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Woody species diversity conservation and carbon sequestration potential of coffee agroforestry systems in the Western Region of Cameroon

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This study sought to assess the contribution of coffee agroforestry systems (CAFS) in conserving tree diversity and carbon stocks in the western region of Cameroon. Inventory was carried out in 52 plots laid out in CAFS and in adjacent secondary forest. Above-ground biomass was estimated using allometric method. A total of 30 species belonging to 19 families were identified in CAFS and 30 species belonging to 15 families in the forest. The Jaccard similarity index between CAFS and forest was 43%. In the CAFS, the average value of Shanon diversity index was 1.61, reflecting a low diversity. The average tree density was 133 stems/ha in CAFS and 345 stems/ha in the forest. The CAFS stored an amount of carbon of 24.28 tC/ha, representing only 10.30% of the average amount of carbon stored by the forest (235.88 tC/ha). In the CAFS, *Elaeis guineensis* was the most dominant species with an important value index of 169.96%. The most efficient species for carbon sequestration were *Triplochiton scleroxylon* with 2.38 tC/tree. These results indicate the need to integrate CAFS as a biodiversity conservation and carbon sequestration land-use system due to the many socio-economic and ecological benefits they provide both in climate change adaptation and mitigation.

Key words: Coffee agroforestry system, diversity, ecosystem services, climate change mitigation, carbon stock.

INTRODUCTION

Global forest cover has drastically decreased from 4128 million ha in 1990 to 3999 million ha in 2015 (FAO, 2016). In tropical regions, extensive conversion of forests and agricultural intensification are typically identified among the most prominent drivers of land-use change and biodiversity loss (Geist and Lambin, 2002). This land-use change is one of the major causes of global climate change (IPCC, 2014). As the impact of climate change is being felt more and more over the years, especially with the perception of small farmers who report lower and / or increased rainfall and shifts in rainy and dry seasons (Ogouwalé, 2006), there is increasing interest to combine

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adaptation and mitigation measures (Locatelli et al., 2008; Lasco et al., 2014). Strategies for offsetting greenhouse gas emissions include the implementation of better agricultural practices such as agroforestry (FAO, 2010). Agroforestry systems have received increased attention as potentially cost-effective options for climate change mitigation due to their potential to reduce carbon dioxide (CO_2) concentrations in the atmosphere by increasing carbon stocks in agricultural lands (FAO, 2010; Hergoualc'h et al., 2012; IPCC, 2014). Albrecht and Kandji (2003) estimated that the potential of carbon storage of tropical agroforestry systems range from 12 to 228 tC/ha.

Improving soil fertility and biodiversity conservation are other ecological services provided by agroforestry (Garrity et al., 2010; Atangana et al., 2014) in addition to ensuring food security (Mapongmetsem et al., 2016). Agroforestry combines both food production and environmental protection and are seen as sustainable and therefore eligible for the reduction of emissions from deforestation and degradation (REDD+) mechanism. This incentive mechanism considers conservation and carbon stock in the prospect of payment for environmental services and could be an economic opportunity for farmers (Takimoto et al., 2008; Atangana et al., 2014; Etchiké et al., 2017).

Coffee agriculture represents about 6.5% of world permanent crop and globally, more than 10.5 million hectares of tropical land is under coffee production (FAO, 2019).In many parts of the world, coffee is traditionally cultivated under tree cover, the farmers retaining or introducing useful woody species into their plantations (Dalliere and Dounias, 1999; Perfecto et al., 2005; Correia et al., 2010; Tadesse et al., 2014a; Denu et al., 2016; Koda et al., 2019). These coffee agroforestry systems (CAFS) contribute to the conservation of wood diversity and carbon storage (Häger, 2012; Hergoualc'h et al., 2012; Tadesse, 2014b; De Beenhouwer et al., 2016; Denu et al., 2016; Kodaet al., 2019).The amount of carbon stored in a CAFS varies depending on management intensity. For example in Ethiopia, compared to nearby natural forests, CAFS have been reported to retain 50 to 75% of carbon (Tadesse et al. 2014b; Vanderhaegen et al., 2015; Denu et al., 2016).

Western Cameroon is a volcanic region in which the cultivation of coffee trees is an age-old practice. However, the 1980s was marked by a deep coffee crisis following the fall in world prices (Guétat-Bernard, 2008). To cope with the situation, production systems evolved towards crop diversification in order to multiply sources of income (Kankeu and Kaffo, 2012; Manga et al., 2013). Most of these farmers grow coffee in agroforestry systems with a wide variety of useful trees. But given the fact that coffee is losing value due to constant drops in its price, smallholder coffee farmers remain poor and the tendency is to convert coffee agroforestry farms to other crop farms. There is a need to check for ecological services these CAFS provide so that they could be valued in the context of payment for environmental services and carbon stock sold as CO_2 emission offsets. Several studies have already been carried out on the biodiversity conservation and carbon storage potential of coffee agroforestry systems in Central and South America (Häger, 2012; Schmitt-Harsh et al., 2012; Richards and Mendez, 2014; Goodall et al., 2015; Zaro et al., 2019) and in East Africa (Tadesse et al., 2014a, b; Vanderhaegen et al., 2015; De Beenhouwer et al., 2016; Bukomeko et al., 2019). In Central Africa and in Cameroon in particular, such studies are still very limited (Manga et al., 2013).Thus, this study is very important and timely as it seeks to evaluate the tree diversity and the carbon sequestration potential of coffee agroforestry systems in the western region of Cameroon.

MATERIALS AND METHODS

Study area

The study was carried out in Kekem sub-division found in the Haut-Nkam division, West Region of Cameroon. The sub-division is located between latitudes 5.01° - 5.15°N and longitudes 10.00° - 10.08°E (Figure 1). The climate of Kekem is of the tropical highland type characterised by two seasons namely; the dry season from November to March and the rainy season the rest of the year. The rainfall here is relatively high with about 1800 to 2000 mm of rainfall per year and temperatures range between 20 and 30°C.Haut-Nkam is a transitional zone between the Mbo plains and the mountain chains of west Cameroon. The altitude is between 600 and 1200 m (PNDP, 2013). Naturally, the vegetation cover is mainly made up of forest and savannah grassland. The grasslands are found in plains, while the forest dominates on hill slopes and tops. Agriculture is by far the main economic activity in the study area. It is mostly carried out on extensive mixed cropping systems. Robusta coffee, cocoa and oil palm are the main cash crops.

Data collection

An inventory was carried out in 5 villages. In coffee farms, sample plots were laid out by adapting the method described by Hairiah et al. (2011) with the marking out of rectangular shaped main plots of 2400 m^2 (40m × 60m) for counting woody trees with a diameter at breast height (dbh) ≥ 30 cm and sub- plots of 800 m^2 (20m × 40m) for woody trees with a dbh≥ 5 cm. A total of 48 main plots were marked out. Four main control plots of 2400 m² (40m × 60m) were established in adjacent secondary forests for counting woody trees with a diameter at breast height (dbh) ≥ 30 cm and in each plot 2 sub- plots of 200 m^2 (5m x 40m) were laid out for counting woody trees with a dbh ≥ 5 cm. The choice to count trees of dbh ≥ 5 cm was made based on the allometric equation used for the biomass calculation. Indeed, the equation used (Chave et al., 2014) considers trees with a diameter of at least 5 cm at breast height.

In each plot we measured height and the diameter at breast height of all woody species including coffee trees. The diameters of coffee trees were also measured at breast height. The diameters were measured using a measuring tape and the height with a clinometer. Species identification was made on the basis of discriminating characteristics of species using dichotomous keys of Cameroon flora, Identification Manual of Vivien and Faure (2012) and vernacular names. The botanical nomenclature adopted is that of Lebrun and Stork (1991-1997). Semi-structured interviews with 30 farmers provided information on indigenous knowledge,

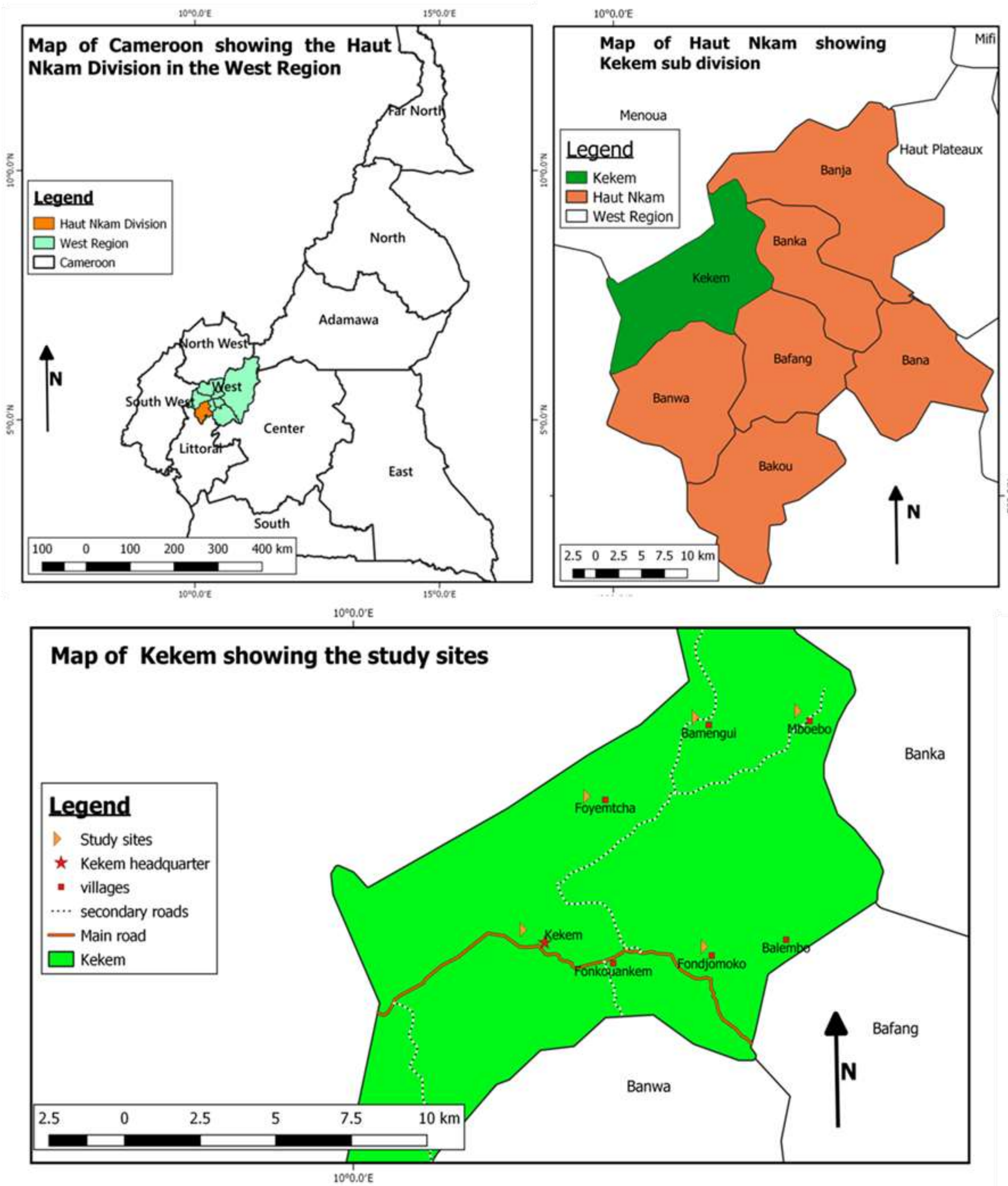

Figure 1. Location of the study area in the western region of Cameroon.

conservation and the introduction of species and their main uses.

Data analysis

Diversity, species richness and floristic composition

The main floristic parameters considered in this study were species richness, the diversity indexes of Shannon and Simpson, Evenness index of Piélou, family importance value index (FIV) and importance value index of species (IVI).

Species richness: This refers to the total number of species that make up a community. To get its values, we need to know the total number of families and species represented in each sub-plot.

Diversity index of Shannon-Weaver (H'): This index helps to measure the probability of interactions between the different species that constitute the community. This index includes components like the number of species present and the number of individuals within these species.

$$H' = -\sum(ni/N)Log_2(ni/N)$$

Where: ni is the total number of individuals of the specie i; and N the number of individuals of all the species.

Evenness Index of Pielou (E): It represents the distribution of species within a particular community. This index varies from 0 to 1 and is at its maximum when the species have equal abundances and at its minimum when one species dominates in the community.

$$E = H'/Log_2 S$$

where, S is the total number of species identified and H' the Shannon index.

Simpson diversity index (D'): This is the probability for two individuals selected randomly to belong to different species. The maximum diversity value is represented by 1 and the minimum diversity is represented by 0(Danais, 1982).

$$D' = 1 - D = 1 - \sum(ni/N)^2$$

where: ni is the number of individuals for a particular species; N is the total number of individuals for all species.

Jaccard index: Its measures the similarity between species composition of two sites.

$$J = \frac{C}{A + B - C}$$

Where A is the number of species for site A, B is the number of species for site B and C the number of species site A and B have in common.

To describe the ecological importance of families and species within the total flora, the Family Importance Value index (FIV) (Mori et al., 1983) and the Importance Value Index (IVI) (Curtis and McIntosh, 1950) were calculated.

FIV= Relative diversity + Relative density + Relative dominance

Where: Relative diversity = (number of species in a family / total number of species) x 100
Relative density = (number of trees in a family / total number of trees) x 100
Relative dominance = (basal area of a family / total basal area) x 100
IVI = Relative Frequency + Relative Density + Relative Dominance
Relative frequency = (frequency of a species / sum of frequencies) x 100
Relative density = (density of a species / sum of all densities) x 100
Relative Dominance = (basal area of a species / sum of all basal areas) x 100.

Stand structure parameters

Vegetation structure was determined by parameters such as density, basal area and distribution of individuals by diameter classes. Density and basal area was estimated using the formula given by Kent and Coker (1992).

Density (D): Density is the number of individuals per hectare. It was calculated by converting the total number of individuals encountered in all plots to equivalent number per hectare, following this formula:

D = N/S

With D the density (stems ha^{-1}), N the number of stems present on the considered surface and S the area considered (ha).
Basal area (BA) provides information on the area occupied by tree sections at 1.30 m from the ground.

$$BA = \frac{\pi}{4}\sum_{n=1}^{n}(Di^2)$$

Where BA is basal area (m^2 ha^{-1}) and D is diameter (m).

Distribution of individuals by diameter classes: The trees were distributed in the different diameter classes of 10 cm amplitude, following the recommendations of Favrichon et al. (1998).The define classes were as such:(5-15 cm), (15-25 cm), (25-35 cm), (35-45 cm), (45-55 cm), (55-65 cm), (65-75 cm), (75-85 cm) and ≥ 85 cm.

Uses of associated trees

Categories of uses were distinguished according to farmer's point of view about the services provided by associated trees.Information about the status of the trees (planted or conserved) was also found.

Biomass and carbon estimation

Above ground biomass: A non-destructive sampling method was used for the determination of total aboveground biomass (AGB). We used the allometric equation proposed by Chave et al. (2014) which is given by the formula:

$$AGB = 0.0673 \times (\rho D^2 H)^{0.976}$$

where, AGB is above ground biomass (in kg), ρ is the specific wood gravity (in $g.cm^{-3}$), D the tree diameter at breast height (in cm) and H the total tree height (in m).

Because palms trees (*E. guineensis*) do not have secondary growth the only parameter considered for biomass estimation is tree height and the model developed by Aguaron and McPherson (2012) was used.

$$AGB = 1.282 \times (7.7H + 4.5)$$

Below ground biomass: The estimation of below ground biomass (root biomass) was calculated using the method by IPCC (2006). This method states that the below ground biomass of trees is gotten by multiplying the value of above ground biomass by the coefficient R which is equal to 0.24.

$$BGB = AGB \times R$$

where, BGB is below ground biomass, AGB is above ground biomass and R is the root/stem ratio.
Carbon stocks were gotten by multiplying the sum of AGB and BGB

Table 1. Species richness and diversity indices per CAFS in different villages and forest.

Sites	Species	Families	Shannon (H')	Simpson (D')	Pielou Evenness (E)
Fonjomonko	7	7	0.48 ± 0.16[c]	0.19 ± 0.05[b]	0.25 ± 0.06[c]
Foyemtcha	16	13	1.72 ± 0.43[b]	0.70 ± 0.23[a]	0.62 ± 0.10[b]
Mboebo	18	15	1.76 ± 0.35[b]	0.70 ± 0.12[a]	0.33 ± 0.07[c]
Kekem center	24	16	1.92 ± 0.48[b]	0.71 ± 0.14[a]	0.35 ± 0.03[c]
Bamengui	19	14	2.16 ± 0.37[b]	0.79 ± 0.20[a]	0.71 ± 0.13[b]
Forest	30	15	3.08 ± 0.39[a]	0.86 ± 0.14[a]	0.91 ± 0.05[a]

On the same column, means bearing the same letter are not significantly different (Newman-Keuls test, 5%).

by the carbon fraction which has a value of 0.47 (IPCC, 2006). It is expressed mathematically as:

$$C = (AGB + BGB) \times 0.47$$

where C is the total carbon stock, AGB is above ground Biomass and BGB is below ground biomass.

Statistical analysis

The Excel spreadsheet Microsoft Office helped to organize the data collected and perform descriptive analyzes for a better characterization of these agroforestry systems. Means value of species richness, diversity indices, densities and carbon stocks were subjected to analysis of variance (ANOVA) using the SPSS software. When the differences were significant between the elements of these coffee agroforestry systems in different villages and forest, we put forward the elements that caused these changes by the test Newman-Keuls.

RESULTS

Tree species composition and diversity

Altogether, out of the 48 plots surveyed in CAFS in five villages, 1066 individuals belonging to 30 species and 19 families were recorded. As for the secondary forest zone, 184 individuals were recorded belonging to 30 species and 15 families. The Shannon diversity indices ranged from 0.48 to 2.16 in CAFS (Table 1) showing low species diversity.

The village where species richness is closest to that of the forest is Kekem center with 24 species, while Fonjomonko is the village with the lowest species richness (7 species). Statistical analysis revealed that there is a significant difference between the Shannon diversity index of the forest and that of CAFS in all the villages and between the villages, there is a significant difference between the Shannon diversity index of Fonjomonko and the other villages ($P < 0.001$).The Simpson diversity index of Fonjomonko (0.19) was low, showing that there is a higher probability that two trees selected randomly may belong to the same species. There is no significant difference between the Simpson diversity indices of the forest and the other villages, except for Fonjomonko. The Piélou Evenness index expresses the distribution of individuals within species and thus, the low index in Fonjomonko (0.25) shows that there is clearly one species that dominates the others.

In terms of the number of species in CAFS, the most represented family was Fabaceae with five species, followed by Apocynaceae (4 species), Sterculiaceae, Arecaceae, Rutaceae and Burseraceae with 2 species each.The other 13 families had only onespecies each.The family importance valu es found in CAFS and in the adjacent forest are presented in Table 2. In CAFS, the most important families were Arecaceae, Burseraceae, Fabaceae, Moraceae and Apocynaceae. CAFS and the forest shared in common eleven families. In the secondary forest, Fabaceae occupied the first place in terms of abundance and dominance followed by Moraceae, Meliaceae, Apocynaceae and Burseraceae.

The Importance value indices of species in CAFS are presented in Table 3. *E. guineensis* had the overall highest importance value index in all the villages (169.96%) followed by *Dacryodes edulis* (47.72%), *Persea americana* (11.63%), *Milicia excelsa* (11.49%) and *Albizia zygia* (7.45%). This is quite evident because these species are the most frequent and abundant in the CAFS of the area. Five species had an IVI less than 0.5 (*Podocarpus mannii*, *Citrus lemon*, *Pterocarpus soyauxii*, *Adansonia digitata* and *Picralima nitida*). In the secondary forest, *Milicia excelsa* had the highest importance value index (43.86%) due its high dominance, and abundance, followed by *Pterocarpus soyauxii* (18.6%), *Alstonia boonei* (17.67%), *Piptadeniastrum africanum* (17.65%) and *Lophira alata* (15.64%).

Similarity between coffee agroforestry systems and forest

Jaccard's indices of similarity were calculated to compare species composition between the CAFS of the different villages and forest (Table 4). From the values of the Jaccard index, almost all were below 0.5, implying that the floristic composition of the CAFS in the five villages are not similar to each other. The CAFS in Fonjomonko have the fewest number of species in common with other villages and those in the Kekem center and Mboebo

Table 2. Family importance value (FIV) of families in coffee agroforestry systems and forest.

Family	Coffee agroforestry systems						Forest
	Global	BAM	FON	FOY	KEK	MBO	
Arecaceae	125.31	68.85	197.61	110.95	123.62	125.49	-
Burseraceae	42.77	65.59	21.18	54.23	39.9	32.95	14.18
Fabaceae	23.24	38.67	17.11	19.24	24.79	16.39	94.89
Moraceae	15.43	16.04	14.78	23.1	7.19	16.04	32.25
Apocynaceae	14.31	6.35	-	20.6	17.68	26.9	15.34
Lauraceae	11.17	14.10	-	11.56	13.48	16.71	-
Rutaceae	10.38	10.87	14.82	7.43	11.11	7.67	-
Myrtaceae	9.07	10.52	14.8	8.07	4.61	7.36	-
Clusiaceae	8.03	13.86	-	11.49	7.79	7.04	7.63
Anacardiaceae	7.44	9.46	19.7	-	-	8.03	-
Annonaceae	4.95	5.37	-	6.8	5.09	7.5	-
Ochnaceae	4.83	9.1	-	-	7.66	7.38	12.95
Cecropiaceae	4.11	-	-	11.83	8.75	-	9.53
Caricaceae	3.96	-	-	7.36	4.74	7.69	-
Sterculiaceae	3.60	-	-	-	11.74	6.27	-
Rubiaceae	2.04	10.20	-	-	-	-	10.11
Bombacaceae	1.37	-	-	-	-	6.58	14.79
Podocarpaceae	1.20	-	-	-	6.01	-	11.81
Adoxaceae	1.16	-	-	-	5.83	-	5.83
Combretaceae		-	-	-	-	-	12.15
Malvaceae		-	-	-	-	-	14.74
Meliaceae		-	-	-	-	-	16.10
Urticaceae		-	-	-	-	-	8.59

BAM: Bamengui; FON : Fonjomonko; FOY : Foyemtcha; KEK: Kekem center; MBO: Mboebo.

villages have more species in common (J = 0.62). Concerning the similarity between CAFS and forest, the overall floristic composition of CAFS is different from that of the forest (J= 0.43). Kekem center which was the village with species richness closest to that of the forest wasalso the village which resembles the forest most, with fourteen species in common (J= 0.35). Eighteen species were found in both the CAFS of at least one village and the forest, among which: *Dacryodes edulis, Milicia excelsa, Albizia zygia, Alstonia boonei, Garcinia kola, Albizia ferruginea, Afzelia pachyloba, Triplochiton scleroxylon* and *Podocarpus mannii.* Only 6 species were found in CAFS in all the villages. These were: *Elaeis guineensis, Dacryodes edulis, Milicia excelsa, Albizia zygia, Psidium guajava* and *Citrus reticulata*.

Structure of coffee agroforestry and forest stands

Stem densitiesand basal areas

The CAFS have an average tree density of 133±24 stems/ha for associated trees and 753±142 stems/ha for the coffee plants. Kekem center has the highest tree density (160 stems/ha) and Fonjomonko the least (109 stems/ha). The forest on its part has an average density of 345.01 ± 28.28 stems/ha (Table 5). This implies that the associated trees density in CAFS is equivalent to 36% of the tree density of the forest. The mean basal area for the CAFS was 15 ± 3 m²/ha, lower than that of the forest (31.09 ± 6.37 m²/ha). This can be explained by the fact that, the trees density in CAFS is lower than in the forest. Fonjomonko is the village where CAFS had the highest basal area (18.32 ± 1.70 m²/ha), followed by Kekem center (15.37 ± 4.77m²/ha) and Mboebo (15.22 ± 3.18m²/ha).

Diameter class distribution

The diameter class distribution of woody vegetation in coffee agroforestry exhibited a tendency towards a bell-curve distribution (Figure 2a). The classes with most abundant individuals were 45-55 cm and 35-45 cm with respectively 27.20 and 26.92% of individuals. Woody vegetation in CAFS has few trees with diameter greater

Table 3. Importance value index (IVI) of species in coffee agroforestry systems and forest.

Species	Coffee agroforestry systems						Forest
	Global	BAM	FON	FOY	KEK	MBO	
Elaeis guineensis	169.96	97.94	272.93	153.66	164.4	160.8	
Dacryodes edulis	47.72	71.43	11.65	62.95	45.95	46.64	5.34
Persea americana	11.63	13.98	-	8.95	15.59	19.61	
Milicia excelsa	11.49	16.42	0.93	22.57	4.69	12.83	43.86
Albizia zygia	7.45	14.12	4.55	6.2	9.39	2.98	7.25
Alstonia boonei	6.77	-	-	8.07	6.38	19.42	17.67
Garcinia kola	6.31	12.68	-	9.41	6.56	2.89	6.14
Albizia ferruginea	4.13	15.95	-	4.7	-	-	7.25
Mangifera indica	3.74	7.28	8.02	-	-	3.42	
Tetrapleura tetraptera	3.60	5.11	-	-	6.57	4.64	7.3
Psidium guajava	3.15	7.8	0.95	3.39	0.87	2.74	
Afzelia pachyloba	3.12	13.48	-	2.14	-	-	8.92
Lophira alata	2.95	6.4	-	-	5.58	2.76	15.64
Myrianthus arboreus	2.95	-	-	7.66	7.09	-	9.62
Citrus reticulata	2.26	1.06	0.97	2.22	4.01	3.06	
Canarium schweinfurthii	1.92	2.91	-	2.22	4.45	-	8.63
Cocos nucifera	1.61	1.41	-	-	1.04	5.61	
Nauclea diderrichii	1.39	6.95	-	-	-	-	8.87
Annona muricata	1.37	1.13	-	1.07	1.76	2.89	-
Carica papaya	1.34	-	-	2.15	0.99	3.54	-
Voacanga thouarsii	1.05	2.63	-	2.64	-	-	-
Voacanga africana	0.93	-	-	-	1.15	3.49	4.33
Cola nitida	0.59	-	-	-	1.78	1.19	-
Triplochiton scleroxylon	0.58	-	-	-	2.89	-	11.23
Unidentified 1	0.51	-	-	-	2.55	-	3.36
Podocarpus mannii	0.45	-	-	-	2.26	-	7.04
Citrus lemon	0.44	1.32	-	-	0.87	-	-
Pterocarpus soyauxii	0.44	-	-	-	2.19	-	18.67
Adansonia digitata	0.30	-	-	-	-	1.49	14.68
Picralima nitida	0.20	-	-	-	0.99	-	-
Piptadeniastrum africanum							17.65
Ceiba pentandra							12.86
Guibourtia tessmannii							11.31
Khaya ivorensis							6.29
Entandrophragma cylindricum							5.31
Unidentified 2							4.33
Unidentified 3							3.05
Unidentified 4							4.66
Unidentified 5							8.31
Entandrophragma candollei							3.29
Podocarpus latifolius							4.03
Musanga cecropioides							8.7

BAM: Bamengui; FON : Fonjomonko; FOY : Foyemtcha; KEK: Kekem center; MBO: Mboebo.

than 85 cm. Small diameter trees represent young growing plants, usually planted by farmers. Larger diameter trees were mostly retained at the time the plantation was established. The same tendency of class diameter distribution was observed in forest with a bell-shape curve (Figure 2b), the classes with most abundant

Table 4. Jaccard indices between the coffee agroforestry systems and forest.

Sites	Jaccard indices					
	Bamengui	**Fonjomonko**	**Foyemtcha**	**Kekem center**	**Mboebo**	**Forest**
Bamengui	1					
Fonjomonko	0.37	1				
Foyemtcha	0.52	0.35	11			
Kekem center	0.48	0.24	0.46	1		
Mboebo	0.48	0.39	0.48	0.62	1	
Forest	0.26	0.09	0.22	0.35	0.23	1
All CAFS	-	-	-	-	-	**0.43**

Table 5. Stem density of trees in coffee agroforestry systems and forest.

Sites	Density (stems/ha)		Basal area (m^2/ha)	
	Associated trees	**Coffee**	**Associated trees**	**Coffee**
Bamengui	127.22 ±19.22	640.56 ± 96.755	13.92 ± 2.30	2.17 ± 0.32
Fonjomonko	109.85 ± 13.49	999.10 ± 67.68	18.32 ± 1.70	3.40 ± 0.23
Foyemtcha	113.23 ± 28.58	731.60 ± 97.91	13.41 ± 2.04	2.49 ± 0.34
Kekem center	160.31 ± 42.58	689.10 ± 112.57	15.37 ± 4. 77	2.34 ± 0.38
Mboebo	157.76 ± 44.6	704.56 ± 111.33	15.22 ± 3.18	2.39 ± 0.38
Forest	345.01 ± 28.2		31.09 ± 6.37	-

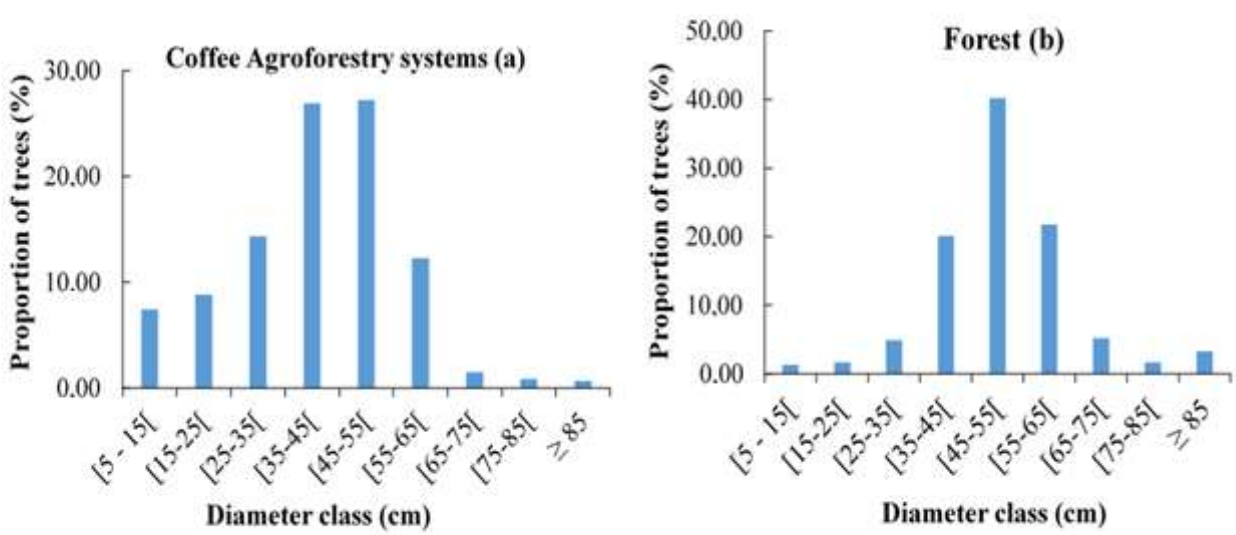

Figure 2. Size class distribution of the trees species in (a) CAFS and in (b) Forest.

individuals being 45-55 cm with 40.22% of individuals.

Uses of associated trees

The conservation or introduction of woody species into CAFS largely responds to the different needs of households. The interviews with farmers showed that about 73% of tree species were planted, while 27% were conserved during plantation establishment. Five uses have been identified for trees associated with coffee. These are:

(i) Fruit production: concerns trees that produce edible

Table 6. Average carbon stock in the coffee agroforestry systems and forest.

Sites	Carbon stocks (tC/ha)	
	Associated trees	Coffee
Bamengui	29.47 ± 4.15	1.05 ± 0.15
Fonjomonko	10.16 ± 1.17	1.64 ± 0.11
Foyemtcha	26.96 ± 6.65	1.20 ± 0.17
Kekem center	24.37 ± 10.23	1.13 ± 0.18
Mboebo	24.18 ± 7.57	1.15 ± 0.18
Forest	235.88 ± 12.15	

fruits which are destined for home consumption or for sale (*Persea americana*, *Dacryodes edulis*, *Citrus reticulata, Canarium schweinfurthii, Cocos nucifera, Carica papaya, Mangifera indica*, *Garcinia kola, Psydium guajava, Citrus lemon, Annona muricata* and *Cola nitida*).
(ii) Medicinal: concerns trees whose barks or fruits are used mainly for medicinal purposes (*Alstonia boonei, Voacanga africana*, *Picralima nitida* and *Tetrapleura tetraptera*).
(iii) Oil production: specifically of *Elaeis guineensis* whose fruits are used for the production of palm oil which generates considerable income.
(iv) Wood: this comprises trees that are kept in the farms principally to be used as fuel wood or timber (*Milicia excelsa, Lophira alata, Nauclea diderrichii, Triplochiton scleroxylon, Pterocarpus soyauxii*, *Afzelia pachyloba* and *Podocarpus mannii*).
(v) Shade: for trees which are kept in the farms to shade coffee or because they are too large to be cut down. All the other trees that serve for other purpose but especially tall ones can also serve as shade trees.Some of these shade trees are also leguminous species that contribute to the improvement of soil fertility (*Albizia zygia*, *Albizia ferruginea*, *Afzelia pachyloba, Pterocarpus soyauxii and Tetrapleura tetraptera)*.

Carbon stock in agroforestry systems and forest

Carbon stock in CAFS was on average 24.28± 6.71 tC/ha with the associated trees contributing to 94.8% of this amount (23.03tC/ha) and coffee trees the remaining 5.2% (1.25 tC/ha). The adjacent forest on the other hand, stocked an average of235.88 ± 12.15tC/ha, which is 9.7 times higher than that of the CAFS (Table 6). From this, we deduce that CAFS stock about 10.30% of the amount of carbon stocked by the forest in this same area. Among the five villages, the carbon stocks of associated trees in the CAFS ranged from 10.16 ± 1.17 tC/ha for Fonjomonkoto 29.47 ± 4.15 tC/ha for Bamengui. At 5% significance level, there is a significant difference between the amount of carbon stocks in the CAFS of Fonjomonko and those of other villages (P = 0.007). In Fonjomonko the low carbon stock in CAFS is due to the very high abundance of *E. guineensis* which represented 89.6% of individuals counted in this village with an IVI of 272.93%.

Carbon stock allocation by different species

In terms of contribution of species to the total carbon stock, the top five species in the forest were *Milicia excelsa, Lophira alata, Pterocarpus soyauxii, Piptadeniastrum africanum* and *Alstonia boonei.* In the CAFS, the greatest contribution was made by *Milicia excelsa*, *Elaeis guineensis*, *Dacryodes edulis, Alstonia boonei* and *Lophira alata* (Figure 3). In the CAFS, *Elaeis guineensis* and *Dacryodes edulis* had a good contribution to carbon storage in general due to their high abundance. They are indeed the two most abundant species with 56.47% and 16.23% of individuals respectively. The three other species (*Milicia excelsa, Alstonia boonei* and *Lophira alata)* have a good contribution to carbon sequestration due to their large size and high wood density, and also because they are among the most efficient species (Table 7).

Carbon sequestration performance was evaluated based on the average amount of carbon stored by a tree of the species. From Table 7, it can be seen that the best performing species were *Triplochiton scleroxylon*, *Milicia excelsa*, *Podocarpus mannii*, *Lophira alata* and *Canarium schweinfurthii*, which are mostly secondary forest species that are conserved at the time of setting up the coffee plantation. Efficient species accumulated high average carbon per tree due to high specific wood densities (*Milicia excelsa* and *Lophira alata*) or relatively large size (*Triplochiton scleroxylon, Podocarpus mannii, Alstonia boonei, Canarium schweinfurthii* and *Mangifera indica*). Majority of non-forest species planted by farmers stored low average amounts of carbon per tree (*Elaies guineensis*, *Persea americana, Citrus reticulata, Psidium guajava, Carica papaya* and *Annona muricata*).

DISCUSSION

Floristic richness and diversity

A total of 30 woody species belonging to 19 families were recorded in the coffee agroforestry systems of Kekem. In the natural forest, 30 species belonging to 15 families were identified. The species richness of CAFS is similar to that of 30 species and 16 families found by Manga et al. (2013) in the western highlands of Cameroon. This similarity can be explained by the fact that these two study areas are ecologically close. However, this richness is lower than that of 44 species found by Dallière and Dounias (1999) in the CAFS in Central region of Cameroon. It is also lower than those found in other parts

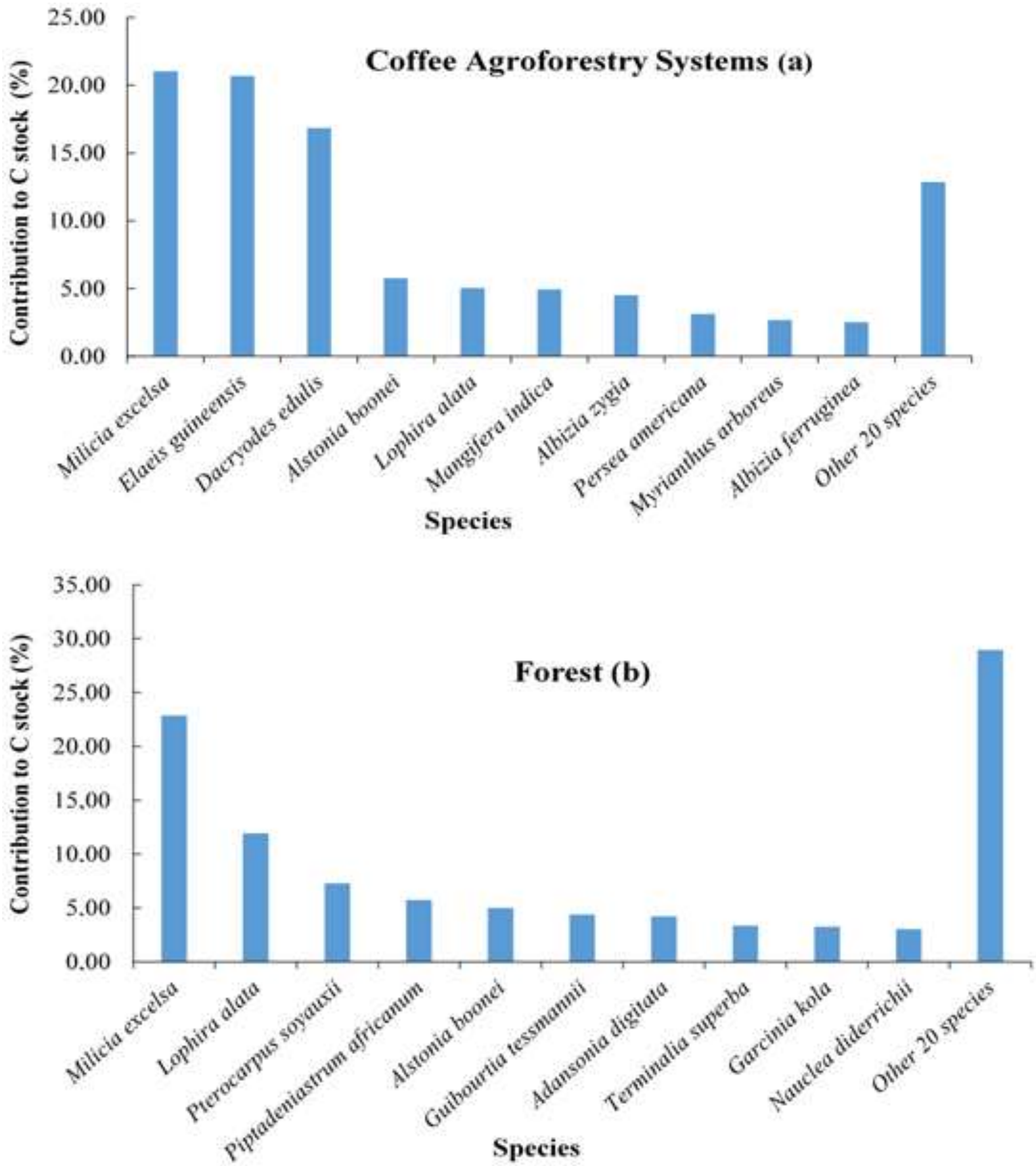

Figure 3. Contribution of species to the total carbon stock in: (a) CAFS and (b) Forest.

of the world: 47 species found by Richard and Mendez (2014), 91 species found by Tadesse et al. (2014a) and 138 species found by Koda et al. (2019) for smallholder coffee systems in El Salvador, Ethiopia and Togo respectively. This difference can be explained by the endogenous knowledge and cultural practices of these peoples and more technological itinerary adopted in establishing these coffee agroforestry systems (Mapongmetsem, 2017). In the study area, farmers conserve or introduce into their coffee farms, only trees species that are really useful to them and eliminate unnecessary ones, this choice being guided by the socio-economic and ecological benefits of the species.

The Shannon-Weaver diversity index (H') in CAFS ranged from 0.48 to 2.16 with a mean of 1.61, reflecting low diversity. The low diversity was also confirmed by a Simpson's diversity index of 0.62. The low Pielou evenness (0.45) obtained show a low distribution of

Table 7. Carbon sequestration performance of species.

Species	Average diameter (cm)	Number of individuals	Average biomass per tree of the species (kg/tree)	Average carbon per tree of the species (tC/tree)
Triplochiton scleroxylon	89.17	1	2378.2	2.38
Milicia excelsa	55.03	31	1700.13	1.70
Podocarpus mannii	74.20	1	1686.23	1.69
Lophira alata	37.61	11	1143.49	1.14
Canarium schweinfurthii	50.64	5	952.04	0.95
Mangifera indica	51.20	13	917.41	0.92
Alstonia boonei	44.56	21	688.16	0.69
Myrianthus arboreus	44.52	10	669.01	0.67
Albizia ferruginea	36.52	12	527.38	0.53
Afzelia pachyloba	32.80	12	480.68	0.48
Tetrapleura tetraptera	34.18	12	478.72	0.48
Pterocarpus soyauxii	29.14	2	435.62	0.44
Albizia zygia	35.45	26	433.79	0.43
Nauclea diderrichii	34.08	3	354.99	0.35
Unidentified species	33.76	2	317.68	0.32
Cola nitida	30.89	3	313.04	0.31
Adansonia digitata	45.86	1	274.69	0.27
Voacanga thouarsii	30.41	4	267.76	0.27
Dacryodes edulis	30.04	173	243.71	0.24
Voacanga africana	31.05	4	181.16	0.18
Garcinia kola	21.50	25	164.24	0.17
Persea americana	26.13	49	159.43	0.16
Cocos nucifera	26.71	7	107.99	0.11
Picralima nitida	24.52	1	91.84	0.09
Elaeis guineensis	46.86	602	86.06	0.09
Citrus lemon	18.95	2	74.12	0.07
Citrus reticulata	15.16	10	55.16	0.06
Psidium guajava	16.59	11	47.47	0.05
Carica papaya	14.01	6	11.52	0.01
Annona muricata	11.94	6	7.04	0.01

individuals within species due to the fact that *E. guineensis* was the dominant species. The Shannon index of CAFS in the study site was very low compared to the values of 3.5 and 4.06 recorded respectively by Tadesse et al. (2014a) in Ethiopia and Koda et al. (2019) in Togo. This difference can be explained by the fact that associated trees in Kekem are highly selected to leave just a few species that are really useful to farmers. Of the 30 species identified in the natural forest which was the control, 18 were found in agroforestry systems, representing a species conservation rate of 60%. This may be justified by the fact that during the establishment and evolution over time of the coffee plantations, the farmers are able to conserve forest species that have both socio-economic and environmental benefits to coffee and households. However this figure should be put into perspective, because taken separately, the rate of species conservation varies significantly between villages. In Fonjomonko, CAFS share only 3 species (10%) in common with the natural forest while in Kekem center, they share in common 14 species (46.67%). Among the trees species found in CAFS, four are considered vulnerable (*Afzelia pachyloba, Garcinia kola, Lophira alata, Nauclea diderrichii*) and one is near threatened (*Milicia excelsa*) according to the IUCN Red List (2019). We found that conversion of forests to coffee agroforestry systems resulted in a loss of at least 40% of forest-based woody species. This loss is close to the 34% loss found by Tadesse et al. (2014a) in Ethiopia but is lower than the 54% loss by Mbolo et al. (2016) in cocoa agroforestry systems in central region of Cameroon.

Despite this loss, for income diversification purposes, farmers replace some native forest trees with species that are useful to them. Thus, 12 species that are not found in natural forest were identified in the CAFS. It was observed that the choice of conserving or introducing trees in the CAFS is guided by their uses, but also by the market opportunities available to farmers. Thus, in order to fill the gaps in coffee production or to keep the inflow of agricultural income constant, these farmers are shaping their farm by prioritizing the conservation/introduction of trees whose fruits or products will be consumed by family or sold. Priority is given to species of high socio-economic value and to those whose planting and regeneration techniques are mastered by farmers. This concerns trees that produce edible fruits and that are usually planted by farmers (*Citrus reticulata, Dacryodes edulis, Elaeis guineensis, Persea americana, Mangifera indica, Garcinia kola, Psydium guajava* and *Annona muricata*). The species useful for wood and shade are those that are most often conserved at the time the plantation is established, and are also species found in the adjacent forest (*Milicia excelsa*, *Lophira alata, Albizia ferruginea, Nauclea diderrichii, Pterocarpus soyauxii, Albizia zygia, Afzelia pachyloba*).

In addition to shading, four other uses were mentioned by the coffee farmers which were: medicine, wood, fruit production and palm oil production. The latter use is provided by *Elaeis guineensis* which was the most abundant species found in the CAFS in the study area. In the Western Highlands of Cameroon, Manga et al. (2013) found that *Persea americana* was the most abundant species while *E. guineensis* was the least abundant. This difference can be explained by the proximity of the study area to the Littoral region, which is one of the main production basins of oil palm in Cameroon and is an important source of income for smallholders (Ndjogui et al., 2014).

Structure of coffee agroforestry systems and forest

The average tree density found in CAFS was133 ± 24 stems/ha and was equivalent to about 38.5% of the tree density in the adjacent secondary forest (345 ± 28 stems/ha). The tree density in CAFS is similar to the 108 ± 59 stems/ha recorded by Goodall et al. (2015) in San Ramon in Nicaragua; and is lower than the 207 stems/ha and 246.38 stems/ha recorded by Tadesse et al. (2014a) and Koda et al. (2019) in smallholder coffee systems in southwest Ethiopia and Togo respectively. The basal area of associated trees in CAFS (15 m^2/ha) fell within the range of 11 to 16 m^2/ha found by Manga et al. (2013), but was smaller than those of 54.5 and 27.99 m^2/ha found by Tadesse et al. (2014a) and Koda et al. (2019) respectively. This difference can be explained by much higher stem densities in the study sites of the latter authors than in ours.

In CAFS, size class distribution of stems followed a bell-shaped curve indicating a regeneration deficit with the largest numbers of stems concentrated above 35 cm. This could be due to the selective removal of saplings by coffee farmers or a non-renewal of big trees. This distribution is similar to that described in coffee agroforestry systems in Highlands of Western Cameroon by Manga et al. (2013), but is different to the J-inverted distribution observed in Guinea (Correia et al., 2010), in Ethiopia (Denu et al., 2016) and in Togo (Koda et al., 2019).

Carbon sequestration potential

The amount of carbon stock in CAFS was about 24.28 tC/ha on average. This value fell within the low end of the range of 12 to 228 tC/ha reported by Albrecht and Kandji (2003) for tropical agroforestry systems, and is similar to the value of 24.4 tC/ha reported in CAFS in El Salvador by Richards and Mendez (2014). However this value is less than the average carbon stock reported for comparable carbon pools in CAFS in other parts of the world. For example, Schmitt-Harsh et al. (2012) found 83.39 tC/ha in western highlands of Guatemala; Goodall et al. (2015) found 49.25 tC/ha in Nicaragua; Denu et al. (2016) and Tadesse et al. (2014b) reported respectively 61.5 tC/ha and 153 tC/ha in southwest Ethiopia; and Zaro et al. (2019) recorded a carbon stock of 75.80 tC/ha in CAFS with rubber trees in southern Brazil. These disparities recorded by several similar studies may be related to the fact that the studies were carried out in different areas with different climatic and ecological conditions and, as such, the wood density, the species as well as the stem densities of trees associated with coffee varied. In the study area the most abundant species with an overall relative abundance of 56.47% and an IVI of 169.96% was *E. guineensis* which, because of its very low wood density do not contribute to carbon sequestration the same way as forest species.

The carbon stock of the natural forest has been estimated at 235.88 tC/ha. The average carbon stock on CAFS represents about 10.30% of the average amount of carbon stored by the adjacent forest. The difference in carbon sequestration between CAFS and forest is due to the high stem density, wood density and diameter of trees found in the forest. In agroforestry systems, the most abundant species was *E. guineensis*. Despite the fact that this species had a very high abundance compared to other species, it had a low performance interms of carbon sequestration, that is, only 0.09 tC/tree.The best performing species were *Triplochyton scleroxylon, Milicia excelsa, Podocarpus mannii, Lophira alata* and *Canarium schweinfurthii.* However these species had low abundance (only 1, 31, 1,11 and 5 individuals respectively).

The 10.30% of carbon stored by CAFS compared to natural forest is smaller than the 75, 62 and 52% reported in Ethiopia by Denu et al. (2016), Tadesse et al. (2014b) and Vanderhaegen et al. (2015) respectively. This great difference is mainly due to the less abundance of carbon sequestration efficient species in CAFS of the study area. Although CAFS stock less carbon than the forest, they represent one of the most diverse farming systems and agroforestry trees can still store more carbon than other cropping systems (Kirby and Potvin, 2007).

With an average offset price of $3.2 per ton of CO_2 from voluntary carbon markets (Ecosystem Marketplace, 2019), the amount of carbon stored in CAFS in Kekem could enable farmers to earn an additional $294/ha. However, these figures could even be higher if all the carbon pools, particularly litter and soil organic carbon were taken into consideration. These amounts of money may afford an opportunity for coffee farmers to manage such systems for greater carbon sequestration. Thus, payment for environmental services mechanism would promote climate mitigation and adaptation benefits in addition to its socio-economic and ecological benefits if CAFS are integrated into conservation. In fact, the farmers' perception of climate change in the area is very real and in order to adapt to these changes, they are increasingly opting not only for the diversification of crops, but also of cropping systems, the collection and marketing of non-timber forest products in addition to the benefits brought by coffee plants (Mapongmetsem, 2017). This opportunity of payment of carbon credit would encourage the conservation and planting of trees and would reduce the observed tendency of conversion of CAFS to other cropland by farmers in the study area with the drop in coffee prices.

Conclusion

Significant differences were recorded between coffee agroforestry systems and the forest in terms of diversity, tree density and carbon stock. Although tree density is much higher in the forest, CAFS contributed significantly to the conservation of woody species because they share in common 60% of the species with the forest. In CAFS, some forest species were being replaced with non-forest species that are useful and can contribute to income generation and farmers' livelihood. Farmers have mainly oriented their coffee farms towards diversification of production. As a result, the associated trees are mainly introduced/conserved for fruit production, palm oil production and the needed shade for coffee trees. Compared to forests, CAFS contributed little to carbon storage because the more abundant trees were less efficient in terms of carbon storage. However, the amount of carbon stored remains higher than in other non-agroforestry cropping systems. The ecological service linked to carbon sequestration and wood diversity conservation offers a possibility of financial benefits in case of payment for ecosystem services. To farmers, this would then not only raise awareness of climate change and the need for conservation, but would also contribute to the improvement of their livelihood. Farmers should been couraged to plant/conserve more tree species that are useful but also have good carbon sequestration potential.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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