Carbon stock Assessment of four selected Agroforestry Systems in Owerri-West Local Government Area, Nigeria.

ABSTRACT

Aim: The aimof the study is to generate data on the carbon stock in four predominant agroforestry systems in the southeast Nigeria. Agroforestry(AF) system studied were oil palm, plantain, Bush mango and mixed agroforestry systems.

Methods: Methodologies adopted were measurement of diameter at breast height(dbh) of woody species, soil and litter sampling and the use of allometric equations in the determination of biomass carbon.

Results: The results obtained showed that total agroforestry carbon ranged from160.2±102.2Mg C ha^{-1} to 130.7 ±93.2 Mg C ha^{-1}. Mixed AF system recorded the highest total biomass carbon of 8.39 ±1.4 Mg C ha^{-1} and lowest in bush mango AF. There was significant positive relationship between total biomass carbon and species richness and total agroforestry carbon. Also, SOC positively with all the ecological parameters examined. Soil organic carbon contributed significantly to the total agroforestry carbon recorded in this study.

Conclusion: With the level of carbon stock observed in the biomass and soils of the agroforestrysystems in the region, agroforestry practices should be encouraged to boost climatechange mitigation.

1.0 INTRODUCTION.

Agroforestry is one of the land-use management systems whereby trees are planted with agricultural crops. This farming practice plays very important role in sustaining ecosystem goods and services and in mitigating climate change. Agroforestry systems absorb excess carbon dioxide from the atmosphere for the process of photosynthesis. Carbon is stored in tree biomass and in soil that helps protect natural carbon sinks through the improvement of land productivity and the provision of forest products on agricultural lands [1].

Agroforestry practice is seen as one of the greenhouse gas reduction strategies under the Kyoto Protocol, which was adopted in 1997. As a result, the sequestration potential of agroforestry systems has received attention by the global community and many countries are currently adopting the practice intheir climate change mitigation strategy [2], [3].

Globally, the land areas covered with various types of Agroforestry systems is estimated to be around 1.6×10^9 hectares, with an aboveground biomass sequestration potential of 1.1–2.2 billion t C in the coming 50 years [4]. The carbon sequestered in an agroforestry system mainly depends on the species diversity, arrangement, and role of components within the system, which in turn is determined by the ecological, socioeconomic aspects and previous land use practices[5],[1].

The capacity of agroforestry systems to store C differs across different agroecological landscapes. Montagnini, and Nair, [6] reported that storage potential for semiarid, sub-humid, humid, and temperate regions was estimated at 9, 21, 50, and 63 t C ha^{-1} , respectively. Also extensive reviews were carried out by[7] for West African countries (extending from Arid Sahara Desert to humid region Guinea) and they reported that biomass C stocks ranged from 22.2 to 70.8 t C ha^{-1}. There are many similar studies conducted in various regions of the continents [8]. From global report, the total biomass C stock for agroforestry systems ranges between 12 and 228 t C ha^{-1}[1][9] also reported that agroforestry practices stored C ranging from 0.29 to 15.21 t C ha^{-1} yr^{-1} in their aboveground biomass and can have from 30 to 300 t C ha^{-1} in their soil down to one-meter depth. Soil C stock for the 0–60 cm soil layer differs among different land uses and regions. Lal, (2004) [10] noted that C stock in the 0-60 cm soil layer is 121–123 t ha^{-1} for tropical forests and 110–117 t ha^{-1} for tropical savanna.The results obtained from various studies onagroforestry practices in diverse ecological conditions showed that tree-based agricultural systems, compared to treeless systems, stored more carbon in deeper soil layers near the tree than away from the tree; higher soil organic carbon content was associated with higher species richness and tree density [11].

Agroforestry systems promotes efficient water utilization in smallholder farmers in rural communities, improve microclimate, enhance soil productivity and nutrient cycling, improve farm productivity, and increase farm income as well as sequestering carbon [12].There is need for better understanding of above-ground tree biomass and soil organic carbon stocks for proper management of the carbon pools in agroforestry systems. However, extensive research is required for agroforestry systems to be used in global agendas of carbon sequestration [11].

The objective of this research work was to assess the carbon stock in selected agroforestry systems in Owerri-West Local Government Area in Imo state, Nigeria.

2.0 MATERIALS AND METHODS:

This research was carried out in Owerri-West Local Government Area (LGA) Imo state,southeast Nigeria (Figure 1). which is located between 6°59'19.1" and 6°54'42.3"Elongitudeand between 5°31'43.8" and 5°16'49.2"N latitude. Figure 2 shows a satellite imagery of theOwerri-west Local government area. The soil formation which is Pliocene to Miocene in age consists of coastal plain sands, which is about 0.05–2.0 mm in size, with minor clay beds which is made up of isolated gravels, conglomerates, and very coarse sandstone in some places. Benin Formation is overlain by

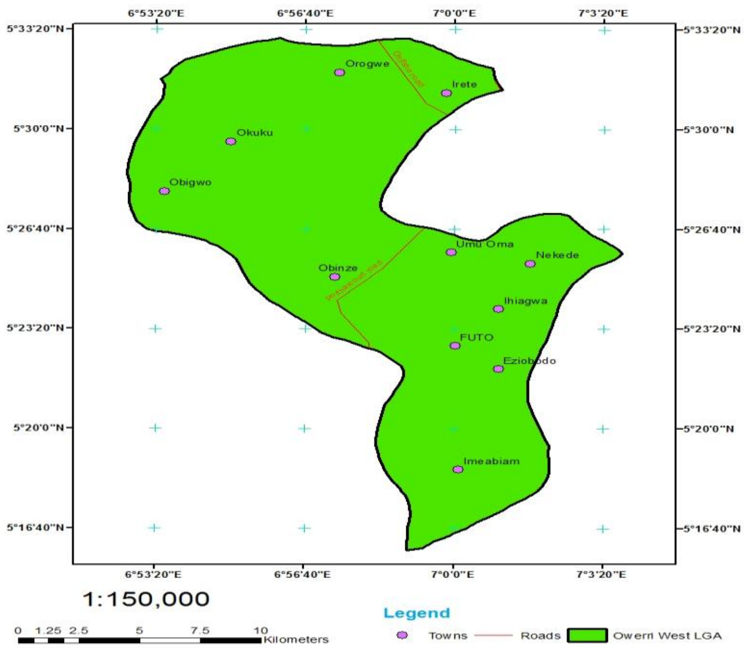

Fig. 1. Map of Owerri west local government area showing the major towns

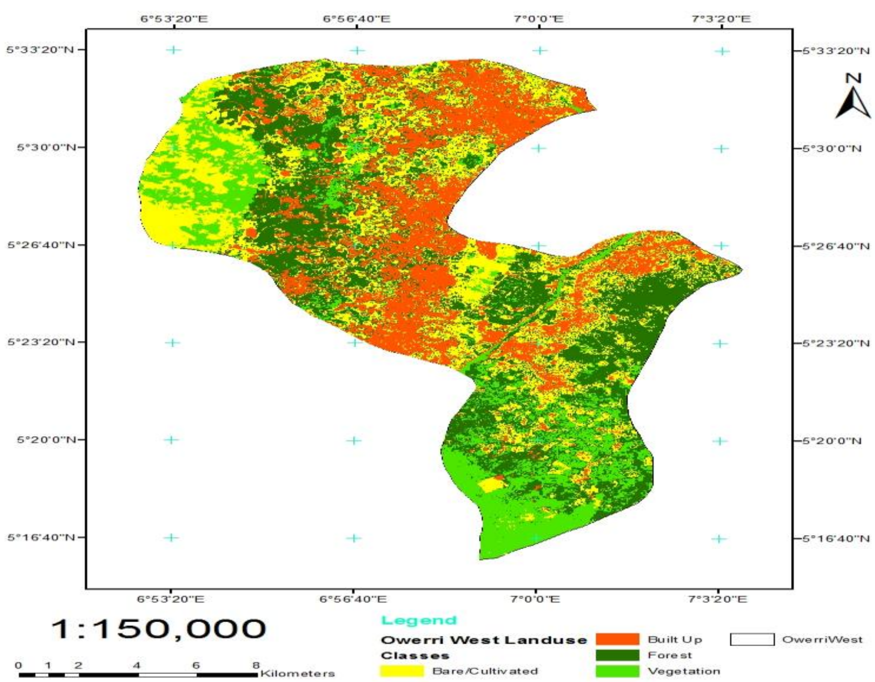

Fig 2. Land use satellite imagery of Owerri west Local government area.

alluvium deposits and underlain by Ogwashi-Asaba Formation which consists of lignite, sandstones, clays and shale. The area has humid tropical climate, with mean annual precipitation of 2200 mm and average annual temperature of 30^{o} C. Rain fall pattern is bimodal with peaks in July and August.

The entire area of the zone is 294.6 sq.km, which is divided into different land-use types, such as agricultural land and agroforestry together, accounts for 27.3%, along with natural forest (32.4%) built up area (23.3% and vegetation 17% (Table 1).

Table 1. Land use of the study area

s/n	**Study area**	**Area covered (sq.km)**	**%**
1	Built Up	68.5	23.3
2	Vegetation	50.2	17
3	Bare Soil/Cultivated Land	80.5	27.3
4	Forest	95.4	32.4
	Total area	294.6	100

The soil type is Nitisol and the texture is predominantly clay. The livelihood of the community under this district is mainly dependent on agroforestry practices and paid employment. They use mixed farming, including non-fruit trees, fruit trees, crops, vegetables, spices production, and very limited animal husbandry focused on, goats, piggery, and poultry.Although there are several types of agroforestry systems practiced by the farmers, the main and most common which were used for this study are (1) *Elaeisguineensis* (oil palm tree) based agroforestry system (2) *Irvingiagabonensis (bush mango)* based agroforestry system and (3) Plantain (*Musa paradisiaca*) agroforestry system and (4) mixed multistory agroforestry system (Table 2).

Table 2: Characteristics and location of the agroforestry system of the study area.

Characteristics	Agroforestry systems			
	Oil palm tree AFS	Bush mango AFS	Plantain AFS	Mixed multistory AFS
Location	Ndigwu	Obinze	Eziobodo	Avu/ Umuguma
Topography	Gentle slope	Flat land	Gentle slope	Flat land
Dominant plant species	Oil palm tree, cassava, *Albizia amara (Roxb.)*	Bush mango, elephant grass	Plantain plant, *Pleiospermiumalatum*	*Azadirachta indica,Magnifera indica,Trichilia prieuriana*
Handling activities	Tree trimming, ripping of unwanted plants,	Trimming, , pollarding, Farm house waste	Tree trimming, ripping of unwanted plants, Farm house waste	Tree trimming, pollarding

These agroforestry systems identified for sampling are located at Ndigwu, Obinze, Eziobodo and Avu / Umuguma. The topography ranged from gentle slope to flat and AF systems are meanly maintained by occasional trimming of over grown plants and cutting down dead trees.

2.1. Sample collection:

The agroforestry systems with similar gradient and altitudes within Owerri-west landscape were identified and mapped out for data collection. In each agroforestry site a randomly nested quadrat of 20 × 20 m size was mapped out for the inventory of trees/shrubs. All woody species including fruit trees and non- fruit trees with DBH ≥2.5cm diameter and height ≥1.5m was measured and recorded.The inventory was aimed to obtain data for the biomass estimation. The quadratssize in this study collaborated with previous work in the literature [2]. Within each quadrant, three 50 × 50 cm small plots for litter sampling were laid out. In addition, soils (0-20cm, 20-40cm)were collectedusing soil auger, from five different points and bulked to form composite soil sample. A total of 140 composite samples were collected from the three subplots. The soils were sieved through a 5-mm mesh screen and mixed to a uniform color and consistency then a subsample of 500g was taken for carbon analysis. Soil samples were taken to Environmental Management Central laboratory, Federal University of Technology, Owerri for Soil Organic Carbon (SOC) analysis using Walkley-Black method [13] and an additional 80 soil samples were collected using soil core sampler for bulk density determination of bulk density (g cm^{-3}). The soil C stocks (Mg C ha^{-1}) were computed by multiplying the C content (%), bulk density (g cm^{-3}), and layer thickness (cm).

2.2. Biomass and carbon stock determination.

Estimation of total above ground biomass(AGB) and below ground biomass (BGB) for tree and shrubs were done for each of the 4 selected agroforestry systems. The biomass estimation was done using nondestructive method which involves use of allometric equations. This is because destructive methods of tree harvesting is costly, time consuming and labour intensive.

To compute the AGB and BGB, and their respective carbon stock,allometric equation developed by [14] was used. Tree/shrub biomass was converted to C by multiplying the above-ground biomass by 0.5

$$TCS = (AGB+BGB) \times 0.5 \qquad 1$$

TCS= total carbon stock, AGB= above ground biomass, BGB= below ground biomass and 0.5 conversion factor. Earlier researchers have come to the conclusion that carbon stock is 50% of the total biomass of a tree [15], [16], [17][18].

The AGB was estimated using the allometric equation thus

$$AGB = 0.091 \times d^{2.472}; \quad R^2 = 0.78, \quad n=60 \qquad 2$$

Where, AGB in (dry mass per tree in kg, 'd' is diameter at breast height in cm. previous authors revealed that AGB is strongly correlated with tree diameter[19], [20],[21].

$BGB = 0.49 \times AGB^{0.923}$; $R^2 = 0.90$ n= 60 3

Where, BGB (dry matter per tree in kg)

Bulk density (BD) and soil organic carbon:

SOC stock (Mg C ha^{-1}) was calculated by multiplying the concentrations (%) of soil carbon, the Bulk density (g cm^{-3}) and depth of the sampled soil[22]

SOC (Mg C ha^{-1}) = BD (g cm^{-3}) * % C * soil depth (cm) 4.

For carbon litter determination a small sample (2 grams) of each one of the herbaceous vegetation and litter layer was analyzed for carbon content determination using Walkley-Black method. Carbon storage in herbaceous vegetation and litter layer was computed using the formula [23]

C stored (Mg C ha^{-1}) = Total dry weight * C content.

2.3. Vegetation analysis:

In this study, species richness, evenness and species diversity were determined.

Species richness(Y) = $S/\sqrt{N}$, where Y = Species richness, S= Number of species, N = Total number of individuals.

Species diversity Shannon-Wiener = $H' = -\Sigma^{s}_{i} p_i \log p_i$,

where *s* is the total number of species in the sample, *i* is the total number of individuals in one species, p_i (a decimal fraction) is the number of individuals of one species in relation to the number of individuals in the population, and the log is to base-2 or base-*e*. Equitability (Evenness) was calculated by using Simpson's index and expressing it as a proportion of the maximum value.

2.4 Statistical analysis: The vegetation composition of the different agroforestry systems was compared. Analysis of Variance (ANOVA) ($\alpha=0.05$) was performed to assess the differences in vegetation composition, biomass and soil carbon stock in the agroforestry system under study. Regression analysis was used to test the relationship between tree carbon stock with tree species richness- and tree density.

3.0 RESULTS AND DISCUSSION

The highest number of species, genera and family were recorded in the mixed agroforestry system. These species are composed of trees, shrubs and crop components. Bush mango AFS has 13 different species and10 genera and forms the second largest diverse agroforestry system (table 3). Oil palm recorded the least number of species and genera in the AFS.

Table.3.. The species, genera and their families identified in various agroforestry systems in the study area

AFS	**Species**	**Genera**	**families**
Oil palm	10	8	5
Bush mango	13	10	6
Plantain	11	9	7
Mixed AF	16	11	9

The agroforestry systems studied had a total of 50 plant species, 38 genera and 27 families. All the agroforestry systems differed ($p<0.05$) in terms of the species richness, diversity and equitability (Table 4). The Shannon diversity index of mixedagroforestry was significantly higher than other AF. However, Bush mango number of individual species and equitability differed among plantain and mixed AF systems. Species richness and Shannon diversity index didn't differ for the mixed and Bush mango AF systems.

Table 4..Summary of the mean (± Std) vegetation characteristics of the agroforestry systems

AFS	Species richness	Species diversity (H')	Equitability
Mixed AF	3.5± 1.3a	0.78±0.02a	0.84±0.2b
Bush mango	3.4± 1.7a	0.68±0.01a	0.92±0.6a

Plantain	1.7± 0.9b	0.34±0.02b	0.56±0.2c
Oil palm	1.2±0.3c	0.21±0.03c	0.43±0.3d
p-value	0.05	0.001	0.001

Same letters within column are not significantly different

The tree stand, diameter at breast height (DBH) and basal area of the mixed AF were higher than other AF systems and differed significantly with other AFS. (Table 3) the mean diameter at breast height ranged from 9.2 cm in bush mango AF to 12.8cm in mixed AF. The least mean tree stand occurred in plantain AF'

Table 5. The Mean (±sd) tree species density, DBH and height of agroforestry practices

AFS	Tree stand (ha^{-1})	DBH(cm)	Height (m)	BA(m^{-2} ha^{-1})
Oil palm	12.3±1.2c	11.2±3.4b	13.2±5.6b	2.5±0.22c
Bush mango	14.8±3.5b	9.2±4.5c	11.3±6.3c	2.3±0.42c
Plantain	8.2±2.1d	8.1±2.3d	9.4±4.2d	3.4±1.3b
Mixed AF	45.3±13.4a	12.8±5.3a	15.2±5.6a	16.2±2.3a
p-value	0.05	0.05	0.02	0.05

Same letters within column are not significantly different

Biomass Carbon stack

The mean values of above and below ground carbon stock are presented in table 6. The total biomass carbon stock ranged from 3.73±0.7MgC ha^{-1} to 8.39±1.4 Mg C ha^{-1}. The bush mango AF biomass carbon significantly differed from oil palm, plantain and mixed AF systems. The total biomass carbon in the mixed AF was higher than all the other AFS. The litter biomass at the plantain AF was higher than other AF systems and differs significantly from oil palm and mixed AF.

Soil organic carbon of the top soil(0-20cm) ranged from 76.4 Mg C ha^{-1} to 89.5Mg C ha^{-1}. The highest was recorded at mixed AF and the least was at oil palm AF. The sub-soil organic carbon (20-40cm) also ranged from 47.8 Mg C ha^{-1} to 61.3 Mg C ha^{-1} and highest value recorded in mixed AF and the least in oil palm AF. The total agroforestry Biomass carbon was highest in mixed AF (160.2 Mg Cha^{-1}) and lowest in Oil palm AF. The mixed AF biomass carbon differed significantly from other agroforestry systems studied. However, total biomass carbon in other agroforestry systems didn't differ significantly (P>0.05)

Table 6. Mean (±standard deviation; n=3) biomass carbon, soil carbon (SOC), litter and agroforestry system total carbon stocks (Mg ha^{-1}) for each of the four studied agroforestry practices) and results of 1-way ANOVA (at α=0.05)

Biomass	Oil palm AF (Mg ha^{-1})	Bush mango AF (Mg ha^{-1})	Plantain AF (Mg ha^{-1})	Mixed AF (Mg ha^{-1})	P=0.05
Above ground biomass(AGB)	3.8±1.2	2.5±1.3	3.4±0.7	4.5 ±2.3	0.02
Below ground (BGB)	2.3±1.9	1.23±0.8	2.34±0.89	3.89±1.3	0.067
Biomass total	6.1±2.2^{b}	3.73±0.7^{c}	5.74±1.2^{b}	8.39±1.4^{a}	0.022
Litter	0.42±0.02^{c}	1.03±0.05^{a}	1.34±0.65^{a}	0.98±0.2^{b}	0.12
SOC(0-20cm)	76.4±12.5	77.4±34.2	78.3±23.1	89.5±23.4	0.065
SOC(20-40cm)	47.8±9.4	54.3±13.4	52.2±10.5	61.3±12.7	0.043
Agroforestry total	130.7±93.2^{b}	136.5±89.2^{b}	137.6±79.3^{b}	160.2±102.2^{a}	0.032

Same letters within rows are not significantly different at 5% probability level.

Table 7.: Relationship between ecological characteristics and carbon stock in the AFS

Ecological characteristics	DBH	SOC	TBC	TAFC
Richness	-0.57*	0.21	0.56*	0.66**
Shannon diversity (H')	-0.68**	0.32	0.19	-0.32
Equitability	-0.66*	0.23	0.21	0.41

DBH=diameter at breast height, SOC= soil organic carbon, TBC=total biomass carbon, TAFC=total agroforestry carbon. * Significant at 5% probability.

The spearman correlation between the ecological characteristics and carbon stock is presented in table 7. There is significant negative relationship between the diameter at breast height and the species richness, Shannon diversity index and equitability. The soil organic carbon had positive relation with all the ecological parameters but the relationship is not significant (p>0.05). Total biomass carbon and total agroforestry carbon had positive and significantly correlated with species richness.

DISCUSSION

Vegetation characteristics:

From the study, the highest species richness and species diversity recorded in mixed AF is similar to results obtained in previous studies in south east Nigeria and some parts of western Nigeria [24]in natural agroforestry systems but lower than results obtained in north central of Nigeria. This could be due to environmental variability such as altitude, soils, topography, species adaptability and management strategy[25]. Relatively high species richness recorded in Bush mango AF may be as a result of large number of exotic and indigenous tree species present. Although the species evenness was highest in bush mango, woody species diversity was highest in mixed AF due to higher species richness.This result collaborate earlier result from a humid tropical ecosystem in south east Nigeria [18]

Carbon stock

Generally, the amount of carbon stored varies between different agroforestry systems [26]. The mean above and below ground biomass values in this study are within values reported by [2] in indigenous AF systems in Southeastern Rift-Valley Landscapes, Ethiopia. The mean AGB ranged from 81.1 to 255.9 t ha^{-1} and for BGB from 26.9 to 72.2 t ha^{-1}. The highest C stock was found in Coffee–Fruit tree–Enset based (233.3 ± 81.0 t ha^{-1}). But however, our result is higher than the carbon stock obtained in West African Sahel region and in Kenya, respectively[15],[27]. The level of variation observed in biomass among different AF systems might be attributed to the types of trees and shrubs in AF, environmental conditions, soil chemical characteristics, extent of land degradation, and age of the AF system [1]. Very low land degradation, good environmental conditions, and longer-aged AF systems probably accounted for high biomass production and storage. The AF we studied represents a relatively stable AF with less degradation,thus the appreciable biomass recorded in this study.

To combat rising CO_2 in the atmosphere, carbon sequestration becomes very beneficial when stored in woody portion of plant species in AFS. Another advantage of having these perennial systems is that C sequestration does not have to end after harvesting the wood component because thestems or branches can also store carbon if processed in any form of longlasting products [28].

Globally soils in AF systems help in sequestering atmospheric CO_2[29]. The SOC stocks recorded in the top and sub-soils are considerably higher than the biomass C stocks of AF systems. These results collaborated with the findings of [30],who reported SOC (0–60 cm) from 77–135 Mg ha^{-1}. Swamy [31]also reported the SOC stocks from Agrisilviculture of Chhattisgarh, Central India is 27 Mg ha^{-1} on average for of 0–60 cm soil depth.

The mixed forest and plantain AF had the highest SOC at both top and sub-soils when compared with Oil palm and bush mango AF. The mixed AF had more herbaceous species and appears to be less disturbed relative to other AFS. The Cultivation of land using tillage practice causes soil disturbance which might cause aggregate breakdown thus releasing previously held SOC [33].

Regarding the biomass C of individual AFS, mixed forestry recorded highest values when compared with other AFS. Luedeling, and Neufeldt,(2012) [7] did an extensive reviews of biomass C stocks for West African Sahel countries. They discovered that extremely arid and humid regions of Guinea had lower C values from 22.2 to 70.8 t ha^{-1} than values reported in this study. A global biomass C review on AFS by [1], [32]showed that biomass C ranges from 12 to 228 t ha^{-1}. Therefore one can conclude that the biomass C stocks of the studied AF systems fall within the global value range for AF systems and falls within the range of tropical forests and savanna in Brazil and India [34], [20].

Carbon sequestration and biodiversity conservation are the most fundamental global environmental challenges, particularly in drylands. Sustainable biodiversity conservation and carbon sequestration are proven means to mitigate current global warming. In the AF systems we examined, there was a negative but significant correlation between species richness and diameter at breast height, and positive correlation with total Biomass carbon and total agroforestry carbon on the other hand. These results are consistent with the positive correlation reported by [35]. We report that SOC stock increases with increasing species richness and Shannon diversity index in all four AF system. Naturally, ecosystems with high tree diversity sequester more carbon in the soil than those with lower tree diversity[36].

CONCLUSIONS

The agroforestry systems studied include oil palm AF, bush mango AF, mixed AF and plantain AF systems. These agroforestry systems were randomly selected in the area as they were predominant among the indigenous people. Dominant plant species include woody trees, shrubs and herbaceous species.

Results obtained showed that all the agroforestry systems stored carbon. The highest amount of biomass carbon was recorded in mixed AF followed by oil palm AF. However, the highest carbon stored was in the soil component and the litter. This calls for proper soil management for sustainable carbon sequestration.

We noted that there is relationship between SOC stock and species diversity (i.e. species richness and Shannon diversity). The ecosystem C stock of these AF systems compared favorably well with those obtained from other tropical forests and other AF systems in West African countries and India.

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