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Plant Biodiversity and Structure of Robusta Coffee (*Coffea canephora* var. *robusta*) Agroforests in Cameroon

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Abstract

Agroforests are man-made ecosystems in which crops are associated with a main perennial species like Robusta Coffee Agroforests (RCAs), which is counted among the main modes of perennial crops production in Cameroon. Despite the rich ecosystem services provided, the diversity of Associated Species (AS) found in these RCAs and the structure of the landscapes they form remain little known in Cameroon. The current study aimed to inventory AS and characterize the structure of RCAs in four sites (Ayos, Malantouen, Melong and Nkongsamba) belonging to three robusta coffee production basins in Cameroon. A systematic inventory with dendrometric measurements of the wood AS and coffee trees was carried out on 120 one-hectare plot unit, i.e. 30 plots per site. The results showed that 102 AS belonging to 83 genera and 41 families were identified in these RCAs. The RCAs of Ayos in the dense rainforest zone with bimodal rainfall pattern were the most diverse with 71 species, followed by those of Melong and Nkongsamba with respectively 39 and 33 species respectively in the dense rainforest zone with monomodal rainfall pattern, and Malantouen with 33 species in the high savannahs of the west. Structurally, average coffee tree and AS densities founded ranged from 1208 - 1456 plants/ha and 71 - 214 stems/ha and those of basal area from 7.29 - 17.40 m^2/ha for coffee trees and 7.97 - 16.14 m^2/ha for AS in function of site. Basis on the vertical stratification, the proportion of the 3 - 6 m stratum, which is mainly represented by introduced AS, varied from 38% - 62% depending on the site. The results of this study showed that RCAs contribute to the conservation of plant biodiversity, given the specific richness identified in these ecosystems.

Keywords

Associated Species, Species Richness, Horizontal Structure, Vertical Structure, Production Basin

1. Introduction

The coffee crisis of the late 1980s led to a devaluation of the market value of coffee and a gradual loss of interest in this crop by producers (Ngapgue, 2010). Thus, the monoculture systems that prevailed before this crisis gradually changed into polyculture systems, notably agroforests, whose aim was to develop new income sources by diversifying the species of interest in the coffee plantation (Kamga, 2002; Ngapgue, 2010).

Agroforests are man-made ecosystem in which crops are grown in association with a main perennial species (Ngomeni et al., 2021). These systems provide many ecosystem goods and services to people for their well-being. They are therefore one of the potential solutions to be implemented to face the challenge of ecological intensification of agroecosystems (Madountsap et al., 2019).

Like it is the case for different agroforestry systems, Robusta Coffee Agroforests (RCAs) in which several tree species of interest are found, despite their anthropization status, attempt to mimic the landscape of natural ecosystems. They allow the conservation of a number of ecological functions of natural ecosystems including air and soil regulation, biodiversity conservation, etc. (Hergoualc'h et al., 2012; Atangana et al., 2014; Denu et al., 2016; Sibelet et al., 2019; Temgoua et al., 2020). However, the landscape of these systems by varying from simple to complex systems (Beer et al., 1998), influences also the ecological function their provide (Madountsap et al., 2019). This variability is conditioned by Associated Species (AS) plant diversity and especially by their structural characterization, which are the result of the ecological environment and human activities; the needs and expectations of the farmers (Beer et al., 1998). For example, Schroth et al. (2004) found that, the complex agroforestry system with diverse and structurally complex shade canopies are among the systems types that are most likely to conserve a significant portion of the original forest biodiversity.

RCAs remain poorly studied in Cameroonian production basins (Avana et al., 2004; Ousmanou, 2005; Temgoua et al., 2020). It is imperative that more studies be considered for a better understanding of their structural organization. A better knowledge of these RCAs would help in the definition of the best strategies for sustainable management of RCAs in different coffee production basins, knowing that they are contrasted from the biophysical and human point of view. Thus, the general objective of the study was to characterize the diversity of AS and the structure of RCAs production basins in Cameroon, with the purpose of boosting their competitiveness.

2. Material and Methods

2.1. Study Area

The present study was carried out in four sites belonging to three robusta coffee production basins in Cameroon, contrasted by their biophysical and socio-economic environment: 1) Nkongsamba and 2) Melong (2˚6'' - 6˚12''N; 8˚48'' - 10˚30''E) in the Moungo production basin of a dense rainforest zone with monomodal rainfall pattern characterized by a relatively high population density (305, 255 hbts/km^2), essentially made up of migrants. 3) the Malantouen (4˚54'' - 6˚36''N; 9˚18'' - 11˚24''E) site in the Western Highlands production basin with monomodal rainfall pattern, with a relatively low population density (42 hbts/Km^2), mainly indigenous; and 4) the Ayos site (2˚6'' - 4˚54''N; 10˚30'' - 16˚12''E) located in a dense humid forest zone with bimodal rainfall pattern, with a low population density (18 hbts/Km^2), mainly indigenous (Ngomeni et al., 2021). Phytogeographically, the Moungo production basin belongs to the low- and medium-altitude Biafran Atlantic forest, with vegetation that is essentially made up of highly anthropized forest galleries in Nkongsamba, and dominated by savannahs in Melong. The Centre-South-East production basin belongs to the Guinean-Congolese semi-deciduous rainforest of low and medium altitude. The Western Highlands production basin is made up of shrub savannahs and gallery forests (Onana et al., 2019). In the Nkongsamba and Melong sites, where producers are faced with the problem of land tenure, access is relatively easy on the large markets. The Malantouen site is landlocked, whereas the Ayos site is not very developed, and land is available. Agricultural activities are predominant in all these sites, with an emphasis on cash crops such as coffee. The problems encountered by coffee farmers are those known throughout the Cameroonian agricultural sector, notably the lack of supervision, financing, agricultural inputs and mechanization of perennial culture like the coffee (Ngomeni et al., 2021).

2.2. Data Collection

Floristic data collection of AS and coffee tree were collected in 30 RCAs in each site, using the basic sampling design recommended by Hairiah et al. (2010). In this study, the sampling design consisted at delineating one-hectare plots in each RCA within which data were collected. In each plot unit, a systematic floristic inventory was made of all AS with a diameter ≥5 cm, as well as their nature (retained or introduced), and of all coffee plants. Dendrometric measurements including diameter, height and crown diameter were taken on the inventoried species in order to calculate the parameters for characterizing the structure of the RCAs. Diameter was measured at 1.3 m above the ground for AS and at the 20 cm above the ground for coffee trees. The total height from the ground to the top of the crown, and the crown diameter (from the left to the right end of the crown for coffee trees and AS by projection of the crown to the ground) were also measured. The AS were then assigned to the height classes as defined by Soto-Pinto et al. (2013):

- stratum 1: between 1 and 3 m;
- stratum 2: between 3 and 6 m;
- stratum 3: between 6 and 12 m;
- stratum 4: between 12 and 20 m;
- stratum 5: >20 m.

2.3. Data Analysis

R software (version 3.4.1.) was used for data analysis (R Core Team, 2018). The Biodiversity R package of the R software was used for the characterization of the plant diversity of the RCAs of the study sites. Parametrics texts like ANOVA and Turkey's were used for significance and 2-to-2 comparisons of variables between sites respectively. Adobe Illustrator CC 2019 software was used for landscape illustration of RCAs by site based on data such as: abundance by diameter and height classes, strata, crown diameter, and most abundant AS by stratum.

2.3.1. Associated Species Plant Characterization

The following diversity indices were used in this study to characterize the plant diversity of the RCAs:

1) Species richness which corresponds to the total number of AS identified in the RCAs of each site;

2) Shannon's diversity index: $\text{ISH} = -\sum \text{Ni}/\text{N} \times \log[\text{Ni}/\text{N}]$ with Ni = efficiency of species i; N = number of all species;

3) Piélou's equitability which is the ratio of the diversity of a stand or sample to the number N of species present in the plot: $\text{EQ} = \text{ISH}/\log(\text{N})$;

4) Simpson's index: $\text{D} = 1 - \sum\{[\text{ni}(\text{ni}-1)]/[\text{N}(\text{N}-1)]\}$, where: ni = Frequency of species i in the sample; N = Sum of frequencies of all species in the sample;

5) Sorensen's index of floristic similarity: $\text{Ks} = 2\text{c}/(\text{a}+\text{b}) \times 100$ with Ks = Sorensen's index; a = number of species from production site A; b = number of species from production site B; and c = number of species common to both production sites (a + b). K higher than 50% between 2 production sites indicates a high floristic similarity between them.

2.3.2. Robusta Coffee Agroforests Structure Characterization

The following parameters were taken into account for the characterization of horizontal and vertical structure of the RCAs:

1) Ecological importance index (IVI; Curtis & McIntosh, 1951); which is defined by the following formula: IVI = Ar + Dr + Fr.

With: Ar = (ni/N) × 100, where: ni = number of individuals of the species; N = total number of individuals; Relative Abundance expressed as a percentage, gives information on the number of individuals of a species in the different surveys;

Dr = (si/S) × 100, where: si = basal area of the species; S = total basal area; Relative Dominance expressed as a percentage gives an indication of which taxa occupy the most space in the vegetation; Fr = (ri/R) × 100; where ri = number of records where the taxon is present and R=total number of records; the Relative Frequency expressed as a percentage gives an understanding of the social behavior of a taxa and its distribution in the different RCAs of the study sites. The ecological importance index varies from 0 (no dominance) to 300 (mono dominance). A species is considered ecologically dominant when IVI > 10 (Fobane et al., 2017).

2) The abundance of AS stem estimated in hectare (N/ha).

3) The distribution of AS according to diameter classes (N/ha). For this purpose, coffee trees were grouped into diameter classes of 2 cm amplitude, and the AS into diameter classes of 10 cm amplitude.

4) The distribution according to strata (%).

5) Basal area expressed in m^2/ha. $S = \pi Di^2/4$ where: S: basal area; D: diameter at breast height of individual i (m). It gave indications of the degree of competition within the stand and was an indirect measure of ground shading conditions (CRPF, 2011).

3. Results

3.1. Species Richness and Diversity Indices of Robusta Coffee Agroforests

The floristic inventory identified 102 AS belonging to 83 genera and 41 families in all the RCAs sampled (**Table 1**). RCAs of Ayos were found to be the most diversed with 71 AS identified, followed by Melong 39 AS, Nkongsamba 33 AS and Malantouen 33 AS.

The Shannon diversity index showed that the Ayos RCAs are richer in term of AS diversity (3.03) than those of the other sites (1.45 - 2.00). Simpson's index, which ranged from 0.673 to 0.885, showed heterogeneity across sites, and Piélou's Equitability index, which ranged from 0.414 to 0.712 (**Table 2**), showed the abundance of some AS in the floristic background of these RCAs, due to their irregular distribution. The ANOVA test showed that there is a significant difference between the diversity indices considered in this study according to sites (ANOVA, $p \leq 0.05$).

Like Pielou's equitability showed the abundance of some AS in the floristic background of these RCAs, **Table 3** shows the most abundant AS in the RCAs in function of each site.

The proportions of species retained (ASR) and/or introduced (ASI) in the RCAs varied from one site to another. In the RCAs of Malantouen, Ayos and Melong sites, the proportions of ASR were 68%, 67% and 63% respectively. In contrast, the proportion of ASI was higher in Nkongsamba site (63%). The top ten most ecologically dominant AS varied from site to site (**Table 4**). The majority of these AS that have a high ecological importance index per site are ASI.

Table 1. Taxonomic group of associated species identified in RCAs of the study area.

Family	Scientific name	Family	Scientific name	Family	Scientific name
Fabaceae	*Afzelia pachyloba*	Meliaceae	*Cedrela odorata*	Clusiaceae	*Garcinia kola*
	Albizia adanthifolia		*Entandrophragma cylindricum*		*Garcinia lucida*
	Albizia glaberrima		*Khaha ivorensis*	Combretaceae	*Combretum micranthum*
	Albizia gummifera		*Lovoa trichilioides*		*Terminalia superba*
	Albizia lebbeck	Rubiaceae	*Massularia acuminata*	Irvingiaceae	*Irvingia gabonensis*
	Albizia sp.		*Morinda lucida*		*Irvingia grandifolia*
	Albizia zygia		*Nauclea diderrichii*	Musaceae	*Musa paradisiaca*
	Distemonanthus benthamianus		*Shumanniophyton magnificum*		*Musa sapientium*
	Erythrophleum ivorense	Anacardiaceae	*Mangifera indica*	Myrtaceae	*Eucalyptus saligna*
	Erytrina sp.		*Spondias mombin*		*Psidium guayava*
	Pentaclepma macrophylla		*Trichoscypha arborea*	Sapindaceae	*Allophylus africanus*
	Pentaclethra macrophylla	Apocynaceae	*Alstonia boonei*		*Nephelium lappaceum*
	Piliostigma thonningii		*Funtumia elastica*	Tiliaceae	*Christiana africana*
	Piptadeniastrum africanum		*Voacanga africana*		*Glyphaea brevis*
	Pterocarpus soyauxii	Arecaceae	*Elaeis guineensis*	Verbenaceae	*Tectona grandis*
	Scorodophloeus zenkeri		*Phoenix dactylifera*		*Vitex synchoskii*
	Tetrapleura tetraptera		*Raphia vinifera*	Araliaceae	*Polyscias fulva*
Rubiaceae	*Citrus limon*	Euphorbiaceae	*Alchornea cordifolia*	Asparagaceae	*Dracaena arborea*
	Citrus medica		*Margueritaria discoides*	Caricaceae	*Carica papaya*
	Citrus reticulata		*Ricinodendron heudelotii*	Lauraceae	*Persea americana*
	Citrus sinensis	Pinaceae	*Pinu spinea*	Lecythidaceae	*Petersianthus macrocarpus*
	Citrus tachibana		*Pinus sp.*	Melastomataceae	*Memecy splon*
	Zanthoxylum sp.		*Prunus serotina*	Moringaceae	*Moringa oleifera*
	Zanthoxylum macrophylla	Annonaceae	*Annona muricata*	Myristicaceae	*Pycnanthus angolensis*
Malvaceae	*Cola acuminata*		*Pachypodianthum barteri*	Ochnaceae	*Lophira alata*
	Cola nitida	Asteraceae	*Vernonia amygdalina*	Octoknemaceae	*Octoknema affinis*
	Hibiscus sp.		*Vernonia conferta*	Phyllanthaceae	*Bridelia ferruginea*
	Sterculia tragancantha	Bignoniaceae	*Markhamia lutea*	Piperaceae	*Piper criineense*
	Theobroma cacao		*Spathodea campanulata*	Poaceae	*Saccharum spontaneum*
	Triplochiton scleroxylon	Bombacaceae	*Bombax buonoposenze*	Rosaceae	*Prunus avium*
Moraceae	*Antiaris toxicaria*		*Ceiba pentandra*	Sapotaceae	*Manilkara kauki*
	Ficus exasperata	Burseraceae	*Canarium schweinfurthii*	Ulmaceae	*Zeltia tessmannii*
	Ficus mucoso		*Dacryodes edulis*		
	Ficus sp.	Cecropiaceae	*Musanga cecropioides*		
	Milicia excelsa		*Myrianthus arboreus*		

Among them, at least one fertility species is recorded per site and four are common to all sites. These are: *Albizia zygia* and *Petersianthus macrocarpus* in *Ayos*, *Albizia zygia* and *Piptadeniastrum africanum in Malantouen*, *Albizia glaberrima* and *Albizia zygia* in *Melong*, and *Albizia glaberrima* in *Nkongsamba* for the fertilisers; and *Dacryodes edulis*, *Persea americana*, *Elaeis guineensis* and *Musa paradisiaca* for the common ones (Table 4). ASI are the most frequent and abundant in all the sites. In terms of dominance, ASR are most prevalent in Ayos and Malantouen and least prevalent in Nkongsamba and Melong.

Table 2. Floristic composition and diversity indices according to production sites.

Diversity indexes	Nkongsamba	Melong	Ayos	Malantouen
Species richness	33	39	71	33
Number of genera	28	34	62	30
Number of family	21	23	37	23
Shannon	1.45	1.55	3.03	2.00
Pielou equitability	0.414	0.424	0.712	0.573
Simpson	0.673	0.697	0.885	0.777

Table 3. Most abundant associated species in CAFs in function of the sites.

Nkongsamba	Melong	Ayos	Malantouen
Musa paradisiaca (45.96%)	*Musa paradisiaca* (47.05%)	*Musa paradisiaca* (30%)	*Musa paradisiaca* (40.01%)
Theobroma cacao (31.31%)	Elaeis *guineensis* (19.61%)	*Dacryodes edulis* (7.39%)	*Elaeis guineensis* (16.37%)
Elaeis guineensis (12.42%)	*Theobroma cacao* (19.55%)	*Elaeis guineensis* (7.02%)	*Theobroma cacao* (16.32%)
	Dacryodes edulis (6.42%)	*Albizia zygia* (6.65%)	*Albizia zygia* (7.22%)

Table 4. Top ten most ecologically dominant species by site.

Site	Scientific name	Relative Frequency (%)	Relative dominance (%)	Relative abundance (%)	Importance value Index (%)
Ayos	*Dacryodes edulis*	96.67	4.28	7.38	108.33
	Musa paradisiaca	50.00	3.45	29.88	83.83
	Albizia zygia	63.33	8.41	6.65	78.39
	Mangifera indica	70.00	4.27	2.66	76.93
	Persea americana	70.00	2.67	3.62	76.29
	Elaeis guineensis	53.33	15.45	7.01	75.79
	Ficus sp	56.67	5.74	2.47	64.88
	Petersianthus macrocarpus	53.33	6.64	1.79	61.76
	Triplochiton scleroxylon	43.33	5.00	0.06	48.39
	Milicia excelsa	43.33	2.20	1.12	46.65

Continued

Malantouen	*Elaeis guineensis*	73.33	21.82	16.37	111.52
	Musa paradisiaca	53.33	8.90	40.02	102.25
	Albizia zygia	60.00	19.00	7.23	86.23
	Dacryodes edulis	56.67	2.40	3.79	62.86
	Milicia excelsa	36.67	8.14	1.59	46.40
	Theobroma cacao	23.33	4.95	16.32	44.60
	Piptadeniastrum africanum	33.00	5.92	2.73	41.65
	Voacanga africana	33.00	4.10	3.42	37.52
	Cola nitida	30.00	0.50	0.80	31.30
	Persea americana	23.33	0.50	0.78	24.61
Melong	*Musa paradisiaca*	90.00	28.03	47.05	165.08
	Elaeis guineensis	70.00	57.62	19.61	147.23
	Dacryodes edulis	93.33	2.21	6.43	101.97
	Theobroma cacao	53.33	1.82	19.55	74.70
	Persea americana	66.67	0 .78	1.22	68.67
	Albizia glaberrima	46.67	4.10	2.01	52.78
	Psidium guayava	31.63	1.90	0.74	37.66
	Albizia zygia	33.00	0.53	0.40	34.27
	Mangifera indica	23.00	0.67	0.53	24.20
	Voacanga africana	21.68	1.90	0.38	23.96
Nkongsamba	*Elaeis guineensis*	93.33	67.49	12.43	173.25
	Musa paradisiaca	100.00	15.43	45.96	161.39
	Dacryodes edulis	93.33	2.07	2.40	97.80
	Theobroma cacao	50.00	6.36	31.31	87.67
	Persea americana	83.33	1.88	1.16	86.37
	Psidium guayava	43.33	0.14	0.36	43.83
	Mangifera indica	40.00	1.78	0.39	42.17
	Carica papaya	33.33	0.08	0.25	33.65
	Albizia glaberrima	23.33	0.08	0.34	23.75
	Cola nitida	20.00	0.27	0.10	20.37

3.2. Floristic Affinity between Sites

The Sorensen index showed a floristic affinity between the Melong and Nkongsamba on the one hand, and between the Melong and Malantouen on the other hand (Table 5). No floristic affinity between the Ayos and the other sites was noted.

A total of 12 AS were common to the four sites, namely: *Albizia zygia*, *Carica papaya*, *Citrus sinensis*, *Dacryodes edulis*, *Elaeis guineensis*, *Mangifera indica*, *Milicia excelsa*, *Musa paradisiaca*, *Persea americana*, *Psidium guayava*, *Theobroma cacao and Voacanga africana*.

3.3. Structure of Plant Biodiversity

3.3.1. Distribution by Diameter Class of Coffee Trees and Associated Specie

The distribution of coffee tree abundance by diameter class showed a general bell-shaped pattern with peak abundance classes. In Ayos and Malantouen, most individuals were in the [6 - 8[cm class. In the Nkongsamba and Melong sites, the greatest number of individuals was observed in the [10 - 12[cm and [12 - 14[cm diameter classes respectively (Figure 1). In terms of AS, the [10 - 20[cm class had the highest abundance at all sites, which then decreased as the diameter classes increased; hence the inverted "J" curve (Figure 1).

3.3.2. Vertical Structure of Associated Species per Site

Stratification into AS height classes showed that the 3 - 6 m stratum, dominated by ASI, was the most dominant in all sites, with percentage of 38%, 48%, 64% and 64% respectively in Ayos, Malantouen, Melong and Nkongsamba. Also, the 5 stratum (>20 m), dominated by ASR, is the least represented at all sites, with percentage of 6%, 4%, 0% and 2% respectively in Ayos, Malantouen, Melong and Nkongsamba (Figure 2).

3.3.3. Horizontal Structure of Associated Species and Coffee Trees

The horizontal structure of AS and coffee trees was assessed through the crown diameters, densities and basal area of these species.

The average crown diameter was higher for AS (6.29 - 7.58 m) than those of coffee trees (1.89 - 2.62 m) according to the site, while the density of coffee trees varied from site to site and was higher than that of AS (Table 6).

Table 5. Sorensen's index of similarity (%) between production sites.

	Ayos	Malantouen	Melong	Nkongsamba
Ayos	100			
Malantouen	37	100		
Melong	44	53	100	
Nkongsamba	38	45	58	100

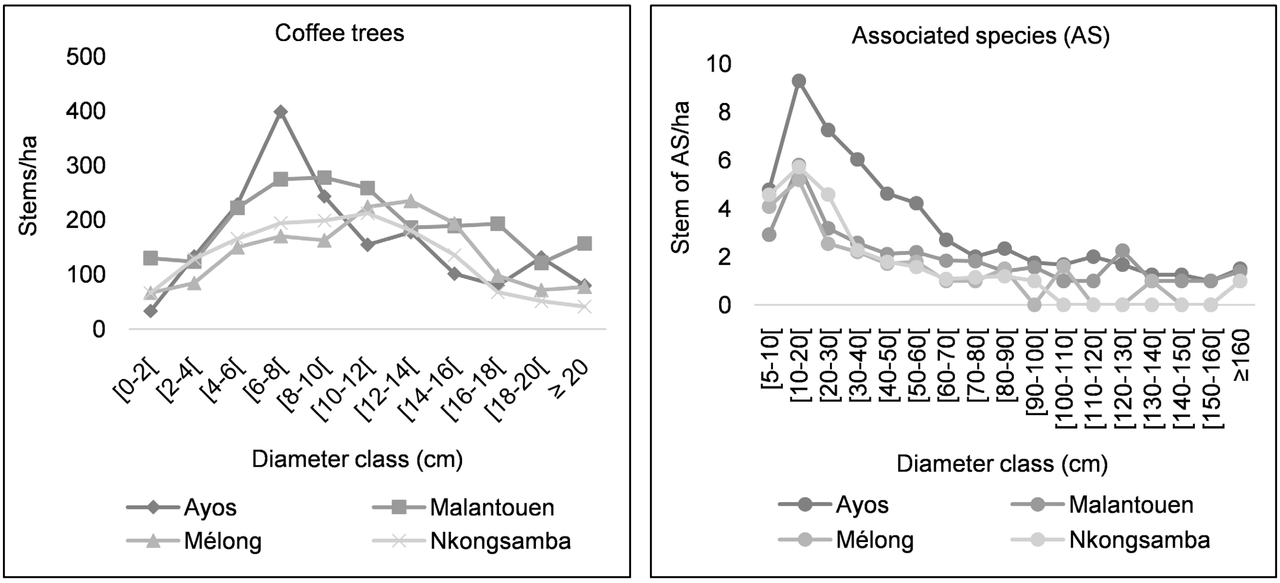

Figure 1. Diameter class distribution of coffee and AS by study site.

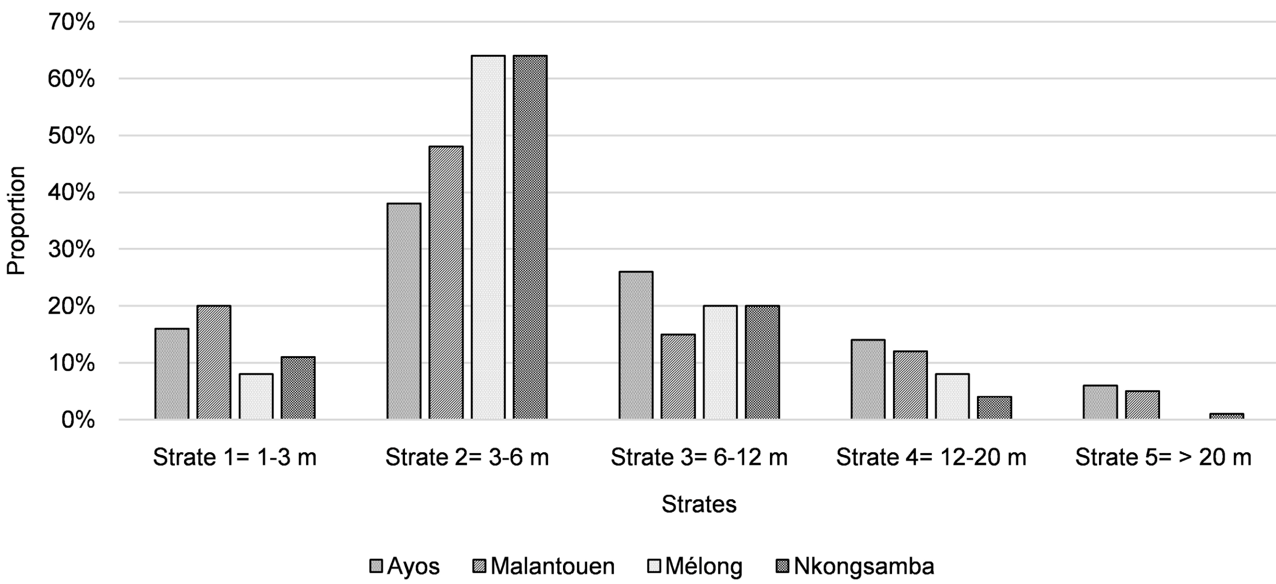

Figure 2. Horizontal stratification of associated trees in function of the site.

A significant difference was observed between sites for both coffee trees and AS (ANOVA, $p < 0.01$). These densities varied between 1456 stems/ha in Malantouen and 1208 stems/ha in Ayos for coffee trees; and between 214 stems/ha in Nkongsamba and 71 stems/ha in Malantouen for AS (Table 6).

A significant difference was also observed between sites for land area under coffee and AS (ANOVA, $p < 0.05$). These basal areas ranged from 16.14 m^2/ha in Malantouen to 7.97 m^2/ha in Ayos for coffee; and from 11.74 m^2/ha in Nkongsamba to 6.96 m^2/ha in Malantouen for AS. The average total basal area (coffee trees + AS) varied between 27.14 m^2/ha in Melong and 18.18 m^2/ha in Ayos (Table 6).

Table 6. Tree crown diameter, abundance and basal area of RCAs.

Production site	Components	Crow diameter (m)	Stems density (N/ha)	Basal area (m^2/ha)
Ayos	Coffee trees	2.62 ± 0.97	1208 ± 259 (a)	7.97 ± 5.73 (a)
	AS	6.74 ± 3.79	73 ± 7 (a)	10.21 ± 8.21(a)
	Total	-	1280 ± 281	18.18 ± 11.42 (a)
Malantouen	Coffee trees	2.49 ± 0.97	1456 ± 344 (b)	16.14 ± 8.79 (a)
	AS	7.58 ± 4.70	71 ± 111 (b)	6.96 ± 4.91 (ab)
	Total	-	1527 ± 317	23.10 ± 8.20 (a)
Melong	Coffee trees	2.36 ± 0.83	1325 ± 249 (ab)	15.68 ± 5.22 (b)
	AS	7.10 ± 3.64	157 ± 95 (ab)	11.46 ± 7.24 (a)
	Total	-	1482 ± 244	27.14 ± 8.11 (b)
Nkongsamba	Coffee trees	1.89 ± 0.70	1311 ± 234 (ab)	12.14 ± 4.19 (ab)
	AS	6.29 ± 3.43	214 ± 227 (ab)	11.74 ± 8.90 (a)
	Total	-	1525 ± 339	23.88 ± 7.01 (ab)

AS: Associated species.

3.4. Architectural Profile of Robusta Coffee Agroforests per Site

As regards the architectural profile of RCA (Figure 3), the upper stratum of the Melong and Nkongsamba sites was dense and mainly dominated by *Elaeis guineensis* (oil palm). The lower stratum was made up mainly of *Coffea canephora* (Robusta coffee), to which are added *Musa paradisiaca* (Banana plantain) and *Theobroma cacao* (Cocoa). In Ayos, the upper stratum was sparsely and consisted of a diversity of AS including *Albizia* sp., *Dacryodes edulis* (Safoutier), *Petersianthus* sp. etc. *Elaeis guineensis*, *Musa paradisiaca* and *Theobroma cacao* colonize the middle stratum; on the other hand, the lower stratum was essentially made up of *Coffea canephora* trees. In Malantouen, the same trends as in Ayos was observed, with the only difference being that the species representing the upper strata showed some divergence.

4. Discussion

4.1. Plant Diversity of Robusta Coffee Agroforests

RCAs are characterized by the integration or conservation of trees in perennial crop systems like coffee (Temgoua et al., 2020). Coffee trees are traditionally grown in association by most farmers who conserve or introduce some useful plant species in their plantations (Lopez-Gomez et al., 2008; Denu et al., 2016; Koda et al., 2019).

Several factors can explain the species richness of these systems, including: agroforest management methods, biophysical environment, and land constraints

(Ngomeni et al., 2021). In this study, the species richness found decreases from Ayos, Melong, Nkongsamba sites to Malantouen site. This can be explained by the fact that we are moving from the dense rainforest zone to the savannah zone, which is accompanied by a gradient of decreasing richness of wild woody flora (Letouzey, 1968). Ayos is located in the semi-deciduous forest zone, still contains a large number of plant species in its natural environment, which is not very anthropised. Furthermore, the availability of arable land in this site, the low population density (18.3 inhabitants/km^2), which is mainly made up of indigenous people who are integrated in their natural environment and want to preserve it as such, predispose to low pressure on natural ecosystems. In contrast, the sites of Nkongsamba and Melong, characterised by a high population density (355 - 205 hbts/km^2), are mainly made up of migrants from the savannah zone, who are generally faced with problems of access to land. This is reflected in the practice of unstructured mixed farming, with its corollaries on the management of natural resources in general, and more particularly on plant resources. Thus, these migrants from Nkongsamba and Melong introduce more plant species of complementary socio-economic interest to them (Montagnini & Nair, 2004; Sonwa et al., 2007; Madountsap et al., 2019). This justifies the abundance of the fruit species *Musa paradisiaca, Elaeis guineensis and Theobroma cacao* in the Melong and Nkongsamba, and therefore the low Pielou equitability values found in these sites.

Ayos is the most diverse site with a Shannon index of 3.03. This site therefore does not have a floristic affinity with the other study sites. The Nkongsamba and Melong sites have similar floristic affinity and AS variability. The geographical and ecological proximity of the two sites, which also belong to the same phytogeographical domain, could justify this affinity. The floristic affinity observed between the Melong and Malantouen sites can be explained by the same coffee growing environment. Indeed, the Malantouen site is located in a natural or anthropised savannah-forest transition zone, where coffee trees are grown in the forest gallery area as in the Melong site (Onana et al., 2019). It is important to note that fruit ASI are of paramount importance to producers regardless of the site. Indeed, *Musa paradisiaca, Elaeis guineensis, Dacryodes edulis* and *Persea americana*, are the four ASI common to all four sites appearing in the top 10 AS with high IVI values per site. This is due to the ability of these species to improve the livelihoods of the owners during the lean season.

4.2. Structure of Robusta Coffee Agroforests

The structure of the RCAs varies according to the production systems and is attributable to the management of the RCAs, the ageing of the orchards, the quality of the plant material, and the pressure of bio-aggressors, amplified by the structural complexity of the systems. The Nkongsamba site is the one in which the greatest number of AS individuals was observed. These AS are essentially made up of fruit trees with high economic potential. Indeed, following the coffee crisis of the late 1980s, most coffee producers opted to diversify the species within their RCAs by massively introducing fruit trees to cushion the drop in coffee prices on the market, and by stopping state subsidies for the acquisition of agricultural inputs (Kamga, 2002; Ngapgue, 2010).

This option was much more noticeable in Nkongsamba, a site with a high population density and a predominantly migrant population, on the one hand because of its greater dependence on income generated by the sale of coffee, which propelled it to become the third largest city in Cameroon in the 1980s; and on the other hand because of its proximity to Douala, a large urban center, and also due to the presence of an agricultural research station in Njombe, located 50 km from Nkongsamba and specialised in the production of improved fruit plant material. In the other sites, these fruit species are found at lower densities. The Melong site, although facing the same land tenure problem as Nkongsamba, has a lower population density. In Malantouen, the isolation of the site does not offer the same market opportunities as in Nkongsamba and Melong. On the other hand, the low level of anthropisation, the availability of land and the presence of a large number of conserved AS, which are also in the minority, justify this situation in Ayos.

At the level of horizontal structure, the AS are densely represented in the RCAs of the Nkongsamba and Melong, and sparsely represented in those of Malantouen and Ayos. The reason for this is the average basal area obtained per site, which is consistent with the morphology of the AS and its density in the RCAs. The abundance of non-tapered AS, an undeniable source of income for producers in the RCAs of the Nkongsamba and Melong, contributes to their congestion and a negative influence on the development of coffee trees. This is justified by the coffee yields of these sites according to our interview make with the agricultural authorities of these sites, which are in the order of 184.7 kg/ha, 292.6 kg/ha, 425.9 kg/ha and 480.2 kg/ha in Melong, Nkongsamba, Malantouen and Ayos respectively.

The RCAs of Ayos site are much more stratified than those of other study sites, due to the agroecological and socio-cultural environment. Indeed, producers in this site are poorly equipped to destroy large trees, and are forced to adapt their activities to the natural environment (Zapfack et al., 2016). These large trees are found in the high strata of 12 - 20 m and >20 m, and do not prevent easy light penetration in the lower strata. Stratum 2 (3 - 6 m) is the most dominant of the five strata defined in the RCAs regardless of the study site. This is due to the presence of introduced AS in this stratum, which are generally medium-sized and therefore dominant in strata 1 and 2, which do not allow sunlight to pass easily. The genera *Musa* and *Elaeis*, which are also present in these two strata, but at high density in the Nkongsamba and Melong sites, contribute to further obstructing the 3 - 6 m stratum 2 in these sites. This stratum 2 directly follows that of the coffee trees, thus exposing them in these two study sites to high competition for solar energy that enters the vegetative development of the plant with these AS. However, in a complex system, the ideal would be to have strata higher than that of the main perennial species to facilitate the physiological phenomena that occur around the main crop (Champeroux & Kham, 1991). High densities, basal area and crown diameters in RCAs imply crowding and thus a negative effect on the phenology of the species. This structural characterization of the RCAs of the study sites, which is the result of management practices, reflects the architectural profiles of the RCAs of these sites as presented in **Figure 3**.

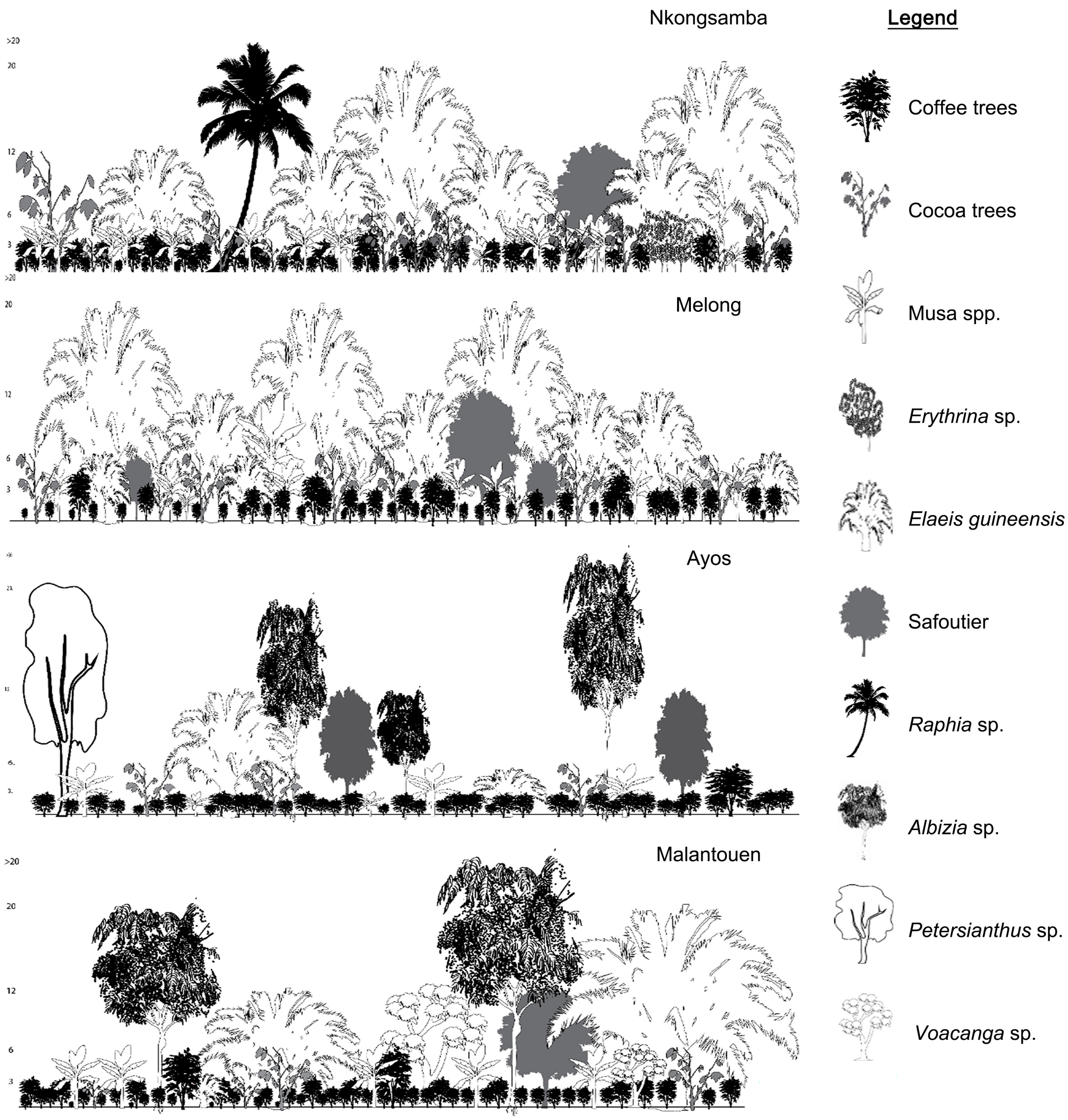

Figure 3. Architectural profile of Robusta coffee agroforests per site.

5. Conclusion

The objective of this study was to characterize the associated species and structure of RCAs in four production sites belonging to three agro-ecological zones contrasted by ecology and socioeconomic conditions. The results showed that the AS and structure of RCAs vary according to the biophysical and socio-economic environment of the sites. With a diversity of 102 AS identified in the RCAs, their contribution to the conservation of plant biodiversity is not negligible. However, the variability of this biodiversity and especially the structural and landscape characteristics of the sites are influenced by the agro-ecological and socio-economic environment, in particular: biophysical conditions and RCAs management methods as applied by the farmers. A coherent exploitation of the results obtained may contribute to develop strategies for sustainable management of RCAs of the studied sites in particular, and those of landscapes presenting similarities biophysical and socioeconomic wise in general.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Atangana, A., Khasa, D., Chang, S., & Degrande, A. (2014). *Tropical Agroforestry*. Springer. https://doi.org/10.1007/978-94-007-7723-1

Avana, M. L., Ketchiamen, L., Atiojio, E., Sonwa, D., & Asaah, E. (2004). *Dynamic of Tree Diversity and Roles in Humid Savannah Agroforestry Systems, Western Cameroon: How Could It Promote Cocoa Cultivation in Lowland Area of the Region? Cacao Agroforestry: Sustainability and Environment—Yaounde, Cameroon* (p. 24).

Beer, J., Muschler, R., Kass, D., & Somarriba, E. (1998). Shade Management in Coffee and Cacao Plantations. *Agroforestry Systems, 38,* 139-164. https://doi.org/10.1023/A:1005956528316

Champeroux, G., & Kham, M. S. (1991). *Manuel du planteur de café laotien* (74 p.). CIRAD-IRCC.

CRPF (Centre Régional de la Propriété Forestière) (2011). *Pour un meilleur partage des usages de la forêt. Colloque Naturparif/ONF 3-4 Octobre 2011.* https://www.natureparif.fr

Curtis, J. T., & McIntosh, R. P. (1951). An Upland Forest Continuum in the Prairie-Forest Border Region of Wisconsin. *Ecology, 32,* 476-496. https://doi.org/10.2307/1931725

Denu, D., Platts, P. J., Kelbessa, E., Tadesse, W. G., & Marchant, R. (2016). The Role of Traditional Coffee Management in Forest Conservation and Carbon Storage in the Jimma Highlands, Ethiopia. *Forests Trees and Livelihoods, 25,* 226-238. https://doi.org/10.1080/14728028.2016.1192004

Fobane, J. L., Onana, J. M., Zekeng, J. C., Biye, H. E., & Mbolo, A. M. M. (2017). Flora Diversity and Characterization of Plant Groups in Atlantic Forests of Cameroon. *Journal of Biodiversity and Environmental Sciences, 10,* 163-176.

Hairiah, K., Dewi, S., Argus, F., Velarde, S., Ekadinata, A., Rahayu, S., & Van Noordwijk, M. (2010). *Measuring Carbon Stocks across Land Use Systems: A Manual* (155 p.). World Agroforestry Centre (ICRAF), SEA Regional Office.

Hergoualc'h, K., Blanchart, E., Skiba, U., Hénault, C., & Harmand, J. M. (2012). Changes in Carbon Stock and Greenhouse Gas Balance in a Coffee (*Coffea arabica*) Monoculture versus an Agroforestry System with Inga densiflora, in Costa Rica. *Agriculture Ecosystems and Environment, 148,* 102-110. https://doi.org/10.1016/j.agee.2011.11.018

Kamga, A. (2002). *Crise économique, retour des migrants, et évolution du système agraire sur les versants oriental et méridional des monts Bamboutos (Ouest Cameroun)* (311 p.). Thèse de doctorat, Université de Toulouse—Le Mirail, Toulouse.

Koda, D. K., Chérif, M., Adjossou, K., Amégnaglo, K. B., Diwediga, B., Agbodan, K. M. L., & Guelly, A. K. (2019). Typology of Coffee-Based Agroforestry Systems in the Semi-Deciduous Forest Zone of Togo (West Africa). *International Journal of Biodiversity and Conservation, 11,* 199-211. https://doi.org/10.5897/IJBC2019.1291

Letouzey, R. (1968). *Etude phytogéographique du Cameroun* (511 p.). Paris, Lechevalier.

Lopez-Gomez, A. M., Williams-Linera, E., & Manson, R. H. (2008). Tree Species Diversity and Vegetation Structure in Shade Coffee Farms in Veracruz, Mexico. *Agriculture Ecosystem and Environment, 124,* 160-172. https://doi.org/10.1016/j.agee.2007.09.008

Madountsap, T. N., Zapfack, L., Chimi, D. C., Kabelong, B. L. P., Forbi, P. F., Tsopmejio, T. I., Tajeukem, V. C., Ntonmen, Y. A. F., Tabue, M. R. B., & Nasang, J. M. (2019). Carbon Storage Potential of Cacao Agroforestry Systems of Different Age and Management Intensity. *Climate and Development, 11,* 543-554. https://doi.org/10.1080/17565529.2018.1456895

Montagnini, F., &, Nair, P. K. R. (2004). Carbon Sequestration: An Underexploited Environmental Benefit of Agroforestry Systems. *Agroforestry Systems, 61,* 281-295. https://doi.org/10.1007/978-94-017-2424-1_20

Ngapgue, J. N. (2010). Réaction du pôle de développement d'une région agricole face à la crise caféière: Exemple de la ville de Foumbot sur les Hauts Plateaux de l'Ouest Cameroun. *International Journal of Advanced Studies and Research in Africa, 1,* 163-176.

Ngomeni, A. F., Bidzanga, N. L. E., Avana, M. L., Tchamba, N. M., & Chimi, D. C. (2021). Potentiel de séquestration du carbone des agroforêts à base de caféier robusta (*Coffea canephora* var. *robusta*) dans les bassins de production du Cameroun. *International Journal of Biological and Chemical Sciences, 15,* 2652-2664. https://doi.org/10.4314/ijbcs.v15i6.31

Onana, J. M., Fobane, J. L., Biye, E. H., Tchatchouang, N. E., & Mbolo, A. M. M. (2019). Habitats naturels des écosystèmes du Cameroun. *International Journal of Biological* *and Chemical Sciences, 13,* 3247-3265. https://doi.org/10.4314/ijbcs.v13i7.22

Ousmanou, I. (2005). *Structure et fonctionnement des jardins de case à base de Caféiers dans les zones humides du Cameroun: Cas des Départements du Koung-khi, Bamboutos, et du Ndé* (50 p.). Mémoire d'Ingénieur des Eaux, Forêt et Chasses, Université de Dschang, Cameroun.

R Core Team (2018). *A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org

Schroth, G., Fonseca da, G. A. B., Harvey, C. A., Gascon, C., Vasconcelos, H. L., & Izac, A. M. N. (2004). *Agroforestry and Biodiversity Conservation in Tropical Landscapes* (525 p.). Island Press.

Sibelet, N., Fréguin-Gresh, S., Le Coq, J. F., Gutiérrez Montes, I., Laffourcade, R., Dhorne, S., Dorgans-cadiLhac, J., Baranger, M., & Constanty, M. (2019). Pressions environnementalistes et stratégies des agriculteurs dans les systèmes agroforestiers caféiers au Nicaragua et au Costa Rica. In *Agroforesterie et services écosystémiques en zone tropicale* (pp. 23-36). Sciences Update & Technologie. Quae edition.

Sonwa, D. J., Nkonmeneck, B. A., Weise, S. F., Tchatat, M., Adesina, A. A., & Janssens, M. J. J. (2007). Diversity of Plants in Cocoa Agroforest in the Humid Forest Zone of Southern Cameroon. *Biodiversity and Conservation, 16,* 2385-2400. https://doi.org/10.1007/s10531-007-9187-1

Soto-Pinto, F. et al. (2013). La zonificación agroecológicadel *Coffea arabica* L. en Cuba. Macizosmontañosos sierra maestra y guamuhaya. *Cultivos Tropicales, 23,* 35-44.

Temgoua, L. F., Etchike, D. A. B., Solefack, M. M. C., Tumenta, P., & Nkwelle, J. (2020). Woody Species Diversity Conservation and Carbon Sequestration Potential of Coffee Agroforestry Systems in the Western Region of Cameroon. *Journal of Horticulture and Forestry, 12,* 35-48. https://doi.org/10.5897/JHF2020.0627

Zapfack, L., Chimi, D. C., Noiha, N. V., Zekeng, J. C., Meyan-ya, D. G. R., & Tabue, M. R. B. (2016). Correlation between Associated Trees, Cocoa Trees and Carbon Stocks Potential in Cocoa Agroforests of Southern Cameroon. *Sustainability in Environment, 1,* 71-84. https://doi.org/10.22158/se.v1n2p71