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Carbon Sequestration in Agroforestry Practices with relation to other Land Uses around Dallo Mena Districts of Bale Zone, Southeastern Ethiopia

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Carbon sequestration is the process through which carbon dioxide is absorbed by plants and stored as carbon in biomass and soil. Agroforestry systems have larger chances to sequester Carbon in the long-term, adding aboveground carbon storage capacity through a broader diversity of living forms, including trees and crops (Murthy *et al.,* 2013). The study was conducted in Dallo Mena districts of Bale located in Oromia regional state of Ethiopia. Therefore, this study aims to estimate the amount of carbon stored in agroforestry, and to compare the potential of agroforestry practices with the other common land uses. Based on this study there is significant difference in mean total carbon stock in the three pools among land uses. From all systems the highest total carbon stock were recorded in Natural forest (426.54±95.51 Mg ha^{-1}) followed by shade grown coffee agroforestry (266.61±56.63 Mg ha^{-1}). In the homegarden agroforestry practice, having encompassed different types of plants, there is significant amount of carbon (185.26±20.71 Mg ha^{-1}) stored in the practice. On the other hand, the lower total carbon stocks were observed in the crop field (97.56±6.85 Mg ha^{-1}). From the two agroforestry practices the highest total carbon stock were estimated from the shade grown coffee agroforestry. Generally agroforestry practices provide dual function through its multi-functional role in providing income and ecosystem services. At the same time store and conserve large amounts of carbon on the system.

Key words: Biomass, carbon pools, carbon sequestration, land uses, total carbon stock

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INTRODUCTION

Carbon sequestration is the process through which carbon dioxide from the atmosphere is absorbed by trees, plants and crops through photosynthesis, and stored as carbon in biomass (tree trunks, branches, grasses, foliage, and roots) and soil (Cook *et al.,* 2013).

Due to high species diversity, tropical regions it contributes a significant role in terrestrial carbon storage. One of the carbon storage methods is storing in plant as plant biomass. Depends on its characters the amount of carbon stored in plant biomass is varying from one species to the other. The significant amount of carbon stored in plant biomass is the one which are stored the perennial type plants species. The age and the amount of biomass production are varying between different species. Due to this direct relationship carbon storage and plant species diversity has highly interlinked. Even the amount of carbon stored in soil is affected by the plant species which are grown in land.

Agro ecosystems with a broader diversity of plant species, living forms and production activities may achieve higher levels of productivity in the long-term while maintaining larger and more stable C stocks (Yachi and Loreau, 1999). Due to high plant species diversity, agroforestry systems have larger chances to sequester C in the long-term than annual cropping systems, adding aboveground C storage capacity through a broader diversity of living forms, including fruit or timber trees, perennial crops and potential fertilizer and fodder trees. Albrecht and Kandji (2003) estimated a potential C sequestration in tropical agroforestry systems of 95 t C ha^{-1} (varying widely between 12 and 228 t C ha^{-1}). Variability in C sequestration and biodiversity can be high within complex agroecosystems, depending on factors such as vegetation age, structure, management practices, land uses and landscape (Montagnini and Nair, 2004).

Agroforestry is one of the land use system which include different components. From those components vegetations which are different crops (annual and perennial) and trees are important components which play a great role in carbon storage. Due to the diversification of vegetations, this system has higher carbon stocks potential than other agricultural monocultures. Due to this factors expansion of agroforestry practices could raise the carbon stocks of Africa's terrestrial systems (Albrecht and Kandji, 2003). According to Dixon *et al*. (1994) globally the estimated sequestration potential by forestry and agroforestry practices is about 1Pg of C per year, corresponding to about 3.7 Pg CO2, or roughly one-eighth of annual global emissions.

According to Brown (1997), aboveground tree biomass store from 120 to 400Mg ha^{-1} of carbon in tropical humid forests and 11Mg ha^{-1} in agricultural land. Due to several environmental factors carbon dynamics can be vary in different ecosystem. In tropical forests dry matter production of a tree forests differs among soil types and fertility status (Clark and Clark, 2000). Different study estimated that belowground C stocks comprise about 60 percent of total C stocks in tropical forest ecosystems (Malhi *et al.,* 1999).

In Dallo Mena district agroforestry practices are well adapted and practiced in a larger area. This practice is also a base for household economy of many smallholder farmers of the area. Agroforestry and other land uses are providing various environmental as well as economical benefits for the community of the district. However, there was no information in relation to comparing the agroforestry practices with other land uses in carbon storage capacity. Therefore, this study aims to estimate the amount of carbon stored in the agroforestry and other land uses, and to compare the potential of agroforestry practices with the other common land uses around Dallo Mena district of Bale zone, Ethiopia.

MATERIALS AND METHODS

Description of the Study Area

The study was conducted in Dallo Mena districts of Bale located in oromia regional state of Ethiopia. The area is located in altitudinal range from 1314 to 1508 m above sea level. The area is characterized by bimodal rainfall patterns with annual rainfall of 986.2 mm and means annual temperature of 22.5°C respectively (Daniel, 1977). According to Ermias et al., (2008) the dominant soil of the area is Nitosol.

According to IBC (2005) classification, the natural forest grown in the district is categorized as Dry Evergreen Afromontane forest type. The dominant farming activities in Dallo Mena woreda is mixed farming systems, livestock and subsistence crop production farming. Coffee is one of the dominant perennial cash crops which supports the livelihood of the community (Feyera, 2006).

METHODS

Sampling Techniques

The four land uses are found adjacent to each other in stratified manner in the order of natural forest (NF), shade grown coffee (SC), homegarden (HG) and annual crop field (CF). Due to the similarity of topography, climate and land use history of all land uses which are originated from the forest land special analog approach was chosen for site selection. The sites differed only in the land use type and soil management practice.

A systematic sampling method was applied to locate the sample plots (Kent and Coker, 1992). For all land uses the data was collected following the transect line. In the process of data collection the first transect line and the first plot were selected purposely inside the land uses. For this study a plot size of 10m x10m was used. This plot size is large enough to encompass all the seedling, sapling, shrubs and woody species diversity for biomass estimation (Mesele *et al.*, 2013).

Sampling Design

Plant Identification and Biomass Estimation

During woody species inventory for biomass estimation the diameter and height measurement of the plant were restricted only for a limited size. For seedlings (< 2.5cm diameter and height < 1m), saplings and shrub (2.5–5cm diameter and height 1-2m) and trees and shrub (≥ 5cm diameter and height ≥ 2m) were recorded by complete count of each plant from the sample plot. In addition to this woody species having DBH ≥ 5cm the diameter at breast height (DBH at 1.3m) were recorded. For coffee, the diameter was measured at 15cm from the ground (D at 15cm) (Segura *et al.,* (2006). In the case of banana plant diameter at 10cm height from the ground (D at 10cm) was measured (Van Noordwijk *et al.,* 2002).The aboveground plant biomass was measured by using allometric models which used for estimating the living plant woody biomass. The biomasses were calculated from individual tree and sum up in to plots. At the end the sum up of all plot result was extrapolated in to hectare basis.

Data Analysis

Carbon Stock Estimation

Model Selection for Biomass Estimation

Due to high species richness of tropical forests it is difficult to use species specific allometric regression model. In order to fill this gap mixed species tree biomass regression models or general allometric model which are compatible to specific location is recommended and applicable (Brown and Schroeder, 1999). During model selection factors like agroecology, rainfall, temperature, altitude range, soil type and accuracy level of the equation were taken as the main criteria for selection.

Aboveground and Belowground Biomass for Carbon Stock Estimation

For tropical dry agroecology with a rain fall of 900mm to1500mm, the allometric equation developed by Brown (as cited in Pearson et al., 2005) was the best model to calculate the biomass of tree and shrub species. This equation was updated regression models developed from Brown *et al.* (1989) and Brown (1997).

$$AGB=0.2035*DBH^{2.3196} \ldots\ldots\ldots\ldots\ldots\ldots (Eq.\ 1)$$

Where, AGB = Aboveground Biomass (kg/tree)

DBH = Diameter at Breast Height (cm)

To calculate the AGB of trees and shrub species grown in agroforestry practices equation developed by Kuyah *et al.* (2012a) was selected. This equation was developed for tree and shrub grown in agricultural land escapes which are having similar environmental condition to the study area.

$$AGB = 0.091 \times d^{2.472} \ldots\ldots\ldots\ldots\ldots\ldots \quad (Eq.\ 2)$$

Where, AGB = Aboveground Biomass (kg/tree)
d = Diameter at Breast Height (cm)

In case of coffee shrub the biomass was calculated according to the following regression equation developed by Segura *et al.,* (2006) for shade tree coffee systems.

$$Log10\ (AGB) = -1.181+1.991 * log10\ (d15) \ldots\ldots\ (Eq.\ 3)$$

Where, AGB=Aboveground Biomass (kg/tree)
d15=Diameter at 15cm height from the ground (cm)

According to Van Noordwijk *et al.,* (2002) the above ground biomass of *Musa paradisiaca* was calculated as;

$$AGB\ Banana= 0.0303*D^{2.13} \ldots\ldots\ldots\ldots\ldots\ldots (Eq.\ 4)$$

Where, AGB Banana = Aboveground Biomass of Banana (kg/tree)
D = Diameter at 10cm above the ground for the banana (cm)

The below ground tree biomass (root biomass) of a woody species grown in natural forest were calculated from aboveground biomass through conversion method. Root biomass is often estimated from root to shoot ratios by taking 25% of aboveground biomass (Roshetko *et al.,* 2002).

$$BGB = AGB \times 0.25 \ldots\ldots\ldots\ldots\ldots\ldots \quad (Eq.\ 5)$$

Where, BGB = Belowground Biomass (kg/tree)
AGB=Aboveground Biomass (kg/tree)

The below ground biomass for trees, shrubs and coffee species which are grown in the agroforestry system were estimated by using Kuyah *et al.* (2012b) equation.

$$BGB = 0.048 \times d^{2.303} \ldots\ldots\ldots\ldots\ldots\ldots (Eq.\ 6)$$

Where, BGB = Belowground Biomass (kg/tree)
d = Diameter at Breast Height (cm)

According to Blomme *et al.,* (2008) the below ground biomass of banana was 31% of aboveground biomass.

BGB Banana =AGB kg/ Banana x 0.31 ………. (Eq. 7)

Where, BGB Banana = Belowground Biomass of Banana (kg/Banana tree)
AGB Banana =Aboveground Biomass of Banana (kg/ Banana tree)

The amount of biomass carbon content for trees and shrubs grown in natural forest were 50% of the biomass (Pearson *et al.,* 2005), for trees and shrubs in agroforestry practices 48% of the biomass (Kuyah *et al.* (2012a), for coffee 43% and for banana which are Enset like plants 41% of the biomass (Mesele, 2013).

Soil Organic Carbon

The soil sample was analyzed for soil organic carbon determination was followed by Walkley and Black (1934) procedure through titration method. Bulk density was determined after drying of core sample soil at 105ºC for 48 hours. Finally the soil carbon stock of each land use was calculated by multiplying the laboratory analytical data, that is in mass per unit mass of soil with the soil's bulk density (BD), and is expressed in mass per volume of soil, and with soil depth, (Zerihun Getu *et al.,* 2011). Finally based on the Wolde *et al.* (2009) the SOC was calculated as follows;

*SOC = C% * D * BD * 2 ……………… ……….(Eq. 8)*

Where, SOC = Soil Organic Carbon (Mg ha^{-1})
C = Carbon Concentration in percent (%)
D = the total depth at which the sample was taken (cm)
BD = Bulk density (g/ cm^3)
2 = Constant Factor

Total Carbon Stock

According to Scmitt-Harsh *et al.* (2012) total carbon stock is the sum of biomass carbon (AGBCS and BGRBCS) and soil carbon of each land use.

TCS = AGBCS + BGBCS + SOC …………..(Eq. 9)

Where, TCS = Total Carbon Stock (Mg ha^{-1})

AGBCS = Aboveground Biomass Carbon Stock (Mg ha^{-1})
BGBCS = Belowground Biomass Carbon Stock (Mg ha^{-1}), and
SOC = Soil Organic Carbon (Mg ha^{-1})

According to Pearson *et al.*, (2005), after calculating the plot based carbon stock, extrapolating the result into hectare basis was carried out by using expansion factor indicated below.

$$Expansion\ factor = \frac{10000m^2}{Area\ of\ plot\ (m^2)} \quad \text{…………… (Eq.10)}$$

Statistical Analysis

Carbon stock for all land uses was tested by using one way ANOVA. Mean comparison of the four systems interms of biomass carbon stock and soil organic carbon stock were tested by least significant difference (LSD) test at $P < 0.05$ by using SAS statistical software version 9.1.3.

RESULTS

Carbon Stocks

Biomass Carbon Stocks

The overall mean value of the AGBC and BGBC of the three land uses were significantly ($p < 0.05$) different from each other (Table 1). While comparing the mean biomass carbon stock higher amount of above (205.14±64.74) and below (51.29±16.18) ground biomass carbon were observed in natural forest. Whereas from the three systems, the lowest aboveground (59.05±6.27) and belowground (18.59±1.89) biomass carbons were observed in the homegarden agroforestry practice. From the two agroforestry practices the biomass carbon of shade grown coffee agroforestry practice (137.64± 47.25) is higher than that of homegarden (77.64±8.16) (Table 1).

Soil Carbon Stocks

According to Bikila and Zebene (2017), the amount of soil organic carbon (SOC) stock among the four land uses were significantly ($p< 0.05$) different from each other and the soil organic carbon content for NF were significantly differed from the other land uses (Table 2). As indicated in the result table due to several factors, the amount SOC stored in the natural forest is (170.11±14.59) higher than the other land uses.

Total Carbon Stock

Table 3 shows mean of total carbon stock in the three pools among the four land uses. From all systems the highest total carbon stock density were recorded in NF (426.54±95.51) followed by shade grown coffee

Table 1. Mean (±SE) above and belowground biomass carbon stocks (Mg ha^{-1}) in natural forest, shade grown coffee and homegarden agroforestry practice in Dallo Mena districts of Bale

Land Use	Mean (± SE)		Total
	AGBC	BGBC	
HG	59.05(±6.27)^{b}	18.59(±1.89)^{b}	77.64(±8.16)
NF	205.14(±64.74)^{a}	51.29(±16.18)^{a}	256.43 (± 80.92)
SC	107.42(±37.36)^{ab}	30.22(±9.89)^{ab}	137.64(±47.25)
P-Value	< 0.001	0.0005	

Means with the same letters across column are not significantly (P < 0.05) different
AGBC = Aboveground biomass carbon, BGBC= Belowground biomass carbon

Table 2. Mean (±SE) carbon content and soil organic carbon stocks (Mg ha^{-1}) of the four land use system (NF, SC, HG and CF) in Dallo Mena districts of Bale

Land Use	Depth (cm)	Mean (± SE)
		SOC (Mg ha^{-1})
CF	100	97.56(±6.85)^{c}
HG	100	107.62(±12.55)^{c}
SC	100	127.96(±9.43)^{b}
NF	100	170.11(±14.59)^{a}
P-value		< 0.0001

Means with the same letters across column are not significantly (P < 0.05) different SE = Standard error and SOC = Soil organic carbon

Table 3. Mean (±SE) of carbon stock in the three pools among the four land use systems (NF, SC, HG and CF) in Dallo Mena districts of Bale

Land Use	Mean (± SE) of Carbon Pools (Mg ha^{-1})			TCS(Mg ha^{-1})
	AGBC(Mg ha^{-1})	BGBC(Mg ha^{-1})	SOC(Mg ha^{-1}	
HG	59.05(±6.27)^{b}	18.59(±1.89)^{b}	107.62(±12.55)^{c}	185.26(±20.71)
NF	205.14(±64.74)^{a}	51.29±16.18)^{a}	170.11(±14.59)^{a}	426.54 (±95.51)
SC	107.42(±37.36)^{ab}	30.22(±9.89)^{ab}	127.96(±9.43)^{b}	266.61(±56.63)
CF	-	-	97.56(±6.85)^{c}	97.56(±6.85)
P-value	< 0.001	0.0005	< 0.0001	

Means with the same letters across column are not significantly (P < 0.05) different AGBC= Above ground biomass carbon, BGBC= Below ground biomass carbon, SOC= Soil agroforestry (266.61±56.63). On the other hand, the lower total carbon stocks were observed in the annual crop field (97.56±6.85).

DISCUSSION

Carbon Stocks

Biomass Carbon Stocks

The highest above and belowground biomass carbon stocks were recorded in the natural forest land uses (205.14±64.74 and 51.29±16.18). This is due to the fact that natural forest has contained different diversified and long aged woody species which have contributed a lot for biomass carbon storage. Woody species diversity, diameter size and density are one of the limiting factors for carbon storage. Due to this reasons total mean biomass carbon of the three land uses are vary from each other.

Dallo Mena natural forest is contains many species diversity, larger diameter size and dense in relative to other land uses. This entire factor may increase the amount of above and below ground biomass carbon which are stored in the NF in relative to other. When we compare this study with others reports, it has showed lower NF AGBC than that reported from Egdu forest (278.08 Mg ha-1) (Adugna et. al., 2013) and higher than Menagasha Suba state forest (133 Mg ha-1) (Mesfin, 2011) and selected church forests in Addis Ababa (122.85 Mg ha-1) (Tulu, 2011).

In other words the lowest above and belowground biomass carbon were observed in the homegarden agroforestry practice (59.05±6.27and 18.59±1.89). Due to farmers land size shortage of the area and high demand for cash crops, most of farmers are focused to plant annual crops (vegetable) than perennial woody species. This will reduce the diversity of woody species which are gown in the farm. These gaps may affect the amount of carbon which is stored in the biomass. Even, the tree species which are gown in the farmers field are trees which has small diameter size.

Due to the direct relations of diameter size and basal area, the amounts of biomass carbon which are stored in this land use type are comparatively less. The amount of biomass carbon stored in Dallo Mena district HG (77.64±8.16) is lower than Gimbo district HG (122.98 ± .93 Mg C ha-1) of Ethiopia (Solomon, 2013).

Shade grown coffee agroforestry practices store about 107.42±37.36 and 30.22±9.89 of mean carbon in the above and belowground biomass which is less than NF and greater than HG. This agroforestry practice is composed of coffee and shade tree woody species as a major component which is perennial in nature. Since it is dominated by woody species it has higher capacity to store carbon in their biomass. Due to the positive interaction of the two woody species for coffee cultivation, farmers were conserving both species for the longer period of time. Due to this reason the shade trees which are gown in this land use has higher diameter size which are directly correlated with higher biomass carbon. The amount of biomass carbon stored in the SC (137.64±47.25 Mg ha-1) of Dallo Mena district is comparable with Enset-coffee system (116 ±65 Mg C ha-1), and higher than Fruit-coffee (79 ±24) and Enset (49 ±44) systems of south-eastern Rift valley escarpments, in Gedeo of Ethiopia (Mesele, 2013). In reverse to this it is less than from dammar agroforestry of Indonesian, where the total AGBC and BGBC stock was 177.8 Mg ha-1 and 44.2 Mg ha-1 (Retnowati, 2003).

Soil Carbon Stocks

The amount of soil organic carbon stock stored in SC, HG and CF was lower than that of the original land use NF. The mean soil organic carbon stock stored in 100cm soil depth of all land uses are; for NF (170.11±14.59), SC (127.96±9.43), HG (107.62±12.55) and CF (97.56±6.85). This higher mean SOC stock can be due to the accumulation of higher organic matter in soil surface and fast decomposition of litter which results in maximum storage of carbon stock (Sheikh *et al.,* 2009). In the forest land due to the high plant coverage there is higher litter accumulation in the soil surface. Since litter is one the organic matter source, it contributes a lot for the improvement of SOC level in the forest ecosystem. For shade grown coffee agroforestry practice, the amount SOC is less than NF and higher than the homegarden and annual crop field. In homegarden agroforestry practice there are larger amounts different plant species litter was recycled in to the soil. At the same time there is a different annual crop which needs intensive soil management for production. As we know intensive soil management is one the major factor which influences the amount of SOC stored in the soil. This entire factor may influence the amount of SOC stored in the soil. Due to this the amount of SOC is low in this system. The same is true for crop field. As a result of soil disturbance for crop management the amount SOC stored in this land use has decreased tremendously.

Total Carbon Stock

The mean total carbon stocks for all land uses are 185.26±20.71, 426.54±95.51, 266.61±56.63 and 97.56±6.85for HG, NF, SC and CF with the overall mean 283.38±37.75 Mg ha^{-1} respectively. The highest total carbon stocks were observed in natural forest and the lowest is in annual crop field. The highest total carbon stock of NF is due to the presence of high woody species diversity, larger diameter size, high biomass recycling and absence of soil disturbance in the systems. As we know NF has a unique characteristic which have high species diversity and contain very large diameter sized woody species which are contribute a lot in biomass carbon accumulation. In other way low total carbon stock is observed in annual crop field. This is due to the absence biomass carbon and high soil disturbance. When we see the farming system of this study area the land is intensively and repeatedly ploughed. This system may affect and decrease the amount of carbon stored in the soil. Due to this factor the amount of total carbon stored in the system is 2(HG), 3(SC) and 4(NF) times higher than that of CF. In the case of the two agroforestry practice (shade grown coffee and homegarden) the amount total carbon stock stored in this system is in between the natural forest and crop field. This is due to the presence diversified perennial woody species and relatively less soil disturbance. In both agroforestry practices for the sake shade, grain (eg. coffee) and income (eg. fruit trees) purpose they contain different woody and other perennial plants species which contribute a lot in biomass carbon storage and nutrient recycling through the litter fall. However, the variation of the different carbon pools in the natural forests and agroforestry system could be due to the density, species variability's, age of trees and accumulation of biomass (Terakunpisut *et al.,* 2007). In other words, higher biomass in natural forests is associated with higher woody species diversity which leads to greater carbon sequestration.

Total carbon stock of the natural forest (426.54±95.51) was higher than reported by Abiot and Zebene, (2013) (334.86±41.1 Mg ha^{-1}) for patch natural forests of Sidama midland, Southern Ethiopia. The amount of total carbon stock in homegarden of Dallo Mena agroforestry practice (185.26± 20.71) was lies with the C sequestration potential of tropical agroforestry systems which is estimated to be between 12 and 228 Mg ha^{-1} (Albrecht and Kandji, 2003). However the result was less than Solomon (2013) (218.85±62.32 Mg ha^{-1}) for homegarden in Gimbo district, southwest Ethiopia, and HG total carbon stock of in India, where the total carbon stock in agroforestry system was 246.5 Mg ha^{-1} (Murthy *et al.,* 2013). But these results were higher than other homegarden systems and humid tropical agroforestry systems in India (Murthy *et al.,* 2013).

Like other agroforestry practice that employ a woody component, shade grown coffee agroforestry practice contribute to the removal of carbon from the atmosphere and its storage on their biomass. The result of total carbon stored in shade grown coffee agroforestry practice (266.61±56.63) is greater than that of in the Metagalpa region of Nicargua, Suárez Pascua (2002) which range from 144.7 Mg C ha^{-1} to 166.7 Mg C ha^{-1} and that of shade grown coffee of the Valle Central, Costa Rica, Avila (2000) which are store from 168.74 Mg C ha^{-1} to 195 Mg C ha^{-1}. But by far less than that of Beer *et al.* (1998) which are up to 1000 Mg C ha^{-1}. On the other way the carbon stock of shade grown coffee agroforestry practice of Dallo Mena district is comparable with that of Enset - coffee system of the south - eastern Rift Valley escarpment of Ethiopia (293 Mg C ha^{-1}) (Mesele, 2013) and Enset-coffee based system of Sidama midland, southern Ethiopia (242.02±39.77 Mg ha^{-1}) (Abiot and Zebene, 2013).

CONCLUSION

Due to presence of high woody species diversity, larger diameter size, high biomass recycling and absence of soil disturbance, the highest amount of carbon stored in the natural forest (NF) than the other land uses (SC, HG and CF). In agroforestry practice for the sake shade, grain and income purpose they contain different woody and other perennial plants species which contribute a lot in biomass carbon storage and nutrient recycling through the litter fall. Based on this nature from the two agroforestry practices the highest total carbon stocks were estimated from the shade grown coffee agroforestry practice. In the homegarden agroforestry practice, having encompassed different types of plants, there is significant amount of carbon stored in the practice. On the other hand, the lower total carbon stocks were observed in the annual crop field.

Dallo Mena district agroforestry practices provide dual function through its multi-functional role in providing income and ecosystem services. At the same time store and conserve large amounts of carbon on the system. Generally, there is significant difference among natural forest, shade grown coffee agroforestry practice, homegarden agroforestry practice and annual crop field in carbon storage capacity.

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