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Plant Diversity, Ecological Services, and Carbon Stock Assessment in Cocoa Agroforestry Plantations of Forest and Savannah Transitions in Cameroon

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Additional information is available at the end of the chapter

Abstract

This study was carried out in cocoa-based agroforestry systems in Mbam and Inoubou department, Center Region, Cameroon. The study aimed at assessing the plant species diversity, ecological services, and carbon sequestration potentials of diverse trees associated in cocoa agroforestry systems. Twenty-seven sampling plots of 100 × 20 m were established in cocoa agroforestry systems in three villages. Our results registered the occurrence of 238 plant species grouped into 16 families in the sampled area. Sterculiaceae, Burseraceae, and Moraceae were the three dominant families. The species richness and diversity that were assessed using the Shannon index were 0.62, 0.66, and 0.68, respectively, while using the Simpson index, they were 1.421, 1.409, and 0.349, respectively, for Mouko, Rionong, and Nyamsong 3. Carbon stock sink was also estimated at 92.03, 55.18, and 46.83 tC/ha. Our results indicate a high flora diversity in cocoa-based agroforests especially with respect to fruit trees where *Tetracarpidium conophorum* is introduced. The total amount of CO_2/ha per village plots is estimated at 337.46, 202.32, and 171.71 tCO_2/ha. Then, the ecological services that should be paid according to 10 US$ per ton of carbon are evaluated at 3374.6, 2023.2, and 1717.1 US$ to the owner of the selected farms.

Keywords: carbon sequestration, REDD+, agroforestry systems, climate change, mitigation

1. Introduction

The concept of REDD+ is always limited to emissions due to deforestation and the increase of carbon sink in land use systems. In order to contribute to the fight against climate change issues in Cameroon, we should develop suitable proposals which target the Clean Development Mechanism (CDM) [1]. The particularity of these projects is to reduce the emission of CO_2.

Agroforestry can be defined as a collective name for land use systems and technologies where woody perennials (trees, shrubs, palms, bamboo, etc.) are deliberately used on the same land management units as agricultural crops [2]. Agroforestry can provide benefits as (i) linking poor households to markets for high-value fruits, (ii) balancing improved productivity with the sustainable management of natural resources, and (iii) maintaining or enhancing the supply of environmental services in agriculture and landscapes for water, soil health, carbon sequestration, and biodiversity conservation [3–4]. In our land use systems, there are non-timber forest products (NTFPs). They are considered with higher potentialities as medicinal and economic values which contribute to break the chain of poverty in rural areas [5–6]. *T. conophorum* (**Photograph 1**) is a local vine from the Euphorbiaceae family which is also called African walnut, cashew nut, conophor seeds, or conophor nuts [7–9]. This species has several properties such as cholesterol-lowering and triglyceride-lowering properties which have been reported [10]. The nutritional properties of seeds have also been fully demonstrated [11–13].

During some inventories, it was estimated that tropical forests can store more than 200 t C/ha in trees [14]. Carbon management in agroforestry systems is a new global concern to mitigate the increased concentration of greenhouse gases in the atmosphere in Congo Basin

Photograph 1. Fruits of *Tetracarpidium conophorum* assessed in Rionong village.

countries. Reforestation cover and finding low-cost methods to sequester carbon in land use systems are emerging tools. As trees grow and their biomass increases, they absorb carbon from the atmosphere and store in the plant tissues and roots. We need to contribute to the Reduction of Emissions derived from Deforestation and Degradation (REDD+). Carbon stock sink varies following the type of trees, and it has been demonstrated that diameter at breast height (DBH) and height are important factors in carbon stock sink variation [15]. Several studies were carried out on the biomass and carbon stock assessment in all ecosystems all over the world [16–20]. These aspects have been partially studied, and there is only a limited amount of work which upholds the notion of the potential of diversity and associated species with *Tetracarpidium conophorum* in agroforestry systems which can contribute to mitigate effects of climate change and improve livelihood options of local farmers. At this time when natural ecosystems are disappearing at an alarming rate, it is clearly necessary today to outline the carbon sequestration potential of agroforestry systems, so that their compensatory role in the mitigation process of climate change be made known in Cameroon.

2. Materials and methods

2.1. Study area

The study was carried out in the Mbam and Inoubou department in Cameroon (**Figure 1**) which appears to be a transitional area covered by forest and savannah. The main cultivation of species there is cocoa plantation. This area is located between 4′39 and 4′49 north and then 11′4 and 11′19 east. Altitude varies from 600 to 900 m [21]. We choose this site because it is located near Yaounde, which includes several markets around where the conophor nuts can be found. Secondly, it is classified among the main area in terms of productivity of *T. conophorum* fruit in Cameroon [13]. There are many vegetal formations that belong to Sterculiaceae (*Pterygota macrocarpa*, *Sterculia tragacantha*, *Cola gigantea*, *Cola altissima*, *Cola cordifolia*, *Triplochiton scleroxylon*, *Mansonia altissima*, etc.) and Ulmaceae (*Celtis zenkeri*, *Celtis tessmannii*) [22].

2.2. Data collection

2.2.1. Floristic inventories

Floristic inventories were performed in cocoa-based agroforestry plantations where the liana (*T. conophorum*) is introduced for several purposes. Data were collected in nine sample plots of 2000 m^2 in each sample village. Trees with a DBH > 5 cm were also assessed with the aim of evaluating the typology of cocoa agroforests associated with liana cultivation. In each plot, species were identified with the use of identification tool keys using various books [23–25] and various volumes of flora of Cameroon. **Figure 2** illustrates the experimental design of inventories carried out in the various cocoa agroforestry sample plots where we record the presence of *T. conophorum*.
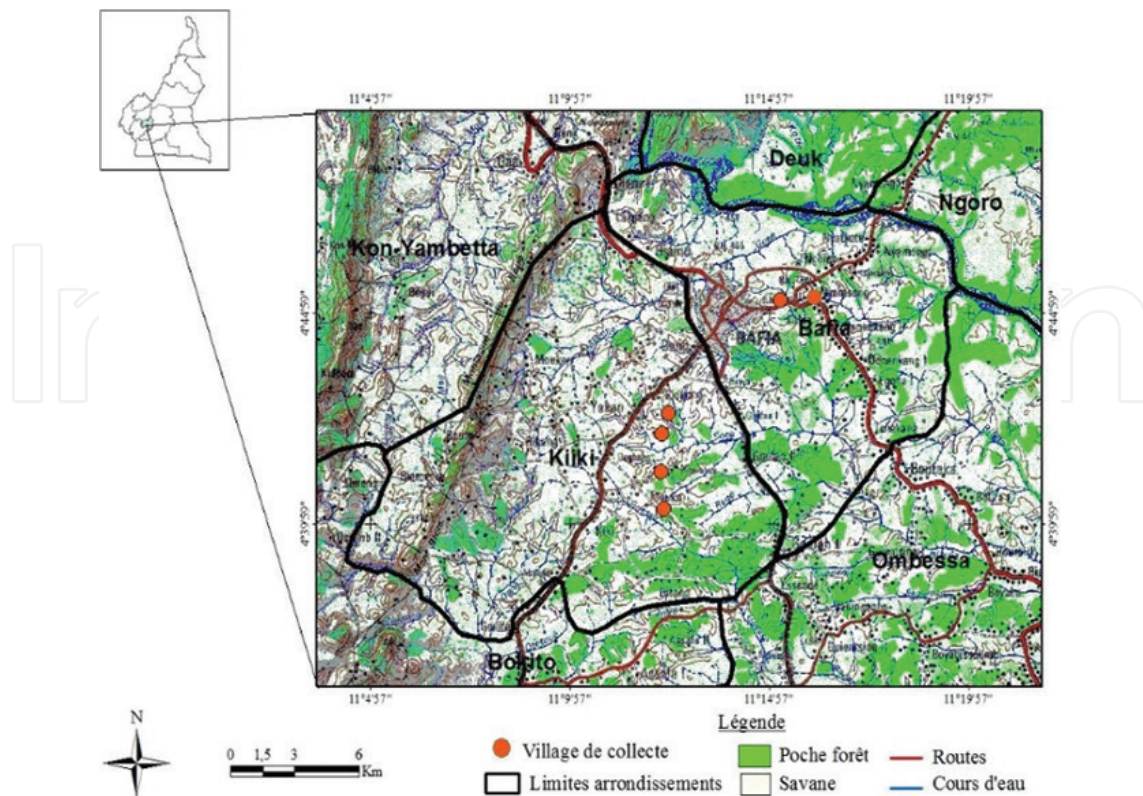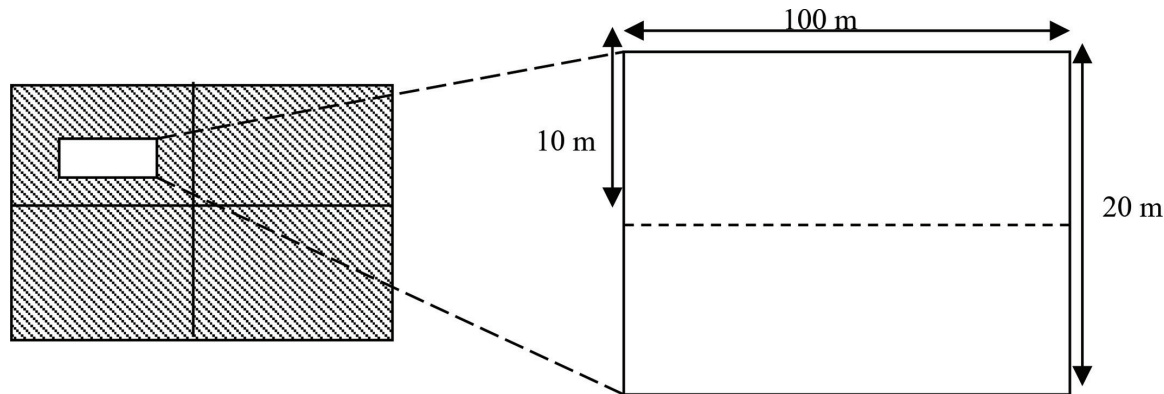
Figure 1. Localization of study site.

Figure 2. Experimental design of inventories carried out in cocoa based agroforests where *T. conophorum* is introduced.

2.2.2. Aboveground biomass (AGB)

AGB was performed using the methodology described by measuring carbon stock manual [26]. This method illustrated by **Figure 3** consists in delimiting a main plot (2000 m²) where all trees with a dbh ≥ 30 cm have been recorded. Another subplot of 40 × 5 m was designed in order to assess trees (30 < dbh < 5 cm). In the subplot 40 × 5 m, other plots of 1 × 1 m were designed in order to collect litter and herbs of understory.
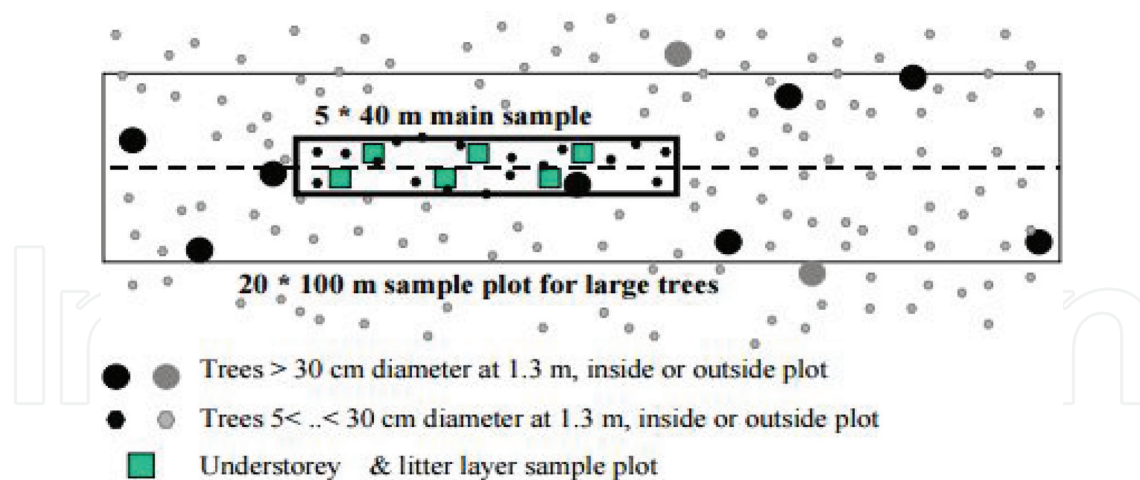
Figure 3. Details of sampling methods according to Hairiah et al. [26].

2.3. Data analysis

2.3.1. Floristic inventories

According to the following formula, we calculated structural parameters and determined the dominant species importance value index (IVI).

- Frequency was estimated for each species with the formula F = (number of plot containing × species/total number of plot) × 100.

- Abundance was estimated for each species using the formula A = (ni/N) × 100, where "ni" is the number of individuals of species i and "N" is the total of the flora.

- The diversity was calculated using the Shannon index to compare the data of various sample sites in terms of diversity of plant species. ISH = $-\Sigma$ pi log^2 (pi), where "pi" is the frequency of species i (ni/N), "ni" is the number of individuals of species i, and "N" is the number of individuals of all species.

- IVI = frequency + abundance + dominance [27].

Diversity parameters were also calculated according to the following formula:

- Shannon index (H′) measures uncertainty about species belonging to a randomly selected individual in the sample. It is expressed according to the proportions of each species: The formula is H′ = $-\Sigma$ = pi log2 (pi) with "pi" proportion of the species "i".

- Simpson index (D′) is a measure of dominance and expresses the probability that two individuals drawn at random from an infinite population belong to the same species. It is expressed from the "pi" frequencies of species where D′ = Σpi^2. The value 0 of this index indicated a maximum diversity, while value 1 represents the minimum diversity.

2.3.2. Aboveground biomass (AGB)

The methodology used in this study was described in the document [1, 28] in cocoa agroforestry systems. Biomass was estimated using allometric model. We used allometric model of Chave [29] to evaluate carbon stock sink sequestration by each tree species. The formula is $AGB = Exp(-2.977 + LN(DBH^2 H\varrho))$ where "ϱ" is the wood density and "DBH" is the diameter at breast height. We, respectively, use the density of all those trees which correspond to each plant species according to wood density database of the Food and Agricultural Organization (FAO). The total carbon stock sink in the selected trees was estimated by summing the values at the level of timbers, herbs, and litters.

2.3.3. Ecological services

To determine ecosystem services derived from the use of species in agroforests, we used ratio CO_2/C (44/12) molecular weight to convert carbon stocks (tC/ha) into tCO_2/ha and, thus, the total CO_2 sequestrated in the farmer's agroforestry demonstration plot [1, 28]. The transaction price for conservation was estimated at 10 US$/$tCO_2$; we used this ratio to estimate the ecological service value derived from the utilization of those land use systems [30].

3. Results

3.1. Floristic composition of cocoa agroforestry systems with *T. conophorum* as an additional plant species for several purposes

The results revealed during our inventories that in different cocoa-based agroforests in the Mbam and Inoubou a total of 230 plant species were recorded belonging to 16 families. These species was distributed as follow: Mouko (86 individuals representing 36% of the total number of individuals), Rionong (53 individuals representing 22% of the total number of individuals), and Nyamsong 3 (99 individuals representing 42% of the total number of individuals). **Figure 4** represents that among the plant species families inventoried in the cocoa-based agroforestry plantations, the six main dominant families are Sterculiaceae, Burseraceae, Moraceae, Anacardiaceae, Bombacaceae, and Araliaceae.

Inventoried cocoa-based agroforestry sampling plots allow to represent relative abundance, relative dominance, relative frequency, and importance value index of species which enable us to characterize farmer's cocoa agroforestry systems in the Mbam and Inoubou as illustrated by **Table 1**. As part of the results, we obtain a Shannon index estimated at 0.62, 0.66, and 0.68, respectively, while Simpson index was 1.421, 1.409, and 0.349, respectively, for Mouko, Rionong, and Nyamsong 3.

3.2. Species plant diversification in cocoa agroforestry systems

During our inventories, we recorded a total number of 230 plant species in sampling plots where *T. conophorum* was present. With these results, it appears that 53 fruiting species
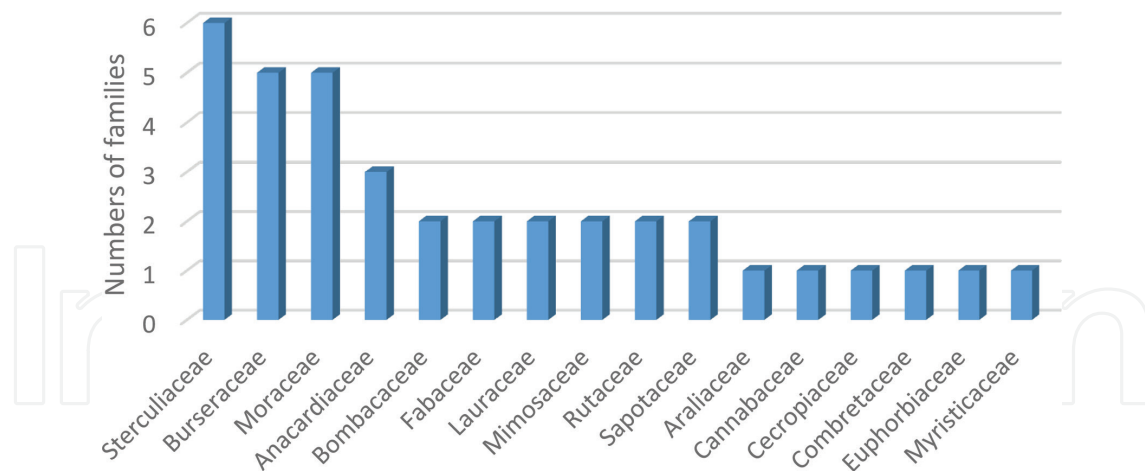
Figure 4. Numbers of family plants species inventoried in the sampled villages in the Mbam and Inoubou.

Scientific names	RA	DR/Ha	RF	IVI
Albizia zygia	4.80	4.80	8.33	17.94
Canarium schweinfurthii	3.77	3.77	5.88	13.42
Ceiba pentandra	2.32	2.32	3.63	8.28
Celtis tessmannii	1.16	1.16	1.81	4.14
Citrus sp	3.77	3.77	5.88	13.42
Cola acuminata	1.92	1.92	3.33	7.17
Dacryodes edulis	5.81	5.81	9.09	20.71
Erythrophleum suaveolens	2.32	2.32	3.63	8.28
Ficus exasperata	3.84	3.84	6.66	14.35
Gambeya lacourtiana	2.32	2.32	3.63	8.28
Mangifera indica	12.79	12.79	20,00	45.58
Milicia excelsa	2.32	2.32	3.63	8.28
Persea americana	3.84	3.84	6.66	14.35

Notes: RA, relative abundance; RD= relative dominance/hectare; RF, relative frequency; IVI, importance value index.

Table 1. values of abundance, dominance, relative frequency and IVI of various plants species characterizing cocoa agroforestry systems in the 3 villages.

represent 23% of the total number of individuals, while 149 cocoa trees represent 65% of the total number of individuals. And the rest of 28 other trees such as medicinal plants, highly marketable trees represent 12% of the total number of individuals as detailed in **Table 2**. From that table, it can be concluded that Nyamsong 3 village has the highest fruit tree rate (40%) compared to Mouko (36%) and Rionong (24%). Floristic inventories reveal that *Mangifera indica* is the most important species according to the dominant species importance value index (IVI). Classes of diameters obtained allow us to appreciate the behavior

Villages	Mouko	Rionong	Nyamsong 3	Total
Fruits trees	19	13	21	53
	36%	24%	40%	
Cocoa trees	55	34	60	149
	37%	23%	40%	
Others trees	4	6	18	28
	14%	22%	64%	
Total	78	53	99	230

Table 2. Diversity of plants species in cocoa based agroforestry plantations in order to diversify farmer's income.

of the vegetation and the most dominant species. But we record that trees with a diameter (9–24 cm) are highly represented in the sampled area. Producers deliberately introduced fruiting species (*Dacryodes edulis*, *Persea americana*, etc.) in order to diversify their cocoa agroforests where *T. conophorum* stems are also introduced. In addition, 69–84 cm class represents trees with higher diameters, and they are present in the three various villages. This class of trees is made up of species such as *Mangifera indica* and *Dacryodes edulis* which appears as to be fruiting species used by producers in order to support the heavy weight of the liana.

3.3. Aboveground biomass of sequestrated agroforestry farmer's plantations with *T. conophorum* as an associate plant species

Results indicated that cocoa agroforestry plantations found in selected villages during sampling permit to assess aboveground biomass through various plant species. A diversity of plants were found, and they can help to estimate the quantity of carbon sink that each tree can store to contribute to fight against the effects of climate change in Congo Basin countries especially in Cameroon. The total carbon sequestered by those sampling plots in recorded villages was estimated at 92.03, 55.18, and 46.83 tC/ha, respectively, at Mouko, Rionong, and Nyamsong 3.

3.4. Ecological services derived from the utilization of trees in cocoa agroforestry systems by farmers

Ecological services are those derived from the use and utilization of plant species in a land use system. From our results, those services can be estimated as follows. The total amount of CO_2/ha per village plots was estimated at 337.46, 202.32, and 171.71 tCO_2/ha, respectively, for Mouko, Rionong, and Nyamsong 3. These results could be a significant importance for targeting the reduction of effects of climate modifications in Cameroon. Then, the ecological services which should be paid according to 10 US$ per ton of carbon

was evaluated at 3374.6 $, 2023.2 $, and 1717.1 $ to the owner of the farms in the Mbam and Inoubou department.

Several ecological services can be derived from the utilization of trees in cocoa-based agroforestry systems. By including trees in agricultural systems, agroforestry can increase the amount of carbon stored in lands devoted to agriculture. We can have several services notably: provision services (diverse products as food, timber, and welfare of the household), regulation services (climatic variation moderation, carbon stock assessment), and support services (biodiversity conservation, soil fertility). Agroforestry can also have an indirect effect on carbon sequestration when it helps decrease pressure on natural forests, which are the largest sink of terrestrial carbon. Another indirect avenue of carbon sequestration is through the use of agroforestry technologies for soil conservation, which could enhance carbon storage in trees and soils.

4. Discussion

4.1. Plant species diversity importance

Floristic inventories revealed the presence of several multipurpose fruiting tree species associated with the cultivation of *T. conophorum* in the Mbam and Inoubou cocoa-based agroforestry plantations. Our floristic inventories reveal the presence of 230 plant species belonging to 16 botanic families. We equally assess an important number of fruiting species which are associated at the cultivation of African walnut. However, these data are different by the ones [31–32]. The results from the previous authors assess a diversity of 116 and 206 species, respectively, in cocoa agroforestry systems in Cameroon. Our results are different from the previous authors because producers intensively introduce fruiting species in their plantations for several ecosystem services. Carbon stock, soil fertilization, and reconstitution are the services provided by cocoa agroforestry systems that local producers can benefit from the integration of local fruiting species. From our results, we can say that cocoa agroforestry plantations have an important diversity in terms of fruiting and associated species. Nevertheless, our findings revealed the presence of the most three important families such as Sterculiaceae, Burseraceae, and Moraceae which are different from the other results [32–34] in the same agroecological area and in the center region in cocoa agroforestry plantations. This observation can be justified by the choice of species which are introduced by the producer at the moment of selection.

Concerning plant species composition, diversity indices calculated revealed that cocoa-based agroforests are less diversified. We obtain a Shannon index of 0.62, 0.66, and 0.68, while the Simpson index as 1.421, 1.409, and 0.349, respectively, for Mouko, Rionong, and Nyamsong 3. These results are different by the ones [35–37] who obtained values such as 4.39 and 4.63 for Shannon index. The Simpson index reveals the way species are distributed or dispatched within the different sites/cocoa agroforest sample sites. And, the results indicated that these agroforests are quite little bit diversified.

4.2. Trees associated with *T. conophorum* in cocoa agroforests

According to inventories and frequency of associated species, we noted that *Mangifera indica* was the most used fruiting species in cocoa-based agroforestry plantations in association with *T. conophorum* in the Mbam and Inoubou. Fruiting species are added to cocoa plantations according to the needs and preferences of local producers and also his desire to diversify his home garden or cocoa farm for more productivity. Another reason for introducing species is to diversify the source of income in order to improve livelihood options. On the other hand, *Mangifera indica* tree species are specially used by local producers as tutors for the liana (**Photograph 2**) because when growing it has a big stem and needs to be supported by a big tree in order to grow well and provide shade for cocoa plantations.

The high percentage of fruiting tree species and useful species in cocoa agroforests and their increased abundance in the more intensely used landscape in the world reflect the fact that farmers intentionally introduce useful tree species in their environment. In Cameroon, one household lives with less than 1US$ per day, and that is why the presence of fruiting species in cocoa agroforests helps farmers achieve their basic needs of food, health, energy, and housing. Results published [32, 38] demonstrated that trees with edible products were the main common tree species found in cocoa agroforests. All are considered as agroforestry tree products (AFTPs) because they are derived from agroforestry trees in the same piece of land. We can have *Dacryodes edulis*, *Mangifera indica*, *Citrus spp.*, *Theobroma cocoa*, *Allanblackia floribunda*, etc.

Photograph 2. One of the biggest stems of *Tetracarpidium conophorum* found in Rionong village in cocoa agroforests.

4.3. Environmental services and carbon sinks

For this work, the estimated percentage of carbon stock sink sequestrated per locality varies as 92.03, 55.18, and 46.83 tC/ha, respectively, to Mouko, Rionong, and Nyamsong 3. Those values represent less than one-fourths of the biomass estimated in some selected agroforestry systems around natural forest stands in the Dja biosphere reserve in the East province of Cameroon. We can say that density and number of species can greatly impact the quantity of carbon sink in some land uses systems (LUS). Diversification is an important tool which contributes to mitigate effects of climate change and climate modifications [39, 34]. Considering the fact that each plant/tree specie can store a specific quantity of carbon through leaves and roots, it is therefore recommended to plant more species in our LUS in order to gather more carbon. Our results obtained on the carbon sink potential are important like the others conducted in cocoa agroforestry systems around the world. Results obtained in our study are superior in Mouko village (92.03 tC/ha), while different from the results found in [40] where the authors revealed an amount of 68.12 tC/ha at Kédia and 76.99 tC/ha at Ediolomo. These results demonstrated that carbon stock sink in cocoa-based agroforestry plantations is higher when there is more fruiting species and other useful tree species for the local producer. It can be explained by the fact that carbon sink depends on several parameters such as the quality and quantity of species which are introduced for diversification or shade purposes. Following this, a study was conducted on carbon stocks [34], and it reveals a higher amount of carbon sink (197.5 tC/ha) in the cocoa agroforests of Bokito in the same geographical area with the sampled localities. This amount of carbon is higher because during the creation of cocoa farms and local producers/farmers introduce several species (fruiting species and medicinal, etc.) in order to provide many services in the farm and then conserve more land for land restoration and protection. The presence of several species in our LUS increases the total quantity of CO_2, which appears to be very high, thus explaining an important ecological and ecosystem service provided by those cocoa agroforests to local farmers and land owners.

5. Conclusion

This study was carried out in order to assess plant diversity and carbon stock assessment by some selected cocoa-based agroforests in the Mbam and Inoubou department of Cameroon. Then, the interest in this work was to show that some tree species introduced in cocoa-based agroforests can store an important quantity of carbon which will contribute to fight, reduce climate change modifications, and diversify farmer's income during the year in order to improve livelihood options. We also estimate ecological services which can be derived from the utilization of those land use systems depending on the trees which have been integrated or associated according to farmer's preferences and needs. We have shown that percentage of fruiting species within the villages was very high, and this demonstrates that cocoa-based agroforestry plantations sometimes need associated trees in order to provide shade for cocoa development. Moreover, we can recommend that cocoa agroforestry systems can also play an important key role in biodiversity conservation. Also, different species were found to be

more or less as reported by other studies using the same methodologies, and we can note that characterization allows us to demonstrate the various family species of trees associated with cocoa agroforestry systems in the Mbam and Inoubou department.

Acknowledgements

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