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Carbon stock assessment in the woody biomass of cocoa and rubber farms: Case of Indénié-Djuablin region in eastern Côte d'Ivoire

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ABSTRACT: The study aims to analyze the management, diversity and the uses of shade trees and then to evaluate the carbon stock in the woody biomass of cocoa and rubber farms. Density and diversity of shade trees were evaluated in 54 plots of 2500 m^2 each, distributed in different cocoa and rubber farms which age varies from one year to more than 15 years. In addition, an investigation was carried out among the peasants to determine the uses of shade trees. The amount of carbon stored in woody biomass of these farms is calculated using allometric models of biomass. In total, 20 species of shade trees were inventoried in cocoa farms and 10 in rubber farms. *Ceiba pentandra* (L.) Gaertn. and *Persea Americana* Mill. are the most important species of these agrosystems. In general, the shade trees provide medical and food products, firewood and timber to farmers. These trees also prevent desiccation of young crop plants and provide nitrogen to soil. The average amount of carbon stored in woody biomass ranges from 50.85 to 145.14 tC/ha in cocoa farms and from 7.04 to 176.68 tC/ha in rubber farms. Shade trees contribute more than 87 % of this amount of carbon in cocoa farms, and only about 17 % in rubber farms. Agroforestry practice in perennial farms contributing to the conservation of multipurpose tree species and would boost the carbon stock in the agricultural sector.

KEYWORDS: Carbon stock, shade trees, plantation, Indénié-Djuablin region.

1 INTRODUCTION

Carbon dioxide (CO_2) is one of greenhouse gases whose the increase in atmosphere is frequently contributing to the reheating of the planet [1]. Carbon, which is one of the components of this gas, is the subject of many exchanges between the various terrestrial, atmospheric and oceanic constituents which form the global carbon cycle. Carbon storage, in the form of woody biomass, is one of the recommended solutions to fight against the climate change [2]. Forest ecosystems capture approximately 9.2 Gt of CO_2 emissions per year while, the emissions of this gas due to land use change is estimated to 4 Gt annually [3]. In the world, this land use change generally profits to expanding agricultural land [4]. In West Africa, particularly in Côte d'Ivoire, this situation is most alarming. Indeed, under the impulse of an economic policy based on agriculture, Ivorian forest lost more than 80 % from 1960 to the beginning of the 21st century [5]. Furthermore, most of this deforestation (96%) took place in unprotected agricultural areas [5]. The regions most affected by this situation are those of the first great cocoa producing areas, such as the regions of the former cocoa loop [6]. In these areas, today and more than elsewhere, the orchard is old and, the forest, ideal cultural precedent, is scarce. Furthermore, to optimize their source of income, farmers opt for new cultural practices.

Thus, following several popularization campaigns of cocoa replanting techniques on non-forest cultivation history [7], some are moving towards so-called improved cocoa plants that do not tolerate, however, shading [8]. Others, on the other hand, replace old cocoa farms and fallows with rubber trees [9] [10], motivated by the substantial economic contribution of this crop [11]. All this leads progressively to the abandonment of the ancient practice of plantations associated with several ligneous preserved or introduced for various uses. Yet, this ancient practice was considered as an important tool for carbon sequestration in the farms [12] [13] [14]. All of the above suggests that changing agricultural practices could significantly reduce the carbon stock in these areas.

This worrying assumption has mobilized the realization of numerous studies evaluating the carbon stock in the agrarian systems of tropical countries. Some focused only on cocoa-based agroforestry systems [15] [16] [17] while others were interested in cultivated plants in particular, those of cocoa and rubber farms [18] [19] [20]. In West Africa, particularly in Côte d'Ivoire where the agrarian landscape is dominated by cocoa and rubber farms [21], these studies are scarce. When they exist, they only concern the above-ground biomass of woody species associated with cocoa farms [22]. However, the amount of sequestered carbon is a function of tree species, geographic areas, planting densities and management of the system [23].

The present study aimed thus, to evaluate the quantity of carbon stored in woody biomass of cocoa and rubber farms in relation to the age of these agrosystems in Indénié-Djuablin region. This region was an important area of the former "cocoa loop" where cocoa and rubber are growing at the expense of forests [6]. Specifically, it aimed to analyze first the management, diversity and uses of the shade trees in these farms, then to evaluate, according to the age classes of the farms, the carbon stock sequestered by the preserved ligneous and the cultivated plants.

2 MATERIAL AND METHODS

2.1 PRESENTATION OF THE STUDY AREA

The Indénié-Djuablin region is located in the eastern part of Côte d'Ivoire, between latitudes 5°53' and 7°10' North and longitudes 3°10' and 3°4' West (Fig. 1). It is subjected to the subequatorial climatic mode [24] with a precipitation annual average of 1.300 mm and an average temperature of 26.3° C. Concerning the relief, it is not very rough with an altitude ranging between 130 and 450 m. This region is characterized by the presence of strongly, moderately and weakly desaturated ferralitic soils with granite soils [25]. The original vegetation belongs to the mesophilic sector of Guinean domain, precisely to the type "semi-deciduous forest with *Celtis* spp., and *Triplochiton scleroxylon* K. Schum." [26].

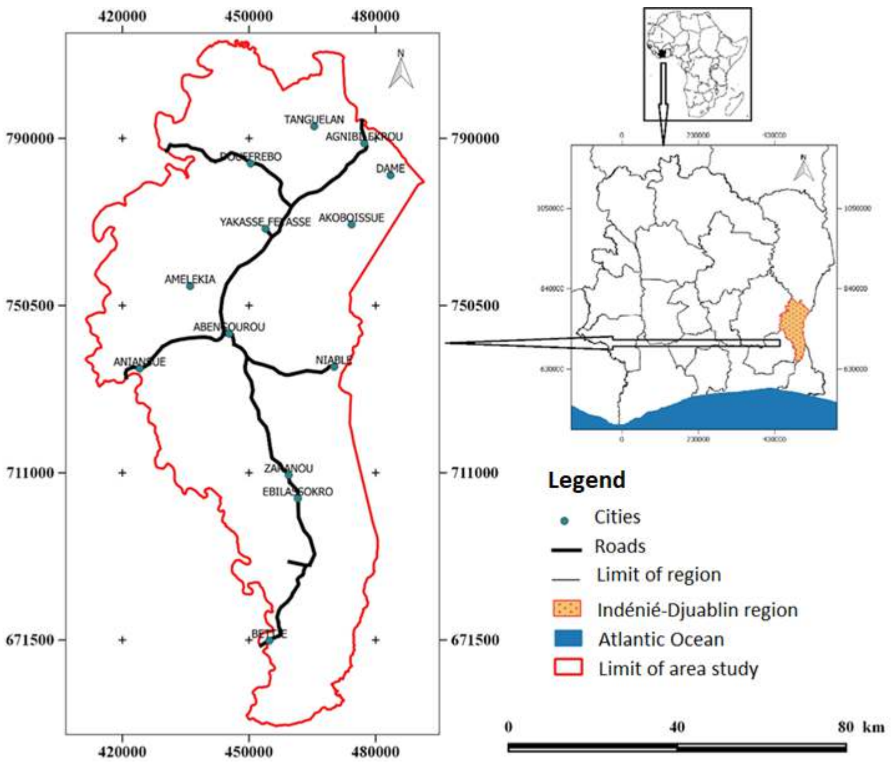

Fig. 1. Location of the study area

2.2 DATA COLLECTION

The sampling was carried out in 27 cocoa farms and 27 rubber farms of Indénié-Djuablin region. For each type of farm, the plots were distributed according to the crop plants stage development (less than 5 years: n = 9. 5-15 years: n = 9. more than 15 years: n = 9). Nine replenishing forest plots serving as controls were also surveyed. Within each farm, a plot of 2500 m^2 (50 m × 50 m) was set up to take into account the minimum area of the different strata [27], [28]. Then all the woody individuals over 2.5 cm in diameter that were there, except crop plants were identified and counted. In these same plots, the diameter at breast height (dbh) of trees including crop plants was measured. Before that stage, information on the uses made of tree species in different farms were collected with the farmers.

2.3 DATA ANALYSIS

2.3.1 WOODY MANAGEMENT IN COCOA AND RUBBER FARMS

Management of woody other than crop plants in farms was analyzed on a density basis. To do this, individuals of of woody species were divided into three diameter classes as defined by [22] including woody recruits (2.5 cm <dbh> 5 cm), young trees (5 cm <dbh> 10 cm) and mature trees (dbh> 10 cm). In each type of farms and for each diameter class, the number of woody trees counted on extent of 2.500 m^2 was reported per hectare.

2.3.2 DIVERSITY OF LIGNEOUS IN COCOA AND RUBBER FARMS

The species richness of the companion trees was calculated for each type of farms. The diversity of these trees was assessed using Shannon diversity index (H ') and Pielou equitability (E) as well as the species importance value index (IVI). Specific richness provided information on the species number of a given environment. The Shannon index (Equation 1) and Pielou equitability (Equation 2) were used to assess the distribution of woody trees while the IVI (Equation 3) allowed to highlight the most important species in the agrosystem.

$$H' \text{ (bit)} = -\sum_{i=1}^{S} (n_i/N) \log_2(n_i/N) \quad (1)$$

$$E = H'/\log_2 S \quad (2)$$

$$IVI\ (i) = \text{relative dominance } (i) + \text{relative density } (i) + \text{relative frequency } (i) \quad (3)$$

In these formulas, H' is the Shannon diversity index, E is the Pielou equitability index, n_i is the number of individuals of species i, N is the sum of individuals of all species, S is the total number of species, lns the theoretical value of the maximum diversity attainable and IVI (i) the value of index of the species i. According to [29], the diversity is low when H' is less than 3, average if H' is between 3 and 4 and high when H' is greater than or equal to 4. As for the equitability index (E), it tends to 1 when the species have a regular distribution. It is close or equal to 0 when species have an irregular distribution [30].

2.3.3 CARBON STOCK ASSESSMENT IN LIGNEOUS BIOMASS OF FARMS

Following the recommendations of [31], this evaluation only concerned woody individuals whose dbh was greater than or equal to 5 cm. Thus, the dbh measurement of these trees helped to estimate the aerial (AGB), root (BGB) and total (Bt) wood biomasses of the different agrosystems. The aerial biomass of *Theobroma cacao* and *Hevea brasiliensis* plants were obtained using respectively the allometric equations (4) and (5) respectively developed by [32] and [33]. For that of woody individuals other than crop plants, the allometric equation (6) was used [34]. The root biomass of a woody individual is estimated at 24% of its aerial biomass [1] and its total biomass is obtained by adding its aerial biomass to its root biomass. Finally, the carbon stock sequestered by each woody individual was obtained by multiplying the total biomass by the carbon fraction (CF) ratio which was 0.47 [1].

$$AGB_{\textit{Theobroma cacao}} = 10^{\left(-1.625 + 2.63 \times \log(dbh)\right)} \quad (4)$$

$$AGB_{\textit{Hevea brasiliensis}} = \text{Exp}(-3.1426) \times (dbh)^{2.69273} \quad (5)$$

$$AGB_{Other} = 0.0673 \times \left(\rho \times (dbh)^2 \times H\right)^{0.976} \quad (6)$$

In these formulas, AGB is the aerial biomass expressed in Kg ; dbh, the diameter at breast height measured in cm; H, the height of the tree measured in m and ρ is the specific density of a species expressed in $g.cm^{-3}$. Specific density determination was made using the Global wood base density database [35]. For species for which there is no available literature on the density, the default value (ρ default = 0.58 $g.cm^{-3}$) was used as recommended by [36].

2.4 STATISTICAL ANALYSIS OF THE DATA

The data was analyzed with R (version 3.5.1) [37]. In each farm type, the diversity parameters (specific richness, Shannon's index and Pielou equitability) and carbon stock were compared between the three age classes. To do this, one-way analysis of variance (ANOVA) was performed after checking the normality and homogeneity of the variables. In case of a significant difference between the means for a given parameter, the Tukey test was immediately applied at the 5% threshold. The latter makes it possible to classify and know which age class are different [38]. In the absence of normality and/or homogeneity of the variables, non-parametric Kruskal-Wallis tests were applied.

3 RESULTS

3.1 MANAGEMENT OF WOODY IN THE COCOA AND RUBBER FARMS

The average number of woody recruits, young trees, and mature trees in secondary forests was respectively of 306.67, 255.56 and 388.89 stems/ha (Fig. 2). In cocoa farms, no woody recruit was collected, whatever the age class of the farms, while that of young trees decreases from one age class to another. Of 17.78 stems/ha for cocoa farms less than 5 years old, this density is zero in farms of more than 15 years old. Only the density of mature trees persists in these farms. She is 146.67 stems/ha for farms under 5 years, 96.11 stems/ha for those of 5 to 15 years and 166.11 stems/ha for farms more than 15 years old. At the level of the rubber farm, there is not woody recruits and young trees since young farms. Only the density of mature trees remained stable in farms under 15 years old. This density was of 40.00 stems/ha for farms under 5 years old and of 33.33 stems/ha for those of 5 to 15 years old.

Fig. 2. Density of the woody companions in cocoa and rubber farms

3.2 DIVERSITY OF WOODY IN THE COCOA AND RUBBER FARMS

In all cocoa farms, 20 species woody companions were identified, distributed in 17 genera and 14 families. However the average value of species declined significantly ($F = 15$; $P < 0.001$) from young to old farms (Table 1). This average was of 5.17 species in cocoa farms under 5 years, of 2. 00 species in those of 5 to 15 years and 2.33 species in cocoa farms of more than 15 years. Like average species values, those of the Shannon Diversity Index varied and declined significantly ($F = 4.808$; $P < 0.001$) with the age of the farms (Table 1). In the rubber farms, 10 species woody companions were recorded, distributed into 10 genera and 8 families. No woody species other than rubber trees, was collected on farms over 15 years while an average of

2.17, 2.00 species was observed in farms less than 5 years old and those of5 to 15 years old (Table 1). Moreover, these observed values did not differ significantly as were the average values of the diversity index and the Pielou equitability.

Persea americana Mill., *Entandrophragma angolense* (Welw.) C.DC., *Alstonia boonei* Wild., *Albizia adianthifolia* (Schumach.) W.Wight, *Ceiba pentandra* and *Trema orientalis* (L.) Blume were the tree species constantly recorded in cocoa farms (Table 2). However, considering both relative density, frequency and dominance, *Persea americana* and *Ceiba pentandra* are dominant (IVI> 5 0%) respectively in cocoa and rubber farms.

Table 1. Variation of the woody diversity in cocoa and rubber farms

Agrosystems	Age class	Specific Richness	Shannon index	Pielou
Forest	**> 15 years**	15.00±0.37	3.53±0.06	0.90±0.01
Cocoa farms	**≤ 5 years**	5.17±0.39a	0.72±0.10a	0.30±0.03a
	5-15 years	2.00±0.42b	0.24±0.09b	0.17±0.06a
	≥ 15 years	2.33±0.27b	0.37±0.09ab	0.27±0.05a
Rubber farms	**≤ 5 years**	2.17±0.80	0.26±0.16	0.13±0.07
	5-15 years	2.00±0.56	0.30±0.16	0.15±0.08
	> 15 ans	0.00±0.00	0.00±0.00	0.00±0.00

For each column and for each type of agrosystem, the values followed by the same letter are not significantly different at the 5% threshold (Tukey test)

Table 2. Dominant Tree Species in Cocoa and Rubber Farms: Scientific Names, Degree of Presence (D), relative Dominance (Dor) and Importance Value Index (IVI)

Agrosystms	Species	D (%)	Dor (%)	IVI
Cocoa farms	*Persea Americana*	**87.67**	15.74	**59.13**
	Entandrophragma angolense	**83.33**	10.89	38.92
	Ceiba pentandra	**50**	22.53	37.35
	Cola nitida	33.33	15.31	34.78
	Alstonia boonei	**66.67**	10.25	32.93
	Trema orientalis	**50**	2.05	20.63
	Albizia adianthifolia	**66.67**	4.51	19.38
Rubber farms	*Ceiba pentandra*	33.33	**75.98**	**115.37**
	Persea americana	33.33	4.43	43.83
	Garcinia kola	16.67	2.19	24.16

3.3 WOODY TREES USES BY FARMERS

Woody trees generally associated with crop plants were known to have therapeutic properties (Table 3). Some of them, such as *Entandrophragma Angolense*, *Albizia adianthifolia*, *Ceiba pentandra*, *Alstonia boonei* and *Trema orientalis* were used to shade young cocoa trees and to fertilize the soil. Others, on other hand, constituted a source of food or income. These species included *Persea americana*, *Cola nitida* (Wind.) Schott & Endl. and *Garcinia kola*. *Entandrophragma angolense* was used as lumber while *Albizia adianthifolia*. and *Cola nitida* were used as firewood.

Table 3. Uses of ligneous plants associated with crop trees : scientific names, use categories and relative density (Dr)

Species names	Use						Dr (%)
	Medicine	Food	Firewood	Construction	Shade	Soil fertilization	
Persea americana	*	*					20.31
Entandrophragma engolense	*			*	*	*	15.62
Cola nitida	*	*	*				13.28
Ceiba pentandra					*	*	10.17
Albizia adianthifolia	*		*		*	*	10.15
Alstonia boonei	*				*	*	9.37
Trema orientalis	*				*	*	7.81
Garcinia kola	*	*					6.25

3.4 CARBON STOCK ASSESSMENT IN WOODY BIOMASS OF COCOA AND RUBBER FARMS

Average values of carbon stored in cocoa trees were 5.41, 16.04 and 17.48 tC/ha respectively in plantations under five, five to 15 years and more than 15 years old (Table 4). The difference between these values is very significant ($F = 55.35$, $P < 0.001$). The amount of carbon stored in cocoa trees increased significantly from cocoa farms of less than five years to those over 15 years old. Whatever the age group of the cocoa farms, the amount of carbon stored in the companion trees did not differ significantly. This was also the case when the cocoa carbon stock is associated with that of the companion trees. This last observation was different in the rubber farms.

The average amount of stored carbon was 3.81 tC/ha in rubber trees less than five years old, 16.04 tC/ha in those aged five to 15 years, and 17.48 tC/ha in rubber farms older than 15 years (Table 4). These average values increased significantly ($F = 32.34$, $P < 0.001$) with the age of the rubber farms. Regardless of the age class of the rubber farms, the amount of carbon stored in the companion woody species did not differ significantly. However, when carbon stock of rubber plants was associated with that of companion trees of rubber plants, the mean values of the amount of carbon stored differed significantly ($F = 19.1$, $P < 0.001$) by one age class to another. The distribution of the amount of carbon stored by age class was the same as that stored in rubber plants.

Among the species of woody companions constantly found, *Ceiba Pentandra* was the one that stocked the most carbon (28.75% of carbon of tree species) (Fig. 3), followed by *Entandrophragma angolense* (18.67% of the carbon of the associated tree species). The woody companions such as *Cola nitida*, *Persea americana*, *Albizia adianthifolia*, *Alstonia boonei* and *Trema orientalis*, stored less carbon (4.35 to 9.69% of the carbon of companion woody species).

Table 4. Carbon stock variation in the woody biomass of cocoa and rubber farms

Agrosystems	Age class	Carbone stock (tC/ha)		
		Crop plants	Companions woody	All woody
Cocoa farms	≤ 5 years	5.41±0.60b	98.49±8.50a	103.90±8.20a
	5-15 years	16.04±0.85a	34.80±9.81a	50.85±10.39a
	> 15 years	17.48±0.70a	127.66±60.18a	145.14±60.58a
Rubber farms	≤ 5 years	3.81±0.29c	3.22±2.43	7.04±2.60c
	5-15 years	40.41±2.93b	39.37±23.92	79.79±25.96b
	> 15 years	176.68±8.83a	0,00±0,00	176.68±8.83a

For each column and for each type of agrosystems, the values followed by the same letter are not significantly different at the 5% threshold (Tukey test)

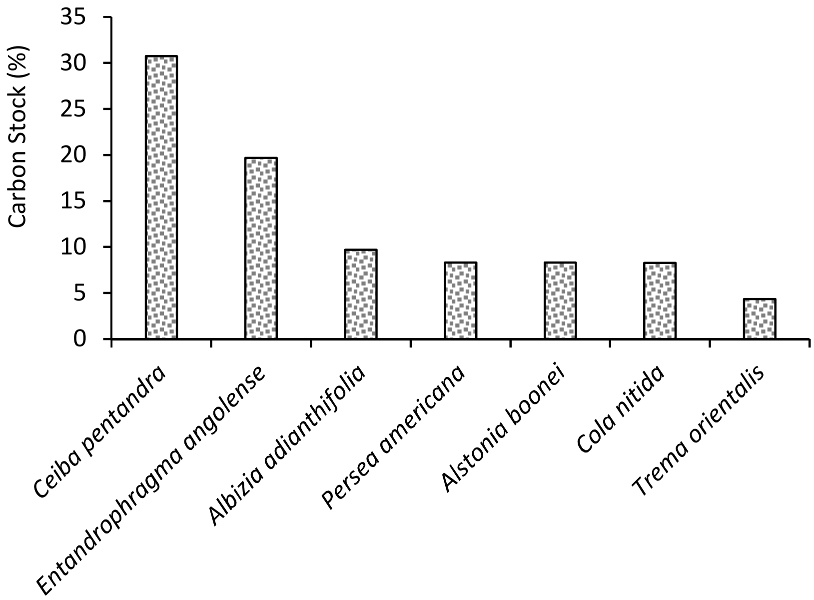

Fig. 3. Woody companions with the largest proportions of carbon stocks

4 DISCUSSION

Forests, plantations and field trees are potential carbon pits [39]. Thus, agroforestry practice contributes to the reduction of greenhouse gases concentration in the atmosphere [40]. However, in Côte d'Ivoire where cocoa and rubber farms dominate the agrarian landscape [21], the ancient practice associating perennial and other woody crops seems to be gradually declining.

In our study area, the density of woody recruits and young trees declined significantly from young plantations to old cocoa farms. However, that of mature trees remained more or less constant. This could be related to how these farms were set up and maintained. In fact, the peasants considerably reduce the number of woody individuals to make the best use of the new fields. However, some woody individuals, whose maintenance was of particular interest to them, were preserved. These include *Entandrophragma engolense*, *Ceiba pentandra*, *Albizia adianthifolia*, *Alstonia boonei* and *Trema orientalis*.

These trees are generally used for agronomic (soil fertilization and shade) and social (traditional medicine, timber) purposes. In addition, with the age of the farms, some of these woody plants, which became too important in number or useless, were eliminated for the growth of cocoa seedlings. At the same time, fruit trees such as *Cola nitida, Persea americana* and *Garcinia kola* were intentionally introduced by farmers. This could explain the fact that the densities of mature trees were statistically constant in the cocoa farms. Such observations were found in central Côte d'Ivoire [5], [41] and in the eastern Cameroon [42].

This form of tree management could explain the significant decline in diversity and number of companion woody companions species in cocoa farms. In addition, it determined the amount of carbon stored in the woody biomass of these farms. Indeed, the amount of carbon stored in cocoa trees increased significantly from young to old cocoa farms while, that stored in companion woods was high, but remained statically unchanged regardless of the age of the farms. However, the amount of carbon stored in the woody biomass of cocoa farms also remained statistically unchanged regardless of farms age. Woody companions stocked more carbon than cocoa trees. This was because farmers usually save in cocoa farms, trees such as *Entandrophragma engolense* and *Ceiba pentandra* that captured large quantity of carbon. This variation of the carbon stock in woody biomass of cocoa farms was also observed in Cameroon [16] and in Central America [17]. It was mentioned there that, compared to trees associated with cocoa farms, cocoa trees have the lowest performance for carbon sequestration. Therefore, abandoning agroforestry practice in cocoa farms could significantly reduce the carbon stock of these farms [16].

As in the cocoa farms of our study area, the density of woody recruits and young trees decreased significantly from young people to old rubber farms. However, the density of mature trees remained constant only in young farms. This situation arises from farmers' mistrust of root disease due to the presence of soil fungi, notably *Fomes lignosus* (Klotzsch) Bres. Indeed, this pathogenic fungus, responsible of the disease commonly known as *fomès*, is the leading cause of rubber tree mortality in plantations [43]. It is propagated either by rhizomorphous soil release or by contact between healthy roots and contaminated roots or infested woody debris. As a result, during the preparation of a field, the farmers cut down all the trees to the stump and set the field on fire. Only a few tree species like *Persea americana* and *Garcinia kola* are intentionally introduced in young plantations by farmers

These species serve as both shade for young rubber trees and a source of traditional medicine. Their fruits were also consumed by the peasants. In addition, with the age of the farms, almost all these woody species were eliminated by the farmers in order to facilitate the height growth of the rubber trees for an optimal production of the latex.

Ceiba pentandra was considered as the potential host of the *Fomes lignosus* ansd according to farmers, the decomposition of individuals of this tree after slaughter in rubber farms plots entails a systematic attack of the plants by the fungus. They therefore prefer not to eliminate large diameter individuals on their farms that explained the dominance of this species in rubber farms. Thus, the low diversity of tree species in rubber farms would be linked to this way of managing these species. Nevertheless, these observations made suggest that peasants engaged more or less in agroforestry practice in the rubber farms in our area of study. However, unlike cocoa farms, the amount of carbon stored in the rubber trees increased significantly while that stored in the ligneous companions was low and remained statistically stable.

Moreover, by combining the amount of carbon stored in the companion woods with that of the rubber plants, the amount of carbon obtained increased significantly from the young to the old rubber farms. The amount of carbon stored in the woody biomass of these farms would be determined by the rubber plants. The more rubber farms become older, rubber plants store large amounts of carbon. This finding was also made in the Philippines [19]. It was observed there that biomass production and the carbon sequestration potential of rubber farms are strongly linked to the age of the farms. In northwestern Ghana, it was also found [18] that rubber trees store more carbon than cacao, oil palm (*Eleais guineensis* Jacq.) and orange (*Citrus sinensis* (L.) Osbeck). As a result, rubber farms can be considered as agrarian systems that do not affect the carbon pool of forests [44]. This suggests that the absence of woody plants other than rubber trees does not limit the carbon stock in the woody biomass of rubber farms. However, the age of plantations seems to be the determining factor for the carbon stock in their biomass.

5 CONCLUSION

This study aimed to evaluate the diversity of tree species and the amount of carbon stored in the woody biomass of cocoa and rubber farms. Investigations carried out in the Indénié Djuablin region have shown that peasants save or introduce different woody species on their cocoa and rubber farms for different uses. The density of mature trees that was estimated at more than five trees per hectare suggested a persistence of agroforestry practice on these farms. This practice ensured a good carbon stock in the woody biomass of cocoa farms, which was not the case in rubber farms. Certainly the cocoa plants stock small amounts of carbon, but the timber associated with crop plants stored high amounts of carbon. In rubber farms, on the other hand, the opposite situation was observed. Actually, the amount of carbon stored in rubber plants increased significantly with the age of the farms and was higher than that of the companion woody plants. Based on this observation, awareness raising on agroforestry practices in cocoa and rubber farms should be encouraged in agricultural countries such as Côte d'Ivoire. This will contribute to the conservation of multipurpose trees and create a carbon reservoir to limit the concentration of greenhouse gases in the atmosphere.

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