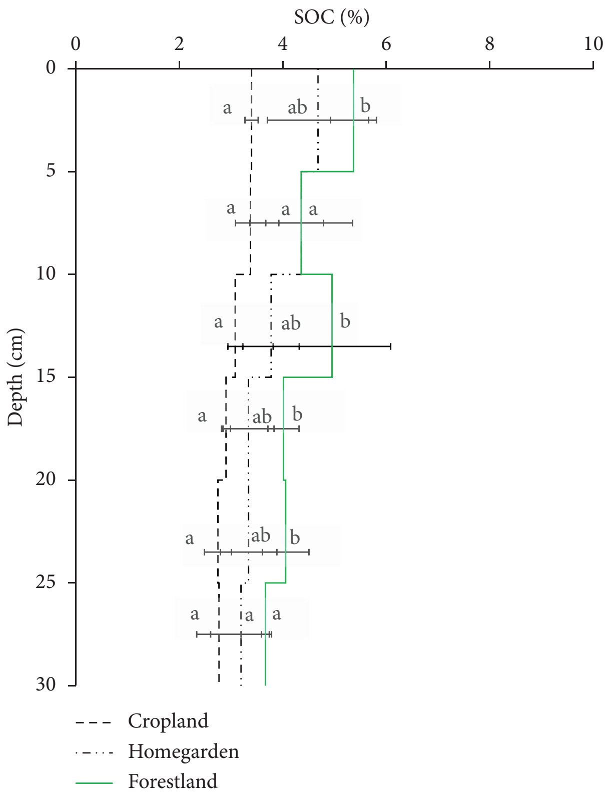

FIGURE 4: SOC depth distribution across the studied land use types in Wondo Genet studied sites (forestland represents the plantation forest; different lower case letter represents the statistical difference at the respective depth band).

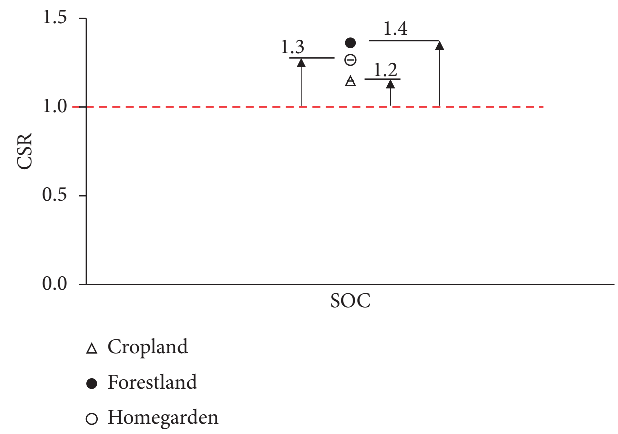

FIGURE 5: Carbon stratification ratio (CSR) across the three land uses at Wondo Genet (forestland stands for the plantation forest).

of crop and plantation forest but not with soil in the homegarden (Figure 4), confirming that homegarden is an intermediate land use type which mimics more towards the forest system. It follows from this that homegarden agroforestry is a system of few trees in nature and found in the midpoint of pure forest and pure crop systems, thereby moderating and compensating the advantages and disadvantages of the two extremes by plant species diversity [6] and providing safe storage of the soil carbon and possesses multiple biogeochemistry pathways as compared to other land use systems.

3.2.2. Carbon Stratification Ratio (CSR). The CSR values in the three land uses are shown in Figure 5. It illustrates that the values of CSR were higher than one across the investigated land uses where the highest (1.4) was in plantation forest soil due to an uninterrupted supply of carbon by litterfall.

In general terms, the higher CSR value (>1) across the land uses indicates a higher amount of SOC in the upper-half soil depth, highlighting the contribution of aboveground input sources such as those definitely from litterfall but possibly from crop residue and other organic inputs. From a climate change perspective, the ratio values imply that the SOC is highly susceptible to any CO_2 emission processes as it is located in the vicinity of the soil surface. Hence, it calls a special attention during land use changes and management planning-related activities in such areas especially for cropland where the soil is directly exposed to oxidation and mineralization in the long off-farming seasons.

3.2.3. SOC Stock. The study found that SOC stocks within the observed depth (0–30 cm) ranged from 69 to 115 Mg ha^{-1} (Figure 6). These results generally are higher than those reported by Batjes [27] for the same depth. The SOC stocks were higher in plantation forest (62%) than both in homegardens (53%) and cropland (40%), suggesting the tendency of carbon storage in the soil systems of the study site. When comparing the SOC stocks, it was statistically different from each other ($p < 0.05$), highlighting the clear difference in their respective ecosystem setups in response to carbon storage. However, when comparing homegarden (87.2 Mg·C·ha^{-1}) in Wondo Genet district (Figure 6) to similar land use, the SOC stock was found to be significantly lower than that of enset- (122 Mg·C·ha^{-1}), enset-coffee- (120 Mg·C·ha^{-1}), and fruit-coffee- (115 Mg·C·ha^{-1}-) based agroforestry systems as reported by Negash and Starr [8]. The differences could be attributed to the differences in sampling strategies, stand structure, management practices, and species composition and associated impacts on the soils between the Sidama and Gedeo setups.

3.3. Carbon Flow Balance Ratio (CFBR) in Homegarden and Plantation Forest Land Uses

3.3.1. Key Assumption. As indicated above, the main assumption here is that the soil is receiving carbon from different natural and artificial sources including litterfall, organic, chemical fertilizers, and from roots [20]. So, it is highly expected that, the upper 30 cm soil layer has accumulated carbon at least for time duration equivalent to the age of the specific land use system, which should be far larger than that of the annual carbon deposit by litterfall pathways. Following this, the CFBR value, which is the ratio of the annual litterfall C input (ALC) to SOC continuum found in the upper 30 cm soil both in plantation forest and homegarden systems, was hypothesized to be below 1.

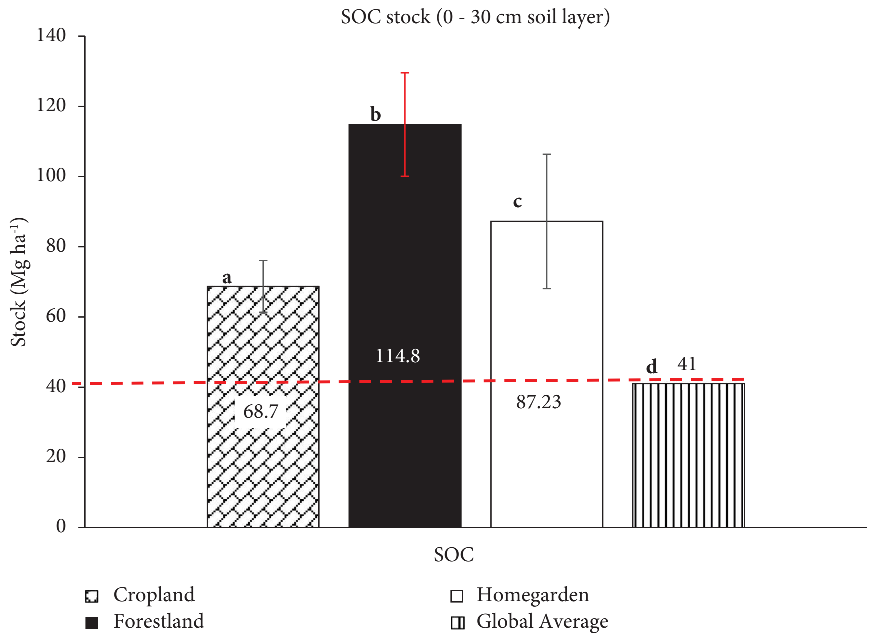

Figure 6: SOC stock (Mg ha^{-1}) across the studied land uses as compared to the global average reported by Batjes [27], which is the level indicated by a broken horizontal line (label with different letter represents the presence of statistical difference). Forestland stands for plantation forest.

However, a higher CFBR in plantation forest (3.4 yr^{-1}) was recorded, indicating that either soil in plantation forest experiences a net loss/very slow carbon accumulation as the litter remains in the litter layer for quite a long time (slow decomposition process) or most of the carbon budget is located in the living system (biomass). In contrast, the lower CFBR in the homegarden (0.77 yr^{-1}) system implied that the soil system is a net storage of soil carbon over time due to annual C input via litter being at least lower than the existing SOC at the time of the investigation. This highlights the importance of homegarden agroforestry practice as a climate change mitigation strategy as it proved to continuously hold carbon in the soil unlike other land uses. In a general context, the result supports the IPCC [28] recognition and recommendation of agroforestry systems as climate change mitigation strategies.

4. Conclusions

The vertical distribution of SOC differs significantly between crop and plantation forest LUs except for depths 5–10 cm and 25–30 cm, while the homegarden possesses intermediate properties shared from both systems. Therefore, our findings contradict with the initial hypothesis of the study. More importantly, the study introduced two systematic ecological indicators to dictate the headlines of land use and could assist policy formulation particularly from a carbon perspective: (1) carbon stratification ratio (CSR) and (2) carbon flow balance ratio (CFBR). From the evaluation of these two indexes, the CSR of the homegarden (1.3) falls between plantation forest (1.4) and cropland (1.2) as well as its relatively lower CFBR (0.77 yr^{-1}) than that of plantation forest's CFBR (3.4 yr^{-1}), indicating agroforestry found in the midpoint of pure forest and pure crop systems and stores carbon in its soil in a continuous pattern. Collectively, it enables to moderate and compensate the advantages and disadvantages of the extremes of the two systems by its rich composition of biota with multiple layers unlike the monospecies of crop and forest plantations. This in turn provides safe storage for the soil carbon and possesses multiple biogeochemistry pathways, making homegarden a system of more stable and efficient in soil nutrient management. Although plantation forests can store huge amounts of carbon, homegarden systems can stand out for their contribution to the social-absolute needs overlapped with smart strategies for climate change mitigation, which is in line with the recent decision of IPCC.

Data Availability

The data used to support the findings of the study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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